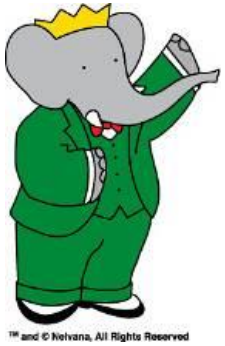


Tau results from B factories

Beauty 2014

Edinburgh

July 17, 2014

Georges Vasseur

CEA, IRFU, SPP, Saclay

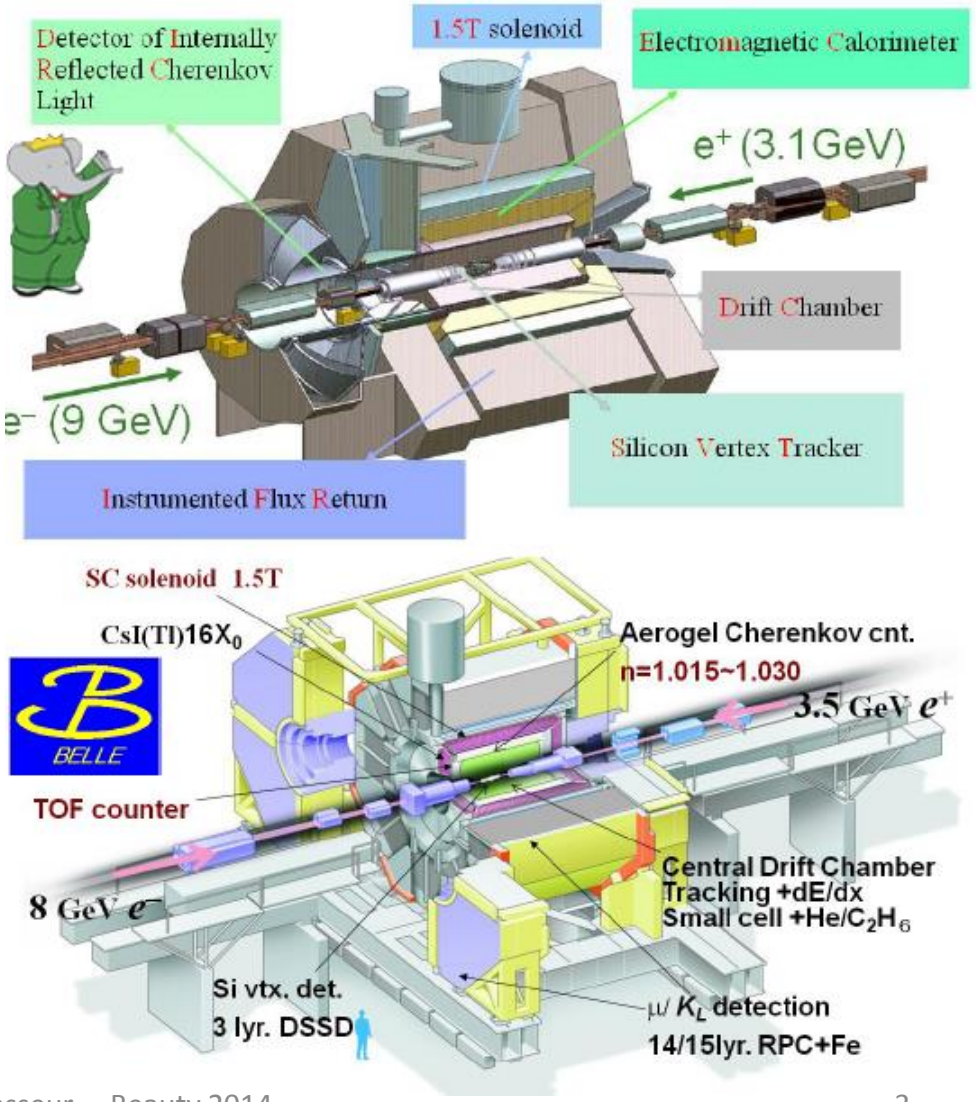
On behalf of the BABAR and BELLE collaborations

Outline

- τ physics at B factories
- τ lifetime
- $|V_{us}|$ measurement
- Branching fraction measurements
- Lepton Flavour Violation

Detectors

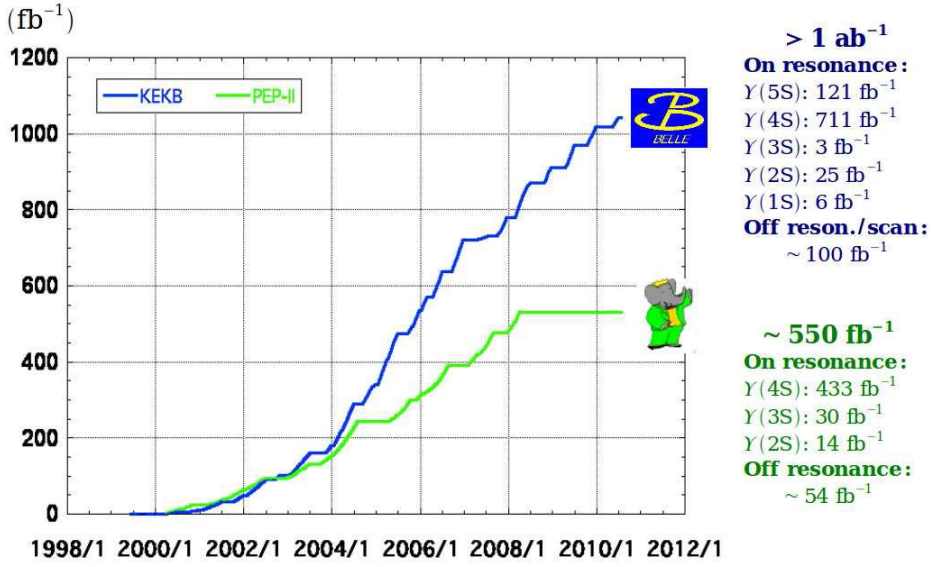
- Asymmetric detectors :
  - e, μ identification
  - K/π separation
  - γ detection
  - π^0, η reconstruction
  - K_s^0 vertexing
  - well defined CM energy



Luminosities

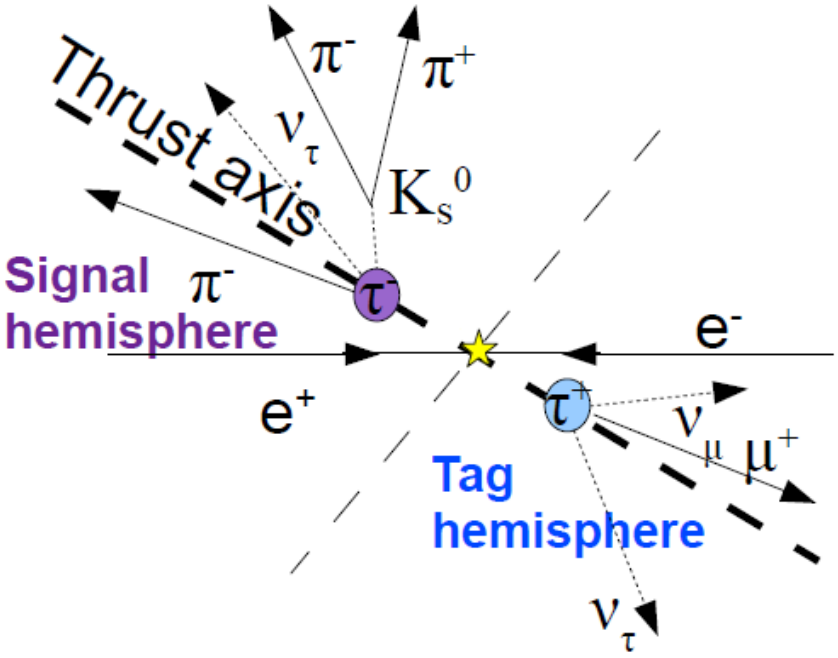
- High statistics of $\tau^+ \tau^-$ pairs produced at B factories:
  - ~ 500 M at BABAR,
  - ~ 900 M at BELLE.

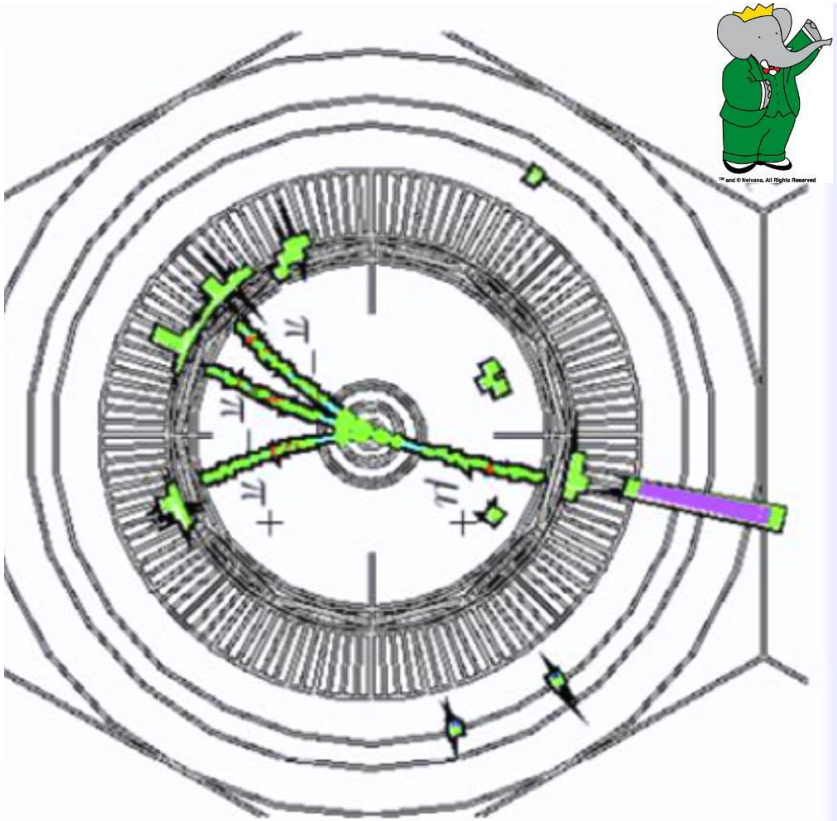
Integrated luminosity of B factories



Decay Mode	Cross-Section (nb)
$\Upsilon(4s) \rightarrow B\bar{B}$	1.1
τ Pair	0.919±0.003
qq q=u,d,s,c	3.4
μ Pair	1.147±0.005
Two-Photon (Barrel)	2.4
Bhabha (Barrel)	25.52

τ pair events



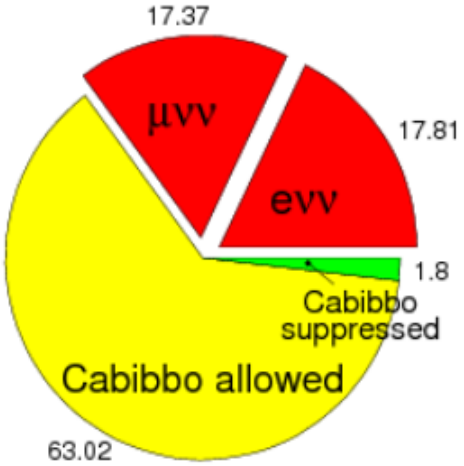


- Jet-like τ pair in CM:
  - τ^+ and τ^- decay products well separated.
  - tag one hemisphere to get a clean τ sample in opposite (signal) hemisphere.
- Use kinematic and event shape to reduce backgrounds.

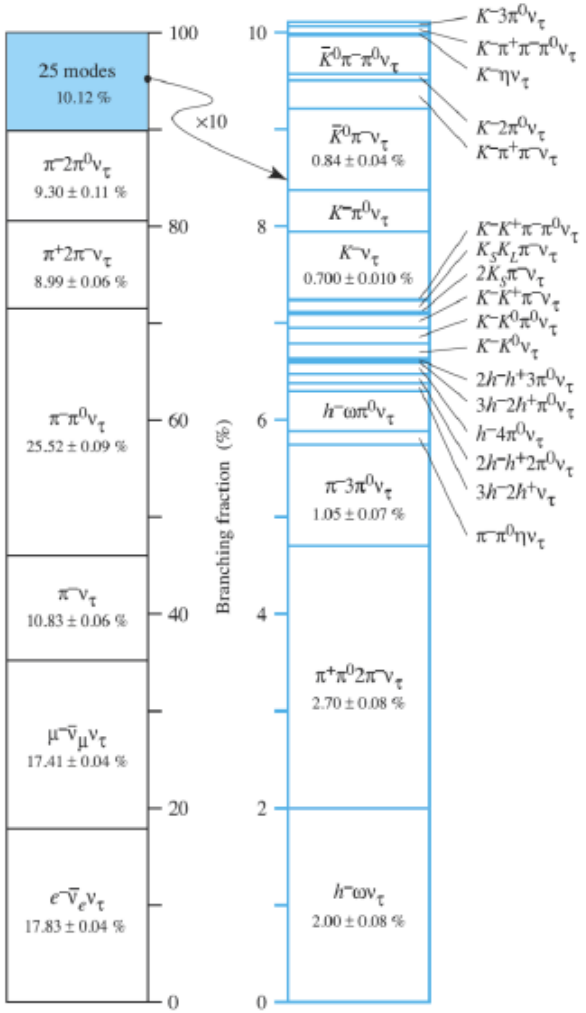
τ decay modes

- Many τ decay modes:

Topology

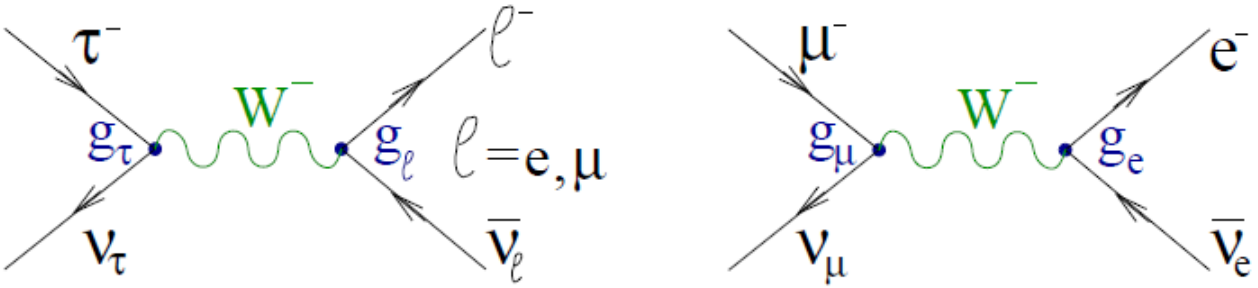


Leptonic/
Hadronic



A. Pich Tau'12

Charged lepton universality



$$\Gamma(L^- \to \ell^- \bar{\nu}_\ell \nu_L(\gamma)) = \frac{\mathcal{B}(L^- \to \ell^- \bar{\nu}_\ell \nu_L(\gamma))}{\tau_L} = \frac{g_L^2 g_\ell^2}{32 M_W^4} \frac{m_L^5}{192\pi^3} F_{\rm corr}(m_L, m_\ell)$$

$$F_{\rm corr}(m_L, m_\ell) = f(x)\left(1 + \frac{3}{5}\frac{m_L^2}{M_W^2}\right)\left(1 + \frac{\alpha(m_L)}{2\pi}\left(\frac{25}{4} - \pi^2\right)\right)$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \ln x, \; x = m_\ell / m_L$$

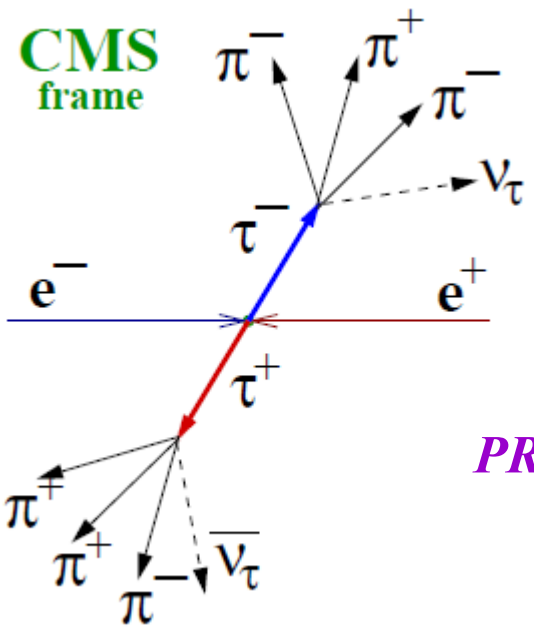
$$\mathcal{B}(\mu^- \to e^- \bar{\nu}_e \nu_\mu(\gamma)) = 1$$

$$\frac{g_\tau}{g_e} = \sqrt{\mathcal{B}(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau(\gamma)) \frac{\tau_\mu}{\tau_\tau} \frac{m_\mu^5}{m_\tau^5} \frac{F_{\rm corr}(m_\mu, m_e)}{F_{\rm corr}(m_\tau, m_\mu)}}, \quad \frac{g_\tau}{g_e} = 1.0024 \pm 0.0021 \text{ (HFAG2012)}$$

$$\frac{g_\tau}{g_\mu} = \sqrt{\mathcal{B}(\tau^- \to e^- \bar{\nu}_\mu \nu_\tau(\gamma)) \frac{\tau_\mu}{\tau_\tau} \frac{m_\mu^5}{m_\tau^5} \frac{F_{\rm corr}(m_\mu, m_e)}{F_{\rm corr}(m_\tau, m_e)}}, \quad \frac{g_\tau}{g_\mu} = 1.0006 \pm 0.0021 \text{ (HFAG2012)}$$

τ lifetime

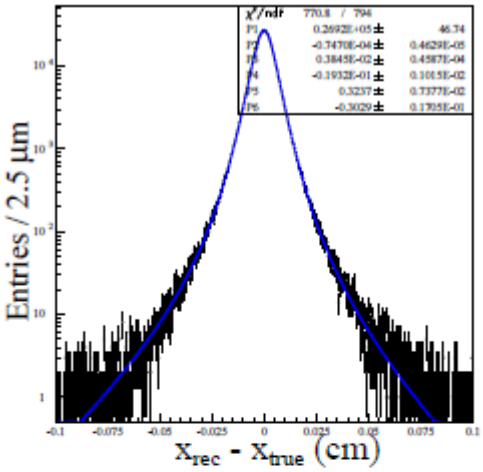
- Analysis based on 711 fb^{-1}. 650 M ττ
- $e^+ e^- \rightarrow \tau^+ \tau^- \rightarrow (\pi^+ \pi^+ \pi^- \nu_\tau , \pi^+ \pi^- \pi^- \nu_\tau)$
  - Good vertex reconstruction.
- Fit of decay length.

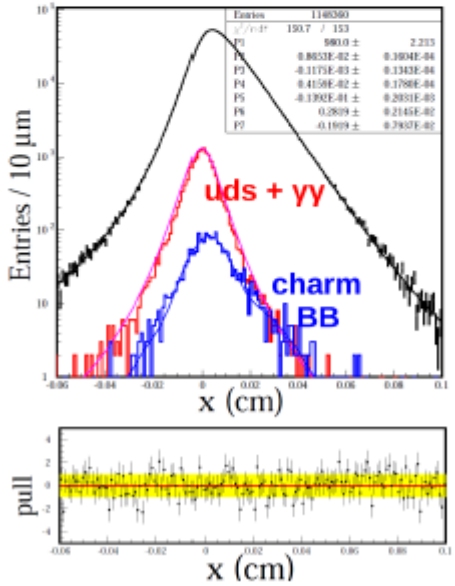


BELLE

$$x = \frac{\ell}{\beta_\tau \gamma_\tau}$$

PRL 112, 031801 (2014)





τ lifetime result

- Main systematic: silicon vertex detector alignment.
- Test CPT conservation.
- Input to test of lepton universality.

$c\tau_\tau = (86.99 \pm 0.16(\text{stat}) \pm 0.10(\text{syst}))\ \mu\text{m}.$

$\tau_\tau = (290.17 \pm 0.53(\text{stat}) \pm 0.33(\text{syst}))$ fs.

$|\tau_{\tau^+} - \tau_{\tau^-}|/\tau_{\text{average}} < 7.0 \times 10^{-3}$ at 90% CL.

PRL 112, 031801 (2014)

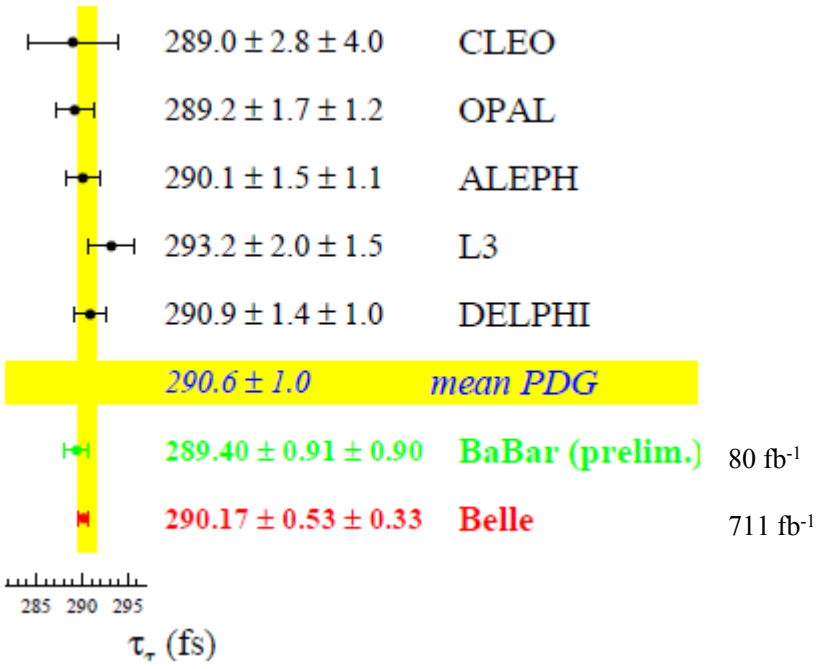
Lepton universality

$g_\tau/g_e = 1.0024 \pm 0.0021$ (HFAG2012)

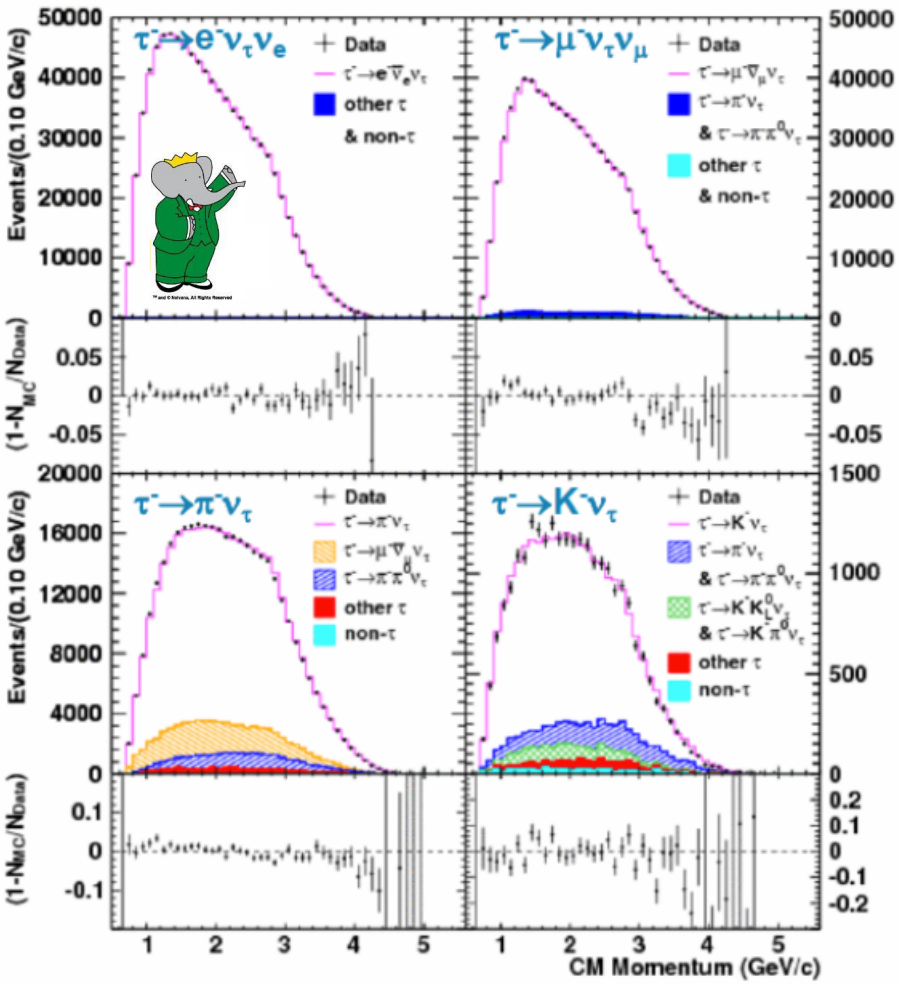
$\mathbf{g_\tau/g_e = 1.0031 \pm 0.0016}$ (new Belle τ_τ)

$g_\tau/g_\mu = 1.0006 \pm 0.0021$ (HFAG2012)

$\mathbf{g_\tau/g_\mu = 1.0013 \pm 0.0016}$ (new Belle τ_τ)



One prong decays



Measurements of ratios to decay to electron (cancels many systematic errors)

$$R_X = \frac{B(\tau^- \to X^- \upsilon_\tau)}{B(\tau^- \to e^- \overline{\upsilon}_e \upsilon_\tau)}$$

$R_\mu = 0.9796 \pm 0.0016 \pm 0.0036$
$R_\pi = 0.5945 \pm 0.0014 \pm 0.0061$
$R_K = 0.03882 \pm 0.00032 \pm 0.00057$

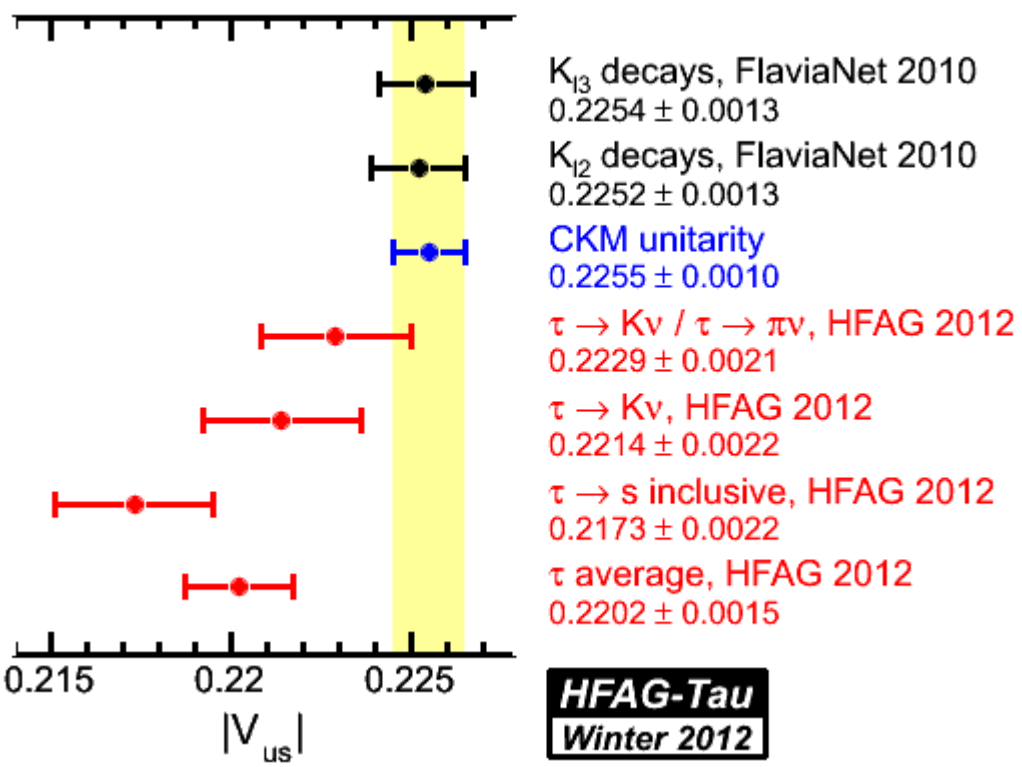
R_K/R_π can be used to determine $|V_{us}|$

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

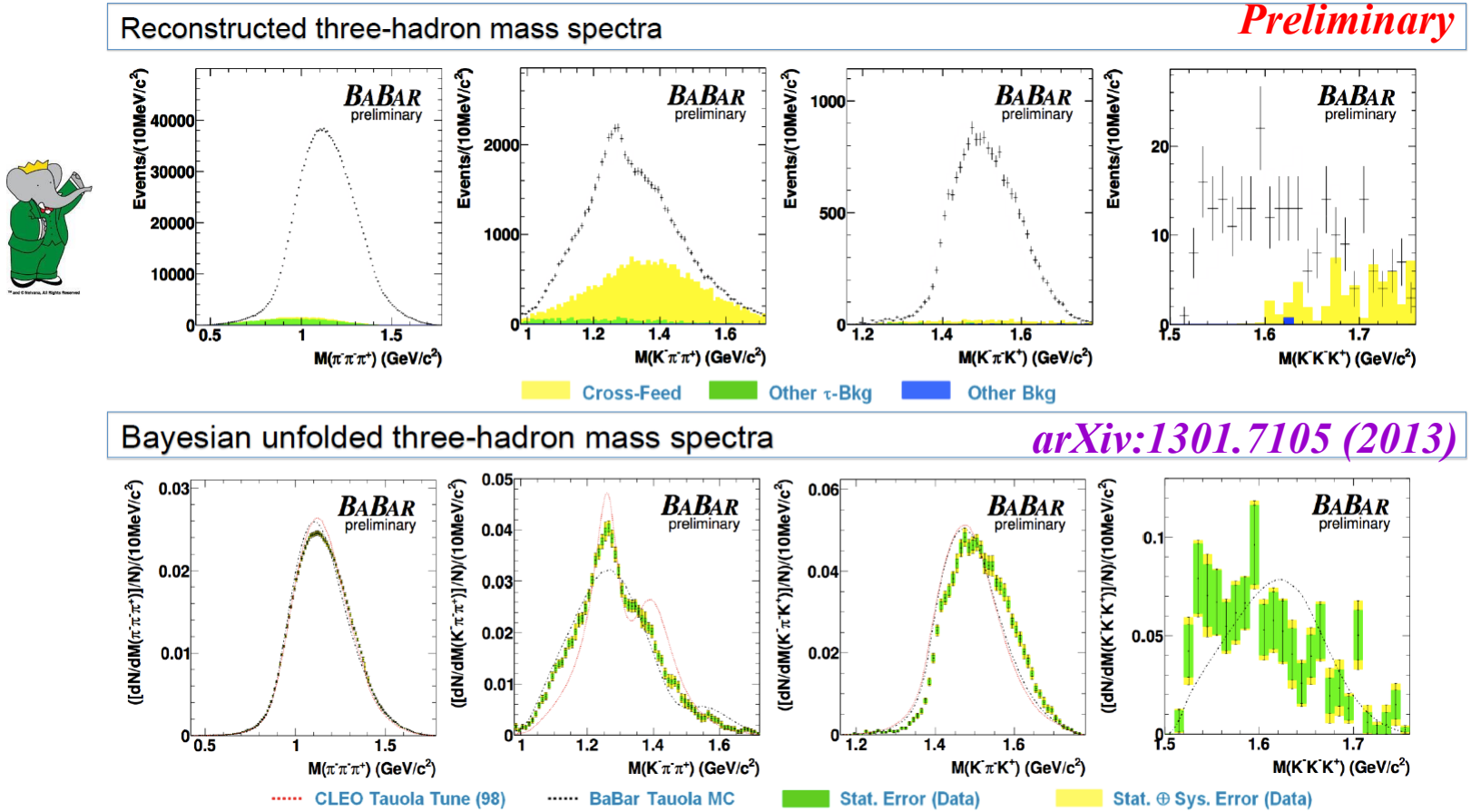
Phys Rev Lett 105, 051602 (2010)

$|V_{us}|$

- Some tension between CKM unitarity and τ average.
- More results from all strange final states needed.



Hadronic spectra in $\tau^- \to h^- h^- h^+ \nu_\tau$



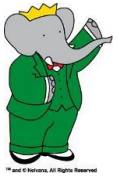
- Important measurements to tune the Monte Carlo.

High multiplicity τ decays

- Study 23 decay modes.

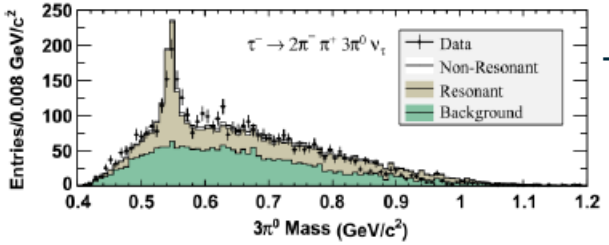
468 fb^{-1} *PRD 86, 092010 (2012)*

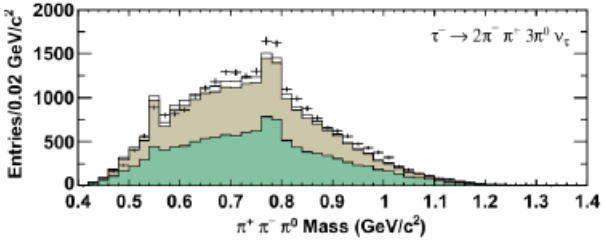
High multiplicity τ decays

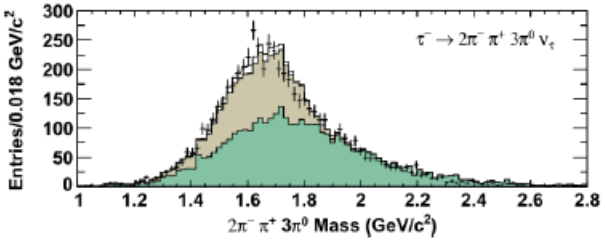


Nonresonnant:

$\tau^- \to 2\pi^-\pi^+3\pi^0\nu_\tau$







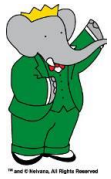
Summary of the results:

Decay mode	Branching ratio (10^{-5})
Resonnant	
$2\pi^-\pi^+\eta\nu_\tau$	$22.5 \pm 0.7 \pm 1.2$
$\pi^-2\pi^0\eta\nu_\tau$	$20.1 \pm 3.4 \pm 2.2$
$\pi^- f_1\eta\nu_\tau$	
$\hookrightarrow 2\pi^+2\pi^-$	$5.2 \pm 0.31 \pm 0.37$
$\pi^- f_1\eta\nu_\tau$	
$\hookrightarrow \pi^+\pi^-\eta$	$12.6 \pm 0.6 \pm 0.6$
$2\pi^-\pi^+\omega\nu_\tau$	$8.4 \pm 0.4 \pm 0.6$
$\pi^-2\pi^0\omega\nu_\tau$	$7.3 \pm 1.2 \pm 1.2$
Nonesonnant	
$3\pi^-2\pi^+\nu_\tau$	$76.8 \pm 0.4 \pm 4.0$
$2\pi^-\pi^+3\pi^0\nu_\tau$	$1.0 \pm 0.8 \pm 3.0$
$3\pi^-2\pi^+\pi^0\nu_\tau$	$3.6 \pm 0.3 \pm 0.9$
Inclusive (incl. η, ω, f_1)	
$2\pi^-\pi^+3\pi^0\nu_\tau$	$20.7 \pm 1.8 \pm 3.7$
$3\pi^-2\pi^+\nu_\tau$	$83.3 \pm 0.4 \pm 4.3$
$3\pi^-2\pi^+\pi^0\nu_\tau$	$16.5 \pm 0.5 \pm 0.9$

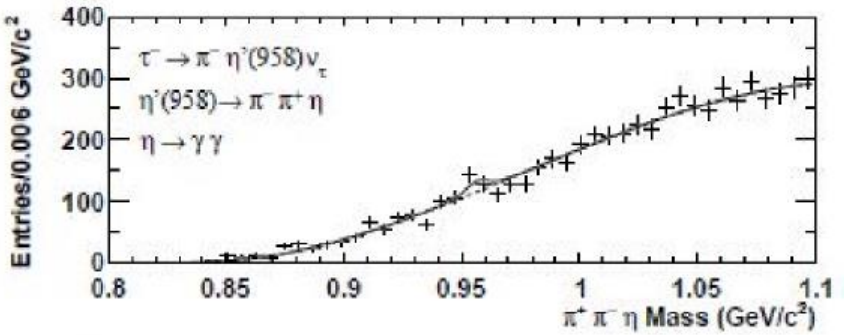
PRD 86, 092010 (2012)

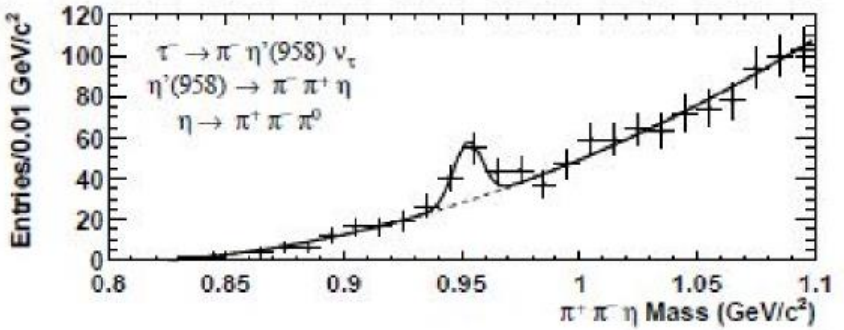
Second class current: $\tau^- \to \pi^- \eta' \nu_\tau$

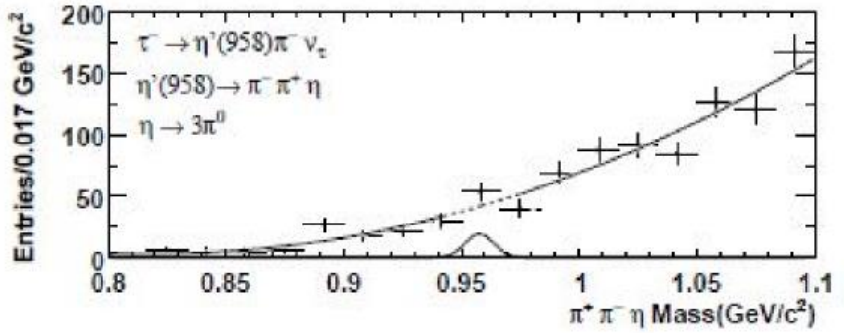
- Hadronic currents:
  - FCC: $J^{PG}=0^{++},0^{--},1^{+-},1^{-+}$
  - SCC: $J^{PG}=0^{+-},0^{-+},1^{++},1^{--}$
- Second class currents:
  - vanish in perfect isospin symmetry ($m_u=m_d$).
  - No evidence found so far.
- Search for SSC $\tau^- \to \pi^- \eta' \nu_\tau$.
  - Peak fully accounted by qq background.
- BR ($\tau^- \to \pi^- \eta' \nu_\tau$) < 4 x 10^{-6} at 90% CL.



PRD 86, 092010 (2012)

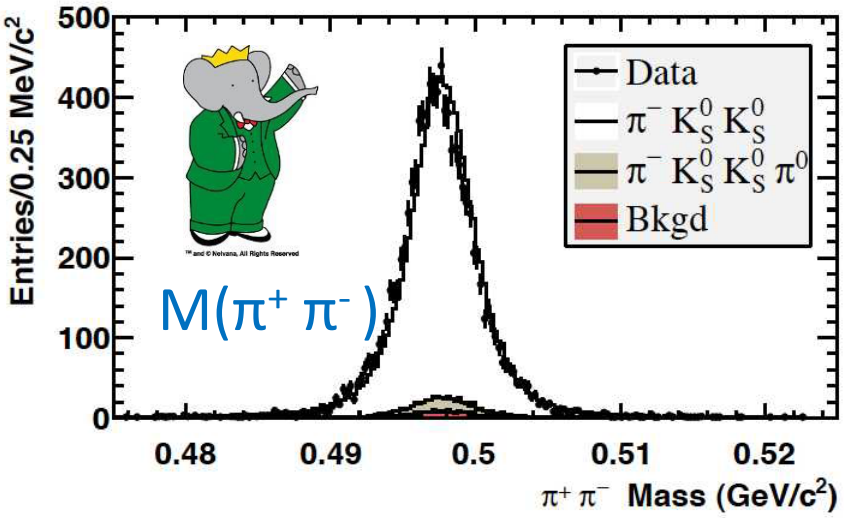


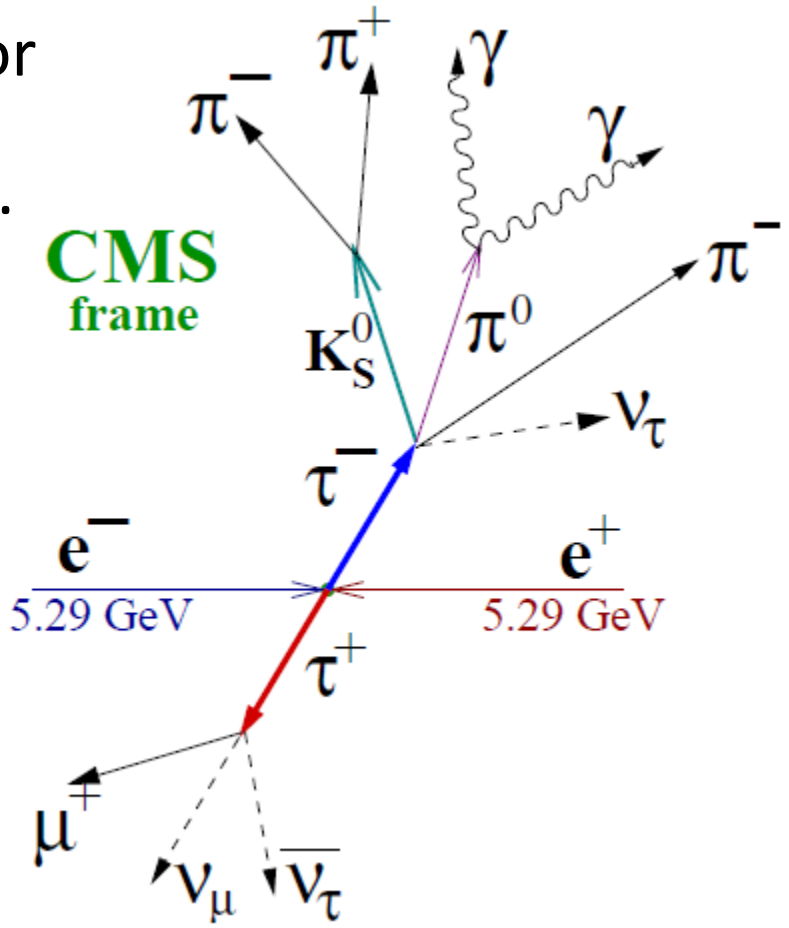




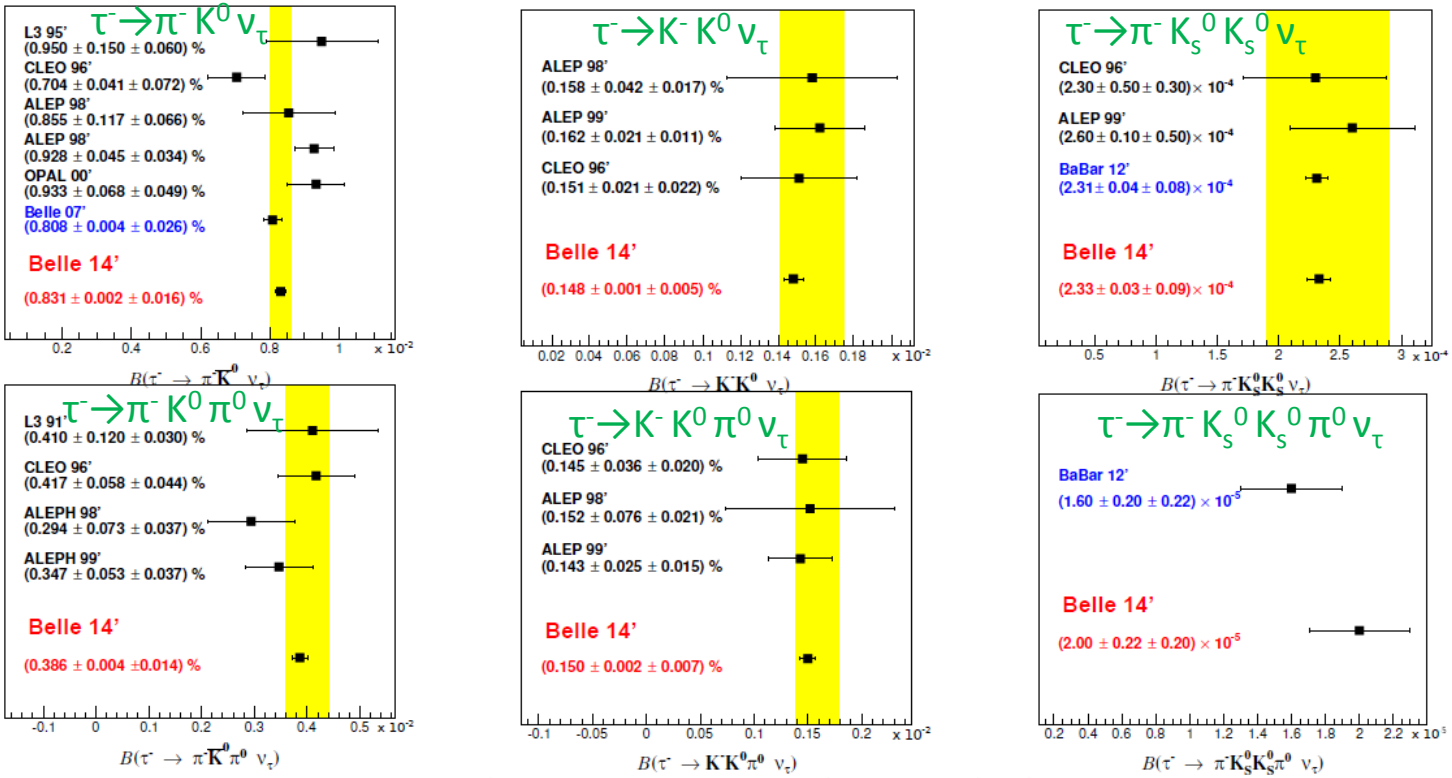
τ^- decay modes with K_s^0

- With 1-prong e/μ tags search for 3 or 5 charged tracks in signal hemisphere for $h^- K_s^0 (K_s^0)(\pi^0) \nu_\tau$.
- K_s^0 candidates from $\pi^+ \pi^-$ pairs with displaced vertex.





Branching fraction results



Yellow bands show the world averages and their uncertainties from PDG:

$\mathcal{B}(\tau^- \to K^- K_S^0 K_S^0 \nu_\tau) < 6.3 \times 10^{-7}$ at 90% CL

$\mathcal{B}(\tau^- \to K^- K_S^0 K_S^0 \pi^0 \nu_\tau) < 4.0 \times 10^{-7}$ at 90% CL

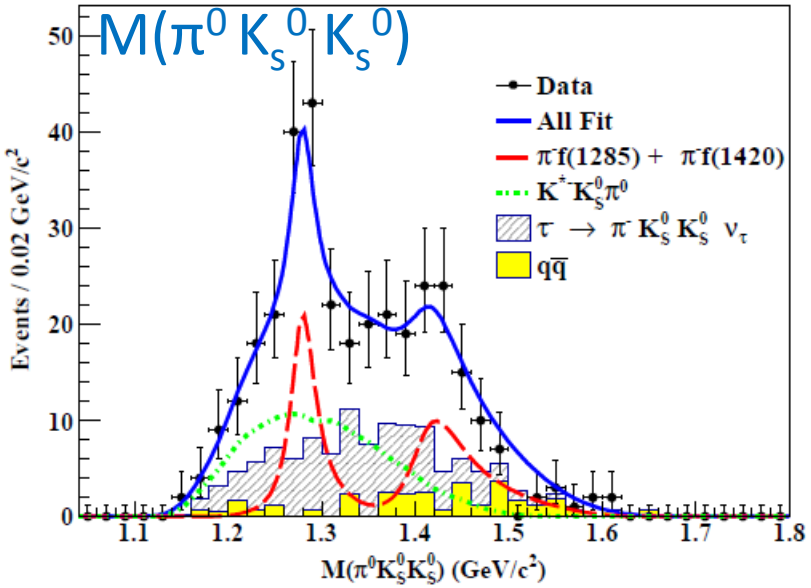
468 fb^{-1} ***PRD 86, 092013 (2012)***

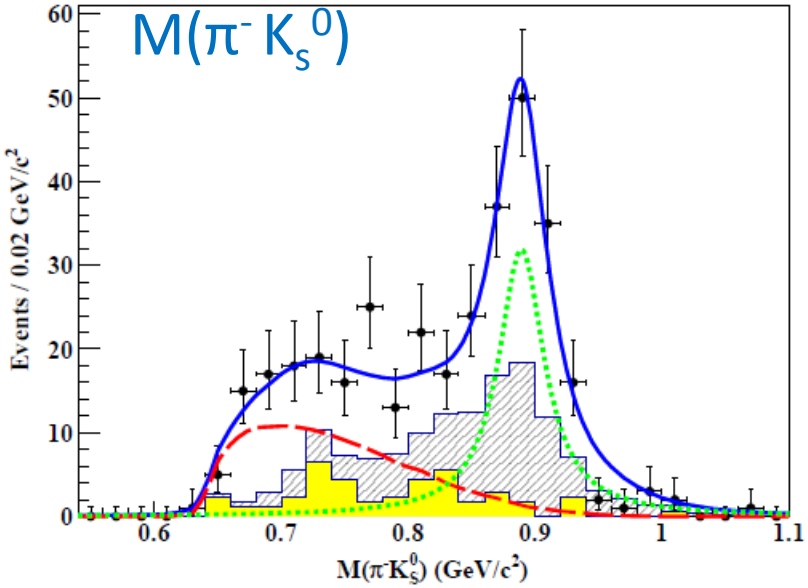
$\mathcal{B}(\tau^- \to K_S^0 X^- \nu_\tau) = (9.14 \pm 0.01 \pm 0.22) \times 10^{-3}$

669 fb^{-1} ***PRD 89, 072009 (2014)***

$\tau^- \to \pi^- K_s^0 K_s^0 \pi^0 \nu_\tau$ dynamics

- Simultaneous fit of $M(\pi^0 K_s^0 K_s^0)$ and $M(\pi^- K_s^0)$.





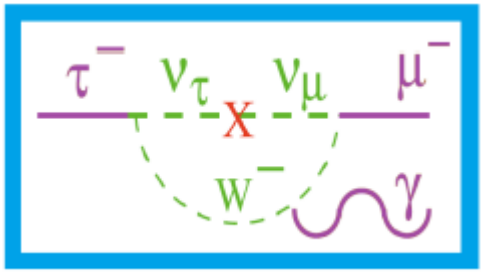
$$\mathcal{B}(\tau^- \to f_1(1285)\pi^-\nu_\tau) \cdot \mathcal{B}(f_1(1285) \to K_S^0 K_S^0 \pi^0) = (0.68 \pm 0.13 \pm 0.07) \times 10^{-5},$$

$$\mathcal{B}(\tau^- \to f_1(1420)\pi^-\nu_\tau) \cdot \mathcal{B}(f_1(1420) \to K_S^0 K_S^0 \pi^0) = (0.24 \pm 0.05 \pm 0.06) \times 10^{-5},$$

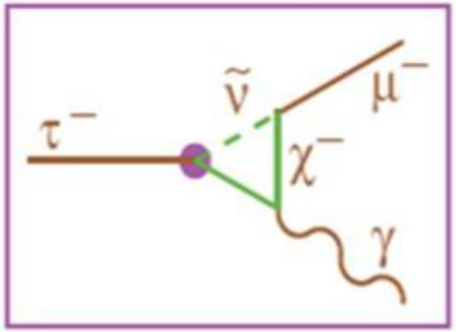
$$\mathcal{B}(\tau^- \to K^*(892)^- K_S^0 \pi^0 \nu_\tau) \cdot \mathcal{B}(K^*(892)^- \to K_S^0 \pi^-) = (1.08 \pm 0.14 \pm 0.15) \times 10^{-5}.$$

LFV in τ decays

- Lepton Flavour Violation:
  - Extremely small in the Standard Model with neutrino mixing.
  - Unambiguous sign of new physics.

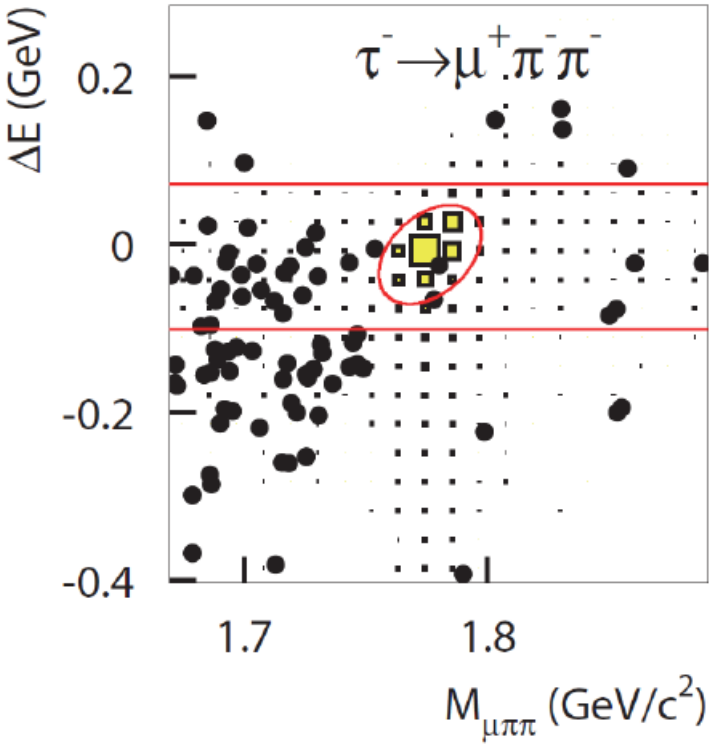


Model	$\mathcal{B}(\tau \to \mu\gamma)$	$\mathcal{B}(\tau \to \ell\ell\ell)$
mSUGRA+seesaw	10^{-8}	10^{-9}
SUSY+SO(10)	10^{-8}	10^{-10}
SM+seesaw	10^{-9}	10^{-10}
Non-universal Z'	10^{-9}	10^{-8}
SUSY+Higgs	10^{-10}	10^{-8}



Search for $\tau \to l\, h\, h'$

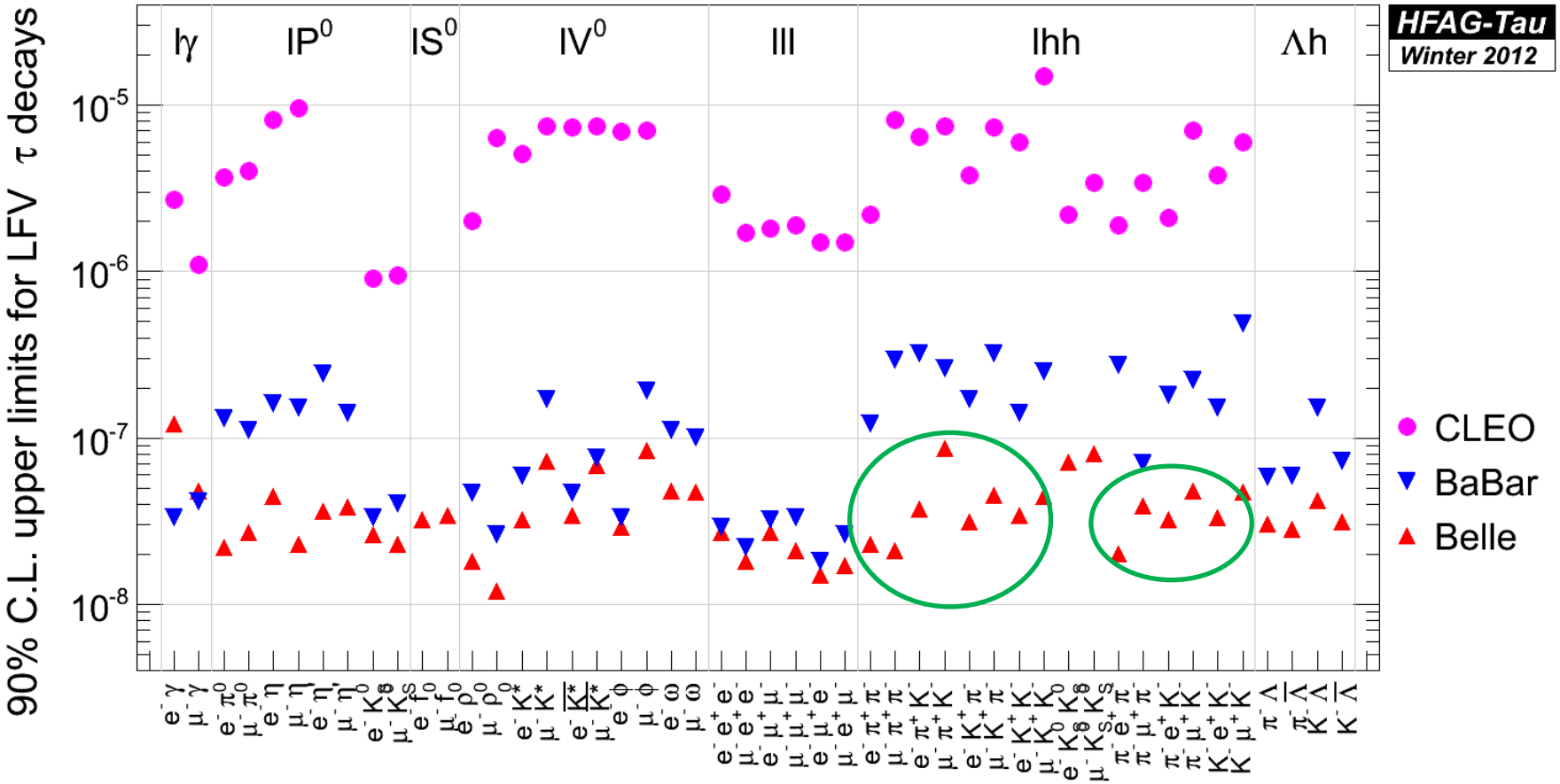
- 14 Lepton Flavour Violation modes investigated:
  - $\tau^- \to l^- h^+ h'^-$ (8 modes)
  - $\tau^- \to l^+ h^- h'^-$ (6 modes, violating lepton number)
- Tag with one-prong decay.
- Search for signal in the (M,ΔE) plane.



BELLE

854 fb^{-1} *PLB 719, 346 (2013)*

LFV in τ decays



- Super B factory to reach 10^{-9} B.R.

Summary

- High statistics of τ pairs at the B factories allows precision tests of Standard Model and search for New Physics.
- Recent measurements of:
  - τ lifetime
  - High multiplicity processes
  - LFV in τ decays