Flavour Physics
With Other Facilities

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IFIC , Valencia

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Flavour Structure of the Standard Model

$$\begin{pmatrix} u & \nu_e \\ d & e^- \end{pmatrix} , \quad \begin{pmatrix} c & \nu_\mu \\ s & \mu^- \end{pmatrix} , \quad \begin{pmatrix} t & \nu_\tau \\ b & \tau^- \end{pmatrix}$$

Why 3 ?

- Pattern of masses
- Flavour Mixing
- $\not{CP}$

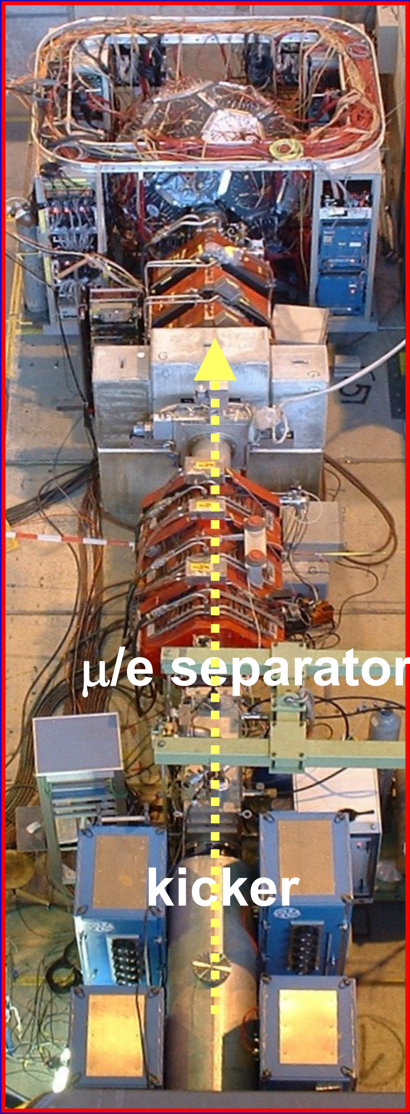
⟷

Related to SSB

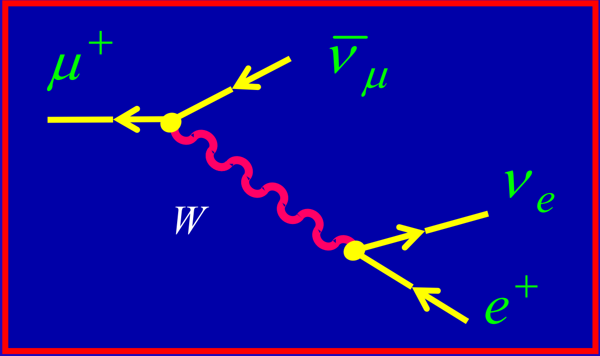
Scalar Sector (Higgs)

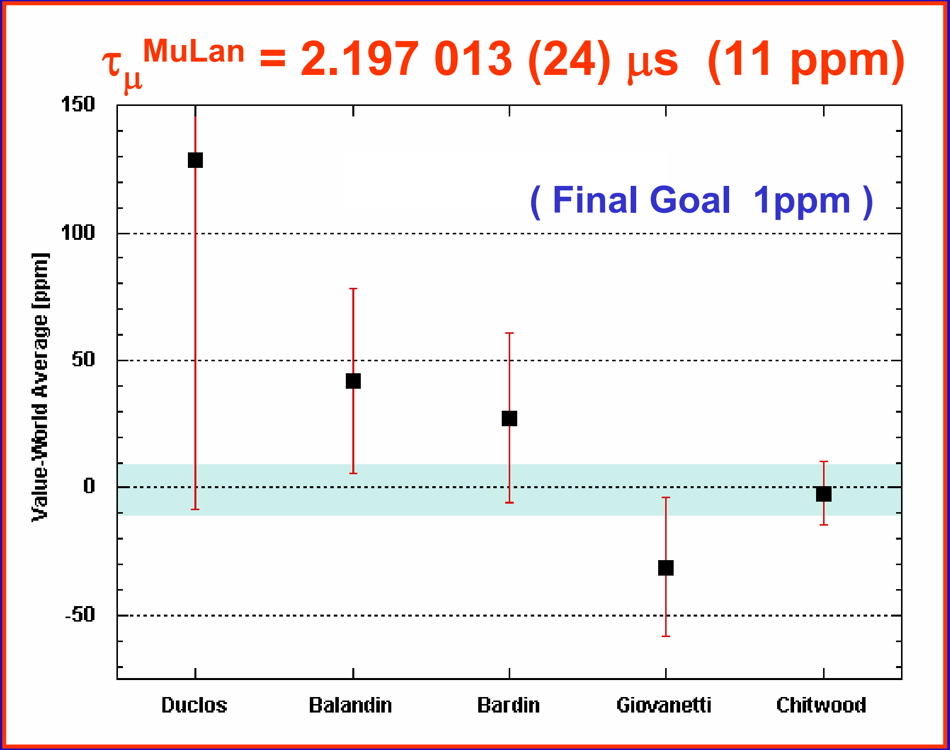
- **Kaon Factories :** u , d , s
- **τcF :** c , τ , ν_τ
- **BF, SuperB :** b , c , τ
- **LC :** t , …
- **νF :** ν_e , ν_μ , ν_τ

MuLan 2007



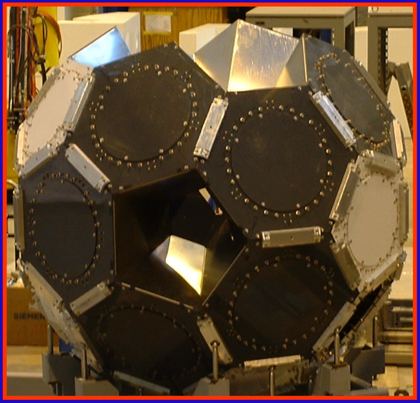
$$\frac{1}{\tau_\mu} = \frac{G_F^2\, m_\mu^5}{192\,\pi^3}\,(1+\delta_{\rm QED})$$





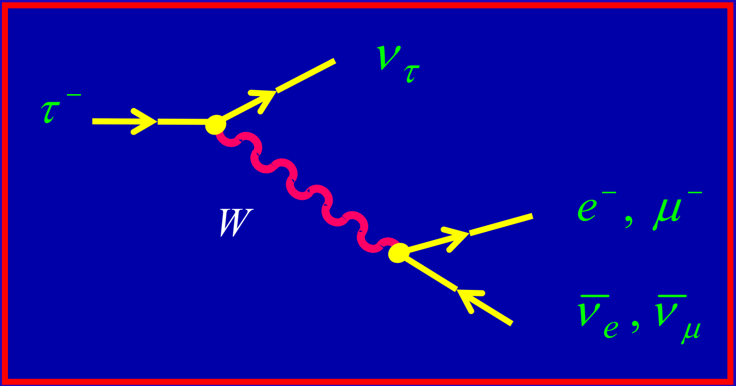
$\delta_{\rm QED}$ known to 0.3 ppm

(van-Ritbergen & Stuart)



New World Average:

τ_μ = 2.197 019 (21) μs → G_F = 1.166 371 (6) x 10^{-5} GeV^{-2} (5 ppm)



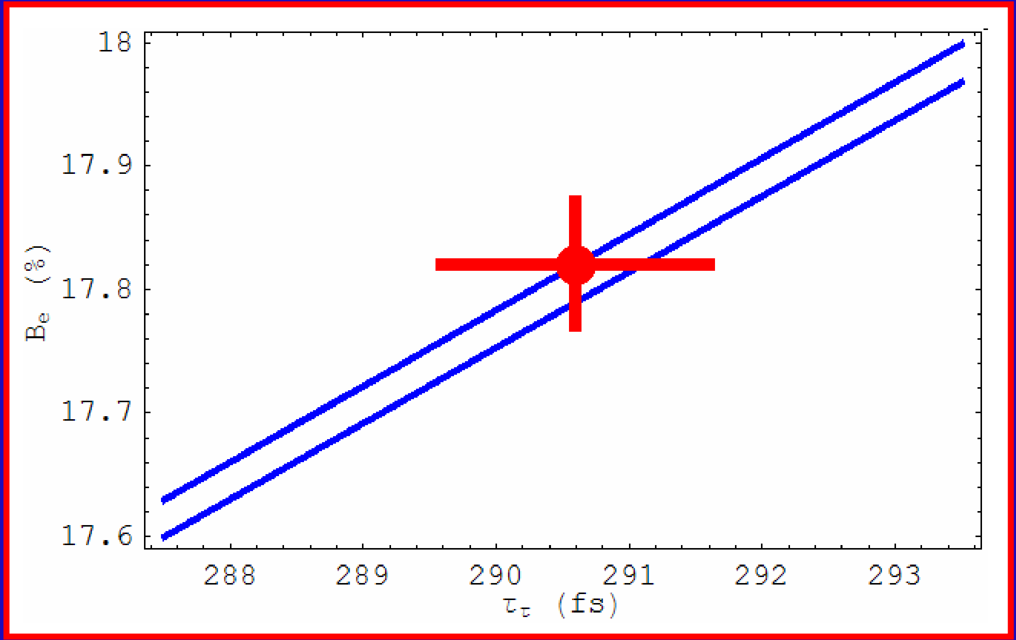
$$\Gamma(\tau \to \nu_\tau \, l \, \bar{\nu}_l) = \frac{G_F^2 \, m_\tau^5}{192 \, \pi^3} \, f(m_l^2/m_\tau^2) \, r_{EW}$$

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

$$r_{EW} = 0.9960$$ (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

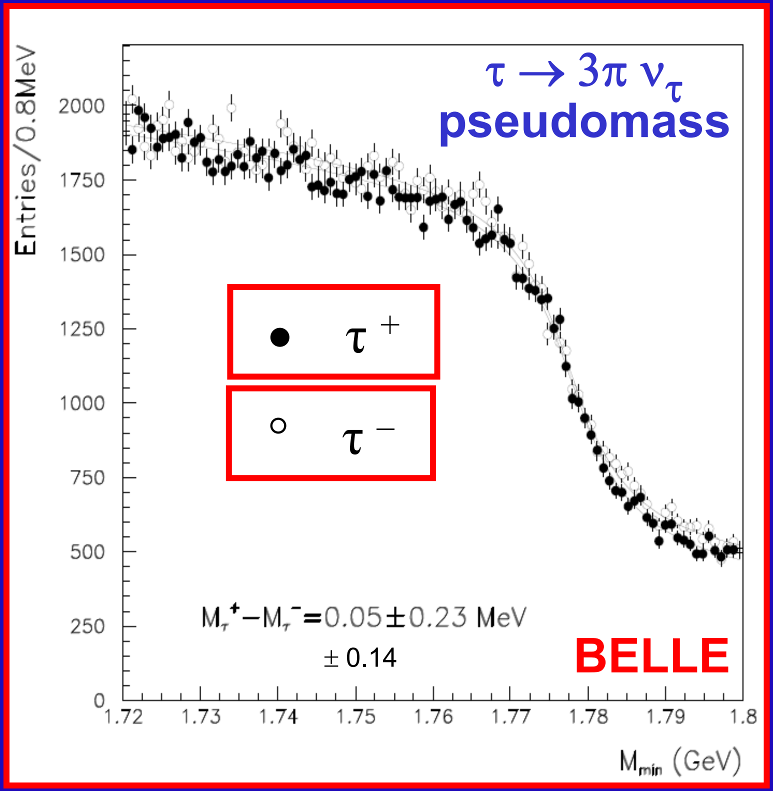
Future Improvements: BABAR , BELLE , KEDR , BESIII , SuperB , …

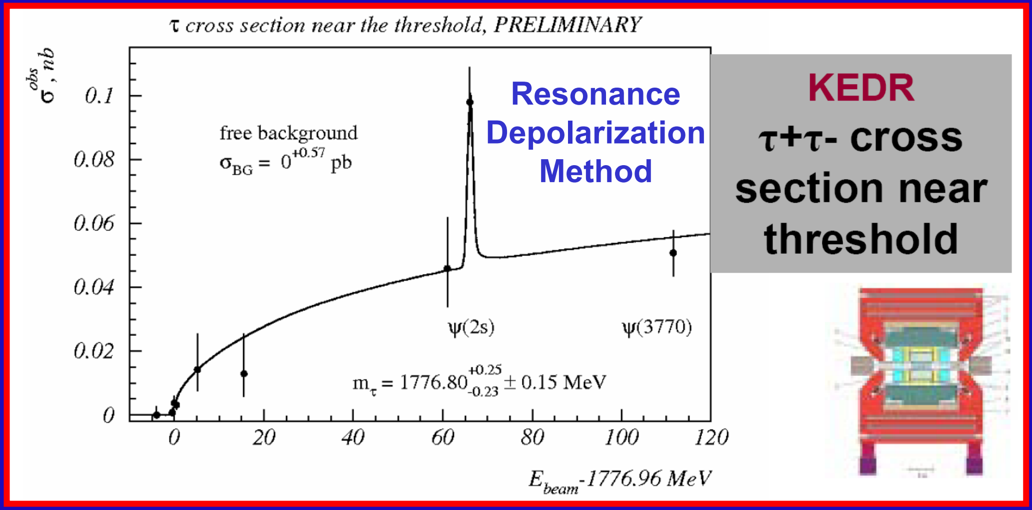
δm_τ ~ 0.023 MeV (12.7 ppm) BESIII

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

$$1776.71 \pm 0.13 \pm 0.32 \;\text{MeV} \quad \text{(BELLE)}$$

$$1776.80 \pm {}^{0.25}_{0.22} \pm 0.15 \;\text{MeV} \quad \text{(KEDR)}$$

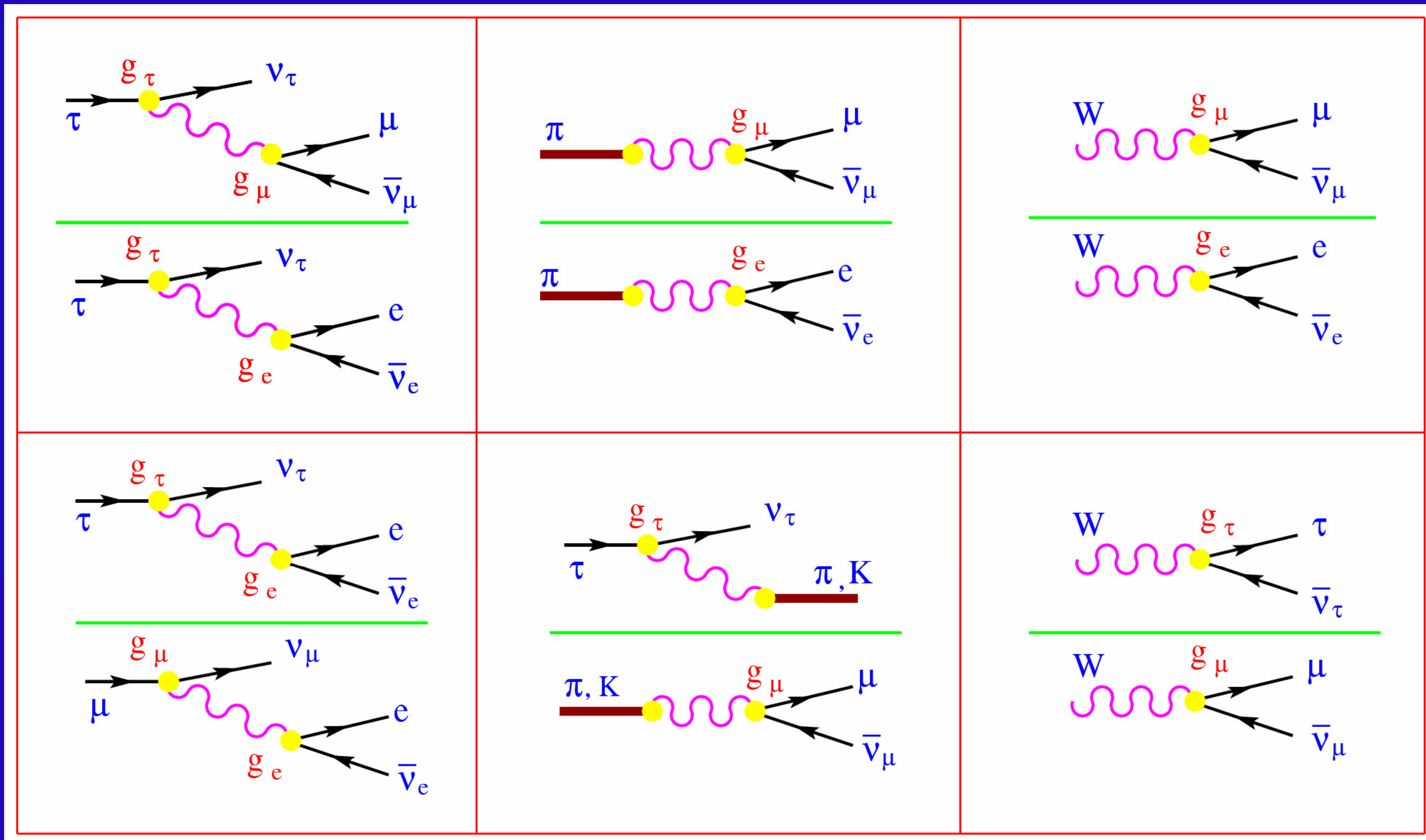




LEPTON UNIVERSALITY

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

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



CHARGED CURRENT UNIVERSALITY

$|g_\tau / g_\mu|$

$B_{\tau\to e} \;\; \tau_\mu / \tau_\tau$	1.0004 ± 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

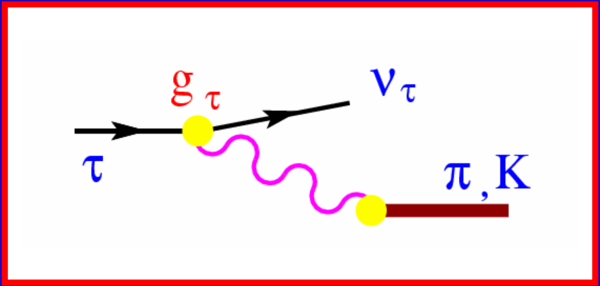
$|g_\mu / g_e|$

$B_{\tau\to\mu} / B_{\tau\to e}$	1.0000 ± 0.0020
$B_{\pi\to\mu} / B_{\pi\to e}$	1.0017 ± 0.0015
$B_{K\to\mu} / B_{K\to e}$	1.012 ± 0.009
$B_{K\to\pi\mu} / B_{K\to\pi e}$	1.0002 ± 0.0026
$B_{W\to\mu} / B_{W\to e}$	0.997 ± 0.010

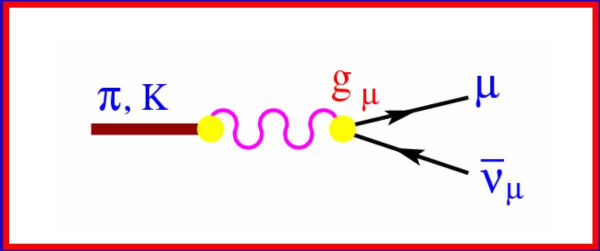
$|g_\tau / g_e|$

$B_{\tau\to\mu} \;\; \tau_\mu / \tau_\tau$	1.0004 ± 0.0023
$B_{W\to\tau} / B_{W\to e}$	1.036 ± 0.014

Assuming Universality:



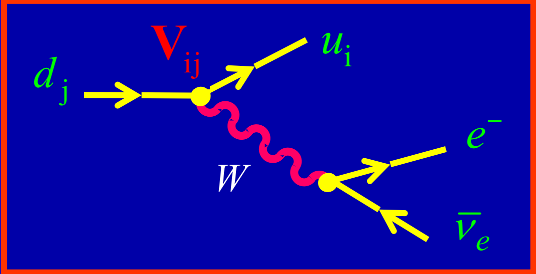
$$\left|\frac{V_{us}}{V_{ud}}\right|\left(\frac{f_K}{f_\pi}\right) = \left(\frac{m_\tau^2 - m_\pi^2}{m_\tau^2 - m_K^2}\right)\sqrt{\frac{\Gamma(\tau^- \to \nu_\tau K^-)}{\Gamma(\tau^- \to \nu_\tau \pi^-)}\;\frac{1+\delta R_{\tau/\pi}}{1+\delta R_{\tau/K}}} = 0.267 \pm 0.005$$



$$\left|\frac{V_{us}}{V_{ud}}\right|\left(\frac{f_K}{f_\pi}\right) = \left(\frac{m_\pi^2 - m_\mu^2}{m_K^2 - m_\mu^2}\right)\sqrt{\frac{m_K^3}{m_\pi^3}\;\frac{\Gamma(K^- \to \bar{\nu}_\mu \mu^-)}{\Gamma(\pi^- \to \bar{\nu}_\mu \mu^-)}\;\frac{1+\delta R_\pi}{1+\delta R_K}} = 0.27618 \pm 0.00048$$

V_{ij} Determination $(0^- \to 0^-)$

K→π l ν , D→K l ν ...



$$\langle P'(k')|\bar{u}_i\gamma^\mu d_j|P(k)\rangle = C_{PP'}\left\{(k+k')^\mu f_+(q^2) + (k-k')^\mu f_-(q^2)\right\}$$

$$\Gamma(P\to P'l\nu) \approx \frac{G_F^2 M_P^5}{192\pi^3}\, |\mathbf{V}_{ij}|^2\, C_{PP'}^2\, |f_+(0)|^2\, \mathcal{I}\, (1+\delta_{RC})$$

$$\mathcal{I} \approx \int_0^{(M_P-M_{P'})^2} \frac{dq^2}{M_P^8}\, \lambda^{3/2}(q^2, M_P^2, M_{P'}^2) \left|\frac{f_+(q^2)}{f_+(0)}\right|^2$$

$f_-(q^2)$ suppressed $\left(m_{u_i} - m_{d_j}\ ,\ m_l\right)$

- Measure the q^2 distribution ➡ $\mathcal{I}$
- Measure Γ ➡ $|f_+(0)|\, |\mathbf{V}_{ij}|$
- Get a theoretical prediction for $f_+(0)$ ➡ $|\mathbf{V}_{ij}|$

Theory is always needed: Symmetries

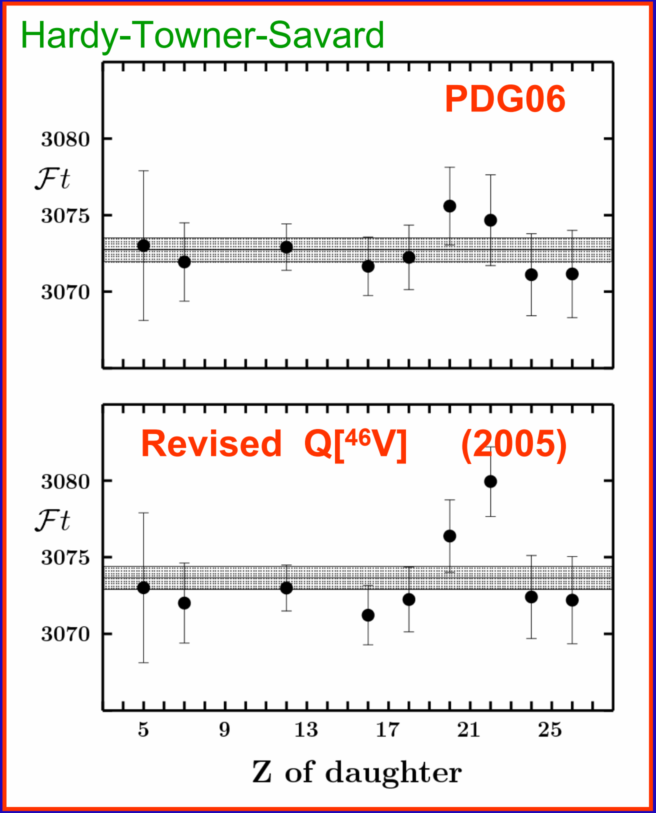
$|V_{ud}|$

$$f_+(0) = 1 + \mathcal{O}[(m_d - m_u)^2]$$

Superallowed Nuclear β Transitions ($0^+ \to 0^+$)

$$|V_{ud}|^2 = \frac{\pi^3 \ln 2}{ft\, G_F^2 m_e^5 (1+\delta_{RC})} = \frac{(2984.48 \pm 0.05)\,\mathrm{s}}{ft\,(1+\delta_{RC})}$$

Nucleus	ft (sec)	V_{ud}
^{10}C	3039.5 (47)	0.97381 (77)(15)(19)
^{14}O	3043.3 (19)	0.97368 (39)(15)(19)
^{26}Al	3036.8 (11)	0.97406 (23)(15)(19)
^{34}Cl	3050.0 (12)	0.97412 (26)(15)(19)
^{38}K	3051.1 (10)	0.97404 (26)(15)(19)
^{42}Sc	3046.8 (12)	0.97330 (32)(15)(19)
^{46}V	3050.7 (12)	0.97280 (34)(15)(19)
^{50}Mn	3045.8 (16)	0.97367 (41)(15)(19)
^{54}Co	3048.4 (11)	0.97373 (40)(15)(19)
weighted ave.		**0.97377 (11)(15)(19)**



$|V_{ud}| = 0.97377 \pm 0.00027$ (Marciano – Sirlin)

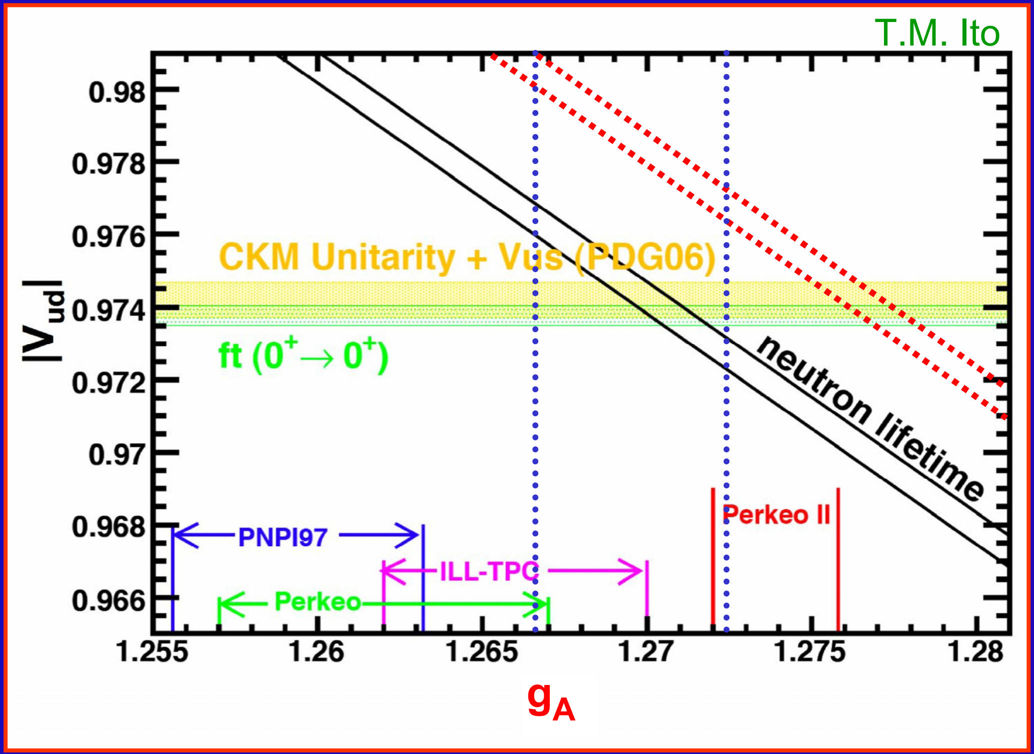
Neutron Decay:

$$|V_{ud}|^2 = \frac{(4908.7 \pm 1.9)\,\mathrm{s}}{\tau_n\,(1 + 3\,g_A^2)}$$

(Czarnecki – Marciano – Sirlin)

PDG06: $\tau_n = (885.7 \pm 0.8)$ s , $g_A = 1.2695 \pm 0.0029$

$\Rightarrow$ $|V_{ud}| = 0.9745 \pm 0.0019$



$\tau_n = (878.5 \pm 0.7 \pm 0.3)$ s

(Serebrov et al, 2005)

PDG06

$|V_{ud}|$ Summary

- **Superallowed Nuclear β Transitions :**

$$|V_{ud}| = 0.97377 \pm 0.00027$$

- **Neutron Decay:** $|\mathbf{V}_{ud}| = 0.9745 \pm 0.0019$

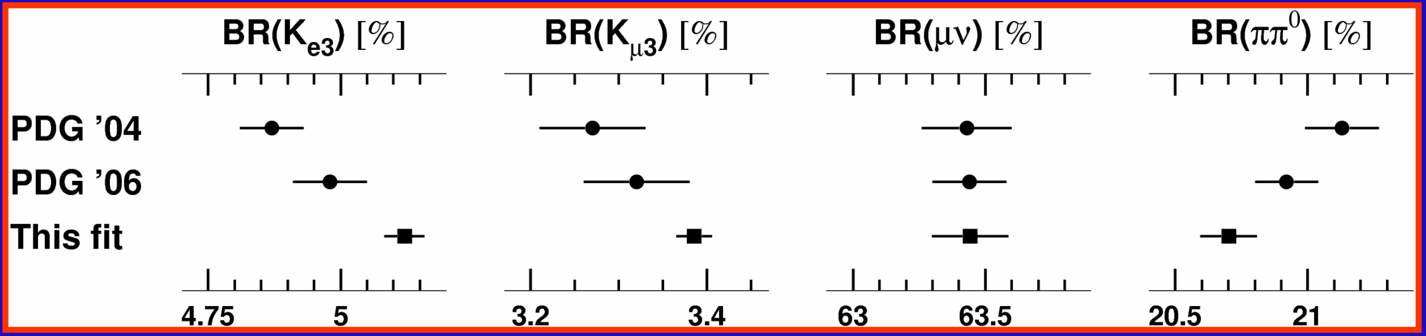
- **Pion Decay:** $\mathrm{Br}(\pi^+ \to \pi^0 e^+ \nu_e) = (1.036 \pm 0.006) \times 10^{-8}$

(PIBETA)

$$|\mathbf{V}_{ud}| = 0.9728 \pm 0.0030$$

K_{l3} Decays

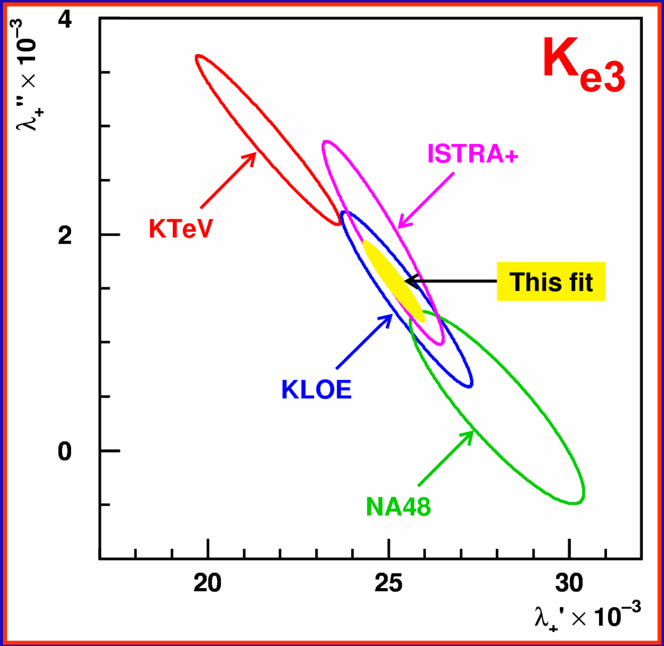
E865, ISTRA+, KLOE, KTEV, NA48

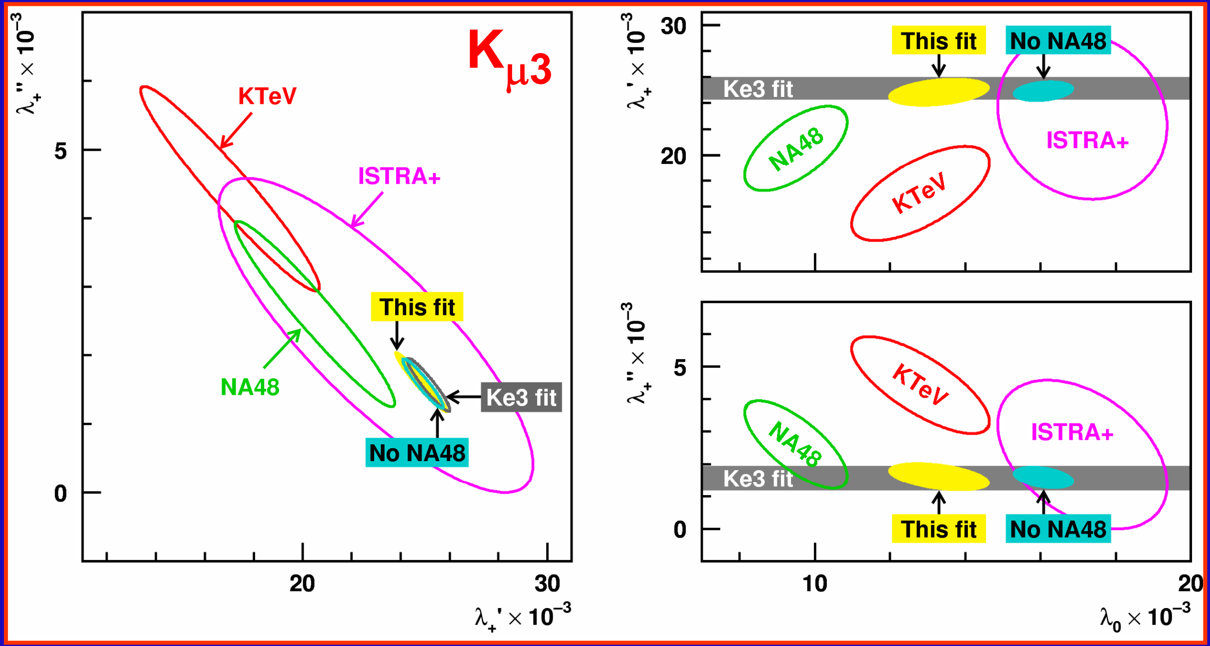


M. Moulson 07

FLAVIA*net* Kaon WG

Form Factor Slopes





			Approx contrib to % err			
Mode	$\vert V_{us}\vert f_+(0)$	% err	BR	τ	Δ	I
$K_L\ e3$	0.21639(55)	0.25	0.09	0.19	0.10	0.09
$K_L\ \mu3$	0.21649(68)	0.31	0.10	0.18	0.15	0.17
$K_S\ e3$	0.21555(142)	0.66	0.65	0.03	0.10	0.09
$K^\pm\ e3$	0.21844(101)	0.46	0.38	0.11	0.24	0.09
$K^\pm\ \mu3$	0.21809(125)	0.57	0.31	0.10	0.45	0.17

$$|f_+(0)\ V_{us}| = 0.21673\ (46)$$

J. Portolés

	Reference	$f_+^{K^0\pi^-}(0)$	
Quark model	[Leutwyler & Roos, 1984]	0.961 (8)	$O(p^4)$
Lattice	[Becirevic et al, 2005]	0.960 (9)	
Lattice	[MILC Collab., 2005]	0.962 (11)	
Lattice	[Dawson et al, 2006]	0.968 (11)	
Lattice	[UKQCD/RBC Collab., 2006]	0.961 (5) !	
	[Bijnens & Talavera, 2003]	0.976 (10)	$O(p^6)$
Kπ scalar f.f.	[Jamin, Oller & Pich, 2004]	0.974 (11)	$O(p^6)$
Large-N_C	[Cirigliano et al, 2005]	0.984 (12)	$O(p^6)$

Large $O(p^6)$ ChPT correction

(Bijnens-Talavera)

$$f_+(0) = 0.97\ (1) \quad \Rightarrow \quad |V_{us}| = 0.2234\ (24)$$

$\Gamma(K^+ \to \mu^+ \nu_\mu) / \Gamma(\pi^+ \to \mu^+ \nu_\mu)$

(Marciano 04)

$$\frac{f_K \, |\mathbf{V}_{us}|}{f_\pi \, |\mathbf{V}_{ud}|} = 0.27618 \pm 0.00048$$

(Jamin-Oller-Pich 06)

$$\frac{f_K}{f_\pi} = 1.208 \pm 0.002 \, {}^{+\,0.007}_{-\,0.014}$$

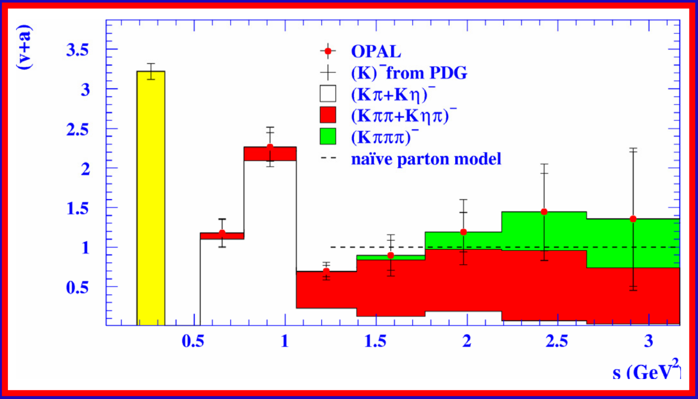
(MILC 06)

$$|\mathbf{V}_{ud}| = 0.97378 \pm 0.00027$$

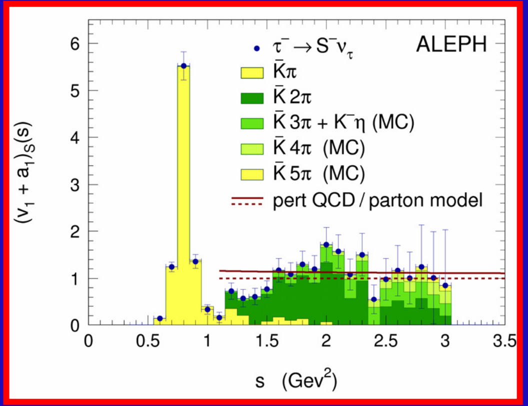
(PDG 06)

$$\Rightarrow \quad |\mathbf{V}_{us}| = 0.2226 \, {}^{+0.0026}_{-0.0014}$$

$R_{\tau,S} = \Gamma(\tau^- \to \nu_\tau S^-) / \Gamma(\tau^- \to \nu_\tau e^- \bar{\nu}_e)$



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



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

$$|V_{us}|^2 = \frac{R_{\tau,S}^{(0,0)}}{\frac{R_{\tau,V+A}^{(0,0)}}{|V_{ud}|^2} - \delta R_{\tau,\text{th}}^{(0,0)}}$$

$$m_s(2\,\text{GeV}) = 94 \pm 6 \;\; \text{MeV}$$

Gámiz-Jamin-Pich-Prades-Schwab

$$|V_{us}| = 0.2220 \pm 0.0031_{\text{exp}} \pm 0.0011_{\text{th}}$$

Simultaneous m_s & V_{us} fit possible with better data

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

$|V_{us}|$ Summary

- K_{l3} : $|V_{us}| = 0.2234 \pm 0.0024$
- $K_{\mu 2} / \pi_{\mu 2}$: $|V_{us}| = 0.2226\,^{+0.0026}_{-0.0014}$
- τ Decay: $|V_{us}| = 0.2220 \pm 0.0033$
- Hyperon Decay: $|V_{us}| = 0.226 \pm 0.005$

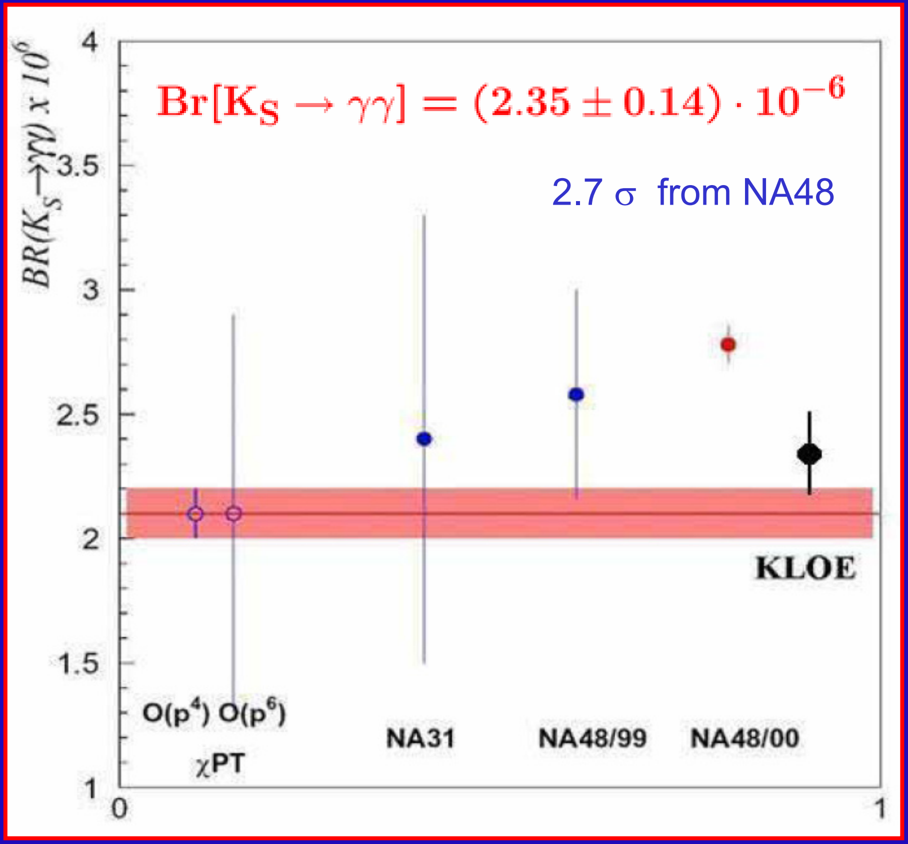
➡ $|V_{us}| = 0.2230 \pm 0.0015$

$$|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 0.9980 \pm 0.0015$$

KLOE

$\mathrm{Br}[K_S \to e^+e^-(\gamma)] < 2.1 \cdot 10^{-8}$ (90% C.L.)

CPLEAR: $< 1.4 \cdot 10^{-7}$



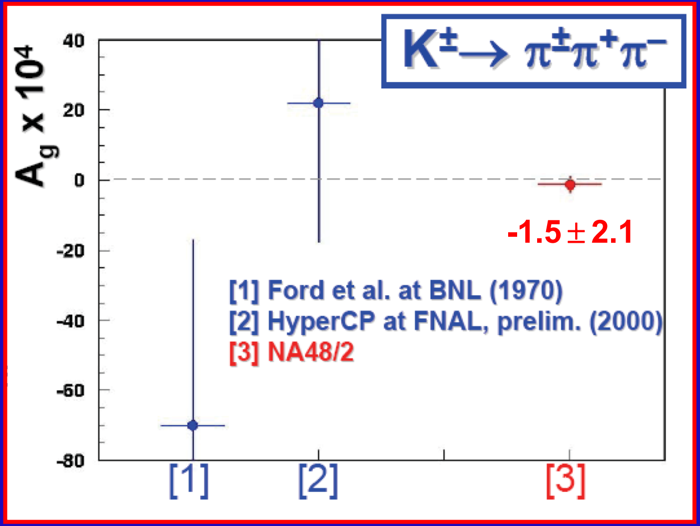
Proposals to upgrade DAΦNE in Luminosity (and Energy)

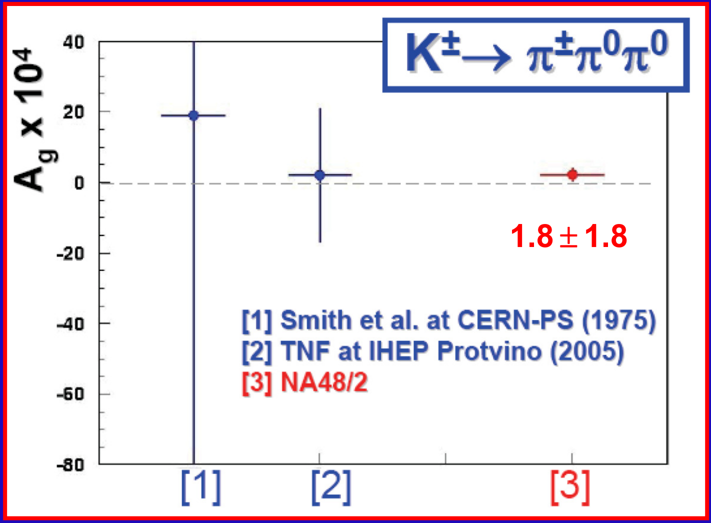
NA48

Direct $\not{CP}$

Slope Asymmetry

$$A_g = \frac{g_+ - g_-}{g_+ + g_-}$$





$$\mathrm{Br}(K^\pm \to \pi^\pm e^+ e^- \gamma) = (1.27 \pm 0.14 \pm 0.05)\cdot 10^{-8}$$

First observation

$$\Gamma(K_{e2})/\Gamma(K_{\mu 2}) = (2.416 \pm 0.043 \pm 0.024)\cdot 10^{-5}$$

PDG 06: 2.45 ± 0.11

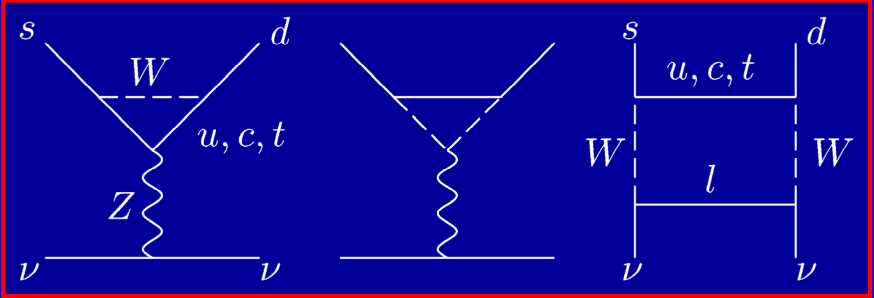
$$\mathrm{Br}(\Xi^0 \to \Lambda^0 e^+ e^-) = (7.7 \pm 0.5 \pm 0.4)\cdot 10^{-6}$$

First measurement

$$\alpha_\Xi\, \alpha_\Lambda = -0.8 \pm 0.2$$

$K \to \pi \nu \bar{\nu}$

$\mathbf{T} \sim F\left(V_{is}^* V_{id}, m_i^2/M_W^2\right) \left(\bar{\nu}_L \gamma_\mu \nu_L\right) \left\langle \pi \left| \bar{s}_L \gamma_\mu d_L \right| K \right\rangle$



$$\mathrm{Br}\left(K^+ \to \pi^+ \nu \bar{\nu}\right) = (8.4 \pm 1.0) \times 10^{-11} \sim A^4 \left[\eta^2 + (1.4 - \rho)^2\right]$$

$$\mathrm{Br}\left(K_L \to \pi^0 \nu \bar{\nu}\right) = (2.7 \pm 0.4) \times 10^{-11} \sim A^4 \eta^2$$

Buras et al

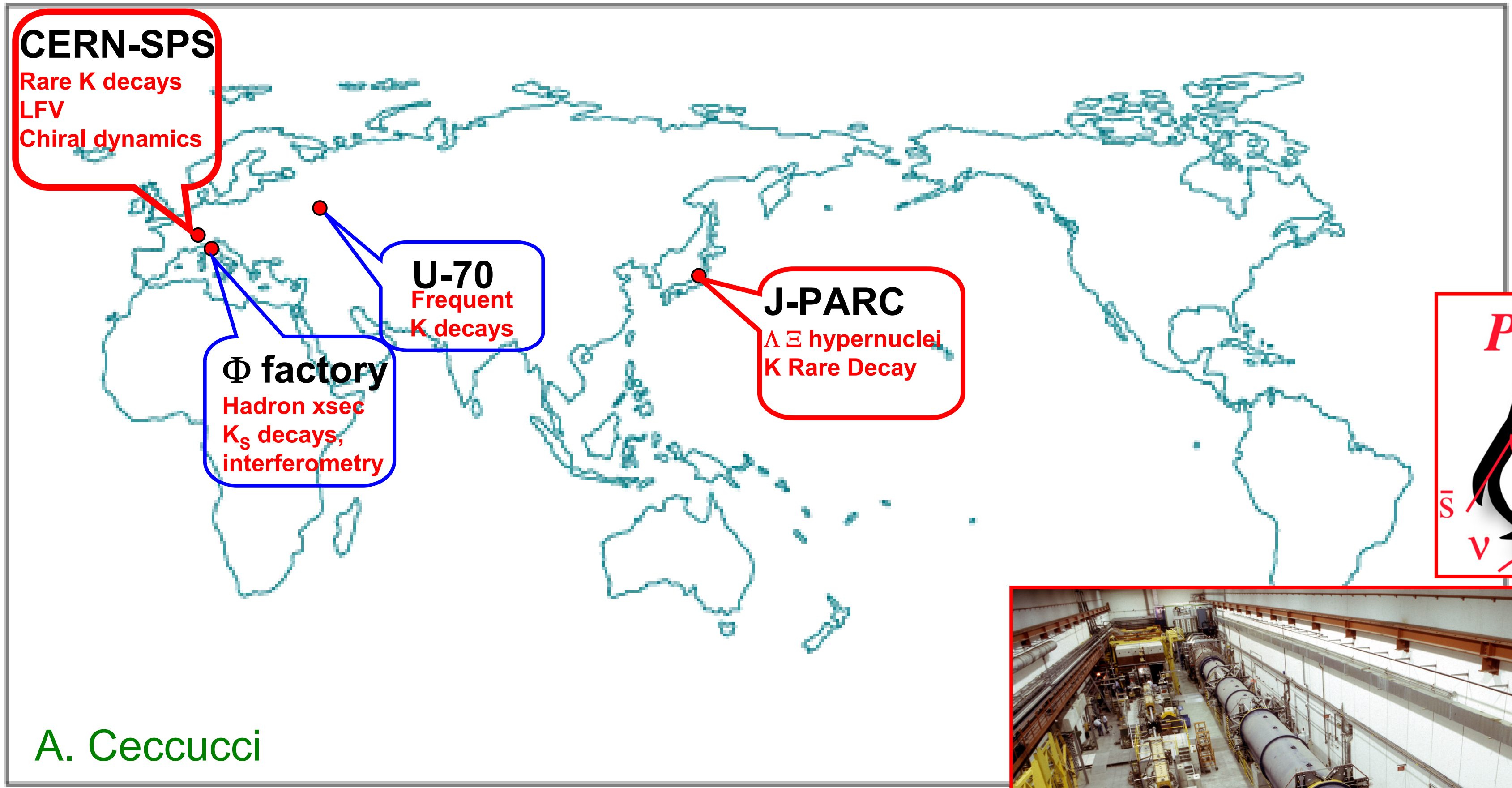
Long-distance contributions are negligible

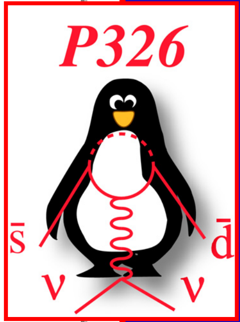
$\mathbf{T}\left(K_L \to \pi^0 \nu \bar{\nu}\right) \neq 0$ ➡ $\not{CP}$

- **BNL:** few events! ➡ $\mathrm{Br}\left(K^+ \to \pi^+ \nu \bar{\nu}\right) = \left(1.47\,^{+1.30}_{-0.89}\right) \cdot 10^{-10}$
- **KEK-E391a:** $\mathrm{Br}\left(K_L \to \pi^0 \nu \bar{\nu}\right) < 2.1 \times 10^{-7}$ (90% C.L.)

New Experiments Needed

Future Kaon Initiatives





NA48/2 → 2×10^{11} kaon decays

P-326 (NA48/3) → $> 10^{13}$ kaon decays

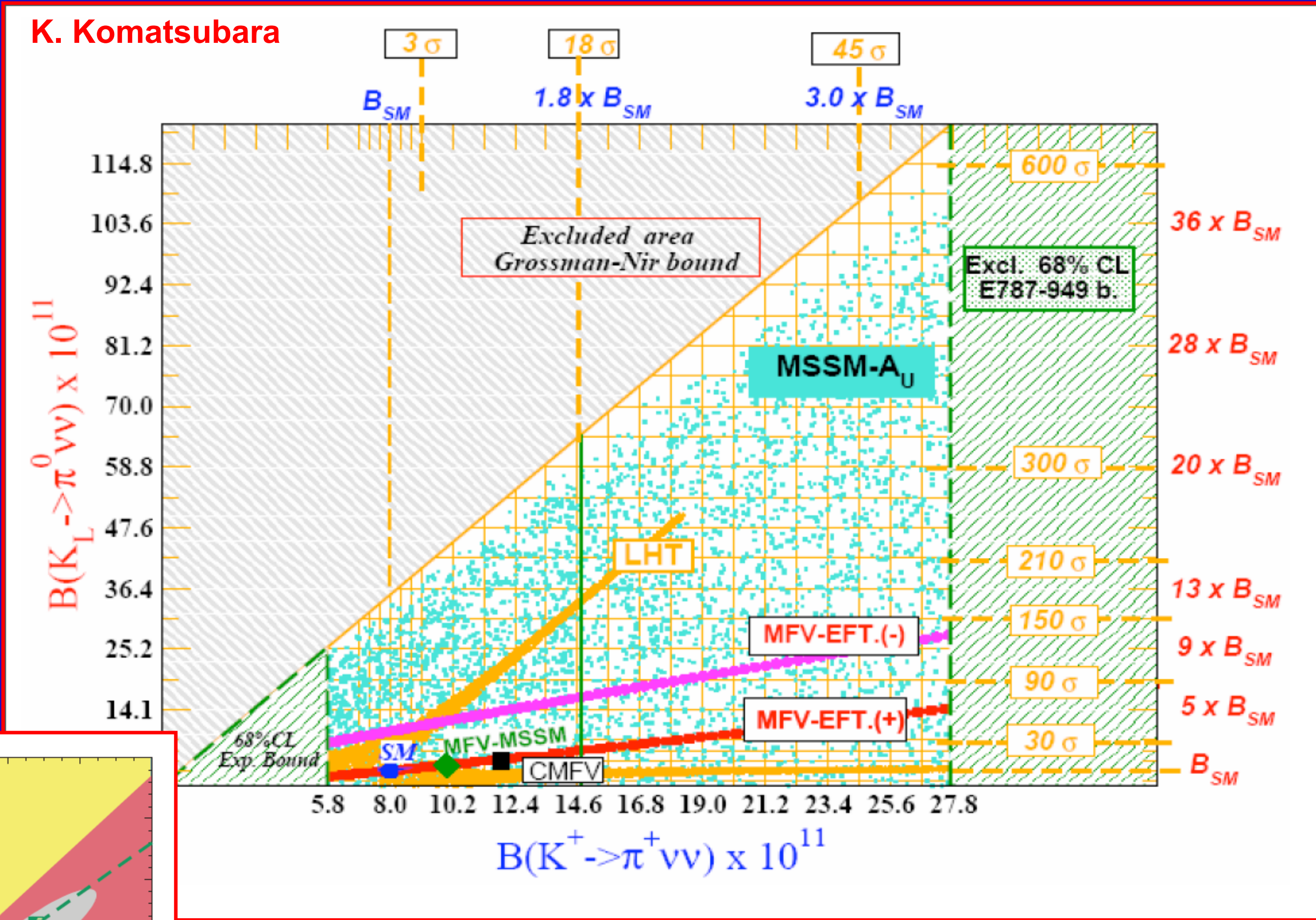
$\Delta[\mathrm{Br}(K^+ \to \pi^+ \nu\nu)] \sim 0.10$

Plans for $K^+ \to \pi^+ \bar{\nu} \nu$

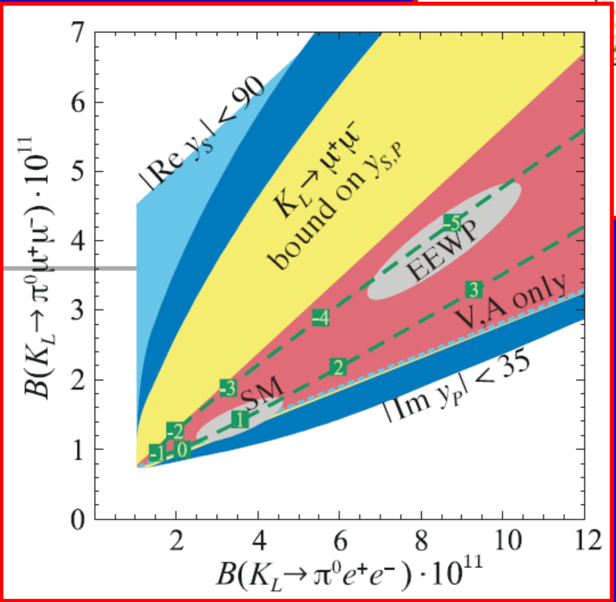
- J-PARC: LoI ; plans to use the BNL-E949 detector
- CERN: P-326 ; about 80 SM events in two years

Plans for $K_L \to \pi^0 \bar{\nu} \nu$

- KEK: E391a ; data taking completed (three runs)
  - Present limit $< 2.1\ 10^{-7}$ 90% CL (10% of Run-1 data)
  - Aims to reach the Grossman-Nir bound ($\sim 10^{-9}$)
- J-PARC: proposal (>2010)
  - Step I: E391a detector at J-PARC ~ SM sensitivity
  - Step II: New detector & dedicated beam-line ~ 100 SM events
- CERN: would need an upgraded proton complex



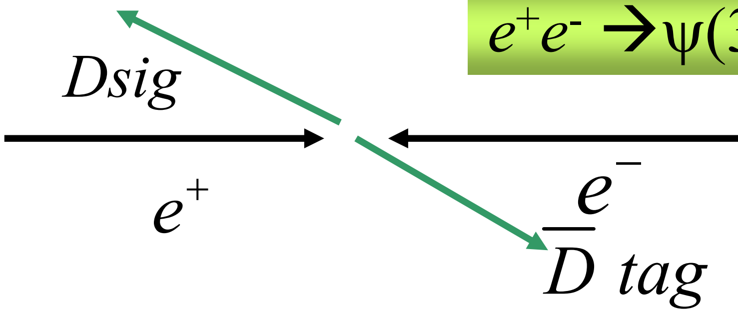
$K_L \to \pi^0 l^+ l^-$



Plenty of Room for New Physics

ψ(3770) Analysis Strategy

$e^+e^- \rightarrow \psi(3770) \rightarrow D\overline{D}$

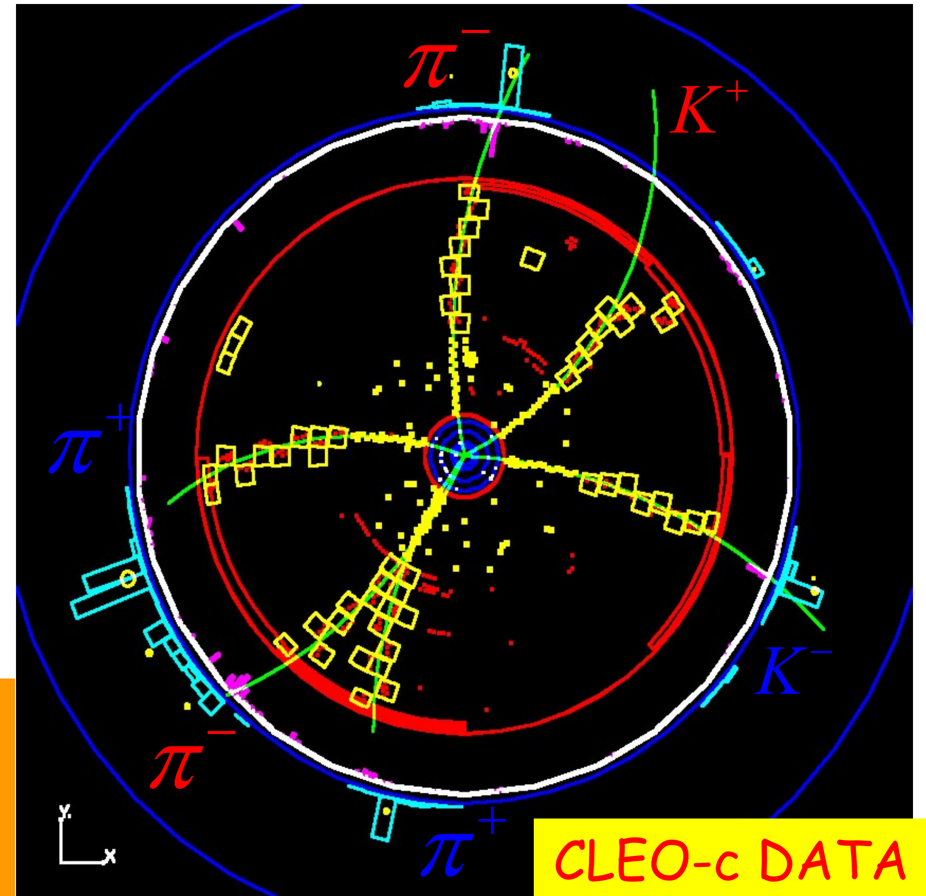


ψ(3770) is to charm what Υ(4S) is to beauty

- ❑ Pure DD, no additional particles ($E_D = E_{beam}$).
- ❑ σ (DD) = 6.4 nb (Υ(4S)->BB ~ 1 nb)
- ❑ Low multiplicity ~ 5-6 charged particles/event

➔ high tagging efficiency: ~22% of D's

Compared to ~0.1% of B's at the Υ(4S)



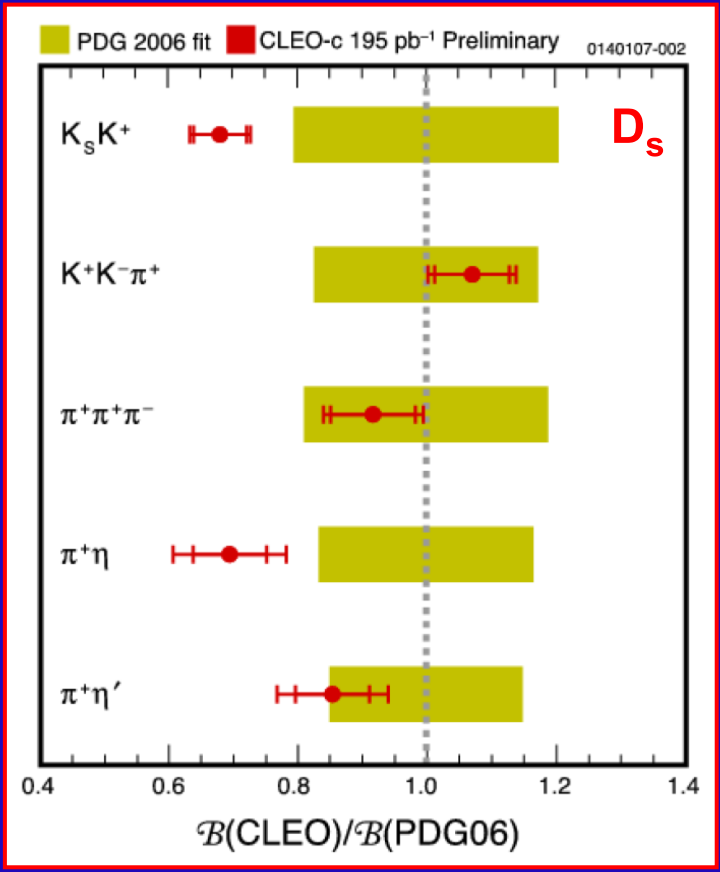
A little luminosity goes a long way:
\# events in 100 pb^{-1} @ charm factory with 2D's reconstructed ~
\# events in 500 fb^{-1} @ Υ(4S) with 2B's reconstructed

$\psi(3770) \rightarrow D^+D^-$

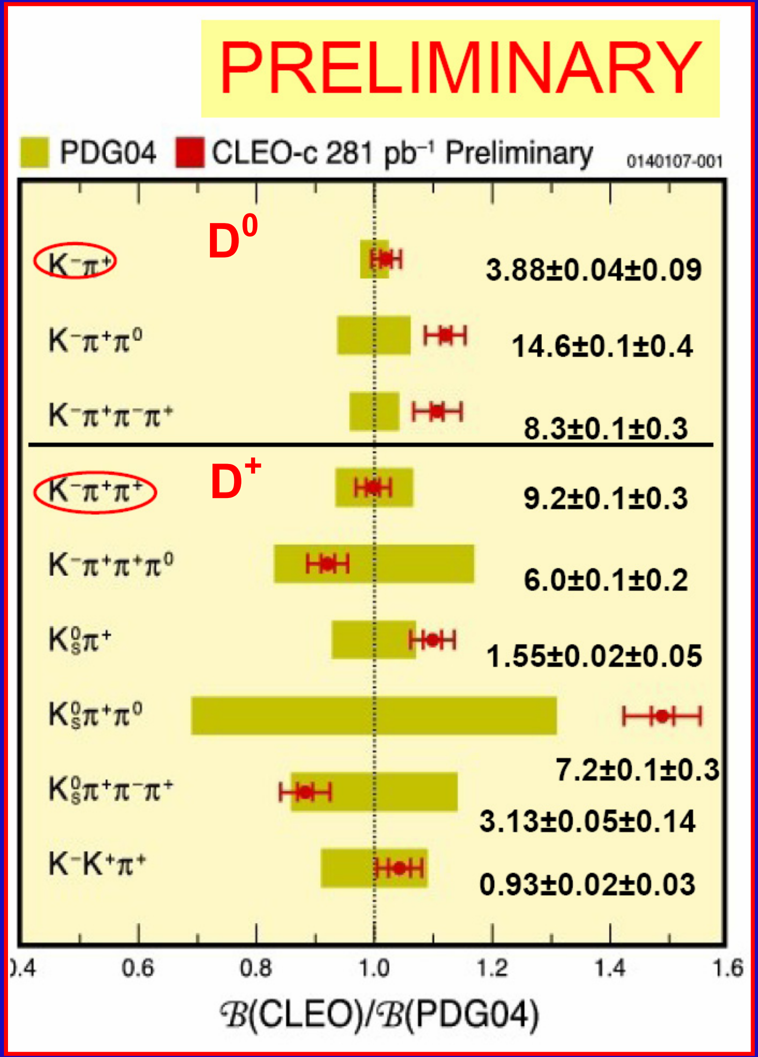
$D^+ \rightarrow K^-\pi^+\pi^+,\ D^- \rightarrow K^+\pi^-\pi^-$

Absolute Hadronic Br's

CLEO-c



D_s^+ Mode	$\mathcal{B}$ (%)
$K_S K^+$	$1.50 \pm 0.09 \pm 0.05$
$K^- K^+ \pi^+$	$5.57 \pm 0.30 \pm 0.19$
$K^- K^+ \pi^+ \pi^0$	$5.62 \pm 0.33 \pm 0.51$
$\pi^+ \pi^+ \pi^-$	$1.12 \pm 0.08 \pm 0.05$
$\pi^+ \eta$	$1.47 \pm 0.12 \pm 0.14$
$\pi^+ \eta'$	$4.02 \pm 0.27 \pm 0.30$



I. Danko (La Thuile 07)

f_D and f_{Ds} : comparison with theory

- Summary of CLEO-c results:

  f_D = (223 ± 17 ± 3) MeV

arXiv:0704.0629

$$f_{D_s} = (274 \pm 13 \pm 7)\ \text{MeV}$$

$$f_{D_s}/f_{D+} = 1.23 \pm 0.11 \pm 0.04$$

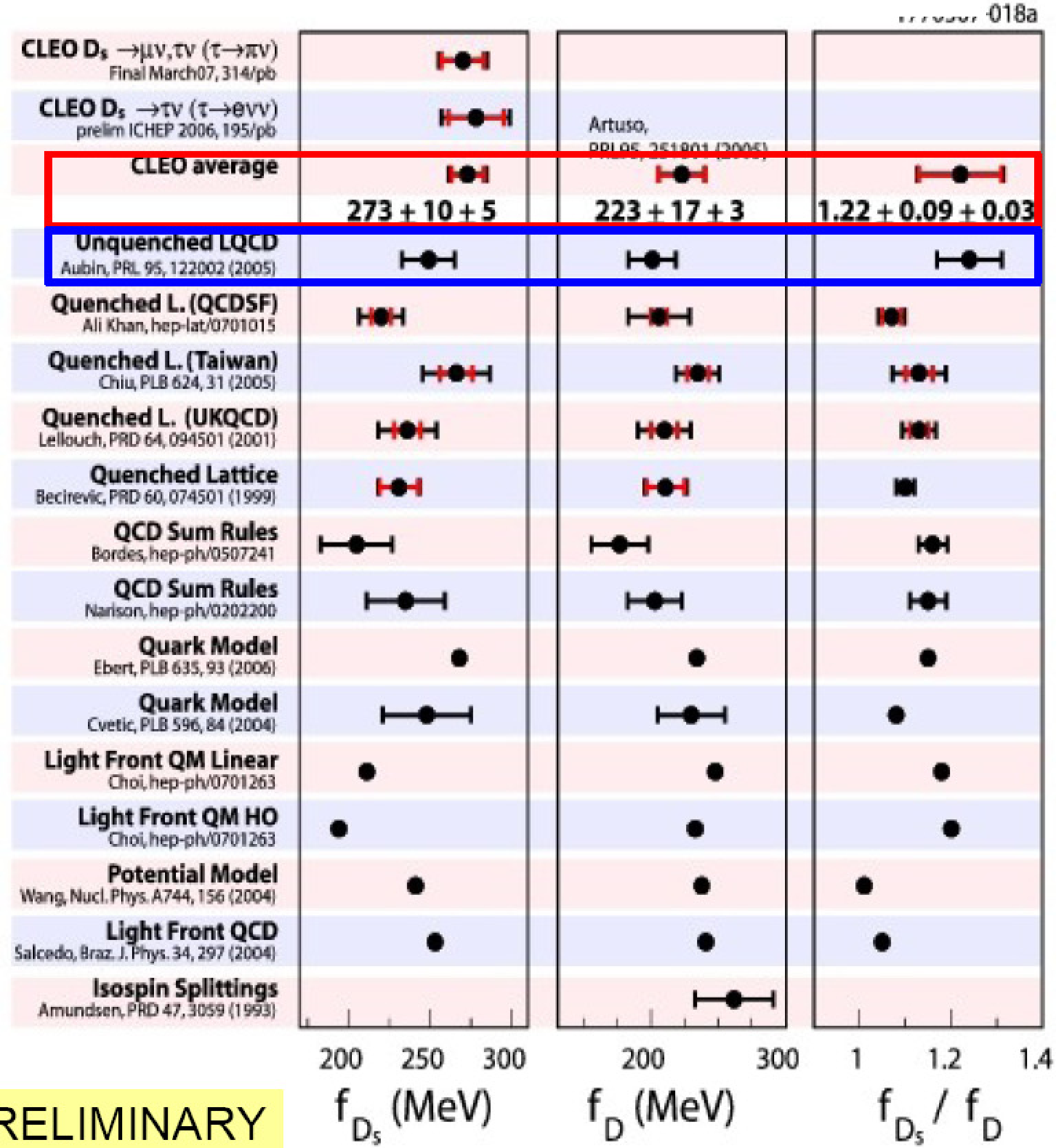
- Consistent with most models
- Statistically limited – more data is on the way!
- Lattice QCD (unquenched) PRL 95, 122002 (2005):

  f_D = (201 ± 3 ± 17) MeV

  f_{Ds} = (249 ± 3 ± 16) MeV

  f_{Ds}/f_D = 1.24 ± 0.01 ± 0.07

systematics limited!

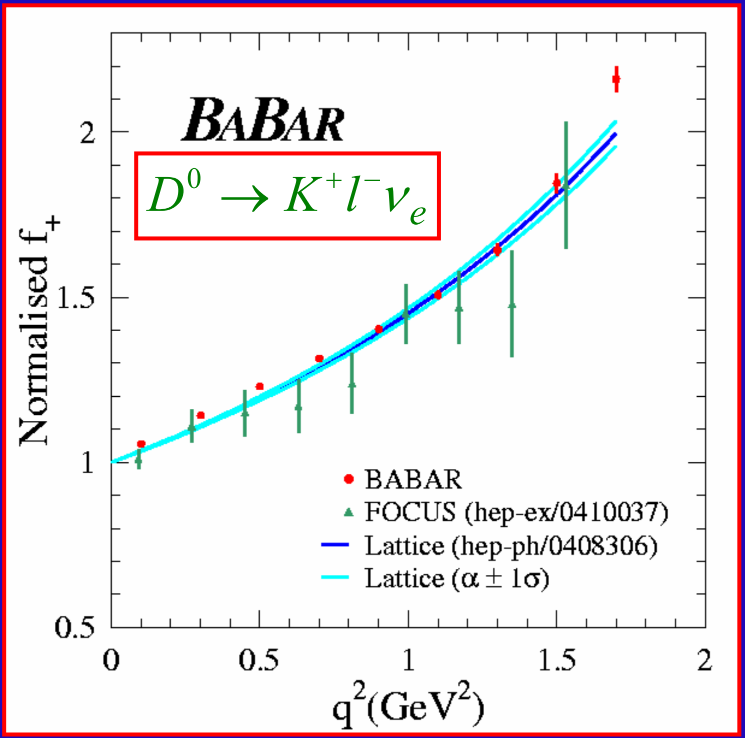


PRELIMINARY

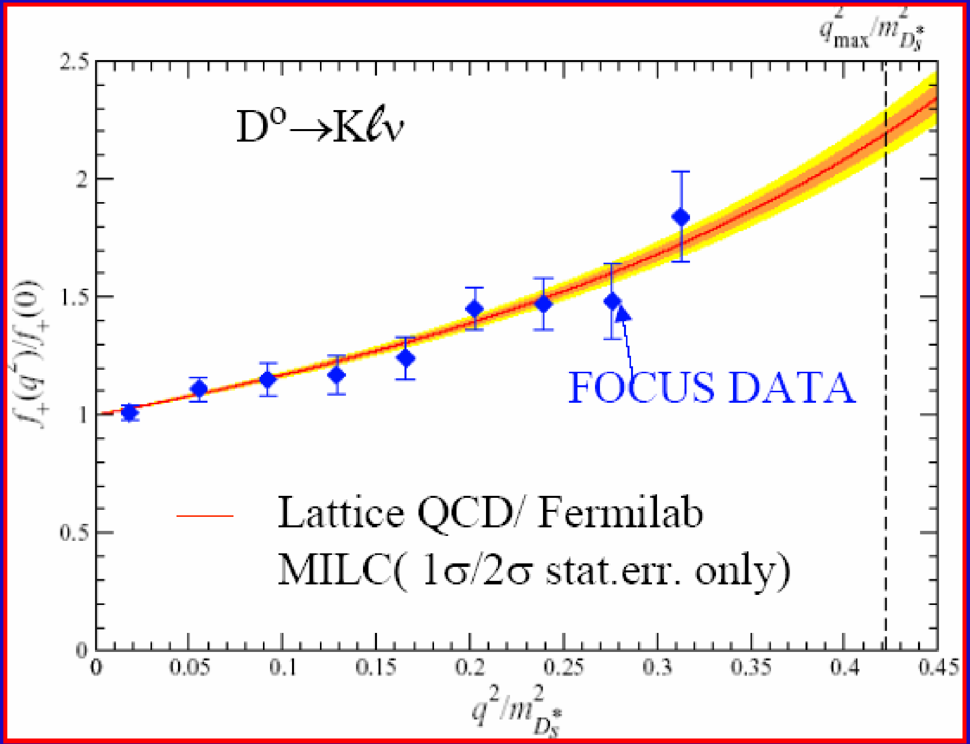
SEMILEPTONIC DECAYS

V_{cs} , V_{cd} ⟷ $f(0)^{th}$

$f(q^2)/f(0)$



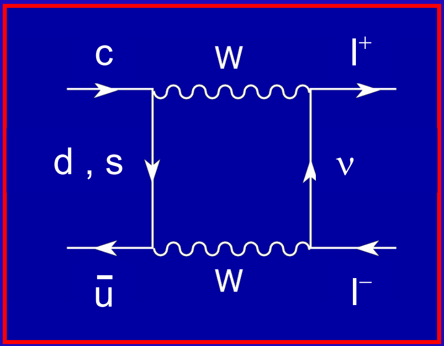
$f(q^2)/f(0)$



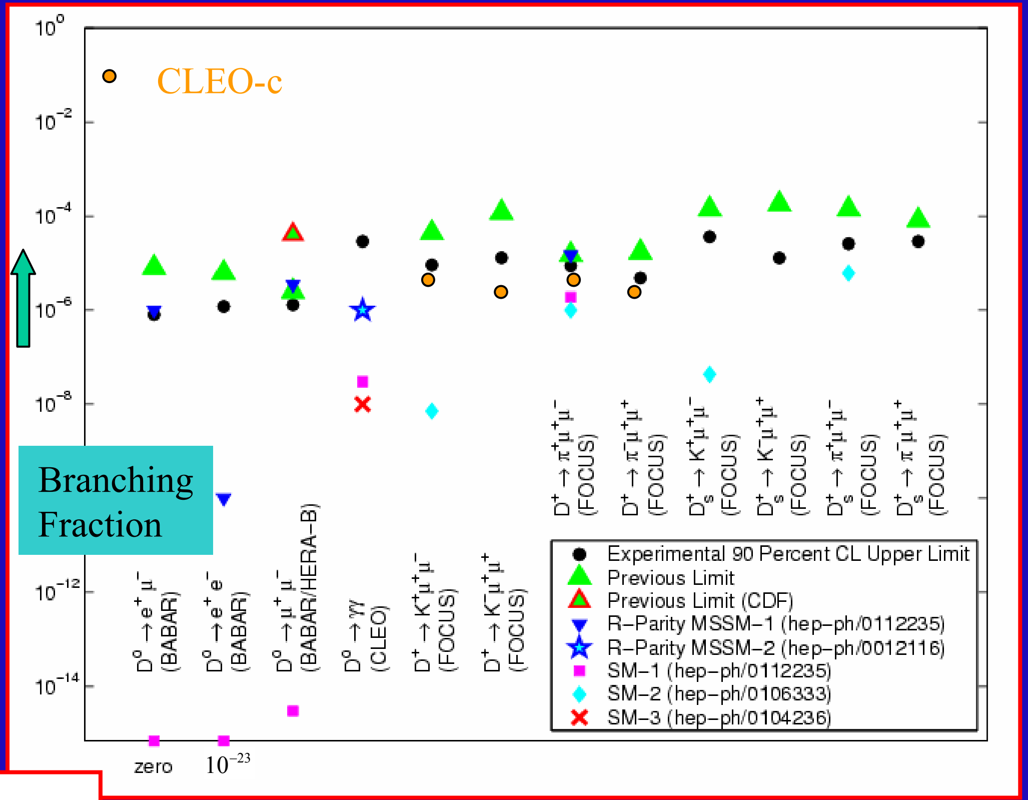
Important Tests of Non-Perturbative QCD Tools

Relevant to Improve Predictions for B's

RARE DECAYS



D. Asner



I. Shipsey

Experimental Sensitivity

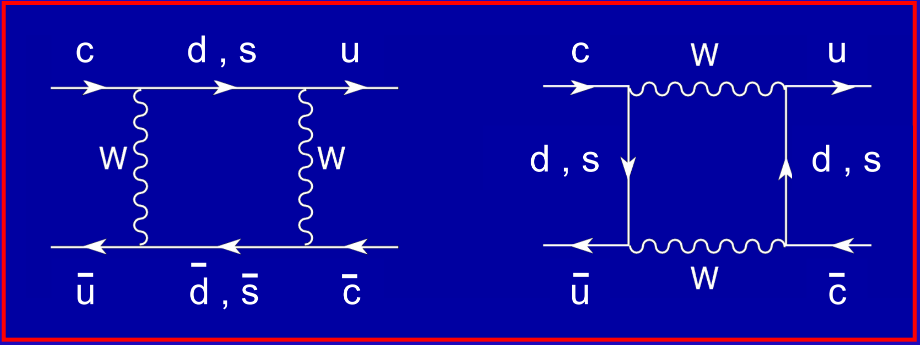
Exp't	$D^0 \to \pi^0 \ell^+\ell^-$ GIM	$D^+ \to \pi^+ \ell^+\ell^-$ GIM	$D^+ \to \pi^- \mu e$ LFV	$D^+ \to \pi^- \ell^+\ell^+$ LNV
Standard Model	10^{-6}	10^{-6}	~0	Forbidden
CLEO-c	1e-5	4e-6	-	2.2e-6
BESIII	5e-8	3e-8	3e-8	3e-8
SuperB (4 GeV)	2e-8	1e-8	1e-8	1e-8
B-factories	?	4e-6	4e-6	4e-6
SuperB (10 GeV)		7e-7	7e-7	7e-7
CDF/D0			?	
LHCb	-			
LHCb (upgrade)	-			

GIM, FCNC, virtual loops, …

Sensitive to New Physics

$D^0 - \bar{D}^0$ MIXING

$$x \equiv \frac{\Delta M}{\Gamma} \quad , \quad y \equiv \frac{\Delta\Gamma}{2\Gamma}$$

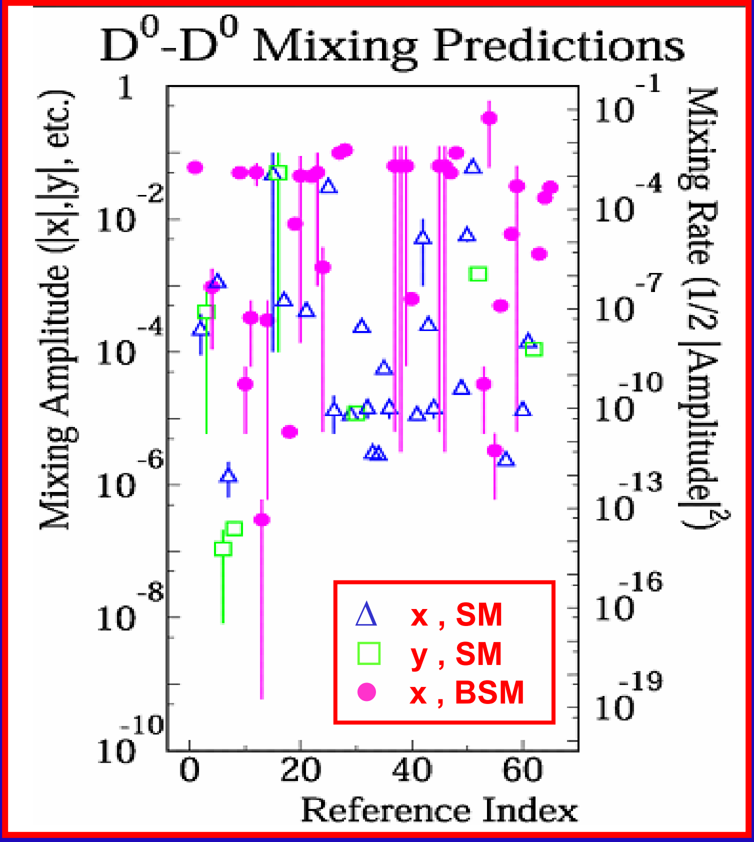


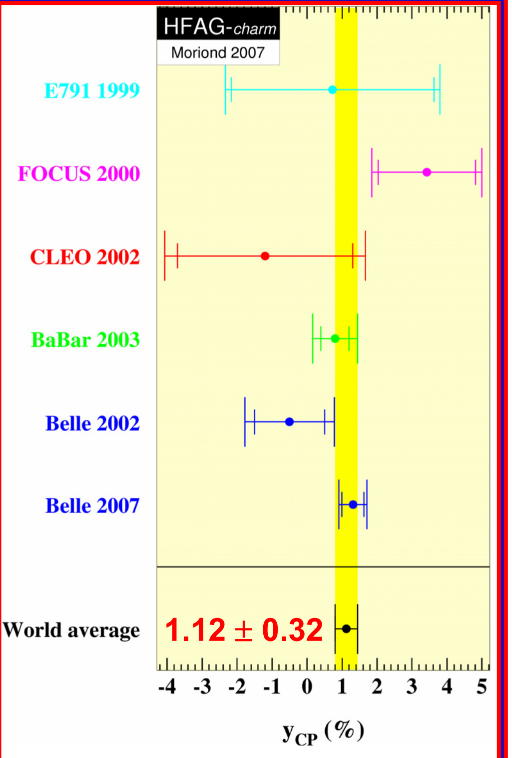
$$\left|\frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}\right|^2 \left(\frac{m_b^2 - m_{s,d}^2}{m_s^2 - m_d^2}\right) \ll 1$$

- Intermediate down-type quarks
- b contribution negligible (~1%)
- **ΔM ~ [SU(3) Breaking]^2**
- $\not{CP}$ very suppressed in the SM

$\not{CP}$: unambiguous signal of New Physics

H. Nelson, A.A. Petrov





D. Asner

"Evidence" for D Mixing: Only 2 results > 3σ

- Babar (384 fb^{-1}) $D^0 \to K\pi$
  - c.w. Belle (400 fb^{-1})

    $x'^2 = (0.18^{+0.21}_{-0.23}) \times 10^{-3}$ $\quad y' = (0.6^{+4.0}_{-3.9}) \times 10^{-3}$

$$x'^2 = (-0.22 \pm 0.30 \pm 0.21) \times 10^{-3}$$
$$y' = (9.7 \pm 4.4 \pm 3.1) \times 10^{-3}$$

- Belle (540 fb^{-1}) $D^0 \to KK,\pi\pi$
  - c.w. W.A. (includes Belle '03)

    $y_{CP} = (0.90 \pm 0.42)\%$

$$y_{CP} = (1.31 \pm 0.32 \pm 0.25)\%$$

- Belle (540 fb^{-1}) $D^0 \to K_S\pi\pi$
  - c.w. CLEO (9 fb-1)

    $x = (1.8 \pm 3.4 \pm 0.6)\%$ $\quad y = (-1.4 \pm 2.5 \pm 0.9)\%$

$$x = (0.80 \pm 0.29 \pm 0.17)\%$$
$$y = (0.33 \pm 0.24 \pm 0.15)\%$$

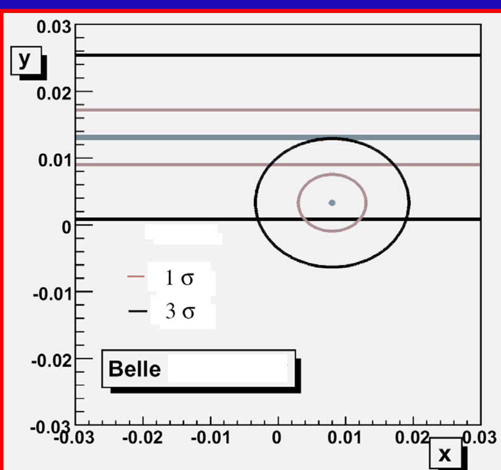
- CLEO-c (281 pb^{-1}) - new results expected soon
  - y, x^2 and cosδ

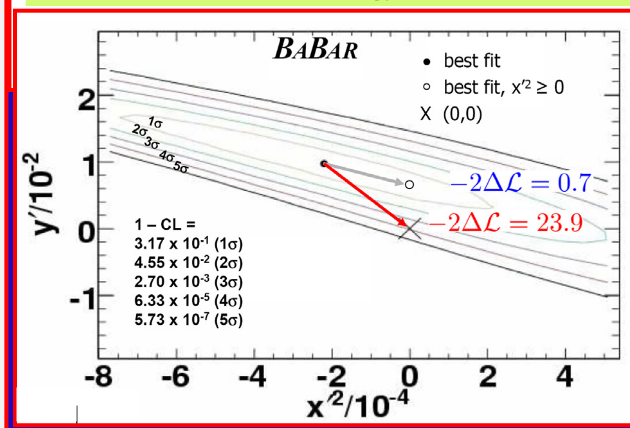
Before Moriond '07

NO MIXING (x,y)=(0,0) excluded:
✓ ~2.1 σ Belle $D^0 \to K\pi$ (no CPV)
✓ ~2.3 σ BaBar $D^0 \to K2\pi/K3\pi$
✓ ~2.2 σ Average y_{CP}

After Moriond '07

NO MIXING (x,y)=(0,0) excluded:
✓ 3.9 σ BABAR $D^0 \to K\pi$ (no CPV)
✓ ~2.4 σ Belle $D^0 \to K_S\pi\pi$
✓ ~3.5 σ New Average y_{CP}=1.12±0.32





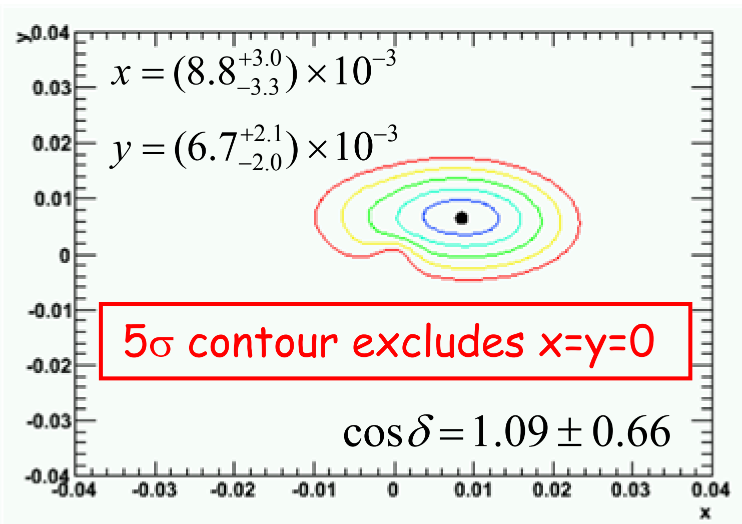
$$y_{CP} = y \cos\varphi + x\,\Delta \sin\varphi \overset{CP}{\to} y$$

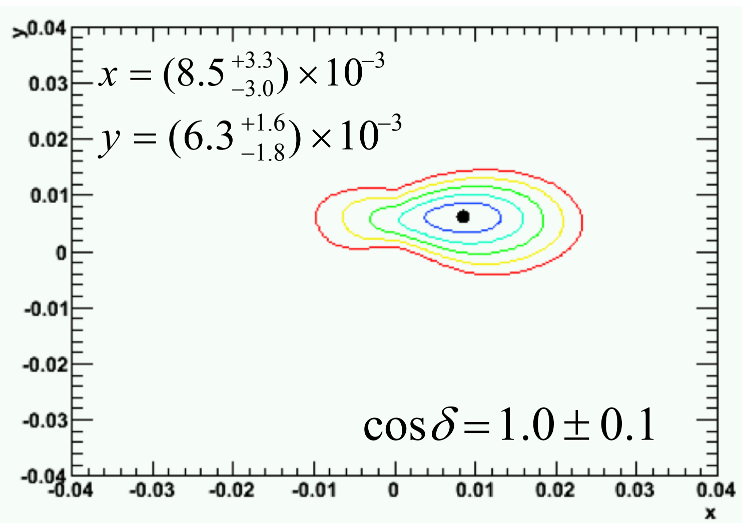
$$x' = x \cos\delta + y \sin\delta$$

$$y' = y \cos\delta - x \sin\delta$$

$D^0 - \bar{D}^0$ MIXING

HFAG
VERY Preliminary





D. Asner

Great Expectations

Exp't / 1 σ	y_{CP} (10^{-3})	y′ (10^{-3})	x'^2 (10^{-4})	cosδ
B-factories ($2ab^{-1}$)	2-3	2-3	1-2	-
SuperB (50 ab^{-1})	0.5	0.7	0.3	-
LHCb (10 fb^{-1}) Only B->D*	?	0.7	0.7	-
LHCb (100 fb^{-1}) Prompt D*	?	?	?	-
CLEO-c (750 pb^{-1})	10	-	2-3	0.1-0.2
BESIII (20 fb^{-1})	4	-	0.5-1	0.05
SuperB - 4 GeV (0.2 ab^{-1})	1-2	-	<0.2	<0.05

- 5σ signal in both y_{CP} & $D^0 \to K\pi$ possible with $2ab^{-1}$ @$\Upsilon(4S)$
- LHCb can confirm signal in $D^0 \to K\pi$ - y_{cp} study in progress
- 5σ time independent signal in y not likely @ BESIII
  - Requires ~1 month run at SuperB (4 GeV)

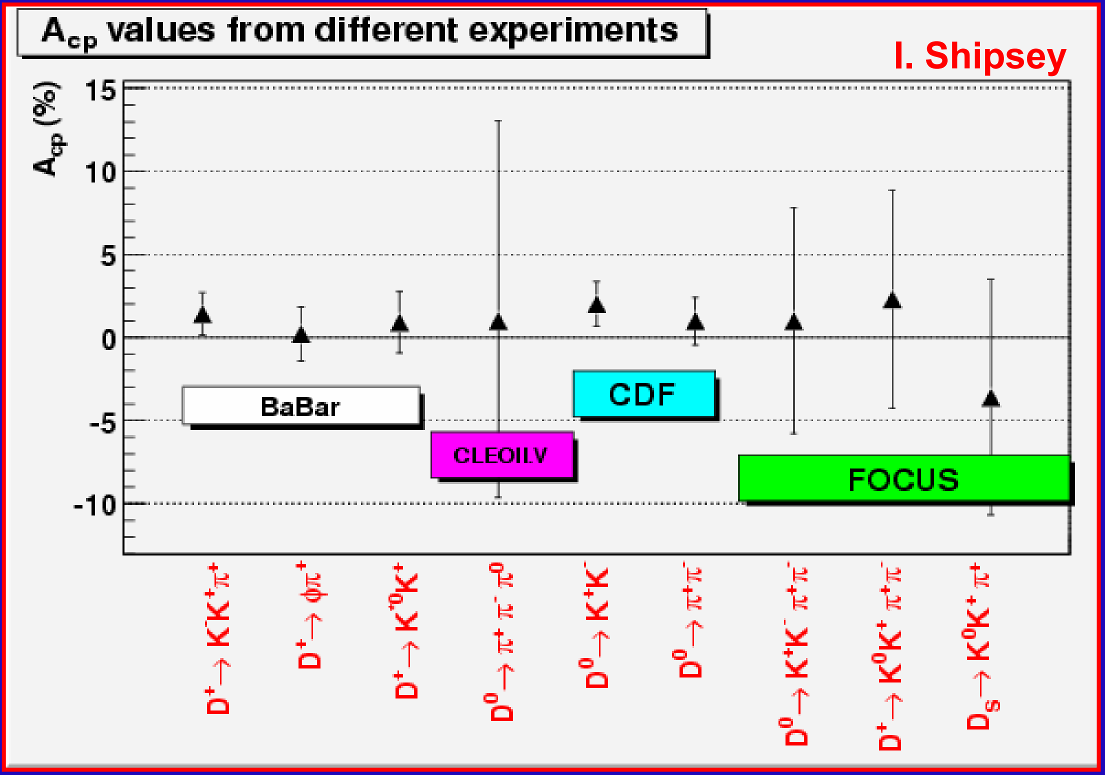
SEARCHES FOR $\not{CP}$ IN D DECAYS

Direct $\not{CP}$

$$\mathcal{A}_{\mathrm{CP}} \equiv (\Gamma - \bar{\Gamma})/(\Gamma + \bar{\Gamma})$$

Strong phase-shifts needed

Non-perturbative uncertainties



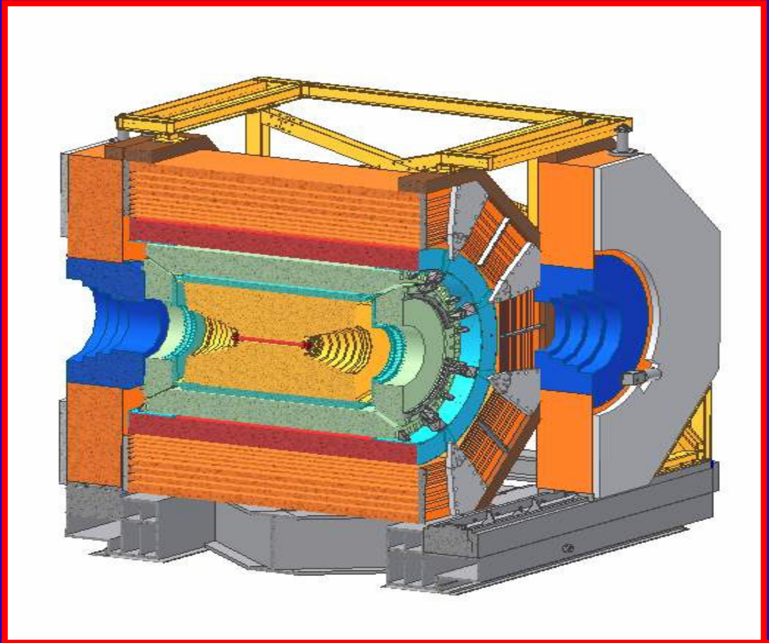
SM Expectations: $A_{CP} \leq 0.1\%$ in SCS, negligible in CA & DCS

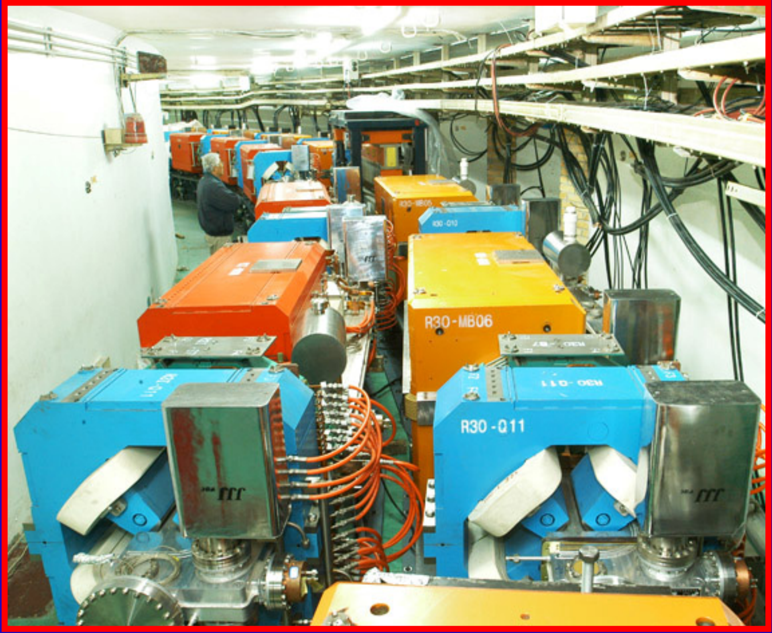
Larger Signals ➡ **New Physics**

BESIII

Threshold Advantages

(Systematics & Backgrounds)



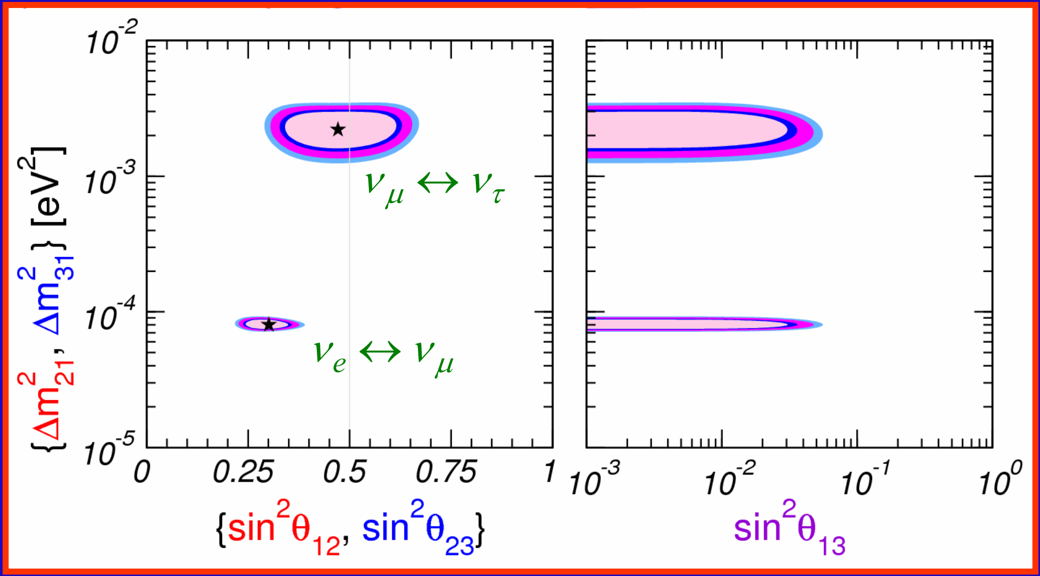


Event statistics

Physics Channel	Energy (GeV)	Luminosity (10^{33} cm^{-2}s^{-1})	Events/year
J/ψ	3.097	0.6	1.0×10^{10}
τ	3.67	1.0	1.2×10^{7}
ψ'	3.686	1.0	3.0×10^{9}
D*	3.77	1.0	2.5×10^{7}
Ds	4.03	0.6	1.0×10^{6}
Ds	4.14	0.6	2.0×10^{6}

$m_\nu \neq 0$ ➡ NEW PHYSICS

Neutrino Oscillations



Weinberg: $$-\frac{c_{ij}}{\Lambda}\,\bar{L}_i\,\tilde{\phi}\,\tilde{\phi}^t L_j^c + \text{h.c.} \xrightarrow{\text{SSB}} -\frac{1}{2}\,\bar{\nu}_{iL} M_{ij}\,\nu^c_{jL} + \text{h.c.} \quad ; \quad M_{ij} \equiv \frac{c_{ij}}{\Lambda}\,v^2$$

$m_\nu > 0.05$ eV ➡ $\Lambda / c_{ij} < 10^{15}$ GeV

Lepton Number Violation. Lepton Mixing. Leptonic $\not{CP}$

Leptogenesis ⟷ Baryogenesis

LEPTON FLAVOUR VIOLATION

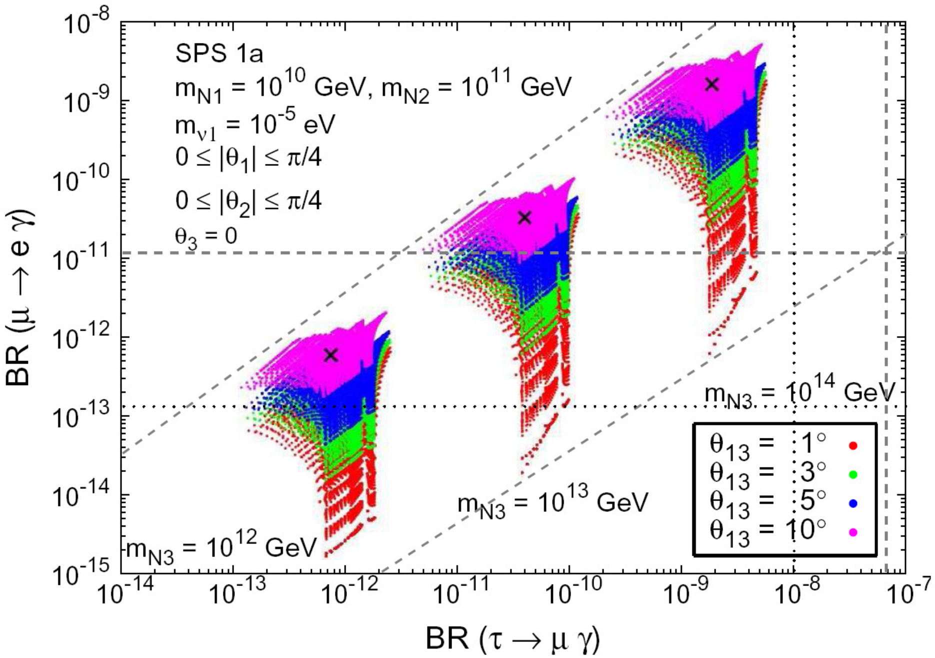
90 % CL Upper Limits on $Br(l^- \to X^-)$ [BABAR / BELLE]

Decay	U.L.	Decay	U.L.	Decay	U.L.
$\mu^- \to e^- \gamma$	$1.2 \cdot 10^{-11}$	$\mu^- \to e^- e^+ e^-$	$1.0 \cdot 10^{-12}$	$\mu^- \to e^- \gamma\gamma$	$7.2 \cdot 10^{-11}$
$\tau^- \to e^- \gamma$	$1.2 \cdot 10^{-8}$	$\tau^- \to e^- e^+ e^-$	$2.0 \cdot 10^{-7}$	$\tau^- \to e^- e^+ \mu^-$	$1.9 \cdot 10^{-7}$
$\tau^- \to \mu^- \gamma$	$4.5 \cdot 10^{-8}$	$\tau^- \to e^- \mu^+ \mu^-$	$2.0 \cdot 10^{-7}$	$\tau^- \to \mu^- e^+ \mu^-$	$1.3 \cdot 10^{-7}$
$\tau^- \to e^- e^- \mu^+$	$1.1 \cdot 10^{-7}$	$\tau^- \to \mu^- \mu^+ \mu^-$	$1.9 \cdot 10^{-7}$	$\tau^- \to e^- \pi^0$	$1.3 \cdot 10^{-7}$
$\tau^- \to \mu^- \pi^0$	$1.1 \cdot 10^{-7}$	$\tau^- \to e^- \eta'$	$2.4 \cdot 10^{-7}$	$\tau^- \to \mu^- \eta'$	$1.4 \cdot 10^{-7}$
$\tau^- \to e^- \eta$	$1.6 \cdot 10^{-7}$	$\tau^- \to \mu^- \eta$	$1.5 \cdot 10^{-7}$	$\tau^- \to e^- K^*$	$3.0 \cdot 10^{-7}$
$\tau^- \to e^- K_S$	$5.6 \cdot 10^{-8}$	$\tau^- \to \mu^- K_S$	$4.9 \cdot 10^{-8}$	$\tau^- \to \mu^- \rho^0$	$2.0 \cdot 10^{-7}$
$\tau^- \to e^- K^+ K^-$	$1.4 \cdot 10^{-7}$	$\tau^- \to e^- K^+ \pi^-$	$1.6 \cdot 10^{-7}$	$\tau^- \to e^- \pi^+ K^-$	$3.2 \cdot 10^{-7}$
$\tau^- \to \mu^- K^+ K^-$	$2.5 \cdot 10^{-7}$	$\tau^- \to \mu^- K^+ \pi^-$	$3.2 \cdot 10^{-7}$	$\tau^- \to \mu^- \pi^+ K^-$	$2.6 \cdot 10^{-7}$
$\tau^- \to e^- \pi^+ \pi^-$	$1.2 \cdot 10^{-7}$	$\tau^- \to \mu^- \pi^+ \pi^-$	$2.9 \cdot 10^{-7}$	$\tau^- \to \Lambda \pi^-$	$0.7 \cdot 10^{-7}$
$\tau^- \to e^+ K^- K^-$	$1.5 \cdot 10^{-7}$	$\tau^- \to e^+ K^- \pi^-$	$1.8 \cdot 10^{-7}$	$\tau^- \to e^+ \pi^- \pi^-$	$2.0 \cdot 10^{-7}$
$\tau^- \to \mu^+ K^- K^-$	$4.4 \cdot 10^{-7}$	$\tau^- \to \mu^+ K^- \pi^-$	$2.2 \cdot 10^{-7}$	$\tau^- \to \mu^+ \pi^- \pi^-$	$0.7 \cdot 10^{-7}$

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

MEG:

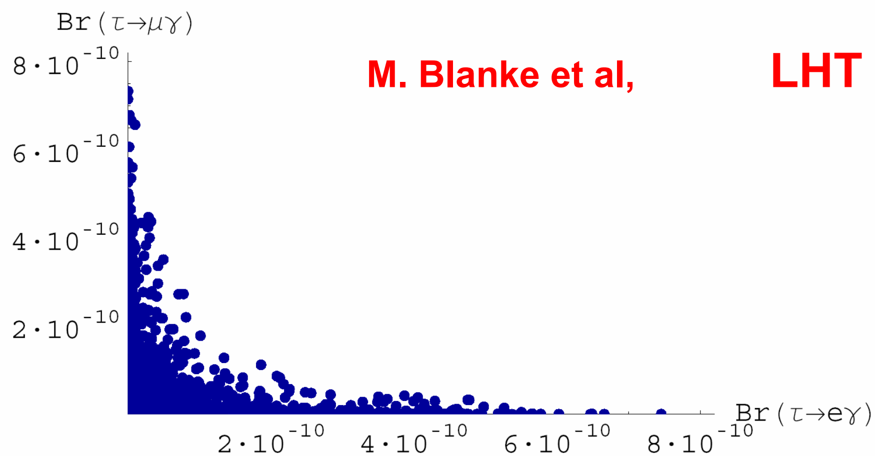
Br(μ→eγ) ~ 10^{-13}

Prism:

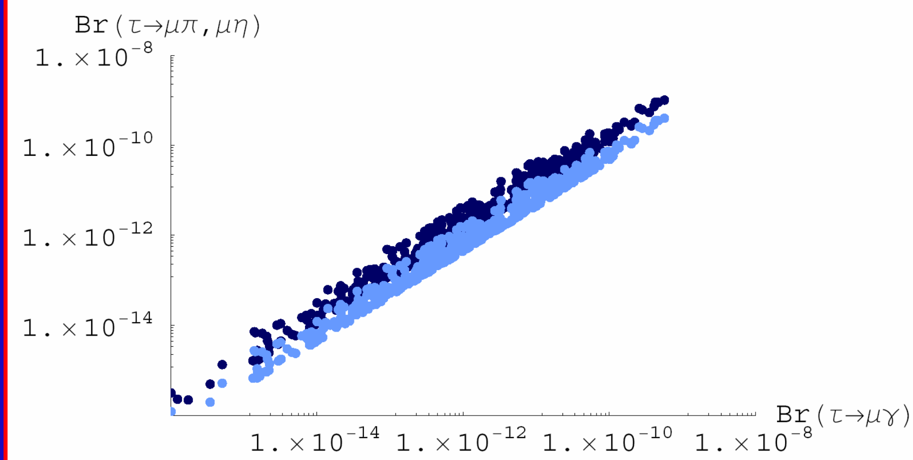
Pr(μ→e) ~ 10^{-18}

SuperB:

Br(τ →μγ) ~ 10^{-9}

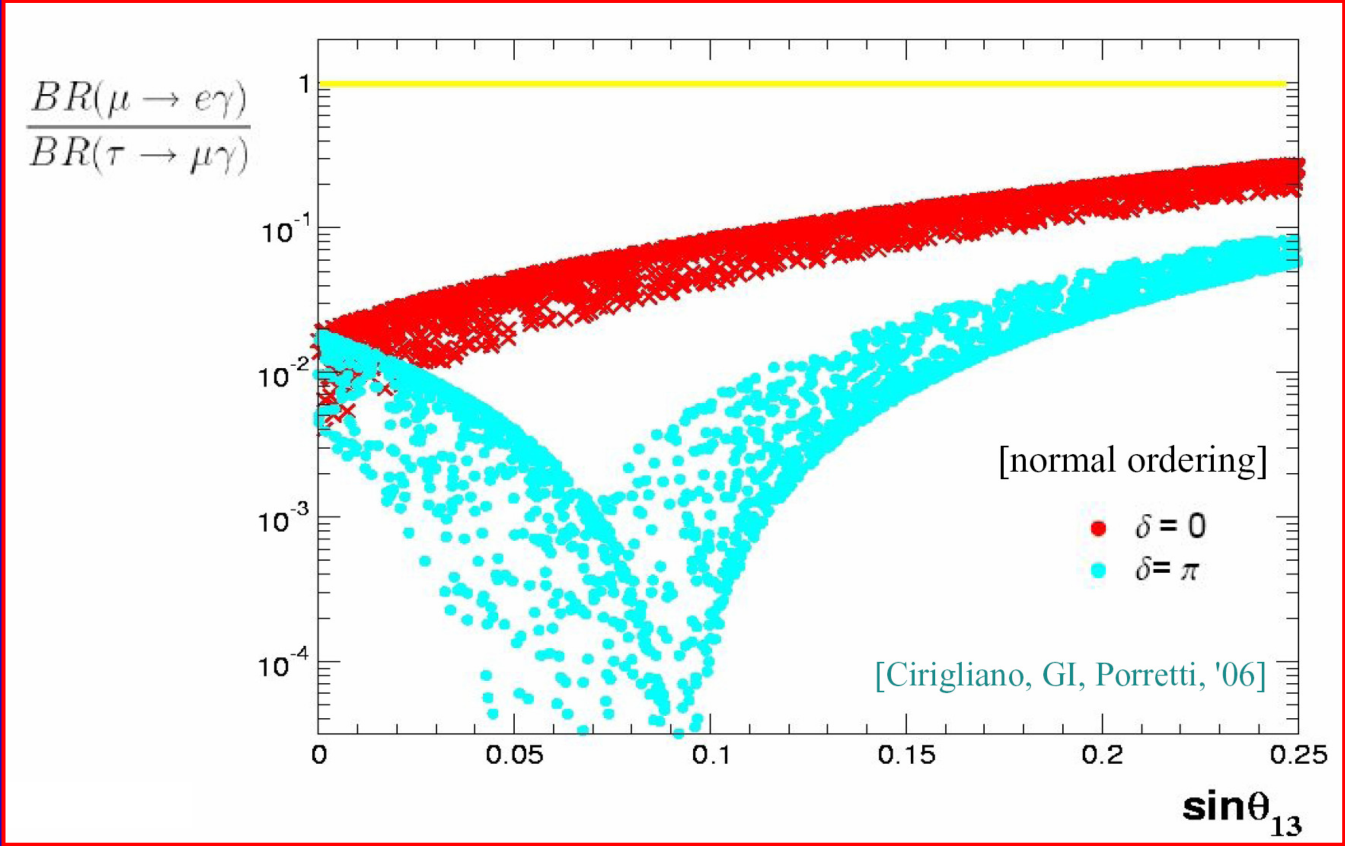


M. Blanke et al, LHT



G. Isidori

Minimal Lepton Flavour Violation



- $\mu \to e\gamma$ should be seen at MEG in most realistic scenarios
- $\tau \to \mu\gamma$ very useful to discriminate different flavor-mixing models

$$B(\tau\to\mu\gamma):B(\tau\to e\gamma):B(\mu\to e\gamma) \sim [\,\lambda^{-4}\ \ \lambda^{-2}\,] : 1 : 1 \sim [500\text{–}10] : 1 : 1 \qquad M_R \gg 10^{12}\ \text{GeV}$$

$$B(\tau\to\mu\gamma):B(\tau\to e\gamma):B(\mu\to e\gamma) \sim \lambda^{-6} : \lambda^{-4} : 1 \sim 10^{4} : 500 : 1 \qquad M_R \ll 10^{12}\ \text{GeV}$$

$\not{CP}$ in τ Decays

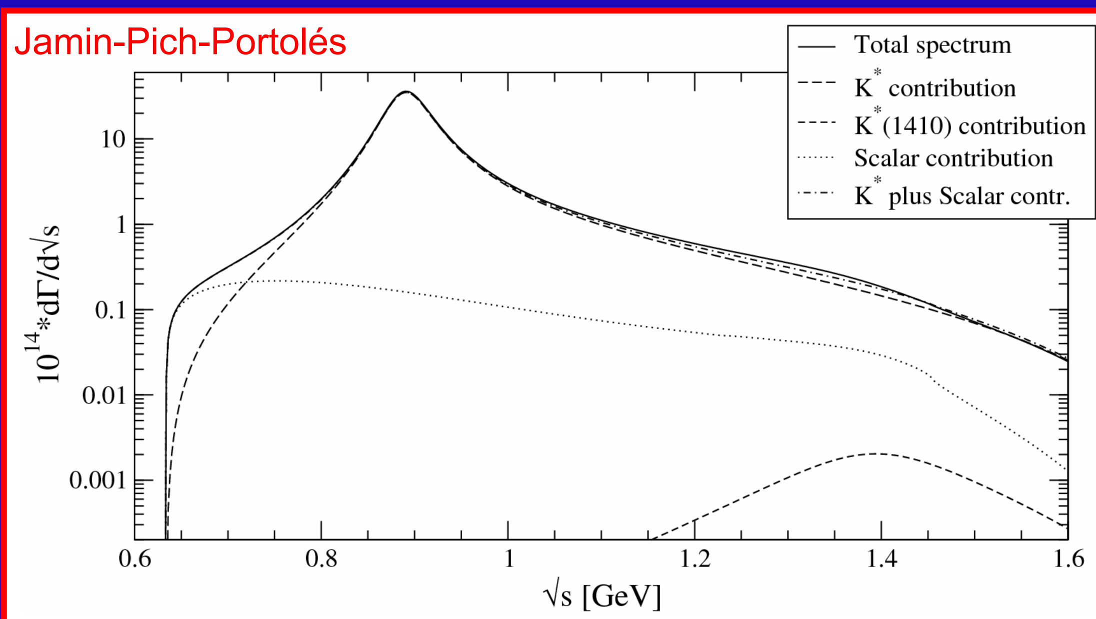
Blind Search for New Physics

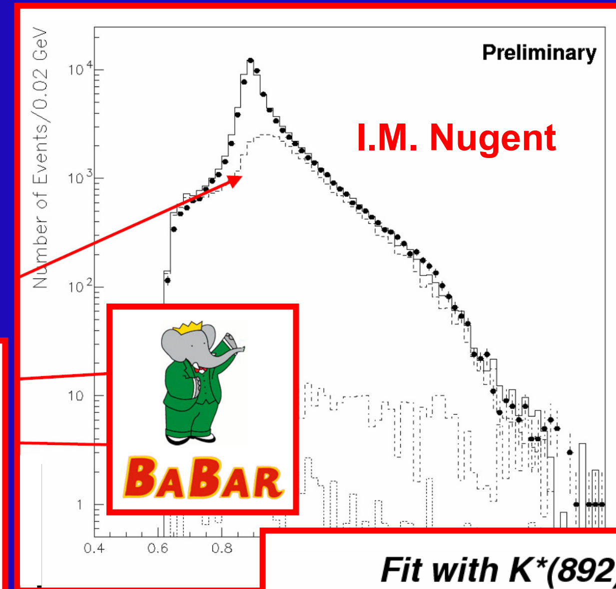
$$\frac{d\Gamma_{K\pi}}{d\sqrt{s}} = \frac{G_F^2|V_{us}|^2M_\tau^3}{32\pi^3 s}\left(1-\frac{s}{M_\tau^2}\right)^2\left\{\left(1+2\frac{s}{M_\tau^2}\right)q_{K\pi}^3\,|F_+^{K\pi}(s)|^2+\frac{3\,q_{K\pi}}{4s}\left(m_K^2-m_\pi^2\right)^2|F_0^{K\pi}(s)|^2\right\}$$

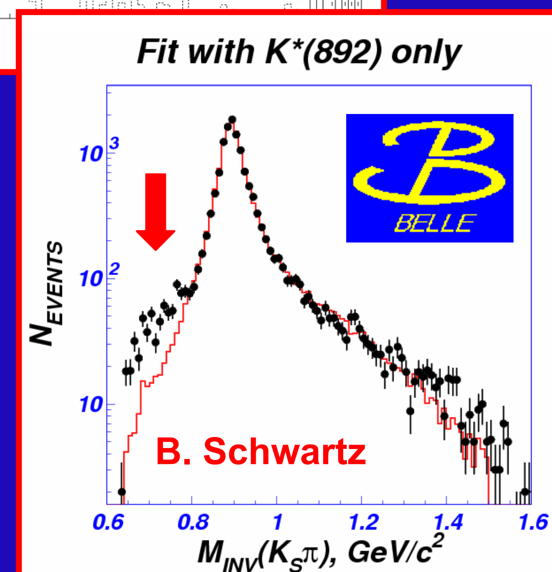
$\tau^- \to \nu_\tau \bar{K}^0\pi^-,\ \nu_\tau K^-\pi^0$

Two Interfering Amplitudes (Dalitz Plot)

SM Strong Phase can be determined







$$B[\tau \to \nu_\tau K\pi]_{\text{exp}} = (1.33 \pm 0.05)\%$$

Huge statistics

Non-b shopping list :

- Lepton Flavour Violation studies
- $\not{CP}$ in the charm sector
- FCNC & Rare D decays
- Universality & Lorentz structure of weak decays (τ)
- First hints on leptonic $\not{CP}$
- …

Backup Slides

D. Asner

Charm Physics Circa 2013

- Hadronic Branching Ratios
  - D^0 & D^+ branching ratios syst. limited at (1-2)% CLEO-c
  - D_s^+ BR stat. limited at 6% CLEO-c
    - CLEO-c will improve to ~4%
    - BESIII will improve to (1-2)%
- Decay constants: statistics limited
  - f_{D+} 7.5% (281pb^{-1}) at 3770. CLEO-c
    - CLEO-c will improve to (4-5)%
    - BESIII will improve to (1-2)%
  - f_{Ds} 4.1% (200pb^{-1}) at 4170. CLEO-c
    - CLEO-c will improve to (2-3)%
    - BESIII can improve
  - $\sigma(f_D/f_{Ds})$ ~ 2% at BESIII (20 fb^{-1})
- Semileptonic Decays
  - BR of Cabibbo suppressed $D^0 \to \pi e \nu$ known to 4% CLEO-c
    - CLEO-c will improve to (2-3)%
    - BESIII can improve
  - Vcs ~ 2%, Vcd ~ 4% CLEO-c
    - CLEO-c will improve Vcd~2%
  - Precision form-factors to improve V_{ub} benefits from more 4 GeV data
- CP tagged Dalitz plot analyses e.g. $D^0 \to CP$ vs. $D^0 \to K_{S,L}\pi^+\pi^-$
  - Important for γ
  - Statistics limited
  - CLEO-c can limit sys err on $\gamma < 3^o$
- Rare Decays
  - CLEO-c sensitivity 10^{-5}-10^{-6}
  - BESIII sensititity 10^{-6}-10^{-7}
  - Standard Model rates ~10^{-8}
  - LHCb sensitivity?
  - SuperB @ ~4 GeV ~SM sensitivity
- Charm Mixing
  - Exploiting quantum coherent initial state CLEO-c will measure $\cos\delta \sim \pm 0.1$
  - BESIII sensitivity to y ~few x 10^{-3}
  - Need LHCb (Upgrade) or SuperB to cover full range of SM expectations
- CP Violation
  - BESIII sensitive to ~SM asymmetry in $D^+ \to K_{S,L}\pi^+$ ~few$\times 10^{-3}$.
  - Need LHCb (Upgrade) or SuperB to reach SM expectation in SCS decay.

KTeV

Preliminary measurements of: **H. Nguyen (Moriond 07)**

- $BR(\pi^0 \to ee\gamma)/BR(\pi^0 \to \gamma\gamma)$

$(1.1539 \pm 0.0045 \pm 0.0152)\ \%$

- $BR(K_L \to \pi^0\gamma\gamma)$ and $BR(K_L \to \pi^0 ee\gamma)$

$BR(K_L \to \pi^0\gamma\gamma) = (1.30 \pm 0.03(stat) \pm 0.04(sys)) \cdot 10^{-6}$

$BR(K_L \to \pi^0 ee\gamma) = (1.90 \pm 0.16 \pm 0.12) \cdot 10^{-8}$

- LFV limits on $K_L \to \pi^0\pi^0\mu e$ and $\pi^0 \to \mu e$

BR$(K_L \to \pi^0\pi^0\mu e) < 1.58 \times 10^{-10}$ *(90% CL)*

BR$(\pi^0 \to \mu e) < 3.63 \times 10^{-10}$ *(90% CL)*