τ Physics: Theory Overview

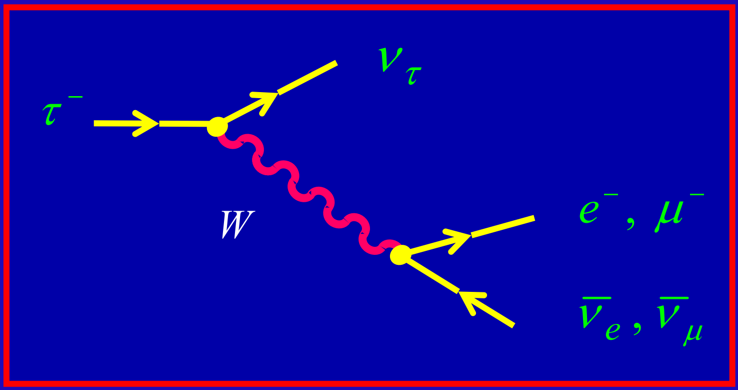
A. Pich

IFIC, Valencia

PhiPsi08

Frascati

7-10 April 2008



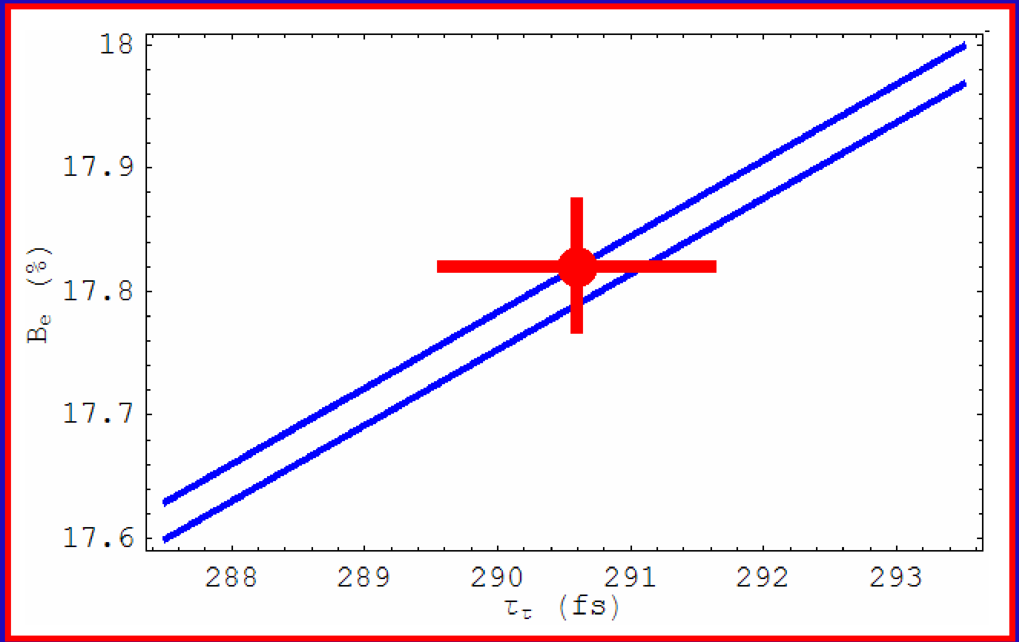
$$\Gamma(\tau \to \nu_\tau\, l\, \bar{\nu}_l) = \frac{G_F^2\, m_\tau^5}{192\,\pi^3}\, f(m_l^2/m_\tau^2)\; r_{EW}$$

$$f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$$

$$r_{EW} = 0.9960$$ (Marciano-Sirlin)

$$B_e = \frac{B_\mu}{0.972564 \pm 0.000010} = \frac{\tau_\tau}{(1632.1 \pm 1.4)\times 10^{-15}\,\mathrm{s}}$$

$$\left(B_\mu/B_e\right)_{\exp} = 0.9725 \pm 0.0039$$



τ_τ , Br($\tau \to \mu$), Br($\tau \to e$) $\sim$ 0.3% precision

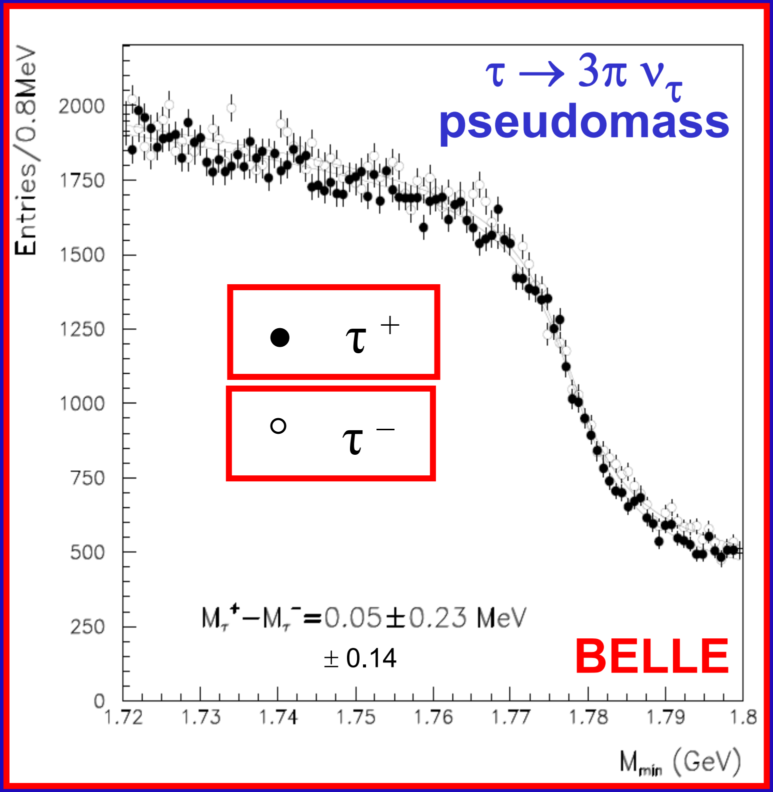
Future Improvements: BABAR , BELLE , KEDR , BESIII , SuperB , …

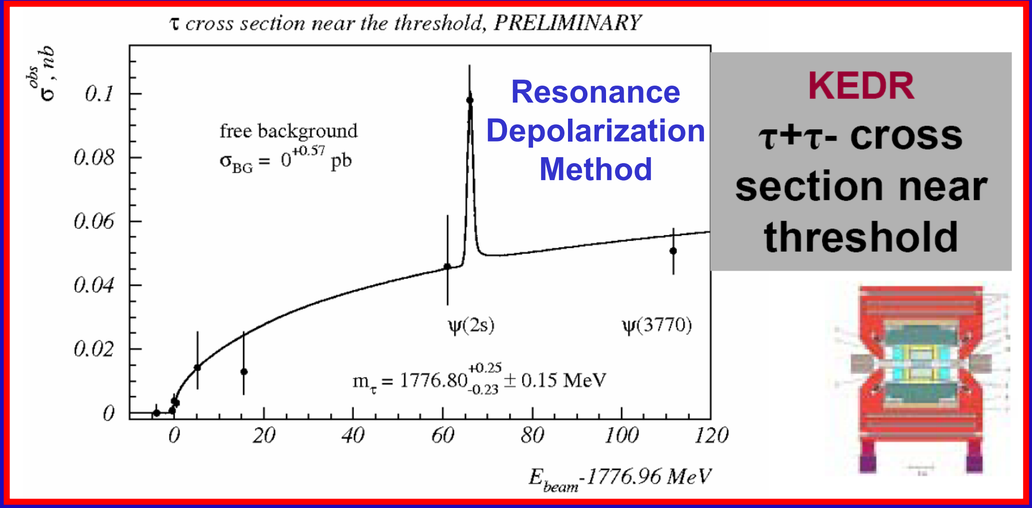
δm_τ ~ 0.023 MeV (12.7 ppm) BESIII

$$m_\tau = 1776.99\,^{+0.29}_{-0.26} \text{ MeV} \qquad \text{(PDG06)}$$

$$1776.61 \pm 0.13 \pm 0.35 \text{ MeV} \qquad \text{(BELLE)}$$

$$1776.81 \pm\,^{0.25}_{0.23} \pm 0.15 \text{ MeV} \qquad \text{(KEDR)}$$

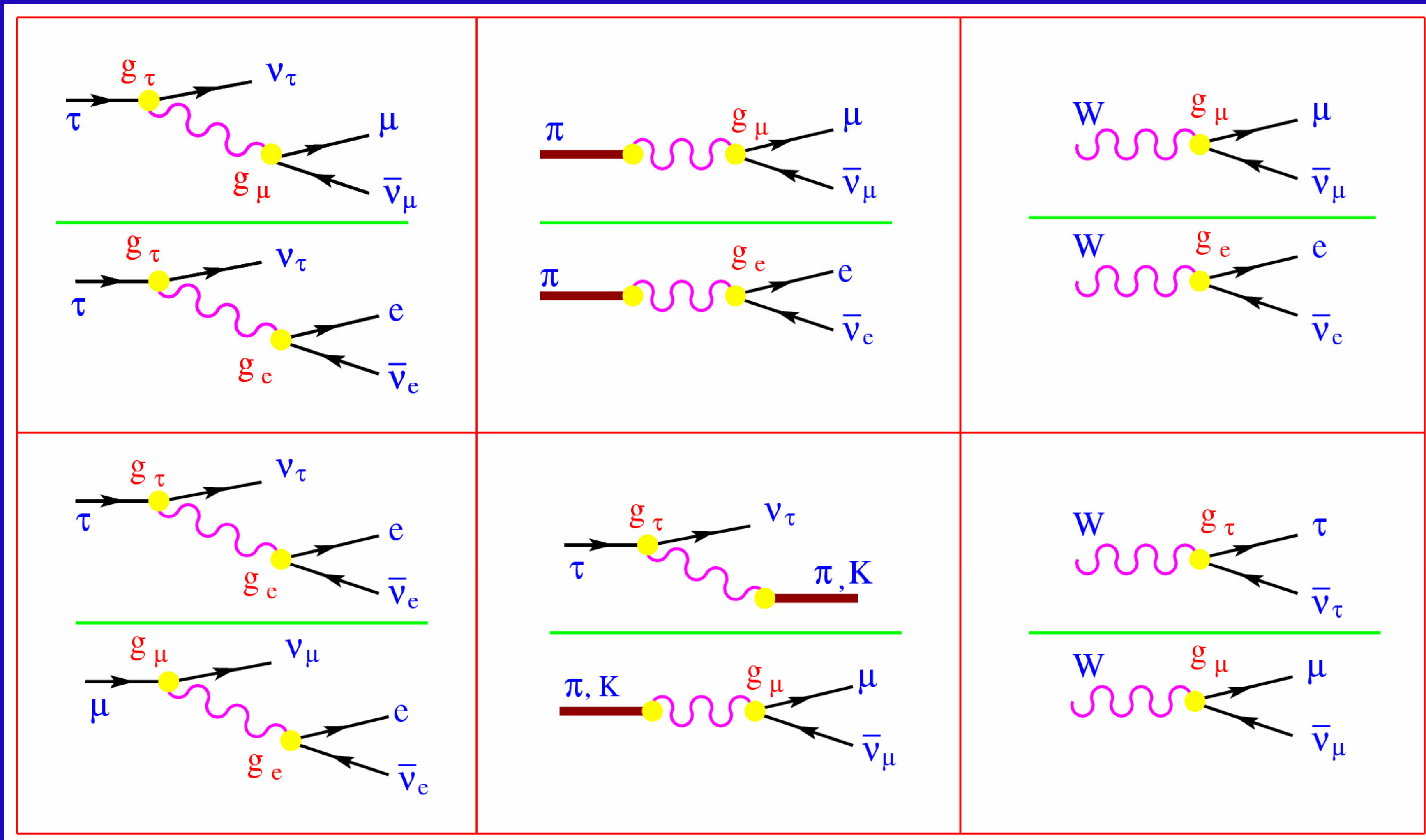




LEPTON UNIVERSALITY

$$\frac{g_\mu}{g_e}$$

$$\frac{g_\tau}{g_\mu}$$



CHARGED CURRENT UNIVERSALITY

$$\left| g_\mu / g_e \right|$$

$B_{\tau\to\mu} / B_{\tau\to e}$	1.0000 ± 0.0020
$B_{\pi\to\mu} / B_{\pi\to e}$	1.0021 ± 0.0016
$B_{K\to\mu} / B_{K\to e}$	1.004 ± 0.007
$B_{K\to\pi\mu} / B_{K\to\pi e}$	1.002 ± 0.002
$B_{W\to\mu} / B_{W\to e}$	0.997 ± 0.010

$$\left| g_\tau / g_\mu \right|$$

$B_{\tau\to e} \;\; \tau_\mu / \tau_\tau$	1.0006 ± 0.0022
$\Gamma_{\tau\to\pi} / \Gamma_{\pi\to\mu}$	0.996 ± 0.005
$\Gamma_{\tau\to K} / \Gamma_{K\to\mu}$	0.979 ± 0.017
$B_{W\to\tau} / B_{W\to\mu}$	1.039 ± 0.013

$$\left| g_\tau / g_e \right|$$

$B_{\tau\to\mu} \;\; \tau_\mu / \tau_\tau$	1.0005 ± 0.0023
$B_{W\to\tau} / B_{W\to e}$	1.036 ± 0.014

LEPTON FLAVOUR VIOLATION

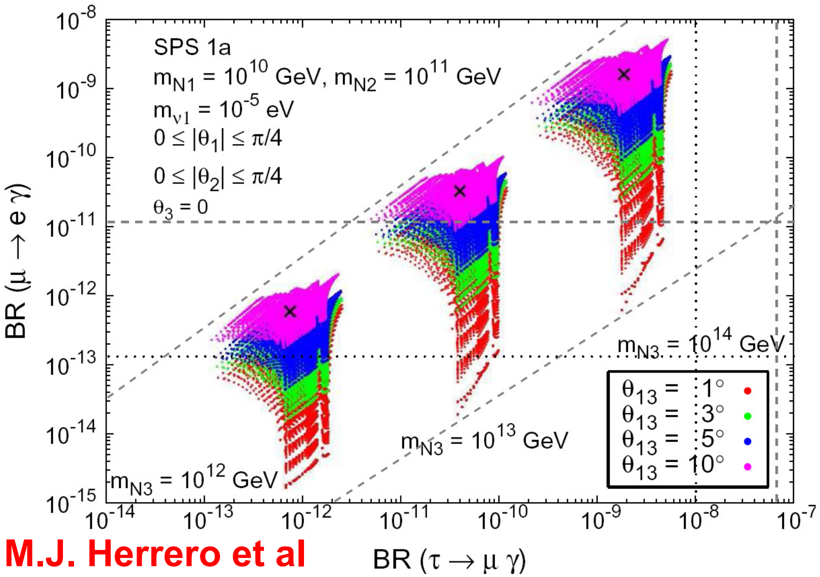
90 % CL Upper Limits on $Br(l^- \to X^-)$ [BABAR / BELLE]

Decay	U.L.	Decay	U.L.	Decay	U.L.
$\mu^- \to e^- \gamma$	$1.2 \cdot 10^{-11}$	$\mu^- \to e^- e^+ e^-$	$1.0 \cdot 10^{-12}$	$\mu^- \to e^- \gamma\gamma$	$7.2 \cdot 10^{-11}$
$\tau^- \to e^- \gamma$	$1.1 \cdot 10^{-7}$	$\tau^- \to e^- e^+ e^-$	$3.6 \cdot 10^{-8}$	$\tau^- \to e^- e^+ \mu^-$	$2.7 \cdot 10^{-8}$
$\tau^- \to \mu^- \gamma$	$4.5 \cdot 10^{-8}$	$\tau^- \to e^- \mu^+ \mu^-$	$3.7 \cdot 10^{-8}$	$\tau^- \to \mu^- e^+ \mu^-$	$2.3 \cdot 10^{-8}$
$\tau^- \to e^- e^- \mu^+$	$2.0 \cdot 10^{-8}$	$\tau^- \to \mu^- \mu^+ \mu^-$	$3.2 \cdot 10^{-8}$	$\tau^- \to e^- \pi^0$	$8.0 \cdot 10^{-8}$
$\tau^- \to \mu^- \pi^0$	$1.1 \cdot 10^{-7}$	$\tau^- \to e^- \eta'$	$1.6 \cdot 10^{-7}$	$\tau^- \to \mu^- \eta'$	$1.3 \cdot 10^{-7}$
$\tau^- \to e^- \eta$	$9.2 \cdot 10^{-8}$	$\tau^- \to \mu^- \eta$	$6.5 \cdot 10^{-8}$	$\tau^- \to e^- K^{*0}$	$7.8 \cdot 10^{-8}$
$\tau^- \to e^- K_S$	$5.6 \cdot 10^{-8}$	$\tau^- \to \mu^- K_S$	$4.9 \cdot 10^{-8}$	$\tau^- \to \mu^- \rho^0$	$6.8 \cdot 10^{-8}$
$\tau^- \to e^- K^+ K^-$	$1.4 \cdot 10^{-7}$	$\tau^- \to e^- K^+ \pi^-$	$1.6 \cdot 10^{-7}$	$\tau^- \to e^- \pi^+ K^-$	$3.2 \cdot 10^{-7}$
$\tau^- \to \mu^- K^+ K^-$	$2.5 \cdot 10^{-7}$	$\tau^- \to \mu^- K^+ \pi^-$	$3.2 \cdot 10^{-7}$	$\tau^- \to \mu^- \pi^+ K^-$	$2.6 \cdot 10^{-7}$
$\tau^- \to e^- \pi^+ \pi^-$	$1.2 \cdot 10^{-7}$	$\tau^- \to \mu^- \pi^+ \pi^-$	$2.9 \cdot 10^{-7}$	$\tau^- \to \Lambda \pi^-$	$7.2 \cdot 10^{-8}$
$\tau^- \to e^+ K^- K^-$	$1.5 \cdot 10^{-7}$	$\tau^- \to e^+ K^- \pi^-$	$1.8 \cdot 10^{-7}$	$\tau^- \to e^+ \pi^- \pi^-$	$2.0 \cdot 10^{-7}$
$\tau^- \to \mu^- K^{*0}$	$5.9 \cdot 10^{-8}$	$\tau^- \to e^- \phi$	$7.3 \cdot 10^{-8}$	$\tau^- \to \mu^- \omega$	$8.9 \cdot 10^{-8}$
$\tau^- \to \mu^+ K^- K^-$	$4.4 \cdot 10^{-7}$	$\tau^- \to \mu^+ K^- \pi^-$	$2.2 \cdot 10^{-7}$	$\tau^- \to \mu^+ \pi^- \pi^-$	$0.7 \cdot 10^{-7}$

Impact of θ_{13} on LFV processes

(All plotted points lead to 'viable BAU' and respect EDM bounds)

$(-\pi/4 \lesssim \arg\theta_1 \lesssim \pi/4,\ 0 \lesssim \arg\theta_2 \lesssim \pi/4)$

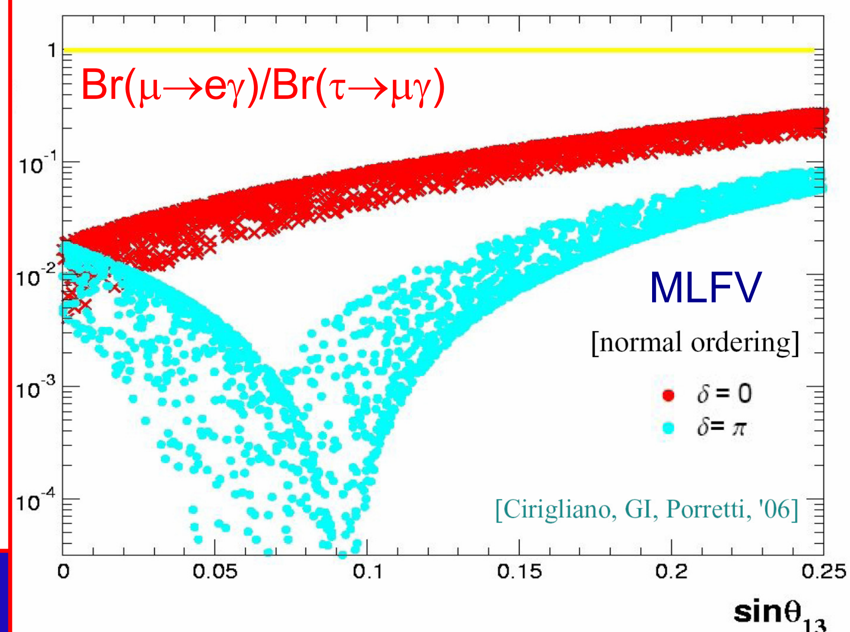


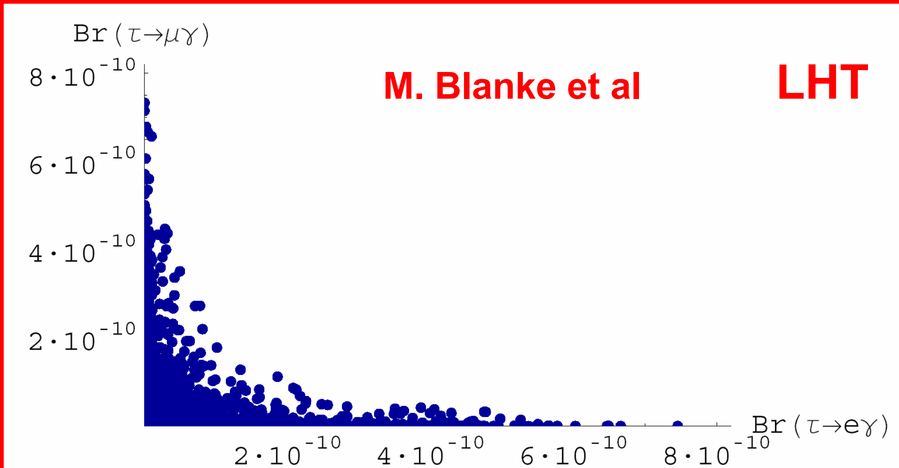
M.J. Herrero et al

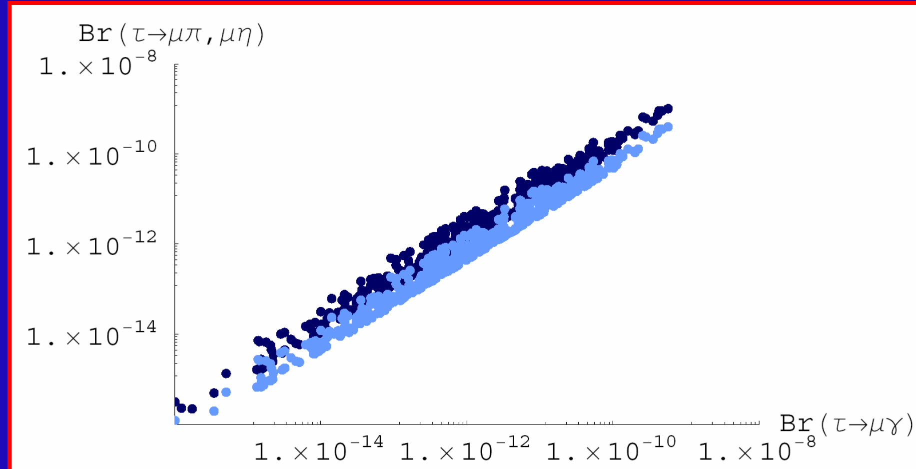
MEG: $Br(\mu \to e\gamma) \sim 10^{-13}$

Prism: $Pr(\mu \to e) \sim 10^{-18}$

SuperB: $Br(\tau \to \mu\gamma) \sim 10^{-9}$



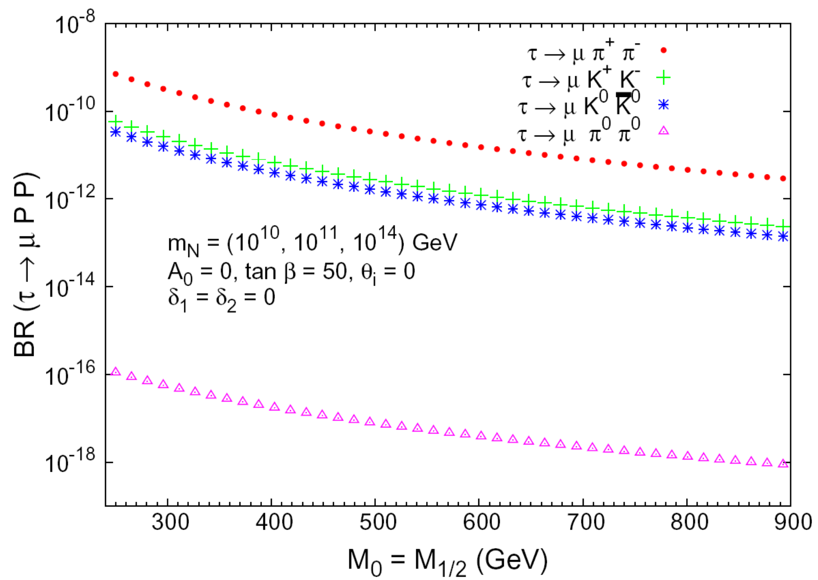


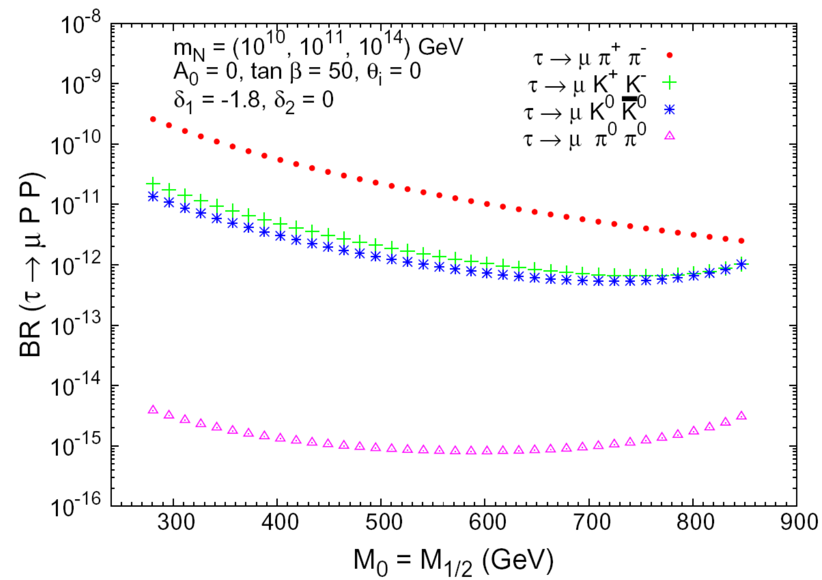


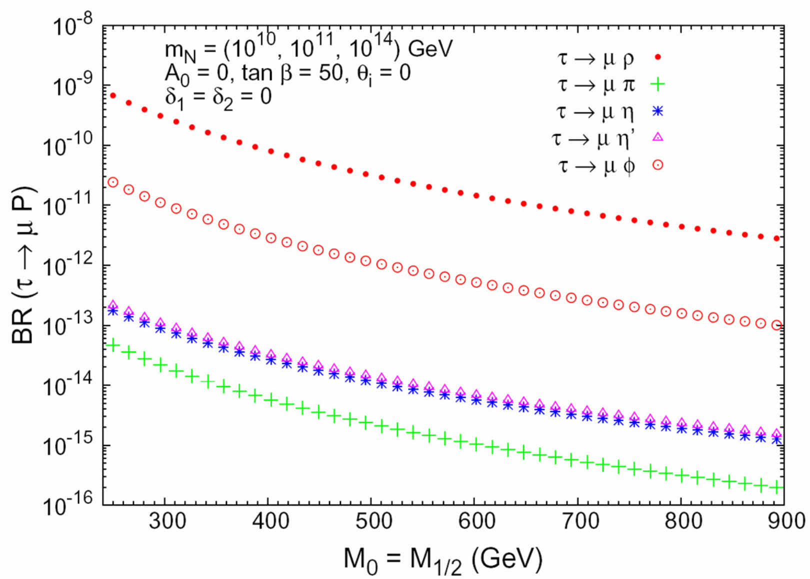
Arganda-Herrero-Portolés 08

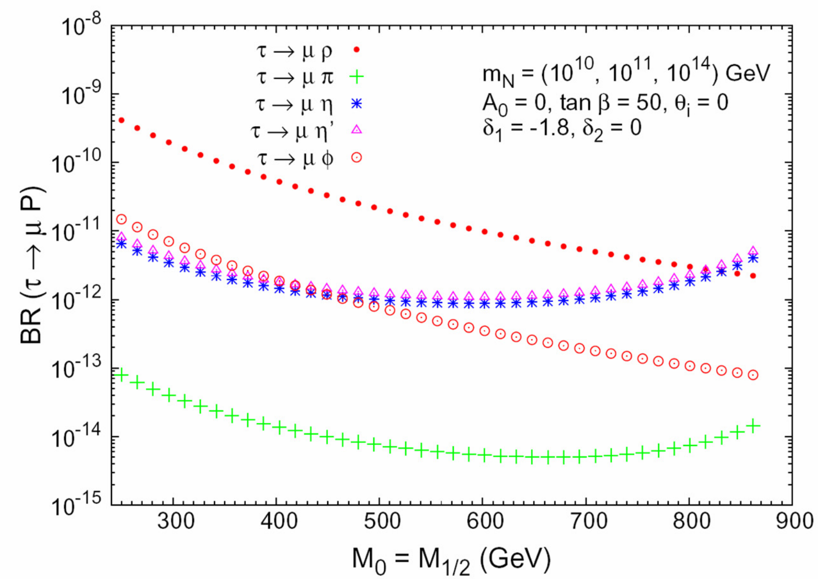
Constrained MSSM–Seesaw Scenarios

CMSSM **NUHM**

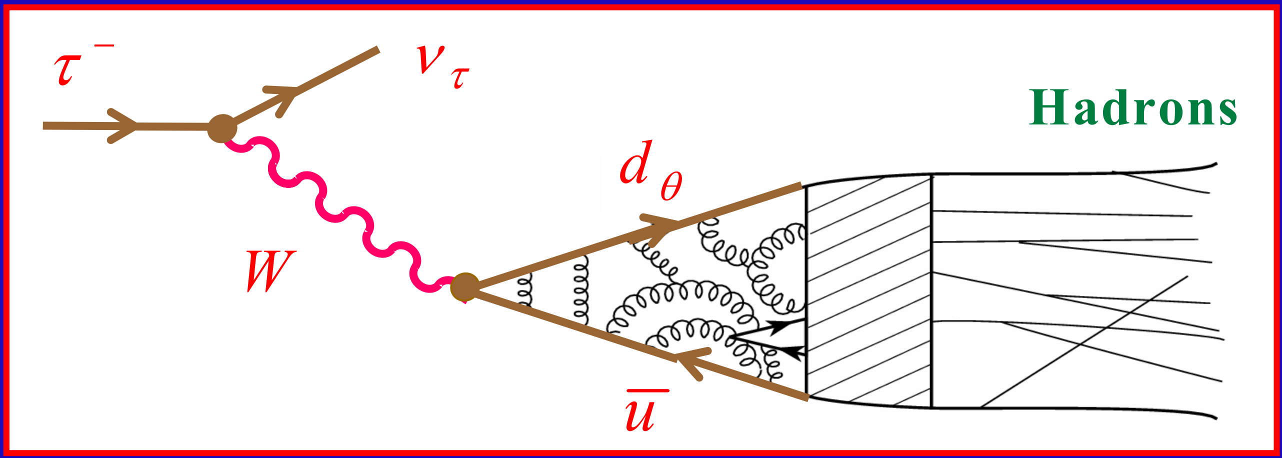








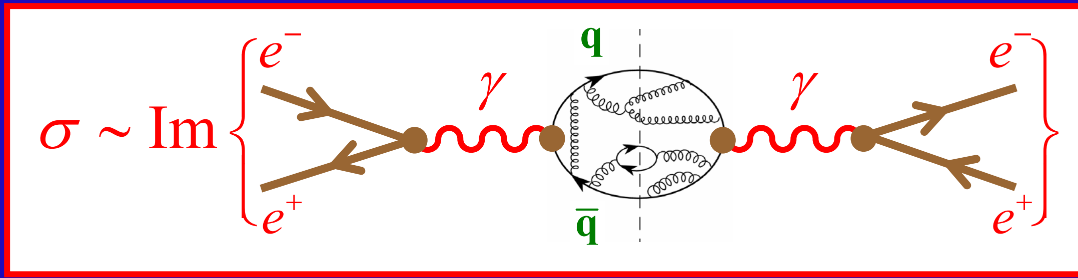
HADRONIC TAU DECAY



$$d_\theta = V_{ud}\, d + V_{us}\, s$$

Only lepton massive enough to decay into hadrons

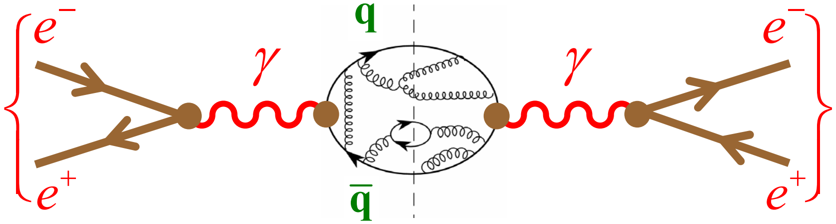
$$R_\tau \equiv \frac{\Gamma\left(\tau^- \to \nu_\tau + \mathrm{Hadrons}\right)}{\Gamma\left(\tau^- \to \nu_\tau\, e^-\, \bar{\nu}_e\right)} \approx N_C \quad ; \quad R_\tau = \frac{1 - B_e - B_\mu}{B_e} = 3.639 \pm 0.011$$



$$\frac{\sigma(e^+e^-\to \mathrm{had})}{\sigma(e^+e^-\to \mu^+\mu^-)} = 12\pi\, \mathrm{Im}\,\Pi_{\mathrm{em}}(s)$$

$$\Pi^{\mu\nu}_{\mathrm{em}}(q) \equiv i\int d^4x\; e^{iqx}\,\langle 0|T[J^{\mu}_{\mathrm{em}}(x)\,J^{\nu}_{\mathrm{em}}(0)]|0\rangle \;=\; \left(-g^{\mu\nu}q^2 + q^{\mu}q^{\nu}\right)\Pi_{\mathrm{em}}(q^2)$$

$\sigma \sim \mathrm{Im}$



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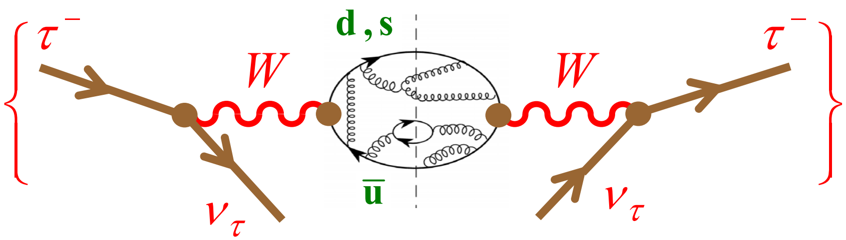
$\Gamma_{\tau \to \nu_\tau + \text{had}} \sim \mathrm{Im}$

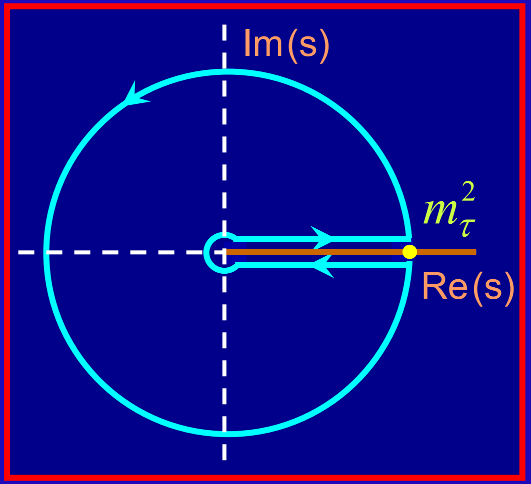


$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \text{had})}{\Gamma(\tau^- \to \nu_\tau e^- \overline{\nu}_e)} = 12\pi \int_0^{m_\tau^2} dx \left(1 - \frac{s}{m_\tau^2} \right)^2 \left[\left(1 + 2\,\frac{s}{m_\tau^2} \right) \mathrm{Im}\,\Pi^{(1)}(s) + \mathrm{Im}\,\Pi^{(0)}(s) \right]$$

$$\Pi^{(J)}(s) \; \equiv \; |V_{ud}|^2 \left[\Pi^{(J)}_{ud,V}(s) + \Pi^{(J)}_{ud,A}(s) \right] \; + \; |V_{us}|^2 \left[\Pi^{(J)}_{us,V}(s) + \Pi^{(J)}_{us,A}(s) \right]$$

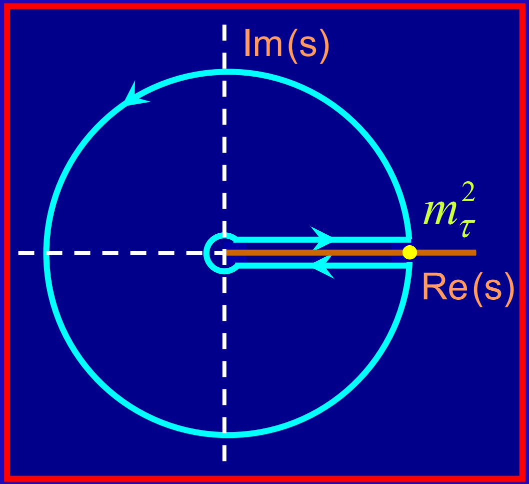
$$\Pi^{\mu\nu}_{ij,J}(q) \equiv i \int d^4x \;\; e^{iqx} \, \langle 0 | T[J^{\mu}_{ij}(x) \, J^{\nu}_{ij}(0)^\dagger] | 0 \rangle = \left(-g^{\mu\nu} q^2 + q^{\mu} q^{\nu} \right) \Pi^{(1)}_{ij,J}(q^2) + q^{\mu} q^{\nu} \; \Pi^{(0)}_{ij,J}(q^2)$$

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \text{had})}{\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)} = 12\pi \int_0^1 dx\,(1-x)^2 \left[(1+2x)\,\mathrm{Im}\,\Pi^{(1)}(x\,m_\tau^2) + \mathrm{Im}\,\Pi^{(0)}(x\,m_\tau^2) \right]$$



$$R_\tau = 6\pi i \oint_{|x|=1} dx\,(1-x)^2 \left[(1+2x)\,\Pi^{(0+1)}(x\,m_\tau^2) - 2x\,\Pi^{(0)}(x\,m_\tau^2) \right]$$

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \mathrm{had})}{\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)} = 12\pi \int_0^1 dx\,(1-x)^2 \left[(1+2x)\,\mathrm{Im}\,\Pi^{(1)}(x m_\tau^2) + \mathrm{Im}\,\Pi^{(0)}(x m_\tau^2)\right]$$

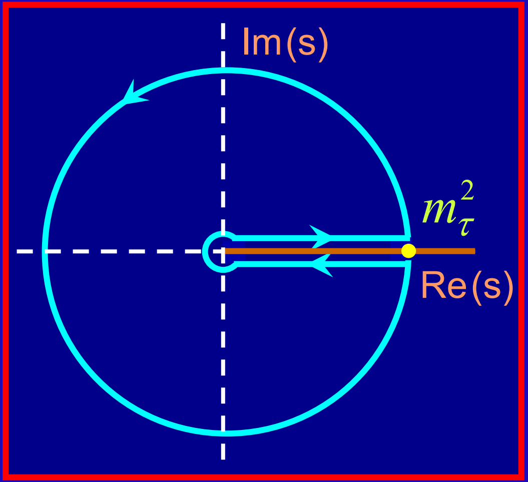


$$R_\tau = 6\pi i \oint_{|x|=1} dx\,(1-x)^2 \left[(1+2x)\,\Pi^{(0+1)}(x m_\tau^2) - 2x\,\Pi^{(0)}(x m_\tau^2)\right]$$

$$\Pi^{(J)}(s) = \sum_{D=2n} \frac{C_D^{(J)}(s,\mu)\,\langle O_D(\mu)\rangle}{(-s)^{D/2}}$$

OPE

$$R_\tau \equiv \frac{\Gamma(\tau^- \to \nu_\tau + \mathrm{had})}{\Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)} = 12\pi \int_0^1 dx\,(1-x)^2 \left[(1+2x)\,\mathrm{Im}\,\Pi^{(1)}(x m_\tau^2) + \mathrm{Im}\,\Pi^{(0)}(x m_\tau^2)\right]$$



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OPE

$$R_\tau = N_C\, S_{\mathrm{EW}}\,\left(1 + \delta_{\mathrm{P}} + \delta_{\mathrm{NP}}\right) = R_{\tau,V} + R_{\tau,A} + R_{\tau,S}$$

$S_{\mathrm{EW}} = 1.0201\ (3)$; $\delta_{\mathrm{NP}} = 0.0001 \pm 0.0017$

Marciano-Sirlin, Braaten-Li, Erler

Fitted from data

$\delta_{\mathrm{P}} = a_\tau + 5.20\ a_\tau^2 + 26\ a_\tau^3 + \ldots \approx\ 20\%$; $a_\tau \equiv \alpha_s(m_\tau)/\pi$

Perturbative: $(m_q=0)$

$\boxed{K_4 = 49.076}$ Baikov-Chetyrkin-Kühn

$$-s\,\frac{d}{ds}\,\Pi^{(0+1)}(s) = \frac{1}{4\pi^2}\sum_{n=0} K_n \left(\frac{\alpha_s(-s)}{\pi}\right)^n \quad ; \quad K_0 = K_1 = 1 \quad , \quad K_2 = 1.63982 \quad , \quad K_3 = 6.37101$$

$$\Rightarrow \quad \delta_P = \sum_{n=1} K_n\, A^{(n)}(\alpha_s) = a_\tau + 5.20\, a_\tau^2 + 26\, a_\tau^3 + 127\, a_\tau^4 + \cdots$$

$$A^{(n)}(\alpha_s) \equiv \frac{1}{2\pi i}\oint_{|x|=1}\frac{dx}{x}\,(1-2x+2x^3-x^4)\left(\frac{\alpha_s(-s)}{\pi}\right)^n = a_\tau^n + \cdots \quad ; \quad a_\tau \equiv \alpha_s(m_\tau)/\pi$$

Perturbative: $(m_q=0)$

$K_4 = 49.076$ Baikov-Chetyrkin-Kühn

$$-s\,\frac{d}{ds}\,\Pi^{(0+1)}(s) = \frac{1}{4\pi^2}\sum_{n=0} K_n \left(\frac{\alpha_s(-s)}{\pi}\right)^n \quad ; \quad K_0 = K_1 = 1 \;,\; K_2 = 1.63982 \;,\; K_3 = 6.37101$$

$$\Rightarrow \quad \delta_{\rm P} = \sum_{n=1} K_n\, A^{(n)}(\alpha_s) = a_\tau + 5.20\, a_\tau^2 + 26\, a_\tau^3 + 127\, a_\tau^4 + \cdots$$

$$A^{(n)}(\alpha_s) \equiv \frac{1}{2\pi i}\oint_{|x|=1}\frac{dx}{x}\,(1-2x+2x^3-x^4)\left(\frac{\alpha_s(-s)}{\pi}\right)^n = a_\tau^n + \cdots \quad ; \quad a_\tau \equiv \alpha_s(m_\tau)/\pi$$

Power Corrections:

$$\Pi^{(0+1)}_{\rm OPE}(s) \approx \frac{1}{4\pi^2}\sum_{n\geq 2}\frac{C_{2n}\langle O_{2n}\rangle}{(-s)^n}$$

$$C_4\langle O_4\rangle \approx \frac{2\pi}{3}\langle 0|\alpha_s G^{\mu\nu}G_{\mu\nu}|0\rangle$$

$$\delta_{\rm NP} \approx \frac{-1}{2\pi i}\oint_{|x|=1} dx\;(1-3x^2+2x^3)\sum_{n\geq 2}\frac{C_{2n}\langle O_{2n}\rangle}{(-x m_\tau^2)^n} = -3\,\frac{C_6\langle O_6\rangle}{m_\tau^6} - 2\,\frac{C_8\langle O_8\rangle}{m_\tau^8}$$

Suppressed by m_τ^6 [additional chiral suppression in $C_6\langle O_6\rangle^{V+A}$]

Similar predictions for $R_{\tau,V}$, $R_{\tau,A}$, $R_{\tau,S}$ and the moments

$$R_\tau^{kl}(s_0) \equiv \int_0^{s_0} ds \left(1 - \frac{s}{s_0}\right)^k \left(\frac{s}{m_\tau^2}\right)^l \frac{dR_\tau}{ds}$$

Different sensitivity to power corrections through k , l

The non-perturbative contribution to R_τ can be obtained from the invariant-mass distribution of the final hadrons:

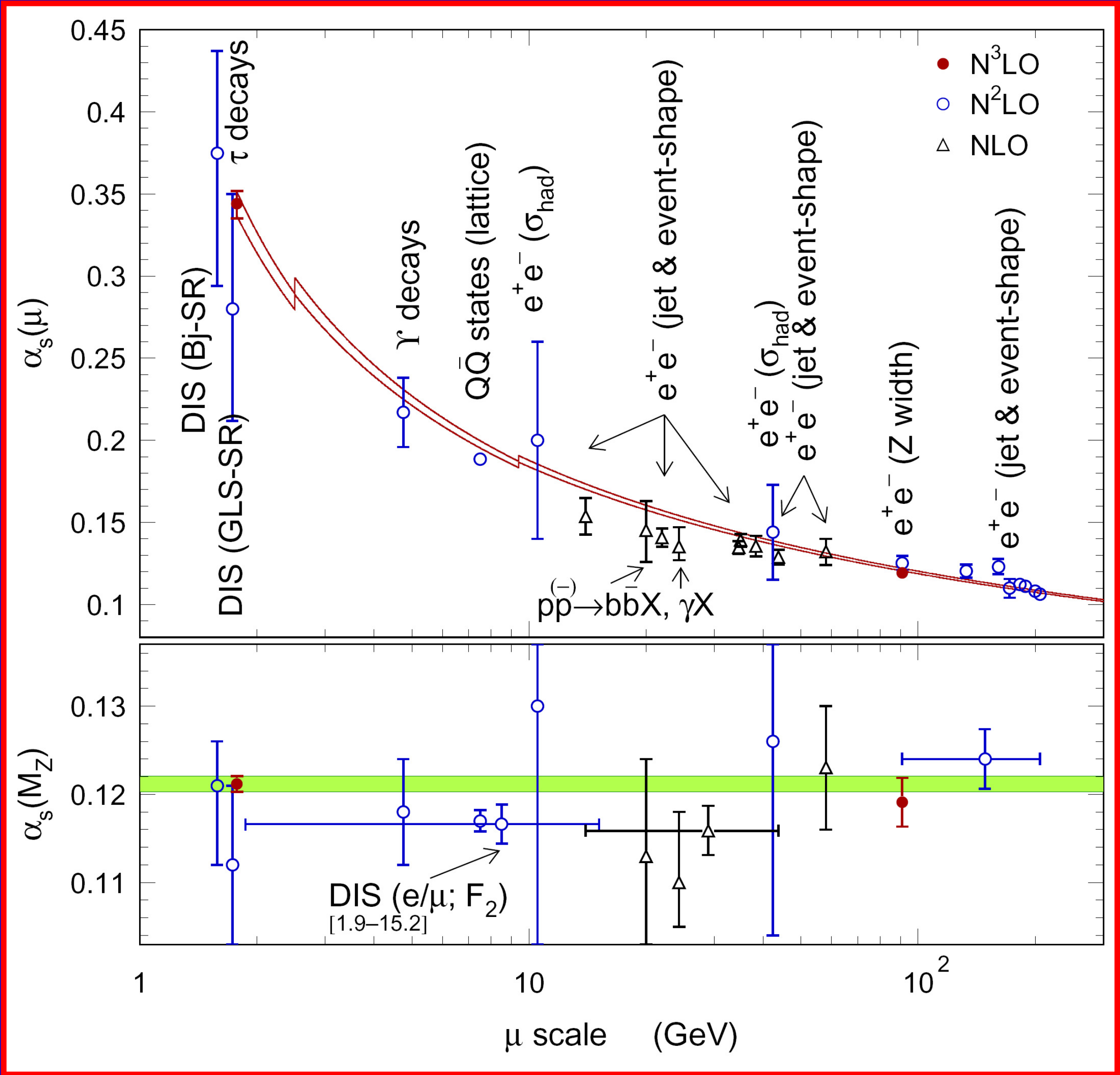
$$\delta_{\mathrm{NP}} = 0.0001 \pm 0.0017$$

Davier et al. (ALEPH data)

$R_{\tau,V} = 1.783 \pm 0.011 \quad ; \quad R_{\tau,A} = 1.695 \pm 0.011 \quad ; \quad R_{\tau,V+A} = 3.478 \pm 0.010$

Davier et al

ALEPH



$$\alpha_s(m_\tau^2) = 0.344 \pm 0.009$$

$$\alpha_s(M_Z^2) = 0.1212 \pm 0.0011$$

$$\alpha_s(M_Z^2)_{Z\,\mathrm{width}} = 0.1191 \pm 0.0027$$

The most precise test of Asymptotic Freedom

$$\alpha_s^\tau(M_Z^2) - \alpha_s^Z(M_Z^2) = 0.0021 \pm 0.0011_\tau \pm 0.0027_Z$$

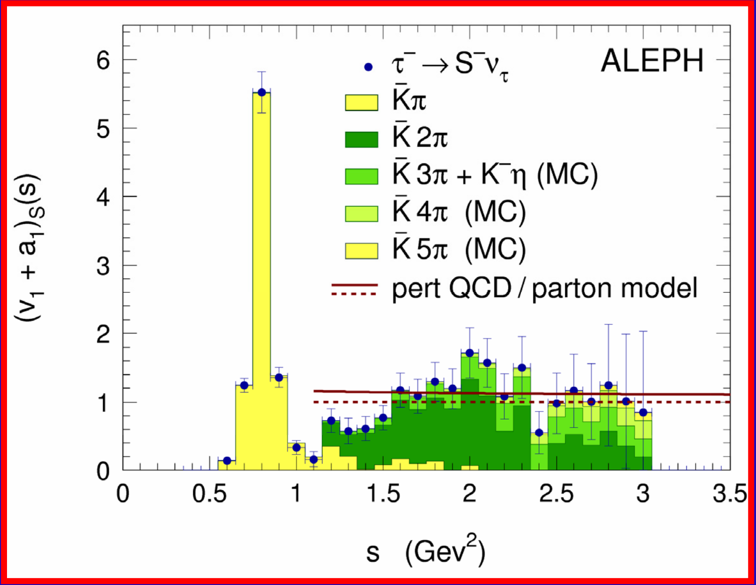
SU(3) Breaking

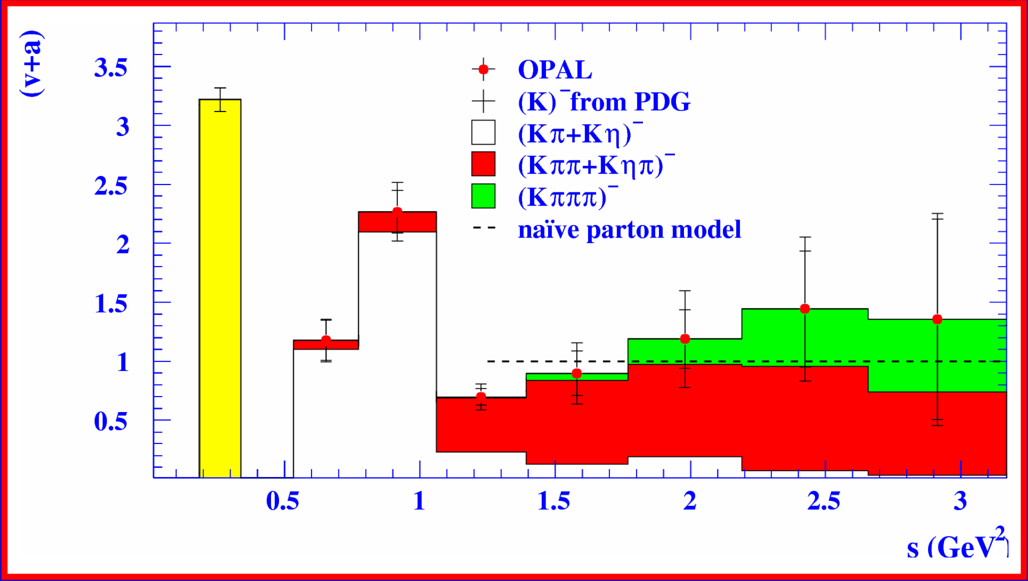
$$R_\tau^{kl} = N_C \, S_{\mathrm{EW}} \left\{ \left(|V_{ud}|^2 + |V_{us}|^2 \right) \left[1 + \delta^{kl(0)} \right] + \sum_{D\geq 2} \left[|V_{ud}|^2 \, \delta_{ud}^{kl(D)} + |V_{us}|^2 \, \delta_{us}^{kl(D)} \right] \right\}$$

$$\Downarrow$$

$$\delta R_\tau^{kl} \equiv \frac{R_{\tau,V+A}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau,S}^{kl}}{|V_{us}|^2} \approx N_C \, S_{\mathrm{EW}} \sum_{D\geq 2} \left[\delta_{ud}^{kl(D)} - \delta_{us}^{kl(D)} \right]$$

Strange Spectral Function: SU(3) Breaking





(k,l)	ALEPH	OPAL
(0,0)	0.39 ± 0.14	0.26 ± 0.12
(1,0)	0.38 ± 0.08	0.28 ± 0.09
(2,0)	0.37 ± 0.05	0.30 ± 0.07
(3,0)	0.40 ± 0.04	0.33 ± 0.05
(4,0)	0.40 ± 0.04	0.34 ± 0.04

$$\delta R_\tau^{kl} \equiv \frac{R_{\tau,V+A}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau,S}^{kl}}{|V_{us}|^2} \approx 24\, \frac{m_s^2(m_\tau^2)}{m_\tau^2}\, \Delta_{kl}(\alpha_s)$$

$\Rightarrow$ $m_s(m_\tau)$ **determination**

V_{us} and QCD uncertainties

$$\delta R_\tau^{kl} \equiv \frac{R_{\tau,V+A}^{kl}}{|V_{ud}|^2} - \frac{R_{\tau,S}^{kl}}{|V_{us}|^2} \approx 24\, \frac{m_s^2(m_\tau^2)}{m_\tau^2}\, \Delta_{kl}(\alpha_s)$$

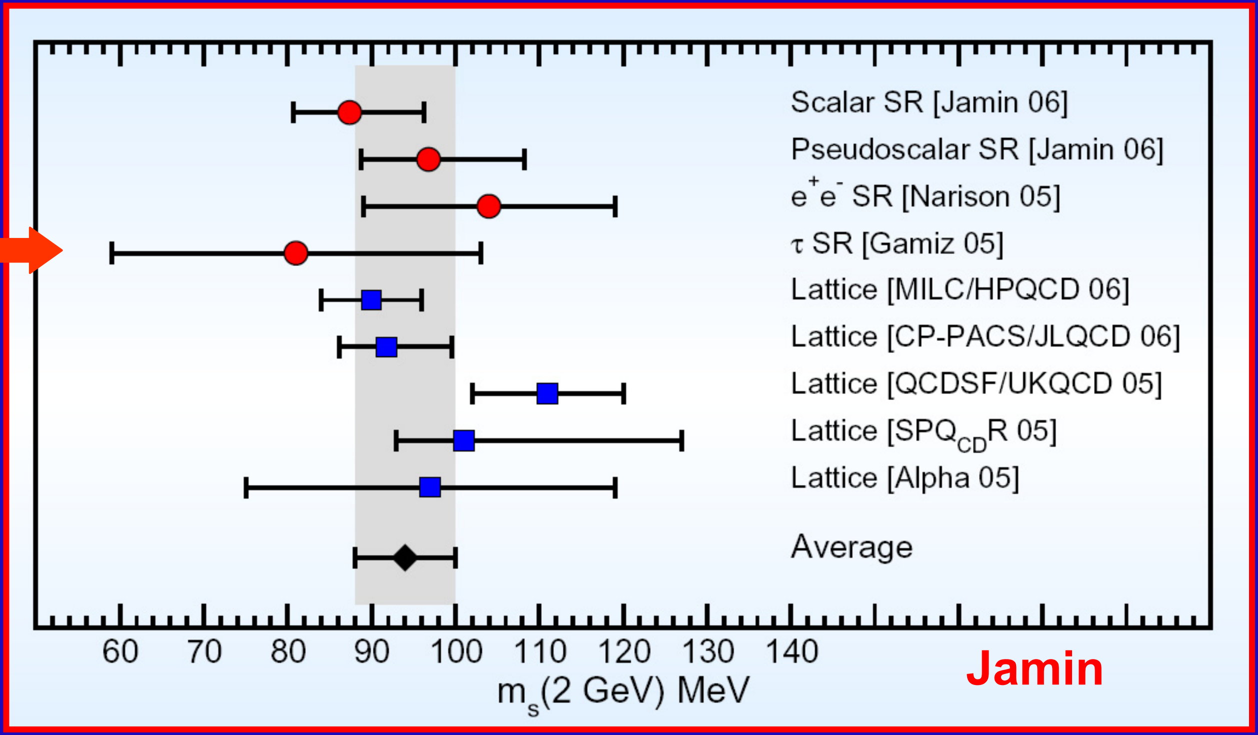
Known to $O(\alpha_s^3)$

- $\Delta_{kl}(\alpha_s)$ gets **longitudinal (J=0)** and **transverse (J=0+1)** contributions
- Divergent QCD series for J=0
- **Longitudinal contribution determined through data:**
  - Kaon pole ($K\to\mu\nu$) (dominant J=0 contribution)
  - Pion pole ($\pi\to\mu\nu$)
  - $(K\pi)_{J=0}$ (S-wave $K\pi$ scattering)
  - …
- Smaller uncertainties

	$R_{us,A}^{00,L}$	$R_{us,V}^{00,L}$	$R_{ud,A}^{00,L}$
Theory:	-0.144 ± 0.024	-0.028 ± 0.021	$-(7.79 \pm 0.14) \cdot 10^{-3}$
Phenom:	-0.135 ± 0.003	-0.028 ± 0.004	$-(7.77 \pm 0.08) \cdot 10^{-3}$

$$\delta R_{\tau,\text{th}}^{00} \equiv \underbrace{0.1544\,(37)}_{J=0} + \underbrace{0.062\,(15)}_{m_s(m_\tau)\,=\,0.100\,(10)} = 0.216\,(16)$$

OPAL τ data



Large uncertainty from V_{us}

Strong sensitivity to V_{us}

$$|V_{us}|^2 = \frac{R_{\tau,S}^{00}}{\frac{R_{\tau,V+A}^{00}}{|V_{ud}|^2} - \delta R_{\tau,\mathrm{th}}^{00}}$$

Gámiz-Jamin-Pich-Prades-Schwab

τ data: $R_{\tau,S}^{00} = 0.1686\ (47)$

$R_{\tau,V+A}^{00} = 3.471\ (11)$

PDG 06: $|V_{ud}| = 0.97377\ (27)$

$$\boxed{|V_{us}|^2 = \frac{R^{00}_{\tau,S}}{\frac{R^{00}_{\tau,V+A}}{|V_{ud}|^2} - \delta R^{00}_{\tau,\mathrm{th}}}}$$

Gámiz-Jamin-Pich-Prades-Schwab

τ data: $R^{00}_{\tau,S} = 0.1686\ (47)$

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PDG 06: $|V_{ud}| = 0.97377\ (27)$

$\delta R^{00}_{\tau,\mathrm{th}} = 0 \Rightarrow |V_{us}| = 0.215\ (3)$

$$\boxed{|V_{us}|^2 = \frac{R^{00}_{\tau,S}}{\frac{R^{00}_{\tau,V+A}}{|V_{ud}|^2} - \delta R^{00}_{\tau,\mathrm{th}}}}$$

Gámiz-Jamin-Pich-Prades-Schwab

τ data: $R^{00}_{\tau,S} = 0.1686\ (47)$

$R^{00}_{\tau,V+A} = 3.471\ (11)$

PDG 06: $|V_{ud}| = 0.97377\ (27)$

$\delta R^{00}_{\tau,\mathrm{th}} = 0 \Rightarrow |V_{us}| = 0.215\ (3)$

Taking as input (from non τ sources) $m_s(m_\tau) = 100 \pm 10\ \text{MeV}$:

$\delta R^{00}_{\tau,\mathrm{th}} = 0.216\ (16) \Rightarrow \boxed{|V_{us}| = 0.2212 \pm 0.0031_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}}}$

$$\boxed{|V_{us}|^2 = \frac{R^{00}_{\tau,S}}{\frac{R^{00}_{\tau,V+A}}{|V_{ud}|^2} - \delta R^{00}_{\tau,\mathrm{th}}}}$$

Gámiz-Jamin-Pich-Prades-Schwab

τ data: $R^{00}_{\tau,S} = 0.1686\ (47)$

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$\delta R^{00}_{\tau,\mathrm{th}} = 0.216\ (16) \Rightarrow \boxed{|V_{us}| = 0.2212 \pm 0.0031_{\exp} \pm 0.0005_{\mathrm{th}}}$

K_{l3}: $|V_{us}| = 0.2233 \pm 0.0024$ $[f_+(0) = 0.97 \pm 0.01]$

The τ could give the most precise V_{us} determination

First Measurements from Babar and Belle

Mode	$\mathscr{B}(10^{-3})$ [15]	Updated $\mathscr{B}(10^{-3})$ with results from [20–22]
K^-	6.81 ± 0.23	[Replace with 7.15 ± 0.03]
$K^-\pi^0$	4.54 ± 0.30	Average with $4.16 \pm 0.18 \Rightarrow 4.26 \pm 0.16$ ($S = 1.0$)
$\bar{K}^0\pi^-$	8.78 ± 0.38	Average with $8.08 \pm 0.26 \Rightarrow 8.31 \pm 0.28$ ($S = 1.3$)
$K^-\pi^0\pi^0$	0.58 ± 0.24	
$\bar{K}^0\pi^-\pi^0$	3.60 ± 0.40	
$K^-\pi^+\pi^-$	3.30 ± 0.28	Average with $2.73 \pm 0.09 \Rightarrow 2.80 \pm 0.16$ ($S = 1.9$)
$K^-\eta$	0.27 ± 0.06	
$(\bar{K}3\pi)^-$ (estimated)	0.74 ± 0.30	
$K_1(1270)^- \to K^-\omega$	0.67 ± 0.21	
$(\bar{K}4\pi)^-$ (estimated) and $K^{*-}\eta$	0.40 ± 0.12	
Sum	29.69 ± 0.86	Updated Estimate: 28.44 ± 0.74 [28.78 ± 0.71]

S. Banerjee

KAON'07

Smaller $\tau \to K$ branching ratios → smaller $R_{\tau,S}$ → smaller V_{us}

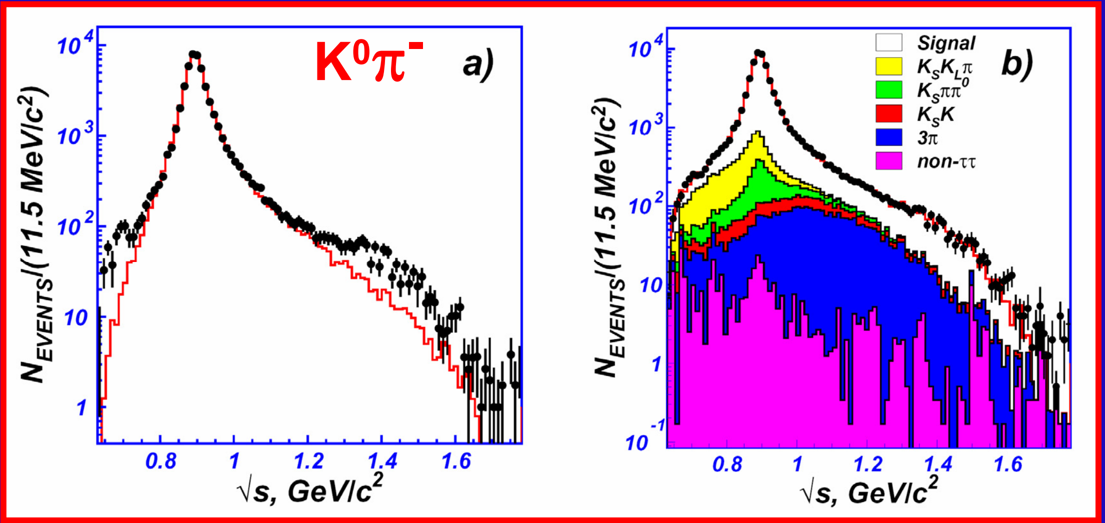
$$R^{00}_{\tau,S}\Big|_{\mathrm{OLD}} = 0.1686\ (47) \quad \longrightarrow \quad R^{00}_{\tau,S}\Big|_{\mathrm{NEW}} = 0.1617\ (40)$$

$$\left|V_{us}\right|_{\mathrm{OLD}} = 0.2212 \pm 0.0031_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}} \quad \longrightarrow \quad \left|V_{us}\right|_{\mathrm{NEW}} = 0.2165 \pm 0.0026_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}}$$

Much more data coming. Precise measurement expected soon

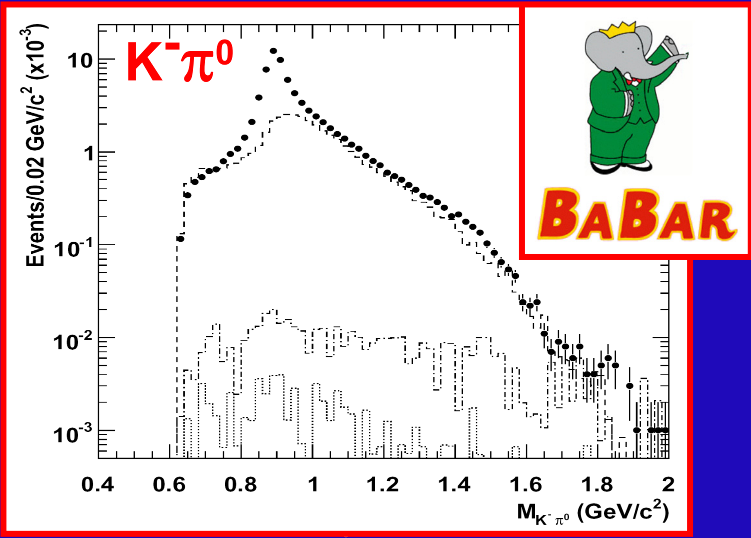
Huge number of $\tau^+\tau^-$ events at the B Factories

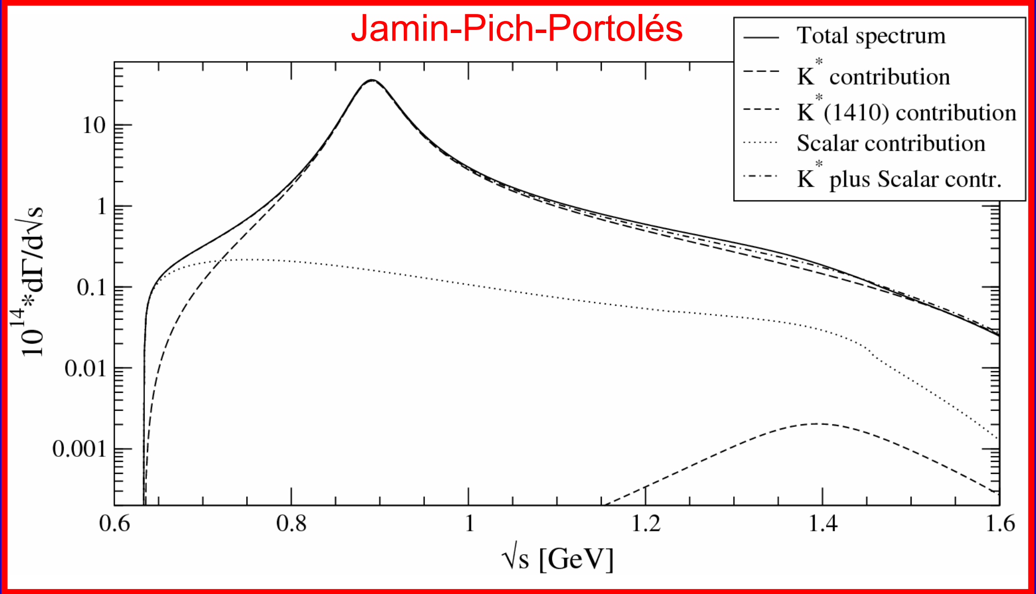
$Br(\tau^- \to K_S \pi^- \nu_\tau) = (0.404 \pm 0.002_{stat} \pm 0.013_{syst})\ \%$



Ongoing data analysis

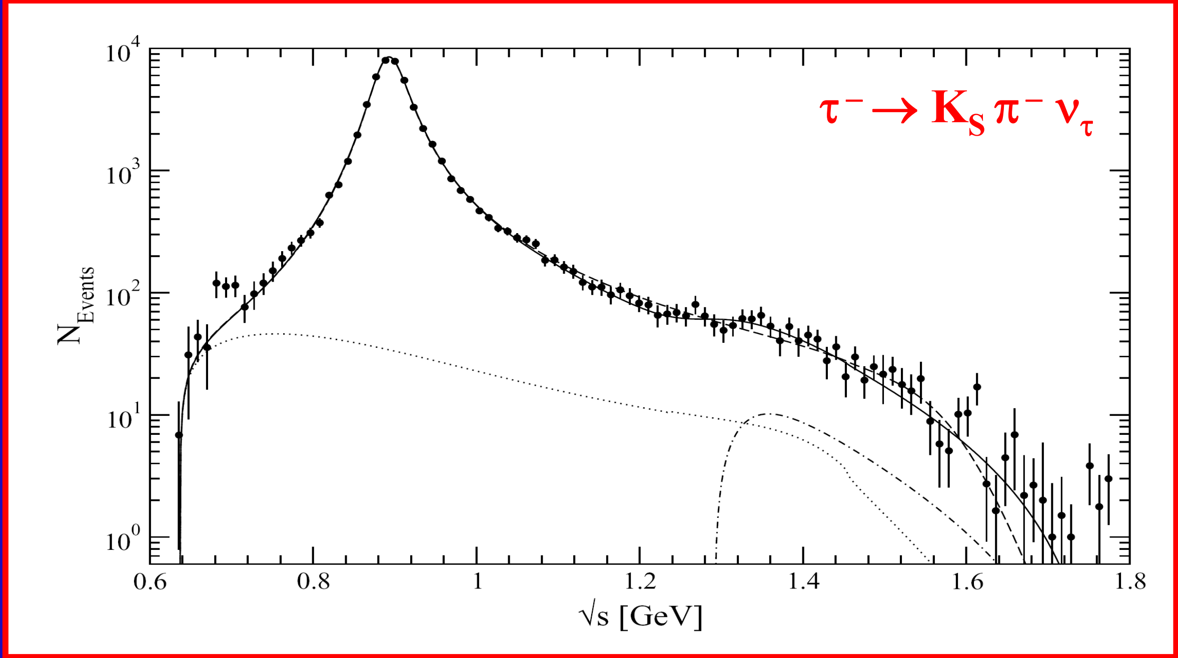
$Br(\tau^- \to K^- \pi^0 \nu_\tau) = (0.416 \pm 0.003_{stat} \pm 0.018_{syst})\ \%$





Jamin-Pich-Portolés 08

RχT Description of BELLE data



Shape fit:

$M_{K^*} = 895.3 \pm 0.2$ MeV

$\Gamma_{K^*} = 47.5 \pm 0.4$ MeV

RχT normalization fixed ➡ $\mathrm{Br}(\tau^- \to K_S \pi^- \nu_\tau)_{th} = (0.427 \pm 0.024)\ \%$

$\mathrm{Br}(\tau^- \to K_S \pi^- \nu_\tau)_{Belle} = (0.404 \pm 0.002_{stat} \pm 0.013_{syst})\ \%$

➡ **Prediction for K_{l3} Form Factor Slopes:**

$$\lambda'_+ = (25.20 \pm 0.33)\, 10^{-3} \quad ; \quad \lambda''_+ = (12.85 \pm 0.31)\, 10^{-4} \quad ; \quad \lambda'''_+ = (9.56 \pm 0.28)\, 10^{-5}$$

EXP: (Flavia*net* Kaon WG) $\lambda'_+ = (25.2 \pm 0.9)\, 10^{-3} \quad ; \quad \lambda''_+ = (16 \pm 4)\, 10^{-4}$

SUMMARY

The τ is a clean laboratory to test the Standard Model

- Precision physics
- QCD tests
- Open questions: $(g\text{-}2)_\mu$
- Hints of new physics: ν's
- Future facilities: τcF, SuperB
- Tool for NP searches: LHC

There is an exciting future ahead

The τ could give the most precise V_{us} determination

- From present τ data one gets:

$$\boxed{|V_{us}| = 0.2165 \pm 0.0026_{\mathrm{exp}} \pm 0.0005_{\mathrm{th}}}$$

- Accuracy similar already to K_{l3}:

$$|V_{us}| = 0.2234 \pm 0.0023 \qquad [f_+(0) = 0.97 \pm 0.01]$$

Interesting challenge for the B Factories & BESIII

A simultaneous m_s & V_{us} fit could be possible

However:

- **Perturbative QCD corrections need to be better understood** (CIPT)

$$\Delta_{00}(\alpha_s)^{L+T} = 0.753 + 0.214 + 0.065 - 0.063 + \ldots$$

$$\Delta_{10}(\alpha_s)^{L+T} = 0.912 + 0.334 + 0.192 + 0.069 + \ldots$$

$$\Delta_{20}(\alpha_s)^{L+T} = 1.055 + 0.451 + 0.330 + 0.232 + \ldots$$

$$\Delta_{30}(\alpha_s)^{L+T} = 1.190 + 0.571 + 0.484 + 0.432 + \ldots$$

$$\Delta_{40}(\alpha_s)^{L+T} = 1.324 + 0.697 + 0.657 + 0.676 + \ldots$$

Sizeable theoretical uncertainties

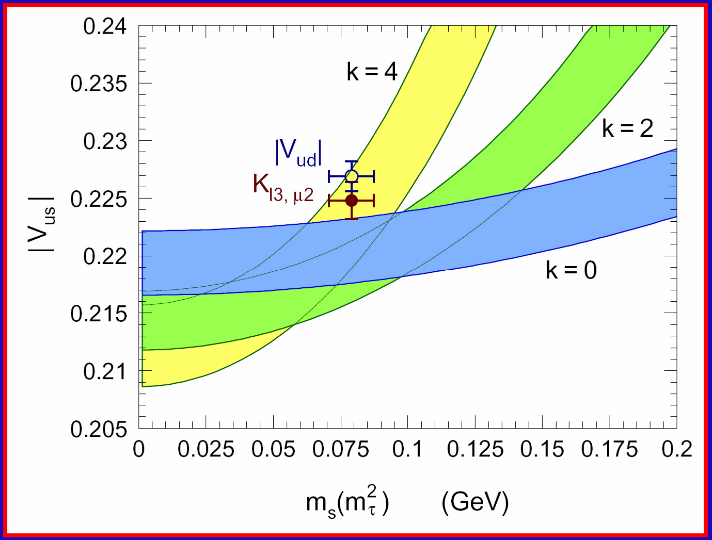
Resummations, pinched weights (Maltman & Wolfe), …

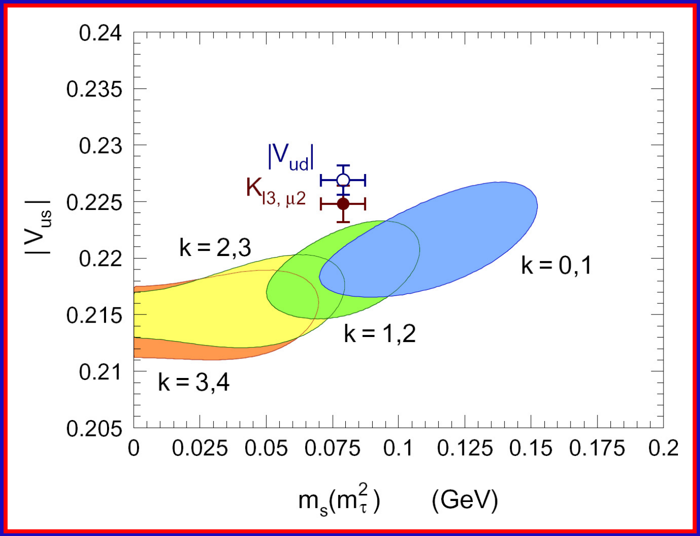
- **Not enough sensitivity with present data**

Large correlations. Low statistics. Missing decay modes …

Davier-Höcker-Zhang ‘05

ALEPH





Taking **V_{us} = 0.2225 (21) :**

Chen et al ’01 , J=0 included

(k,l)	m_s (MeV)	σ_{m_s} (MeV) exp.	$\lvert V_{us}\rvert$	α_s	$\langle m_s\bar{s}s\rangle$	trunc.	R-scale	th.
(0,0)	132	26	13	2	4	9	9	14
(1,0)	120	13	9	3	4	10	11	16
(2,0)	117	10	7	3	6	14	14	21
(3,0)	117	9	8	2	8	19	16	27
(4,0)	103	7	5	3	9	20	19	29

$$m_s(m_\tau) = \left(120\,^{+21}_{-26}\right)\ \text{MeV}$$

$$m_s(2\,\text{GeV}) = \left(116\,^{+20}_{-25}\right)\ \text{MeV}$$

Gámiz et al ’03 , J=0 excluded

Moment	$m_s(m_\tau)$ [MeV]
(0,0)	192 ± 72
(1,0)	164 ± 31
(2,0)	137 ± 20
(3,0)	115 ± 17
(4,0)	100 ± 17

$$m_s(m_\tau) = (122 \pm 17)\ \text{MeV}$$

$$m_s(2\,\text{GeV}) = (117 \pm 17)\ \text{MeV}$$

- Strong k dependence with ALEPH data (m$_s$ decreases with increasing k)

Spectral function underestimated at large invariant masses

$\Rightarrow$ Missing events / modes ($K\pi\pi$, $K\pi\pi\pi$, …)

- Much better behaviour with OPAL data:

(0,0) $\Rightarrow$ $\mathbf{V_{us} = 0.2208\ (34)}$ $\Rightarrow$

Gámiz et al ’05 , J=0 excluded

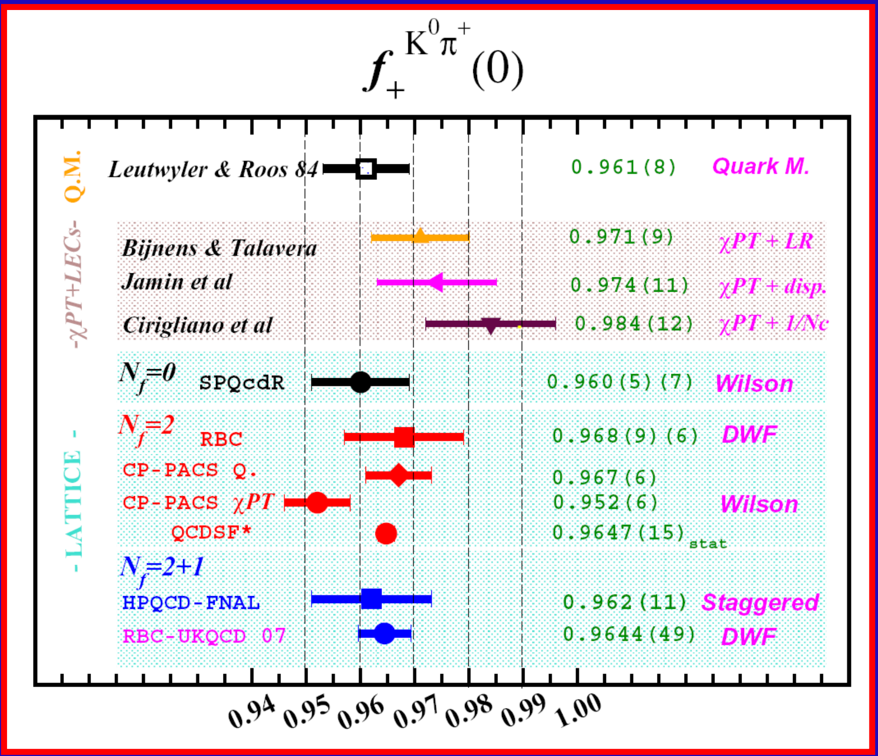
Moment	$m_s(m_\tau)$ [MeV]
(2,0)	89 ± 39
(3,0)	84 ± 27
(4,0)	78 ± 22

$$m_s(m_\tau) = (84 \pm 23)\ \mathrm{MeV} \quad , \quad m_s(2\,\mathrm{GeV}) = (81 \pm 22)\ \mathrm{MeV}$$

- $\tau \to K\nu$ from $K \to \mu\nu$ + OPAL: $\mathbf{V_{us} = 0.2220\ (33)}$

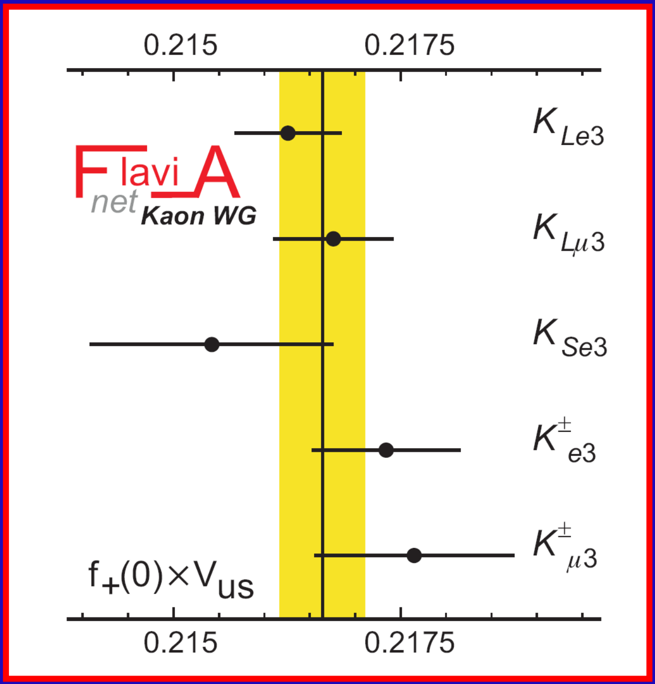
K_{l3} Decays

Large $O(p^6)$ ChPT correction (Bijnens-Talavera)



$O(p^4)$

$O(p^6)$



$$\left| f_+(0)\, V_{us} \right| = 0.2166 \pm 0.0005$$

$$f_+(0) = 0.97 \pm 0.01 \quad \Rightarrow \quad \left| \mathbf{V_{us}} \right| = \mathbf{0.2233 \pm 0.0024}$$