

# Physics Prospects at the Tau-Charm Factory

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1. What can we learn from BEPC.
2. Search for gluonium or hybrid states.
3. Study for  $\tau$  and  $\nu_\tau$ .
4. Comprehensive Study for Charm Physics.
5. Summary

Table 2, The BES Run Situation

Period	Purpose	Data
Sep.89-Jan.90	Debugging & Calibration Run	$3 \times 10^5$
Jan.90-Jun.90	First $J/\psi$ Physics Run	$3 \times 10^6$
Nov.90-Jan.91	Second $J/\psi$ Physics Run	$3 \times 10^6$
Apr.91-May 91	Third $J/\psi$ Physics Run	$3 \times 10^6$
Nov.91-Jan.92	$\tau$ Mass Run	$5 pb^{-1}$
Jan.92-Jun.92	First $D_s$ Run	$3.2 pb^{-1}$
Dec.92-May 93	Second $D_s$ Run	$7.1 pb^{-1}$
Dec.93-Jan.94	$\psi'$ Run	$2.3 pb^{-1}$
Jan.94-May 94	Third $D_s$ Run	$15 pb^{-1}$

$9 \times 10^6 J/\psi$   
 $1.4 \times 10^6 \psi'$   
 $5 pb^{-1} \tau$   
 $25 pb^{-1} D_s$

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# 1. What can we learn from BEPC

(1) Advantages of the threshold region for  $\tau$  and charm study

For example,

## $m_\tau$ measurement

BES  $1776.9 \pm 0.2 \pm 0.2$

$$e^+ e^- \rightarrow \tau^+ \tau^- \begin{cases} \rightarrow e \nu \bar{\nu} \\ \rightarrow \mu \nu \bar{\nu} \end{cases}$$

$5 \text{ Pb}^{-1}$       10 events

Augus  $1776.3 \pm 2.4 \pm 1.4$

$$\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu_\tau$$

$341 \text{ Pb}^{-1}$

$325000 \tau^+ \tau^-$

$10959 (3\pi) \text{ even}$

Background  $2161 \pm 200$

CLEO  $1777.8 \pm 0.7 \pm 1.7$

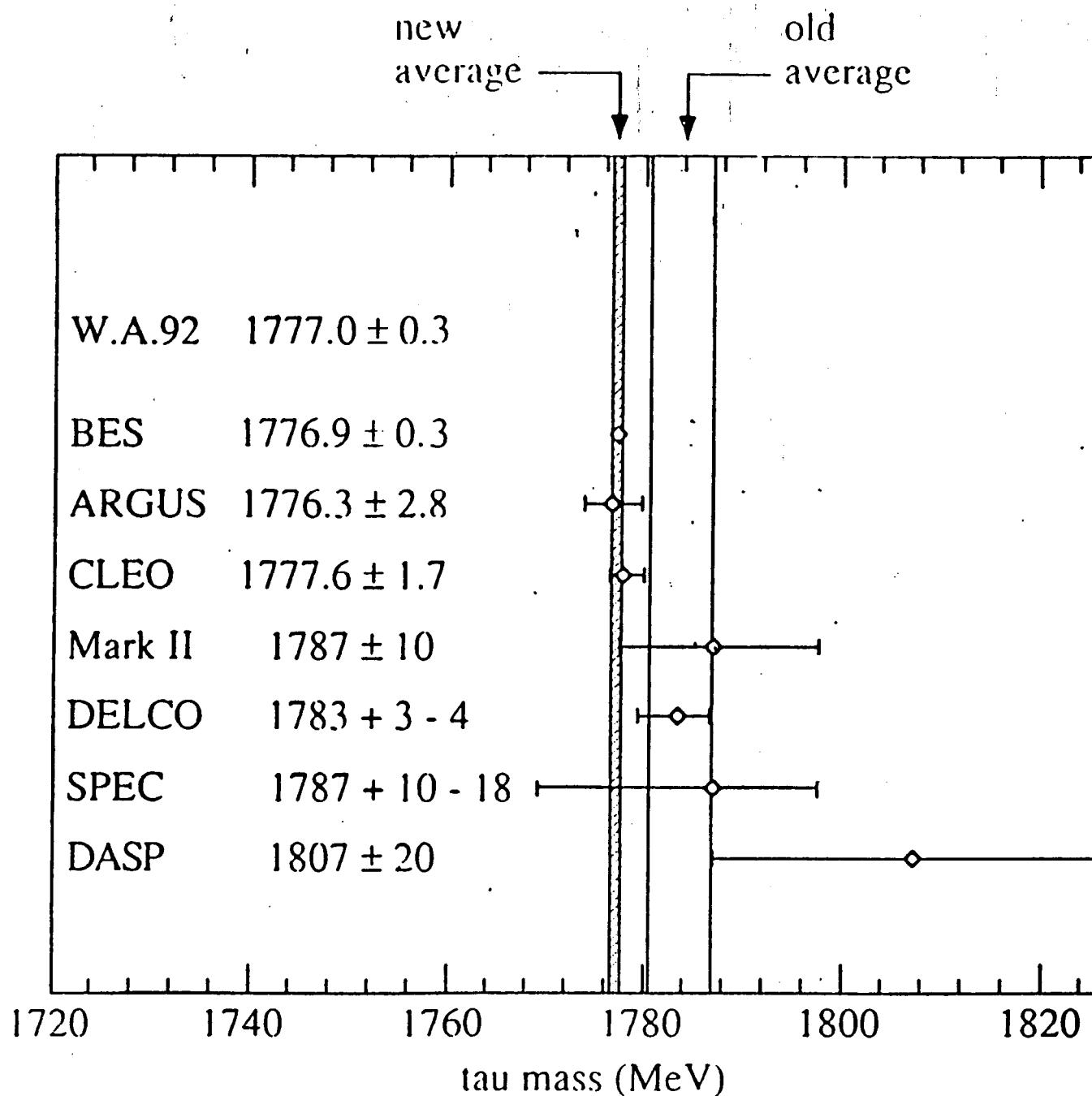
$$e^+ e^- \rightarrow \tau^+ \tau^- \begin{cases} \rightarrow h^- \nu_\tau \\ \rightarrow h^+ \bar{\nu}_\tau \end{cases}$$

$1430 \text{ Pb}^{-1}$

$131000 \tau^+ \tau^-$

$35255 (h^+ h^-)$

$\Rightarrow$  BES systematic error small



# The Physics Results from BES

## $m_\tau$ measurement

### (1) First stage, from $e\mu$ channel

$$e^+ e^- \rightarrow \tau^+ \tau^-$$

$$\leftrightarrow \mu^- \bar{\nu}_\mu \nu_\tau$$

$$\leftrightarrow e^+ \nu_e \bar{\nu}_\tau$$

Background  $\leq 0.12$  for 14  $e\mu$  events

$$m_\tau = 1776.9 {}^{+0.4}_{-0.5} \pm 0.2 \text{ Mev}$$

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$$(m_\tau = 1784.1 {}^{+2.7}_{-3.6} \text{ MeV, PDG'92})$$

### (2) Second stage, from $e\mu, ee, e\pi, e\rho, \mu\pi, \mu\mu, \pi\pi$

Channel	$e\mu$	$e\pi$	$\mu\pi, \mu\mu, \pi\pi$	$ee$	$e\rho$	all
Sel. Evt.s	14	13	12	8	7	54
BG Evt.s	0.12	0.09	0.24	0.09	0.10	0.64
Eff.(%) M-C	14.0	22.4		16.2	5.2	
Eff.(%) 2-dim	11.1 $+4.2$ $-3.5$	21.0 $+7.3$ $-5.9$		15.6 $+7.2$ $-5.6$	5.3 $+2.7$ $-2.0$	
$\sum_{i=1}^n \epsilon_i B_i$ (%) M-C	0.88	0.87	0.92	0.51	0.42	3.60
$\sum_{i=1}^n \epsilon_i B_i$ (%) 2-dim			0.715 $+0.268$ $-0.215$			3.35 $+0.55$ $-0.49$
$M_\tau$ (MeV/c <sup>2</sup> )	1776.9 $+0.4$ $-0.5$	1776.9 $+0.4$ $-0.4$	1776.8 $+0.5$ $-0.5$	1776.9 $+0.6$ $-0.6$	1776.8 $+0.6$ $-0.7$	1776.9 $+0.2$ $-0.2$

$$m_\tau = 1776.9 {}^{+0.2}_{-0.3} \pm 0.2 \text{ Mev}$$

$$1776.9 \pm 0.2 \pm 0.2 \text{ MeV}$$

(2) Physics complements each other at BEPC,  
CESR and LEP

Lifetime of  $\tau$                     LEP

$m_\tau$  measurement            BEPC, CESR

$\Rightarrow$  Lepton Universality

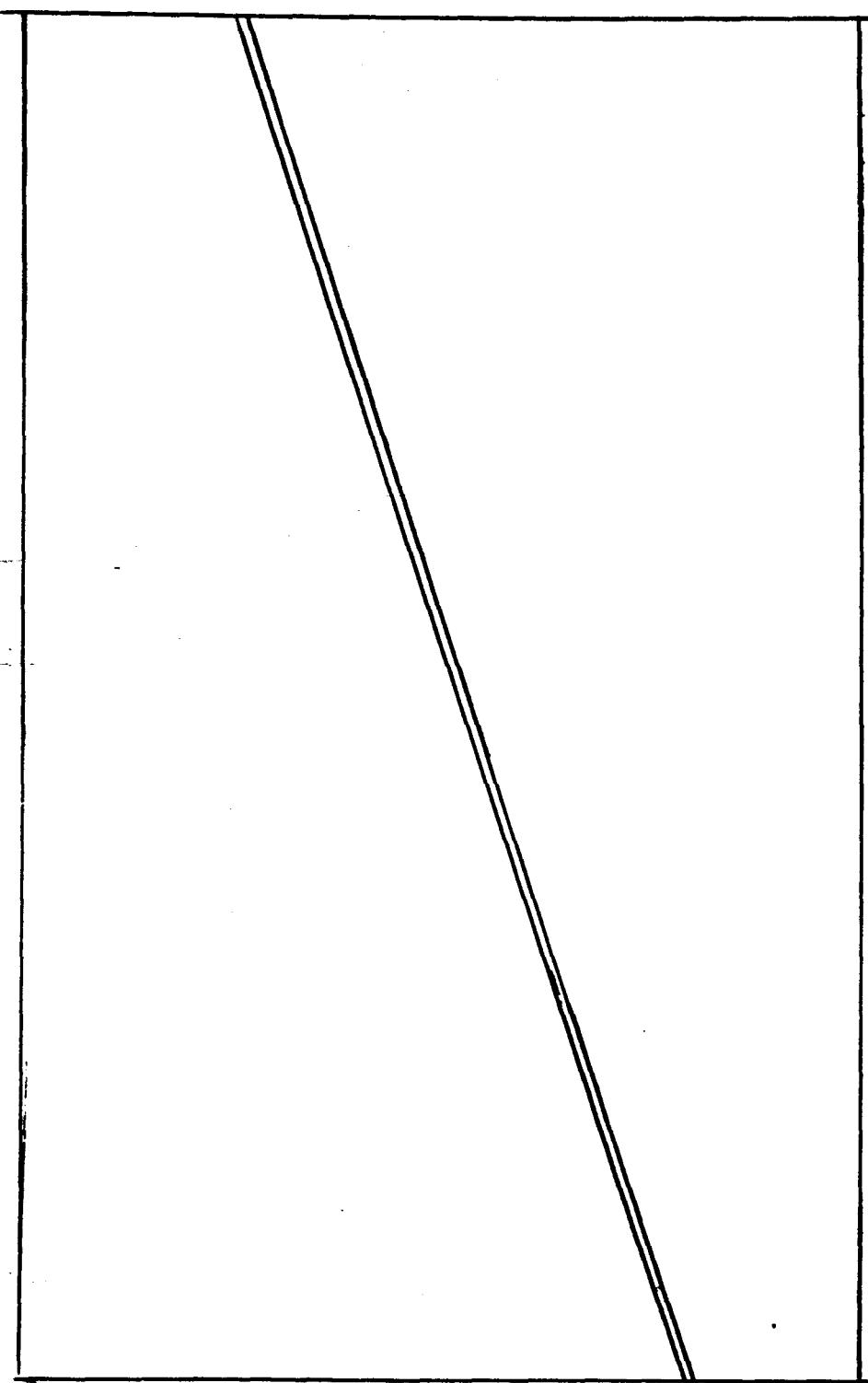
$B_s \rightarrow D_s$

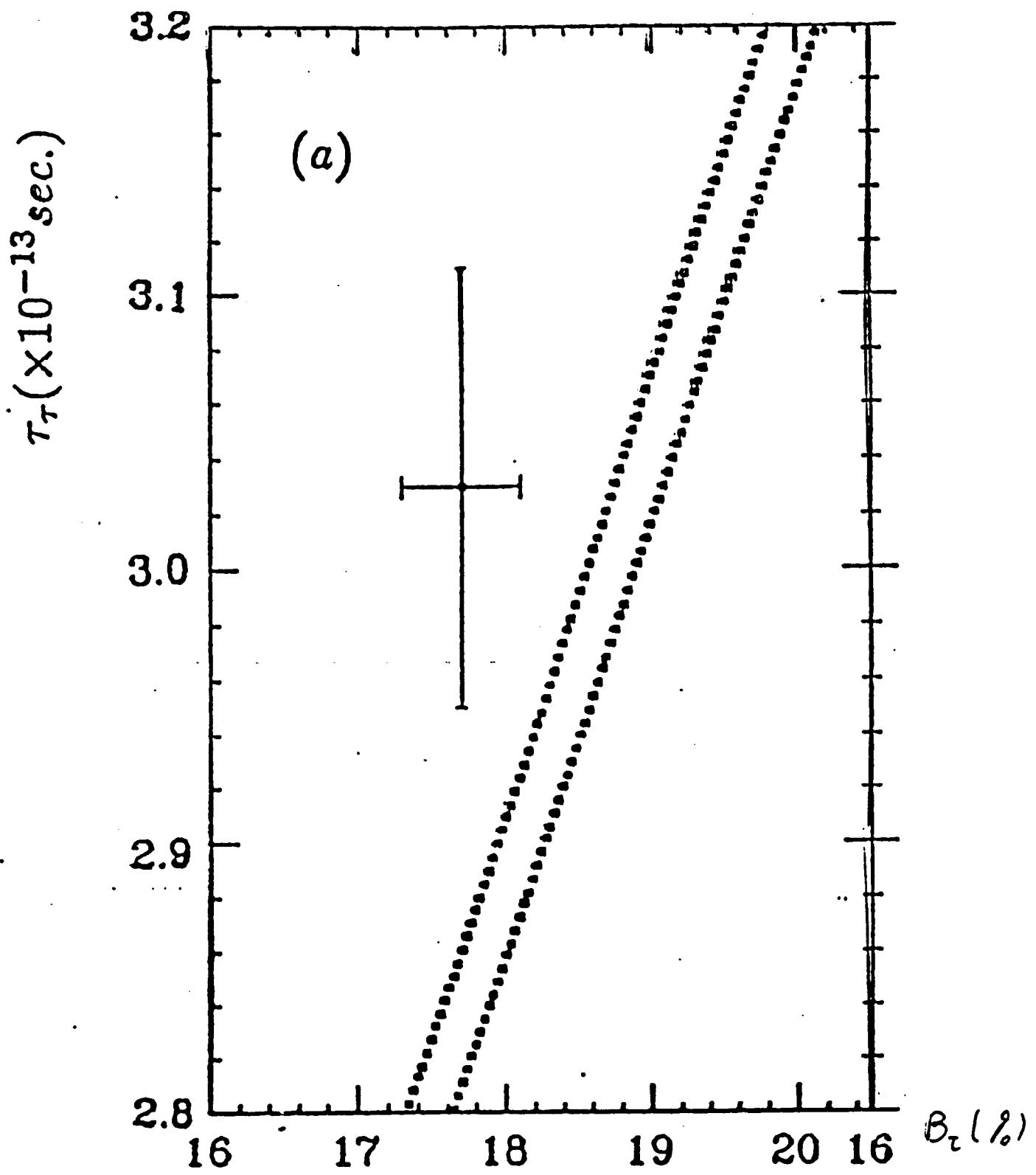
$f_{D_s}$

$D_s \rightarrow \phi \pi$

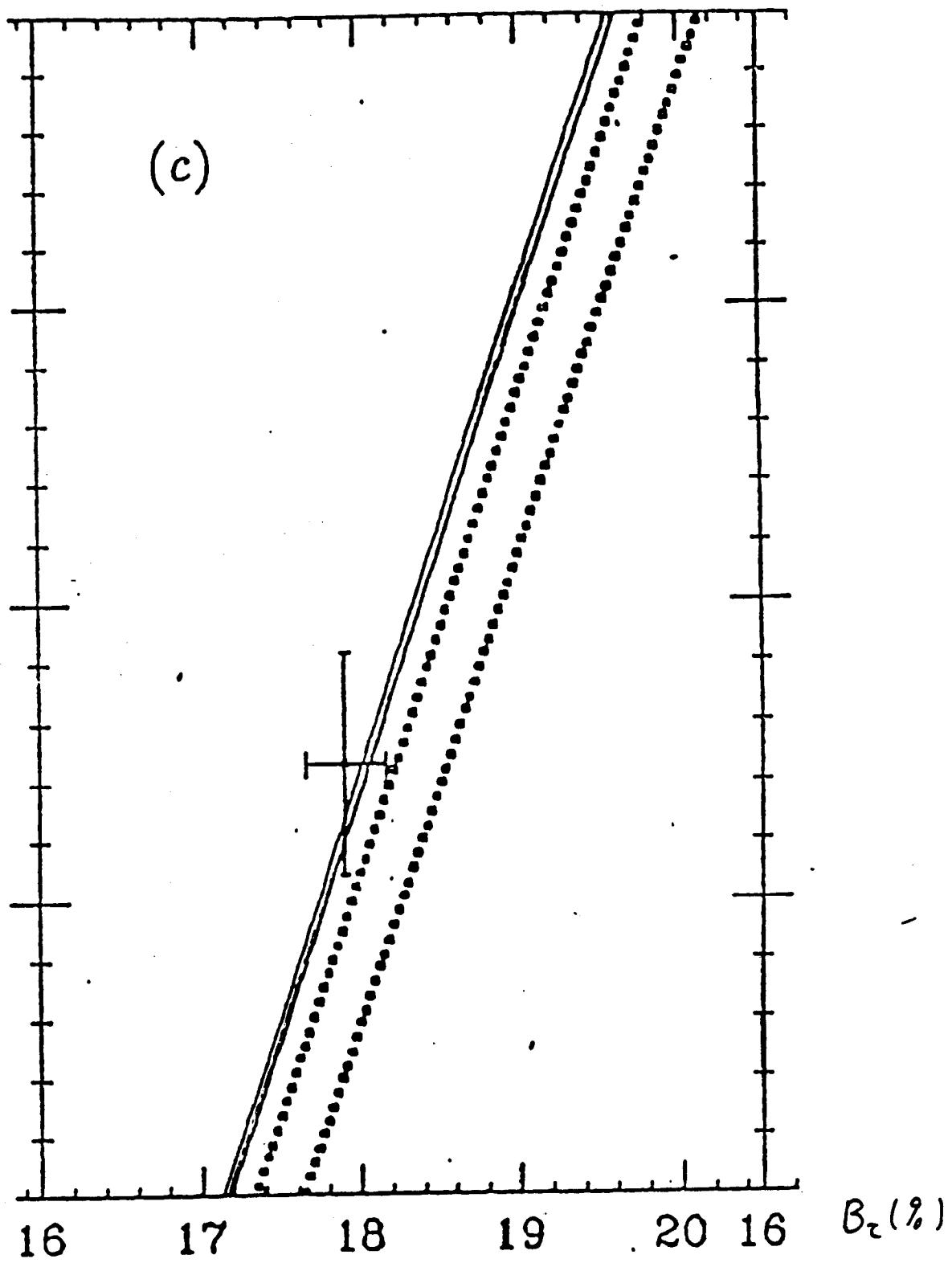
Double-tag

Absolute Br.





(c)



(3) BEPC + BES need the next step

- Luminosity  $10^{30} - 10^{31} \rightarrow 10^{32} \rightarrow 10^{33} \text{ cm}^{-2} \text{s}^{-1}$   
 $E \sim 3 - 6 \text{ GeV}$
- Detector      High resolution

⇒ for better Physics

- Search for gluonium or hybrid states
- Study for  $\tau$  and  $\nu_\tau$
- Comprehensive study for charm physics

## D<sub>s</sub> Results

(1) D<sub>s</sub><sup>+</sup>D<sub>s</sub><sup>-</sup> production cross section at  $\sqrt{s} = 4.03$  GeV  
 using  $\phi\pi$  and  $\bar{K}^{*0}K$  modes have an  $3.2 \text{ pb}^{-1}$   
 data samples

$$\sigma(e^+e^- \rightarrow D_s^+D_s^-) = 727 \pm 227 \text{ pb}$$

(2) Two candidates for purely leptonic decay of D<sub>s</sub>.  
 Three have found.

$$\begin{aligned} e^+e^- \rightarrow & D_s^- + D_s^+ \\ \hookrightarrow & \mu^-\bar{\nu}_\mu \quad \hookrightarrow \bar{K}^{*0}K^+ \\ & \quad \quad \quad \hookrightarrow K^-\pi^+ \end{aligned} \tag{1}$$

$$\begin{aligned} e^+e^- \rightarrow & D_s^+ + D_s^- \\ \hookrightarrow & \phi\pi^+ \quad \hookrightarrow \tau^-\nu \\ \hookrightarrow & K^+K^- \quad \quad \quad \hookrightarrow \mu\nu\nu \end{aligned} \tag{2}$$

$\Rightarrow$

$$f_{D_s} \sim 434 \begin{array}{l} +153 \\ -133 \end{array} \begin{array}{l} +35 \\ -33 \end{array} \quad (f_n = 132 \text{ MeV})$$

(3) D<sub>s</sub>  $\rightarrow \phi\pi$

$$4.2 \begin{array}{l} +9.0 \\ -1.5 \end{array} \begin{array}{l} +1.7 \\ -0.0 \end{array} \pm 0.5 \%$$

$\xi(2230)$  in  $J/\psi$  radiative decays have been studied  
in the following decay modes

$$J/\psi \rightarrow \gamma K^+ K^-$$

$$\gamma K_s^0 \bar{K}_s^0$$

$$\gamma p \bar{p}$$

$$\gamma \pi \pi$$

:

Channel	Mass (MeV)	Width (MeV)
$K^+ K^-$	$2228 \pm 9$	$27^{+23}_{-20}$
$K_s^0 \bar{K}_s^0$	$2229 \pm 9$	$21^{+29}_{-18}$
$p \bar{p}$	$2236 \pm 4$	$18^{+12}_{-10}$
:		

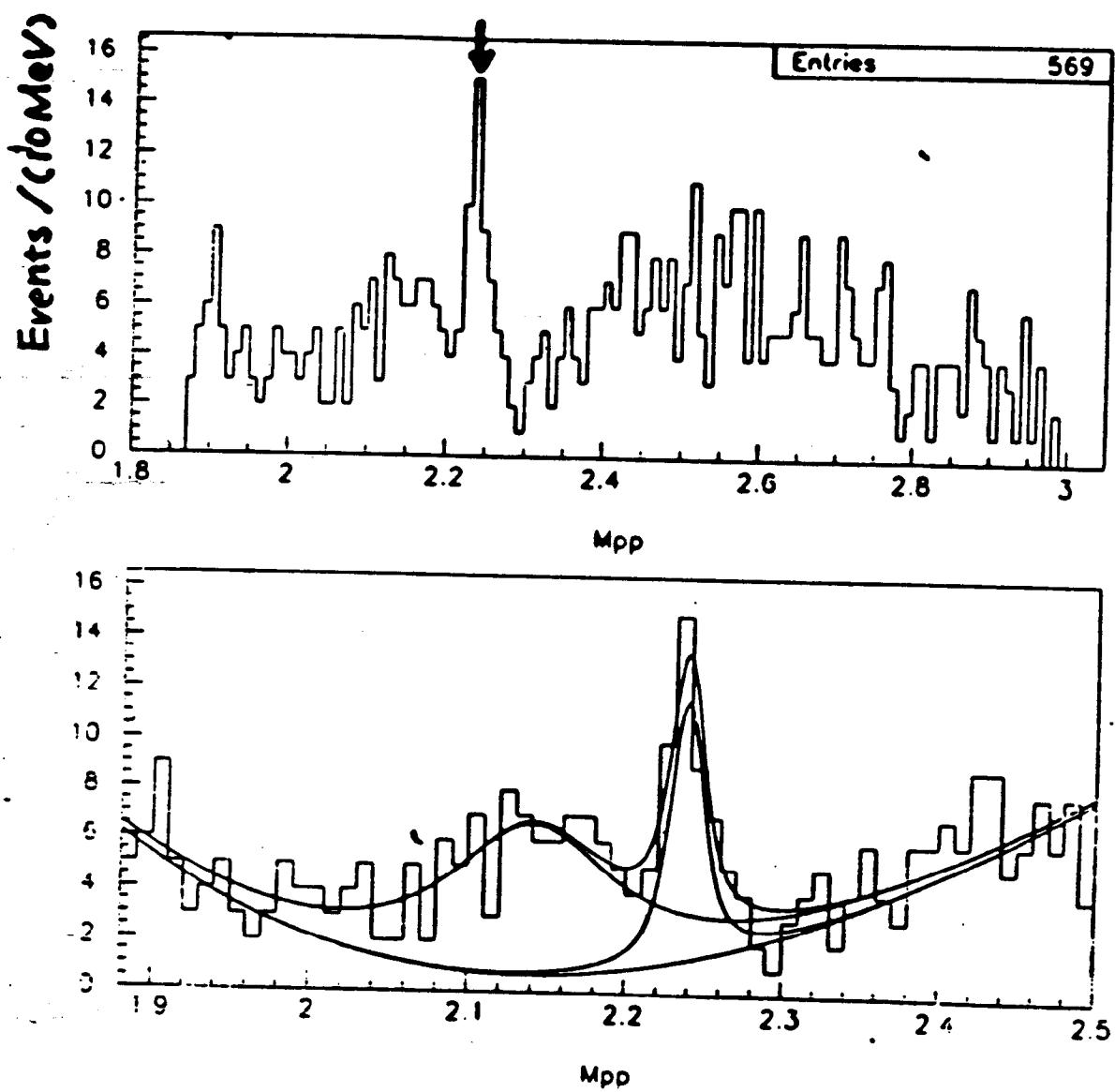
$$Br(J/\psi \rightarrow \gamma \xi) Br(\xi \rightarrow p\bar{p}) = (1.9 \pm 0.6) \times 10^{-5}$$

$$Br(J/\psi \rightarrow \gamma \xi) Br(\xi \rightarrow K^+ K^-) = (3.5^{+1.4}_{-1.3}) \times 10^{-5}$$

$$Br(J/\psi \rightarrow \gamma \xi) Br(\xi \rightarrow K_s^0 \bar{K}_s^0) = (2.3^{+1.3}_{-1.1}) \times 10^{-5}$$

$J/\psi \rightarrow \gamma \xi(2230)$

$\hookleftarrow p\bar{p}$



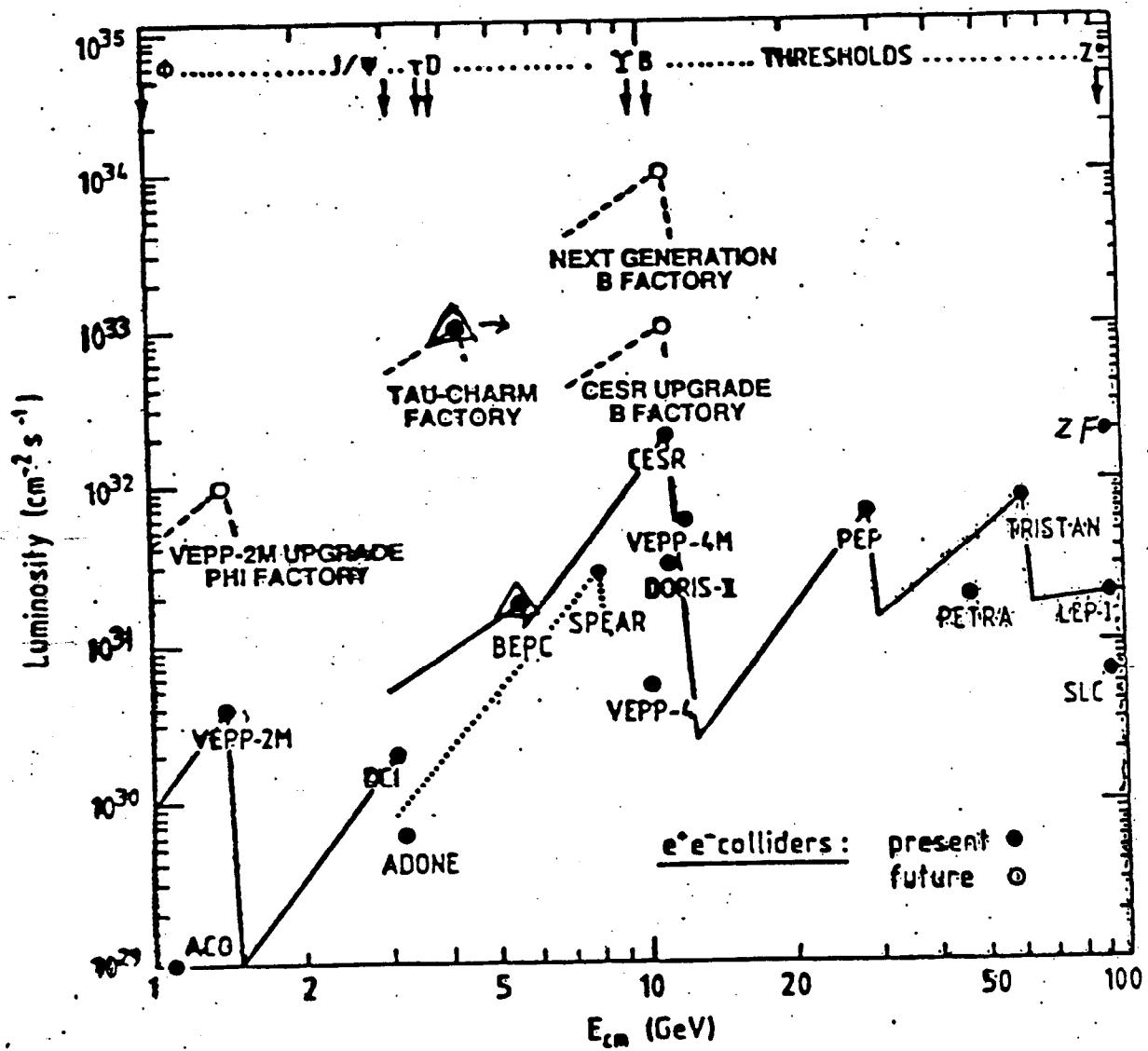


Figure 1

## 2. Search for gluonium or hybrid states - QCD dynamics

\* This is an area of physics which is still limited by statistics and where a TCF will have a major impact.

### (1) $J/\psi$ and $\psi'$

- radiative decays  $J/\psi \rightarrow r + X$
- hadronic decays  $J/\psi \rightarrow \omega/\phi + X$

$$X = \chi(1440), \theta(1720), \xi(2230), \dots$$

Candidates for glueballs

- Oddball  $1^{-+}$  ?

$$J/\psi \rightarrow rX \\ \downarrow \\ rV$$

$$\psi' \rightarrow rX_c \quad X_c \sim 10^8 \text{ at } TC_1 \\ \downarrow \\ \pi X$$

- \* It will be a triumph for QCD if a strong interacting gluonic bound state or a hybrid state is identified.

•  $\psi'$  VP,  $V T^{\text{new}}$  suppression dynamics

$\not{g}\pi, K^*K, \dots$

$\omega f_2$

• Rare decays

$J/\psi \rightarrow D_s + \dots$  weak decay  
 $\rightarrow \gamma + a$   $a = \text{axion}$

(2) Heavy hybrid  $H_Q = (Q\bar{Q}g)$

$$m(H_Q) \approx m(Q\bar{Q}) + 1 \text{ GeV}$$

$$H_c \sim 4 \text{ GeV}$$

at or around the  $D D^*$  threshold  
up to 5 GeV

to find the excited gluonic degrees of freedom.

(3) Charmonium

higher mass  $\psi$  states,  $D, D^*, D^{**}, \dots$

Test Heavy Quark Effective Theory

QCD dynamics

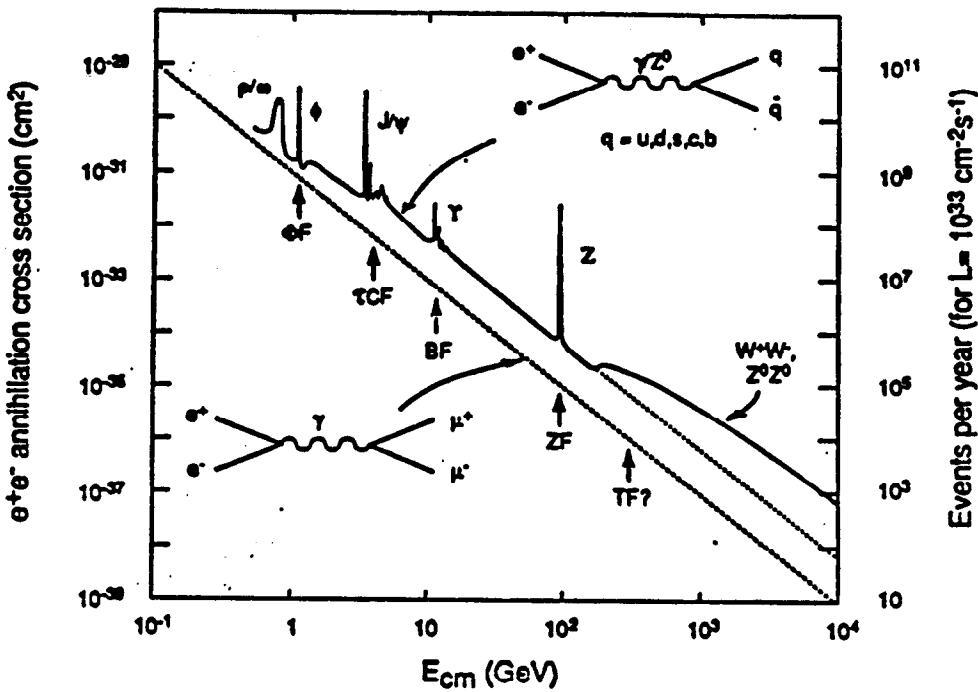


Figure 1: The  $e^+e^-$  annihilation cross-section in the energy range  $1 \text{ GeV} < E_{\text{cm}} < 10 \text{ TeV}$ .

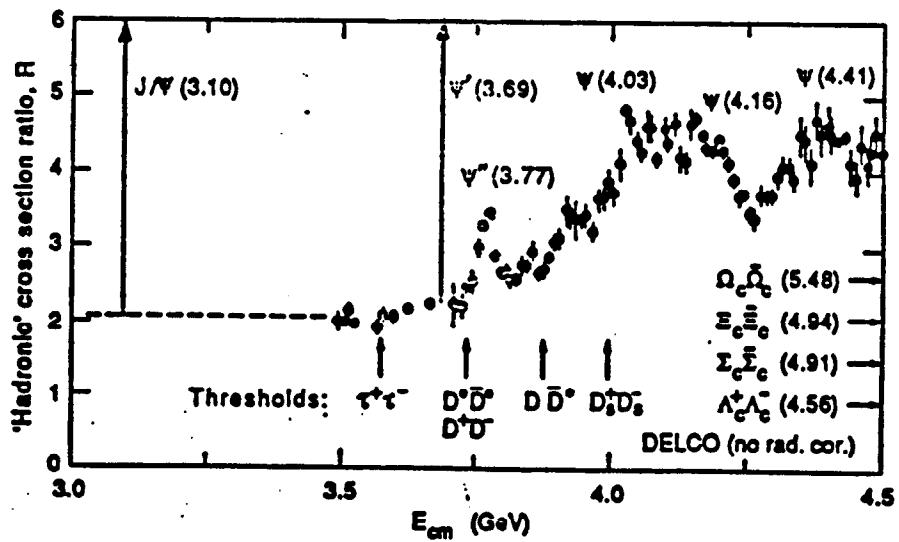


Figure 2: The energy range of the  $\tau$ -charm Factory. The ratio  $R = \sigma(e^+e^- \rightarrow \text{'hadrons'}) / \sigma(e^+e^- \rightarrow \mu^+\mu^-)$ , where 'hadrons' include both  $q\bar{q}$  and  $\tau^+\tau^-$  events. The data are from DELCO at SPEAR.

### 3. Study for $\tau$ and $\nu_\tau$

#### (1) $\tau$ mass and $\nu_\tau$ mass

$m_\tau$  accuracy  $\rightarrow < 0.1 \text{ MeV}$

$m_{\nu_\tau}$  limit

$30 \text{ MeV} \rightarrow 2 \text{ MeV}$

#### (2) $\tau \nu_\tau W$ structure of weak current

can be more accurately analyzed in the threshold region, since the  $\tau$ 's are almost at rest (small radiative corrections)

#### (3) high precision global analysis

branching ratios      precision at  $0.1\%$  level

$\Rightarrow$  Control the backgrounds + systematic erro.

- backgrounds are small

- backgrounds are measurable

- $J/\psi$  and  $\psi'$  peaks

- $\Rightarrow$  Calibrate and monitor the detector

~~B.F. ZF can produce a comparable data samples~~

Particle	Z <sup>0</sup> Factory	B Factory	τ-charm Factory
D <sup>0</sup> (single)	$1.2 \times 10^7$	$1.5 \times 10^7$	$5.8 \times 10^7$ ( $\psi''$ )
D <sup>+</sup> ("")	$0.5 \times 10^7$	$0.7 \times 10^7$	$4.2 \times 10^7$ ( $\psi''$ )
D <sub>s</sub> <sup>+</sup> ("")	$0.3 \times 10^7$	$0.3 \times 10^7$	$1.8 \times 10^7$ (4.14 GeV)
τ <sup>+</sup> τ <sup>-</sup> (pairs)	$0.3 \times 10^7$	$0.9 \times 10^7$	$0.5 \times 10^7$ (3.57 GeV) $2.4 \times 10^7$ (3.67 GeV) $3.5 \times 10^7$ (4.25 GeV)
J/ψ	—	—	$1.7 \times 10^{10}$
ψ'	—	—	$0.4 \times 10^{10}$

Table Comparison of the τ and charm yearly samples at several future e<sup>+</sup>e<sup>-</sup> colliders.  
The assumed integrated luminosities are 2 fb<sup>-1</sup> ( $L_{peak} = 2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ ;  $6.2 \times 10^7$  Z<sup>0</sup>'s) at the Z<sup>0</sup> Factory, and 10 fb<sup>-1</sup> ( $L_{peak} = 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ ) at B or τ-charm Factories.

Very high Statistics

Advantages of τ-CF not only very large data  
but also excellent control of  
systematic errors

- low and measurable background
- τ leptons and D̄D are produced nearly at rest separately kinematically
- τ leptons can be single-tagged since τD are produced below the threshold for b & c production. D too
- J/ψ, ψ'   
to tag      Calibrate and monitor the detector performance  $\Rightarrow$  systematic errors

(4) hadronic  $\tau$  decays

interface PQCD and non-pQCD  
 $\int \alpha_s(m_\tau)$

Second-class weak current

$$\tau \rightarrow \nu_\tau + \pi + \eta$$

(5) Rare decays

$$\tau \rightarrow e\gamma, \mu\gamma$$

$$eX^*, \mu X^*$$

Table Examples of the expected precision at the  $\tau$ cF for some  $\tau$  parameters. Some improved estimates from preliminary analyses are indicated within brackets.

Parameter	Present accuracy	$\tau$ cF sensitivity
$m_\tau$	0.3 MeV	0.1 MeV
$m_{\nu_\tau}$	< 31 MeV	2 MeV
$B_{e,\mu}$	1%	0.1%
$B_\pi$	3%	0.1%
$B_K$	34% (12%)	0.5%
$ g_\tau/g_\mu $	0.6%	0.1%
$ g_\mu/g_e $	0.6%	0.1%
$\rho_{e,\mu}$	6%	0.3% (0.03%)
$\xi_l$	20%	3% (0.2%)
$h_{\nu_\tau}$	22%	0.3%
$\eta_\mu, \delta_l$	-	$\pm 0.03$ ( $\pm 0.002$ )
$\xi'_\mu$	-	15%
$B(\tau^- \rightarrow \pi^- \eta \nu_\tau)$	$< 3 \times 10^{-4}$	$10^{-6}$
$B(\tau^- \rightarrow l^- X)$	< 2%	$10^{-6}$
$B(\tau^- \rightarrow 3l^\pm)$	$< 10^{-5}$	$10^{-7}$
$B(\tau^- \rightarrow \mu^- \gamma)$	$< 4 \times 10^{-6}$	$10^{-7}$
$a_\tau^\gamma$	< 0.1	0.001
$d_\tau^\gamma$	$< 6 \times 10^{-6}$ e cm	$10^{-7}$ e cm

Reduced systematic errors

#### 4. Comprehensive Study for Charm Physics

(1) Pure leptonic decays of  $D$ ,  $D_s$

$$\text{Br} (D \rightarrow \mu\nu) \quad f_D$$

$$\text{Br} (D_s \rightarrow \mu\nu, \tau\nu) \quad f_{D_s}$$

related to  $f_B$ ,  $f_{B_s}$

test QCD,  $SU(3)$  symmetry breaking

(2) Systematic study of charm meson decay

- decay mechanism dynamics
- $V_{cd}$   $V_{cs}$
- Absolute branching ratios for  $D$ ,  $D_s$ ..  
from the per cent level  
to 10% level

(3) There is the potential for observing

$D^0 - \bar{D}^0$  mixing

C P violation up quark!

Rare decays

## 5. Summary

(1) BEPC has got a great of progress and it is natural to make a proposal for the next step

• Upgrade  $\rightarrow$  BEPC II  $10^{31} \rightarrow 10^{32}$

•  $\tau$ -C Factory  $10^{31} \rightarrow 10^{33}$  New detector

$\Rightarrow$  More contributions to  $\tau$ -Charm Physics

- BEPC II
- glueball and hybrid states
  - $H_c$  and Charmonium
  - Raise precision for  $\tau$  and charm meson decays
  - Weak current structure of  $\tau$
  - $f_{D_s}, f_D, V_{cs}, V_{cd}$

$\tau$ -C factory more (broad and deep)

(2) Physics programme of the  $\tau$ -Charm factory and the B factory will complement each other to study the heavy flavored particles and may explore new physics

dynamics <sup>light hadron spectrum</sup>  
glueball  
hybrid

<sup>SM</sup>

(3) For  $T - C$  physics,  $T - CF$  has advantage of the threshold region to make future precision measurements (not only statistics but systematic errors since backgrounds are both small and experimentally measurable).

3.10	$J/\psi$
3.55	below $\tau^+\tau^-$
3.56	above $\tau^+\tau^-$
3.67	highest cross-section ( $\tau^+\tau^-$ )
3.69	$\psi'$
3.77	$\psi''$
4.03	tagged $D_s$
4.14	$D_s D_s^*$
4.57	$\Lambda_c \bar{\Lambda}_c$
4.91	$\Sigma_c \bar{\Sigma}_c$
4.94	$\Xi_c \bar{\Xi}_c$

# Low and measurable background threshold region

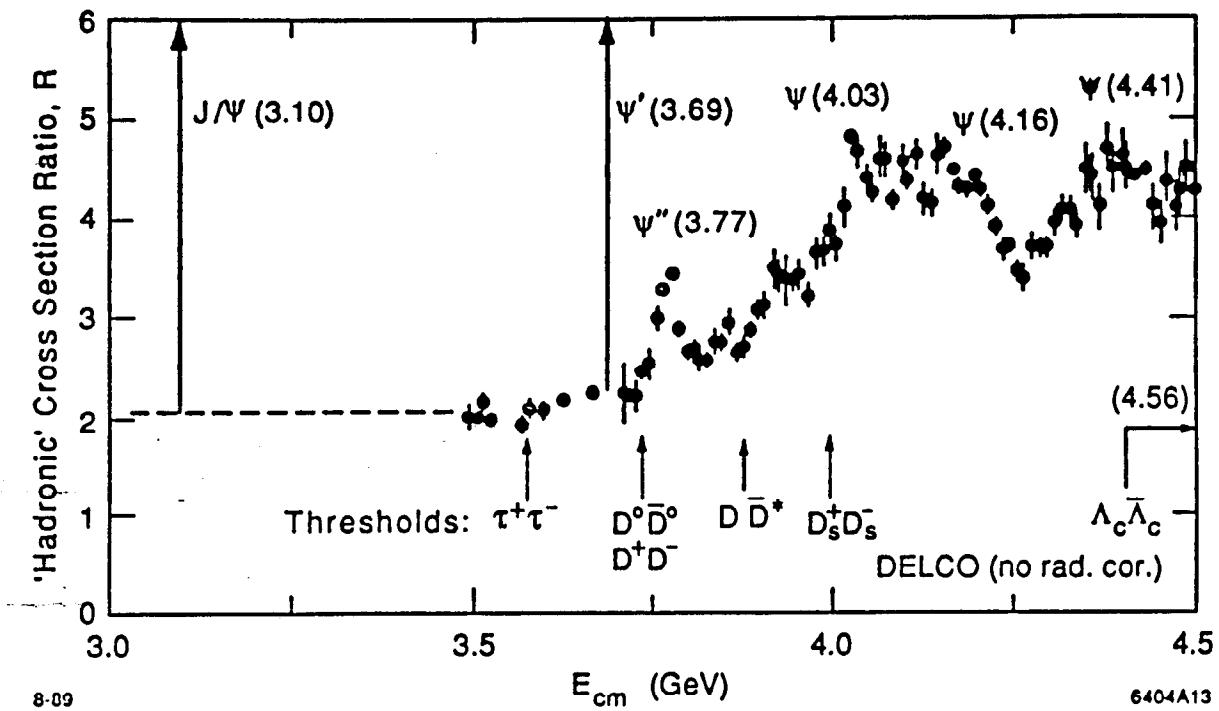


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**Table 3: Physics-reach versus luminosity of the  $\tau$ -charm Factory.**

Luminosity (cm $^{-2}$ s $^{-1}$ )	Physics-reach per 1 year's data
$10^{32}$	<ul style="list-style-type: none"> <li>▷ glueballs, hybrid exotics and hybrid charmonium</li> <li>▷ excited <math>\psi</math> and D states</li> <li>▷ semi-leptonic D decays to <math>O(1\%)</math> precision</li> <li>▷ <math>\tau</math> decay Br's to <math>O(0.1\%)</math> precision</li> <li>▷ <math>\Lambda_c^\pm, \Sigma_c, \Xi_c, \Omega_c</math>, etc. decays to <math>O(5\%)</math> precision</li> <li>▷ V-A structure in <math>\tau</math> decays comparable to precision in <math>\mu</math> decays</li> <li>▷ doubly Cabibbo suppressed <math>D^0, D^\pm, D_s^\pm</math> decays to <math>O(3\%)</math> precision</li> <li>▷ pure leptonic D decays, <math>f_D</math> and <math>f_{D_s}</math> to <math>O(2\%)</math> precision</li> <li>▷ <math>\tau \rightarrow eX</math> limit <math>\simeq 10^{-5}</math>; constraints on <math>\nu_\tau</math> masses below 1 MeV/c<math>^2</math></li> <li>▷ <math>D^0 \bar{D}^0</math> mixing at SM level, <math>10^{-5}</math></li> <li>▷ rare <math>\tau/D/J\psi</math> decays (LFV, FCNC, etc.) to limits <math>\simeq 10^{-7} - 10^{-8}</math></li> <li>▷ direct <math>\nu_\tau</math> mass limit <math>\simeq 2</math> MeV/c<math>^2</math></li> <li>▷ CP violation in D decays at SM level</li> <li>▷ CP violation in <math>\Lambda, \Xi</math> decays at SM level</li> <li>▷ ??</li> <li>▷ ??</li> <li>▷ ??</li> </ul>
$10^{33}$	
$10^{34}$	