Super C-τ: selected topics on physics program

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Physics at e+e- factories

- Precise measurement of CKM-matrix parameters
  - Test of unitarity using different processes (tree/loop, CP/$\not{C}$P),)
- Rare B-meson decays
- D-meson physics
  - Precision measurements
  - Mixing
  - Search for CP violation
  - Rare decays
- τ-lepton physics
  - Precision measurements
  - Search for CP violation
  - Rare decays
- Hadron spectroscopy, search for exotics

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix} .$$

$$\sum_k |V_{ik}|^2 = 1, \quad \sum_k V_{ki} V_{kj}^* = 0$$

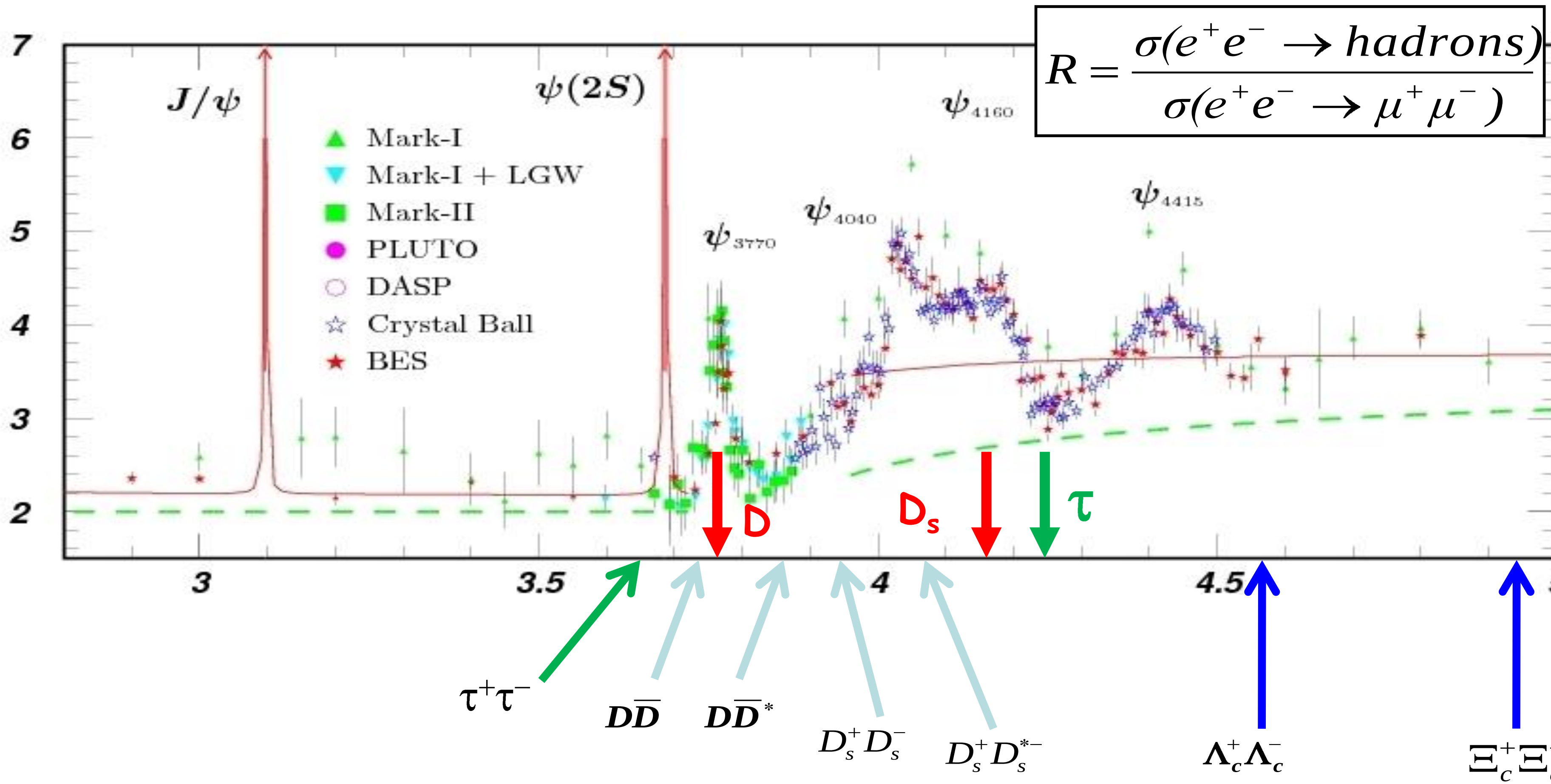
$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$$

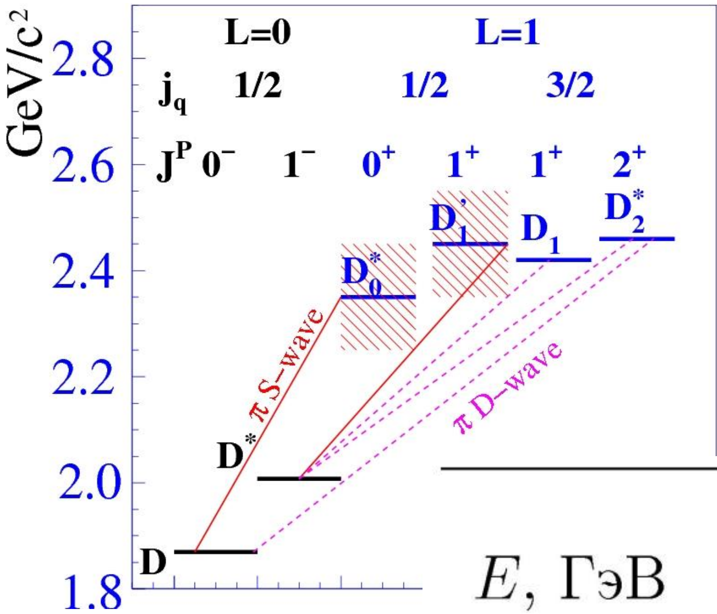
Super C-τ parameters

- Crab Waist collision schime
- Wide energy region: 2E = 2 - 5 GeV
- Luminosity in units of 10^{35} $cm^{-2}sec^{-1}$:
  - 0.6 at 2 GeV
  - 0.9 at 3 GeV
  - 1.0 at 4GeV and higher
- longitudinal electron beam polarization

Energy region

2E = 2 - 5 GeV,





D-мезоны

$D^{\pm}$ (cd), D^0 (du), $D_s^{\pm}$ (ds)

D-meson pair production (σ_{max})

	D^+D^-	$D^0\bar{D}^0$	$D\bar{D}^*$	$D_s^+D_s^-$	$D_s^+D_s^{*-}$
E, ГэВ	3.77	3.77	4.02	4.01	4.17
σ, нб	2.9	3.7	∼6.7	∼0.25	∼0.9

✓Super C-τ factory with L=10^{35} cm^{-2}sec^{-1} can produce 6×10^9 D pairs and 10^9 D_s pair per year (10^7 sec).

✓Super B factory ($\sigma_{cc}+\sigma_{BB}$=2.35 nb) with L=8×10^{35} cm^{-2}sec^{-1} can produce about 2×10^{10} pairs of charmed hadrons per year.

Advantages of D-meson study at Super C-τ

- Particle multiplicity at 3.77 GeV is about two times lower than at 10.6 GeV
- Two body production $e^+e^- \to D\bar{D}$. This allows to use double tag method:
    - fully reconstruct one D
    - then either fully reconstruct the other D (absolute branching ratios)
    - or look for events with one missing particle (leptonic, semileptonic decays)
- Coherent production of D pairs allows to use quantum correlations for D-meson mixing and CP violation studies: C-odd at 3.77 GeV and C-even at 4.01 GeV ($D^* \to D\gamma$)

Leptonic and semileptonic decays

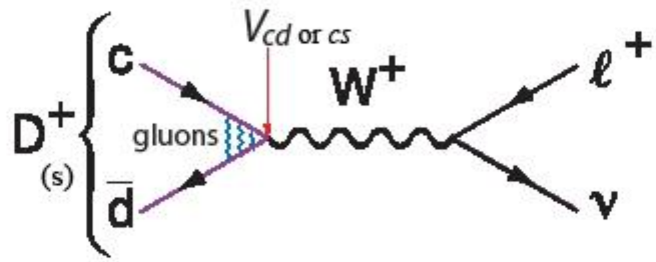
Measurement decay constants and form factors.

Improve understanding of hadronization mechanisms.

Validation of lattice QCD.

With improved theoretical input → determination Vcs and Vcd.

Important for B-physics: extracting Vub from semileptonic B decay.



$$\Gamma(P^+ \to \ell^+ \nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

LQCD	Experiment
f_D=208±4 MeV	f_D=207±9 MeV
f_{Ds}=241±3 MeV	f_{Ds}=257±5 MeV

-measurement of decay probabilities with 0.5% accuracy

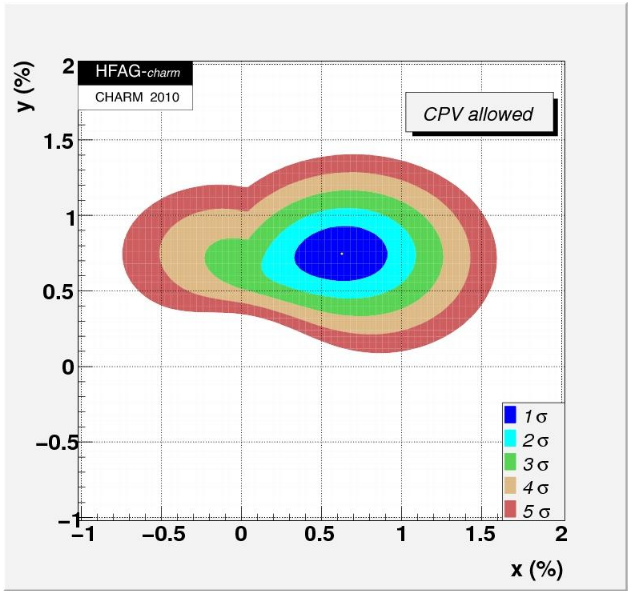
-precision measurement of form factors

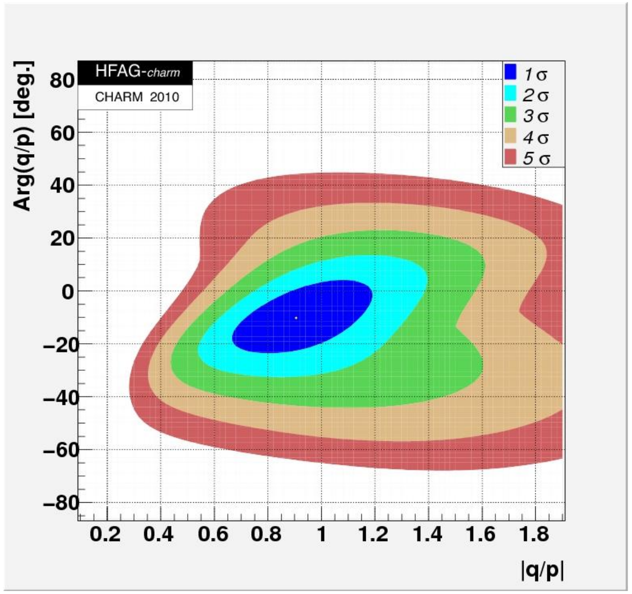
D_0-$\bar{D}^0$ mixing

HFAG average for CHARM 2010

Mass eigenstates: $|D_{1,2}\rangle = \frac{1}{\sqrt{|p|^2+|q|^2}}(p|D^0\rangle \pm q|\bar{D}^0\rangle)$

Mixing observables: $x = \frac{\Delta M}{\Gamma}, \quad y = \frac{\Delta\Gamma}{\Gamma}, \quad R_M = \frac{1}{2}(x^2+y^2), \quad |q/p|, \quad \arg(p/q)$





x=0.63±0.20
y=0.75 ±0.12

|q/p|=0.91±0.17
Arg(q/p)=-10°±9°

D^0-$\bar{D}^0$ mixing at Super C-τ

- Only time integrated measurements
- Using quantum correlations in $e^+e^- \to D^0\bar{D}^0(\pi^0)$ (C-odd) and $e^+e^- \to D^0\bar{D}^{*0} \to D^0\bar{D}^0\gamma$ (C-even)

1ab^{-1} at ψ(3770):

D.M.Asner and W.M.Sun PRD 73, 034024 (2006)
X.D.Cheng et al. PRD 75, 094019 (2007)

$$R_M = \frac{x^2+y^2}{2} = \frac{N[D^0\bar{D}^0 \to (K^-\pi^+)(K^-\pi^+)]}{N[D^0\bar{D}^0 \to (K^-\pi^+)(K^+\pi^-)]}, \frac{N[D^0\bar{D}^0 \to (K^-e^+\nu)(K^-e^+\nu)]}{N[D^0\bar{D}^0 \to (K^-e^+\nu)(K^+e^-\nu)]}$$

About 300 events are expected to detect: $\Delta R_M \sim 3\times10^{-6}$ (6%)

$$y = \frac{1}{4}\frac{\Gamma(l;S_+)\Gamma(X;S_-)}{\Gamma(l;S_-)\Gamma(X;S_+)} - \frac{1}{4}\frac{\Gamma(l;S_-)\Gamma(X;S_+)}{\Gamma(l;S_+)\Gamma(X;S_-)}$$

$\Delta y \sim 4\times10^{-4}$ (~5%)

At 4.02 GeV in $e^+e^- \to D^0D^{*0} \to D^0D^0\gamma$ reaction Dalitz plot analysis also can be used to extract mixing parameters. A.Bondar, A.Poluektov, V.Vorobiev. PRD 82, 091104 (2010)

Expected sensitivity:

1 ab^{-1} at Super C-τ ⟺ 10 ab^{-1} at Super B

Search for CP-violation

Direct CP violation in D decays is expected to be small in SM

- For CF and DCS decays - ~~CP~~ = NP ($D^{\pm}\to K_{S,L}\pi^{\pm}$, $A_{CP}=3.3\times10^{-3}$).
- For SCS decays - $A_{CP}\sim10^{-3}$.

$$A_{CP} = \frac{\Gamma(D\to f)-\Gamma(\bar{D}\to\bar{f})}{\Gamma(D\to f)+\Gamma(\bar{D}\to\bar{f})}$$

Belle: $D^0\to K^+K^-,\pi^+\pi^-$
$A_{CP}(K^+K^-)=(0.43\pm0.30\pm0.11)\%$
$A_{CP}(\pi^+\pi^-)=(0.43\pm0.52\pm0.12)\%$

CLEO: $D^+\to K_S\pi^+$, $K_S\pi^+\pi^0$
$A_{CP}(K_S\pi^+)=(-0.6\pm1.0\pm0.3)\%$
$A_{CP}(K_S\pi^+\pi^0)=(0.3\pm0.9\pm0.3)\%$

At Super C-τ CP asymmetry can be tested with 10^{-3} sensitivity for many final states.

CP violation in mixing:

$$A_{SL} = \frac{\Gamma_{l^+l^+}-\Gamma_{l^-l^-}}{\Gamma_{l^+l^+}+\Gamma_{l^-l^-}} = \frac{1-|q/p|^4}{1+|q/p|^4}$$

$1ab^{-1}$ at $\psi(3770)$:
$\Delta|q/p| < 5\%$

Use of quantum correlations, analyses of Dalitz-plots and T-odd moment distributions for multibody decays increase sensitivity for CPV effects.

Rare D decays

- FCNC ($c \to u\, l^+ l^-$)
  - $D^0 \to \mu^+\mu^-$ SM ~10^{-12} NP - 10^{-6}
    - CDF $B < 4.3\times10^{-7}$
  - $D \to X_u l^+ l^-$ SM ~10^{-6} NP - 10^{-6}
    - D0 $B(D^+ \to \pi^+\mu^+\mu^-) < 3.9\times10^{-6}$
    - CLEO $B(D^+ \to \pi^+ e^+ e^-) < 7.4\times10^{-6}$
- LFV   NP - 10^{-6}
    - BABAR $B(D^0 \to \mu^+ e^-) < 0.81\times10^{-6}$
    - BABAR $B(D^+ \to \pi^+ e^+ \mu^-) < 1.1\times10^{-5}$

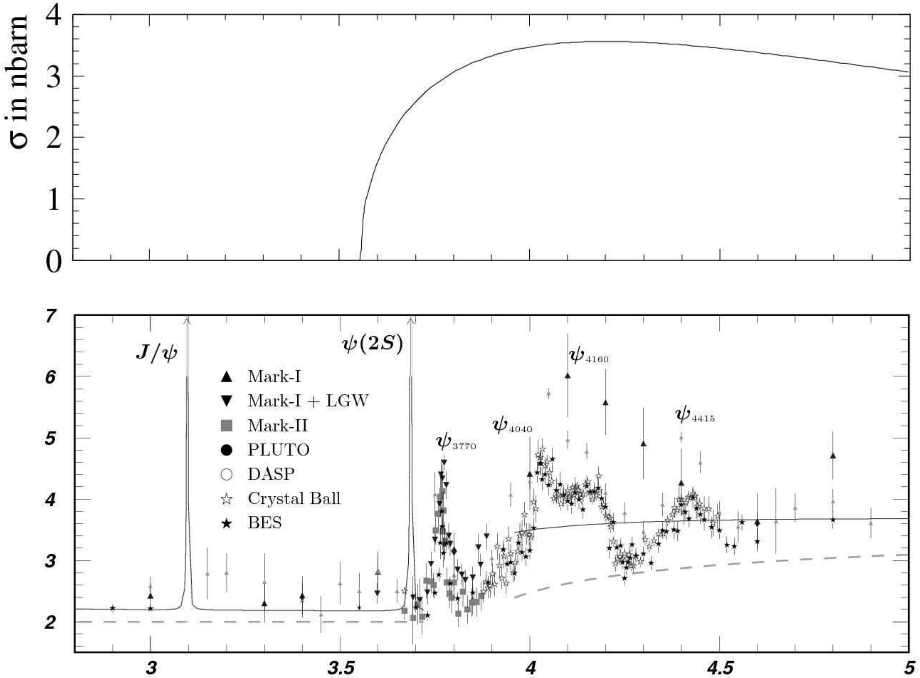
Super C-τ f can provide 10^{-8} sensitivity

Charmed baryons

- Λ_c^+ (udc), M ≈ 2.29 ГэВ, cτ ≈ 60 мкм
- Ξ_c^+ (usc), M ≈ 2.47 ГэВ, cτ ≈ 132 мкм
- $\sigma(e+e- \rightarrow \Lambda_c^+ \Lambda_c^-) \approx 0.5$ nb, 5×10^8/year
  - Precision measurement of absolute BFs
  - Rare decays
  - CPV, with use of the polarized beams

τ physics

Super B: $\sigma(e+e- \rightarrow \tau+\tau-) \approx 0.9$ nb $\Rightarrow$ 7×10^{10} τ pairs



Super C-τ: 2×10^{10} τ pairs

LFV decay $\tau\rightarrow\mu\gamma$

At Super B there is $e+e-\rightarrow\tau+\tau-\gamma$ background. Upper limit $\propto 1/\sqrt{L}$ ~ 2×10^{-9}

At Super C-τ this background is absent, similar or better sensitivity is expected.

Special run near threshold: 3.55 GeV, σ=0.1 nb, $N_{\tau\tau}=10^8$

- ✓τ's are produced at rest $\rightarrow$ kinematic constraint for hadronic decay $\rightarrow$ very clean data sample
- ✓Non-τ background measured below threshold

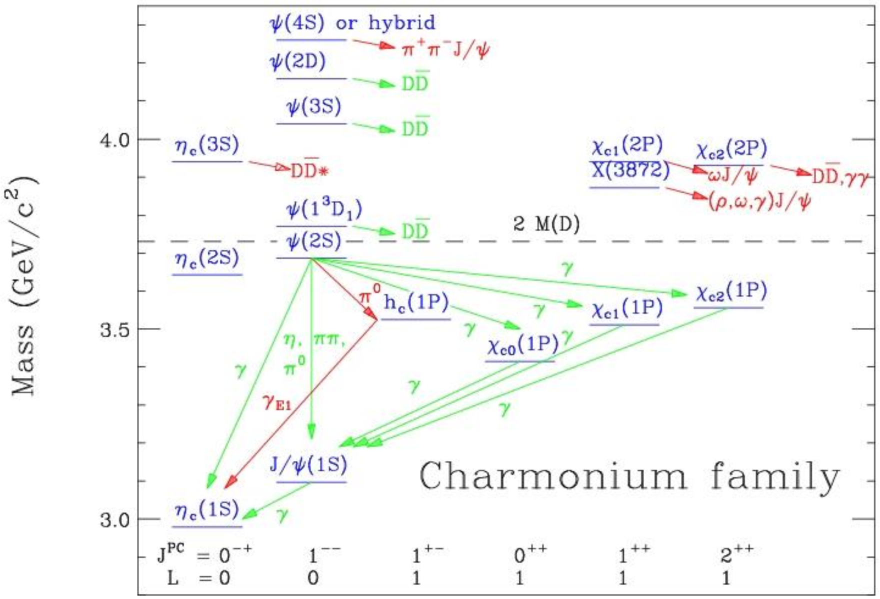
Special run near threshold

- High precision measurement of BF and hadronic spectral functions
  - $e\nu\nu/\mu\nu\nu/\pi\nu/K\nu$ – lepton universality
  - α_s
  - m_s, V_{us}
- Study of Lorentz structure of lepton decay
  - 4 Michel parameters, two depend on τ polarization

Search for CPV in τ decays

- CP-violation $\rightarrow$ new physics, charged Higgs
- Two amplitudes with different weak and strong phases
- $\tau^- \rightarrow K_S \pi^- \nu$, $A_{CP}=3\times10^{-3}$
- $\tau^- \rightarrow K^- \pi^0 \nu$
- Observables
  - Rate asymmetry: $\Gamma(\tau^+ \rightarrow f^+)-\Gamma(\tau^- \rightarrow f^-) \sim \sin\delta \sin\phi$
  - Modified rate asymmetry $\sim \sin\delta \sin\phi$
  - Triple product asymmetry $\sigma\cdot(p_1 \times p_2) \sim \cos\delta \sin\phi$
- Polarization may increase sensitivity by several times

Hadron spectroscopy in charmonium decay



Vectors: $J/\psi - 10^{12}$, $\psi(2S) - 10^{11}$, $\psi(3770) - 2\times10^{9}$, ψ's $- 10^{8}$

In ψ's decays: $\eta_c(1S)$, $\chi_{cJ} - 10^{10}$, $h_c - 10^{8}$

- Low-lying charmonium states decay into light hadrons with relatively small multiplicity

- Choosing specific cc-meson decay mode one can study states with practically any quantum numbers
- Example: $B(J/\psi\to\eta'\gamma)=0.5\% \to 5\times10^{9}$ tagged η' mesons. Recently CLEO performed precise measurement of η' mass and observed decay $\eta' \to 3\pi$.
- Search for glueballs (gg), hybrids (qqg), 4q states

Charmonium states above open charm threshold

Recently observed new charmonium states:

- C^+: **X(3872), X(3940), Y(3940) , Z(3930)**
  - •$\chi_{cJ}(2P), \eta_c(3S)$? Study of radiative decays of $\psi(4040)$, $\psi(4160)$, $\psi(4415)$.
  - •Search for hadronic transition $\psi \rightarrow X,Y,Z$
- 1^{--}: **X(4260),Y(4361),Y(4664)**
  - • $\sigma(e^+e^- \rightarrow X) \sim 50$ pb.
  - • Scan of energy region 3.8-5 GeV with integrated luminosity **100 fb^{-1}**

Recent bottonium example from Belle :

2 charged bottonium-like resonances were observed in $\Upsilon(5S)$ decays

Rare J/ψ decays

$N(J/\psi) \sim 10^{12}$

- Weak decays:
  $J/\psi \to D_s^{(*)} l \nu$, $D_s^{*+} \rho^-$, $D_s^+ \pi^-$ $\quad B \sim (3\text{-}4) \times 10^{-9}$
- CM predicts $Br \sim 10^{-11}$ for weak decays with $\Delta S=0$
  $J/\psi \to D^0 \rho^0$, $D^0 \pi^0$ are sensitive to NP.
- $cc \to ss$ transition: $J/\psi \to \phi\phi$, $B \sim 10^{-8}$
- LFV decay: $J/\psi \to l^+ l'^-$
  $J/\psi \to \tau l$ at SuperC-τ may be more sensitive to LFV than $\tau \to e{+}e{-}l$ at SuperB
- Search for CP violation

Physics from 2-3 GeV

- Precise measurement total hadronic cross section
  - α_s measurement
  - quark masses
  - hadronic contribution to $\alpha_{EM}(s)$
  - hadronic contribution to $(g-2)\mu$
- Together with VEPP-2000 (0.2 – 2 GeV) Super C-τ will cover energy region from 0.2 to 5 GeV.
- High precision measurement of baryon electromagnetic form factors
- With special detector: study of polarized nucleon interaction with material

D mesons

- Spectroscopy
- (Semi)leptonic decays
- Rare decays
- Mixing
- Search for CPV
- ...

Tau

- Spectral functions
- Lepton universality
- Lorentz structure
- Search for CPV
- Search for LFV
- ...

Λ_c

- Absolute BFs
- Semileptonic decays
- Search for CPV
- Rare decays
- ...

Charmonium

- Spectroscopy, decays
- Light hadron spectroscopy
- Rare J/ψ decays
- ...