Physics at tau-charm-beauty facilities

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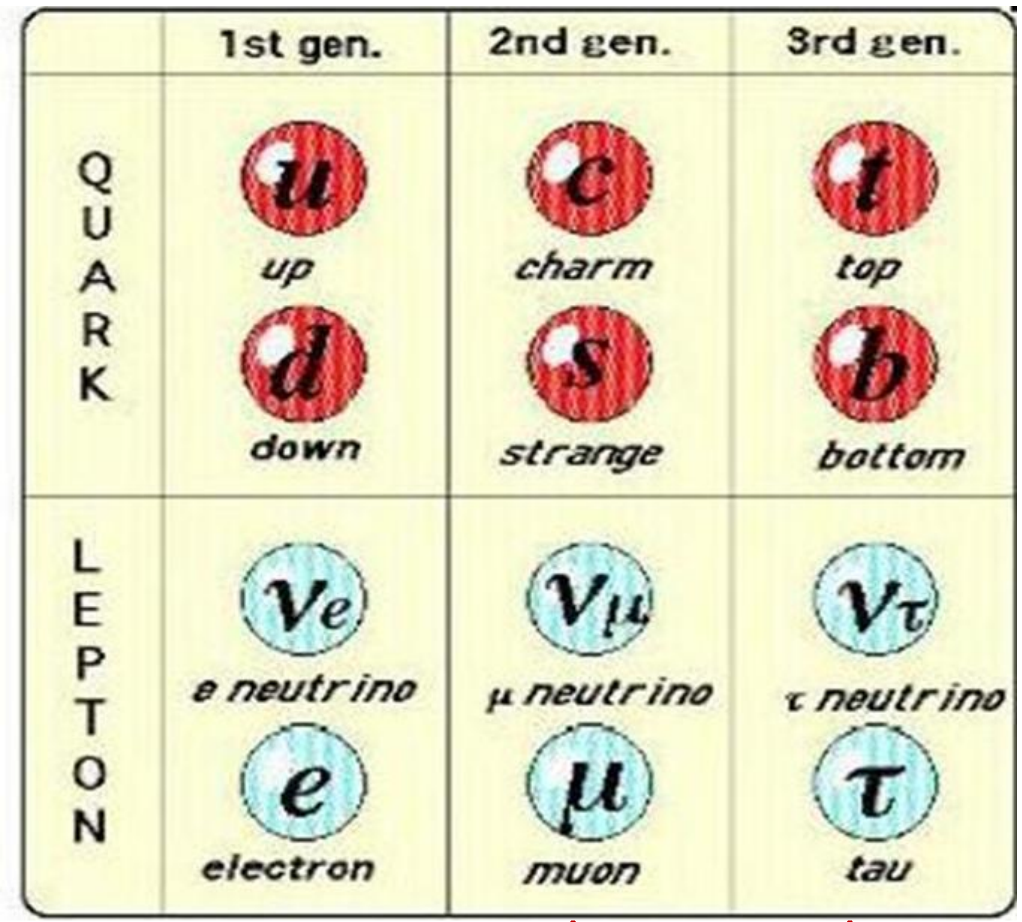
CERN-BINP workshop for young scientists in e+e- colliders
22-24 August, 2016

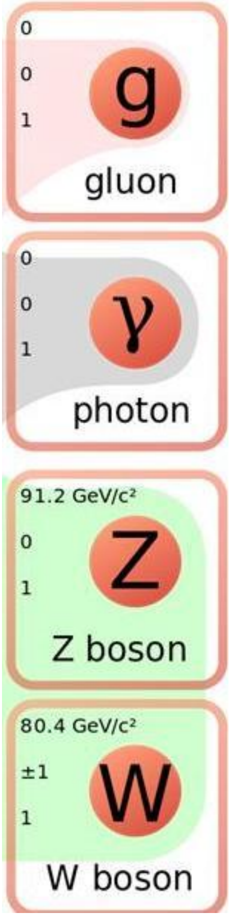
OUTLINE

1. e^+e^- physics introduction
2. e^+e^- facilities
3. New data in tau physics
4. Charm news
5. Beaty physics
6. Future projects
7. Conclusions

Fundamental particles

Matter ↓ s=1/2 Field ↓ s=1





↑ ↑ ↑

Flavors

+3 colours for each quarks

3 generations

+ antiparticles

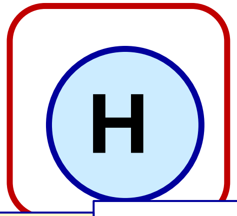
r < 10^{-17} cm !

Total number : 60 + H = 61

All have spin excl H

M(matter) ~ 550 GeV

ΣQ(quarks) = - ΣQ(leptons) !

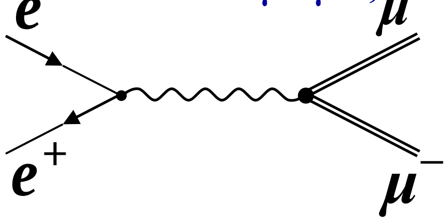


s=0 **125 GeV**

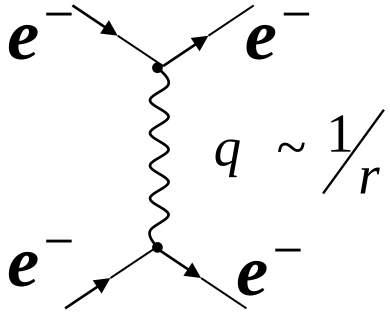
Interactions

Quantum electrodynamics (QED)

$e^+e^- \to \mu^+\mu^-$,

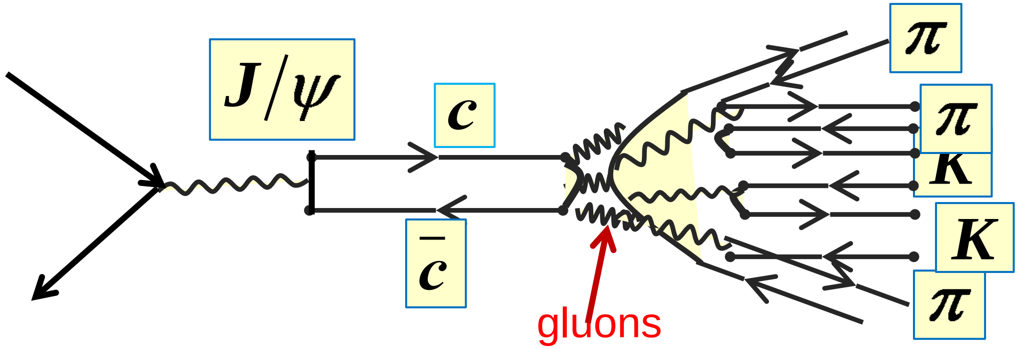


$e^+e^- \to e^+e^-$,



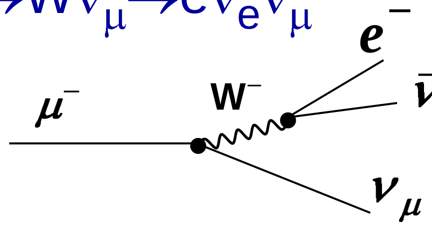
Strong interaction (QCD)

$e^+e^- \to J/\Psi \to$ hadrons

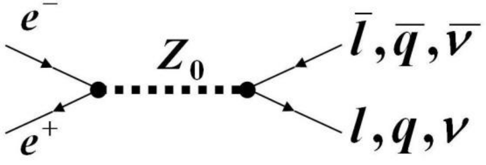


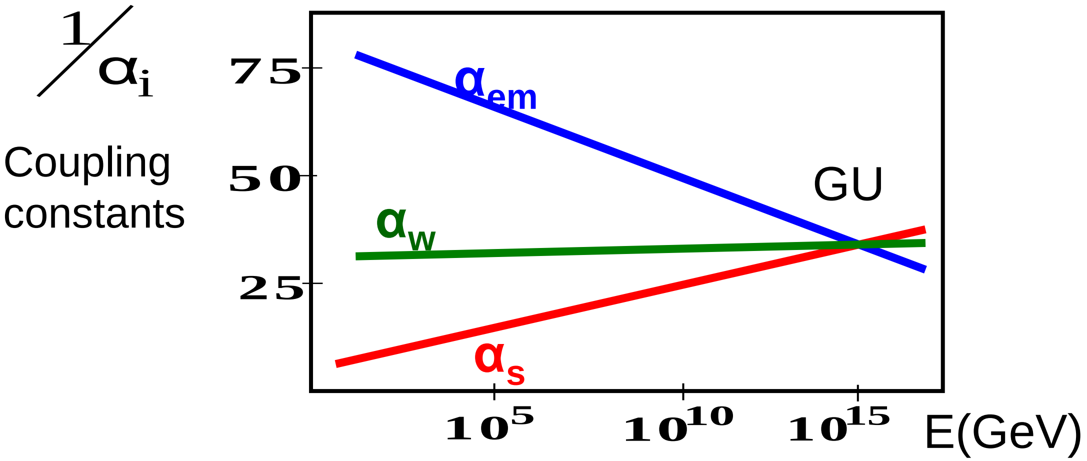
Electroweak interaction (EW)

$\mu \to W\nu_\mu \to e\nu_e\nu_\mu$

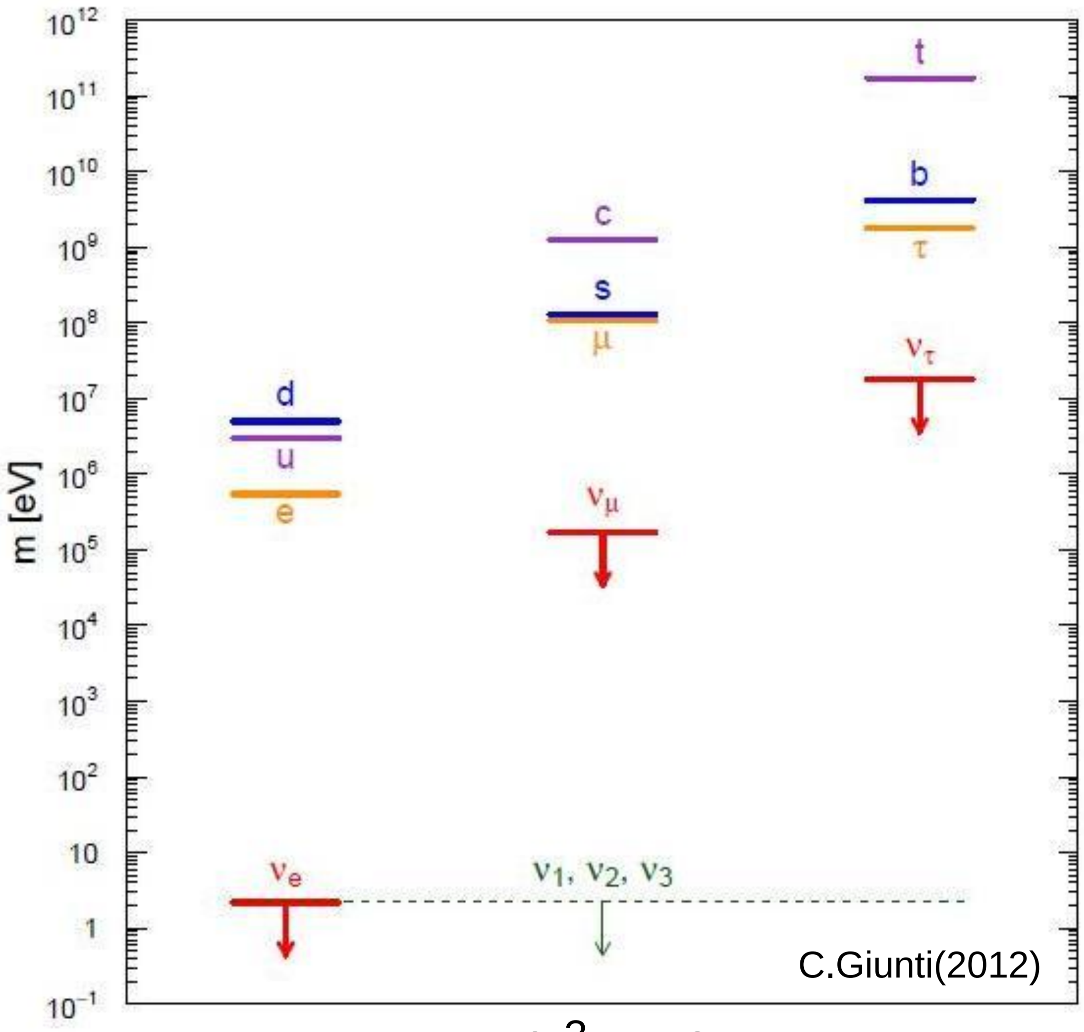


$e^+e^- \to Z^0 \to f^+f^-$,





Masses of fermions



$M_\nu \sim 10^{-3}$ eV ?

Three generations shown

Ranges for quarks :
~ 5 orders of magnitudes

Ranges for leptons :
~ 12 orders of magnitudes

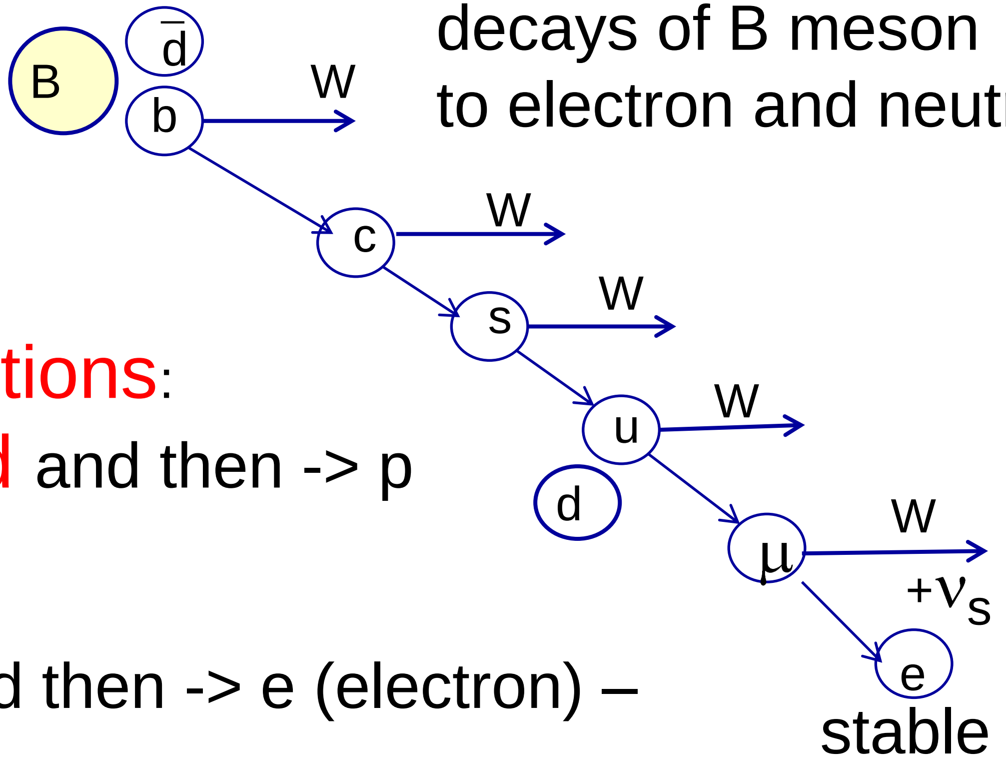
Total range :
~ 14 orders of magnitudes

Flavour conservation/violation

1. Flavour conservation
   in strong and e.m. interactions

$\gamma^* \rightarrow q_i \bar{q}_i,\ \gamma^* \not\rightarrow q_1 \bar{q}_2,$

Chain of subsequent decays of B meson to electron and neutrino

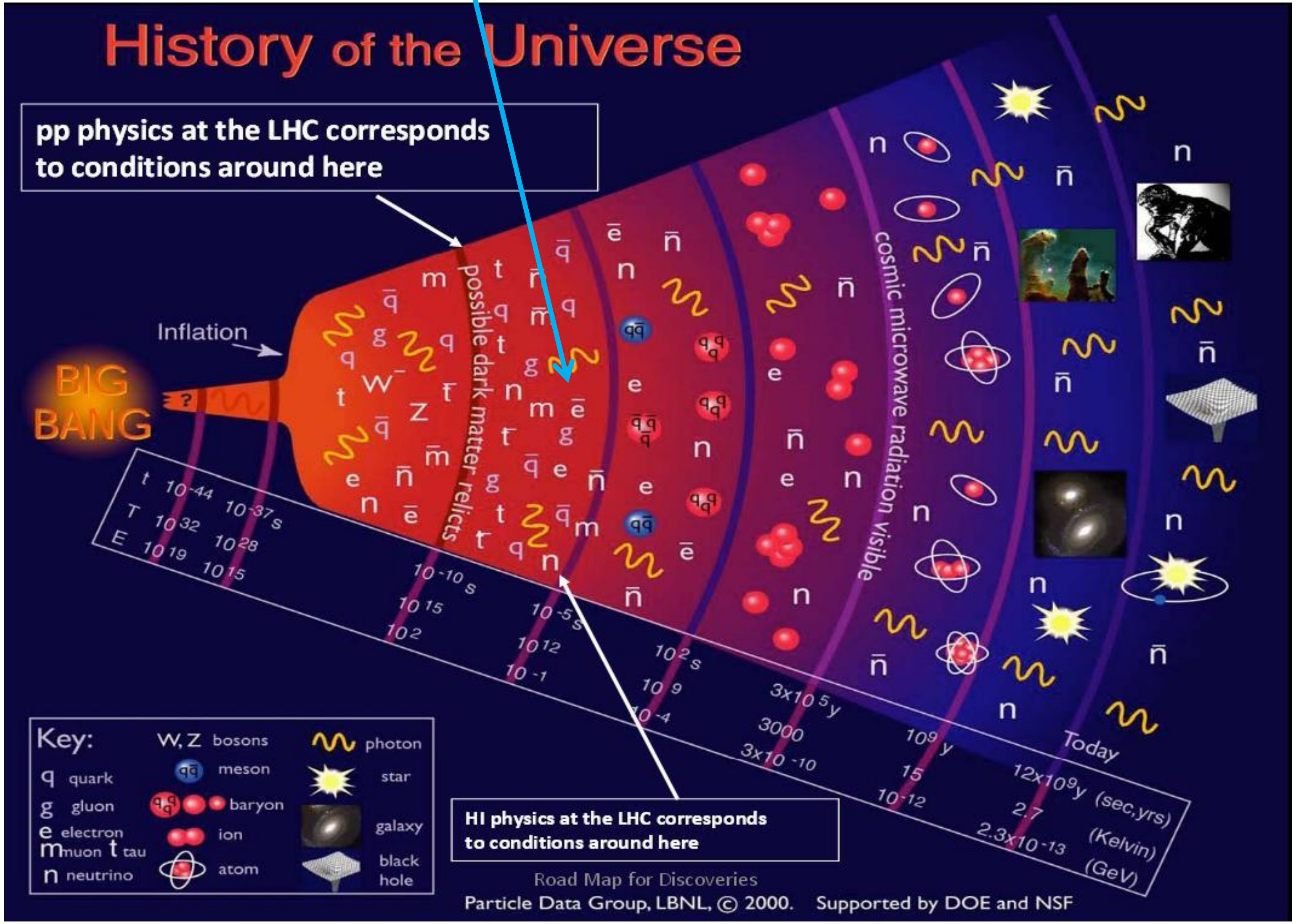


2. Flavour violation in weak interactions:

in heavy flavored baryons b,c,s -> u,d and then -> p (proton) – the only stable baryon

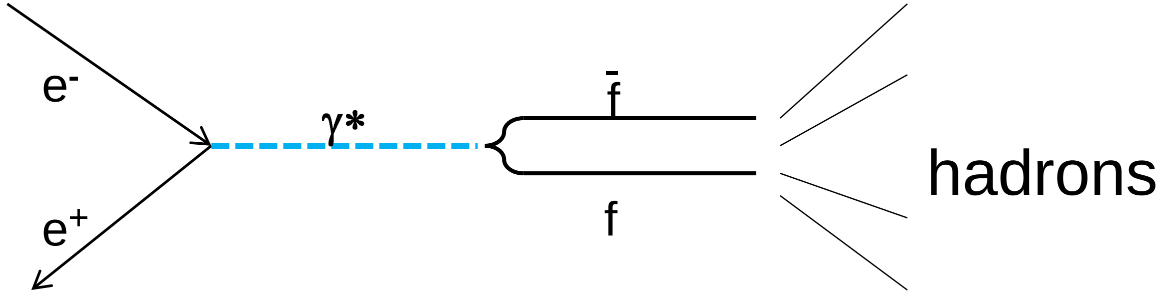
in mesons B,D,K quarks b,c,s -> u,d and then -> e (electron) – the only stable lepton $+\nu_s$

Time when quarks and leptons appeared



Now quarks are seen as jets in $e^+e^- \to$ q qbar process. Similar to $e^+e^- \to \mu^+\mu^-$.

e^+e^- collisions
single photon channel



$f = l, q$

$l = e, \mu, \tau$

$q = u, d, s, c, b, t$

Quantum numbers:

$J = L + S = J_\gamma = 1$

$S = 1$ (spin)

$L = 0, 2$, S,D-waves

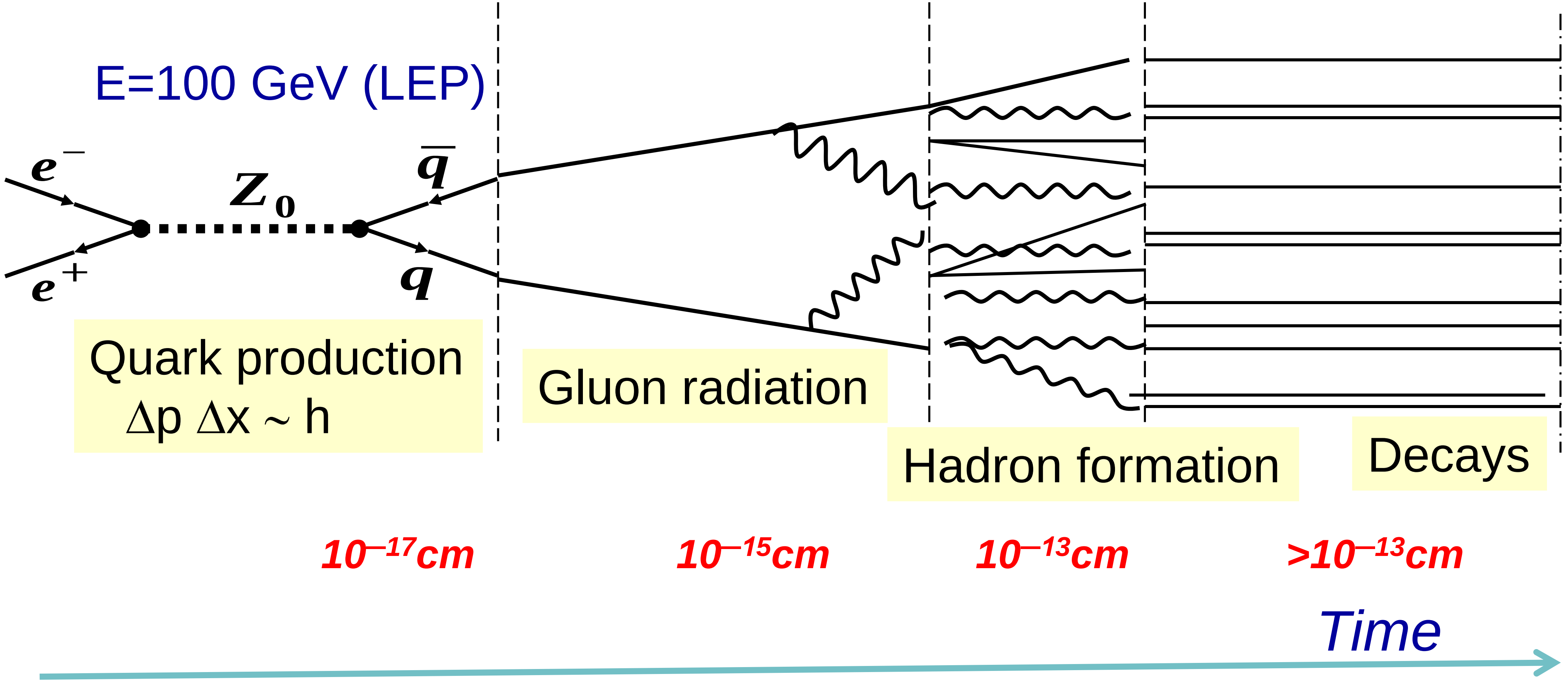
$P = (-1)^L = -1$

$C = (-1)^{L+S} = -1$

${}^3S_1, {}^3D_1 = {}^{2S+1}L_J$

$J^{PC} = 1^{--}$

Space-time picture of e^+e^- – annihilation to hadrons



Polarization in e^+e^- single photon channel

Case of unpolarized beams

e^- γ^* e^+

→ **1/4** →

← **1/4** ←

s_- s_+

→ 0 ←

← 0 →

Half of e^-, e^+ don't annihilate

Case of e^- beam longitudinal polarization

e^- e^+

→ **1/2** →

→ 0 ←

Half of e^+ don't annihilate

Best case

e^- e^+

→ →

or

← ←

Max effect. luminosity

Worst case

e^- e^+

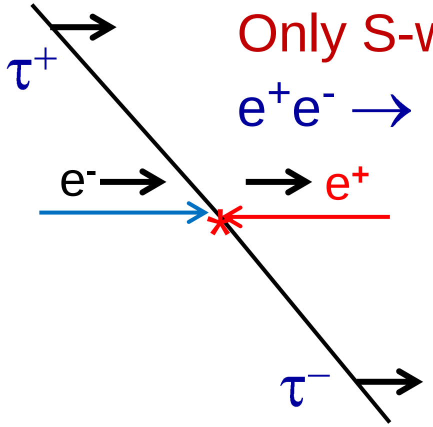
→ ←

or

← →

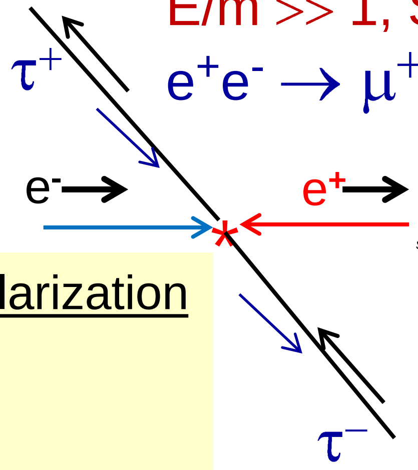
No single photon annihilation
Only two photon physics

Effects of the beam longitudinal polarization



Only S-wave (at threshold)

$e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-, B^+B^-,$



E/m >> 1, S, D waves

$e^+e^- \rightarrow \mu^+\mu^-, \tau^+\tau^-, B^+B^-$

Final tau polarization

$\theta=0$, $\xi=1$

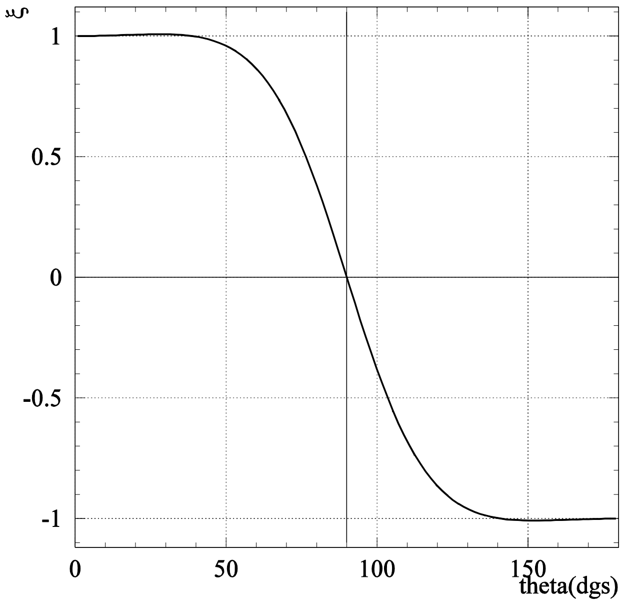
$\theta=30^o$, $\xi\approx1$

$\theta=45^o$, $\xi=0.946$

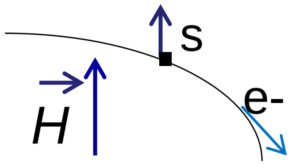
$\theta=60^o$, $\xi=0.8$

$\theta=90^o$, $\xi=0.$

See backups slide



Effects of beam transverse polarization



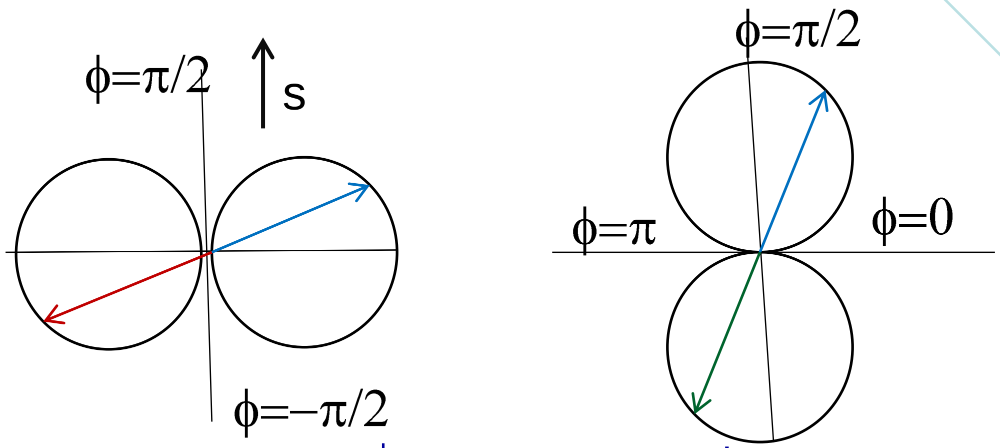
U=±μH $\varepsilon(t) = \frac{8}{5\sqrt{3}}(1-e^{-t/\tau})$

$0.924 = \frac{8}{5\sqrt{3}}$

$1/\tau = (5\sqrt{3}/8)\,\alpha\,(\gamma^5/R^3\,m^2)$

If E=2 GeV, R=100 m , then $\tau \sim 10^6$ sec !

Transverse polarization
leads to azimutal asymmetry

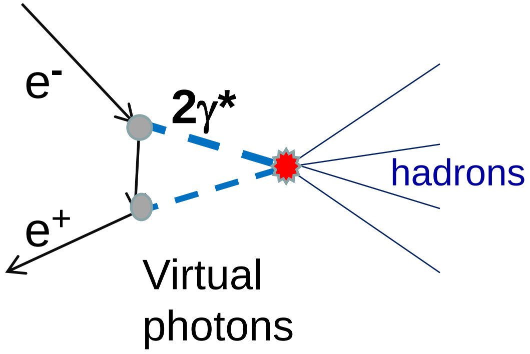


$e^+e^- \to$ qq (jets), $\mu^+\mu^-$, $\tau^+\tau^-$, B^+B^-

$e^+e^- \to \pi^+\pi^-$, D^+D^-,

Asymmetry degree depends
on baryon form factors

e^+e^- collisions
two photon channel



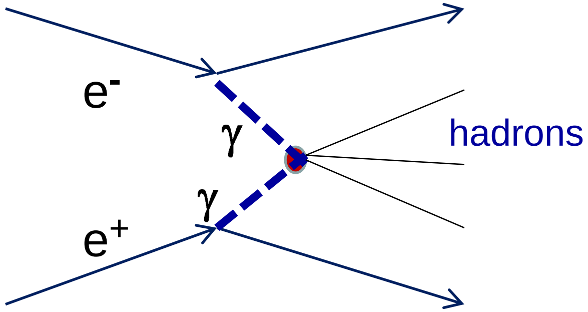
$\sigma_{2\gamma} \sim \alpha^2 \sigma_{1\gamma}$

C = +1
C even quantum numbers
$J^{PC} = 0^{-+}, 0^{++}, 1^{++}, 2^{++}, 2^{-+}$, ..

(P)Scalar helicity suppressed ~ $(m_e/M)^2$.
Vector and Tensor states χ_c, χ_b
can be produced ;

$e^+e^- \to \chi_c, \chi_b$, σ ~ 0.1 pb
Electron width is measured,
Γ_{ee} depends on form factors (QCD)

e^+e^- collisions
two (quasi real) photon - channel - 2



Photon-photon collider

C = +1

C even quantum numbers

Spin 1 - excluded

$J^{PC} = 0^{-+}, 0^{++}, \cancel{1^{++}, 1^{+-}}, 2^{++}, 2^{-+}, ..$

$L_{\gamma\gamma} \sim \alpha^2 \ln\gamma^3 . L_{ee}$

Scalar and tensor states χ_c, χ_b can be produced

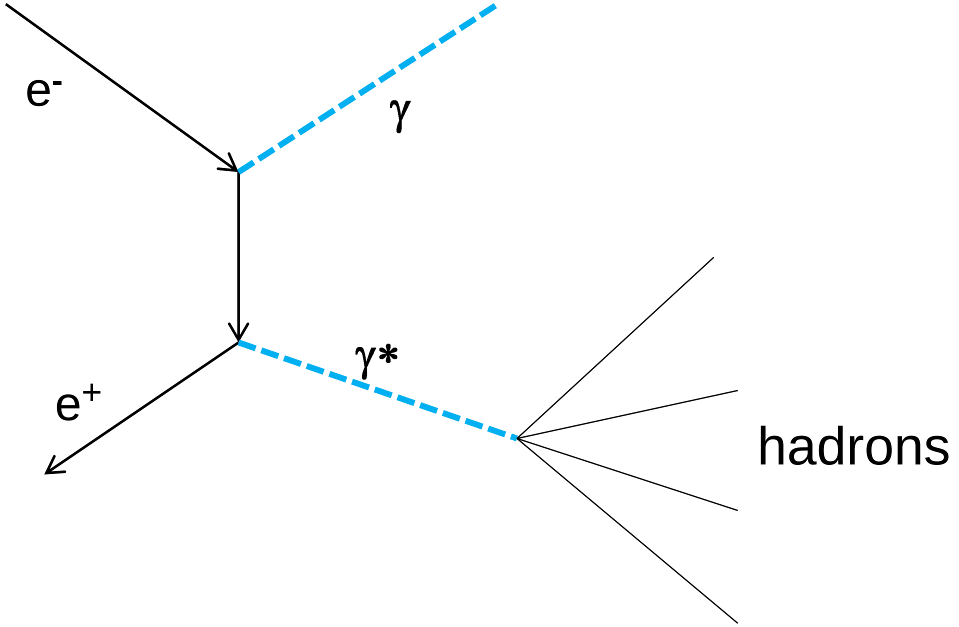
No helicity suppression of scalar states

Spin=1 excluded

Two photon width is measured and

$\gamma\gamma$ to hadron cross section.

e^+e^- collisions
Initial State radiation (ISR)

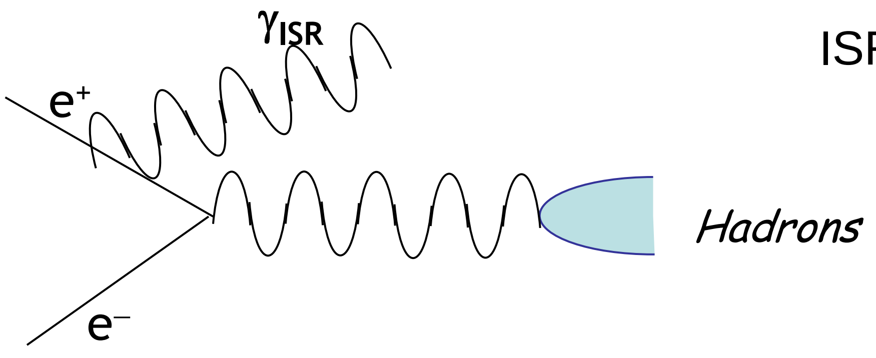


σ (ISR)~ $(10^{-2}$ -$10^{-3})$ σ_{ee}

Quantum numbers:
(the same as in single photon channel)
$J=L+S=J_{\gamma}=1$
$S=1$ (spin)
$L=0,2$, S,D-waves
$P=(-1)^L= -1$
$C=(-1)^{L+S}=-1$

${}^3S_1$, ${}^3D_1$ = ${}^{2S+1}L_J$
$J^{PC}=1^{--}$

e+e→hadrons in ISR



Mhadr < $\sqrt{s}$

ISR – Initial State Radiation or Radiative Return

$$\frac{d\sigma(s,x)}{dx\,d(\cos\theta)} = H(s,x,\theta)\cdot\ \sigma_0(s(1-x))$$

H - radiation function

$$H(s,x,\theta) = \frac{\alpha}{\pi x}\left(\frac{2-2x+x^2}{\sin^2\theta} - \frac{x^2}{2}\right),\quad x = \frac{2E_\gamma}{\sqrt{s}}$$

L_{ISR} ~ 0.3% L_0 ,
with L_0 ~ 0.5 ab^{-1} ---> L_{ISR} ~ 1.5 fb^{-1} !

Advantages of ISR

1. Full energy range from $2m_\pi$ up to $\sqrt{s}$ is available
2. Detection efficiency is flat over reaction mechanism
3. No large radiative corrections

But:

1. Low luminosity < 1 % L_0

Advantages of e+e-

1. Good energy resolution
2. Effective study of narrow resonances

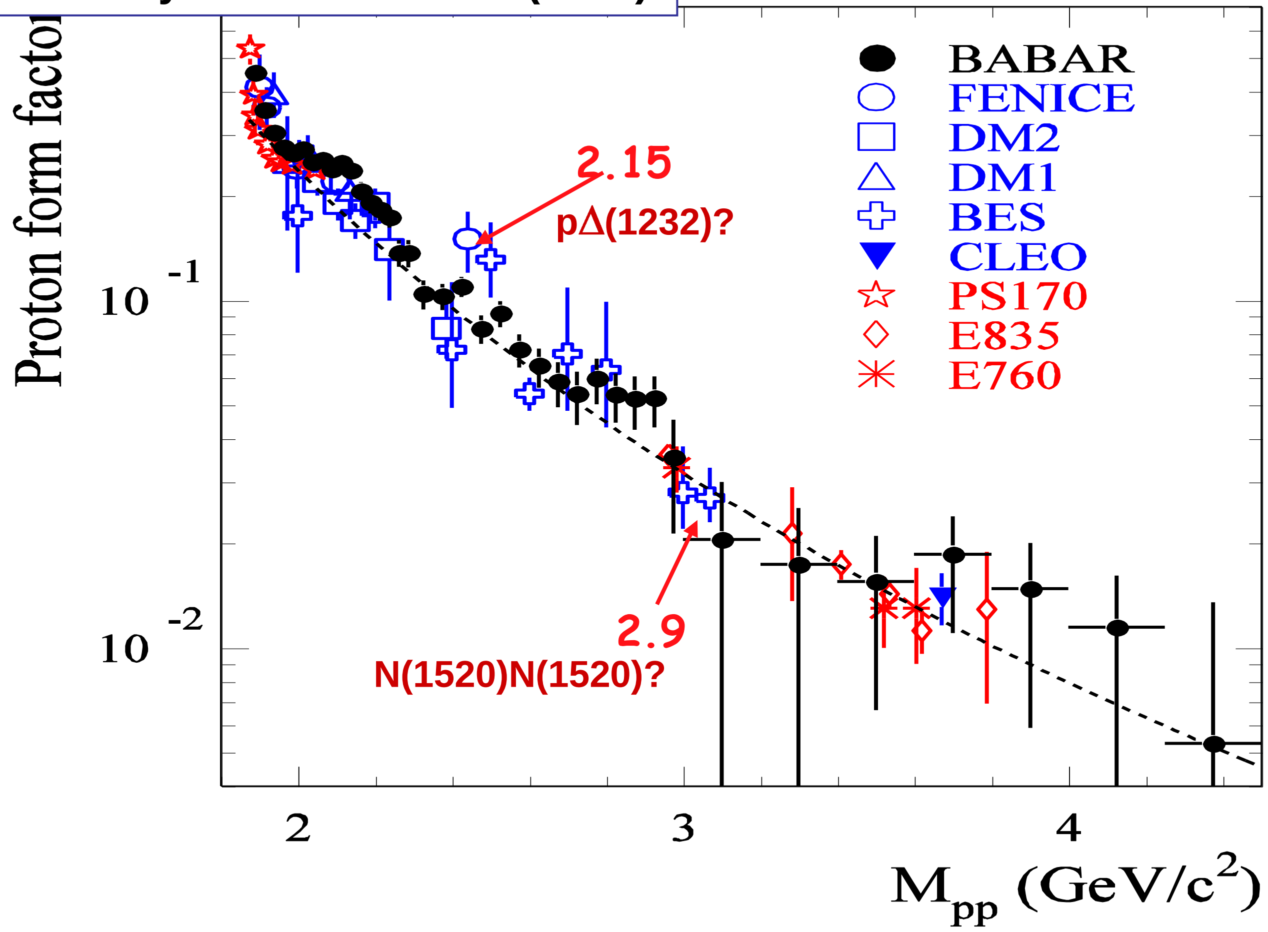
But:

1. No efficiency at small angles θ < 0.2

Example of ISR study

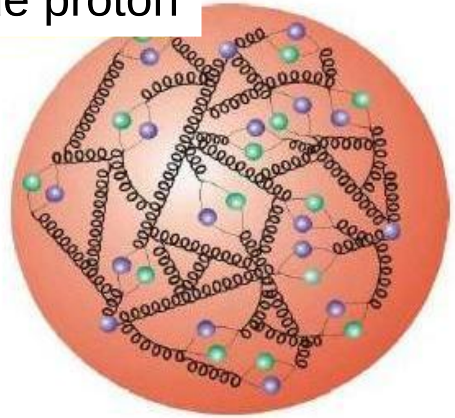
$e^+e^- \to \gamma p\bar{p}$

Babar: PhysRevD.87.092005(2013)



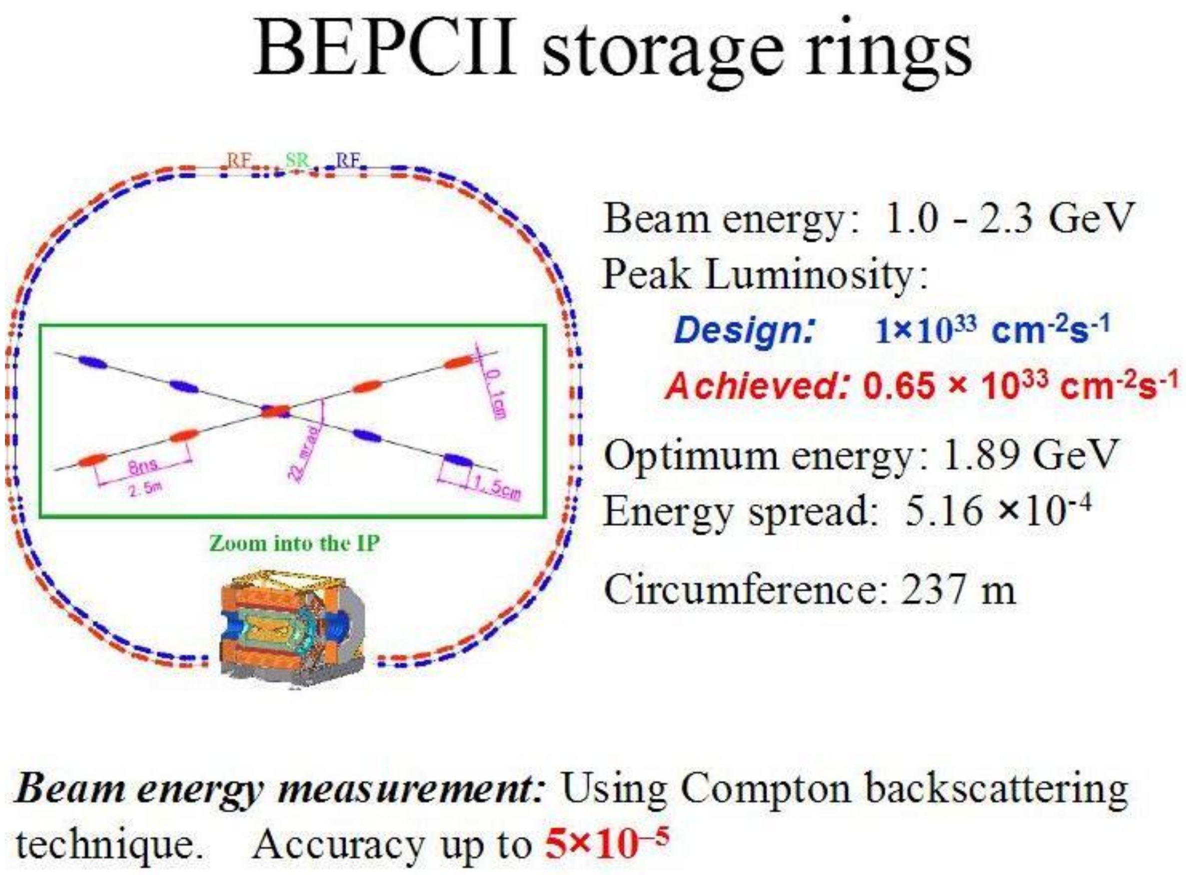
$$F_{pp} \sim \frac{\alpha_s^2(m)}{m^4} \sim \frac{C}{m^4 \ln^2(m^2/\Lambda^2)}$$

Inside proton

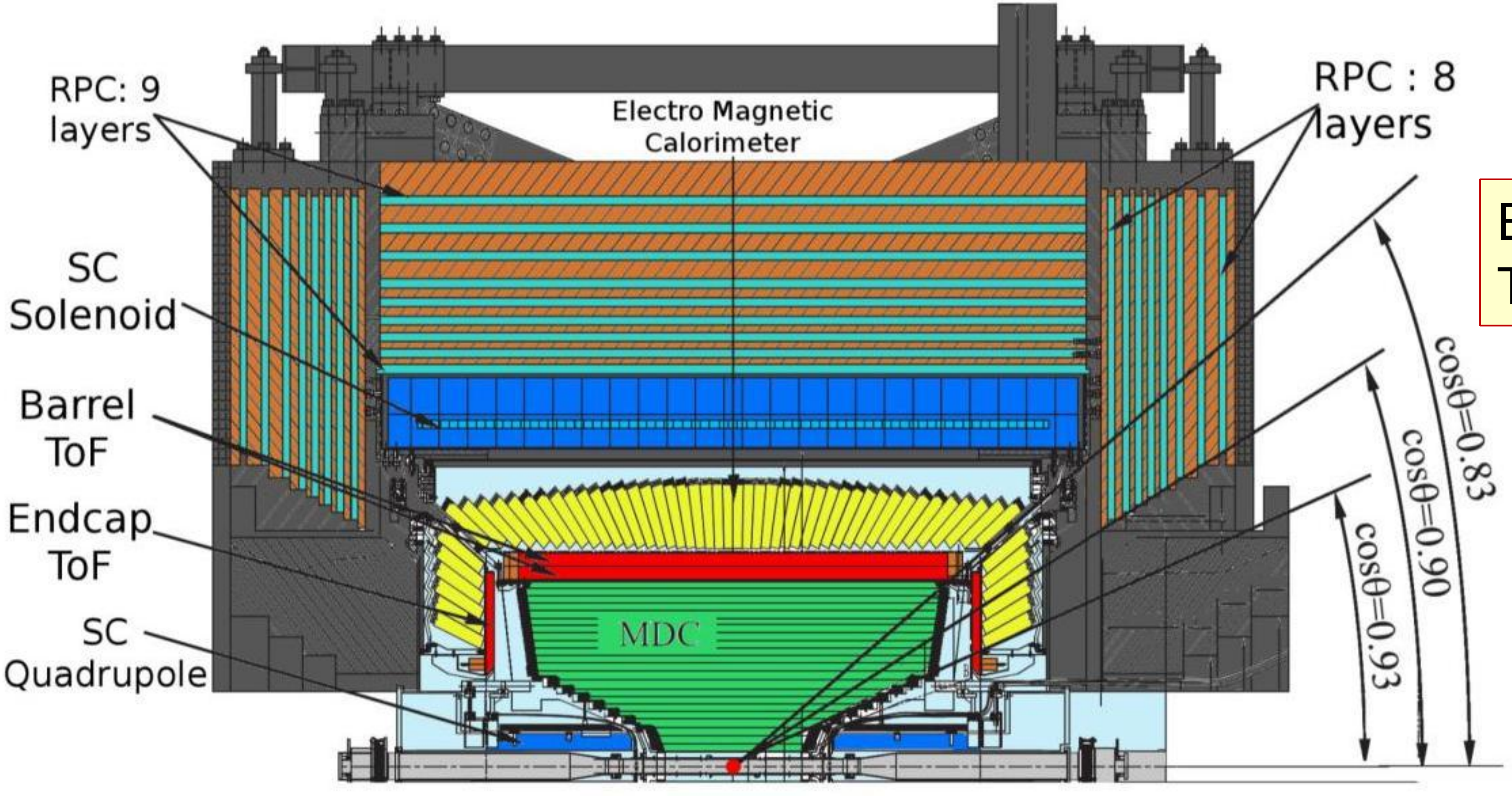


e^+e^- facilities

Outline



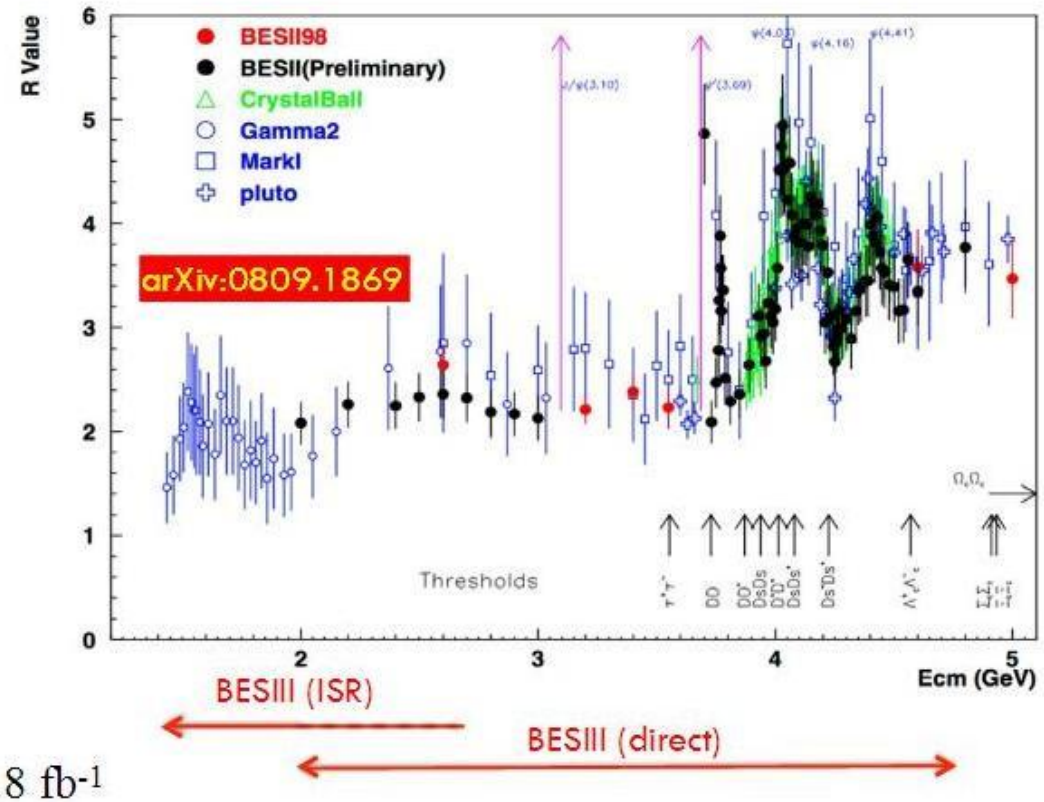
BESIII detector



EMC _CsI(Tl)-2.3%
TOF_<0.1 ns

Summary of BESIII experiments

- **1.3×10^9 J/ψ**
- **5×10^8 $\psi(2S)$**
- 2.9 fb^{-1} @ ψ_{3770}
- 0.5 fb^{-1} @ ψ_{4040}
- 2.3 fb^{-1} @ 4230/4260 MeV
- 0.5 fb^{-1} @ 4360 MeV
- 0.5 fb^{-1} @ 4600 MeV
- 1 fb^{-1} @ ψ_{4415}
- 0.1 fb^{-1} @ 4470/4530 MeV
- 0.04 fb^{-1} around Λ_c threshold
- 1 fb^{-1} @ 4420 MeV
- R scan:
  - 2-3 GeV, 19 points, ~0.5 fb^{-1}
  - 3.85-4.59 GeV, 104 points, ~0.8 fb^{-1}

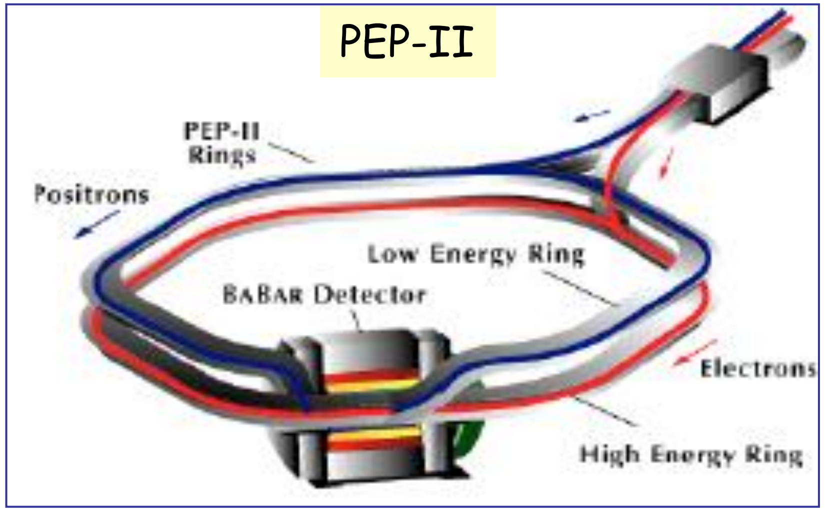


MORE:

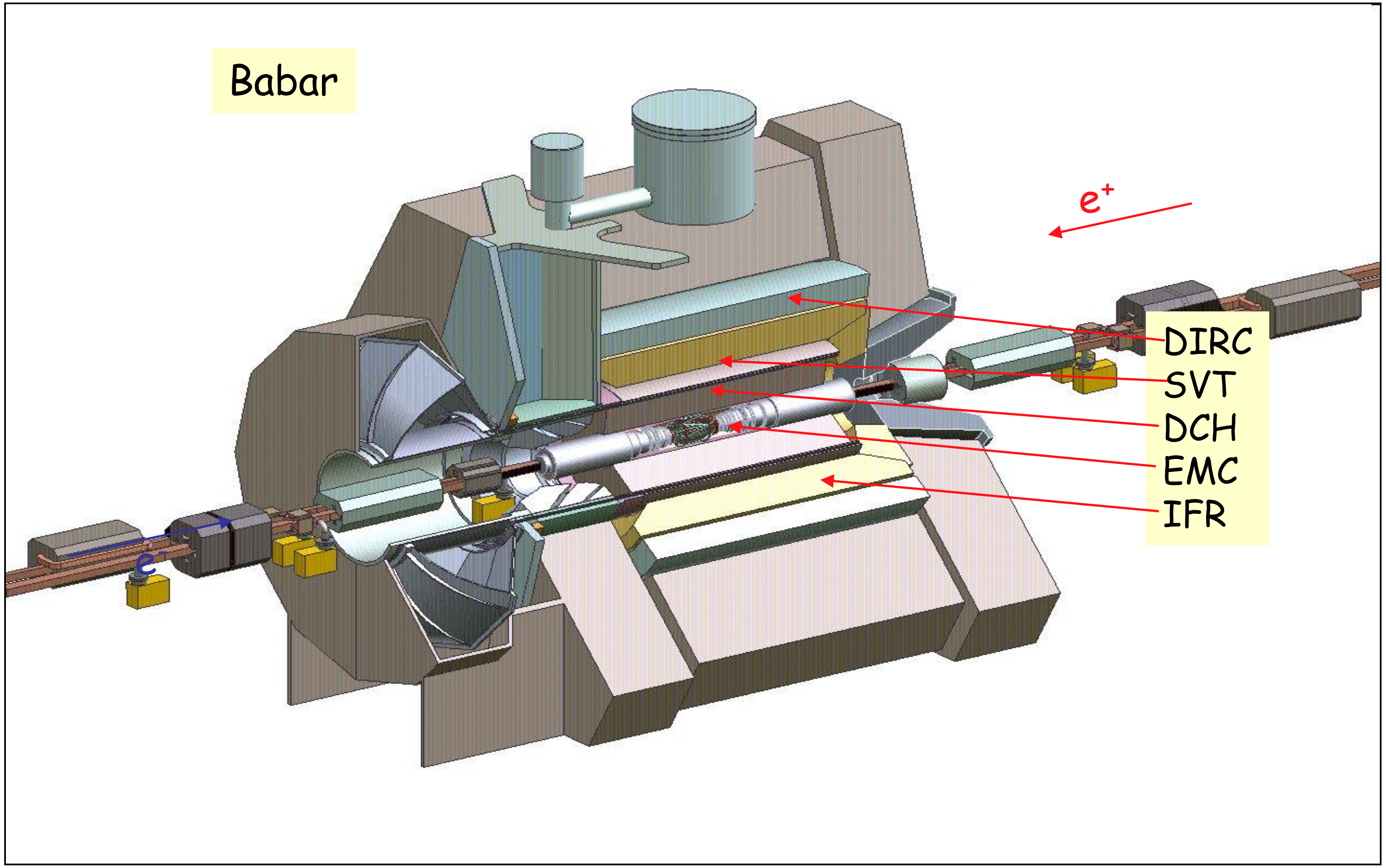
- 3554 MeV 24 pb^{-1} τ mass; 4100-4400 MeV 0.5 fb^{-1} coarse scan
- On-going data taking

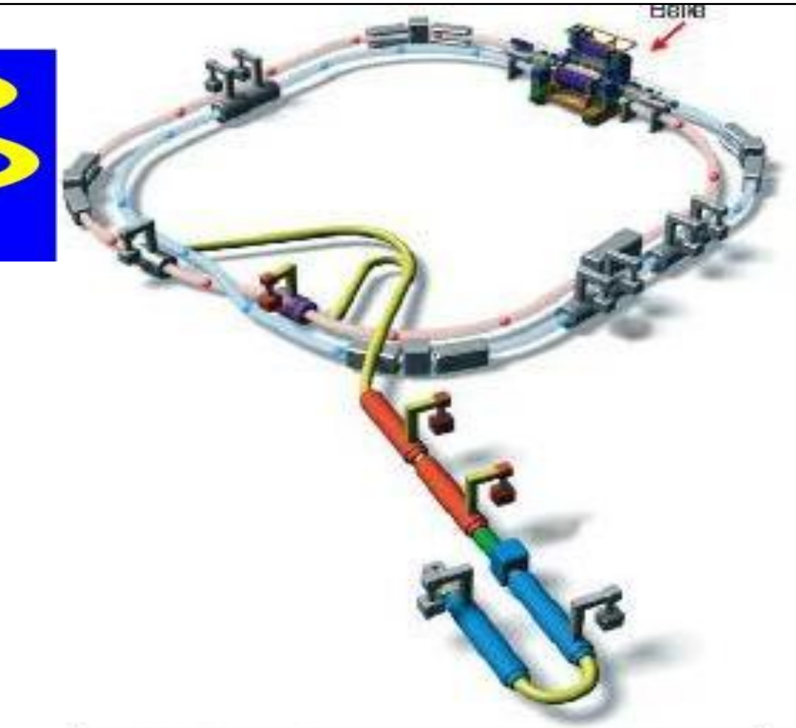
PEP-II e^+e^- collider, Babar detector

E_+ = 3.1 GeV, E_- = 9 GeV

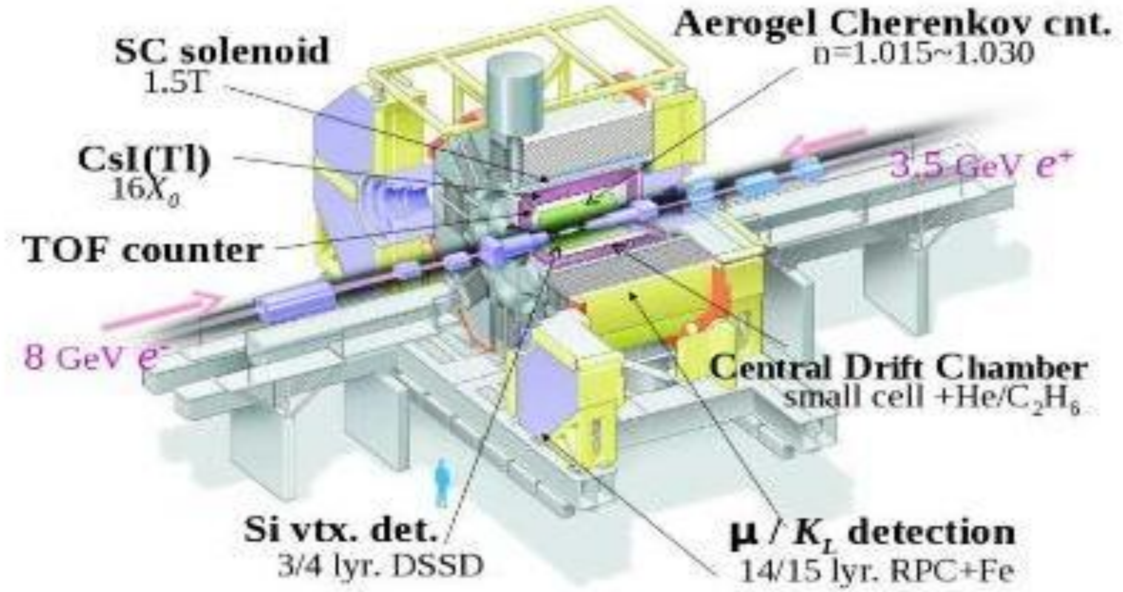


E_{CM} = M(Υ(4S))=10.6 GeV
2000 - 2008 yrs
L_{ins}=10 nb^{-1}/sec
IL = 500 fb^{-1}
N(B) = 10^9





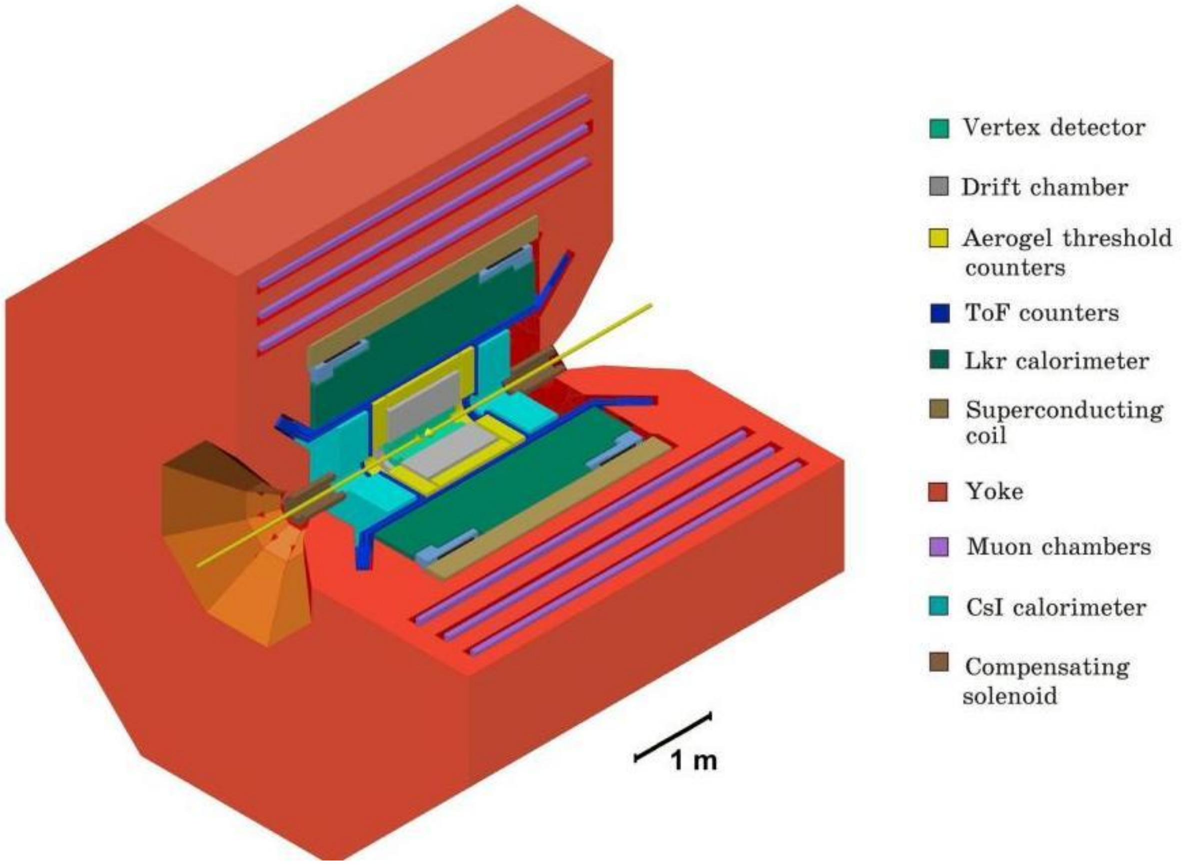
Belle Detector



Process	σ, nb
$e^+e^- \to e^+e^-(\gamma)$ $15^o \leq \theta \leq 165^o$	123.5
$e^+e^- \to \mu^+\mu^-(\gamma)$	1.005
$e^+e^- \to q\overline{q}\ (q = u, d, s, c)$	3.39
$e^+e^- \to b\overline{b}$	1.05
$e^+e^- \to e^+e^- f\overline{f}$ $(f = u, d, s, c, e, \mu, \tau)$	72.6
$e^+e^- \to \tau^+\tau^-(\gamma)$	0.919

- $E_{e^-} = 8$ **GeV**, $E_{e^+} = 3.5$ **GeV**
- **Peak luminosity:** $L = 2.11 \times 10^{34}$ **cm**$^{-2}$**s**$^{-1}$
- **Integrated luminosity:** $\int L dt \simeq 1$ **ab**$^{-1}$, $N_{\tau\tau} \simeq 10^9$
- B-factory is also τ-factory

KEDR at VEPP-4



\+ laser energy calibration

\+ γ –beam

σ/E_γ ~ 2 % at 1 GeV measured BGO

~ 0.5% project

\+ e- beam,

σ/E ~ 2 % at 1 GeV

Physical program at KEDR

E = 2 -12 GeV

1. Measurements of Ψ,Υ,τ masses
2. $\gamma\gamma \rightarrow$hadrons
3. Rad.transitions cc,bb $\rightarrow \gamma$ + X
4. $\mathbf{R} = \frac{\sigma(e^+e^- \rightarrow hadr)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$

Physics at e+e- (τ–c–b) colliders

1. **QED:** $e^+e^- \to e^+e^-, \mu^+\mu^-, \gamma\gamma$, **used for luminosity normalization ~0.1%**

2. **QCD:** $e^+e^- \to M\bar{M}, B\bar{B}$, **multihadrons, X,Y, Z,** $R = \frac{\sigma(e^+e^- \to hadr)}{\sigma(e^+e^- \to \mu^+\mu^-)}$

3. **EW : flavor transitions of low lying b,c $\to$s,u,d, CPV, mixing …**

4. **BSM physics : study of rare decays of τ, D, B; LFV, FCNC, …**

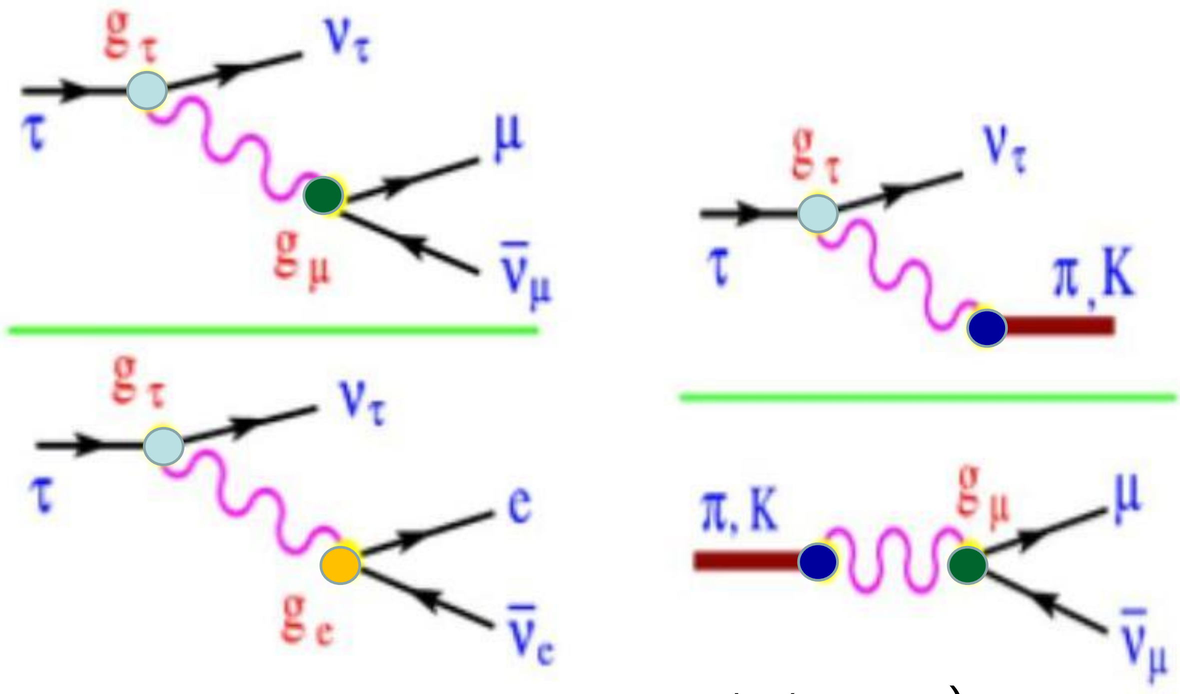
Tau lepton physics in $e^+e^- \to \tau^+\tau^-$ process

Outline

1. e^+e^- physics introduction
2. e^+e^- facilities
3. New data in tau physics
4. Charm news
5. Beaty physics
6. Future projects
7. Conclusions

1. Lepton universality
2. LFV
3. V_{us}
4. α_S
5. $(g-2)_\mu$
6. CPV

Lepton universality, $g_\tau = g_e = g_\mu$, ~10^{-3}



Benerjee(TAU2012)

g_τ/g_e = 1.0031 ± 0.0016,
g_τ/g_μ = 1.0013 ± 0.0016.
g_μ/g_e = 1.0018 ± 0.0014
Checked at ~ 10^{-3} level
(A.Lusiani, HFAG)

LEP: W->μν / W->eν -> g_μ/g_e = 0.997+-0.010
KLOE: K->πμν/ K->πeν -> g_μ/g_e = 1.0010+-0.0025
HFAG: τ->Kν / π->μν -> g_τ/g_μ = 0.9857+-0.0079

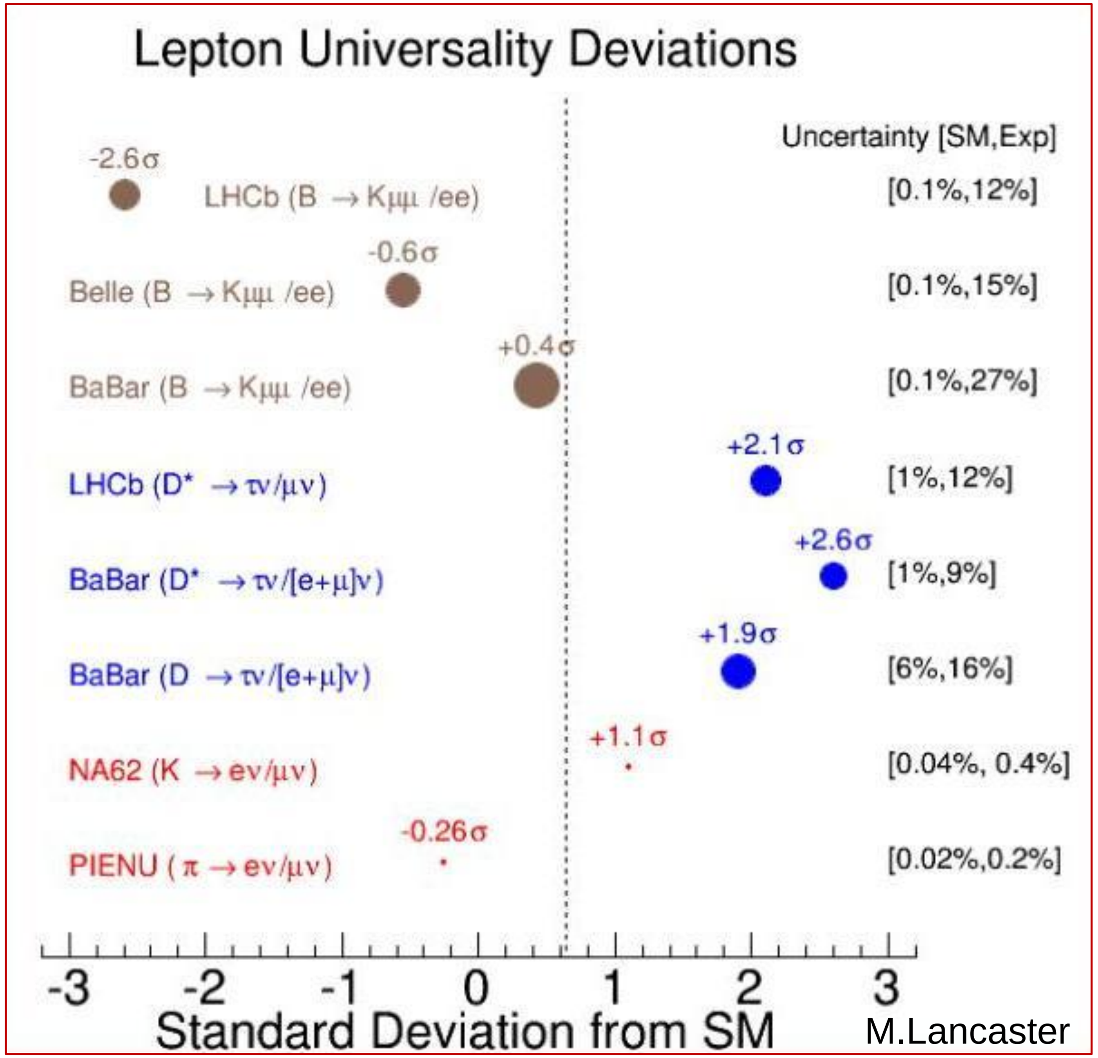
Basic relations

$$\Gamma(L \to \nu_L \ell \bar{\nu}_\ell(\gamma)) = \frac{B(L \to \nu_L \ell \bar{\nu}_\ell)}{\tau_L} = \frac{G_L G_\ell m_L^5}{192\pi^3} f\left(\frac{m_\ell^2}{m_L^2}\right) r_W^L r_\gamma^L ,$$

$$G_\ell = \frac{g_\ell^2}{4\sqrt{2}M_W^2} \qquad f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x$$

$$r_W^L = 1 + \frac{3}{5}\frac{m_L^2}{M_W^2} \qquad r_\gamma^L = 1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)$$

Lepton universality in K,D,B decays



Different sign of deviation
in D and B decays !

τ Michel parameters – SM test

$e^+e^- \to \tau^+\tau^-$, $\tau_1 \to l\nu\nu$, $l = e, \mu$; 1409.4969

Lepton spectrum in τ decay ,1409.4969
(depends on Michel parameters)

$$\frac{d\Gamma(\tau^\mp)}{d\Omega dx} = \frac{4G_F^2 M_\tau E_{\max}^4}{(2\pi)^4}\sqrt{x^2 - x_0^2}\Big(x(1-x) + \frac{2}{9}\rho(4x^2 - 3x - x_0^2) + \eta x_0(1-x)$$

$$\mp\frac{1}{3}P_\tau cos\theta_\ell \xi\sqrt{x^2 - x_0^2}\left[1 - x + \frac{2}{3}\delta(4x - 4 + \sqrt{1 - x_0^2})\right]\Big),\ x = \frac{E_\ell}{E_{\max}},\ x_0 = \frac{m_\ell}{E_{\max}}$$

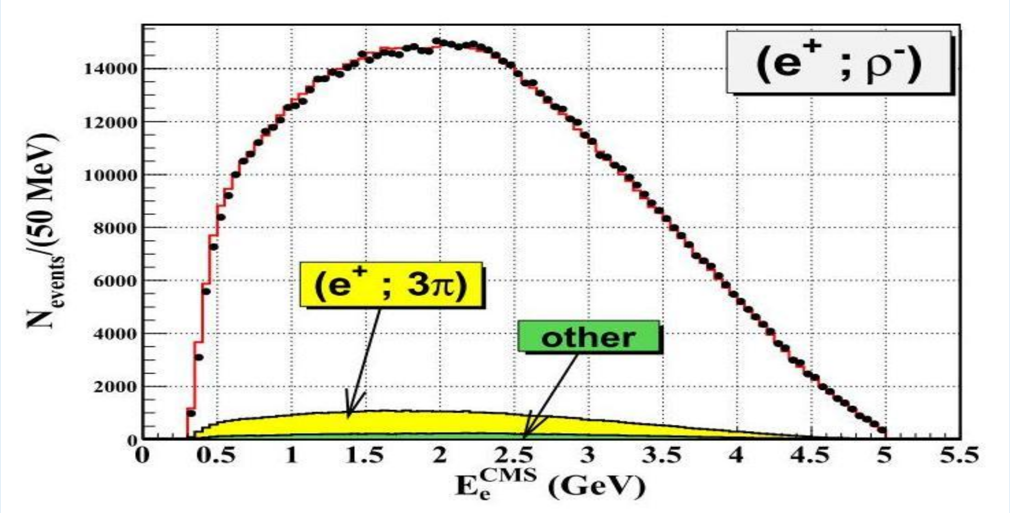
In the SM: $\rho = \frac{3}{4}$, $\eta = 0$, $\xi = 1$, $\delta = \frac{3}{4}$

τ Michel parameters

Michel parameters (MP) - parameters in lepton spectrum $\tau_1 \to l\nu\nu$, sensitive to EW modification, NP

$e^+e^- \to \tau^+\tau^-$, ΔL = 485 ifb, arXiv1409.4969 (2014)

$\tau_1 \to l\nu\nu$, l = e, μ ; $\tau_2 \to \rho\nu \to \pi\pi^0\nu$,
spin-spin correlation,
precisely measured 9 dim phase space kinematics,
fit gives four MP uncertainties



Belle results

ρ	- 0.0027
η	- 0.0081
$\xi_\rho\xi$	- 0.0047
$\xi_\rho\xi\delta$	- 0.0040

MP accuracy

this work :	**~ 0.5 %**
PDG :	**~ 1-3 %**
for muon :	**~ 0.1 %**

Lepton flavor violation (LFV) in tau decays

$\tau \to \mu\gamma$

$B_{\tau\mu\gamma} < 5.10^{-8}$ (Belle)

LF conserved when $m_\nu=0$

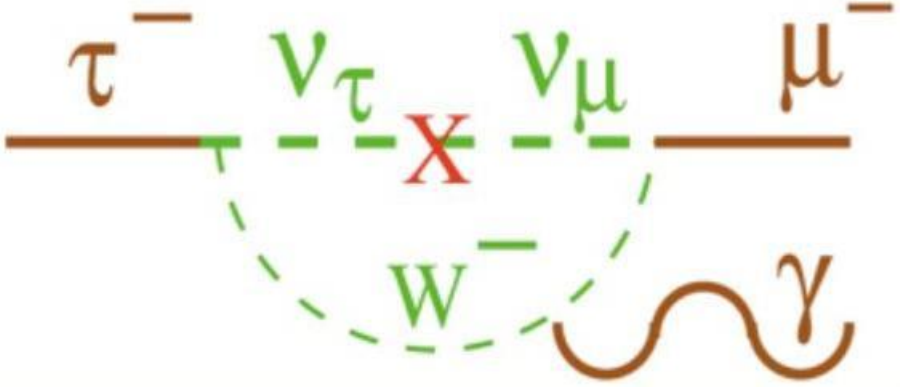
ν oscillations lead to $m_\nu \neq 0$

SM extended to $m_\nu \neq 0$

SM estimate 10^{-54} is many orders below experiment

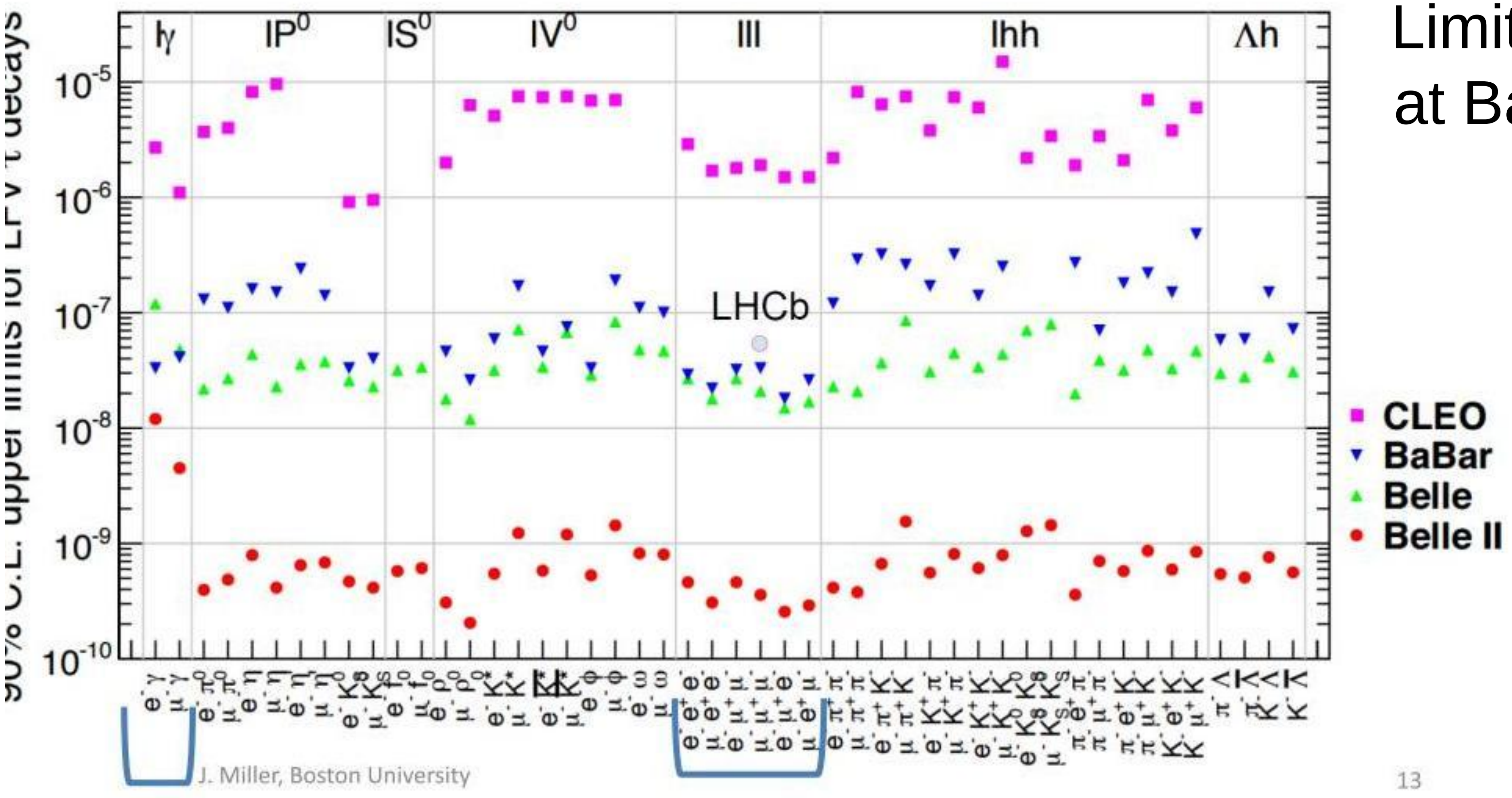
LFV will be a sign of new physics (W---H charged)

$BF(\tau \to \mu\gamma) \sim \alpha/\pi \, (\Delta m_{23}/M_W)^4 \, BF(\tau \to \mu\nu\nu) \sim 10^{-54}$



Some modells predict $B_{\tau\mu\gamma}$ at $10^{-8} – 10^{-9}$

Summary of Tau LFV decay limits



Limits on Br($\tau \rightarrow l\gamma, 3l$) ~ 2.10^{-8} at Babar and Belle.

CVC

CVC – establishes a relation between τ – lepton decays to vector hadronic state and corresponding isovector channel of e+e- annihilation cross section

$\sigma_{I=1}(K\bar{K}) \sim \Gamma\,(\tau \to K^+K_S\nu_\tau)$

Vector spectral function V(m) definition

$$V(m) = \frac{1}{N}\frac{dN}{dm}\frac{1}{m(M_\tau^2 - m^2)^2(M_\tau^2 + 2m^2)}\frac{B(\tau \to K_S K\nu)}{B(\tau \to e\nu\nu)}\frac{M_\tau^6}{12\pi V_{ud}^2}$$

Relation between V(m) and e^+e^- cross section

$$V(m) = \frac{m^2}{4\pi^2\alpha^2}\sigma_{e^+e^- \to K\bar{K}(I=1)}(m)$$

Mass spectrum

CVC using examples:

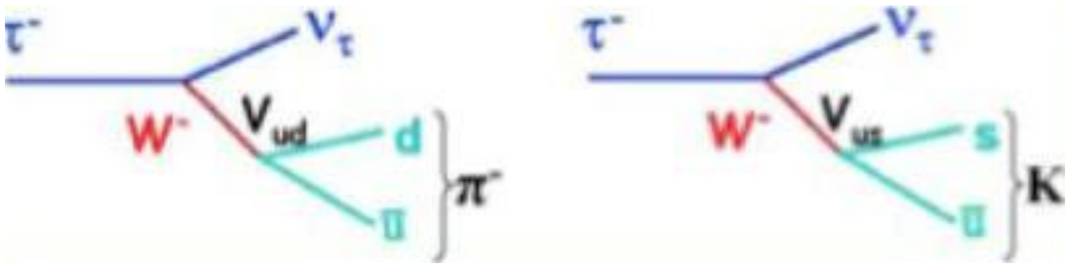
1. $\tau \to \pi^+\pi^0\nu_\tau$, CLEO, BELLE, $(g\text{-}2)_\mu$, ~1%
2. $e^+e^- \to \eta\pi^+\pi^-, \omega\pi^0$, VEPP-2000, ~3%

VEPP-2000 with SND and CMD-3

is a ‘player’ in τ – physics !

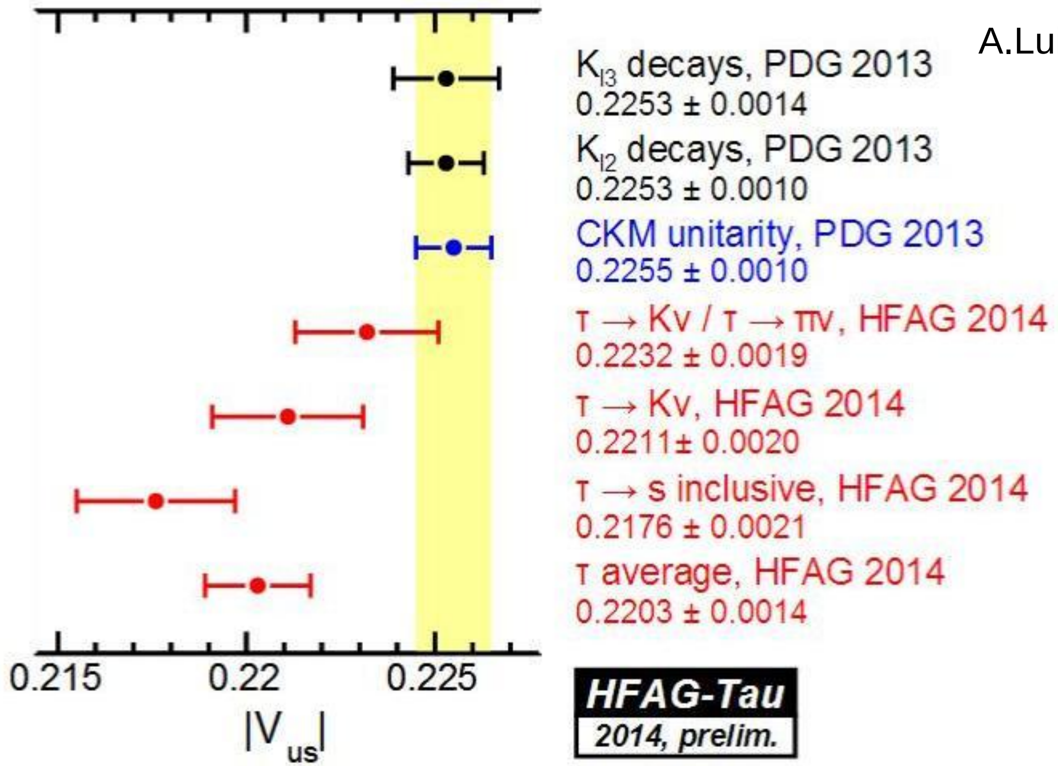
$E_{max} > m_\tau$!

V_{us}



V_{us} calculated from π, K decay constant and τ decays.

V_{us} from τ agrees with V_{us} from CKM triangle.



A.Luisiani,2014

V_{us} from $\tau \to K\nu$ decay

$$B(\tau^- \to K^-\nu_\tau) = \frac{G_F^2 f_K^2 |V_{us}|^2 m_\tau^3 \tau_\tau}{16\pi\hbar}\left(1 - \frac{m_K^2}{m_\tau^2}\right)^2 S_{EW},$$

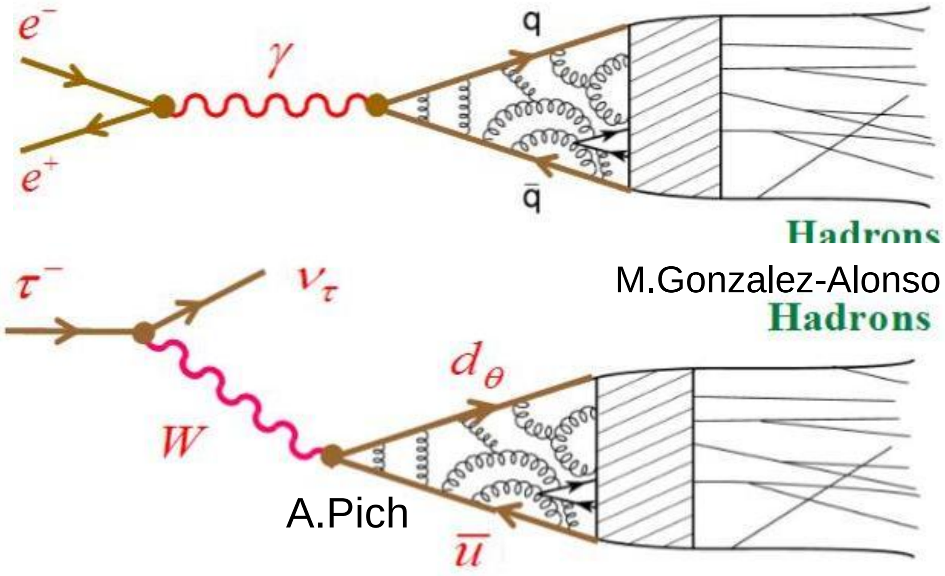
$V_{us} = 0.2212 \pm 0.0020$

V_{us} from $\tau \to K\nu$ and $\tau \to \pi\nu$ ratio decays

$$\frac{B(\tau^- \to K^-\nu_\tau)}{B(\tau^- \to \pi^-\nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{\left(1 - m_K^2/m_\tau^2\right)^2}{\left(1 - m_\pi^2/m_\tau^2\right)^2} \frac{r_{LD}(\tau^- \to K^-\nu_\tau)}{r_{LD}(\tau^- \to \pi^-\nu_\tau)}.$$

$V_{us} = 0.2232 \pm 0.0019$

$\alpha_S(m_\tau)$



M.Gonzalez-Alonso

$R_\tau = \Gamma(\tau \to \nu + \text{hadrons})/\Gamma(\tau \to e\, \nu\nu) \cong 3.636$,

QCD predicts R_τ, comparison of QCD and R_τ

gives $\alpha_S(m_\tau)$ value

0.332±0.013,

that leads to $\alpha_S(m_Z)$

0.1202±0.0015.

If compare with $\alpha_S(m_Z)$ value from Γ_Z

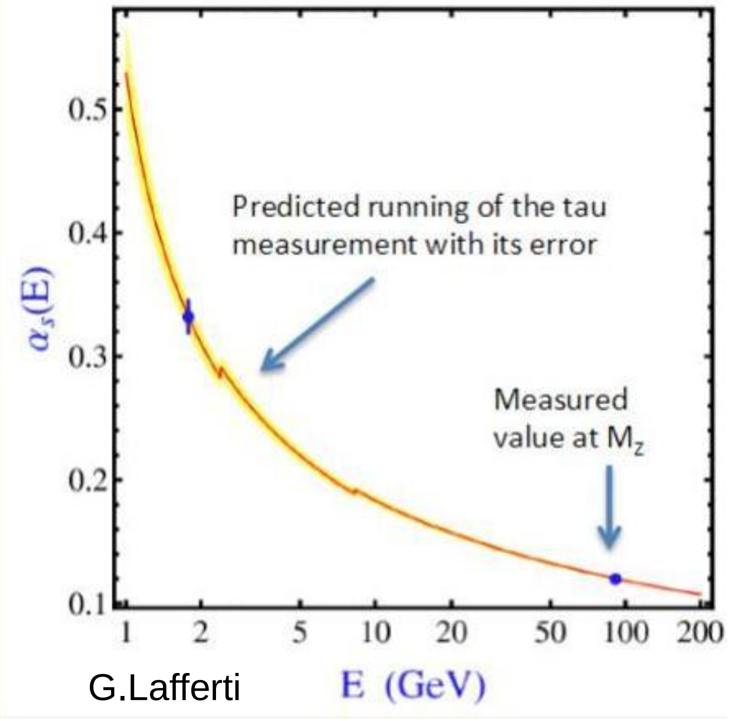
0.1197±0.0028,

The difference between them is

0.0005±0.0032.

This is the precise test $\alpha_S(E)$

QCD dependence

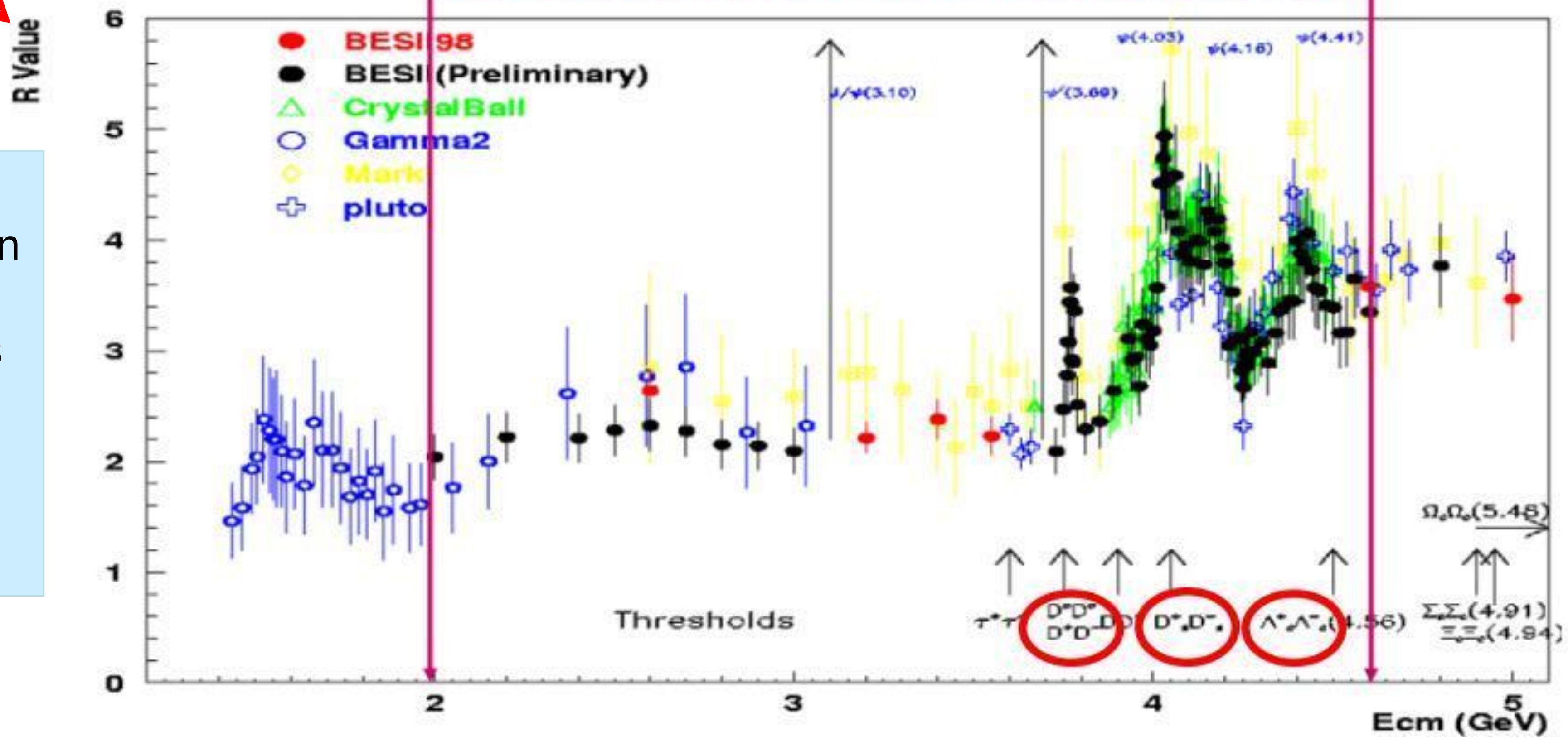


Charm energy region

Cross section
In units of R :

$$R = \frac{\sigma(e^+e^- \to hadr)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$

2 ~ 4.6 GeV



Outline
1. e^+e^- physics introduction
2. e^+e^- facilities
3. New data in tau physics
4. Charm news
5. Beaty physics
6. Future projects
7. Conclusions

Quarkonia are similar to atom

c, b -quarks are heavy:

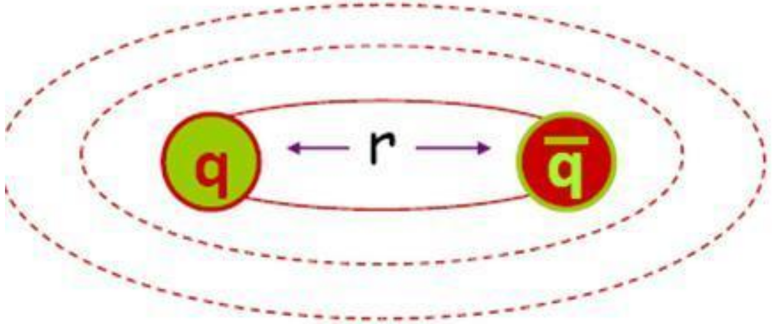
$m_c \sim 1.5$ GeV $\sim 1.6\ m_p$;

$m_b \sim 4.5$ GeV $\sim 4.8\ m_p$;

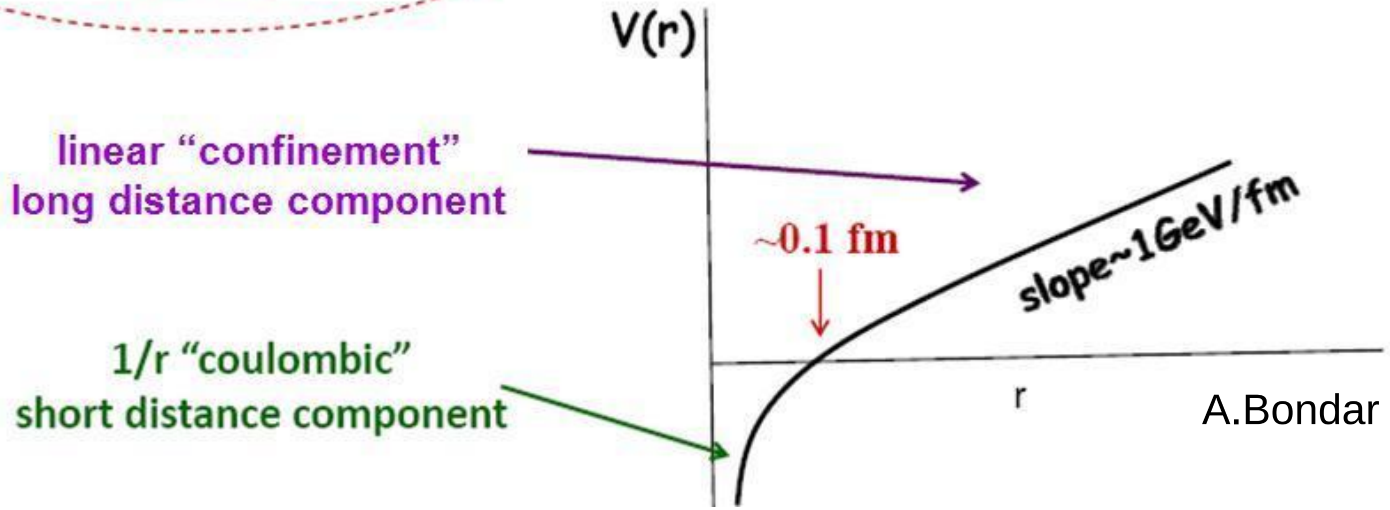
velocities are small:

$v/c \sim 1/4$ (for $b\bar{b}$, $v/c \sim 0.1$)

non-relativistic QM applies



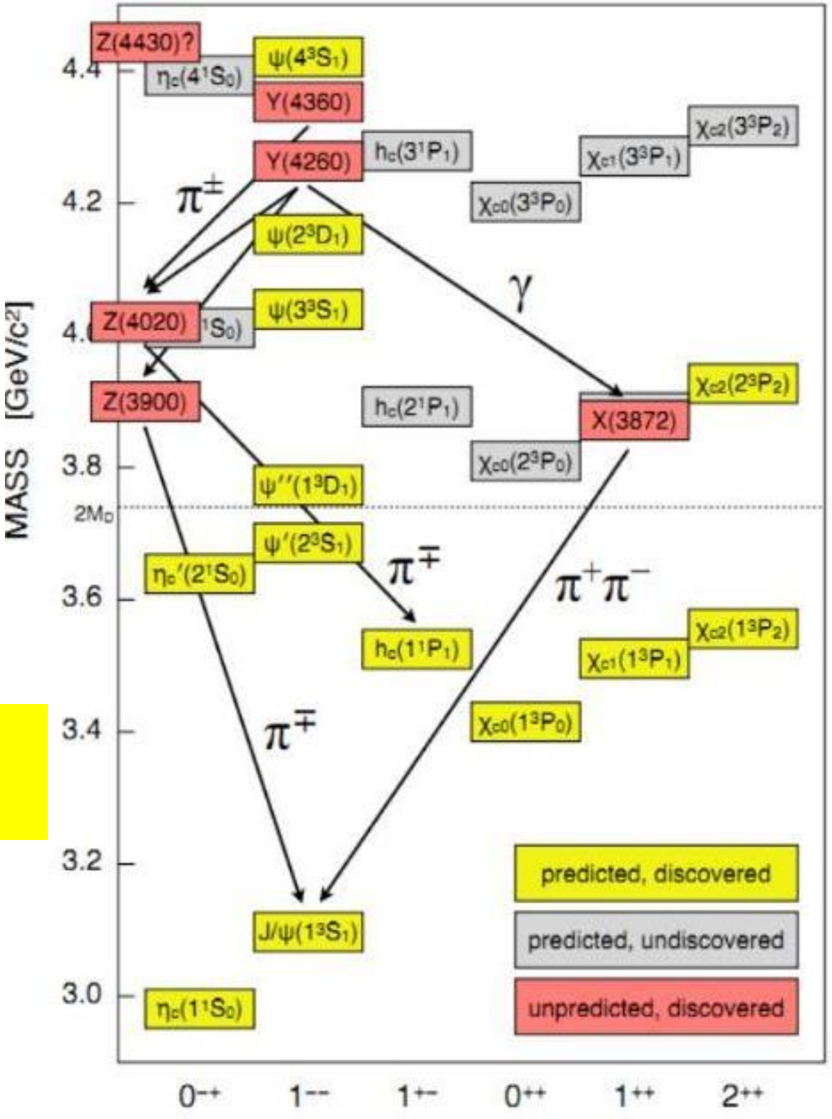
$$-\frac{\hbar^2}{2m_r}\nabla^2\Psi + V(r)\Psi = E\Psi$$

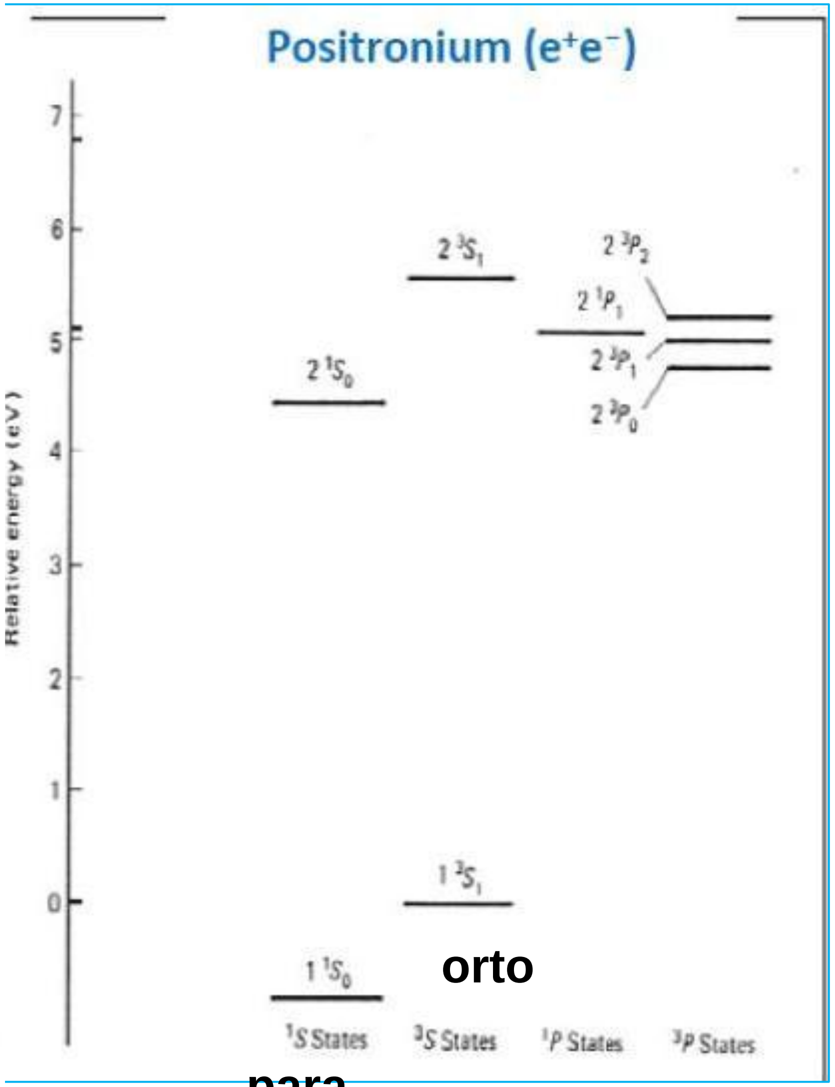


A.Bondar

A comparison of charmonium and positronium structure

$q\ \bar{q}$

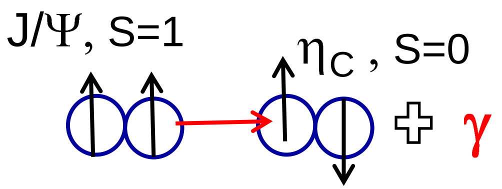




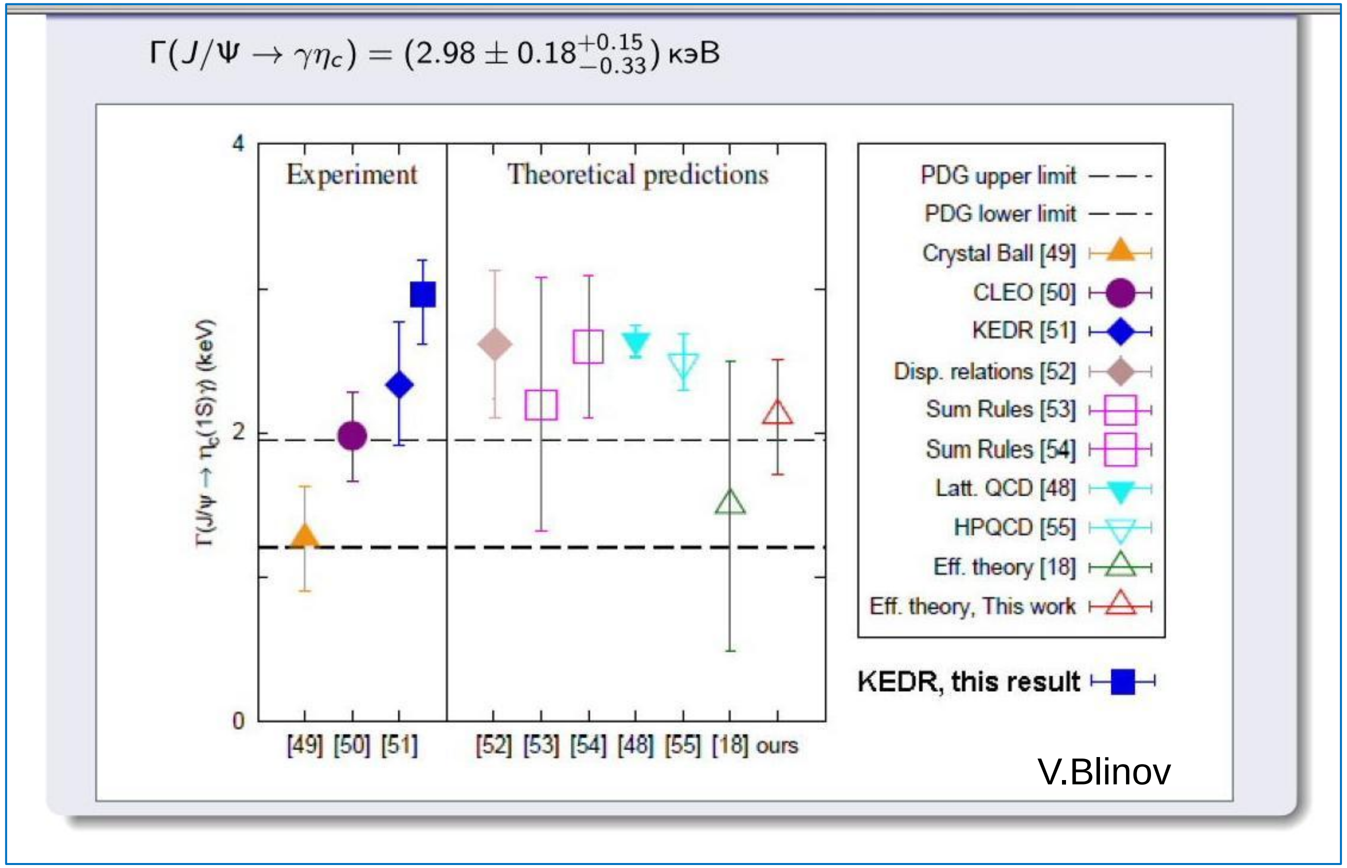
orto

para

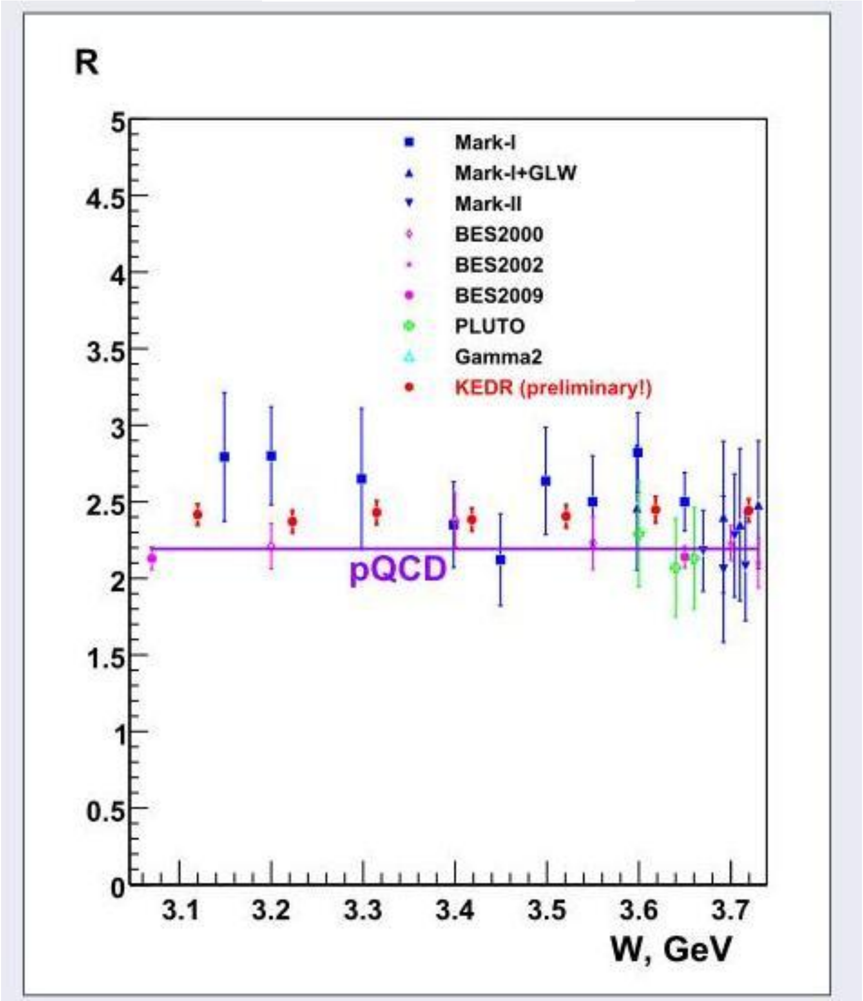
KEDR recent results



Magnetic dipole transition



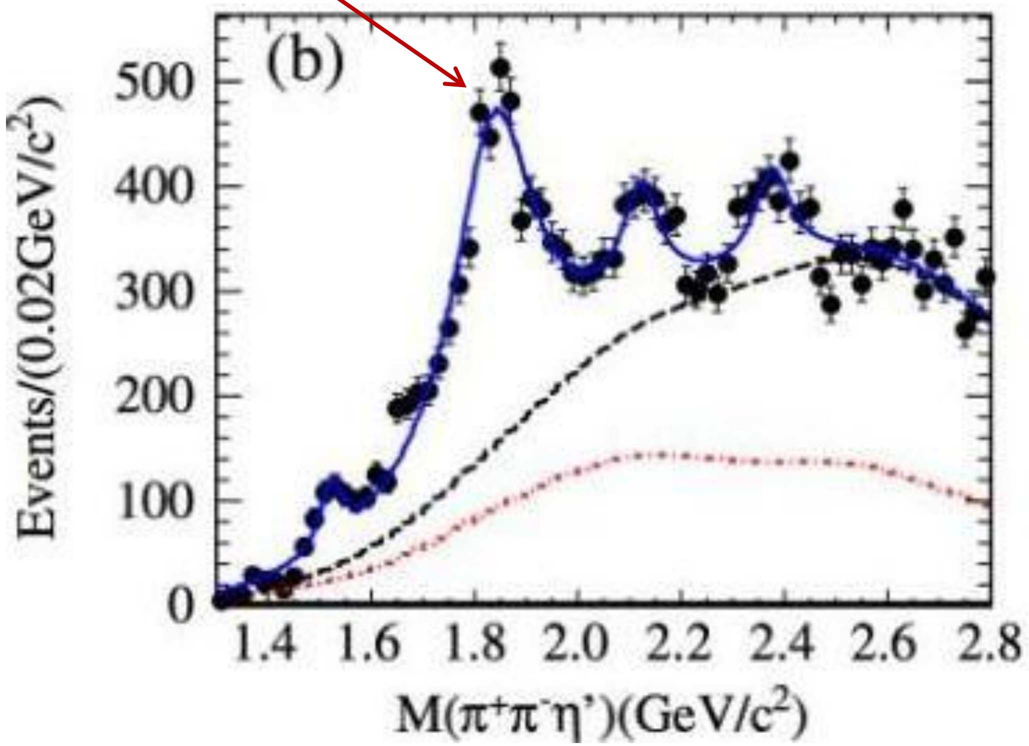
$$R = \frac{\sigma(e^+e^- \to hadr)}{\sigma(e^+e^- \to \mu^+\mu^-)}$$



$J/\Psi \rightarrow \gamma\pi\pi\eta'$

X(1835)

X(1835) : BESIII



X(1835)

L=0 : $\eta' f_0 \rightarrow 0^{-+}$

L=1 : $\eta' f_0 \rightarrow 1^{++}$

PDG:

$\pi(1800)$: 0^{-+}

?

Nature X(1835):

- p-pbar effect
- excited η'
- η' - f_0 - molecule

(physics below J/Ψ)

Second channel :

$$J/\psi \rightarrow \gamma K^0_S K^0_S \eta$$

$X(1835) \rightarrow \eta f_0(980)$

X,Y,Z states in charmonium

X,Y,Z are new objects in quarkonium systems.
Most of them – unexpected.
They have quantum numbers of cc and bb states
They may have electric charge !
Their nature – molecule, hybrid, 4-quark ?
No X,Y,Z found in Y(1S) decays

X

- charmonium-like states with $J^{PC} \neq 1^{--}$
Observed in B decays, e^+e^-, pp and pp collisions

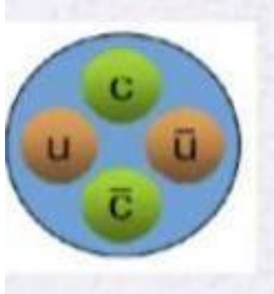
Y

- charmonium-like states with $J^{PC} = 1^{--}$.
Observed in direct e^+e^- annihilation or in ISR

Z

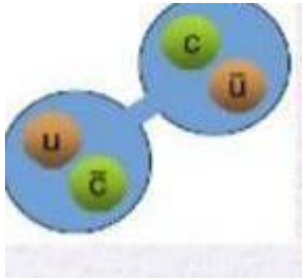
- charmonium -like complex states . Must contain at least a cc(bb) and a light qq pair

Exotic states



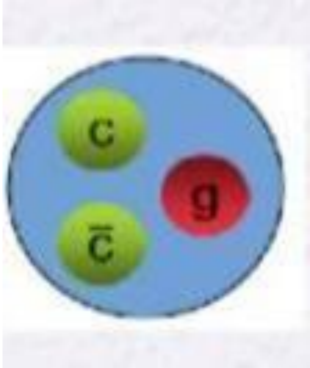
4q-mesons

States of tightly bound quarks. Decay to ordinary hadrons via the position reordering.



Molecular mesons

Weakly bound through pion exchange pairs of mesons. Decay to constituent mesons or J/Psi +X.



Hybrid mesons

Bound states of gluon and colored diquark.

X states
(BES III)

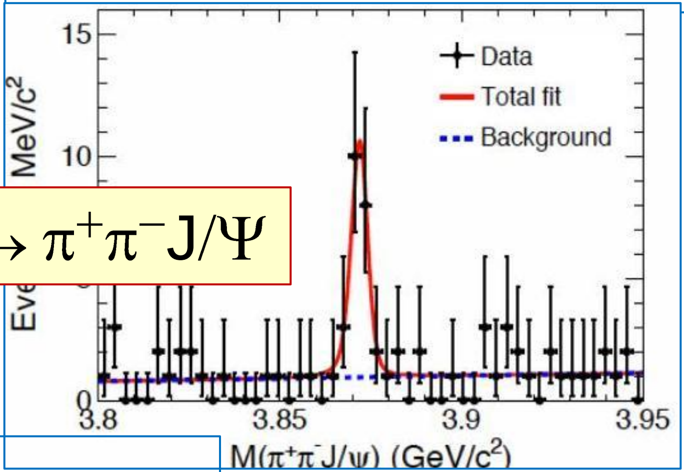
X - charmonium-like states with JPC ≠ 1
Observed in B decays, e^+e^-, pp and $p\bar{p}$ collisions

X(1835) considered
In previous slide,
$J^{PC} = 0^{-+}, 1^{++}, ..$

$X(1835) \rightarrow \eta' f_0(980)$

X(3872)

$e^+e^- \rightarrow \gamma\, X(3872) \rightarrow \gamma\pi^+\pi^- J/\Psi$
Earlier observed in B-decays
$J^{PC} = 1^{++}, ..$

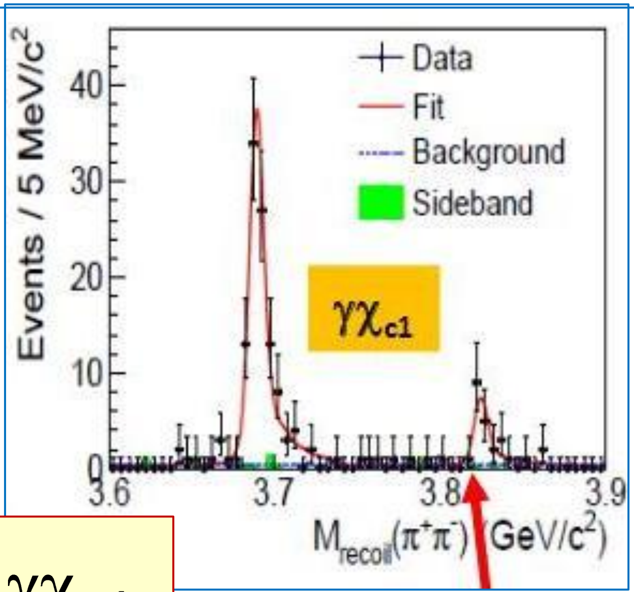


$X(3872) \rightarrow \pi^+\pi^- J/\Psi$

X(3872) = ccuu ?
But :
$M(X(3872))=M(D^{*0}) + M(D^0))$
X(3872) = hadronic molecule ?

X(3823)

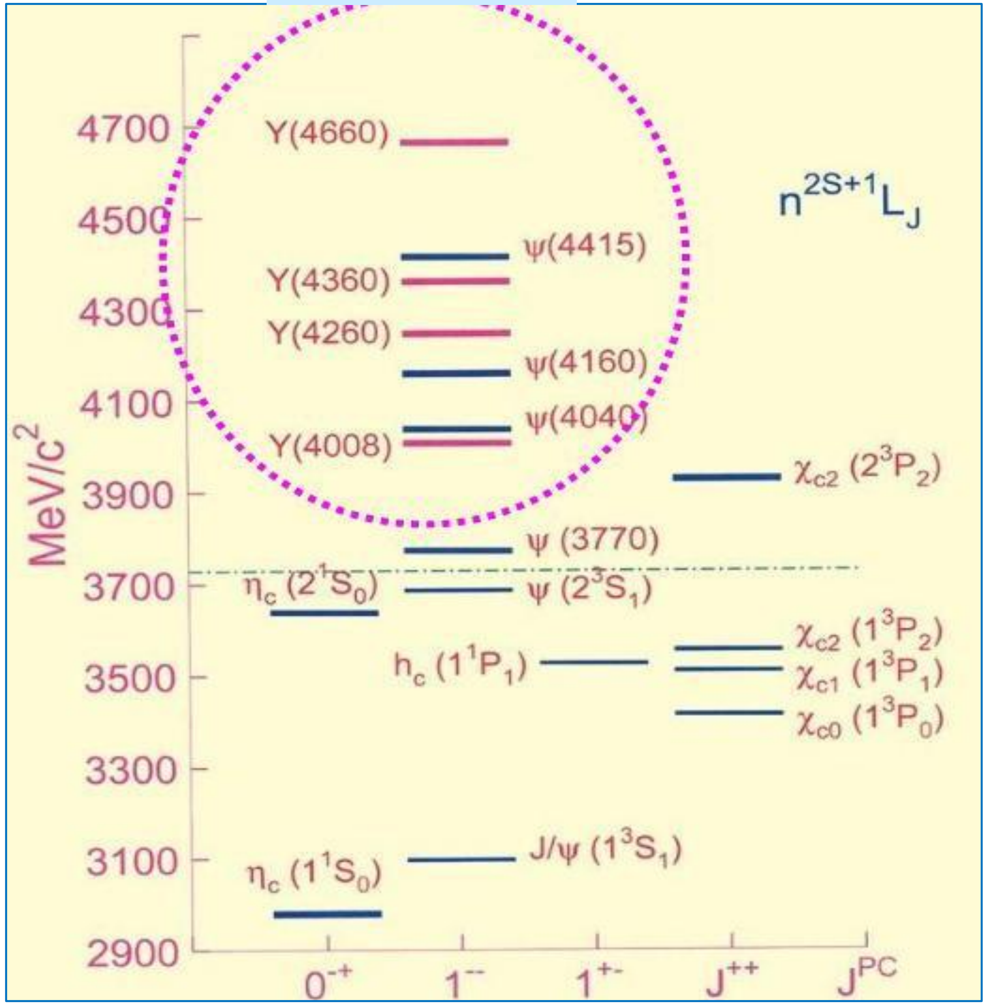
$e^+e^- \rightarrow \pi^+\pi^-\, X(3823) \rightarrow \gamma\pi^+\pi^-\chi_{c1}$
Earlier observed in B-decays
$J^{PC} = 2^{--}, ..$ (as 1^3D_2 ?)



$X(3823) \rightarrow \gamma\chi_{c1}$

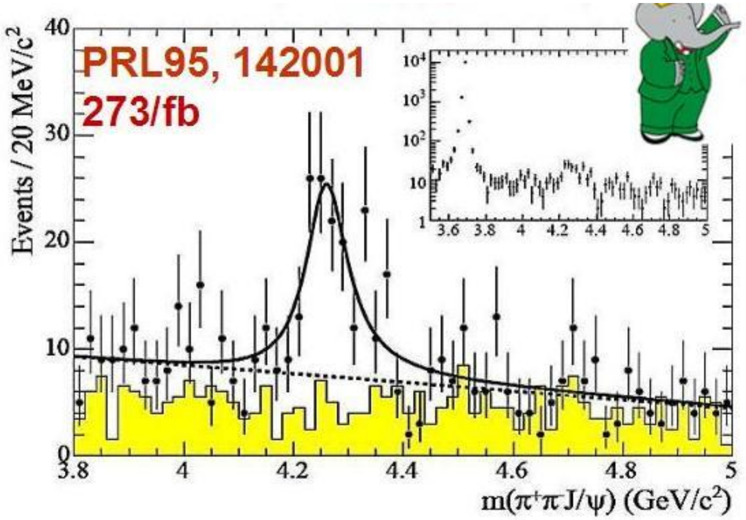
Seen in recoil mass
May be not exotic

Y states

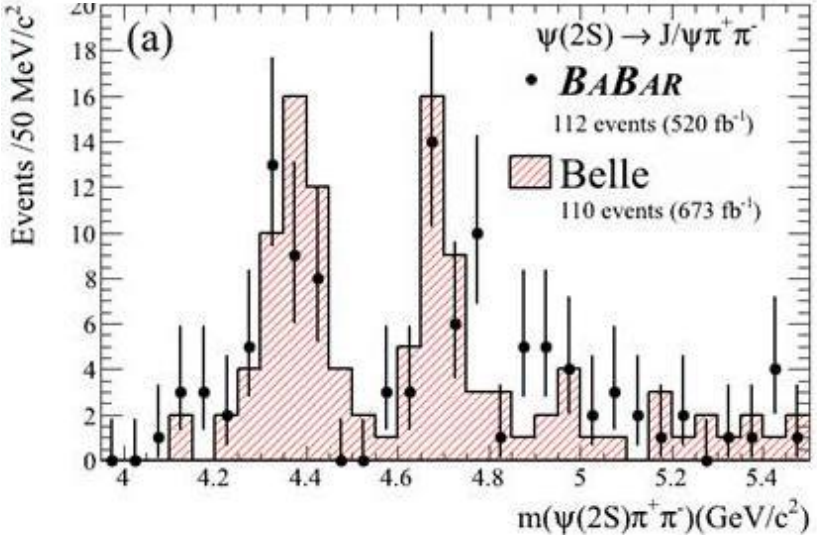


C.Yuan

Y_c - charmonium-like states with $J^{PC} = 1^{--}$.
Observed in direct e^+e^- annihilation or in ISR



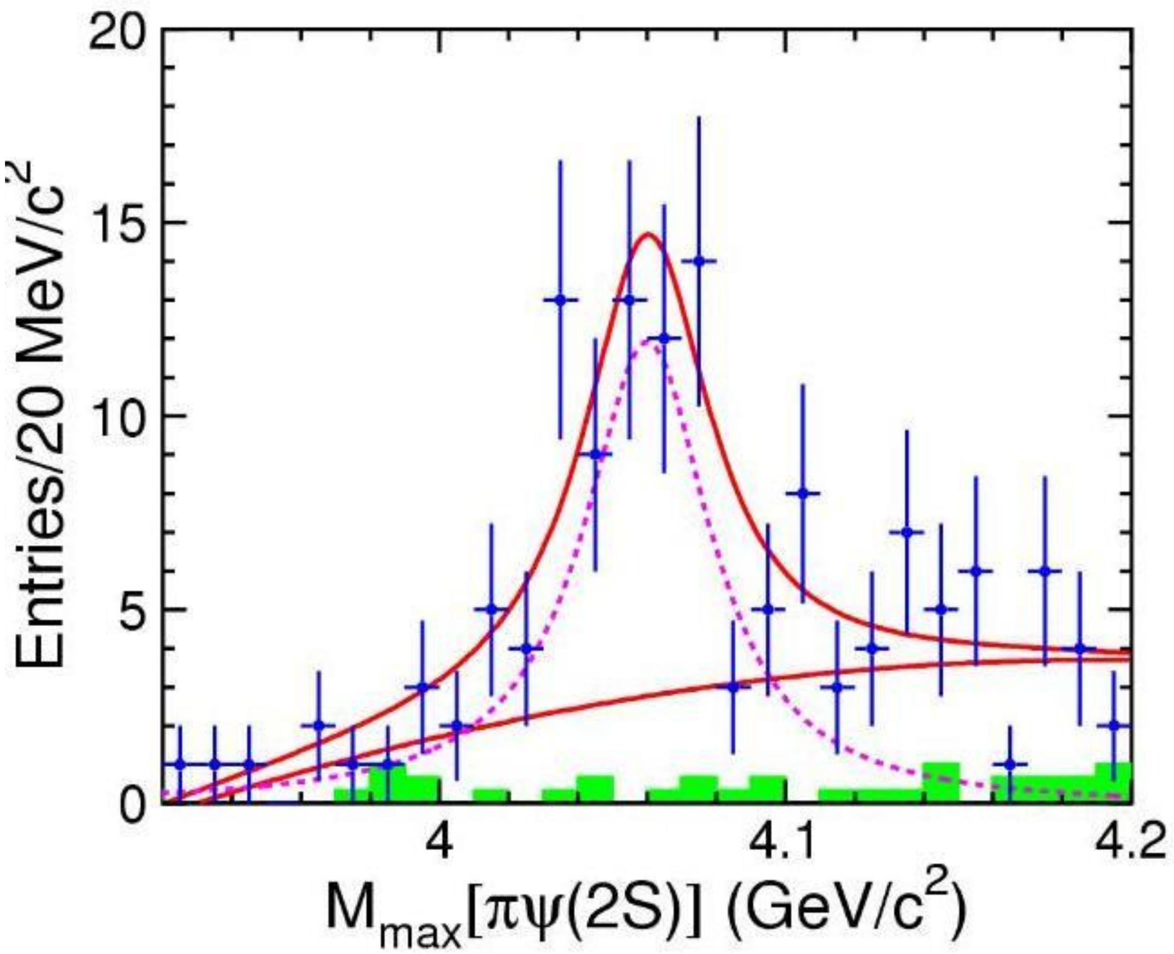
Y(4260)$\to$
J/$\Psi\pi\pi$, γX(3872),
ISR,
M(Y)=30MeV +
2M(D^*_S), -> hadr.
molecule with posit.
bound energy



Y(4360), Y(4660)
Y_c $\to\Psi$(2s)$\pi\pi$

All Y_S found
Unexpected
(shown red)

Observation of Z_c in $Y(4360) \to \pi\pi\Psi(2S) \to \pi Z_c$ (4054)

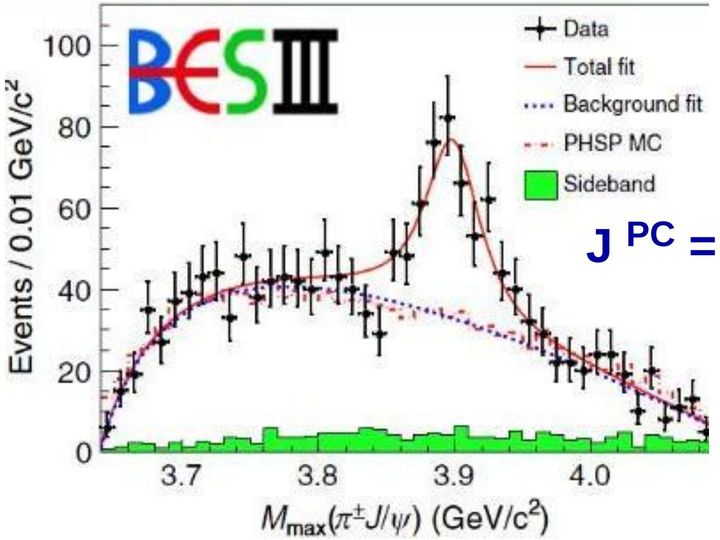


$Z_c \to \pi\Psi(2S)$,
M_Z=4054 MeV,
charged
charmonium state

Z states:

- charmonium -like states . Must contain at least a cc and a light qq pair

$e^+e^- \to \pi^{\pm} Z_c(3900)^{\pm} \to \pi^+\pi^- J/\psi$



$J^{PC} = 0^{-+}$?

$Z_c \to \pi J/\Psi$

Table of Z states

State	Z_c decay	Reaction
$Z_c\,(3900)^{\pm 0}$	$\pi^{\pm 0} J/\Psi$	$e^+e^- \to \pi^{\pm 0} Z_c$
$Z_c\,(3885)^{\pm 0}$	$(D\ \bar{D}^*)^{\pm 0}$	$e^+e^- \to \pi^{\pm 0} Z_c$
$Z_c\,(4020)^{\pm 0}$	$\pi^{\pm 0} h_c$	$e^+e^- \to \pi^{\pm 0} Z_c$
$Z_c\,(4025)^{\pm 0}$	$(D^*\ \bar{D}^*)^{\pm 0}$	$e^+e^- \to \pi^{\pm 0} Z_c$

Nature of Z states:
- tetraquark ?
- hadronic molecule
- hadro charmonium ?
- hybrid

$c\bar{c}g,\ cq\bar{q}\,\bar{c},\ (\bar{c}q)(c\bar{q}),\ c\bar{c}\pi\pi,\ \ldots$

All Z_c found unpredicted

e^+e^- B factory

Outline

The B factory is e^+e^- collider,
operating in energy region of production
of particles with b quark.
Energy interval max ~ 9 – 13 GeV in c.m.s.
(η_b – Υ(6s) – B_c - region)

e^+e^- B factories summary

Cross sections at Y(4S)

e + e - -> $\tau + \tau -$	**0.919 nb**
e + e - -> $\mu + \mu -$	**1.147 nb**
e + e - -> uds –	**2.09 nb**
e + e - -> c cbar --	**1.3 nb**
e + e - -> b bar --	**1.05 nb**

Integrated luminosity

Babar ~ 500 ifb

Belle ~ 1000 ifb

Number of produced events

$\tau\tau$ ~ 1.4 10 ^{9}

$\mu\mu$ ~ 2.2 10 ^{9}

bb ~ 1.6 10 ^{9}

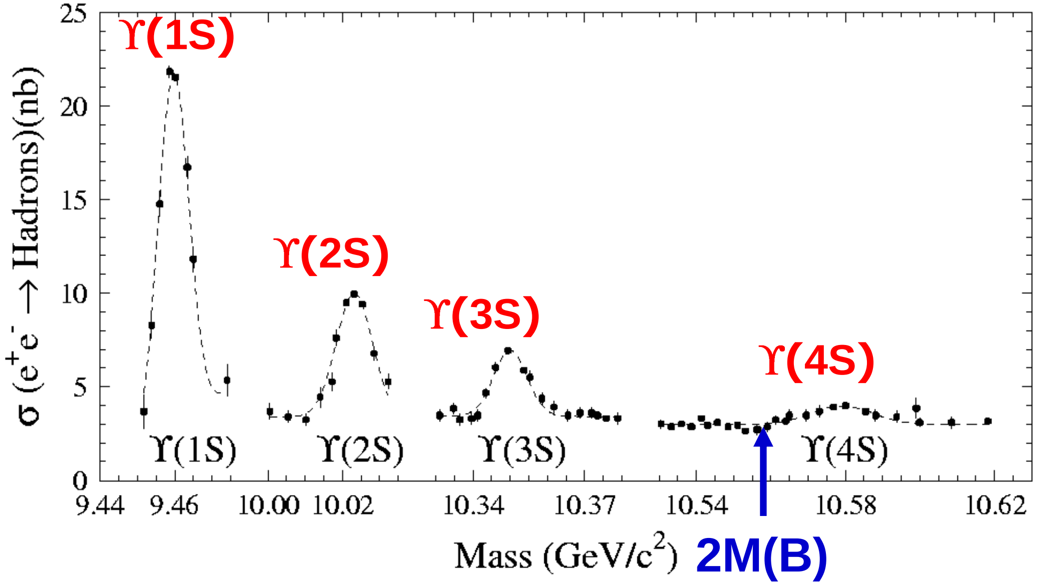
cc ~ 2. 10 ^{9}

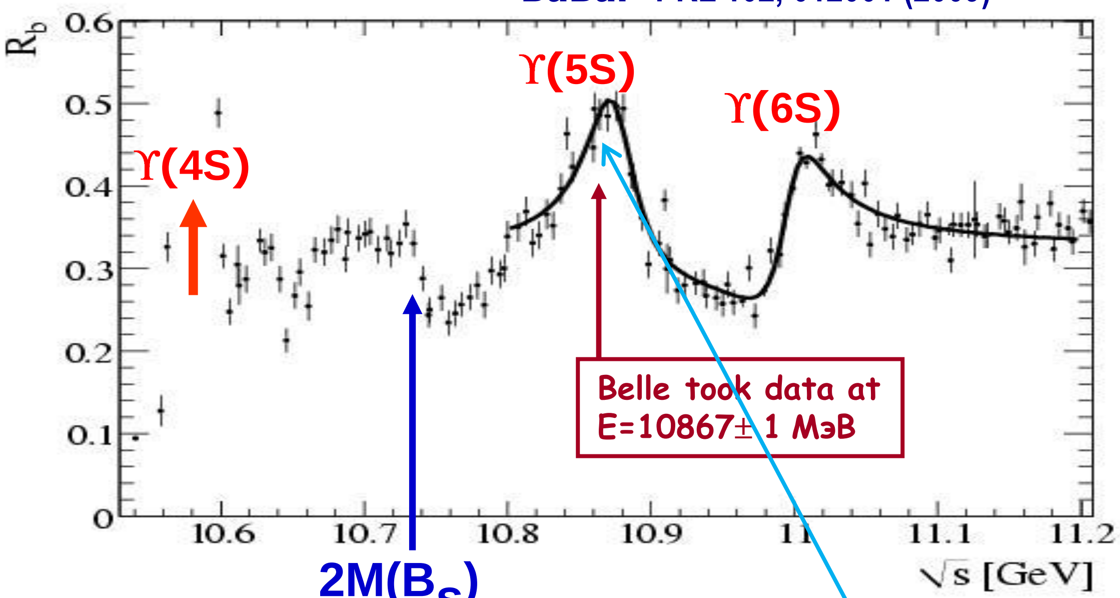
uds ~ 3.1 10 ^{9}

All flavours $> 10^9$ events

Two b_s, τ_s in an event,
self_tagging kinematics

e^+e^- hadronic cross-section in Y region





$e^+ e^- \to \Upsilon(4S) \to B\bar{B}$, where B is B^+ or B^0

$e^+ e^- \to b\bar{b}\ (\Upsilon(5S)) \to B^{(*)}B^{(*)}$, $B^{(*)}\bar{B}^{(*)}\pi$, $BB\pi\pi$, $B_s^{(*)}\bar{B}_s^{(*)}$, $\Upsilon(1S)\pi\pi$, Υ X …

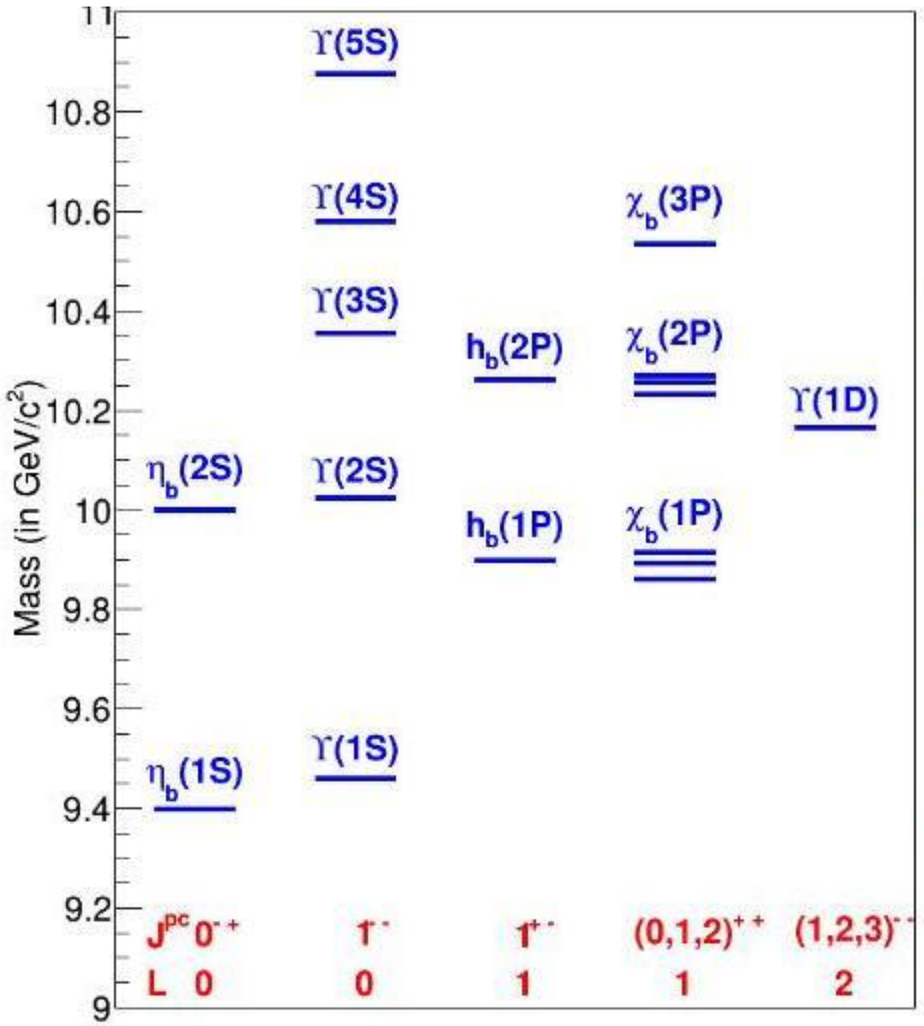
$N(B_s) \approx 4.6\ 10^7$ ev/ab^{-1}
This is 20 times less than N(B) at Y(4S)

main motivation
for taking data at ϒ(5S)

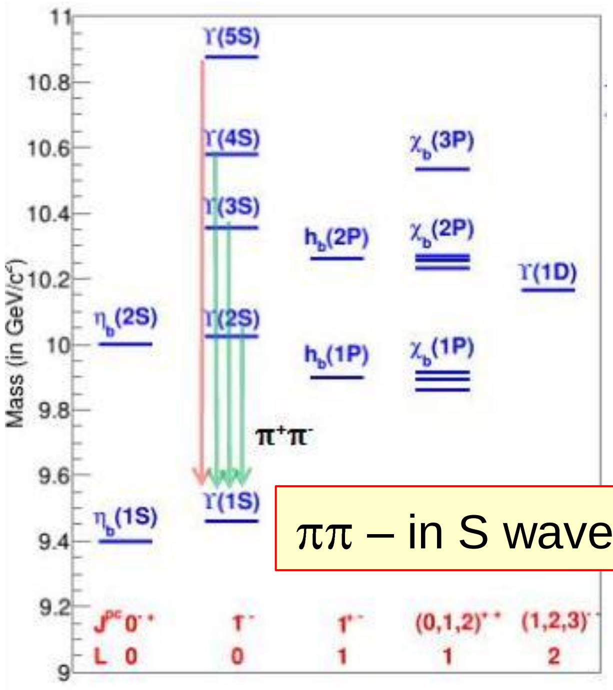
$M(B_c)$ = 6.3 GeV

BABAR and BELLE important results

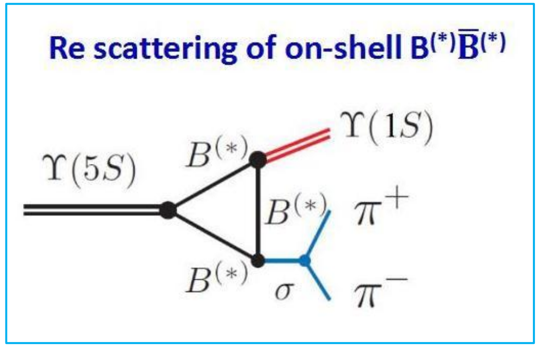
2001 - CPV in B-mesons
2002 - $B \to K\, l^+ l^-$
2003 - CPV in $B \to \phi\, K_S$
2004 - CPV in $B \to K\, \pi$
2005 - $b \to d\gamma$
2006 - $B \to \tau\, \nu$
2007 - CPV in $B \to \rho+\, \rho-$
2008 - D_0 mixing
2009 - $B \to D\,(*)\, \tau\nu$

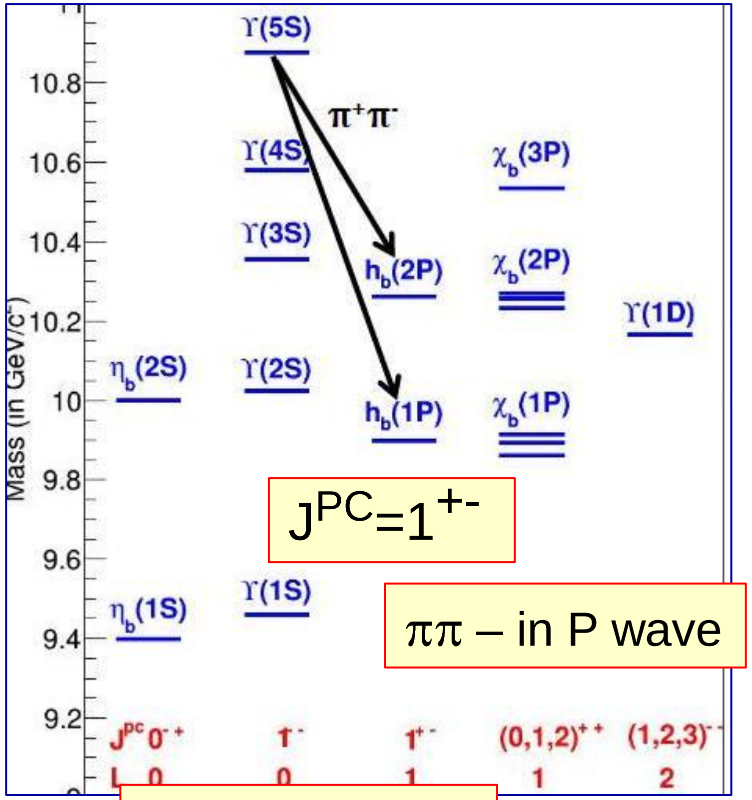


Transitions between bb quarkonium



ππ – in S wave



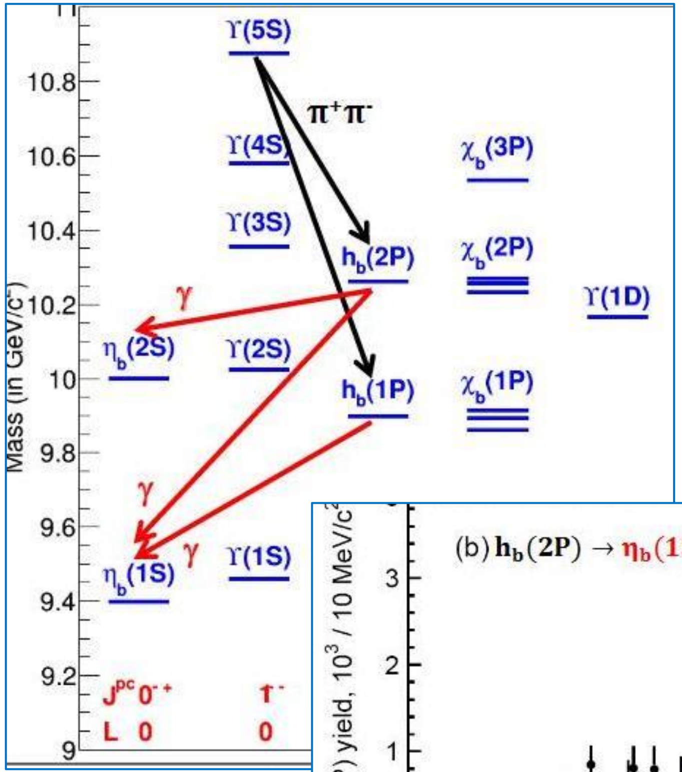


$J^{PC}=1^{+-}$

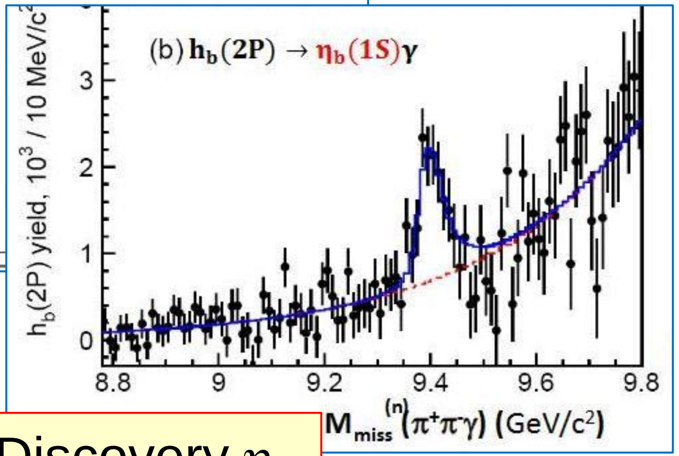
ππ – in P wave

Discovery h_b

See next slide



$J^{PC}=0^{-+}$

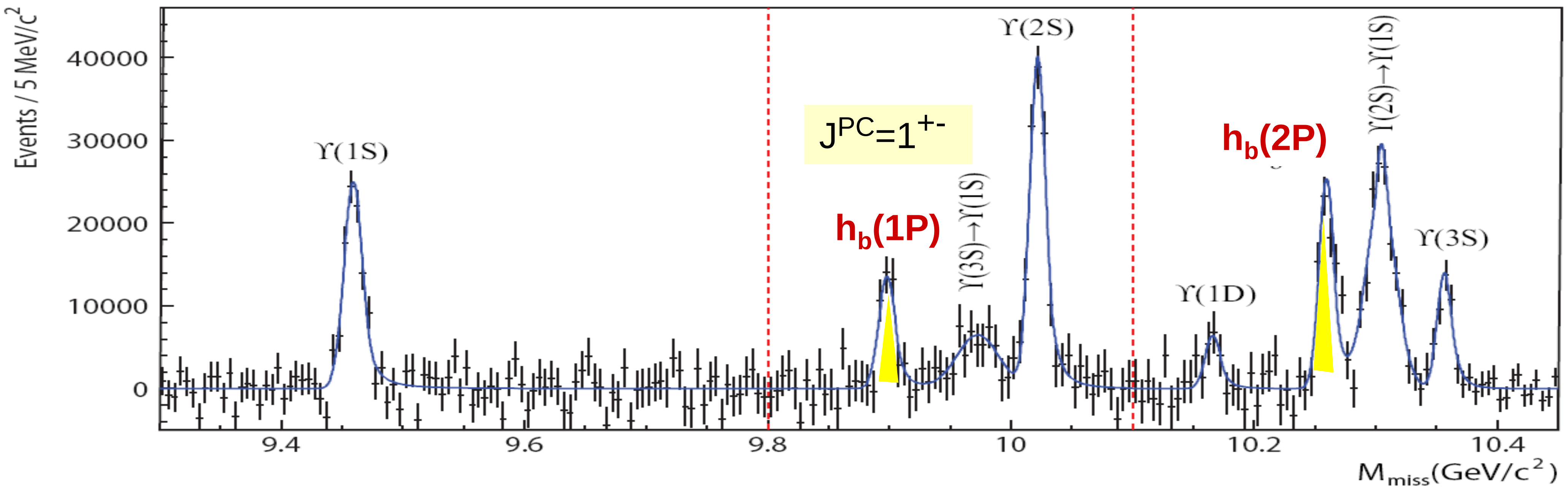


Discovery η_b

$J^{PC}=0^{-+}$

Observation of $h_b(1P,2P)$

$e^+e^- \to \Upsilon(5S) \to h_b(nP)\ \pi^+\pi^-$ Belle PRL 109. 232002 (2012), PRL108,032001(2012)



ΔM_{HF}(**1P**) = +0.8 ± 1.1 MeV
ΔM_{HF}(**2P**) = +0.5 ± 1.2 MeV

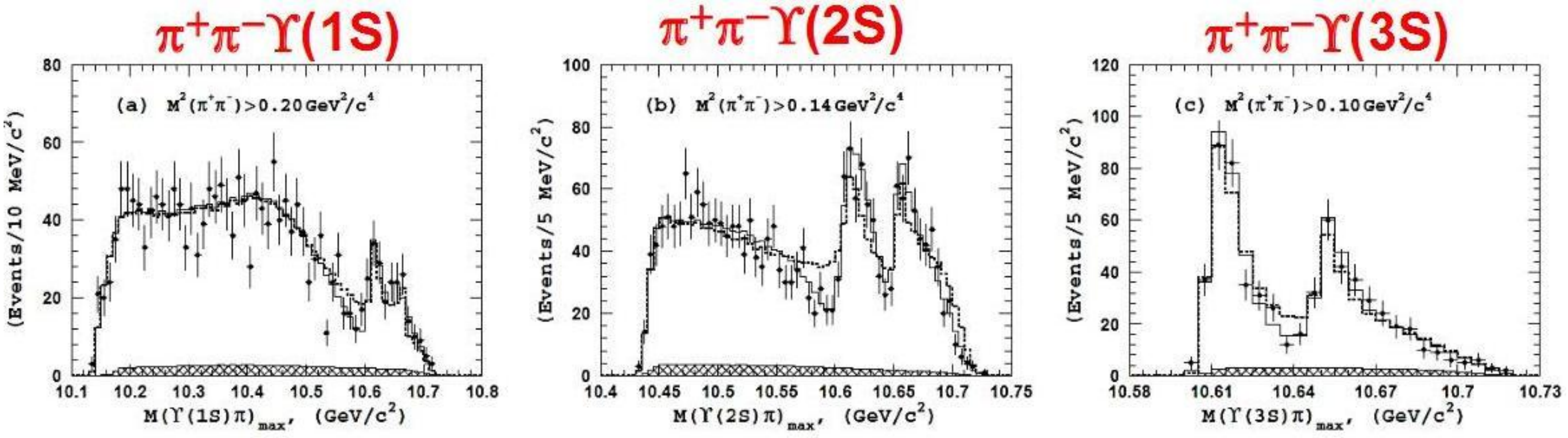
L=1, S=0, P=$(-1)^{L+1}$=1, C=$(-1)^{L+S}$=-1, $J^{PC}=1^{+-}$

Hyperfine splitting (1^{+-} - 1^{++}) is not seen

Observation of Z_b in $\Upsilon(5S)\to\pi\pi\Upsilon(nS)\to\pi Z_b$

(not predicted !)

$Z_b(10610)$, $Z_b(10650)$, $J^P = 1^+$



$Z_b \to\pi\Upsilon(nS)$, n=1,2,3

$B_s \to \mu\mu$, $B_d \to \mu\mu$

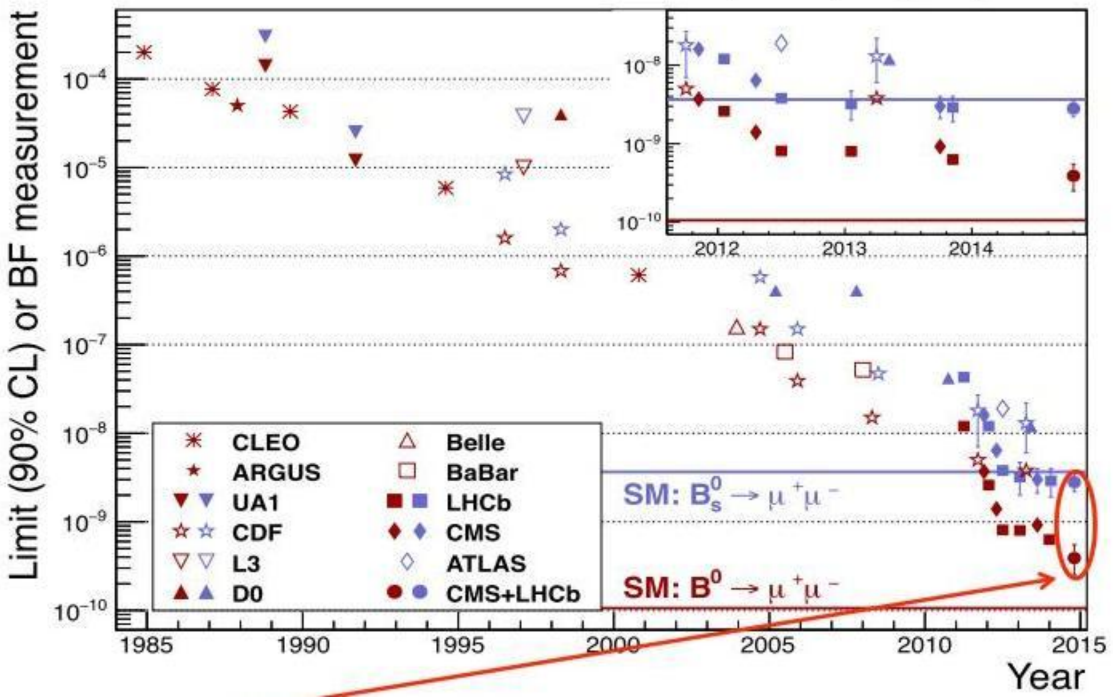
$B_d = (b\bar{d})$, $B_s = (b\bar{s})$,

Standard model : $B_s \to \mu\mu = 3.65 \pm 0.23\ 10^{-9}$

$B_d \to \mu\mu = 1.06 \pm 0.09\ 10^{-10}$

Strongly suppressed in SM,
by FCNC and helicity

G.Lanfranchi LHCb and CMS coll., Nature, 522 (2015) 68

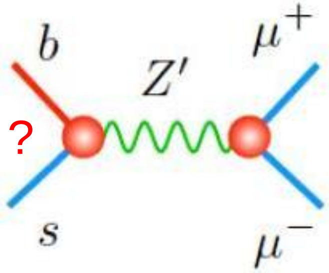


Experiment : $B_s \to \mu\mu = 2.8 \pm 0.65\ 10^{-9}$

LHCb, CMS $B_d \to \mu\mu = 3.9 \pm 1.5\ 10^{-10}$ 2.2σ !

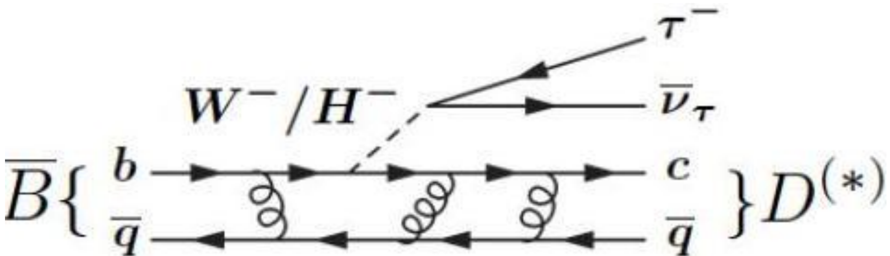
LHCb and CMS have advantages in statistics.
BELLE2 can confirm their result.

New physics ?



Semileptonic decays

$$R(D^{(*)}) = BR(B \to D^{(*)}\tau\bar{\nu}) / BR(B \to D^{(*)} l\bar{\nu})$$



G.Lafranchi

No suppression in SM

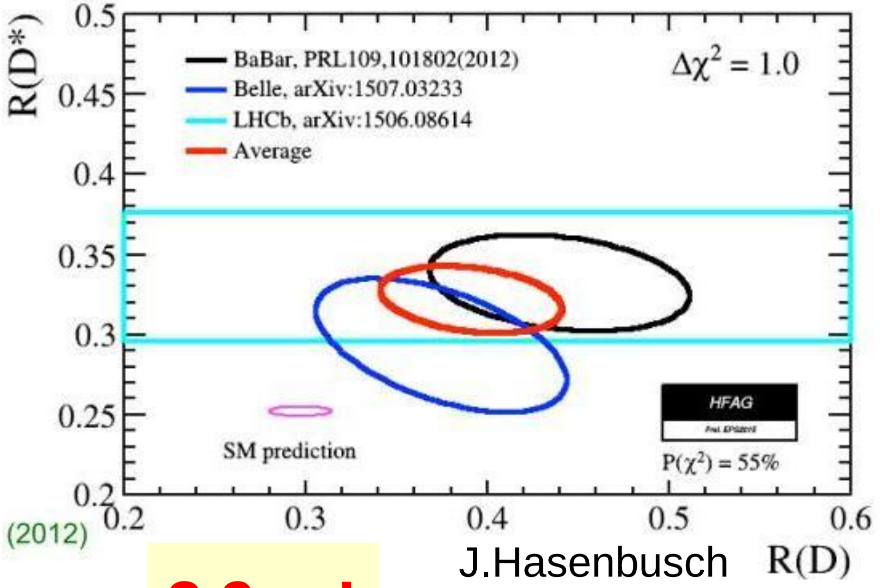
Data, HFAG:
R(D*)=0.322±0.018±0.012
R(D) =0.391±0.041±0.028

SM
R(D*)=0.252±0.003
R(D) =0.300±0.010

Most serious deviation from SM

Models:
Leptoquarks
Composite higgs
Z'
Hadronic effects

Cancellations:
- In theory calculations,
- In experimental systematics



J.Hasenbusch

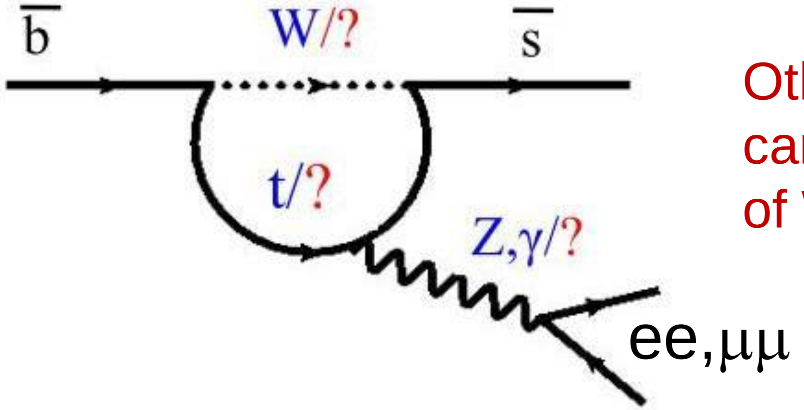
3.9 σ !

Decays with ee or $\mu\mu$ pairs

$$R_k = BR(B^+ \to K^+\mu^+\mu^-)/BR(B^+ \to K^+e^+e^-)$$

PDG : $BR(B^+ \to K^+l^+l^-) \sim 5.10^{-7}$

$R_k(SM) = 1.00 \pm 0.01$
$R_k(LHCb)=0.745 \pm 0.08 \pm 0.036$
$\mu\mu$ deficit at $M_{l+l-} < 2.5$ GeV

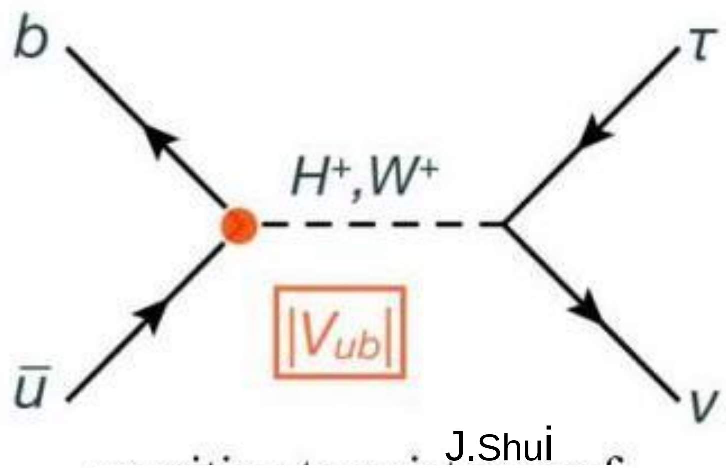


Other heavy particles can contribute instead of W, t, Z.

Decay $B^+ \to \tau^+\nu_\tau$

2-3 neutrinos in an event !

Only V_{ub} suppression



Precise SM prediction:

$$Br(B \to l\nu) = \frac{G_F^2 m_B}{8\pi} m_l^2 \left(1 - \frac{m_l^2}{m_B^2}\right) f_B^2 |V_{ub}|^2 \tau_B$$

Experiment: $BR(B \to \tau\ \nu) = (11.4 \pm 2.2)\ 10^{-3}$

Theory: $BR(B \to \tau\ \nu) = 7.4\ 10^{-3}$

(exp.- theory) ~ 1.8 σ !

$B^+ (\bar{b}u) \to W^+ \to \tau^+\nu_\tau$

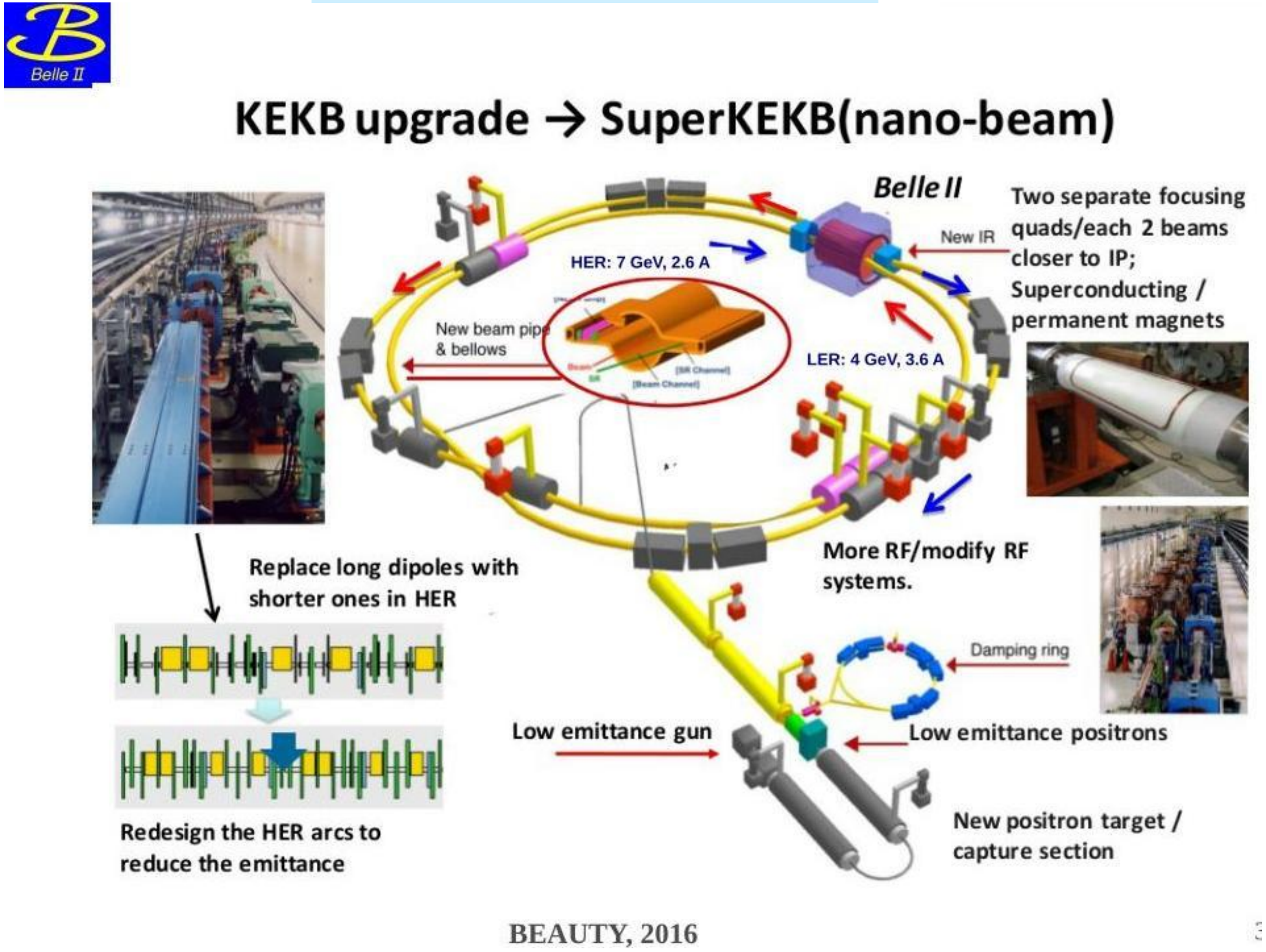
Future projects in τ-c-b physics

Outline

1. e^+e^- physics introduction
2. e^+e^- facilities
3. New data in tau physics
4. Charm news
5. Beaty physics
6. Future projects
7. Conclusions

1. SuperKEKB - B factory
2. Super C-Tau-Charm factory
   - Novosibirsk
   - Bejing

SuperKEKB Project



Super KEK-B

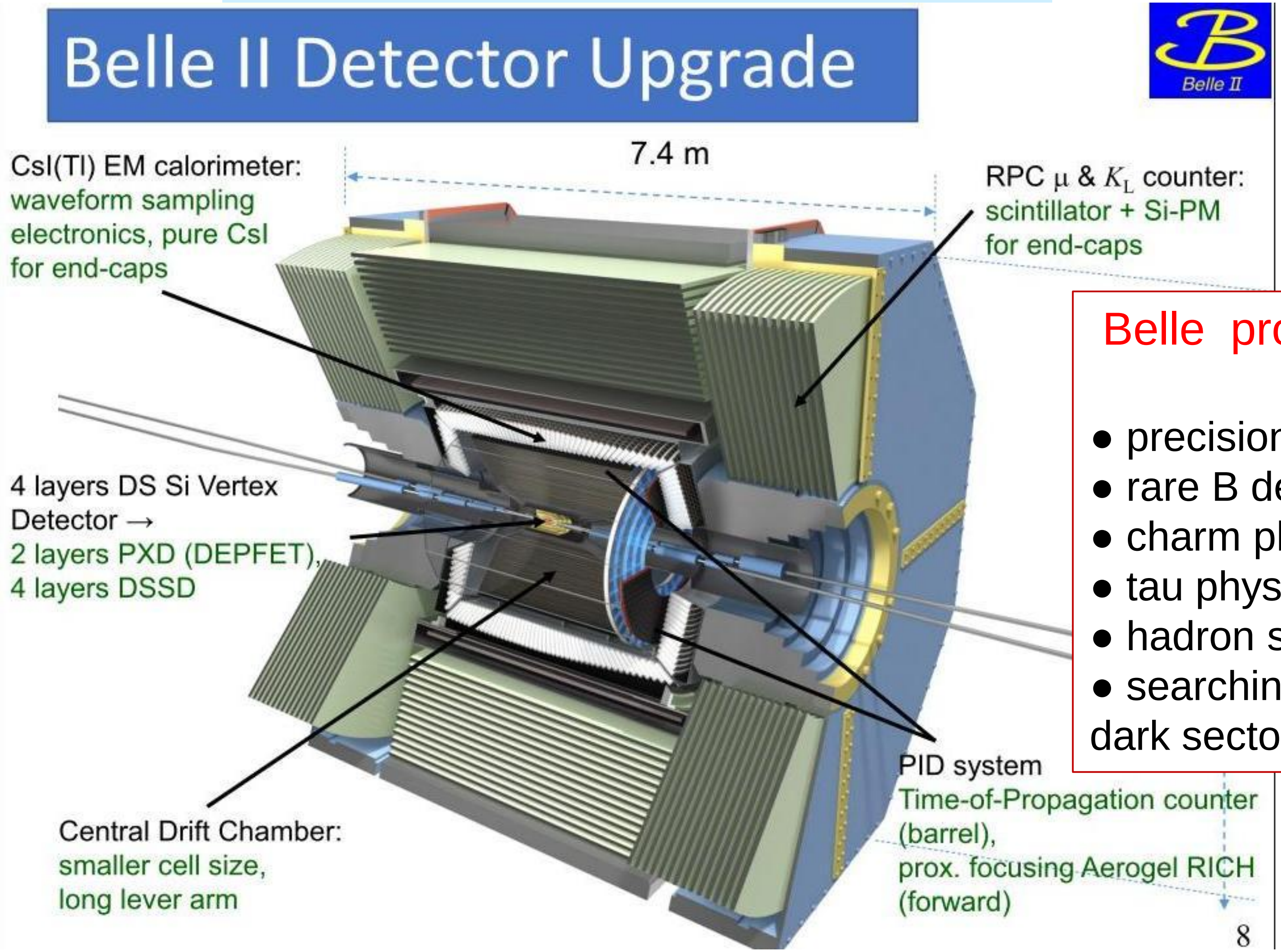
- increased beam current,
- reduced beam size,
- higher beam background,
- larger crossing angle,
- $L_{int} \rightarrow 50\ ab^{-1}$

2017 – collisions tuning
- partial BELLE2

2018 – full comissioning

$L_{max} = 8\ 10^{35}\ cm^{-2}s^{-1}$

BELLE-2 for Super KEK-B



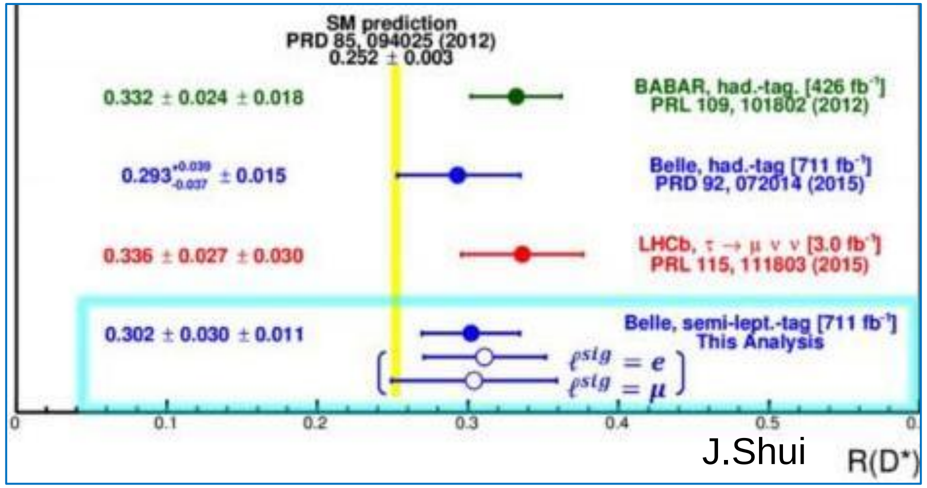
2017 – collisions tuning
- partial BELLE2
2018 – full comissioning

Belle program at SuperKEKB

- precision measurements of CKM elements
- rare B decays physics
- charm physics - mixing, CPV, rare decays,..
- tau physics - LFV, CPV, ...
- hadron spectroscopy - bottomonium, exotics
- searching for new physics - Higgs BSM, dark sector, leptoquark, ...

BELLE II prospects in physics

$$R(D^{(*)}) = \frac{\Gamma(B^0 \to D^{(*)} \tau \nu)}{\Gamma(B^0 \to D^{(*)} l \nu)_{l=\mu,e}}$$



new Belle measurement
R(D*) = 0.302 ± 0.030(stat) ± 0.011(syst)

BELLE-II goal → ± 0.01 (12σ instead of 3.9σ ?)

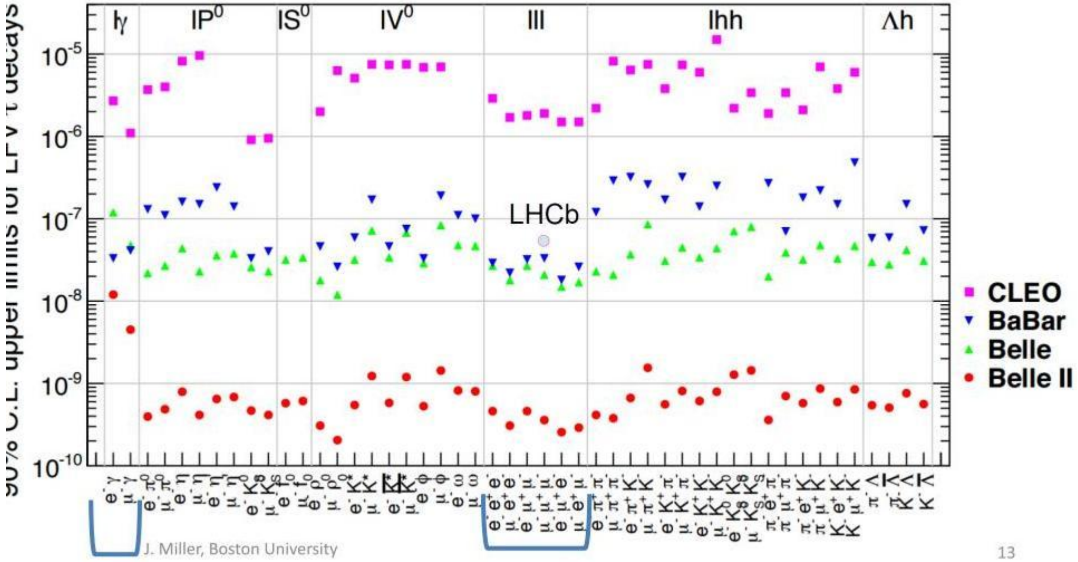
LFV

$\tau \to \mu\gamma$, BR limit 4 10^{-8} → 3 10^{-9}

$\tau \to \mu\mu\mu$, BR limit2 10^{-8} → 8 10^{-10}

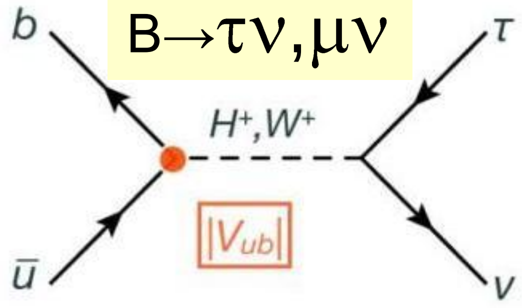
NP models → 10^{-7} → 10^{-10}

Belle II compared to CLEO, Babar, Belle, LHCb



BELLE II prospects in physics

$B \to \tau\nu, \mu\nu$



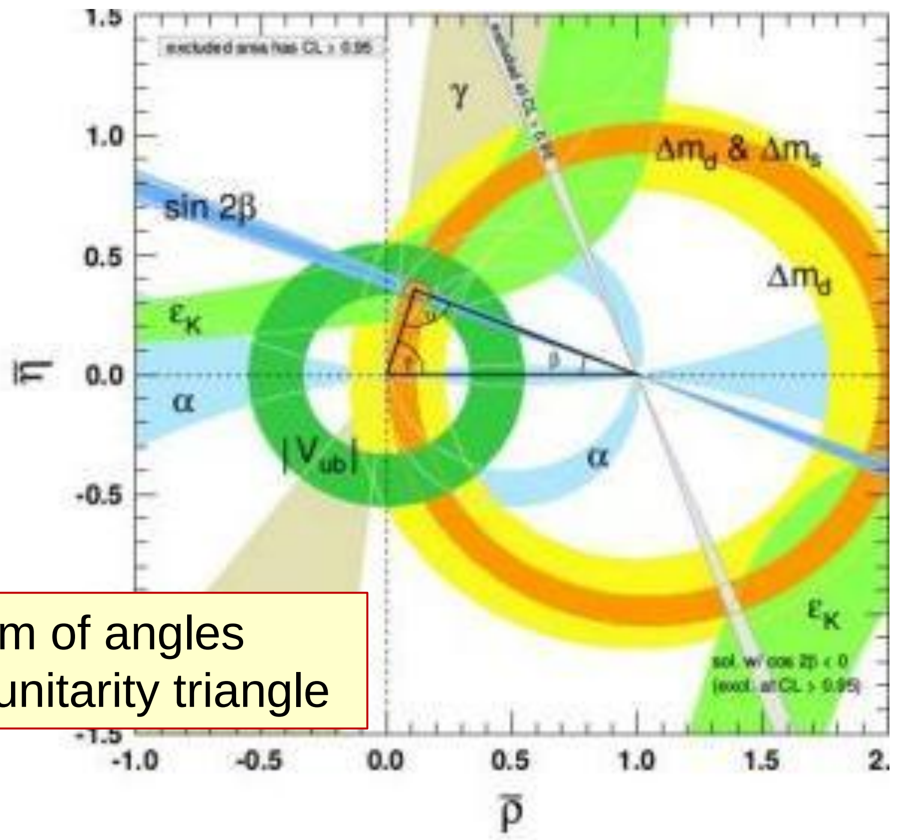
sensitive to existence of
a charged Higgs (H-b-u)

$BR(B\to\tau\nu) = 1.14\pm0.22)\times10^{-4}$ - current measurement
SM = 0.75×10^{-4}
Suppressed by V_{ub} in SM,
but could be enhanced by NP process,
e.g., charged Higgs

Belle II could reduce the error in $BR(B\to\tau\nu)$ to 5%

For $BR(B\to\mu\nu)$ $\to$10 %

Instead of 1.8 σ → 7 σ ?



Sum of angles
of unitarity triangle

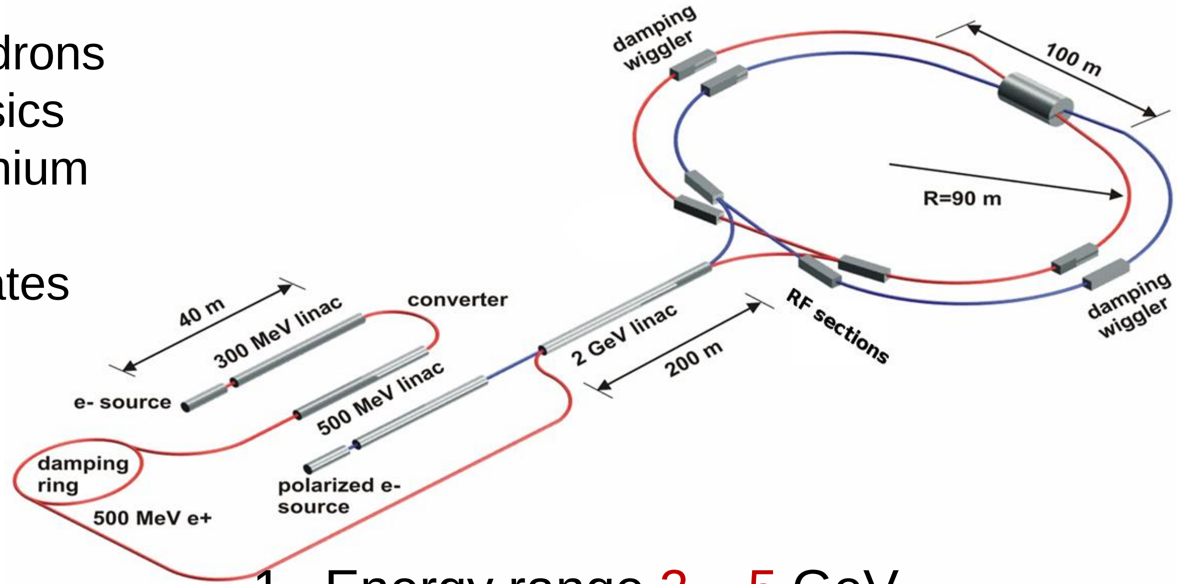
current $\alpha+\beta+\gamma$ = (175±9)º (PDG)

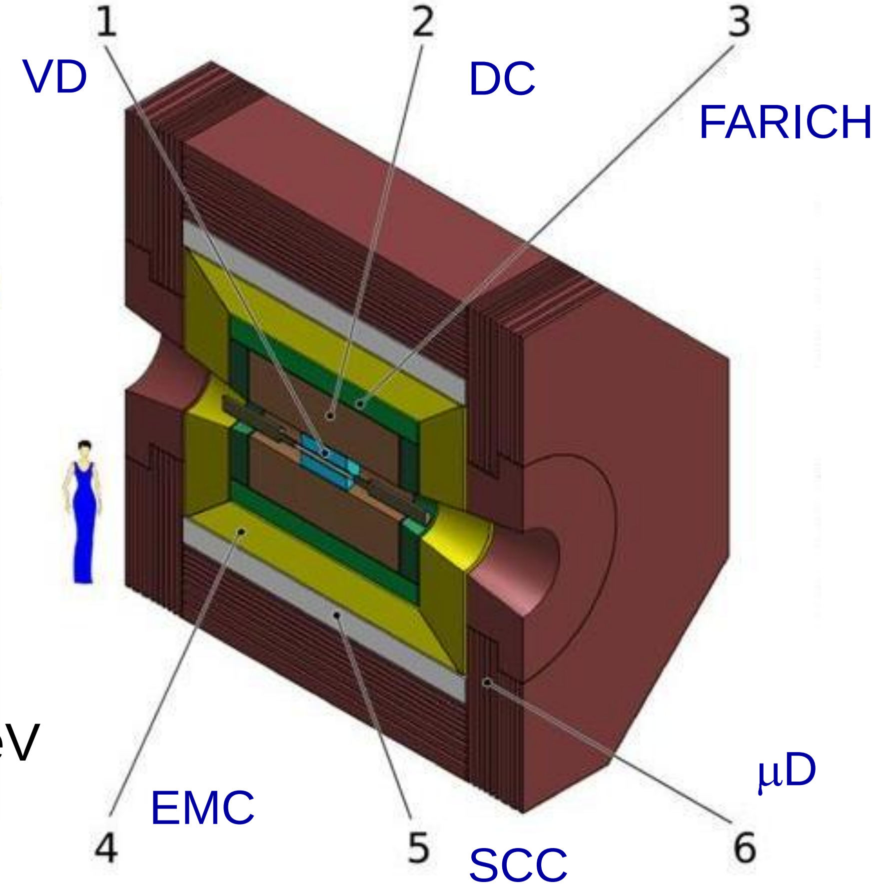
BELLE II : $\alpha \sim 0.3$º, $\beta \sim 1.0$º, $\gamma \sim 1.5$º
Instead of 9^{o} → 2^{o} ?

Super C-Tau project in Novosibirsk

Physics at tau-charm facility

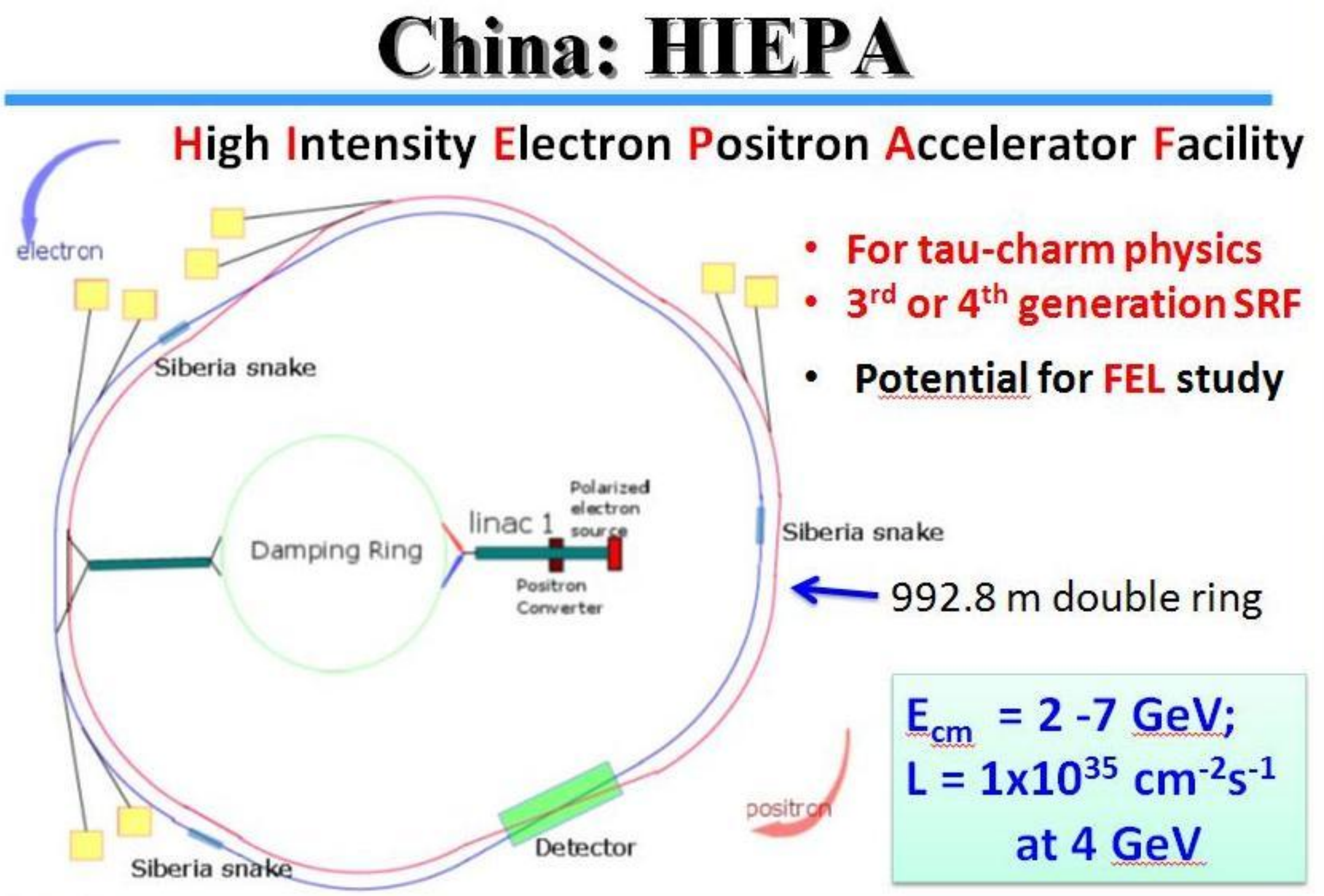
1. *QCD and*
2. Light hadrons
3. Tau physics
4. Charmonium
5. Charm
6. X,Y,Z states





1. Energy range 2 – 5 GeV
2. Max luminosity 10^{35} cm-^{2}s^{-1} at 4 GeV
3. e^{-} beam polarization available
4. Energy spread 10^{-4} – 10^{-3}
5. Laser energy calibration

Super C-Tau factory project in China



- Polarization available
- on one beam
- Symmetric machine
- with low currents and crabbed waist solution for the interaction region

H.P.Peng, Tau2014

Production rate / year

SCTF, 1 ab^{-1}

J/Ψ - 1 10^{11}

DD - 3 10^{9}

D_s D_s – 3 10^{9}

$\tau^+\tau^-$ - 3 10^{9}

Compare with BELLE-II, at Y(4S), L= 10 ab^{-1}

Charm - 10^{10}

$\tau^+\tau^-$ - 10^{10}

Conclusions

1. First generations B-factories in KEK and SLAC completed data taking with overall luminosity of 1.5 inv.ab.
2. CP-violation in b-sector is confirmed, many new results in τ–c–b physics are obtained. Some results are in tension with SM.
3. BES-III continues data taking with max luminosity of 10^{33} $cm^{-2}s^{-1}$.
4. BELLE-2 detector in KEK is close to start data taking at upgraded collider with the max luminosity of 8 10^{35} $cm^{-2}s^{-1}$.
5. A project of super-charm-tau collider is developing in Novosibirsk and Bejing
6. e^+e^- facilities in τ–c–b physics are in strong competitions with LHC detectors LHCb, ATLAS, CMS.

Thank you for listening !

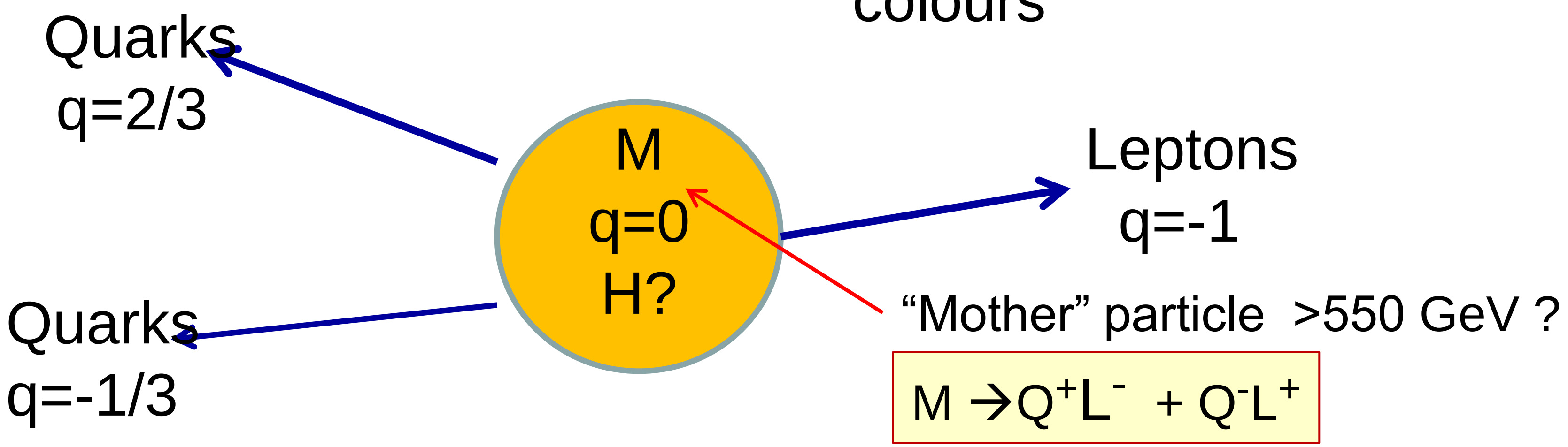
Backup slides

Total electric charge of quarks and leptons = 0

$(3 * (2/3) + 3 * (-1/3)) * 3 + (-1) * 3 = 0$!

- separately for particles and antiparticles - puzzle !

colours



Quarks and leptons could be relatives .
Hint of transition between quarks and leptons?

Total electron and proton charge = 0

$q(p)+q(e^-)=0$

Why ?

Hint of mutual transitions between them ?

Model of grand Unification

Search of proton decay $p \rightarrow \pi^0 + e^+$

$\tau_p > 10^{32}$ years

Fundamental constant and dimensions

Three dimensions

[*l*] - length
[*t*] - time
[*m*] - mass

Three constants

h - Plank constant (min. spin)
c - light speed (max speed)
+
G = hc/m_P^2 = 6.7 10^{-8} $cm^3\ gr^{-1}\ s^{-1}$

$$m_P = 1{,}2 \cdot 10^{19}\ GeV/c^2\ ;$$

Dimensions do not directly correspond to constant

Redefinitiom of constants:

$$\boldsymbol{l_P = \hbar c/m_P = 10^{-33}\,\text{см}}$$

$$t_P = l_P/c = 10^{-43}\ \mathrm{sec}$$

Physical program for S-C-Tau facility

Physics below J/Ψ

- Search of multiquark states with s-quark
- Hadron form factors
- Study of Y(2160)
- …

Physics below open charm

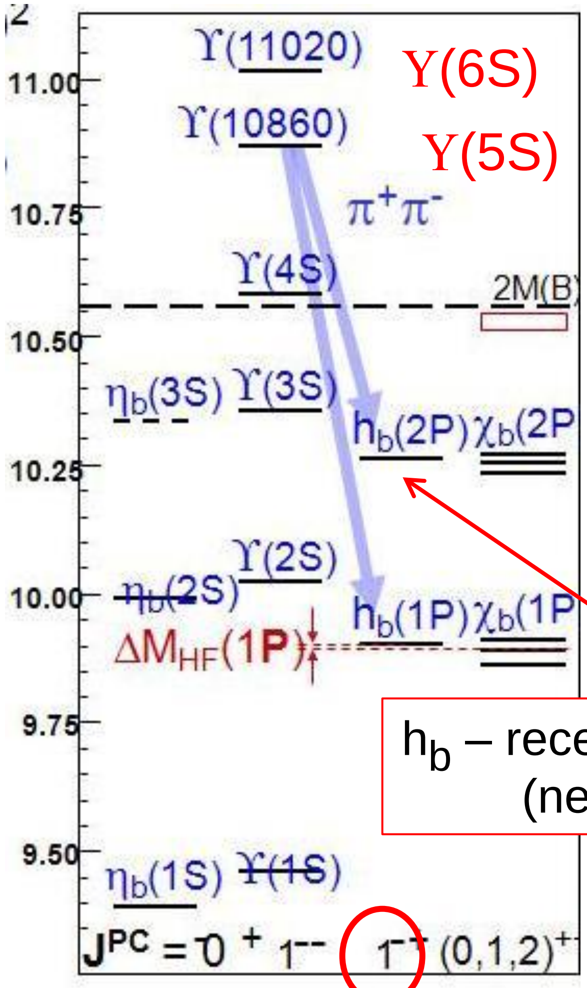
- Light hadron spectroscopy
- Rare and forbidden decays
- Physics with τ lepton
- Process of LFV and CPV

Above threshold of open charm

- Physics with D mesons
- Charm baryons
- f_D and f_{Ds}
- D_0 -D_0 mixing
- X,Y,Z particles

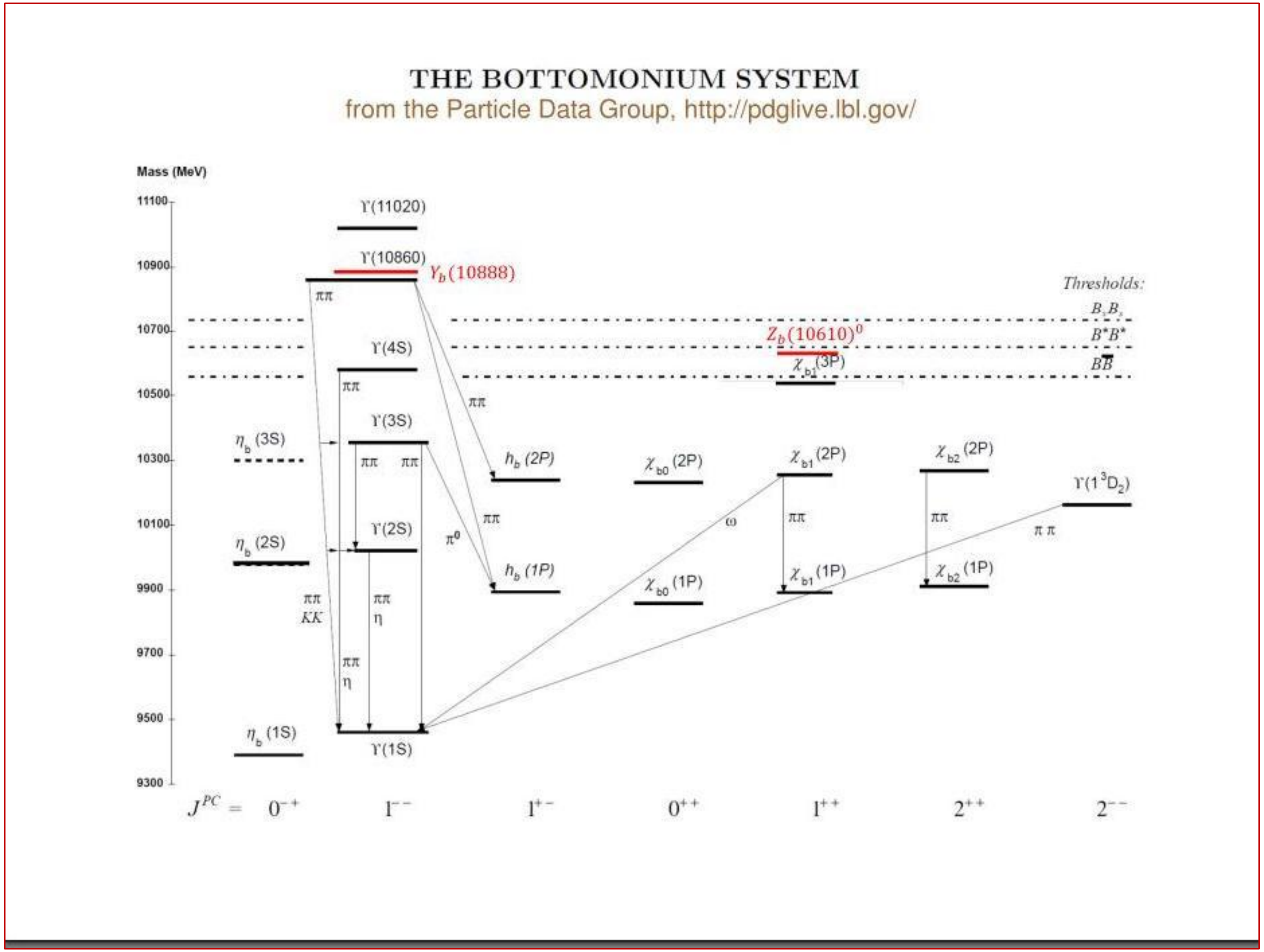
1. QCD and
2. Light hadrons
3. Tau physics
4. Charmonium
5. Charm
6. X,Y,Z states

Levels of bottomonium



h_b – recently found (next slide)

Should be 1^{+-}



STCF: Machine Parameters

	INFN	BINP	China
Beam Energy, GeV	1.0-2.3	1.0-2.5	1.0-3.5
Circumference, m	340.7	813	992.8
Number of bunches	530	390	540
Bunch Current, mA	3.29	4.4	5
Beam Current, A	1.0-1.745	1.7	2.7
Emittance Horiz, nm	56.11-4.89	8	10
Emittance Vert, nm	0.015-0.012	0.04	0.05
Bunch length, mm	10.1-6.9	16-10	10
beta x (IP), cm	7	4	100
beta y (IP), cm	0.06	0.08	0.1
RF frequency, MHz	476	508	500.06
Luminosity, $cm^{-2}s^{-1}$	$0.2\text{-}1 \times 10^{35}$	$0.63\text{-}1 \times 10^{35}$	1.05×10^{35}

Y.Sakai

Tau polarization in $e^+e^- \to \tau^+\tau^-$ process, electrons – longitudinally polarized (R.Li)

$$\boldsymbol{\xi}_{\rm ph}\cdot \boldsymbol{N} = \pm\frac{(\boldsymbol{e}_z\boldsymbol{N})}{1-\frac{\beta^2}{2}\boldsymbol{N}_\perp^2} = \pm\frac{\cos\theta}{1-\frac{\beta^2}{2}\sin^2\theta}$$

- tau longitidunal polarization

$$\boldsymbol{\xi}_{\rm ph}\cdot\frac{\boldsymbol{e}_z-\boldsymbol{N}(\boldsymbol{e}_z\boldsymbol{N})}{|\boldsymbol{e}_z-\boldsymbol{N}(\boldsymbol{e}_z\boldsymbol{N})|} = \pm\frac{\frac{1}{\gamma}\sin\theta}{1-\frac{\beta^2}{2}\sin^2\theta}$$

- tau transverse polarization

$$\boldsymbol{\xi}_{\rm ph}\cdot\boldsymbol{e}_z = \pm\frac{\frac{1}{\gamma}+\left(1-\frac{1}{\gamma}\right)(\boldsymbol{e}_z\boldsymbol{N})^2}{1-\frac{\beta^2}{2}\boldsymbol{N}_\perp^2} = \pm\frac{\frac{1}{\gamma}+\left(1-\frac{1}{\gamma}\right)\cos^2\theta}{1-\frac{\beta^2}{2}\sin^2\theta}$$

- tau polarization along electrons

$$\boldsymbol{\xi}_{\rm ph}^2 = \frac{1-\beta^2\boldsymbol{N}_\perp^2}{\left(1-\frac{\beta^2}{2}\boldsymbol{N}_\perp^2\right)^2} = \frac{1-\beta^2\sin^2\theta}{\left(1-\frac{\beta^2}{2}\sin^2\theta\right)^2}$$

- tau polarization