Is there any Physics between \( \psi \)‘s and \( \Upsilon \)’s

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This energy region was studied at $e^+e^-$ colliders just once at SPEAR collider (1972-1990) at SLAC in the late 1970s with MARK-I and Crystall Ball detectors.
R data from SLAC–SPEAR

- MARK–1 Siegrest PRL 36(1976)700 Run I (22 points)
- MARK–1 Siegrest PRL 36(1976)700 Run II (37 points)
- MARK–1 Rapidis PRL 39(1977)526 (21 points)
- MARK–1 Siegrest PRD26(1982)969 (78 points)
- MARK–1 Siegrest PRD26(1982)969 (109 points)

- Crystal Ball Usterheld SLAC–PUB–4164(1986) (22 points)
- Crystal Ball Edwards SLAC–PUB–5160(1990) Run 1 (4 points)
- Mark–2 Schindler PR D 21 (1980) 2716 (22 points)

pQCD (RHAD)
R Data from DESY–DORIS for √s = 3 to 11 GeV

- PLUTO Criqee P93(1982)161 (48 points)
- DESY–HEIDELBERG Gleisler PL B76(1976)560 (24 points)
- DSP Brandeis PL B76(1976)561 (72 points)
- DSP–2 Albrecht F16(1982)193 (1 point)
- LENA Niczyporuk ZP C15(1982)299 (95 points)
- CRYSTAL–BALL Jababeleski ZP C40(1988)49 (1 point)
- ARGUS Albrecht ZP C54(1992)13 (1 point)

R Data from DESY–DORIS for √s = 7.3 to 7.8 GeV

- PLUTO Criqee P93(1982)161 (1 point)
- LENA Niczyporuk ZP C15(1982)299 (14 points)

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Up to now theory (pQCD) is used to verify data. PDG uses only Xball data, showing MARK data (in grey) as absurdity and nonsense.

This is incorrect method to resolve contradictions. Important mission for Super-c-tau Factory is to verify pQCD calculations with high precision to be used in g-2 calculations.
Exclusive two body cross section

e^+e^- \rightarrow D(*)D(*) cross sections in the region 5-7 GeV are expected to be smooth and structurless, but their behavior is of importance for theory.

Asymptotics of heavy meson form-factors
A.G. Grozin, M. Neubert

No reliable model for intermediate region
Exclusive two body cross section

Can be measured by Super-B Factory via ISR, but x-talk between channels is a serious problem.
Exclusive multi-body cross section

\( e^+e^- \rightarrow D^{(*)}D^{(*)} \eta \pi, \ e^+e^- \rightarrow D^{(*)}D_s^{*}\) cross sections can show structures due to numerous \(D^{**}\) thresholds in the interval 4.4-5.6 GeV.

\[ \psi(4415) \rightarrow D_2 D \text{ is the most distinct feature.} \]

But many more in other exclusive channels can be observed.
Excited D-mesons study

e^+e^− → D(*)D(*) π dynamics can be used to search for and measurement of the quantum numbers for new excited D** states at √s ~ 4.4-5.6 GeV. Now all 1P (first orbital excitations) are known; many new (1D, radial) are waiting for their discovery.

e.g. in e^+e^− → DDπ, in Dπ there can be 1−, 2+, 3− etc. resonances. To search for new resonance (e.g. D(2S)-radial excitation with M~2.6 GeV) one needs to fit Dalitz-plot \( M^2(D\pi)\%M^2(D\pi) \). Even broad resonances can be identified! Partial reconstruction (one D and π) is sufficient. For study of excited D, D_s with masses 2.5-3.5 GeV, √s > 5.0 GeV required.
Two-body baryonic cross section

$e^+e^- \rightarrow \Lambda_c \bar{\Lambda}_c$ near threshold bump surprised everybody, and still not understood

Two-body baryonic cross section

There are many more such charmed ground state baryons, that have a pair production in 5-7.3 GeV region.

It is interesting to compare cross section behavior at threshold for $\Xi_c^{0/+} \Xi_c^{0/+}$, $\Omega_c^0 \Omega_c^0$ and doubly charmed baryon pairs.

And many more final states with excited baryons...

$M(\Xi_c^{0/+} \Xi_c^{0/+}) = 4.936/4.940$ GeV
$M(\Omega_c^0 \Omega_c^0) = 5.390$ GeV
$M(\Xi_{cc}^{0/+} \Xi_{cc}^{0/+}) = 7.242$ GeV
Study of charm baryon decays

If cross section is enhanced near threshold for $e^+e^- \rightarrow B_c \bar{B}_c$ this process is the perfect tool to study weak decays of charmed (doubly charmed) baryons including absolute Br’s measurement.

$\Xi_c^{0/+}$ $\Omega_c^0$ no absolute Br were measured; only few modes were measured relative to $\Xi\pi$ / $\Xi 2\pi$ / $\Omega \pi$.

Double charmed $\Xi_{cc}^{0/+}$ only one of two isospin partners was observed in a single mode.
A mediator between DM and SM should exist; Different portals open depending on dark mediator $X$

- Scalar portal $\rightarrow$ Dark Higgs
- Pseudoscalar portal $\rightarrow$ Axion
- Vector portal $\rightarrow$ Dark Photon
- Neutrino portal $\rightarrow$ Sterile Neutrino
Search for dark photon

DP can be searched in the process $e^+e^- \rightarrow A'\gamma$; $A'$ decaying into SM or DM particles. The cross section became high if $\sqrt{s}\sim M_{A'}$, but the signature in case of invisible $A'$ decay is implicit: just single soft photon.

If $A'$ has a mass $\sim 5\text{--}7\text{GeV}$ and decay to SM particles, e.g. $\mu^+\mu^-$, c-tau factory can compete with B-factories.
Summary

There are a plenty of interesting tasks for the energy range 5-7 GeV

- Inclusive cross section
- Behavior of exclusive DD two body cross section
- Structure in three body (quasy two body D**D) cross sections
- Search for new excited D and Ds states in Daliz plot $ee \rightarrow D(s)_1D(*)\pi/K$
- Study of charmed baryon pair production.
- Search for new excited charmed baryons.
- Study of weak decays of charmed (doubly charmed) baryons.
- Search for Dark Physics.

THANK YOU!