Hadronic decay studies of τ Lepton in Belle

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(Seoul nat'l univ.)

April 19, 2011

Hadronic decay studies of τ Lepton in Belle

KEKB/Belle experiment

International Collaboration: Belle

"To study the origin of CP violation (with B meson decay)"

BINP
Chiba U.
U. of Cincinnati
Ewha Womans U.
Fu-Jen Catholic U.
U. of Giessen
Gyeongsang Nat'l U.
Hanyang U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

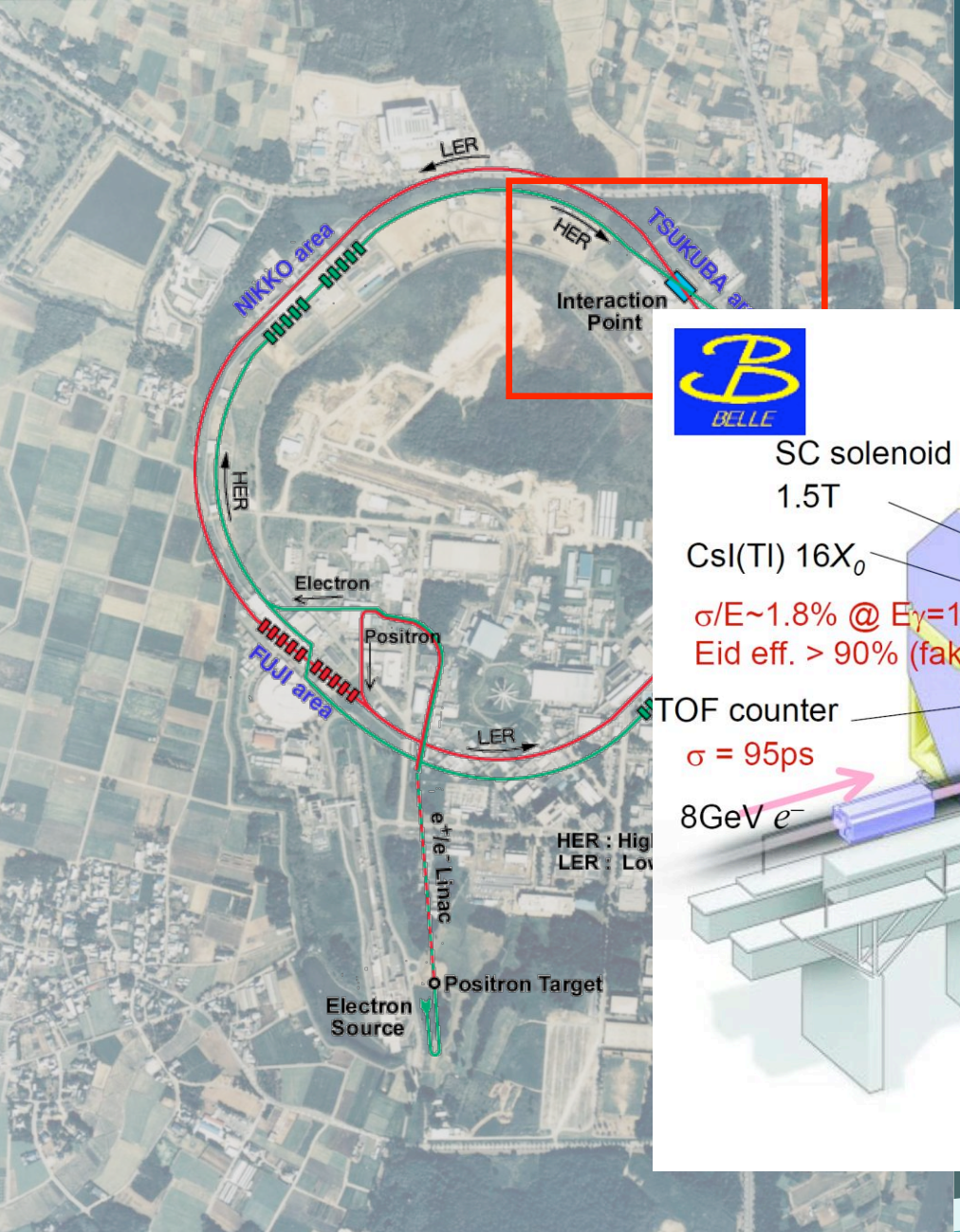
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne

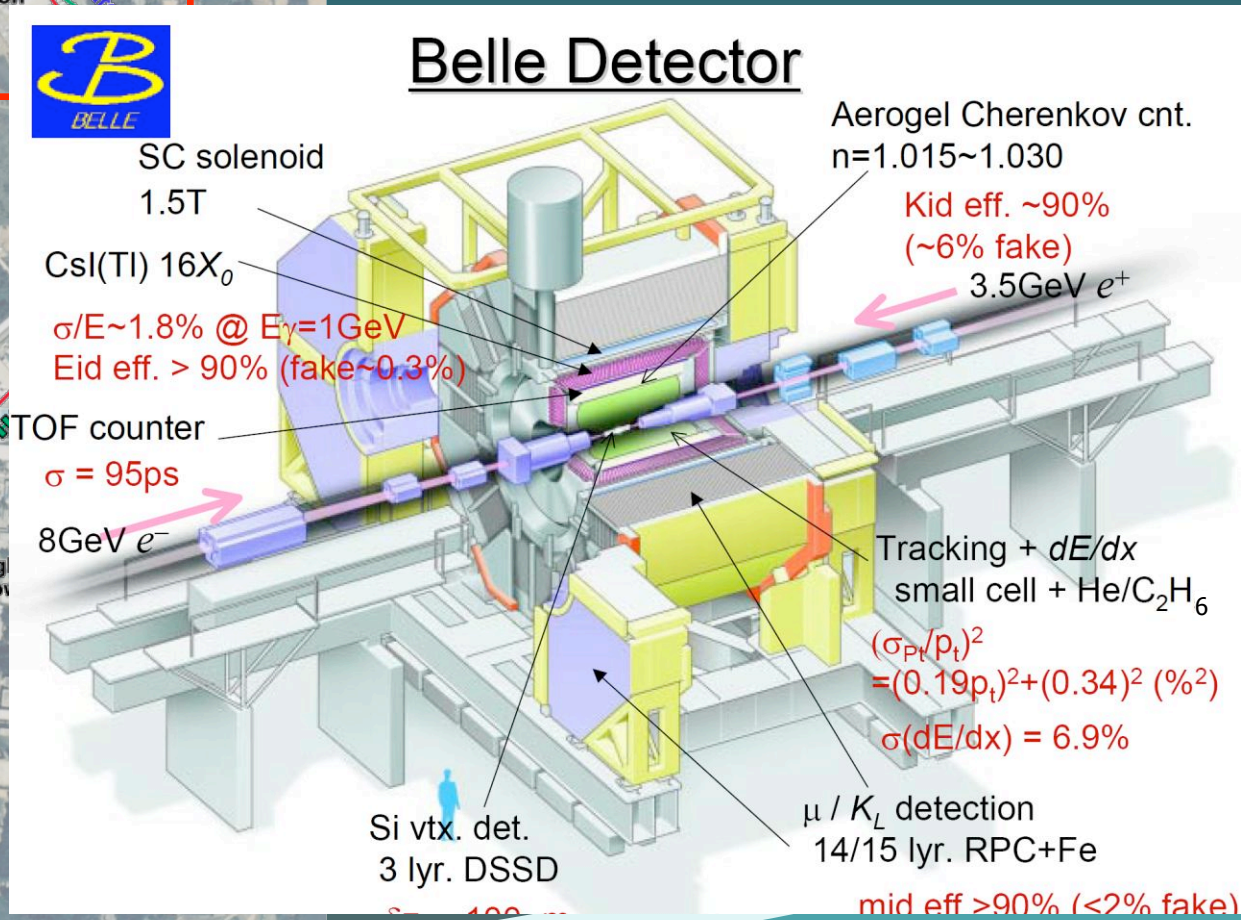
Nagoya U.
Nara Women's U.
National Central U.
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Nova Gorica
Osaka U.
Osaka City U.
Panjab U.
Peking U.
Princeton U.
Riken
Saga U.
USTC

Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
INFN Torino
Toyama Nat'l College
VPI
Yonsei U.

14 countries, 55 institutes, ~400 collaborators

Korea is the largest foreign group in Belle

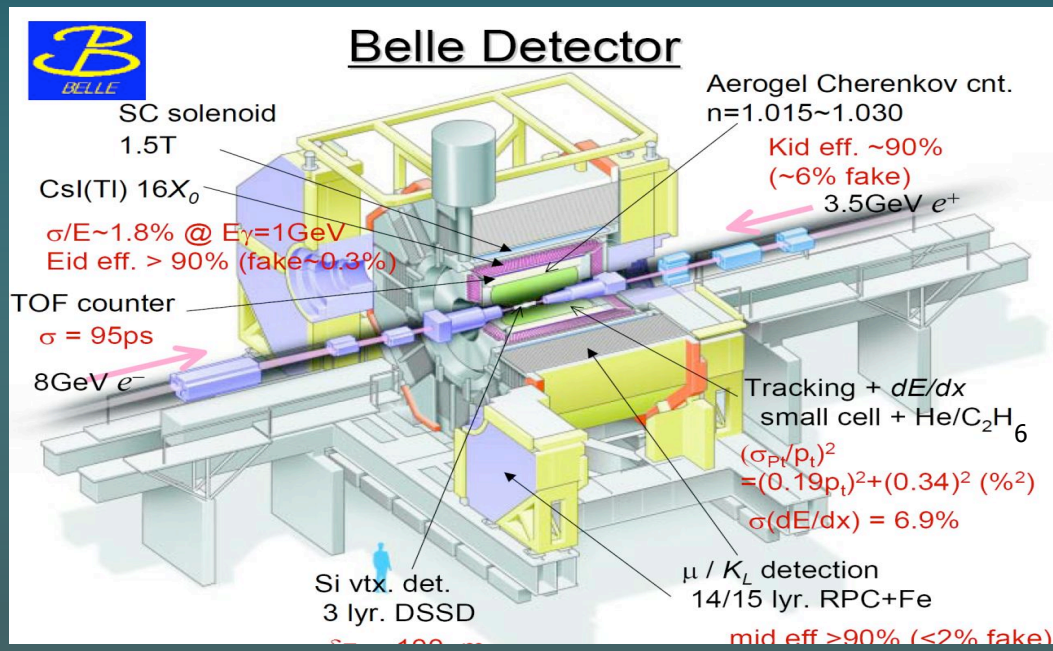


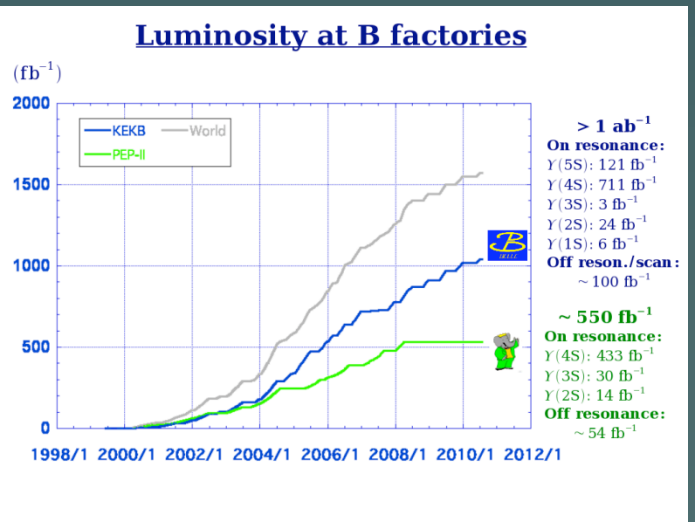


Tsukuba-shi, Ibaraki-ken, Japan

KEKB/Belle experiment

- General purpose detector optimized to
  - Precise vertxing
  - PID
  - EM shower resolution
- Asymmetric beam energy (8GeV e-, 3.5GeV e+) to boost B mesons





- World highest intensity e+e- collider : 2.11×10^{34} /cm^2/s
- Accumulated world largest data sample for Υ(nS) decay : 1.014 ab^{-1}
- Operation terminated June 30, 2010

Top 3 cited paper from Belle

PRL 91, 262001 (2003)
555 times cited (as of today)

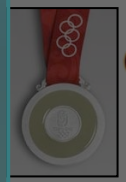
Observation of a narrow charmonium-like state in exclusive $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$ decays

S.-K. Choi,[5] S. L. Olsen,[6] K. Abe,[7] T. Abe,[7] I. Adachi,[7] Byoung Sup Ahn,[14]
H. Aihara,[43] K. Akai,[7] M. Akatsu,[20] M. Akemoto,[7] Y. Asano,[48] T. Aso,[47] V. Aulchenko,[1]

Abstract

We report the observation of a narrow charmonium-like state produced in the exclusive decay process $B^{\pm} \to K^{\pm}\pi^{+}\pi^{-}J/\psi$. This state, which decays into $\pi^{+}\pi^{-}J/\psi$, has a mass of $3872.0 \pm 0.6(\text{stat}) \pm 0.5(\text{syst})$ MeV, a value that is very near the $M_D + M_{D^*}$ mass threshold. The results are based on an analysis of 152M B-B events collected at the $\Upsilon(4S)$ resonance in the Belle detector at the KEKB collider. The signal has a statistical significance that is in excess of 10σ.

526 times cited (as of today)



Observation of Large CP Violation in the Neutral B Meson System

K. Abe[9], K. Abe[37], R. Abe[27], I. Adachi[9], Byoung
G. Alimonti[8], K. Asai[21], M. Asai[10], Y. Asano[44], T
A. M. Bakich[35], E. Banas[25], S. Behari[9], P. K.
A. Bozek[25], T. E. Browder[8], B. C. K. Casey[8], P.
B. G. Cheon[34], R. Chistov[14], S.-K. Choi[7], Y.

Abstract

We present a measurement of the Standard Model CP violation parameter $\sin 2\phi_1$ based on a 29.1 fb^{-1} data sample collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric-energy e^+e^- collider. One neutral B meson is fully reconstructed as a $J/\psi K_S$, $\psi(2S)K_S$, $\chi_{c1}K_S$, $\eta_c K_S$, $J/\psi K_L$ or $J/\psi K^{*0}$ decay and the flavor of the accompanying B meson is identified from its decay products. From the asymmetry in the distribution of the time intervals between the two B meson decay points, we determine $\sin 2\phi_1 = 0.99 \pm 0.14(\text{stat}) \pm 0.06(\text{syst})$. We conclude that we have observed CP violation in the neutral B meson system.

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(2002)
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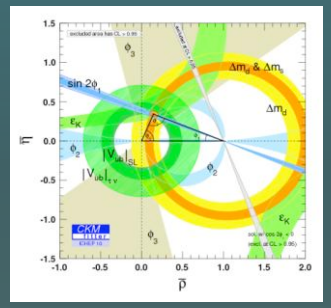
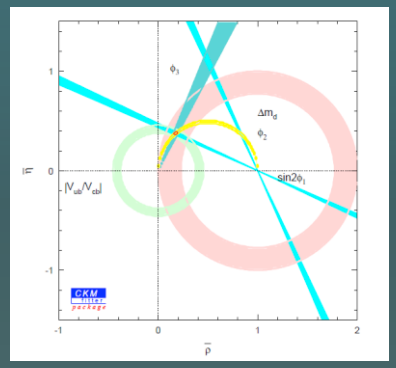
tion parameter $\sin 2\phi_1$
t the $\Upsilon(4S)$ resonance
One neutral B meson
is reconstructed in a $J/\psi K_S^0$, $\psi(2S)K_S^0$, $\chi_{c1}K_S^0$, $\eta_c K_S^0$, $J/\psi K^{*0}$, or $J/\psi K_L^0$ CP-eigenstate decay channel and the flavor of the accompanying B meson is identified from its decay products. From the asymmetry in the distribution of the time interval between the two B meson decay points, we obtain $\sin 2\phi_1 = 0.719 \pm 0.074(\text{stat}) \pm 0.035(\text{syst})$.

I. Bizjak,[13] A. Bondar,[2] A. Boz
B. C. K. Casey,[7] P. Chang,[25] Y
Y. Choi,[37] Y. K. Choi,[37] M. D

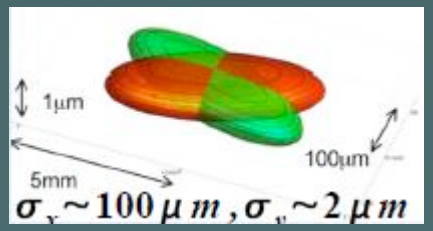
Belle-II

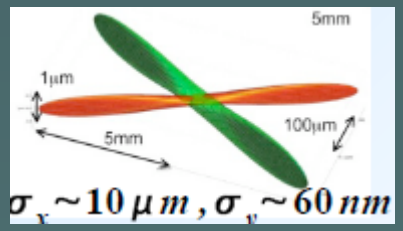
- "To explore new physics beyond the Standard Model to understand various properties of flavor structure, with O(10) times larger data sample."
  - LHC : Direct search for NP in the energy frontier
  - SuperKEKB : Indirect search for NP in the luminosity frontier
- NP sensitive processes :
  - b→sss penguin decays
  - DCPV in B →Kpi
  - B →tau nu
  - CPV in D decays
  - LFV in tau decays…….



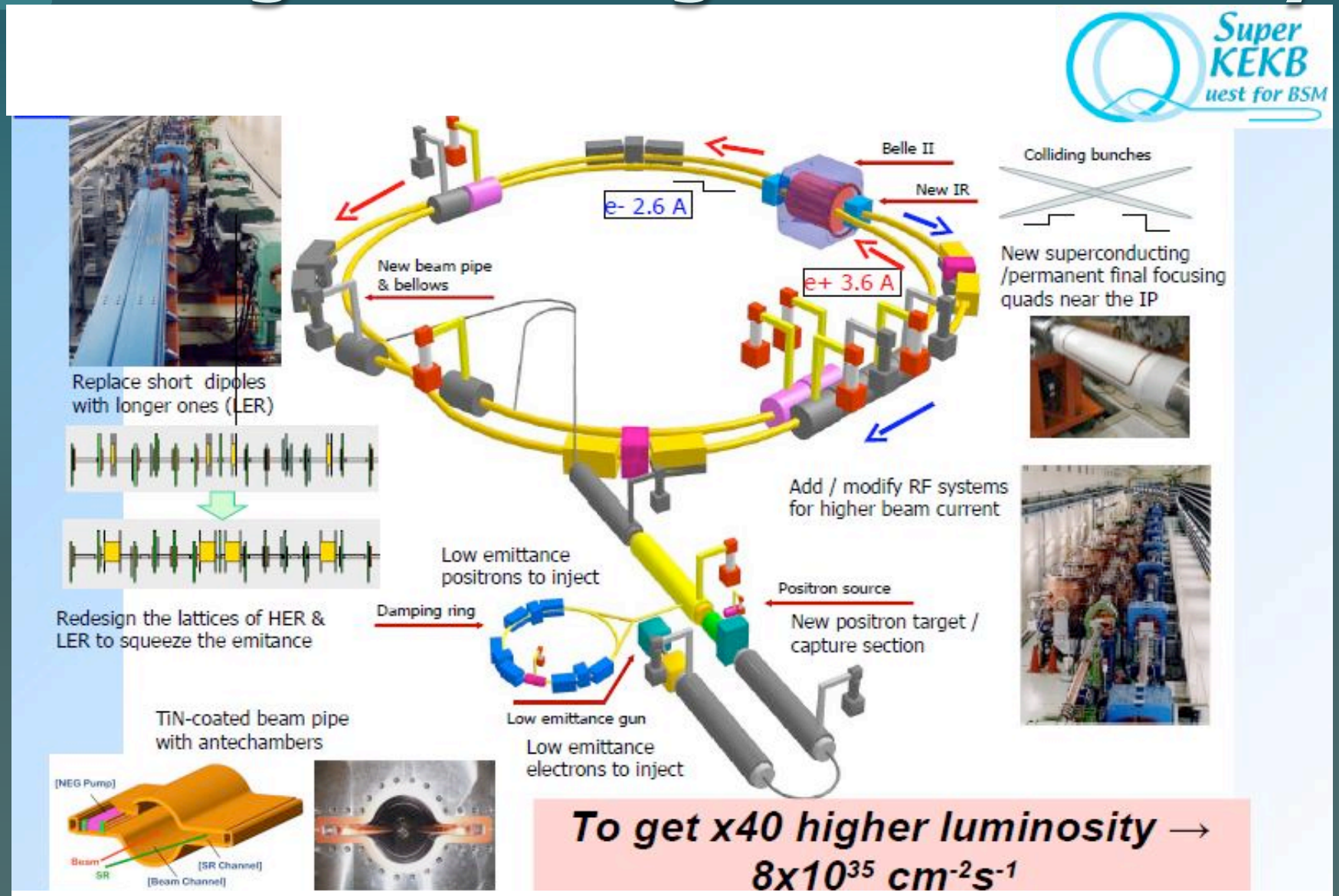


How to obtain higher luminosity? : By squeezing beams



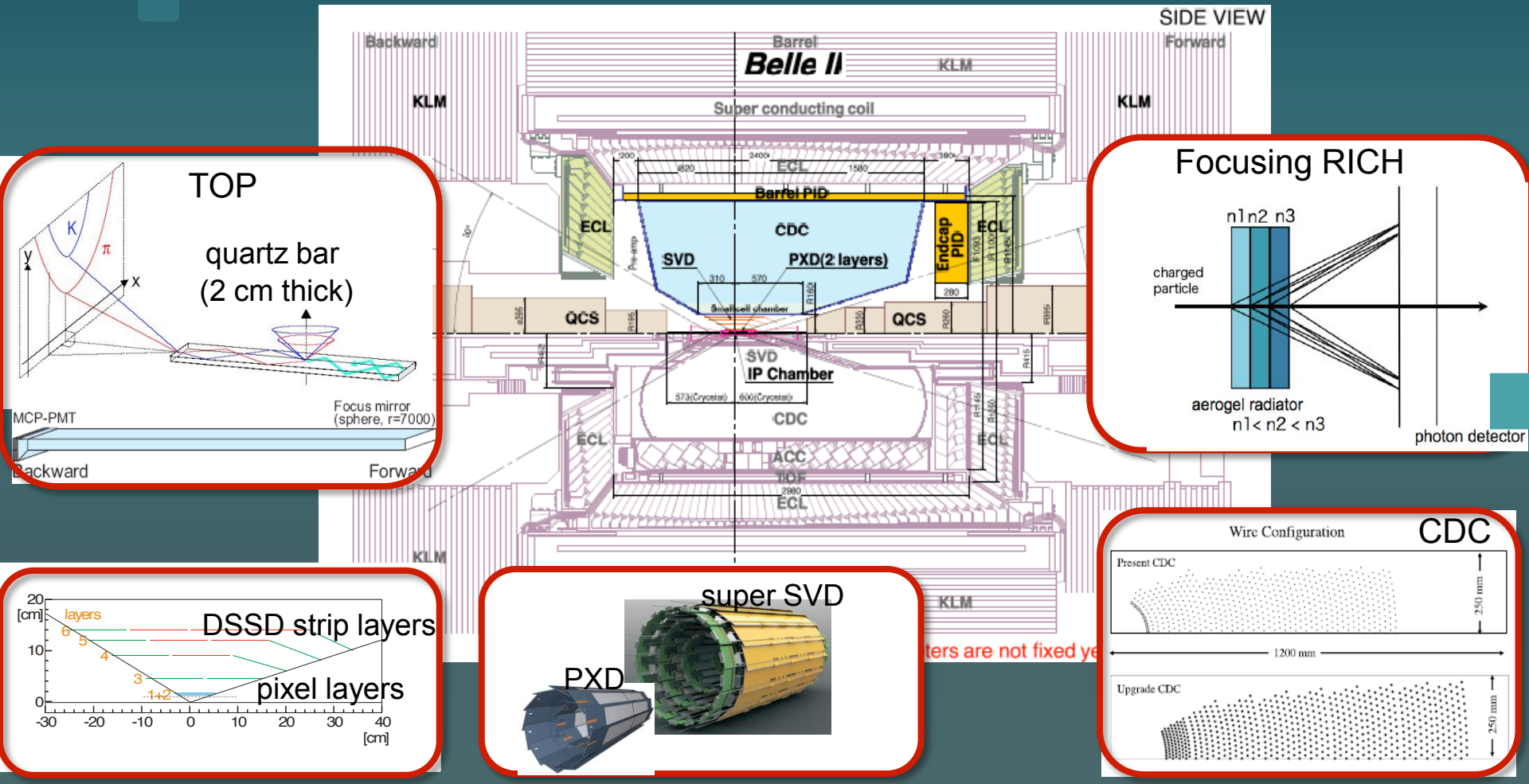


To get 40x higher luminosity



(Slide by S.Korpar, DISCRETE 2010)

Upgrade to Belle-II



- Completely new DAQ and TRG system (max. 30kHz with 3.4% deadtime)
- Upgrade DAQ for Barrel ECL (keeping up CsI(Tl))
- Endcap ECL : see next page…

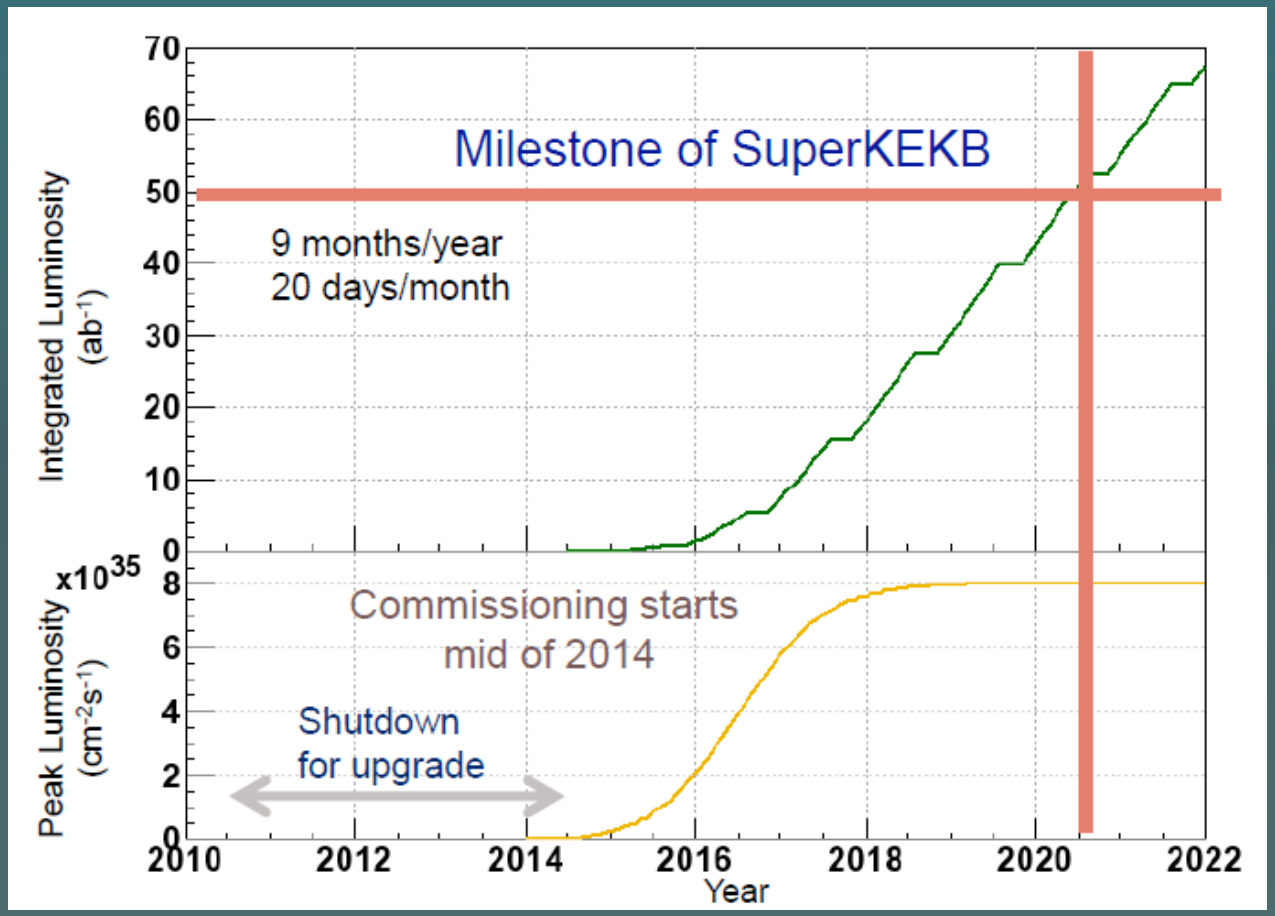
Plan for Endcap ECL

- Due to xO(10) larger beam BG, we need faster and radiation hard crystal
- Baseline option : Upgrading to CsI(pure)
- Another options : PWO (Korean group) or BSO (Nara group)
- Final decision will be done in this or next year. Upgrade will be done after 2015.

Crystal	CsI(Tl) (Belle)	CsI (Baseline option)	BSO (Nara W.U.)	$PbWO_4$ (Korean)
Density (g/cm^3)	4.51	4.51	6.8	8.3
Radiation Length (cm)	1.85	1.85	1.15	0.9
Molière Radius (cm)	3.5	3.5		2.0
Luminescence [b] (nm) (at peak)	550	320	480	420
Decay Time [b] (ns)	1300	35 6	100 2.4,26	30 10
Light Yield [b,c] (%)	45	3-4	3-4	0.1 0.6
d(LY)/dT [b] (%/ ^{o}C)	0.3	-0.6	-2.0	-1.9
Radiation hardness (rad)	10^3	10^{4-5}	10^{6-7}	10^{6-7}
Experiment	CLEO *BABAR* Belle, BES III	KTeV, E787		CMS,ALICE PANDA
Pro		Known tech. No need to change geometry	Better energy resol. Smaller crystal, Small decay time Radiation hard	
Con		Not enough radiation hard No improvement of ECL performance	Not proven for Mass prod./large crystal	Small LY Need cooling

Plan for Future

Commissioning start at 2014
Will be ready for data taking at the early of 2015
Achieve 50 ab^{-1} at 2020-2021



Status of Belle-II

- SuperKEKB and Belle-II upgrade is approved last year by Japanese government (~100M$ for 2011~2013).
- Belle detector has been rolled out from IP
- Another Super B-factory : Italian government approved their SuperB project at INFN, at the end of last year : another new competition

After the Earthquake

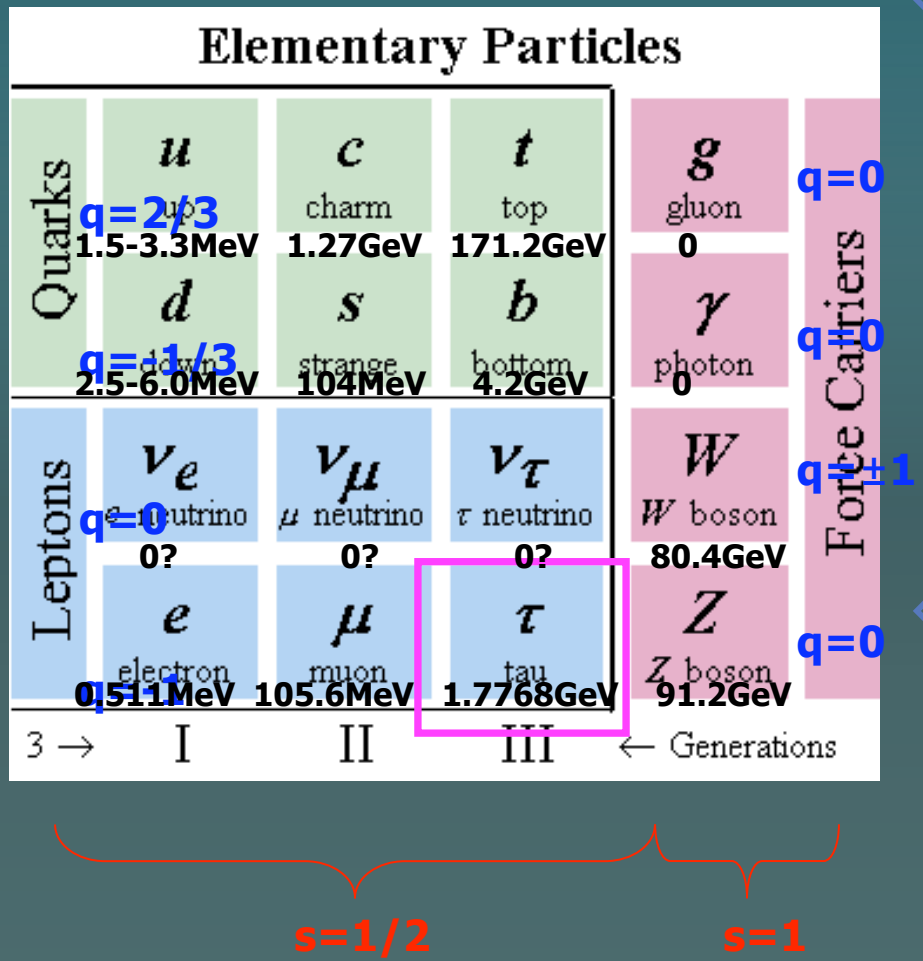
- Some of maintainable damages are found at LINAC, almost no damage on KEKB, Belle nor Tsukuba campus.
- The experimental facilities at J-PARC did not get damaged too much, where some of the supporting facilities (ex. road) are damaged. Unestimatable shutdown before resuming is announced.
- Belle MC and Data are planed to be copied to outside of KEK to continue data analysis.
- Any delay on Belle-II is not announced officially, though negligible but unavoidable delay is expected. Many of the detector R&Ds are going on outside of Japan.

On Earthquake

As is now well known, Japan suffered a terrible earthquake and tsunami on March 11, which has caused tremendous damage, especially in the Tohoku area. Fortunately, all KEK personnel and users are safe and accounted for. The injection linac did suffer significant but manageable damage, and repairs are underway. The damage to the KEKB main rings appears to be less serious, though non-negligible. No serious damage has been reported so far at Belle. Further investigation is necessary. We would like to convey our deep appreciation to everyone for your generous expressions of concern and encouragement.

Hadronic decay studies of τ Lepton in Belle

The τ Lepton



- The heaviest lepton : 1776.84 ± 0.17 MeV (2008PDG)
  - The only lepton which can decay to hadron
  - Clear environment to study QCD
- $\sigma(e^+e^- \to \tau^+\tau^-) = 0.919$nb ($\sigma(e^+e^- \to BB) = 1.05$nb) at Υ(4S) : a tau-factory

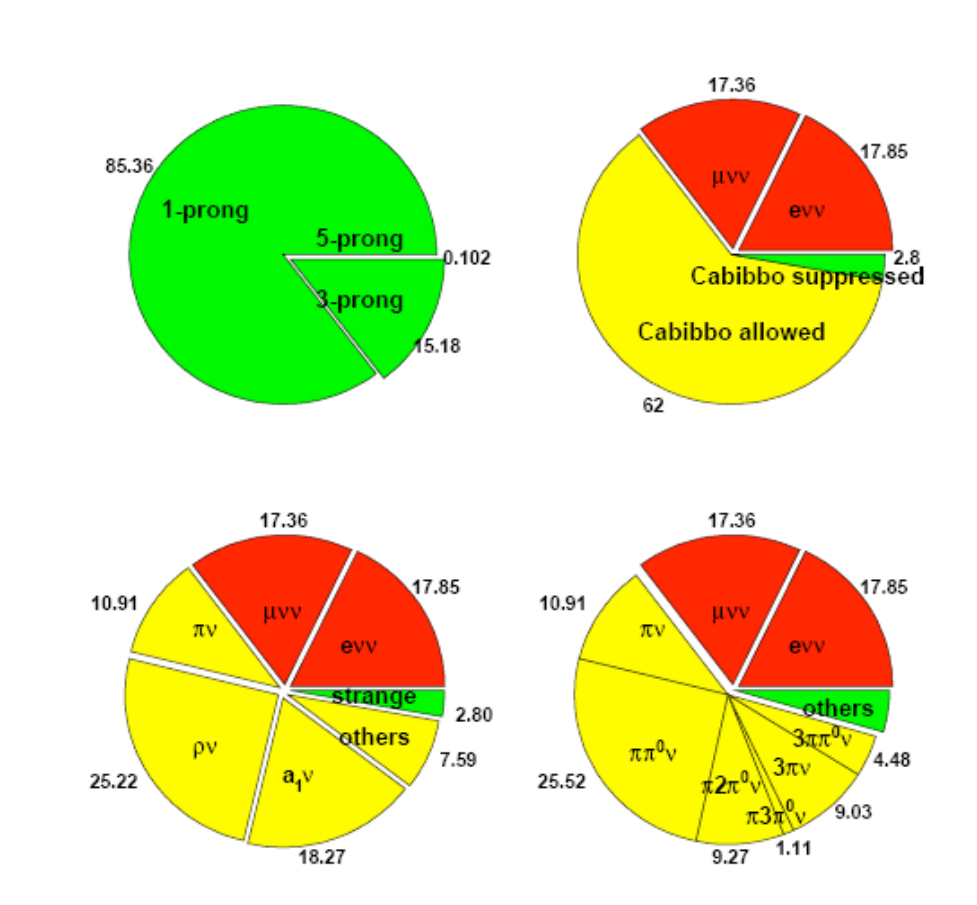
How much τ's do we have?

Group	Beam energy	Int. Luminosity (fb^{-1})	$N_{\tau\tau}$ ($x10^6$)
LEP	Z-pole	0.34	0.33
CLEO	10.6 GeV	13.8	12.6
BABAR	10.6 GeV	516	482
Belle	10.6 GeV	1014	933
Tau-charm factory	4.2 GeV	10	32,000
Belle-II	10.6 GeV	50,000	46,000
SuperB	10.6 GeV	75,000	69,000

$\sigma(e^+e^- \rightarrow \tau^+\tau^-) = 0.919nb$ at 10.6GeV

Decay properties of tau lepton

- One-prong decay are dominant : ~85%
  - $\tau \to e\nu\nu$, $\tau \to \mu\nu\nu$, $\tau \to \pi\nu$, $\tau \to a_1(\pi\pi^0\pi^0)\nu$, $\tau \to \rho\nu$ .....
- Hadronic decay : ~65%
- Strange hadronic decay : ~2.8%



Main decay modes	
1 prong	~85%
3 prong	~15%
5 prong	~0.1%
7 prong	$<2.4\times10^{-6}$

Hadronic decay studies of τ Lepton in Belle

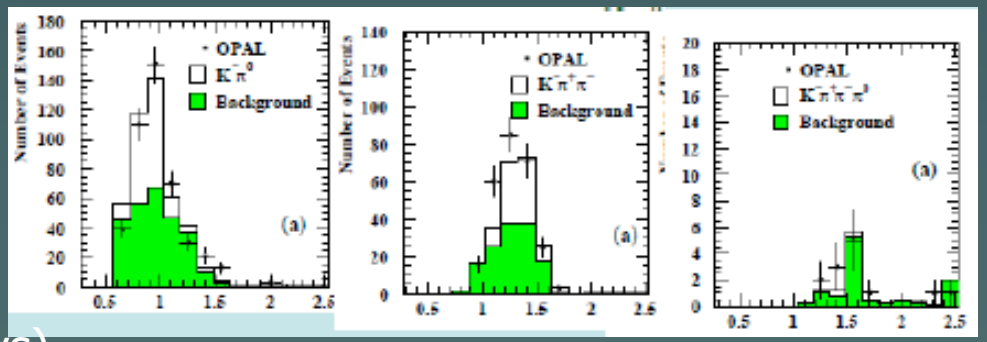
Physics with Tau Lepton

Goal/Dream	Category	Physics	Important factors
New Physics	Absent in SM	● Lepton Flavor Violation ● Charged Lepton CPV ● τ EDM ● CPT violation	Luminosity Background
	Precision Measurement, search for deviation from SM	● Lepton Universality m_t, τ –lifetime, Be, B_μ, B_π, B_K ● $(g-2)_\tau$	Particle ID (π/K) π^0
Hadrons Understand various pQCD and non-pQCD aspect s of Hadrons	Inclusive Measurements sum	● (strange) Br, spectral functions α_s, Vus, m_s , $(g-2)_\mu$?/CVC	Knowledge of decay angles Spin-Spin corr.
τ is an ideal to study hadrons	Exclusive Measurements String Theory helps us? AdS/CF	● Br, mass spectrums ● Form Factors(A,V, S) ● Resonances. Rare decays	Knowledge of τ direction Beam polarization

Slide by H.Hayashii (TAU10)

Hadronic decays of tau lepton

- The only lepton which can decay to hadrons
  - Rather large mass (1.78GeV)
  - Clean initial state - single τ pair decays decide the kinematics
- Test of CVC and evaluation of a_μ from spectral function.
- Measurements of important physics quantities : V_{us}, m_s, α_s
- Look for leptonic CP violation (NP)



Have been waiting for enough statistics from B-factories (especially, to measure strangeness decays)

Hadronic τ decay programs

- Non-strange final state
  - $\tau \to \eta\pi\nu_\tau$, $\tau \to \eta'\pi\nu_\tau$: Second Class Current
  - $\tau \to \pi\pi^0\nu_\tau$: Test of CVC and $(g-2)_\mu$ (PRD78:0701006,2008)
  - $\tau \to \eta\pi\pi^0\nu_\tau$: Wess-Zumino anomaly
- Strange final state
  - $\tau \to K\pi\nu_\tau$, $\tau \to K\eta X\nu_\tau$, $\tau \to K_s n(\pi/K)\nu_\tau$,
  - 3-prong : $\tau \to h^\pm h^+ h^- \nu_\tau$ ($h = \pi, K$)
  - V_{us} measurement
  - V_{us} using $\Gamma(\tau \to K\nu_\tau)/\Gamma(\tau \to \pi\nu_\tau)$
  - Strange spectral function and V_{us}, m_s measurements
- Other researches
  - 5-prongs, 7-prongs....
  - τ mass, life time measurements (via $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$)
  - Search for CP violation in the charged lepton : $\tau \to K_S\pi\nu_\tau$, $\tau \to K\pi\pi\nu_\tau$

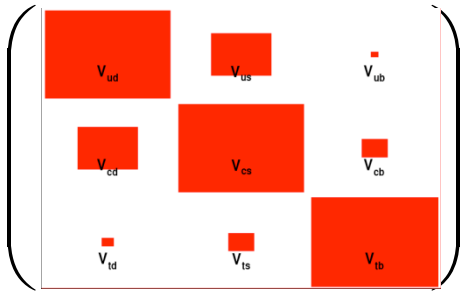
OK, tau is a well-known particle.
You may not be interest too much.

There was an issue of Vus measurement from *BABAR* which shows how important this study is.

Cabibbo Kobayashi Maskawa matrix

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

$$V_{CKM} =$$

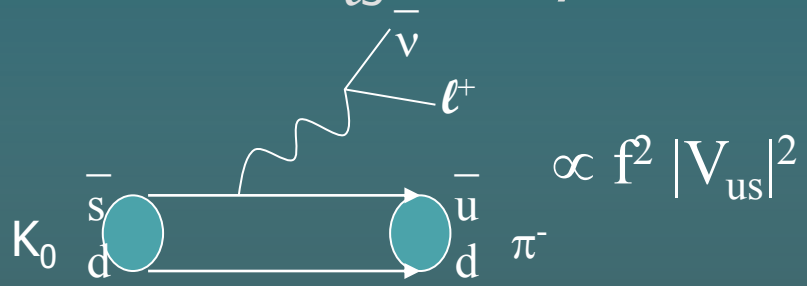


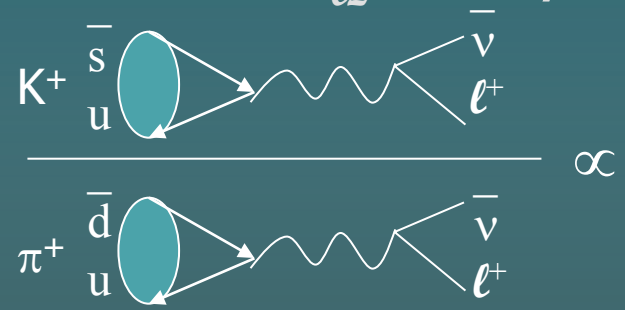
$$= \begin{pmatrix} 0.97428(15) & \boxed{0.2253(7)} & 0.00347(16) \\ 0.2252(7) & 0.97345(16) & 0.0410(11) \\ 0.00862(26) & 0.0403(11) & 0.999152(45) \end{pmatrix}$$

(PDG2010, assuming unitarity)

V_{us} meas. from Kaon decay

- Estimate from the unitarity condition :
  $|V_{ud}|^2+|V_{us}|^2+|V_{ub}|^2 = 1 \Rightarrow |V_{us}| = 0.2255\pm0.0010$
- From $K_{\ell 3}$ decays or From $K_{\ell 2}$ decays





$$\propto \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2}{f_\pi^2}$$

Measurement of $K_{L,S}$ properties

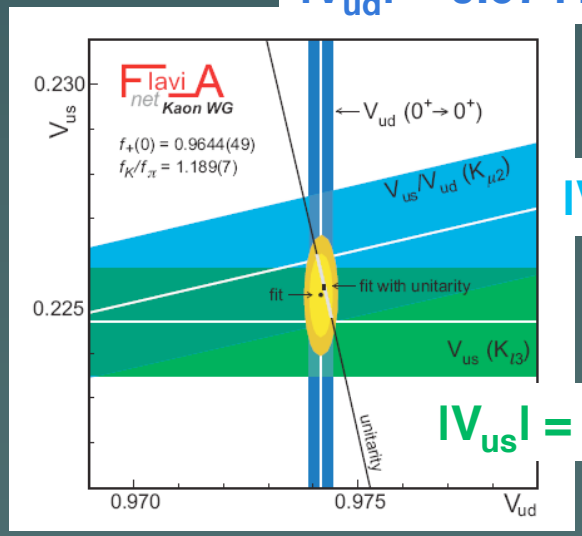
Measurement of K+- properties

FlaviAnet WG performed all the summarizing work for recent measurements (KLOE, KTeV..) (arXiv:1002.1654)

W/o unitarity : |Vud| = 0.97417(26), |Vus| = 0.2253(9)

W/ unitarity : |Vus| = 0.2255(7)

$|V_{ud}| = 0.97418(26)$



$|V_{us}|/|V_{ud}| = 0.2321(15)$

$|V_{us}| = 0.2246(12)$

V_{us} meas. from τ decay

$$R_\tau = \boxed{\frac{\Gamma(\tau^- \to (hadrons)^- \nu_\tau)}{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)}} = R_{\tau,non\text{-}strange} + R_{\tau,strange}$$

Measured from the branching fraction and mass spectra

$$|V_{us}|^2 = \frac{R^W_{\tau,\ strange}}{R^W_{\tau,\ non\text{-}strange}/|V_{ud}|^2 - \delta R^W_\tau}$$

Determined from Finite Energy Sum Rule ($\delta R^W_\tau \sim 0.06 \times R^W_{\tau,\ non\text{-}strange}/|V_{ud}|^2 \pm 10\%$ $\rightarrow$ 0.4% at Vus :relatively small)

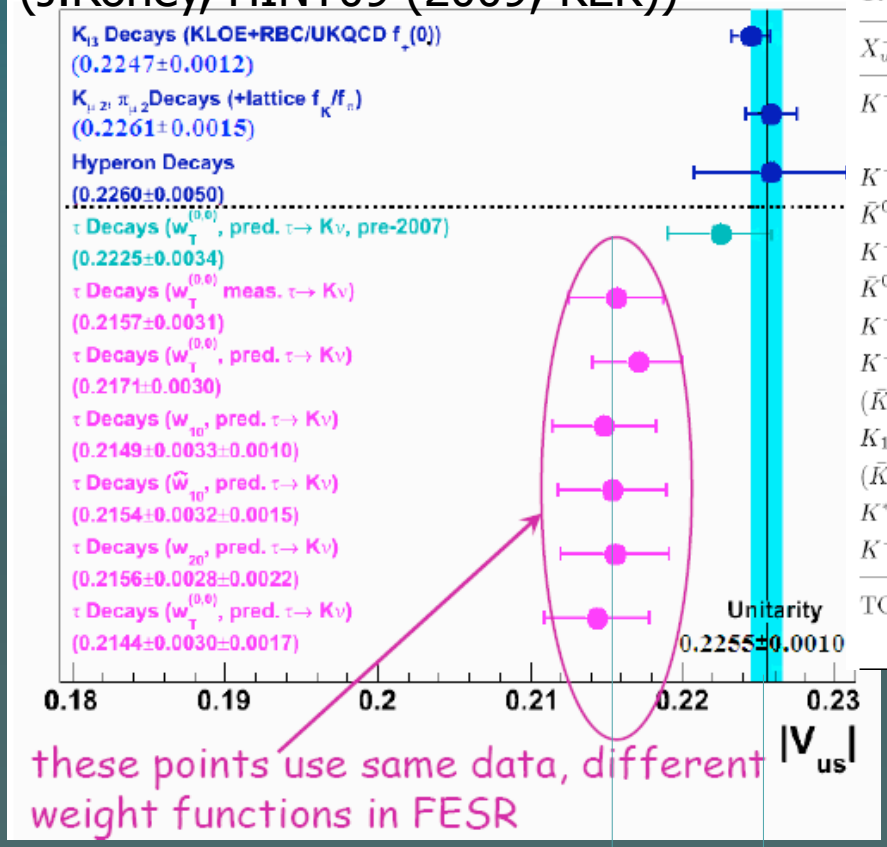
$$R_\tau = \frac{1 - BF(\tau \to e\nu\nu_\tau) - BF(\tau \to \mu\nu\nu_\tau)}{BF(\tau \to e\nu\nu_\tau)} = R_{\tau,non\text{-}strange} + R_{\tau,strange}$$

What we only need is

inclusive measurement of strange decays of τ

Result of V_{us} from τ decay

(J.Roney, HINT09 (2009, KEK))

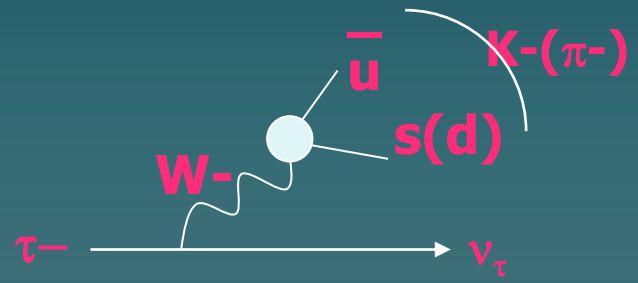


S. Banerjee, ICHEP '08 (arXiv 0811.1429)

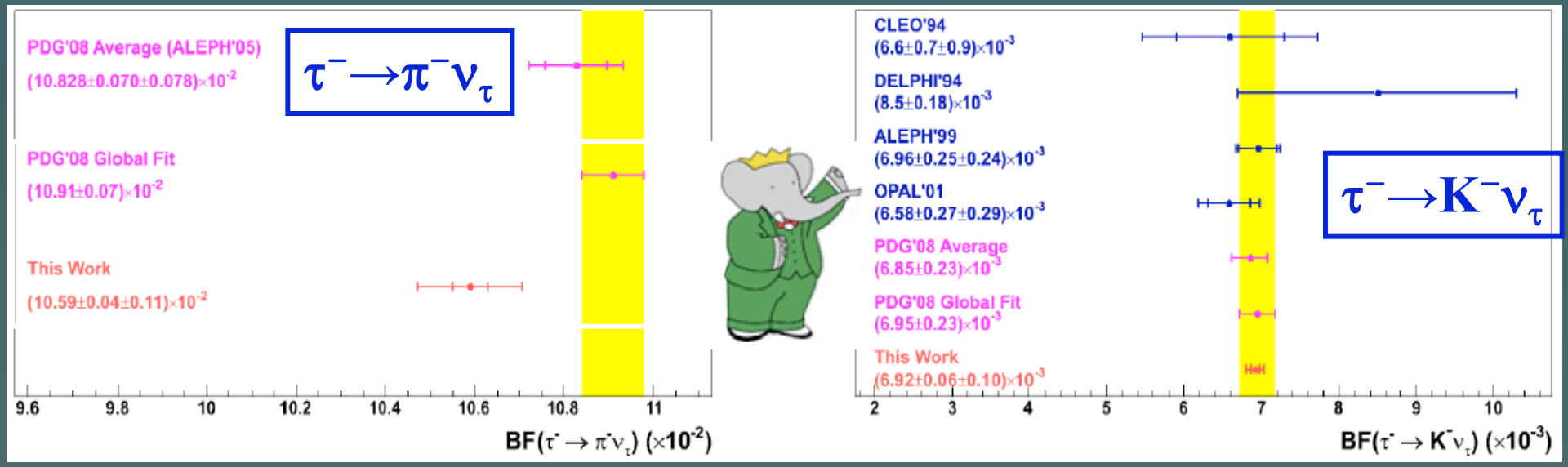
X_{us}^-	$\mathcal{B}_{\text{World Averages}}$ (%)	
K^- [τ decay]	0.690 ± 0.010	*BABAR* '08 prelim
([$K_{\mu 2}$])	(0.715 ± 0.004)	Gamiz et al. '07
$K^-\pi^0$	0.426 ± 0.016	*BABAR* '07
$\bar{K}^0\pi^-$	0.835 ± 0.022 $(S = 1.4)$	Belle '07, *BABAR* '08 prelim
$K^-\pi^0\pi^0$	0.058 ± 0.024	PDG
$\bar{K}^0\pi^0\pi^-$	0.360 ± 0.040	PDG
$K^-\pi^-\pi^+$	0.290 ± 0.018 $(S = 2.3)$	*BABAR* '08 Belle '08 prelim
$K^-\eta$	0.016 ± 0.001	Belle '09
$(\bar{K}3\pi)^-$ (est'd)	0.074 ± 0.030	Davier et al. '06, Banerjee '07
$K_1(1270) \to K^-\omega$	0.067 ± 0.021	Davier et al. '06, Banerjee '07
$(\bar{K}4\pi)^-$ (est'd)	0.011 ± 0.007	Davier et al. '06, Banerjee '07
$K^{*-}\eta$	0.014 ± 0.001	Belle '09
$K^-\phi$	0.0037 ± 0.0003 $(S = 1.3)$	Belle '06, *BABAR* '08
TOTAL	2.8447 ± 0.0688	
	(2.8697 ± 0.0680)	

- ~3σ differences with unitarity!

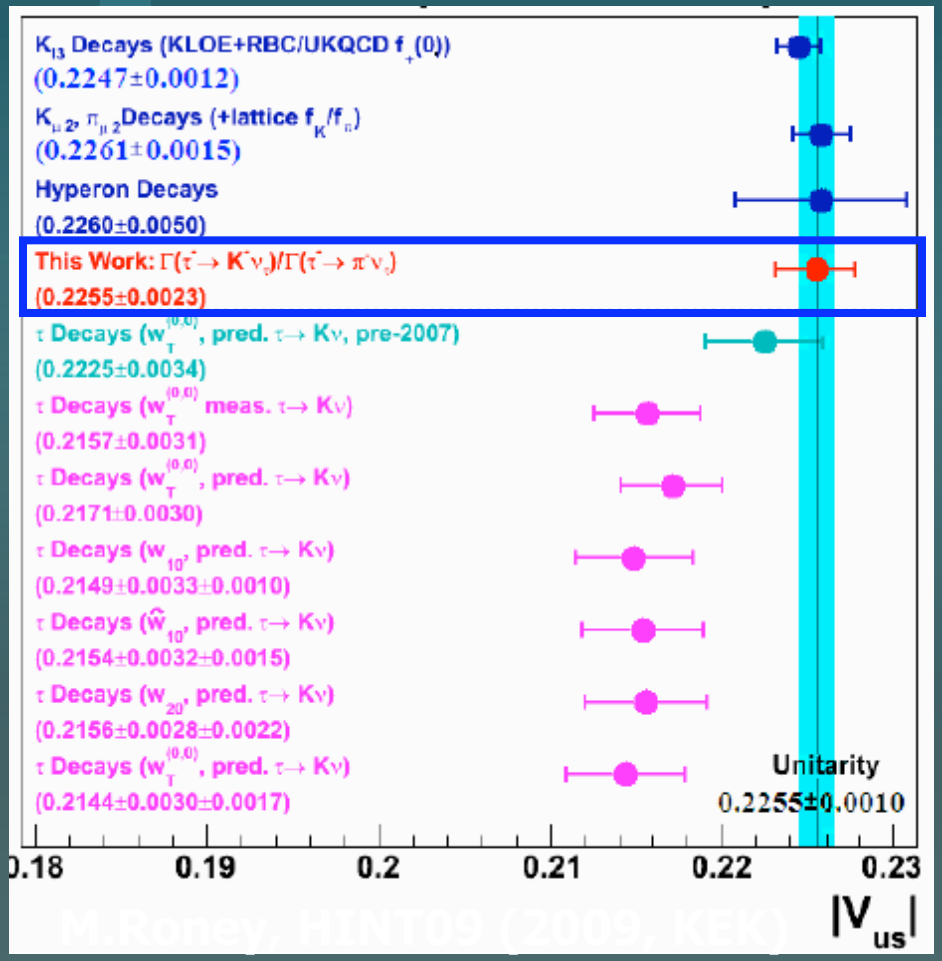
Another method: $\tau \to K/\pi\ \nu_\tau$



$$\frac{B(\tau \to K\nu)}{B(\tau \to \pi\nu)} = \frac{f_K^2}{f_\pi^2}\frac{|V_{us}|^2}{|V_{ud}|^2}\frac{(1-m_K^2/m_\tau^2)^2}{(1-m_\pi^2/m_\tau^2)^2}$$



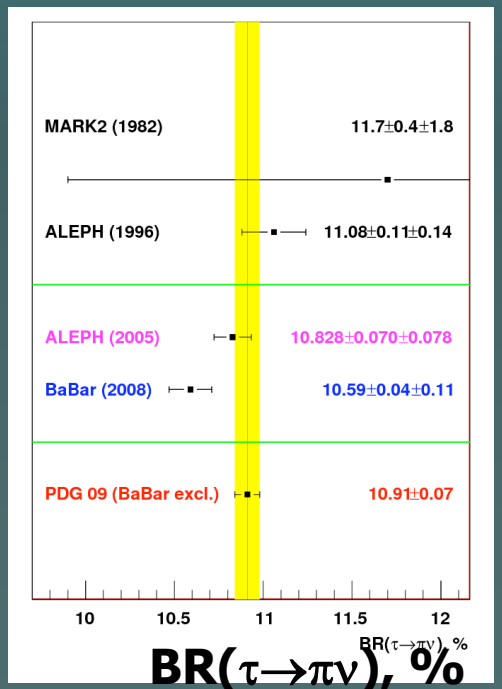
Result of V_{us} from $\tau \to K/\pi\ \nu_\tau$



M.Roney, HINT09 (2009, KEK)

$|V_{us}| = 0.2255 \pm 0.0023$

Consistent with unitarity.

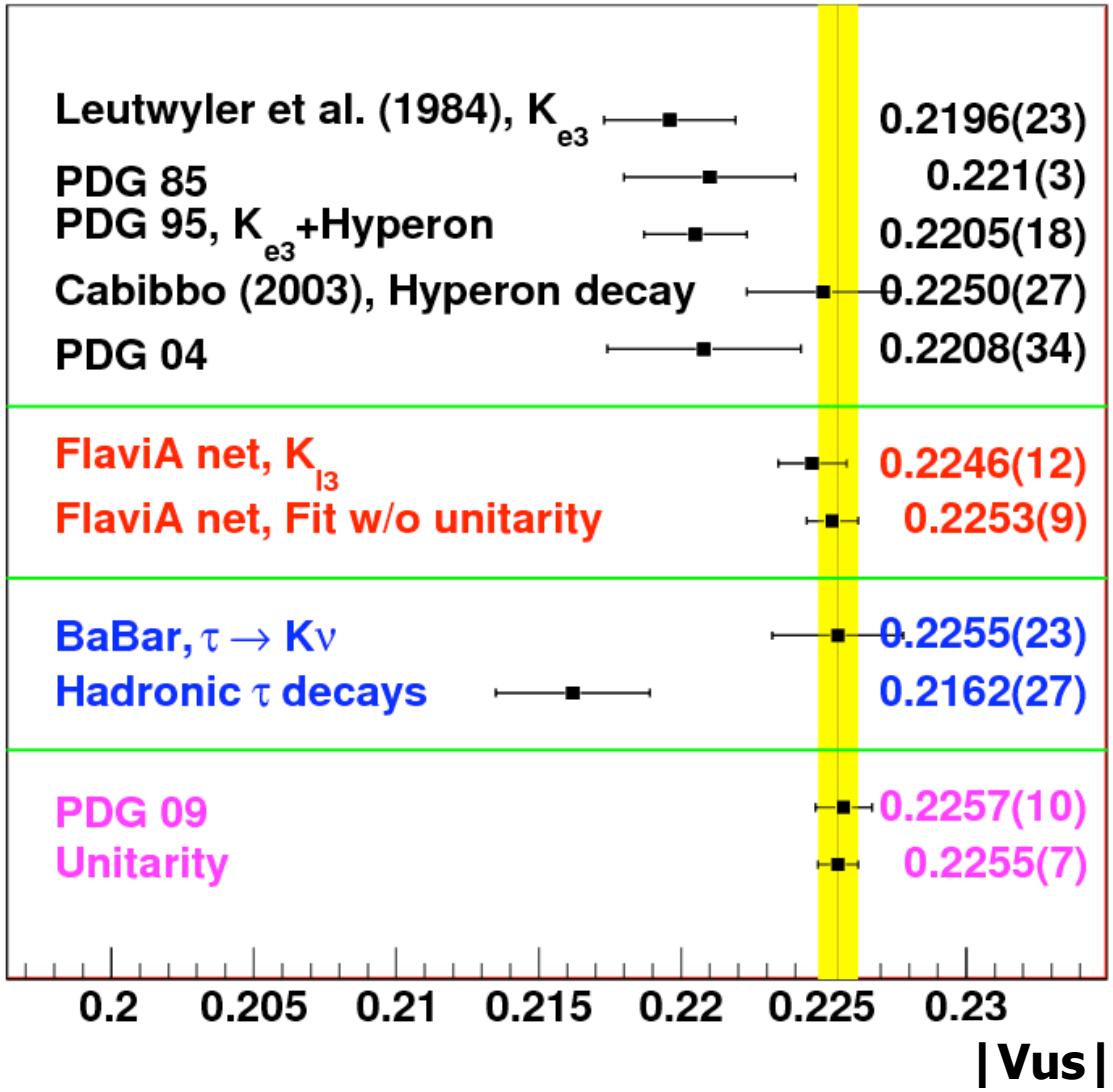


If BR($\tau \to \pi\nu$;PDG09) is used?

$|V_{us}| = 0.2217 \pm (<0.0023)$

(1.2σ from unitarity)

Summary on Vus



How can we improve this situation?

- We just used "00-th" moment to obtain Vus :

Mass spectrum : experimental input

$$R_\tau^{kl} \equiv \int_0^{M_\tau^2} ds \left(1-\frac{s}{M_\tau^2}\right)^k \left(\frac{s}{M_\tau^2}\right)^l \frac{dR_\tau}{ds} = R_{\tau,NS}^{kl} + R_{\tau,S}^{kl}$$

$$= 3 S_{EW}\{(|V_{ud}|^2 + |V_{us}|^2)(1+\delta^{kl(0)}) + \ldots\}$$

E.Gamiz, PRL94 (2005), OPAL, EPJC7 (1999)

Corrections calculated from (various) perturbation theories which depends on m_s : theoretical input

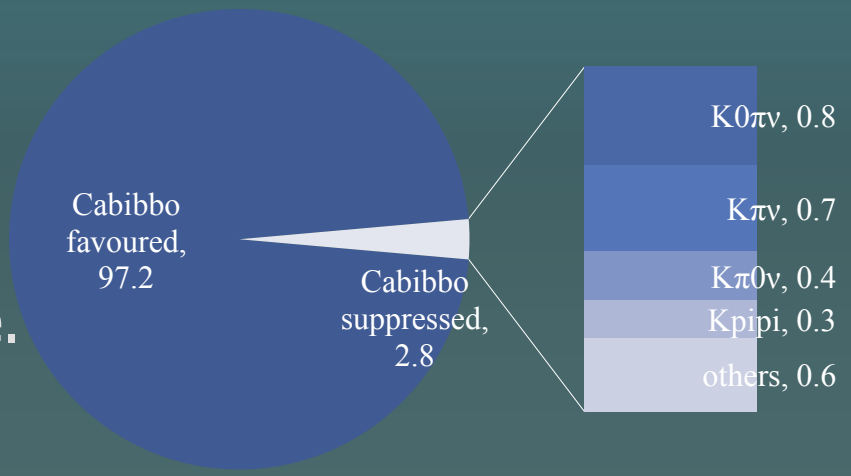
Simultaneous fitting on ms and Vus is the ultimate approach to measure Vus from tau decays

: but we have to know **all the mass spectra**

Strange decay of τ

- Therefore, we have to measure all the BR of strange decay of tau (BR <~1%)
- Plus, we have to measure all the mass spectra of hadronic tau decays.

- These are only possible at B-factories:
  - Large data sample : Statistics is enough.
  - Good π/K separation is possible.
  - Clean environment to measure V_{us} : Uncertainties are dominated by experimental error.



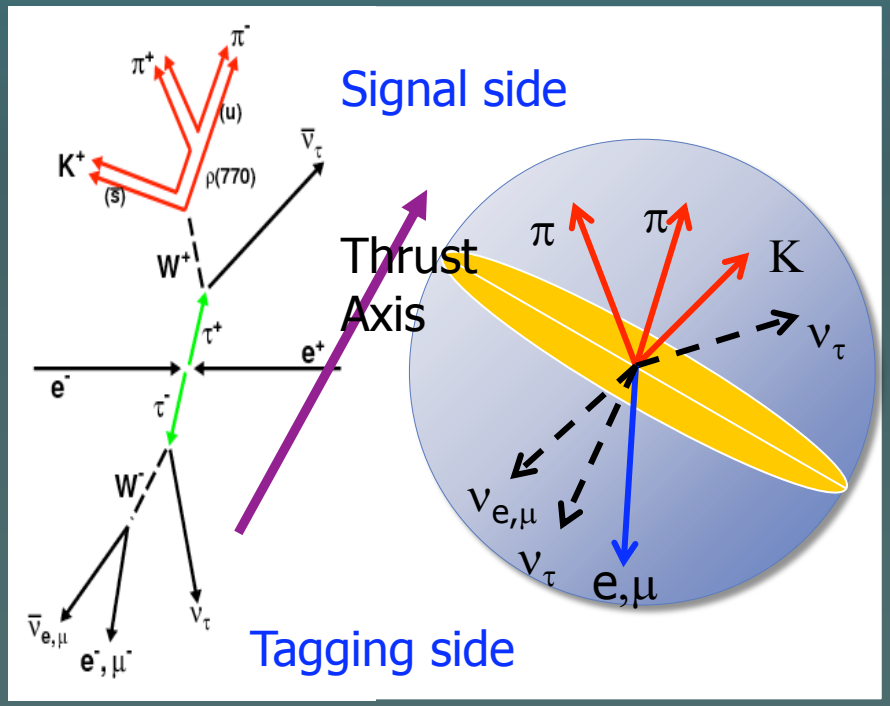
Hadronic decay studies of τ Lepton in Belle

Basic Analysis Techniques

Features of τ pair decays : **Low mult., Large P_T, missing E_{tot} and P_{tot}**

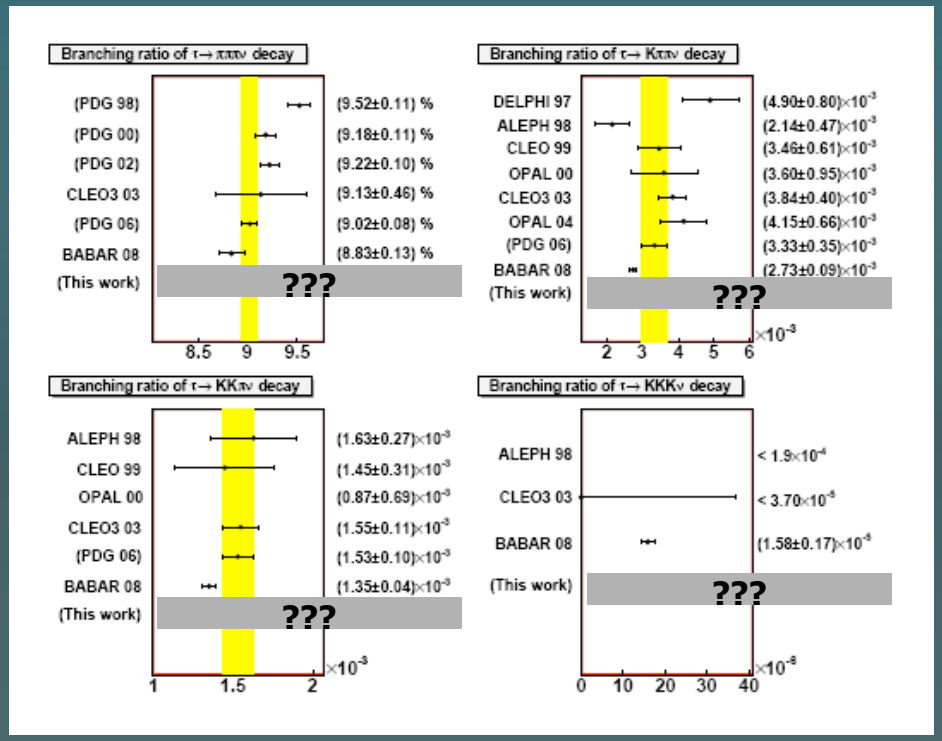
Main backgrounds	Discrimination
Bhabha, dimuon ($e^+e^- \rightarrow e^+e^-$, $\mu^+\mu^-$)	Reconstructed total energy, momentum, multiplicity
Continuum ($e^+e^- \rightarrow qq$, q=udscb)	Event topology, thrust, invariant mass, multiplicity
Two-photon	Small transverse momentum, M_{miss}, P_{miss} recon.
Beam background	Quality of decay vertex
Other tau decays	Efficient reconstruction of signal mode

- Typically, require pure leptonic decay in the tagging side.
- In many cases, π/K separation is very important.
- Estimate the tau decay background from the MC, or the sideband of resonances



Example : Three-prong decays $\tau^- \to h^- h^+ h^- \nu_\tau$

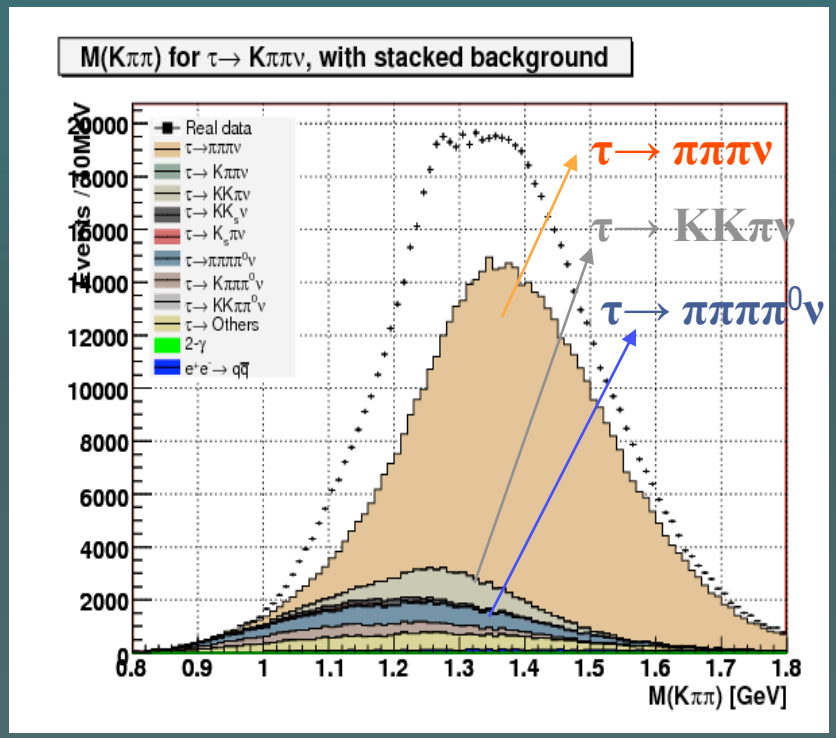
- $\tau \to \pi\pi\pi\nu_\tau$ ($a_1 \to \rho\pi$), $\tau \to K\pi\pi\nu_\tau$ ($K_1 \to K^*\pi$, $K_1 \to K\rho$), $\tau \to KK\pi\nu_\tau$, $\tau \to KKK\nu_\tau$ (no neutral particles)



- The works from BABAR showed scatter with previous measurements.
- No mass spectra had been measured.

$\tau^- \to h^- h^+ h^- \nu_\tau$

- Main BG come from cross-feeding between 4 decay modes : strong correlation



These are one of the signal modes, due to the fake of pion or kaon

The BG can not be estimated from MC, since we cannot trust its shape.

Strategy is :

1. Measure unfolded mass spectra
2. Tune the efficiencies (and fake rates)
3. Obtain BR with new eff.

Unfolding

- We want to know the "real" spectra apart from any detector effect.
- The backgrounds due to mis-particle ID are also "detector effects" (non linear effect)
- We can remove all the detector effect by "unfolding" mass spectra – an "inverse problem"

A : response matrix
(describing detector effect)

b : distribution before unfolding

$$\hat{A}x = b$$

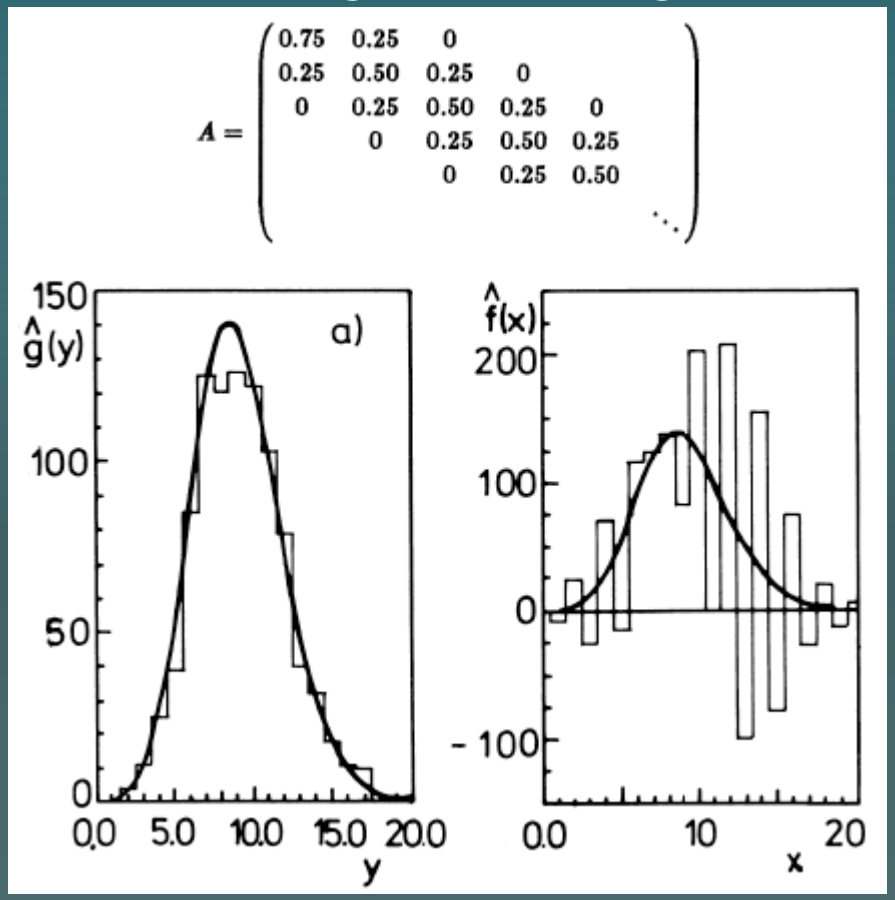
x : real (unfolded) distribution
(cross-feed background subtracted)

The problem is that $x = A^{-1}b$ will never work…

What happens if we do not unfold properly?

$$Ax = g \quad \Rightarrow \quad x = A^{-1}g$$

$$A = \begin{pmatrix} 0.75 & 0.25 & 0 & & & \\ 0.25 & 0.50 & 0.25 & 0 & & \\ 0 & 0.25 & 0.50 & 0.25 & 0 & \\ & 0 & 0.25 & 0.50 & 0.25 & \\ & & 0 & 0.25 & 0.50 & \\ & & & & & \ddots \end{pmatrix}$$



Example by B.Blobel (DESY-84-118)

Small fluctuation in the input distribution is amplified which lead to an unstable solution.

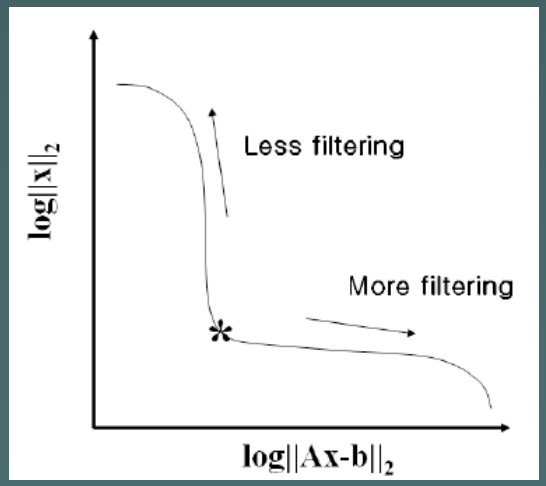
Regularization

- The problem of solving Ax=b should be modified like :

$$min\{||Ax-b||_2^2+\lambda^2||Lx||_2^2\}$$

(A.Hoecker and V.Karvelishvili, NIMA 372 (1996))

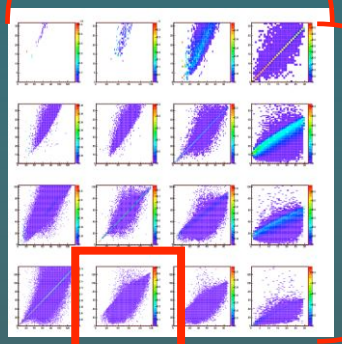
  - Very popular method in HEP ("GURU" package)
  - λ : regularization parameter
  - L : a-priori information on the curvature of the solution
  - This method also involves the inversion of any matrix, and Singular value decomposition (SVD) is used.



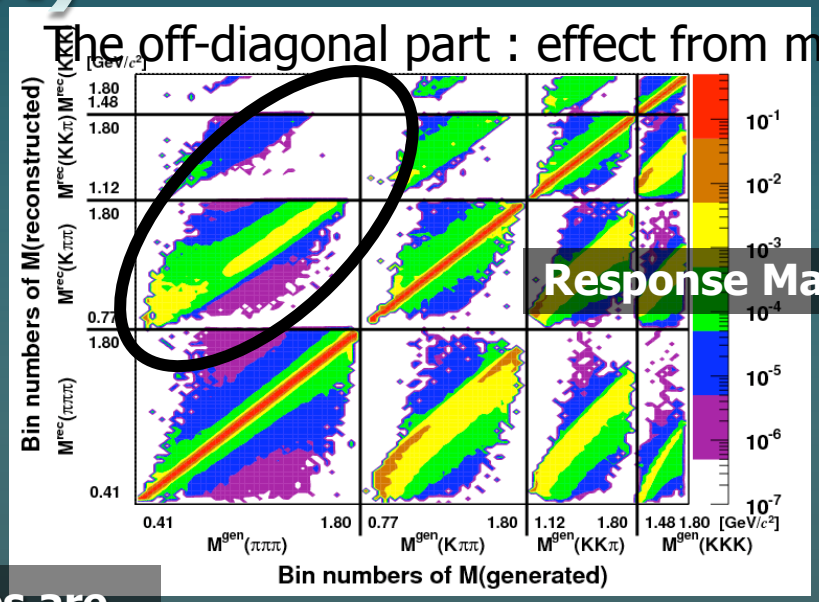
Mass spectrum before unfolding (b) / Response matrix (A)

Generated decay mode / mass bin

Reconstructed decay mode / mass bin



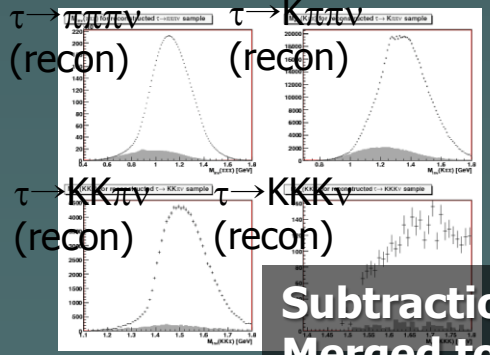
The off-diagonal part : effect from mis-PID



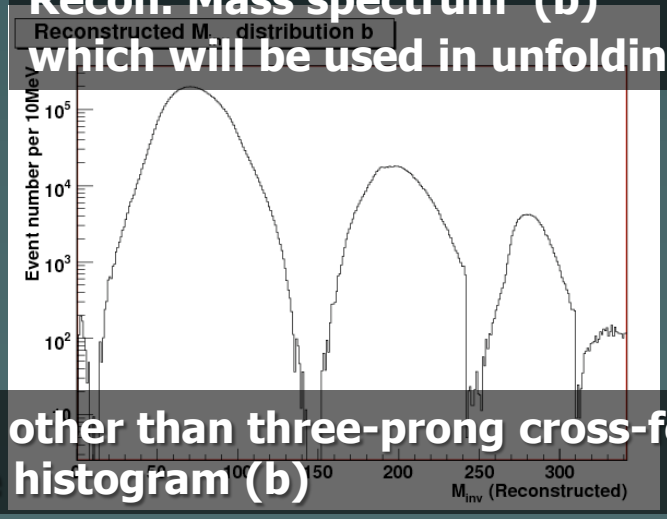
Response Matrix (A)

16 sub-respose matrices are merged to a matrix (A)

Ex) Response matrix (probability) that real τ→Kππν events are reconstructed as τ→πππν mode



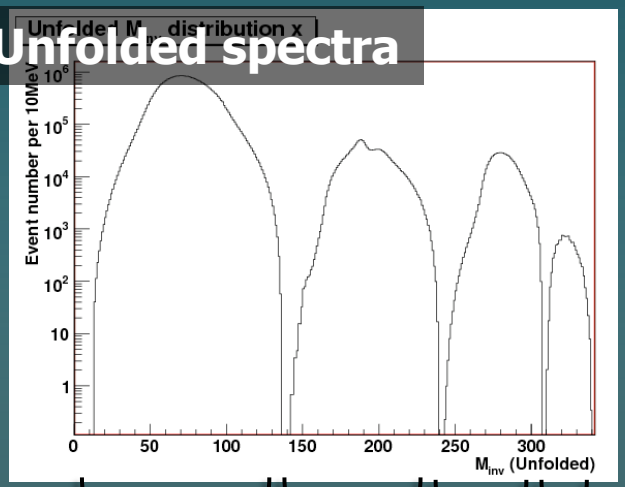
Recon. Mass spectrum (b) which will be used in unfolding



Subtraction of BG other than three-prong cross-feeds
Merged to a single histogram (b)

Result of Unfolding (x)

Unfolded spectra



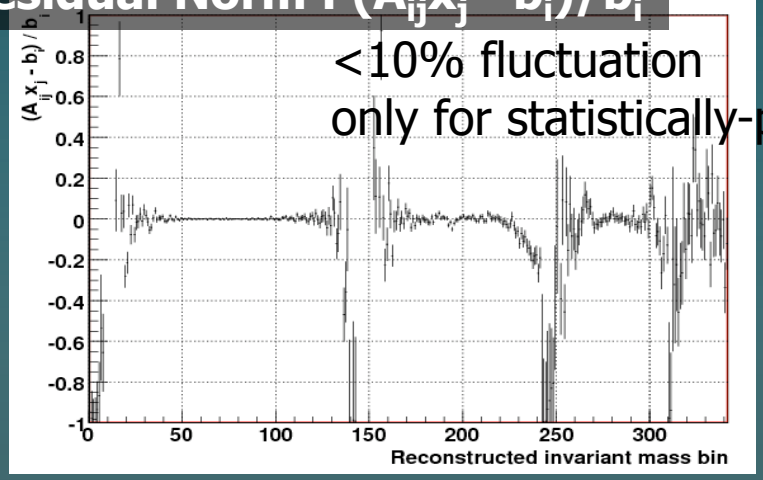
0.41~1.8
M(πππ) [GeV]

0.77~1.8
M(Kππ) [GeV]

1.12 ~ 1.8
M(KKπ) [GeV]

1.48~1.8
M(KKK) [GeV]

Residual Norm : $(A_{ij}x_j - b_i)/b_i$

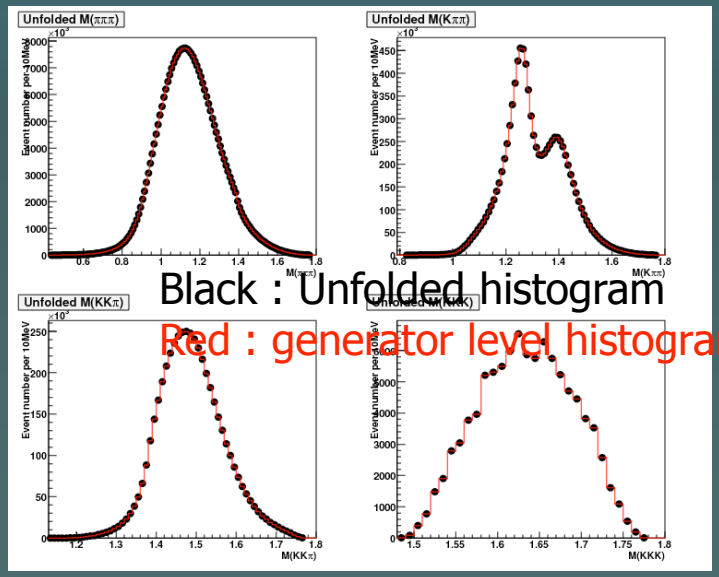


<10% fluctuation
only for statistically-poor bins

Check on unfolding algorithm :

Use independent signal MC sample, unfold and compare with generator level mass spectra

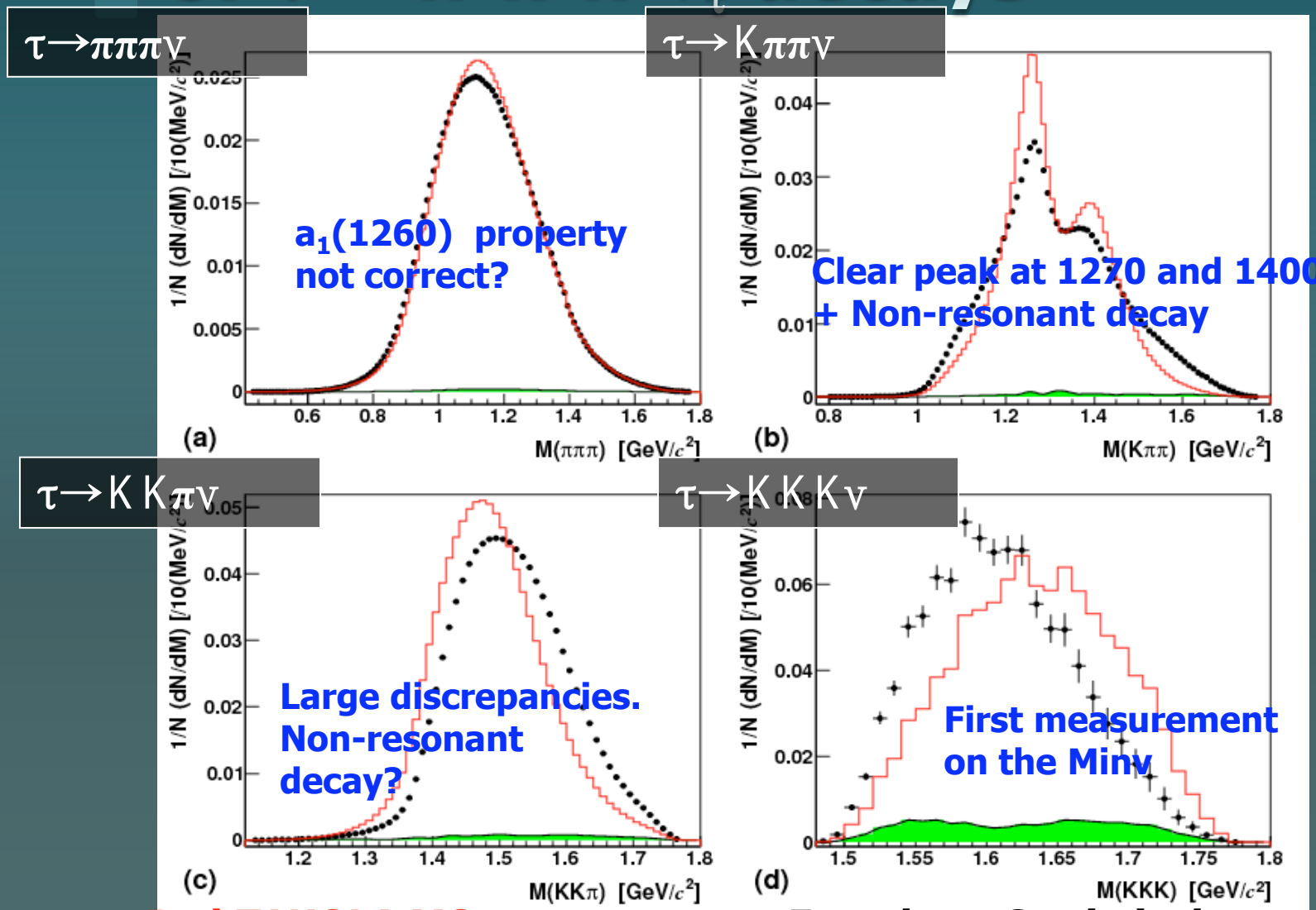
Less than 0.5% diff. for all mass range



Black : Unfolded histogram

Red : generator level histogram

Unfolded mass spectrum of $\tau^- \to h^- h^+ h^- \nu_\tau$ decays



Red:TAUOLA MC

Black:unfolded mass spectrum

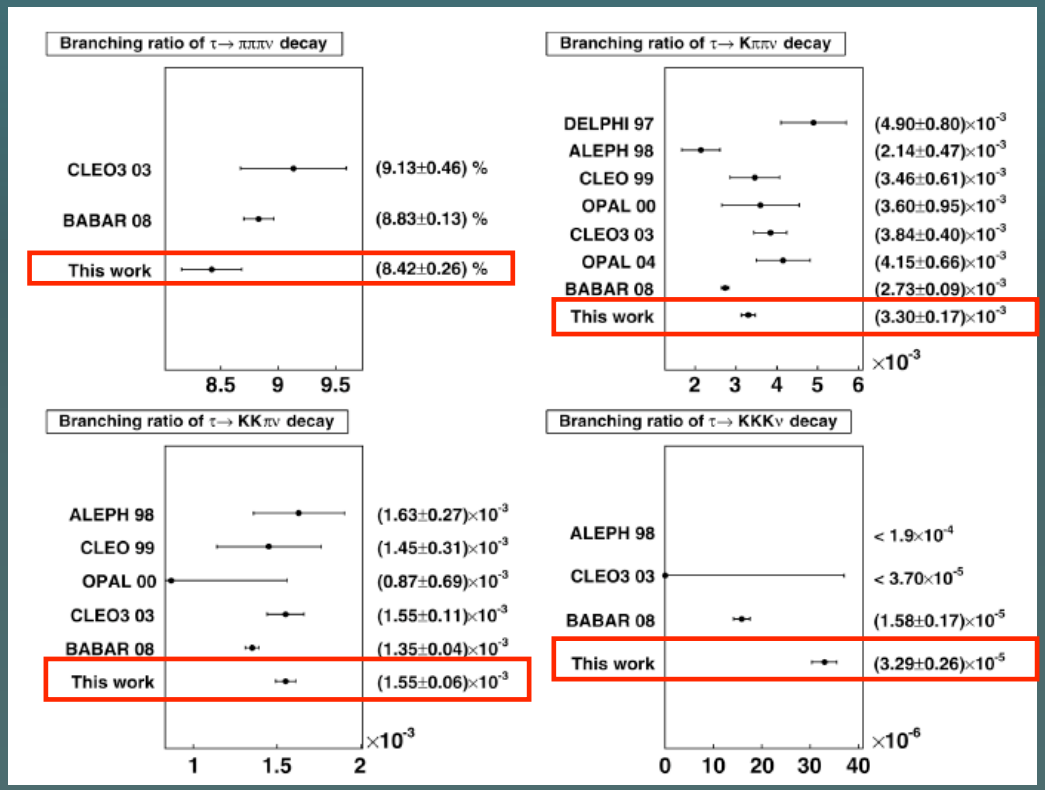
Error bar : Statistical error

Green band : Systematic error

BR measurement

- Knowing the unfolded mass spectrum, we rescale the efficiency and fake rate, and obtain :

$$N_i^{\text{true}} = \sum_j (\mathcal{E}^{-1})_{ij} (N_j^{\text{rec}} - N_j^{\text{other}})$$

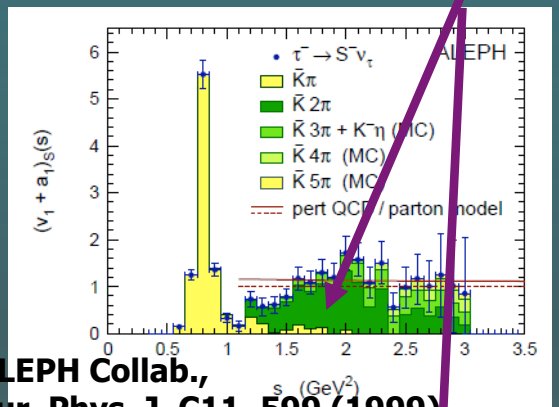


(PRD81,113007)

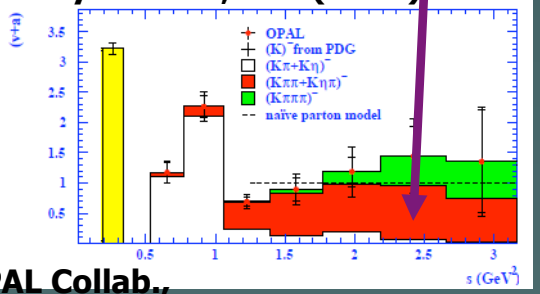
Results : Contributions to spectral function

$$v_1^S(s)/a_1^S(s) = \frac{m_\tau^2}{6|V_{us}|^2 S_{ew}} \left(1 - \frac{s}{m_\tau^2}\right)^{-2} \left(1 + \frac{2s}{m_\tau^2}\right)^{-1} \frac{B(\tau \to (V/A)^{(S=-1,J=1)}\nu_\tau)}{B(\tau \to e^-\bar{\nu}_e\nu_\tau)} \frac{1}{N_{V/A}} \frac{dN_{V/A}}{ds}$$

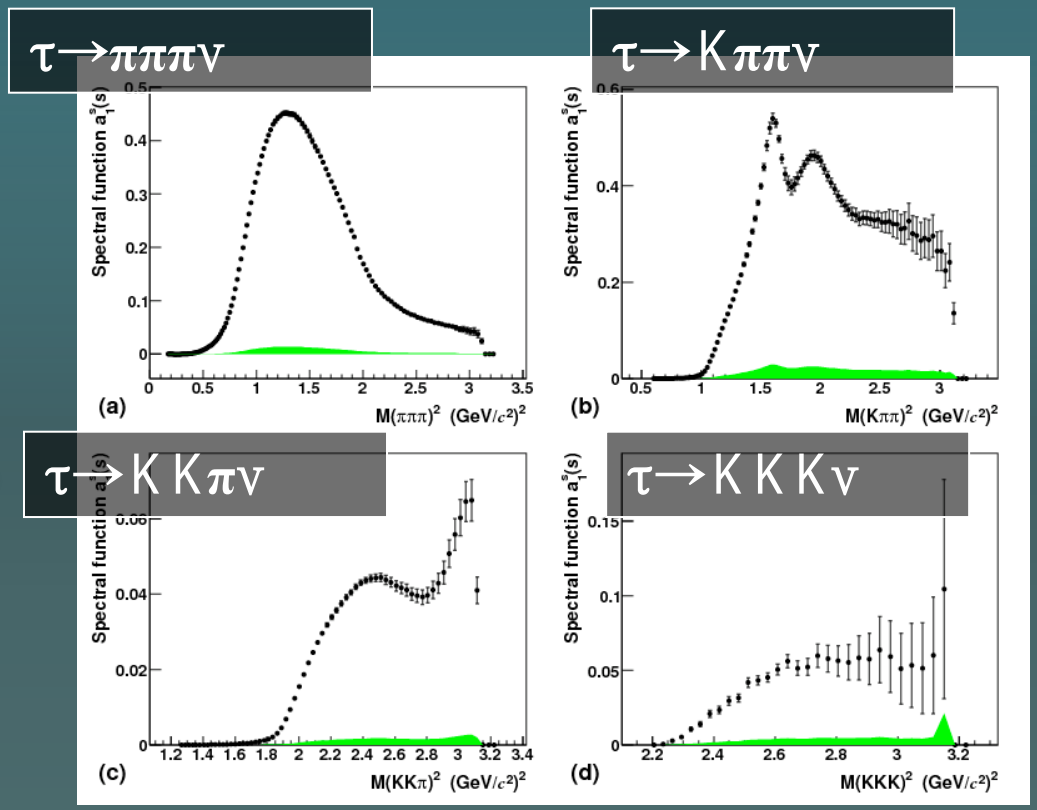
Large contribution from $\tau \to K\pi\pi\nu$



ALEPH Collab., Eur. Phys. J. C11, 599 (1999).



OPAL Collab., Eur. Phys. J. C35, 437 (2004).



The spectral function can be improved significantly.

Way to go

mode	Br	Spectral func.
K		-
Kπ		(no. e-matrix)
Kππ		
Kπππ+Kη	(Kη)	
K4π		
KKK		

- Once the spectral function is measured, Vus and other quantities can be estimated, but before that :
- Missing parts should be studied.
- This is the responsibility of B-factories

Summary

- Belle was a successful experiment in the study of CPV of B meson decay
- Also it was a tau-factory. Many tau decay mode has been studied in Belle.
- Tau lepton decay is mainly SM-concern, rather than NP.
- However, in understanding SM, tau lepton provides good environments.
- Studying tau lepton is also important in SuperB projects, which will enhance our understanding of SM.