Z-Factory Physics

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---Working Group for Physics at Z-factory---

1. Introduction

-Why Z-Factory ?-

High Energy Physics (Accelerator) Future

Physics & Techniques for Z^0-Factory

Accessibility in China (prospect)

2. Physics Topics for Z-Factory (Theoretical considerations only so far)

Z boson properties (Precision Test SM & New Physics)

τ lepton physics (Precision Test SM & New Physics)

c, b-hadron physics (QCD)

3. Further Work

Deep & wide studies (Working Group)

A report and a special issue: **Science China G, 2010**

The Working Group

Theorists who are interested in the topic were organized themselves (Working Group: the physics at Z-factory).

The members of the (theoretical) working group:

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The 'door' is open !

Why Z-factory?

High Energy Physics (Accelerator) Future

a. 'Precision' Frontiers:

ϕ-factory (DAΦNE)
τ-Charm physics (BEPC+BESIII: for 5 and more years)
B-factory: Super-B (Japanese)
Z-factory (Giga-Z? ILC)

b. 'High Energy' Frontiers:

Tevatron (close soon)
LHC (just starting)
ILC (under consideration)
CLIC (under studying)
etc

Physics & Techniques

Physics & Techniques for Z-Factory ($L=10^{2\sim3}L_0$)

Physics:

LEP-I: $L_0=2.4 \bullet 10^{31}cm^{-2}s^{-1}$

SLC: $L_0=0.6 \bullet 10^{31}cm^{-2}s^{-1}$

Open new fronties for ‘precision observation’

($\sim 10^{10}$ Z/year, but is it worth enough in physics ?)

Techniques: LINAC developed by ILC

(superconductor cell techniques etc)

ILC: $L \sim 10^{34}cm^{-2}s^{-1}$

Therefore $L=10^{2\sim3}L_0$ accessible technically

$E^{Z\text{-facroty}} \sim 0.1 \bullet E^{ILC}$ cheaper comparatively

Accessibility in China?

CHP future: After BEPCII+BESIII (5 or more years later)

Cost: Roughly ten percents of ILC (1TeV)

China development:

GDP is going up 10% each year

High-tech requirements

International duty (contributions to HEP)

5~7 years later

In comparison with BEPC in 80 decade of last century:

Worth of BEPC/GDP, etc

The key point is 'worth' in physics & else, so theoretical investigation goes further first ! (Useful references for ILC also)

2. Physics Topics for Z-Factory

Z boson properties (Precision Test SM & New Physics)

The Status:

LEP-I:

Scan 88GeV~94GeV $15.5 \cdot 10^6$ hadronic events

$1.7 \cdot 10^6$ leptonic events

Detectors: Aleph, Delphi, L3, Opal.

SLC:

At Z-peak $0.6 \cdot 10^6$ events

(electron polarization beam: 70%)

Detector: SLD

Very precision and rich results for Z-boson properties were achieved and indicated the predictions of SM work well:

The results about Z-boson

Quantity	Value	Standard Model	Pull	Dev.
m_t [GeV]	$170.9 \pm 1.8 \pm 0.6$	171.1 ± 1.9	-0.1	-0.8
M_W [GeV]	80.428 ± 0.039	80.375 ± 0.015	1.4	1.7
	80.376 ± 0.033		0.0	0.5
M_Z [GeV]	91.1876 ± 0.0021	91.1874 ± 0.0021	0.1	-0.1
Γ_Z [GeV]	2.4952 ± 0.0023	2.4968 ± 0.0010	-0.7	-0.5
$\Gamma(\text{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	–	–
$\Gamma(\text{inv})$ [MeV]	499.0 ± 1.5	501.59 ± 0.08	–	–
$\Gamma(\ell^+\ell^-)$ [MeV]	83.984 ± 0.086	83.988 ± 0.016	–	–
σ_{had} [nb]	41.541 ± 0.037	41.466 ± 0.009	2.0	2.0
R_e	20.804 ± 0.050	20.758 ± 0.011	0.9	1.0
R_μ	20.785 ± 0.033	20.758 ± 0.011	0.8	0.9
R_τ	20.764 ± 0.045	20.803 ± 0.011	-0.9	-0.8
R_b	0.21629 ± 0.00066	0.21584 ± 0.00006	0.7	0.7
R_c	0.1721 ± 0.0030	0.17228 ± 0.00004	-0.1	-0.1
$A_{FB}^{(0,e)}$	0.0145 ± 0.0025	0.01627 ± 0.00023	-0.7	-0.6
$A_{FB}^{(0,\mu)}$	0.0169 ± 0.0013		0.5	0.7
$A_{FB}^{(0,\tau)}$	0.0188 ± 0.0017		1.5	1.6
$A_{FB}^{(0,b)}$	0.0992 ± 0.0016	0.1033 ± 0.0007	-2.5	-2.0
$A_{FB}^{(0,c)}$	0.0707 ± 0.0035	0.0738 ± 0.0006	-0.9	-0.7
$A_{FB}^{(0,s)}$	0.0976 ± 0.0114	0.1034 ± 0.0007	-0.5	-0.4
$\bar{s}_\ell^2(A_{FB}^{(0,q)})$	0.2324 ± 0.0012	0.23149 ± 0.00013	0.8	0.6
	0.2238 ± 0.0050		-1.5	-1.6
A_e	0.15138 ± 0.00216	0.1473 ± 0.0011	1.9	2.4
	0.1544 ± 0.0060		1.2	1.4
	0.1498 ± 0.0049		0.5	0.7
A_μ	0.142 ± 0.015		-0.4	-0.3
A_τ	0.136 ± 0.015		-0.8	-0.7
	0.1439 ± 0.0043		-0.8	-0.5
A_b	0.923 ± 0.020	0.9348 ± 0.0001	-0.6	-0.6
A_c	0.670 ± 0.027	0.6679 ± 0.0005	0.1	0.1
A_s	0.895 ± 0.091	0.9357 ± 0.0001	-0.4	-0.4
g_L^2	0.3010 ± 0.0015	0.30386 ± 0.00018	-1.9	-1.8
g_R^2	0.0308 ± 0.0011	0.03001 ± 0.00003	0.7	0.7
$g_V^{\nu e}$	-0.040 ± 0.015	-0.0397 ± 0.0003	0.0	0.0
$g_A^{\nu e}$	-0.507 ± 0.014	-0.5064 ± 0.0001	0.0	0.0
A_{PV}	$(-1.31 \pm 0.17) \cdot 10^{-7}$	$(-1.54 \pm 0.02) \cdot 10^{-7}$	1.3	1.2
$Q_W(\text{Cs})$	-72.62 ± 0.46	-73.16 ± 0.03	1.2	1.2
$Q_W(\text{Tl})$	-116.4 ± 3.6	-116.76 ± 0.04	0.1	0.1
$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to X e\nu)}$	$\left(3.55^{+0.53}_{-0.46}\right) \cdot 10^{-3}$	$(3.19 \pm 0.08) \cdot 10^{-3}$	0.8	0.7
$\frac{1}{2}(g_\mu - 2 - \frac{\alpha}{\pi})$	$4511.07(74) \cdot 10^{-9}$	$4509.08(10) \cdot 10^{-9}$	2.7	2.7
τ_τ [fs]	290.93 ± 0.48	291.80 ± 1.76	-0.4	-0.4

Measurements vs SM prediction: SM works well !

If Z-factory may improve the results substantially, the systematical errors must be suppressed.

Constraints for new physics!

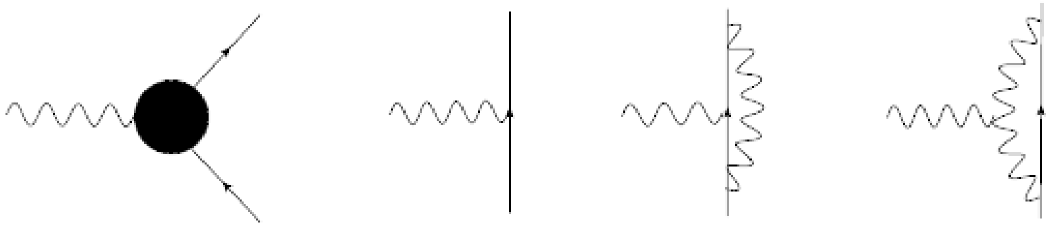
The Z effective coupling (to lepton)

New Physics: **(W.G. Ma et al, Z.-X. Yue et al, K.M. Yang et al, X.-Q. Li et al, L. Han et al, J.-J. Cao et al etc)**

Multi-Higgs Model, Little Higgs Model, RPV SUSY Model, Extra Z-boson Model etc

- **The effective coupling Z-ff' (tree and loops & specially f,f' are leptons) :** $\Gamma^{\mu}_{Zf\bar{f}}$ **Vertex**

$Z\tau\bar{\mu}\left(Z\bar{\tau}\mu\right)$ **is a very strong constraint to the models, and Z-factory will offer the precise measurements of it.**



New physics through tree and/or loop diagrams

The neutral flavor change vertex

- **The coupling ZAAA (A-CP odd light Higgs): 'A' strong couple to leptons (especially to $\tau\bar{\tau}$ pair) and the decay $\tau\bar{\tau}$ of Z to A are very strong constraints to such models.**

etc

Some special models are very sensitive to the coupling of Z-boson to τ lepton and relevant decays, thus Z-factory is crucial for this kind of models.

The Models:

Lepton number violation → Baryon number violation

→ Cosmology baryon number generation.

τ lepton physics

Very good source of τ lepton (L, Han et al, J.J. Cao et al)

- **Production rate: the resonance effects to enhance besides High *L***
- **Production at a much high energy (much higher than threshold) thus cause greater boost effects than B-factory (good for vertex detector)**
- **Rare decays (sensitive to new physics):**

$$\tau \to e\gamma,\ \ \tau \to \mu\gamma,\ \ \tau \to \bar{\mu}\mu\mu,\ \ \tau \to \mu\bar{e}e,\ \ \tau \to \bar{e}ee,$$ **etc**

the upper bound for τ lepton rare decays will be suppressed much

- **Polarized beam of e^-e^+ and CP violation relating to τ lepton**

电子束极化的条件下（如SLC上的实验），末态轻子对左右前后不对称大小为

$$A_{LRFB}^{0,\ell} = \frac{3}{4}|P_e|A_\ell = \frac{(\sigma_F - \sigma_B)_L - (\sigma_F - \sigma_B)_R}{(\sigma_F + \sigma_B)_L + (\sigma_F + \sigma_B)_R}\frac{1}{|P_e|}$$

τ lepton physics

比较无极化极化束条件（如**LEP**上的实验）

$$A_{FB}^{0,\ell} = \frac{3}{4} A_e A_\ell = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

极化束的优点在于，可以在统计精度上使测量值优于非极化束条件下的测量，例如，**75％**电子极化可给出相当与非极化束条件下的**25**倍统计量的精度。

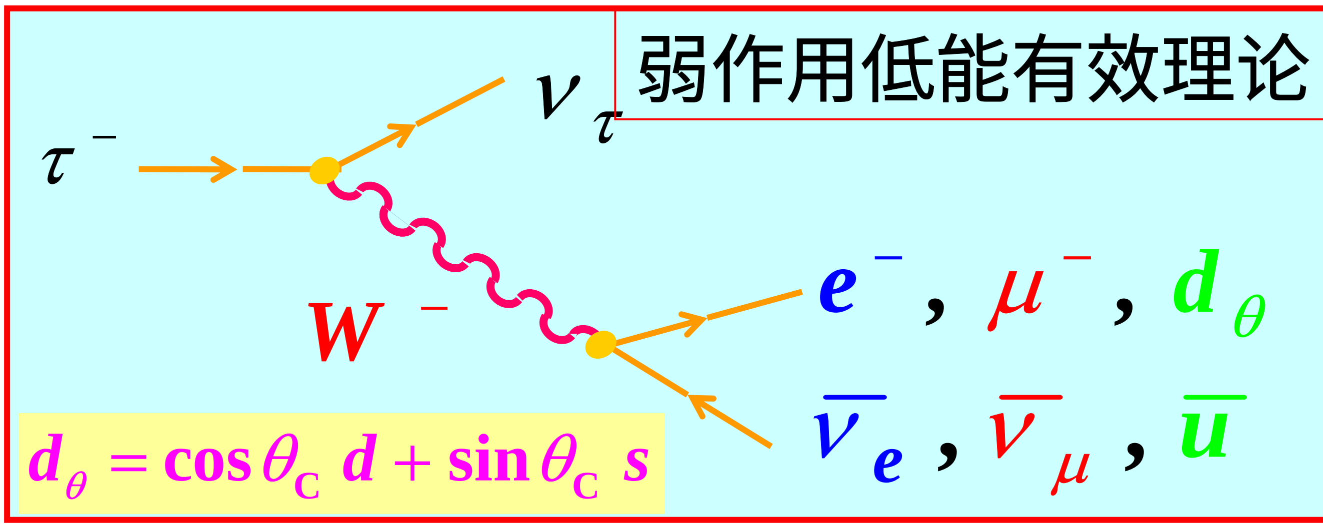
Polarized e^- and/or e^+ beam produces $\tau^+\tau^-$ pair:

CP violation: **to measure CP(T)-odd operators precisely**

To measure the CP violation in τ – decays beyond SM: (numerous events with great boost)

τ lepton physics

- **Hadronic and pure leptonic decays (test of universality sensitive to QCD and light hadron physics):**



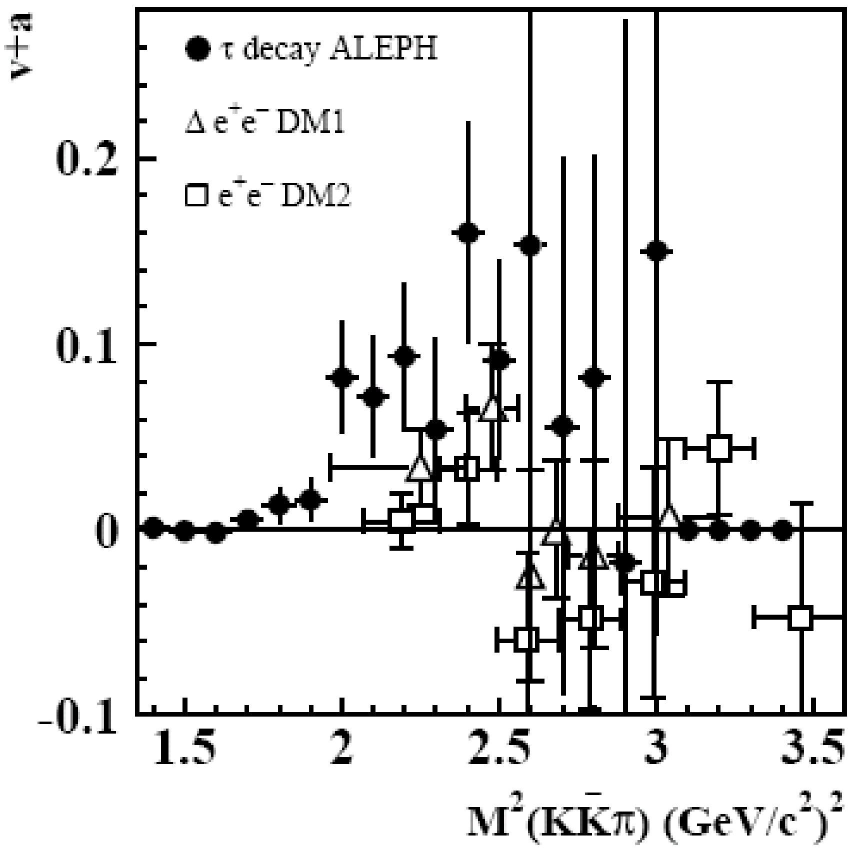
$$\tau \to hadron(s) + \nu$$

$$\tau \to \nu l \overline{\nu}$$

To determine the quantum numbers of the 'excited' states (vector and axial vector currents respectively)

τ lepton physics

例如：在$KK\pi$末态的 V 与 A 贡献



$$\sigma^{(I=1)}\left[e^+e^- \to K\bar{K}\pi\right] = \frac{4\pi\alpha^2}{s}\upsilon\left[\tau^- \to (K\bar{K}\pi)^-\nu_\tau\right]$$

Aleph & CLEO:

A: (75±25)%

etc

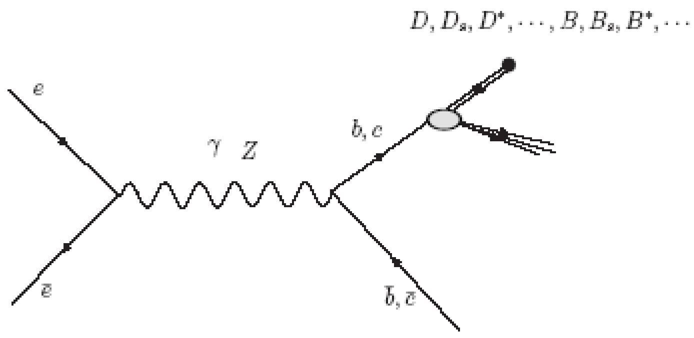
c, b-hadron physics (QCD)

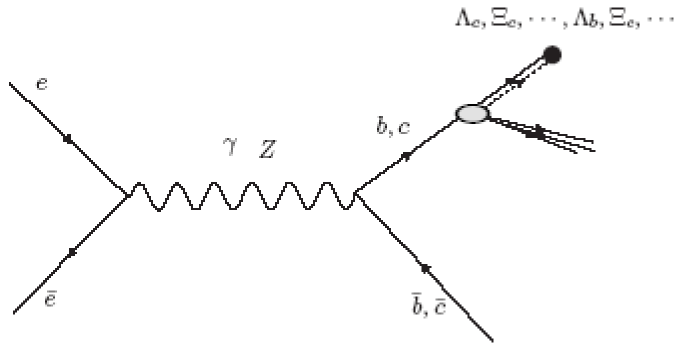
c, b-quark fragmentation: (Z.-G. Si, et al)

•Non-perturbative fragmentation models: LUND , Webber Cluster, Quark Combination (ShangDong) Model.

•The best place to test the model.

Fragmentation functions (FFs) from c or b quark:





$$D_c^{J/\psi}, D_c^{\eta_c}, \cdots \quad D_c^{B_c}, D_c^{B_c^*}, \cdots D_b^{\Upsilon}, D_b^{\eta_b}, \cdots \quad D_b^{B_c}, D_b^{B_c^*}, \cdots$$

$$D_c^{\Xi_{cc}}, D_c^{\Xi_{bc}}, \cdots \quad D_b^{\Xi_{bc}}, \quad D_b^{\Xi_{bb}}, \cdots$$

c, b-hadron physics (QCD)

1. b-hadron studies (competitions from LHCb)

- **B-meson: excited states etc,**
- **Bs meson: mixing, CP violation, rare decays, excited states etc,**
- **Bc meson: production mechanism(s), decays, excited states etc,**
- **b-baryons (Λ_b, Ξ_b, Ω_b , etc): production mechanism(s), decays, excited states etc,**
- **Double heavy baryons (Ξ_{bc}, Ξ_{bb}, etc): production mechanism(s), decays, excited states etc,**
- **ISR production of $b\bar{b}$-like X, Y, Z particles: production mechanism(s), properties etc**

2. c-hadron studies (competitions from B-factories, Tevatron, LHCb etc) :

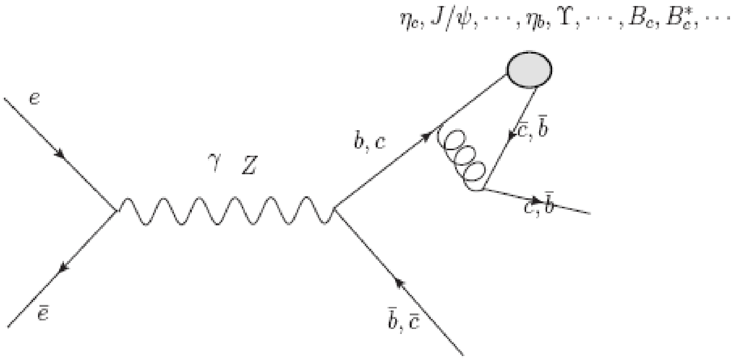
- **D-meson: $D^0 - \bar{D}^0$ mixing, CP violation, to confirm the excited states etc,**

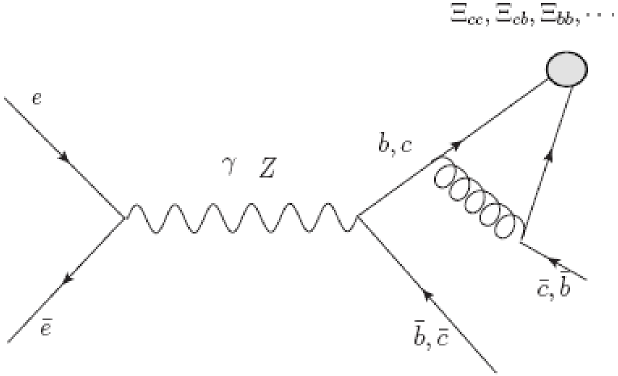
c, b-hadron physics (QCD)

- Ds meson: to confirm the excited states etc,
- c-baryons (Λ_c, Ξ_c, Ω_c, etc): production mechanism(s), to confirm the decays, excited states etc,
- Double heavy baryons (Ξ_{cc}, Ω_{cc}, etc): production mechanism(s), decays, excited states etc,
- To confirm the ISR production of X, Y, Z particles: production mechanism(s), properties etc,

c, b-hadron physics (QCD)

Production mechanisms: (X.G. Wu et al)





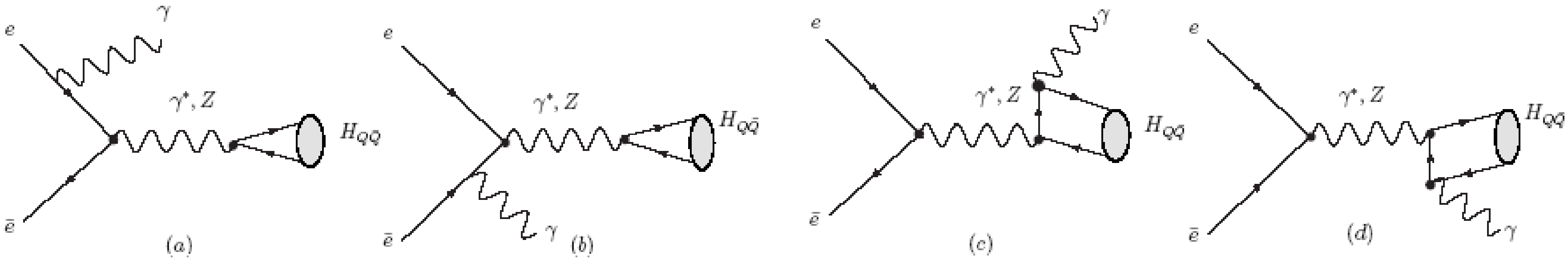
At LEP-I: Bc meson just a few (J/Ψ+π) events, thus at Z-factory a few thousands of such events ! ⟹ Many decay modes can be observed, and excited states may be seen too. The cross-sections for heavy quarkonia and excited states are similar to that of Bc meson but they are easy to observe.

The cross-section of double heavy baryon production is the same in magnitude, thus the situation is similar to Bc meson.

c, b-hadron physics (QCD)

Production of heavy quarkonia and 'X'-type particles via two-body exclusive production with a photon:

$$e^+(p_1) + e^-(p_2) \to \gamma(p_3) + H_{Q\bar{Q}}(P)$$



Here $H_{Q\bar{Q}}$: $\eta_c, J/\psi, \cdots \ \eta_b, \Upsilon, \cdots \ X_{c\bar{c}}, \cdots \ X_{b\bar{b}}, \cdots$

	$^3S_1$	$^1S_0$	$^3P_0$	$^3P_1$	$^3P_2$	$^1P_1$
$\sigma_{(c\bar{c})}(pb)$	0.934	0.662×10^{-3}	0.328×10^{-4}	0.197×10^{-3}	0.661×10^{-4}	0.615×10^{-3}
$\sigma_{(b\bar{b})}(pb)$	0.565×10^{-1}	0.475×10^{-2}	0.128×10^{-4}	0.838×10^{-4}	0.930×10^{-4}	0.833×10^{-4}

c, b-hadron physics (QCD)

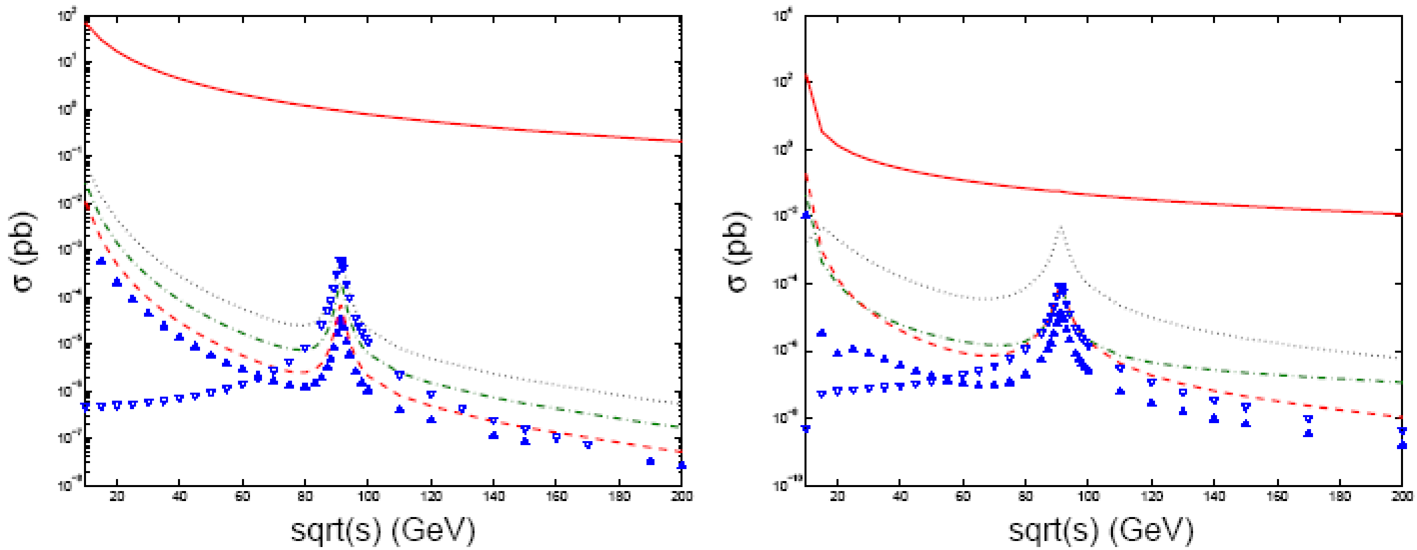


FIG. 2: (color online) Total cross sections for the processes $e^- + e^+ \to \gamma + H_{Q\bar{Q}}$ versus the collision energy. The red solid, the black dotted, the blue up-solid-triangle, the green dash-dotted, the red dashed and the down-hollow-triangle lines stand for $Q\bar{Q}$ in ${}^3S_1$, ${}^1S_0$, ${}^3P_0$, ${}^3P_1$, ${}^3P_2$, ${}^1P_1$ respectively. The left figure is for charmonium and the right one is for bottomonium.

c, b-hadron physics (QCD)

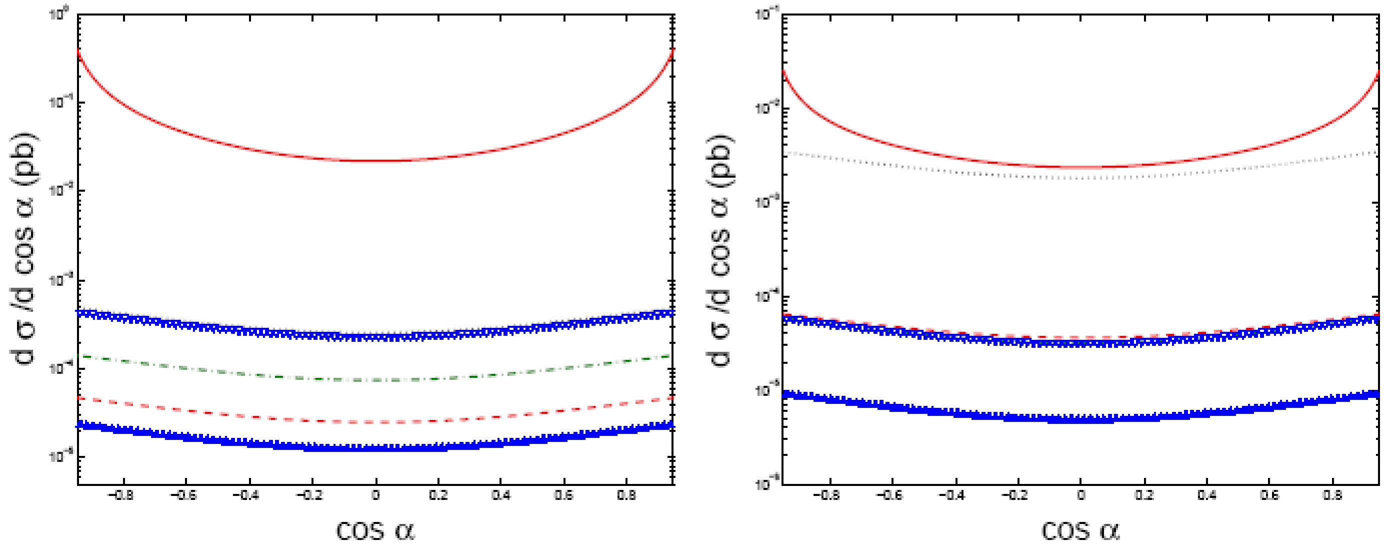


FIG. 3: (color online) Differential cross sections for the processes $e^- + e^+ \to \gamma + H_{Q\bar{Q}}$ versus $\cos\alpha$ at a C.M.S. energy as Z-mass. The red solid, the black dotted, the blue up-solid-triangle, the green dash-dotted, the red dashed and the blue down-hollow-triangle lines stand for $Q\bar{Q}$ in $^3S_1$, $^1S_0$, $^3P_0$, $^3P_1$, $^3P_2$, $^1P_1$ respectively. The left figure is for charmonium (the dotted line and the blue down-hollow-triangle almost emerge together almost) and the right one is for bottomonium (the red dashed line, the green dash-dotted line and the blue down-hollow-triangle emerge together almost).

c, b-hadron physics

$(c\bar{c})$ & $(b\bar{b})$ **mass spectra :** **(G.L. Wang et al; X.Q. Li et al)**

n $J^{PC}(^{(2S+1)}L_J)$	Th$(c\bar{c})$	Ex$(c\bar{c})$	Th$(b\bar{b})$	Ex$(b\bar{b})$
1 $0^{-+}(^1S_0)$	2980.3(input)	2980.3	9390.2(input)	9388.9
2 $0^{-+}(^1S_0)$	3576.4	3637	9950.0	
3 $0^{-+}(^1S_0)$	3948.8		10311.4	
1 $1^{--}(^3S_1)$	3096.9(input)	3096.916	9460.5(input)	9460.30
2 $1^{--}(^3S_1)$	3688.1	3686.09	10023.1	10023.26
3 $1^{--}(^3D_1)$	3778.9	3772.92	10129.5	
4 $1^{--}(^3S_1)$	4056.8	4039	10368.9	10355.2
5 $1^{--}(^3D_1)$	4110.7	4153	10434.7	
6 $1^{--}(^3S_1)$	4329.4	4421	10635.8	10579.4
7 $1^{--}(^3S_1)$	4545.9		10852.1	10865

The D-wave dominant 1^{--} states of $(b\bar{b})$ have not observed yet !

c, b-hadron physics

b-hadron excited states:

Some excited states, such as those of Bc meson and baryons Λ b, Ξ b, Ω b , ……., Ξ bc, Ξ bb, etc, can be expected to observe at Z-factory only, although still difficult.

b-rare decays:

$$B_s \to e^+e^-,\ B_s \to \mu^+\mu^-,\ B_s \to e^+\mu^-,\ B_s \to e^-\mu^+ \ \textbf{etc}$$

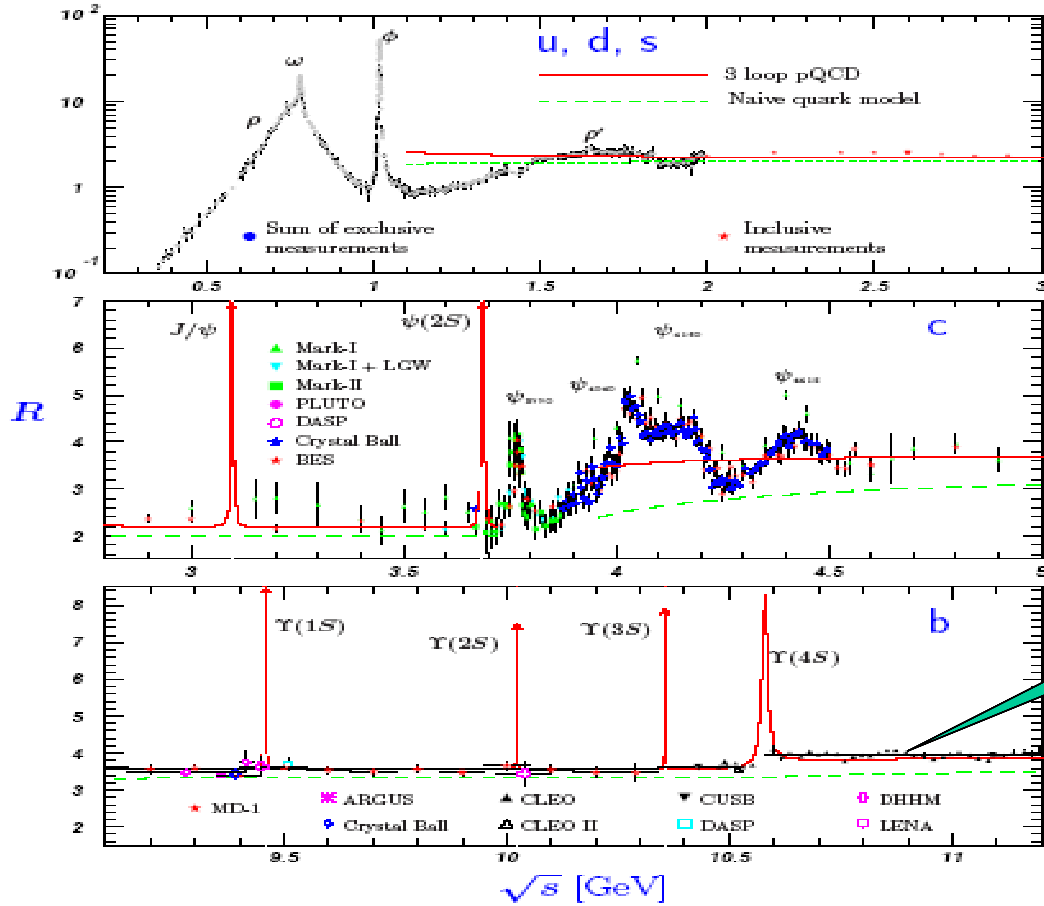
Heavy quarkonium physics:

a. **Puzzle or not ? for Υ (η_b) production mechanism**
b. **Υ (η_b) excited states (even hybrids)**
c. **Exotics X_b, Y_b, Z_b via ISR similar to B-Factory**

etc

c, b-hadron physics

$(b\bar{b})$-like X, Y, Z particles (ISR):



The cross-section is smaller than that of X off Z-peak, because charge Q_b= -1/2 Q_c!

Structures

In Summary

- **The first step**

  Theoretical considerations

  (to focus on the worth in physics)

  How?

  Quantitatively

  Isolating from the other factors

- **Great advantages in study of τ lepton physics & b-hadron physics**

  Discovering new physics can be expected in τ lepton physics !

  A lot of b-hadron physics can be done uniquely !

3. Status and further work

- **About 20 papers are completed and will publish in *Science China G* as a special issue in 2010**

欢迎投稿

Impact factor: 0.973
Immediacy index: 0.320

■从今年开始，中英文两刊成为两本独立的刊物，不再对照发表。中文为核心刊物，英文被 SCI，EI 索引。

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3. Further work

- **Deeper & wide theoretical studies:**
  To find more important subjects or topics,
  More precise quantitative comparisons (thorough studies and M.C. simulation)
- **The first goal within one or two years is to present a preliminary report on the important physics at Z-factory besides publishing papers based on the investigations and idea interactions (activities within and outside Group Working) etc**

Suggestions, Comments & Supports

Welcome your suggestions, comments and Supports even your join!

We wish our works can be used as a reference for one option in determining **CHEP** ***future !***

Thanks for your interests of Z-Factory ***!***