Z-Factory & Hadron Physics

Based on a report by Chinese Z-factory working group

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Outline

Introduction

An option for future Chinese High Energy Physics

The Super Z-factory (SZF)

High Energy Physics @ SZF

- Tests of SM and to search for hints beyond SM
  - High precision & rare physics for Z-boson etc
- Flavor physics & QCD physics

Hadron Physics QCD @ SZF

- (Many unique and interesting features)
- Heavy and Double heavy Hadron physics

Summary

Z-factory

The Z-Factories:

An e^+e^- collider running at the Z resonance (properly apply the resonance effects)

Resonance effects for all kinds of fermions, except t-quark in SM!

The old ones

LEP-I: $\mathcal{L}_0 = 2.4 \bullet 10^{31} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Scan 88GeV~94GeV

$1.55 \cdot 10^7$ hadronic events; $1.7 \cdot 10^6$ leptonic events.

Detectors: Aleph, Delphi, L3, Opal.

SLC: $\mathcal{L}_0 = 0.6 \bullet 10^{31} \mathrm{cm}^{-2}\mathrm{s}^{-1}$

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

(Especially electron polarization beam: 70%)

Detector: SLD

Super Z-factory (SZF)

Based on modern techniques a Z-factory with luminosity below is accessible:

$\mathcal{L} = 10^{4\sim5}\mathcal{L}_0 = 10^{35\sim36}\text{cm}^{-2}\text{s}^{-1}$ even higher

Z-boson events > 10^{12} /year

Note: **LEP-I** $\mathcal{L}_0 = 2.4 \bullet 10^{31}\text{cm}^{-2}\text{s}^{-1}$

SLC $\mathcal{L}_0 = 0.6 \bullet 10^{31}\text{cm}^{-2}\text{s}^{-1}$

Still run at energy: ~ 91 GeV (around m_Z)

The significances of SZF

- **Precision test of SM （clue for new physics）**
- **QCD & hadron physics**

The plans in the world：

ILC，CEPC，FCC-ee(TLEP) but $\mathcal{L} = 10^{34}\text{cm}^{-2}\text{s}^{-1}$

The options for CHEP after BEPC+BES

- **CEPC+SppC**：

  CEPC： e^+e^- circle collider,
  Energies: 240GeV (91GeV, 180GeV……)
  $\mathcal{L}=2\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

  SppC: pp circle collider,
  Energies: 71.2TeV(?)
  $\mathcal{L}=1.2\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (?)

- **SZF:** e^+e^- circle collider,
  Energies: 91GeV……
  $\mathcal{L}=2\times10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

- **HIEPA:** e^+e^- circle collider,
  Energies: 2-7GeV
  $\mathcal{L}=(0.5\text{-}1.0)\times10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

The physics

The tasks of HEP after Higgs being discovered:

- To understand EW breaking etc
- Looking for new physics beyond SM
  - Direct evidences (observation)
  - Indirect evidences by precision tests
  - Evidences from cosmology etc
  - Neutrino problems
- New phenomena within SM:
  - QCD problems (PDF, FF, hadron physics, QGP, phase transition etc)

Test of the mechanism：

masses of Bosons

$2m_W = g_2 v$, $2m_Z = (g_1^2 + g_2^2)^{0.5} v$

$v = 247\text{GeV}$

Fermion masses from Yukawa couplings to Higgs

$$L = g_{hff} \bar{f} H f + \frac{g_{hhh}}{6} H^3 + \frac{g_{hhhh}}{24} H^4 + \eta_v V_\mu V^\mu (g_{hvv} H + \frac{g_{hhvv}}{2} H^2)$$

$$g_{hff} = \frac{m_f}{v}, \quad g_{hvv} = \frac{m_v^2}{v}, \quad g_{hhvv} = \frac{2m_V^2}{v^2} \qquad g_{hhh} = \frac{3m_H^2}{v}, \quad g_{hhhh} = \frac{3m_H^2}{v^2}$$

$$V = W^\pm \; or \; Z \,; \quad \eta_v = 1 \; for \; V = W \,, \quad \eta_v = 0.5 \; for \; V = Z.$$

The discovery of Higgs in 2012:

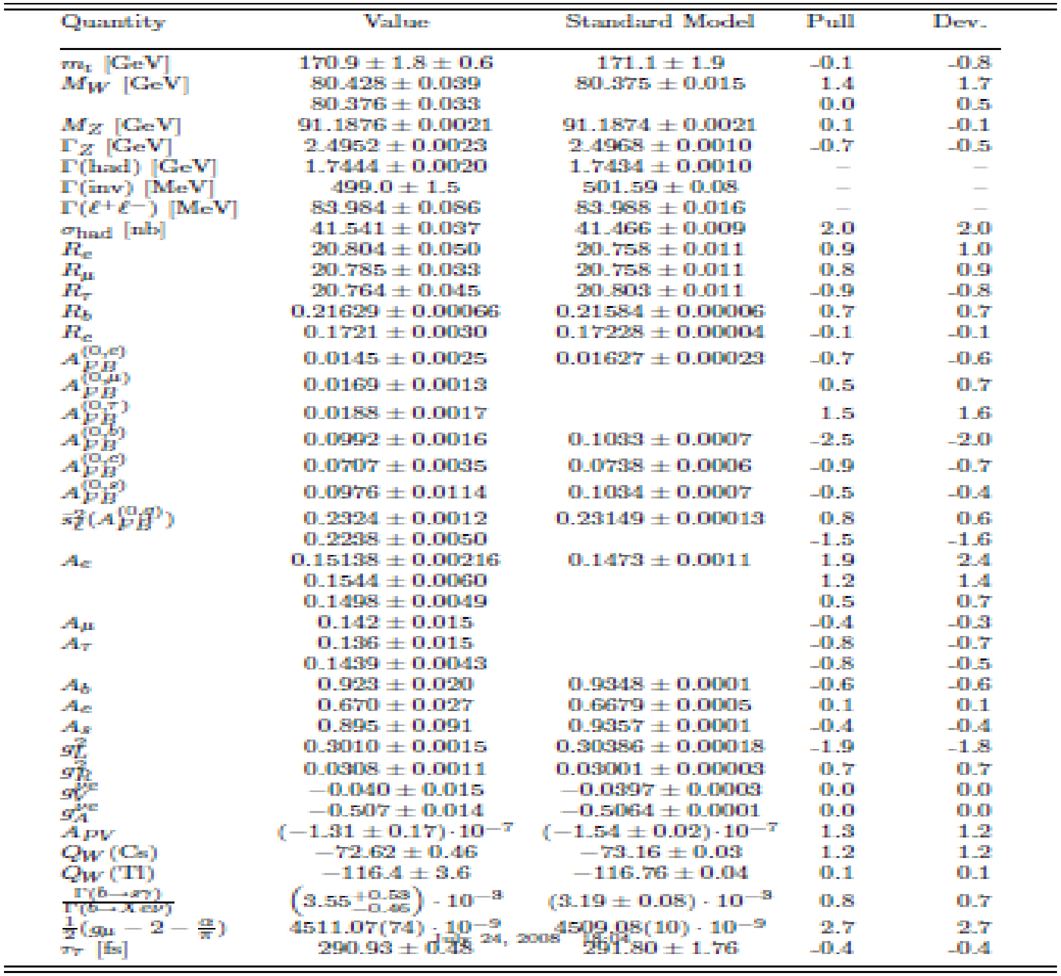
m_H=125GeV

All of the couplings above are fixed, thus we may compare the couplings with the measured ones so to test the mechanism（LHC）！

The physics

- **Precision & rare physics for Z-boson:**

Exp. measurements (LEP-I, SLC) vs Theor. prediction (SM)



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
$\Gamma(\mathrm{had})$ [GeV]	1.7444 ± 0.0020	1.7434 ± 0.0010	–	–
$\Gamma(\mathrm{inv})$ [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
$Q_W(\mathrm{Cs})$	-72.62 ± 0.46	-73.16 ± 0.03	1.2	1.2
$Q_W(\mathrm{Tl})$	-116.4 ± 3.6	-116.76 ± 0.04	0.1	0.1
$\frac{\Gamma(b\to s\gamma)}{\Gamma(b\to Xe\nu)}$	$\left(3.55^{+0.53}_{-0.46}\right) \cdot 10^{-3}$	$(3.19 \pm 0.08) \cdot 10^{-3}$	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

(look for evidences beyond SM)

The effective coupling Z-ff′ (in tree and loops & especially when f, f′ are leptons) constraints for new physics!

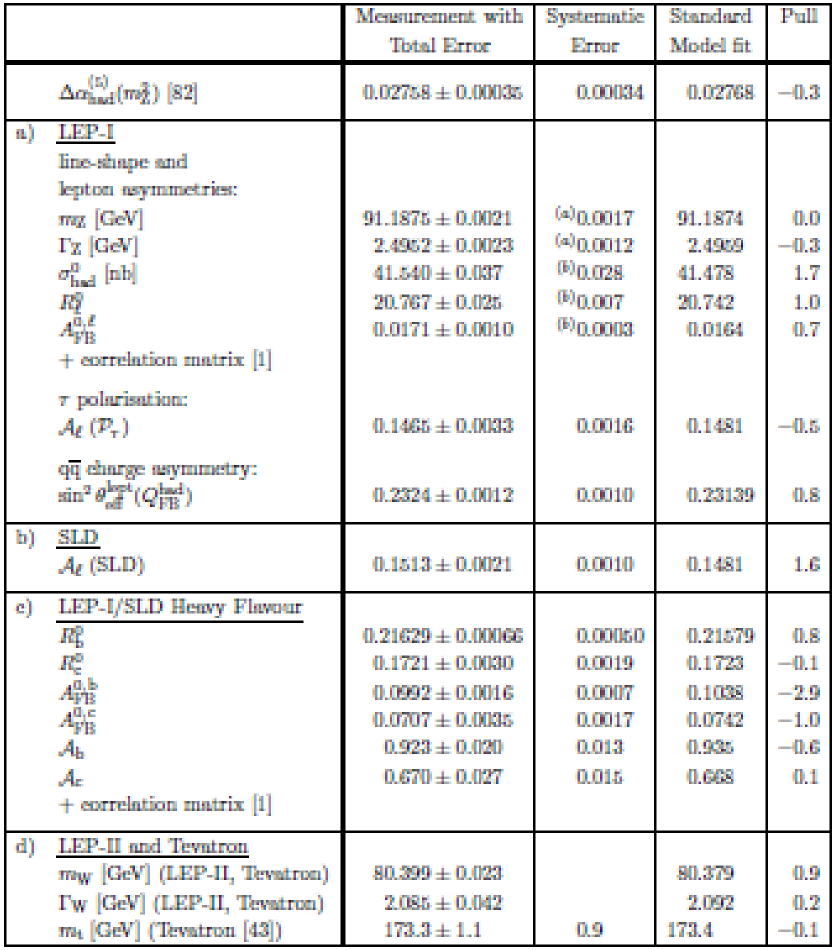
(Taken from PDG)

SM works well so far, but the pulls are 'dominant' by experimental errors.

The physics

- ## Precision & rare physics for Z-boson:

  Exp. measurements (LEP-I, SLC) vs Theor. prediction (SM)



	Measurement with Total Error	Systematic Error	Standard Model fit	Pull
$\Delta\alpha^{(5)}_{\rm had}(m_Z^2)$ [82]	0.02758 ± 0.00035	0.00034	0.02768	−0.3
a) LEP-I line-shape and lepton asymmetries:				
m_Z [GeV]	91.1875 ± 0.0021	$^{(a)}$0.0017	91.1874	0.0
Γ_Z [GeV]	2.4952 ± 0.0023	$^{(a)}$0.0012	2.4959	−0.3
$\sigma^0_{\rm had}$ [nb]	41.540 ± 0.037	$^{(b)}$0.028	41.478	1.7
R^0_ℓ	20.767 ± 0.025	$^{(b)}$0.007	20.742	1.0
$A^{0,\ell}_{\rm FB}$	0.0171 ± 0.0010	$^{(b)}$0.0003	0.0164	0.7
+ correlation matrix [1]				
τ polarisation:				
$\mathcal{A}_\ell$ ($\mathcal{P}_\tau$)	0.1465 ± 0.0033	0.0016	0.1481	−0.5
$q\overline{q}$ charge asymmetry:				
$\sin^2\theta^{\rm lept}_{\rm eff}(Q^{\rm had}_{\rm FB})$	0.2324 ± 0.0012	0.0010	0.23139	0.8
b) SLD				
$\mathcal{A}_\ell$ (SLD)	0.1513 ± 0.0021	0.0010	0.1481	1.6
c) LEP-I/SLD Heavy Flavour				
$R^0_{\rm b}$	0.21629 ± 0.00066	0.00050	0.21579	0.8
$R^0_{\rm c}$	0.1721 ± 0.0030	0.0019	0.1723	−0.1
$A^{0,{\rm b}}_{\rm FB}$	0.0992 ± 0.0016	0.0007	0.1038	−2.9
$A^{0,{\rm c}}_{\rm FB}$	0.0707 ± 0.0035	0.0017	0.0742	−1.0
$\mathcal{A}_{\rm b}$	0.923 ± 0.020	0.013	0.935	−0.6
$\mathcal{A}_{\rm c}$	0.670 ± 0.027	0.015	0.668	0.1
+ correlation matrix [1]				
d) LEP-II and Tevatron				
m_W [GeV] (LEP-II, Tevatron)	80.399 ± 0.023		80.379	0.9
Γ_W [GeV] (LEP-II, Tevatron)	2.085 ± 0.042		2.092	0.2
m_t [GeV] (Tevatron [43])	173.3 ± 1.1	0.9	173.4	−0.1

(Taken from arXiv:1012.2367)

SM works well so far, but the pulls are ‘dominant’ by experimental errors.

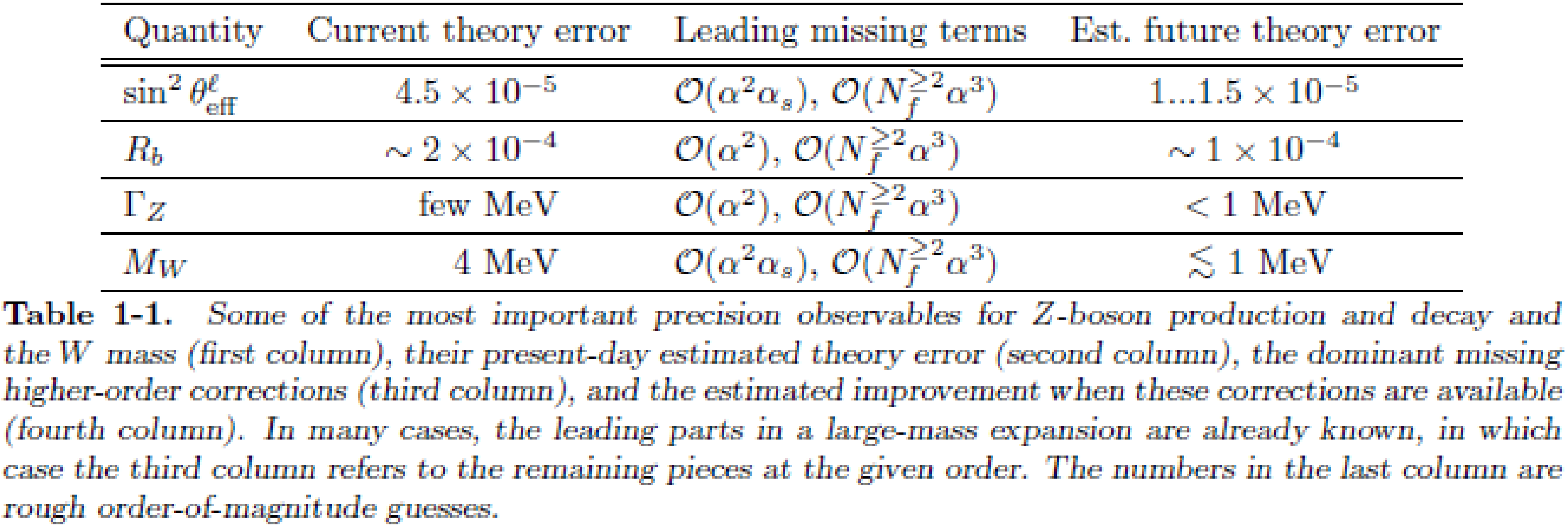
It is very difficult to suppress the expt. errors, but with better designed detectors and much higher statistics of events it is possible to confirm some hences @ super Z-factory.

Theoretical loop calculations have been made progresses steadily recently

Polarization beam is helpful !

The physics

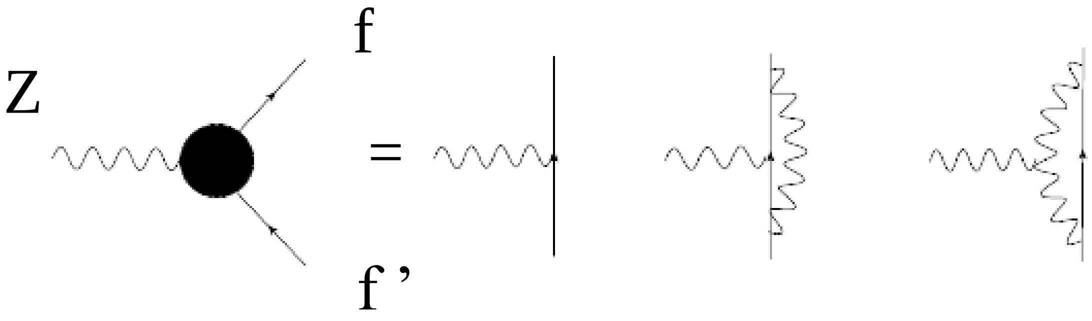
arXiv:1310.6708



Quantity	Current theory error	Leading missing terms	Est. future theory error
$\sin^2\theta^{\ell}_{\rm eff}$	4.5×10^{-5}	$\mathcal{O}(\alpha^2\alpha_s)$, $\mathcal{O}(N_f^{\geq2}\alpha^3)$	$1...1.5\times10^{-5}$
R_b	$\sim2\times10^{-4}$	$\mathcal{O}(\alpha^2)$, $\mathcal{O}(N_f^{\geq2}\alpha^3)$	$\sim1\times10^{-4}$
Γ_Z	few MeV	$\mathcal{O}(\alpha^2)$, $\mathcal{O}(N_f^{\geq2}\alpha^3)$	<1 MeV
M_W	4 MeV	$\mathcal{O}(\alpha^2\alpha_s)$, $\mathcal{O}(N_f^{\geq2}\alpha^3)$	$\lesssim1$ MeV

Table 1-1. *Some of the most important precision observables for Z-boson production and decay and the W mass (first column), their present-day estimated theory error (second column), the dominant missing higher-order corrections (third column), and the estimated improvement when these corrections are available (fourth column). In many cases, the leading parts in a large-mass expansion are already known, in which case the third column refers to the remaining pieces at the given order. The numbers in the last column are rough order-of-magnitude guesses.*

The rare (tiny) physics relevant to Z boson directly



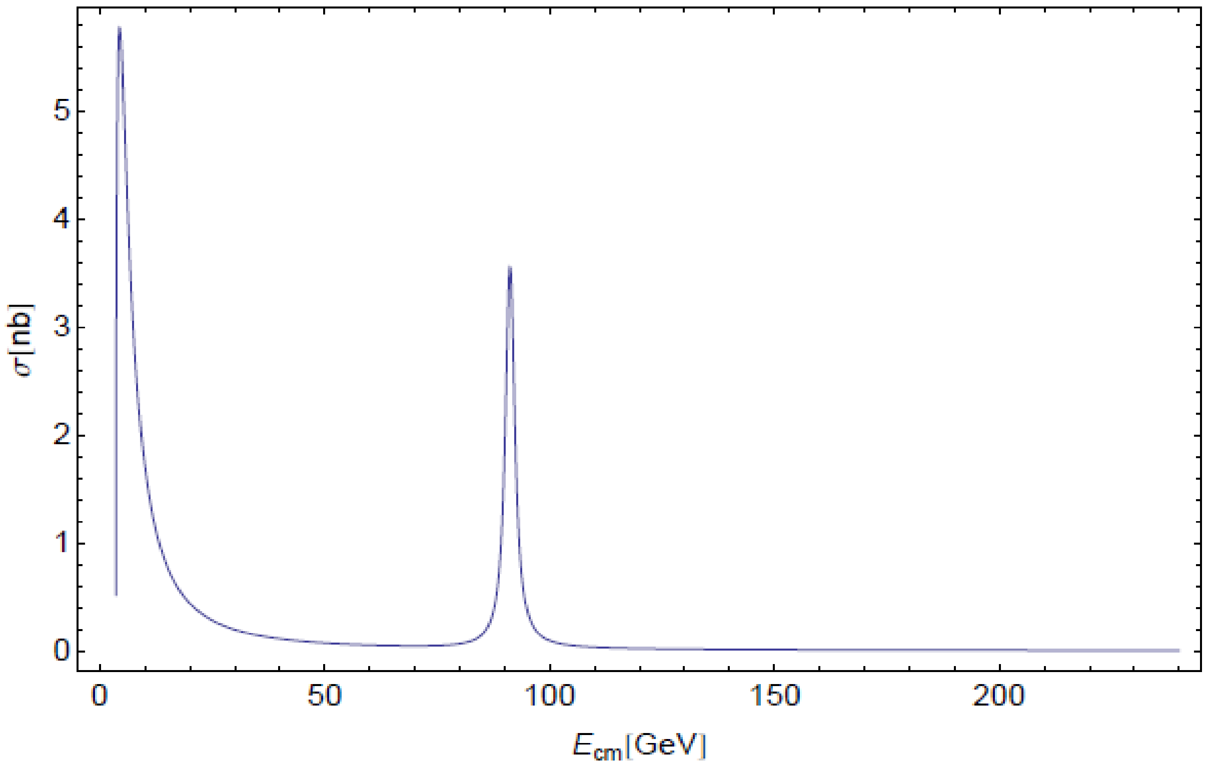
Lepton number violation & FCNC processes; CPV; d_f^Z etc.

Longitudinal component of Z-boson couple to a pair of fermions ~ m_f

The physics

τ-lepton is special (the heaviest lepton)

Very good place of τ-lepton physics (@ Z-factory):



Based on SM: m_Z, $\mathrm{Sin}^2\theta_W$, α, Γ_Z, etc

σ(cross-section) @ Z-peak ~ 0.5 σ @ the highest one (threshold) ~ 2.3 σ @ B-factory

3×10^{10} **τ pairs/year**

τ is the heaviest lepton in SM!

An important factor is the Lorentz boost effects !

The physics

LEP-I example:

the data samples recorded between 1991 and 1995 with OPAL

69778 τ-pair events

CPV of $V_{Z\tau\tau}$:

(weak dipole)

$$\mathrm{Re}(d_\tau^w) = (0.72 \pm 2.46 \pm 0.24) \times 10^{-18}\, e\ \mathrm{cm}$$

$$\mathrm{Im}(d_\tau^w) = (0.35 \pm 0.57 \pm 0.08) \times 10^{-17}\, e\ \mathrm{cm}$$

If we define:

$$\epsilon_\tau \equiv \frac{\Delta\Gamma_{Z^0\to\tau^+\tau^-}}{\Gamma_{Z^0\to\tau^+\tau^-}} \quad , \quad \text{where} \quad \Delta\Gamma_{Z^0\to\tau^+\tau^-} = \frac{|d_\tau^w|^2}{24\pi} m_Z^3 \left(1 - \frac{4m_\tau^2}{m_Z^2}\right)^{3/2}$$

The limit means:

$$\epsilon_\tau < 7.2 \times 10^{-3} \qquad \text{using} \quad |d_\tau^w| \qquad \text{and}$$

$$\epsilon_\tau < 8.9 \times 10^{-4} \qquad \text{assuming} \quad \mathrm{Im}(d_\tau^w) = 0$$

$$\Gamma_{Z^0\to\tau^+\tau^-} = (83.88 \pm 0.39)\ \mathrm{MeV}$$

precision of the test of $\mathcal{CP}$ invariance

a level of one in thousand

Statistics errors quite large, so there are rooms to improve the measurement(s) !

New result: It is greatly helpful that the direction of produced τ is measured.

The physics

New Physics:

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

The effective couplings $Zf'\bar{f}$

For leptons: $Z\tau\bar{\tau}\,,\quad Z\mu\bar{\tau}\,,\quad Z\tau\bar{\mu}\,,\quad Ze\bar{\tau}\,,\quad Z\tau\bar{e}$

It is expeced that Z-factory will offer the most precise constraint on them.

When f=f', the fermion, is b-quark or c-quark or a light quarks

R_b & R_c

$$A_{\rm FB} \equiv \frac{\sigma(\cos\theta > 0) - \sigma(\cos\theta < 0)}{\sigma(\cos\theta > 0) + \sigma(\cos\theta < 0)} = \mathcal{R}_{\rm FB}\,\tfrac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$A_{\rm LR} \equiv \frac{\sigma(\mathcal{P}_e > 0) - \sigma(\mathcal{P}_e < 0)}{\sigma(\mathcal{P}_e > 0) + \sigma(\mathcal{P}_e < 0)} = \mathcal{A}_e.$$

Difficulties are in identifying the flavor

The physics

- **τ-lepton physics:**

If 10^{12} Z-bosons/year or higher, then 10^{10} τ -lepton pairs (more)/year with quite great Lorentz boost effects may be produced @ Super Z-factory.

Therefore, the rare decays

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

and/or CPV in decays may reach to up-to 10^{-10} level (even higher) !

- **Neutrino physics:**

The invisible width of Z-boson ⇨ 3 (2.984±0.008)

Types of light neutrinos and how big a room left for the light neutrinos mixing with the sterile ones and else.

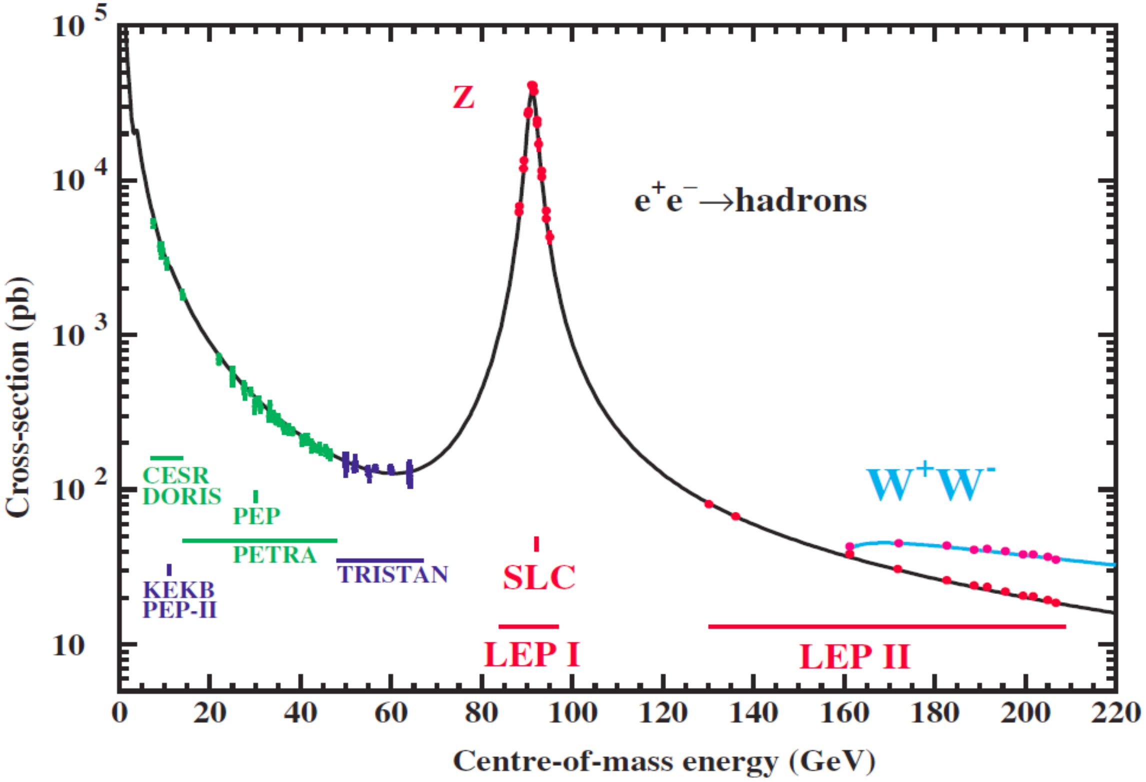
The physics

- **Flavor physics & QCD physics etc**

  Z-factory vs super B-factory & τ-charm factory

  c, b-hadron physics (especially open bottom)

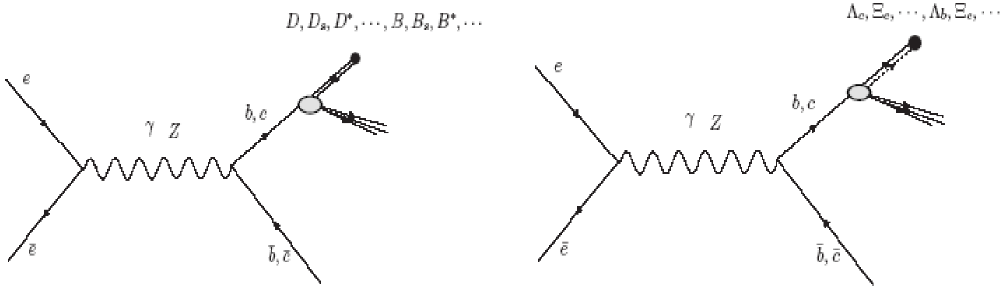
The production of hadrons @ e^+e^- -collider



The physics

- **QCD physics**

◆**Fragmentation functions (FFs):**



For example:
FF of a (heavy) hadron from a quark c or b or a light quark or a gluon etc .

Significance: **experimentally to use them for flavor tag in hadron collisions etc.; theoretically to understand QCD & models etc.**

The FF for b or c-quark to ground, excited B or D meson and to bottom or charm baryon etc.

Also polarized fragmentation functions:

◆ The Polarized fragmentation functions：

For example： b to Λ_b^0

$$e^+ + e^- \to b + \bar{b}$$

$$b \to \Lambda_b^0 + \cdots$$ **Frag. Func.**

$$\Lambda_b^0 \to \Lambda_c^+ + \pi^-$$ **To measure polarization**

- ◆**Non-perturbative fragmentation models: LUND , Webber Cluster, Quark Combination (ShangDong) Model. It is the best place to test the models.**

The physics

Flavor & hadron physics

Light flavors & hadrons (contain light quarks only)

$m_{u,}$ $m_{d,}$ $m_s < \Lambda_{QCD,}$

Heavy flavors & hadrons (contain heavy quarks)

$m_b > m_c > \Lambda_{QCD,}$ (without t-quark)

We need to understand both kinds of the hadrons and advantages to understand the heavy hadrons:

- pQCD applicable due the 'heaviness' ;
- Effective theories: Heavy flavor effective theory, NRQCD etc;
- Mass hierarchy of b, c quarks (small, mixing);
- Lifetime for heavy component 'matches' the detectors;
- etc

The physics

◆c, b-flavor physics (especially ‘Lorentz boost’)

D-meson: $D^0 - \bar{D}^0$ **mixing:**

Due the Lorentz boost and the lifetime of D meson, at Z-factory the CP violation in the mixing can be observed, whereas it is impossible at B-factory.

The physics

◆c, b-hadron physics

$Br(Z \to b\bar{b}) = (15.12 \pm 0.05)\%\,, \quad Br(Z \to c\bar{c}) = (12.03 \pm 0.21)\%\,,$

Heavy flavored hadrons: mesons and baryons

CKM elements, mixing, CPV, rare processes

$Br(Z \to B + X) = (6.08 \pm 0.13)\%\,, \quad Br(Z \to B_s + X) = (1.59 \pm 0.13)\%$

$Br(Z \to \Lambda_c + X) = (1.54 \pm 0.33)\%\,, \quad Br(Z \to \Xi_c + X) = seen\,,$

$Br(Z \to \Xi_b + X) = seen\,,$

$\Lambda_b \ \ (???)\,, \quad Br(Z \to b - baryon + X) = (1.38 \pm 0.22)\%$

Many baryon states need to be confirmed!

The physics

◆ **Double heavy hadrons :**

$$Br(Z \to b\bar{b}b\bar{b}) = (3.6 \pm 1.3) \times 10^{-4}$$

$$Br(Z \to b\bar{b}c\bar{c}) \sim 10^{-3}\,, \quad Br(Z \to c\bar{c}c\bar{c}) \sim 10^{-3}$$

$H_{QQ'}$:

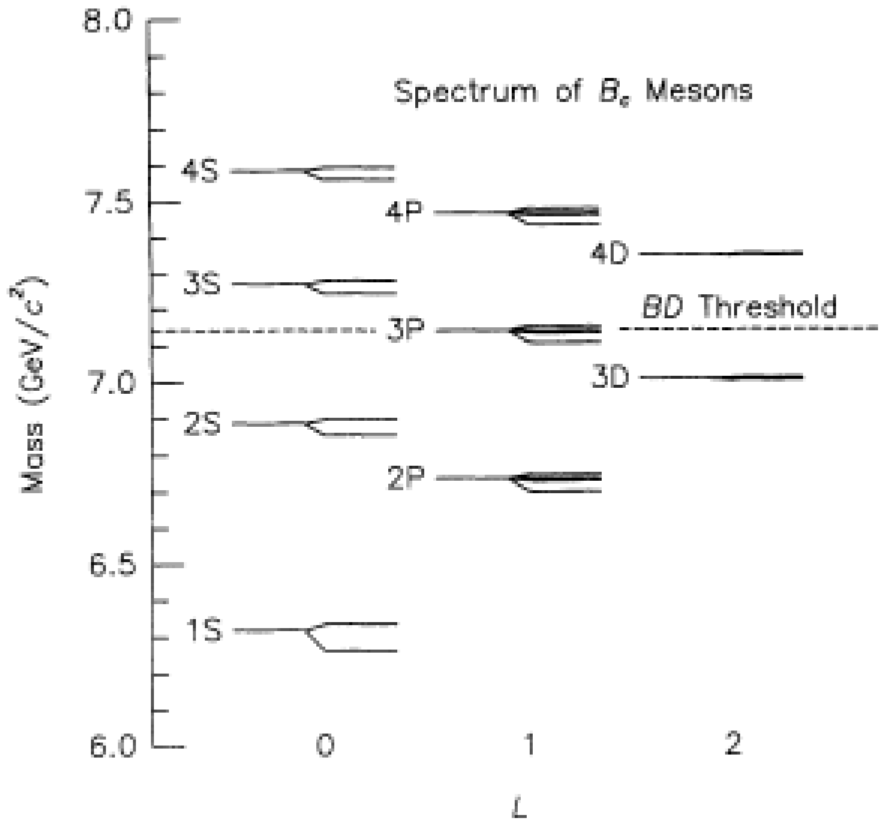
B_c meson, ……, Ξ_{cc}, Ω_{cc}, Ξ_{bc}, Ω_{bc} , Ξ_{bb}, and their excited states:

- **Their production can be estimated by pQCD reliable;**
- **The ground states decay 'weakly' that they have a comparatively long lifetime (1.0~0.1ps) and one can trace the vertices in vertex detector from production to decay (with the Lorentz boost).**

The physics

Take example B_c meson & its excited states to illustrate :

The spectroscopy:



$(c\bar{b})$: $B_c\,, B_c'\,, \cdots\,; B_c^*\,, {B^*}'_c\,, \cdots\,;\ \chi_{B_c}^J\,, \cdots\,;\ h_{B_c}\,, \cdots$

Bc: $(c\bar{b})$ ground state $({}^1S_0,\quad J^P=0^-)$

Bc: $(c\bar{b})$ ground state $({}^1S_0,\quad J^P=0^-)$

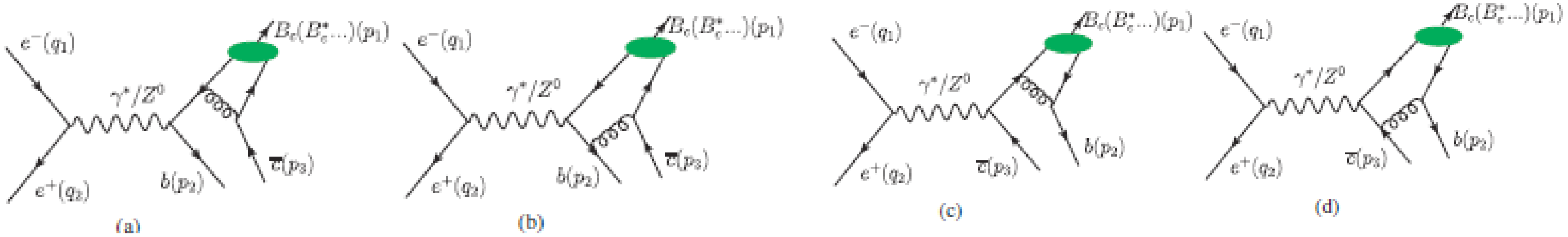
B*c: $(c\bar{b})$ 1^{st} excited state $({}^3S_1,\quad J^P=1^-)$

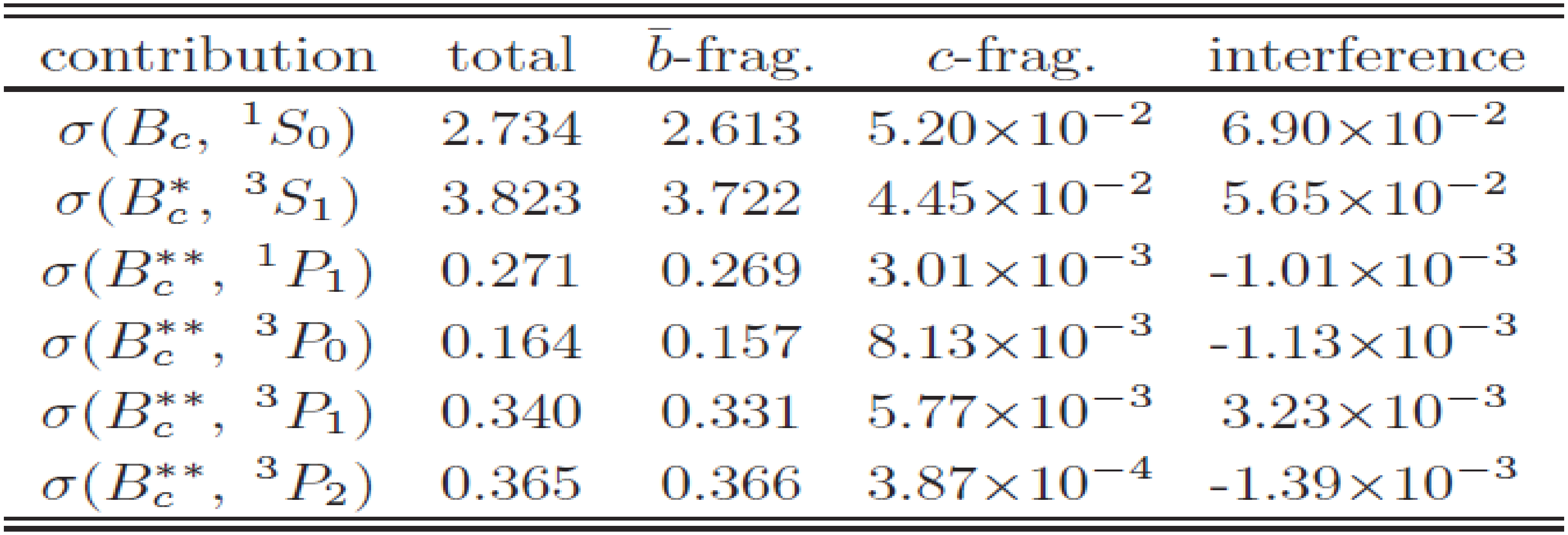
$\chi_{B_c}^J$: $(c\bar{b})$ P-wave excited states $({}^3P_J\,,\ J^P=0^+\,,1^+\,,2^+)$

h_{B_c}: $(c\bar{b})$ P-wave excited state $({}^1P_1,\quad J^P=1^+)$

The physics

Production (estimated reliably by NRQCD):

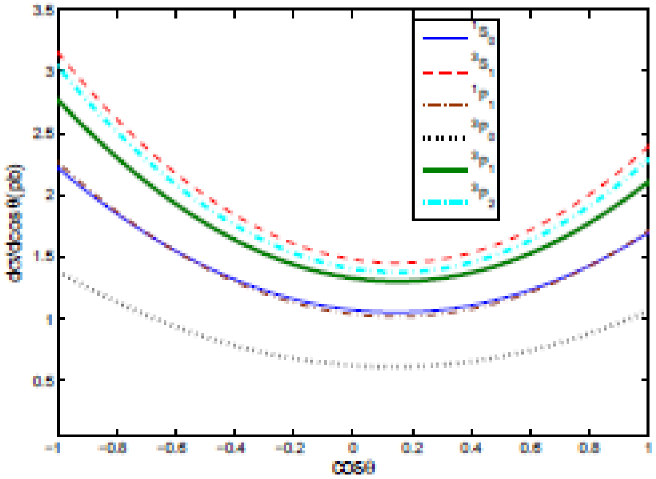




contribution	total	$\bar{b}$-frag.	c-frag.	interference
$\sigma(B_c,\ ^1S_0)$	2.734	2.613	5.20×10^{-2}	6.90×10^{-2}
$\sigma(B_c^*,\ ^3S_1)$	3.823	3.722	4.45×10^{-2}	5.65×10^{-2}
$\sigma(B_c^{**},\ ^1P_1)$	0.271	0.269	3.01×10^{-3}	-1.01×10^{-3}
$\sigma(B_c^{**},\ ^3P_0)$	0.164	0.157	8.13×10^{-3}	-1.13×10^{-3}
$\sigma(B_c^{**},\ ^3P_1)$	0.340	0.331	5.77×10^{-3}	3.23×10^{-3}
$\sigma(B_c^{**},\ ^3P_2)$	0.365	0.366	3.87×10^{-4}	-1.39×10^{-3}

The cross sections in *pb*.

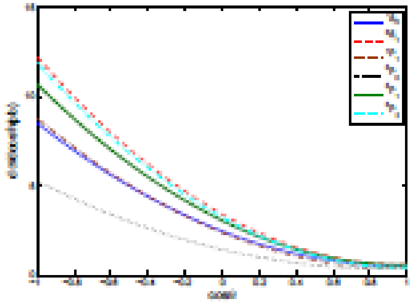
The physics

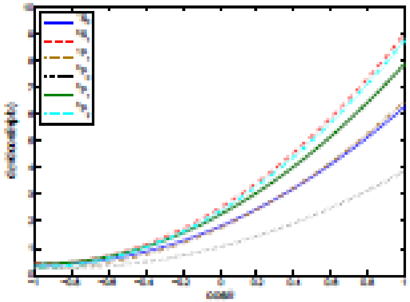


Differential cross sections for various states.

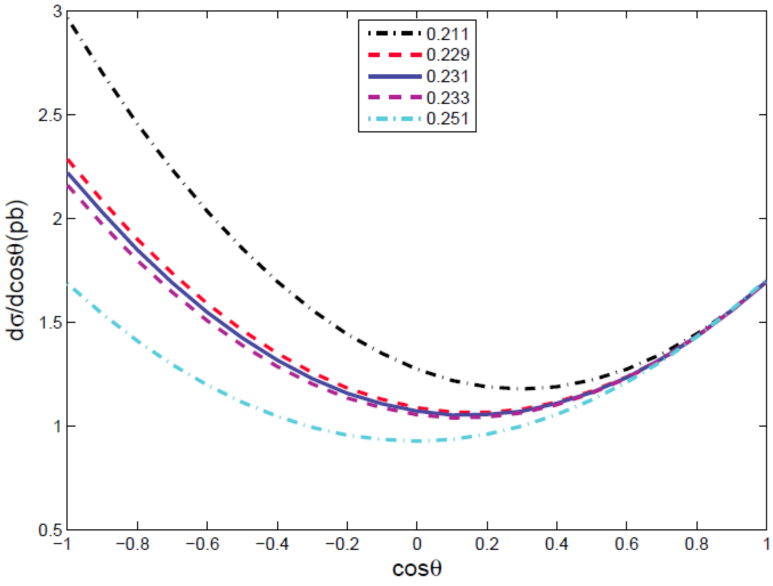
Z couples to fermions in vector and psudo-vector that makes the asymmetry in forward and backward, thus the asymmetry in production may be used to measure SinΘ_W !

The polarized e+e- beams make the asymmetry stronger.





The physics



The dependence on the Wenberg angle $\mathrm{Sin}\Theta_W$.

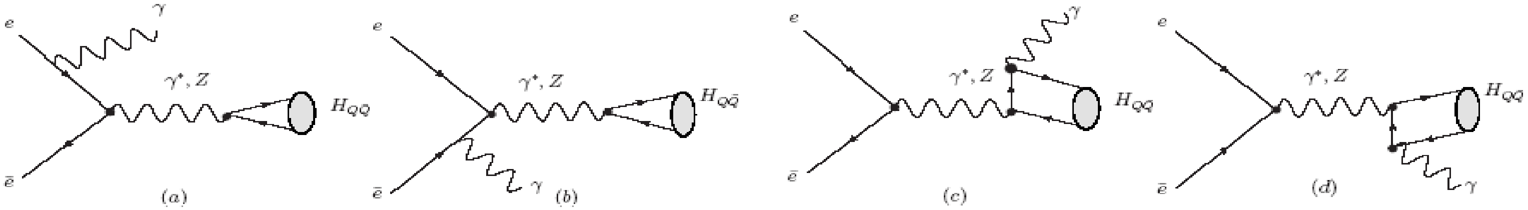
The physics

- **Another example:o measure the spectrum for heavy quarkonia & exatics:**

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

Two body final state!
(monoenergy photon)

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

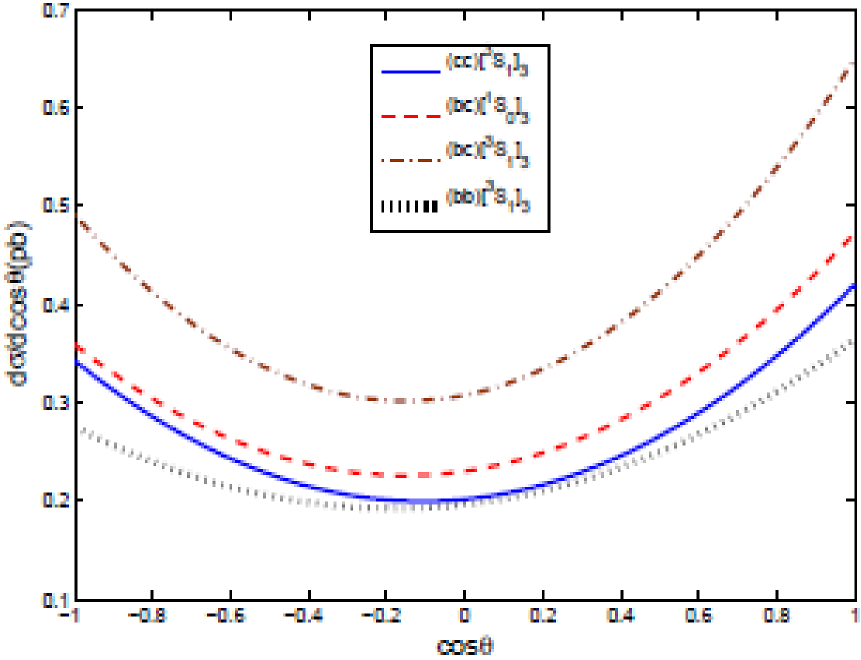


	$^3S_1$	$^1S_0$	$^3P_0$	$^3P_1$	$^3P_2$	$^1P_1$
$\sigma_{(c\bar{c})}(pb)$	0.934	0.662×10^{-3}	0.328×10^{-4}	0.197×10^{-3}	0.661×10^{-4}	0.615×10^{-3}
$\sigma_{(b\bar{b})}(pb)$	0.565×10^{-1}	0.475×10^{-2}	0.128×10^{-4}	0.838×10^{-4}	0.930×10^{-4}	0.833×10^{-4}

The physics

One more example:

The production of baryons Ξ_{cc}, Ξ_{bc}, Ξ_{bb} (in *pb*):



（其中 Ξ_{bb}的截面乘了因子10！）

The physics

Heay flavored exotic hadrons:

Tetraquarks (Z$^+$(3900),….):

$$(Q\bar{Q}'q\bar{q}'),(Q\bar{Q}'Q\bar{q}'),(Q\bar{Q}'q\bar{Q}'),(Q\bar{Q}'Q\bar{Q}')\ :\ Q,Q'=c,b;\ \ q,q'=u,d,s$$

Pentaquarks (Pc$^+$(4450), Pc$^+$(4380),….):

$$(Q\bar{Q}'qq'q''),(Q\bar{Q}'Qqq'),etc\ :\ Q,Q'=c,b;\ \ q,q',q''=u,d,s$$

Hybrads:

$$(Q\bar{Q}'g),etc\ :\ Q,Q'=c,b;\ \ g=gluon$$

Advantages in studying the heavy exotic hadrons:

The 'mixing' and 'interferences' are simple;

The heavy components decay in the detector;

etc

Summary

- There are may interesting and important physics:
  - ◆ Highly precise tests of SM, looking for direct and indirect evidence for new physics
  - ◆ FFs for heavy and double heavy hadrons
  - ◆ Heavy flavor physics
  - ◆ Heavy and double heavy hadron physics
- The luminosity of SZF $\mathcal{L} \geq 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is crucial for hadron physics
  - ◆ There is no crucial luminosity for such physics as 'highly precise test of SM, …..'
  - ◆ For some QCD problems and hadron physics, The luminosity $\mathcal{L} \geq 10^{35}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is crucial, as the production in the order of *pb*.

Thanks !