Electroweak physics at low energy

(recent experimental results on the muon (g-2) and tau decays)

B.A.Shwartz

Budker Institute of Nuclear Physics, Novosibisrsk, Russia

Plan

- Muon (g-2) and R measurements
  - (g-2) experiment and theory
  - direct R measurements in e^+e^-
  - R measurement by ISR
- Search for LFV in tau decays
- Hadronic tau decays
  - $\tau^- \to \pi^- \pi^0 \nu_\tau$ decay and CVC
  - Search for 2-d class currents
  - V_{us} evaluation from τ hadronic decays
- Lepton universality and τ–lepton mass measurement
- Perspectives

Muon Anomalous Magnetic Moment

$$\vec{\mu} = g \frac{e}{2m} \vec{s}, \quad a = (g-2)/2.$$

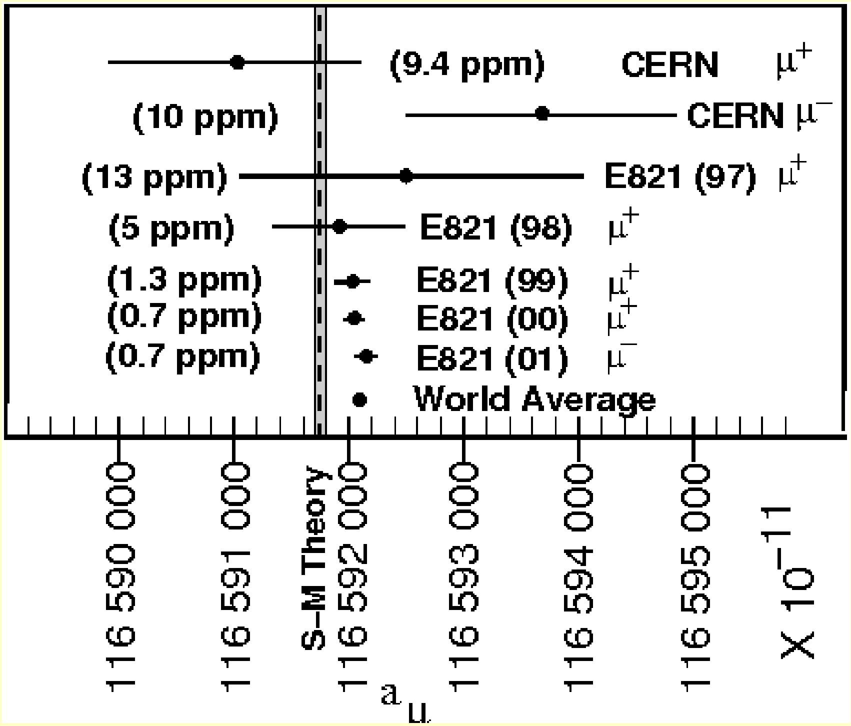
In Dirac theory for pointlike particles $g = 2$, higher-order effects (or new physics) $g \neq 2$

a_μ is measured with a 5×10^{-7} relative accuracy:

G.W. Bennett et al., 2004, 2006 $a_\mu = (11659208.0 \pm 6.3) \times 10^{-10}$.

a_e is measured with a 4.9×10^{-10} accuracy, but a_μ is much more sensitive to new physics effects: the gain is usually $\sim(m_\mu/m_e)^2 \approx 4.3 \times 10^4$.

Any significant difference of a_{exp} from a_{th} indicates new physics beyond the Standard Model.



Muon Anomalous Magnetic Moment

$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{EW} + a_\mu^{had}$$

Contribution	a_μ, 10^{-10}
Experiment	11659208.0 ± 6.3
QED	11658471.8 ± 0.016
Electroweak	15.4 ± 0.1 ± 0.2
Hadronic	693.1 ± 5.6
Theory	11659180.3 ± 5.6
Exp. - Theory	27.7 ± 8.4 (3.3σ)

By TAU-08

The difference between experiment and theory is 3.3σ!

QED and Electroweak contributions

QED

$$a_\mu^{\rm QED}\cdot 10^{10} = \Sigma C_i\left(\frac{\alpha}{\pi}\right)^i = \begin{array}{rr} & 11614097.3\ (\text{1-loop}) \\ + & 41321.8\ (\text{2-loop}) \\ + & 3014.2\ (\text{3-loop}) \\ + & 38.1\ (\text{4-loop}) \\ + & 0.4\ (\text{5-loop}) \end{array}$$

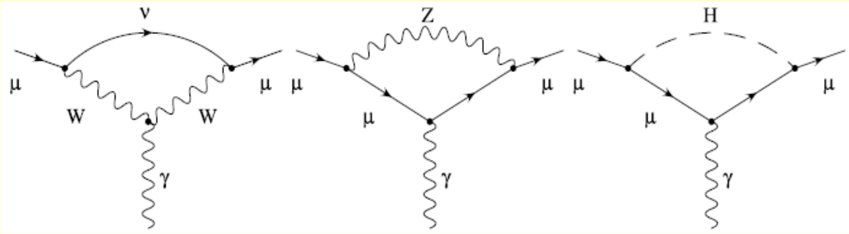
Terms up to α^3 are known analytically, a recent more accurate numerical calculation of the 4 terms and the leading log α^5 terms was done by (T. Kinoshita and M. Nio, 2005; A.L. Kataev, 2006):

From the latest value of a_e (G. Gabrielse et al., 2006; M. Passera, 2006): α^{-1} = 137.035999710(96),

$a_{QED} = (116584718.09 \pm 0.14 \pm 0.08) \times 10^{-11}$:

The errors are due to: a/ $O(\alpha^5)$, b/ α

Electroweak



One-loop electroweak contributions

A.Czarnecki et al. 2002

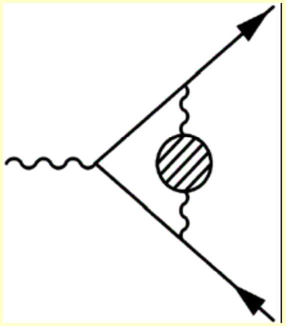
$(15.4 \pm 0.1 \pm 0.2) \times 10^{-10}$

The errors are due to: a/ hadr. loops, b/ M_H, M_t, 3-loop effects.

LBL $(10.5 \pm 2.6) \times 10^{-10}$

J. Prades, E. de Rafael, A. Vainshtein

Hadronic contribution a_{had}

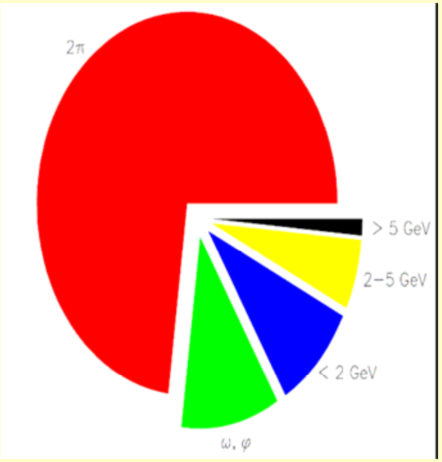


$$a_\mu^{had,LO} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds \frac{R(s)\hat{K}(s)}{s^2}$$

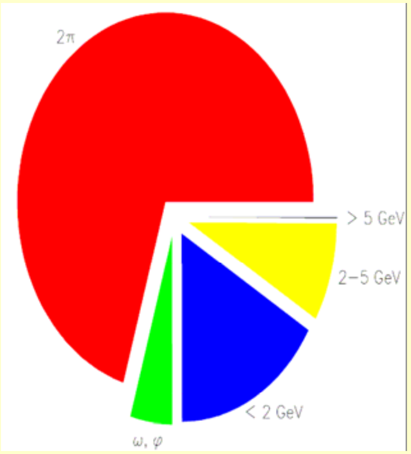
$$R(s) = \frac{\sigma(e^+e^- \to hadrons)}{\sigma(e^+e^- \to \mu^+\mu^-)}, \quad \sigma_{\mu^+\mu^-} = \frac{85.86nb}{s[GeV^2]}$$

$\hat{K}$ grows from 0.63 at $s = 4m_\pi^2$ to 1 at $s \to \infty$, $1/s^2$ emphasizes the role of low energies, particularly important is the reaction $e^+e^- \to \pi^+\pi^-$ with a large cross section below 1 GeV.

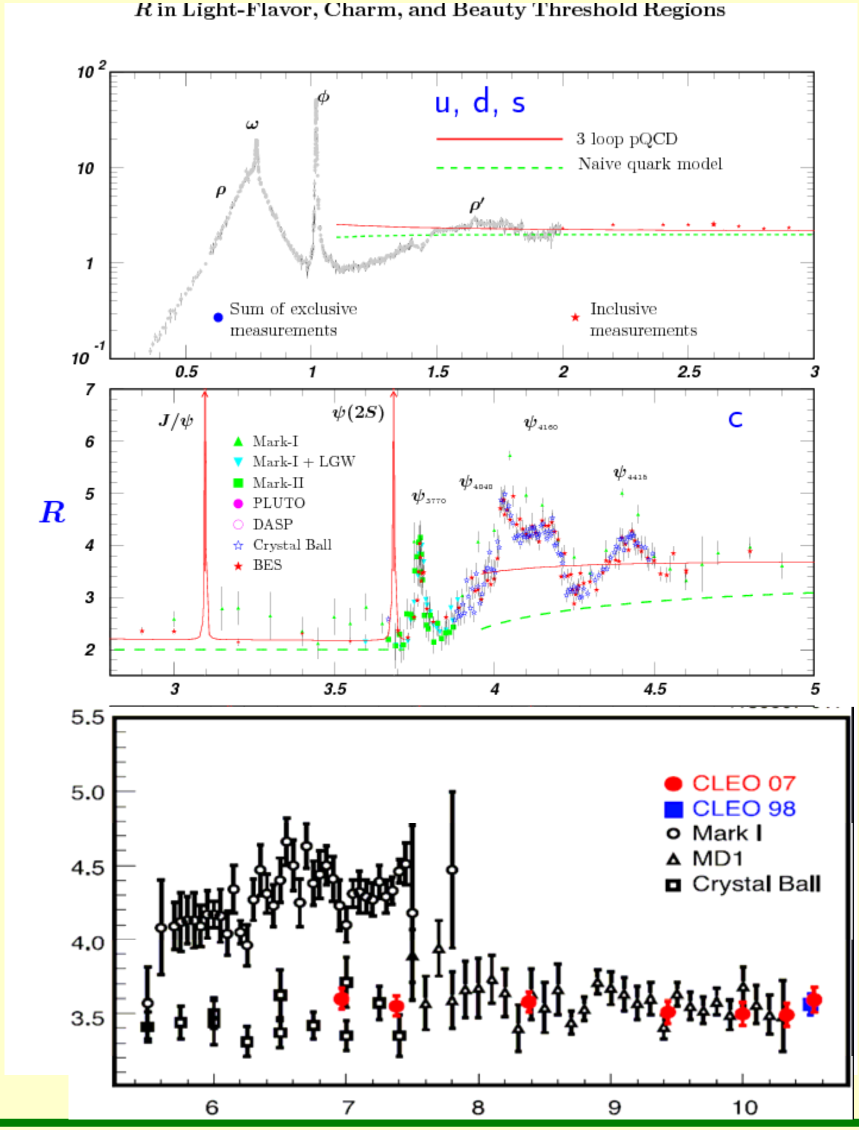
Central values



Uncertainties



R - measurements



$$R_{QCD} = R^{(0)}\left[1+\frac{\alpha_s}{\pi}+C_2\left(\frac{\alpha_s}{\pi}\right)^2+C_3\left(\frac{\alpha_s}{\pi}\right)^3+....\right]$$

$$R^{(0)} = 3\sum_q e_q^2, \quad C_2 = 1.411, \quad C_3 = -12.8$$

The most surprising feature of this graph is that the simple quark model with pQCD corrections works down to 1.5 GeV!

Taking R=R_{QCD} we can estimate the $a_{\mu,had}$ value with ~30% accuracy, but to obtain 1% level of the precision, O(1000) man-years of effort were spent in the last two decades!

Why is R Measurement Interesting?

1. *Tests of perturbative QCD*

QCD sum rules

-quark masses, quark and gluon condensates

-Higher order QCD corrections

- Λ_{QCD}, $\alpha(s)$

2. Hadronic corrections to fundamental parameters:

Running fine structure constant - $\alpha(M_Z^2)$

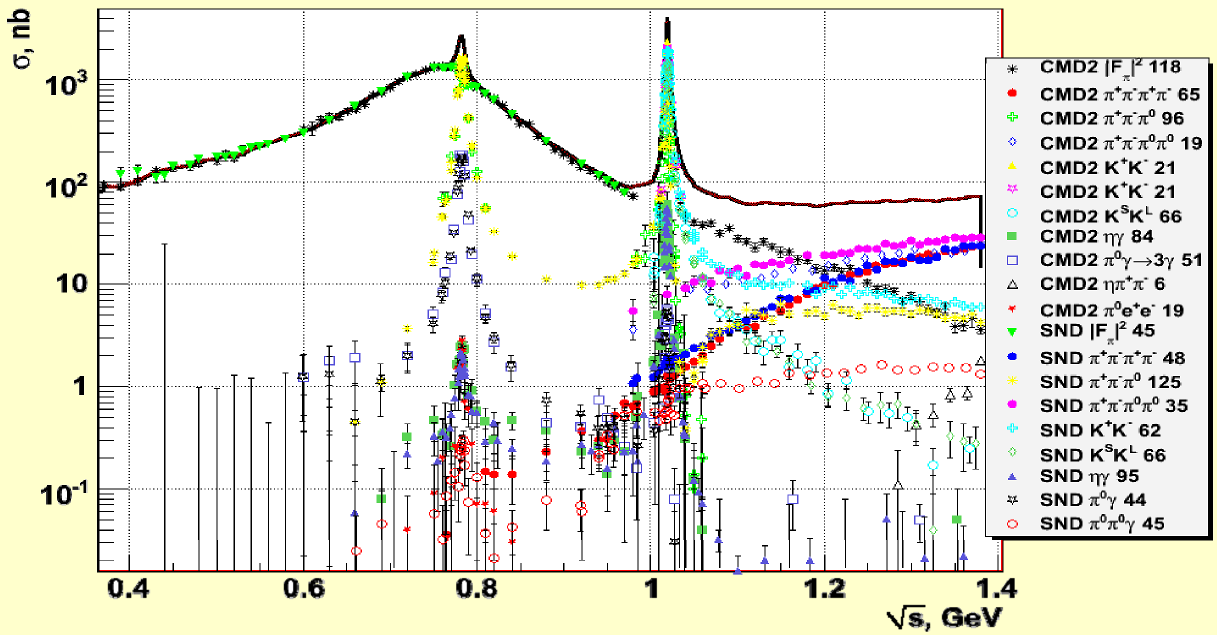
Anomalous magnetic moment of the muon

……………………………….

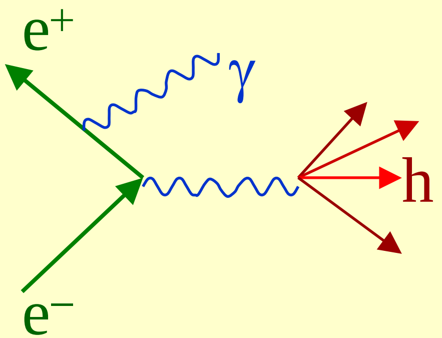
Depending on the problem, different energy ranges are important.

In the energy range below 2 GeV the total hadronic cross section is obtained as a sum of the exclusive cross sections.

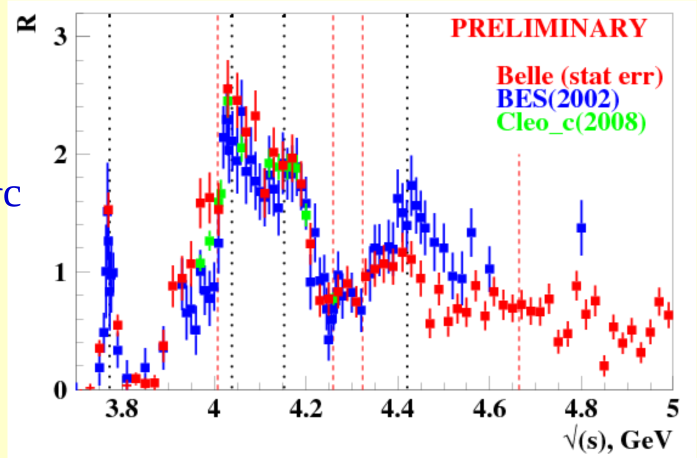
Overview of the results from VEPP-2M e^+e^- collider.



The last years a lot of new data were obtained in the ISR processes by BaBar, Belle and KLOE

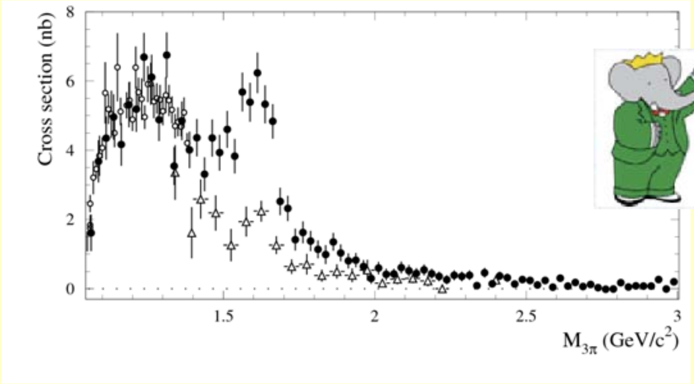


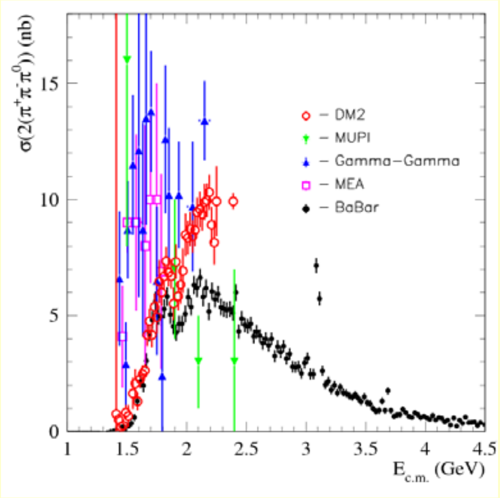
R_c

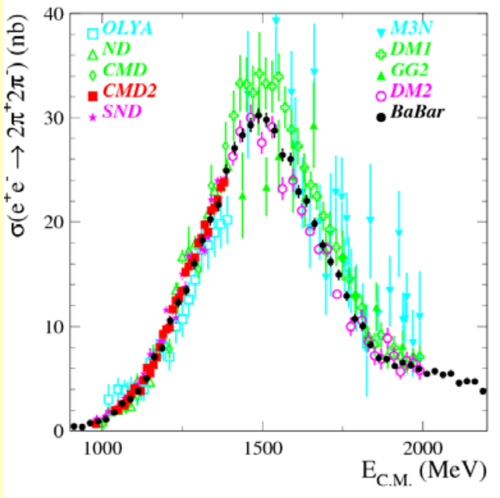


BES: $R_{tot} - R_{uds}$;

B,C : $\sum R_{excl}$

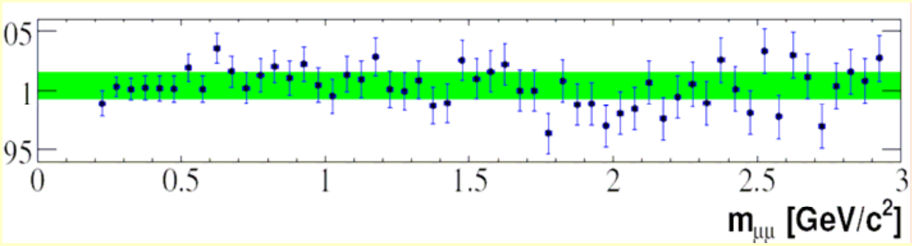


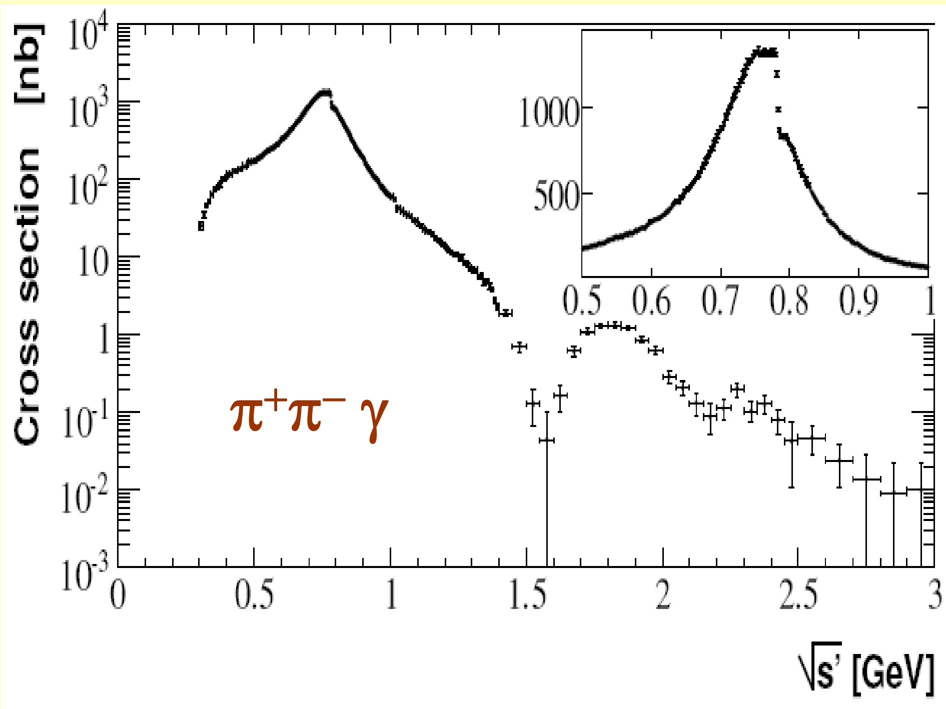


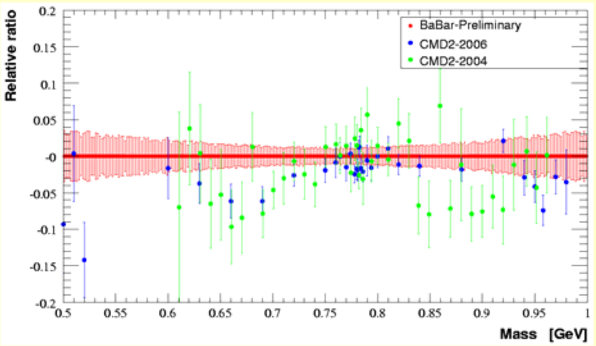


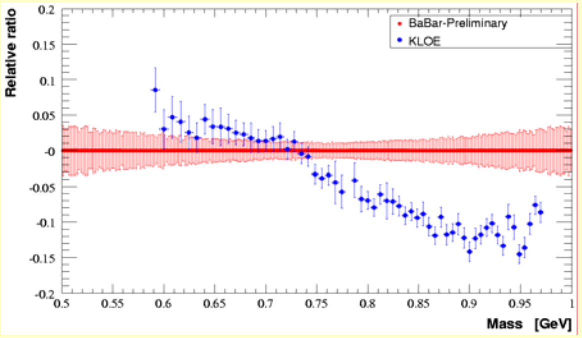
$\pi^+\pi^-\gamma$ - Last minute from BaBar

$\mu^+\mu^-\gamma$ - exp/QED









Computing $a_\mu^{\pi\pi}$

$$\frac{\sigma^{data}_{\mu\mu\gamma}}{\sigma^{NLO\ QED}_{\mu\mu\gamma}} = 1 + (4.0 \pm 2.0 \pm 5.5 \pm 9.4) \times 10^{-3}$$

From $\pi^+\pi^-$ threshold to 1.8 GeV

$$a_\mu^{\pi\pi(\gamma)} = (514.1 \pm 2.2 \pm 3.1) \times 10^{-10}$$

Previous e^+e^- data: $(502.8 \pm 3.2) \times 10^{-10}$

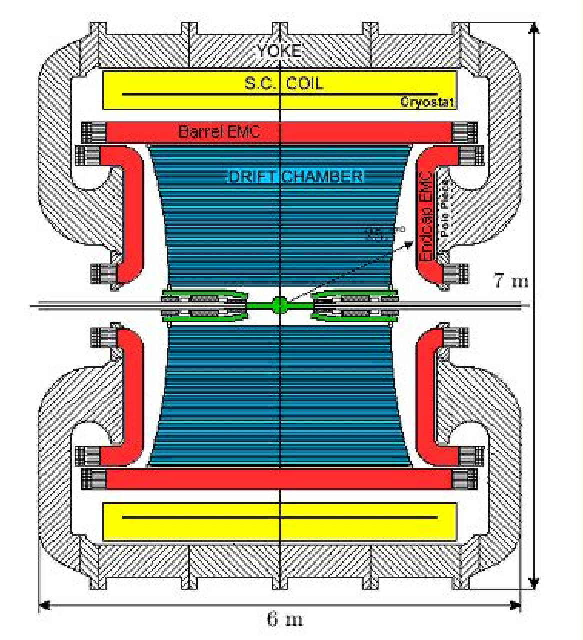
updated value from $\tau^- \to \pi^-\pi^0\nu_\tau$: $(514.3 \pm 3.0) \times 10^{-10}$

M.Davier et al., arXiv:0906.5443v1 (hep-ph)

According to these results $\Delta a_{\mu,hadr}$ reduces to $\sim 2\sigma$

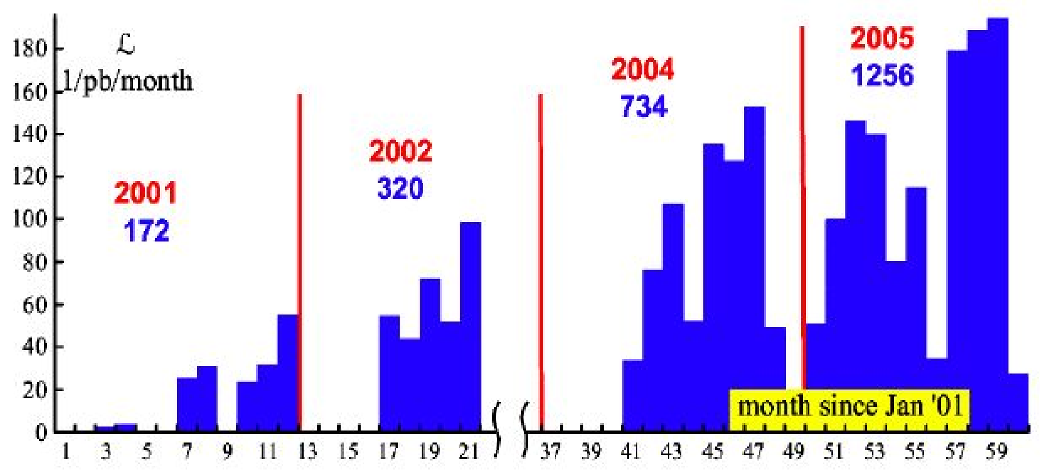
Results from KLOE

- e^+e^- collider at M_Φ: $\sqrt{s} \sim 1.019$ GeV
- angle btw the beams @ IP ~ 2×12.5 mrad
- residual momentum in LAB ~ 13 MeV

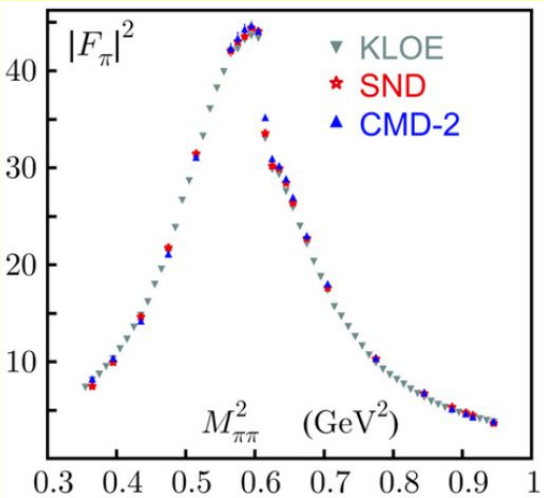


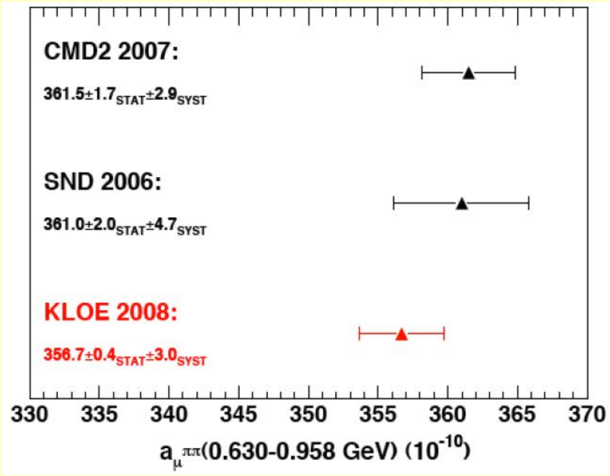
2001-05: ~ 2.5 fb^{-1} at M_Φ
2006: ~ 250 pb^{-1} at $\sqrt{s}$=1 GeV + scan

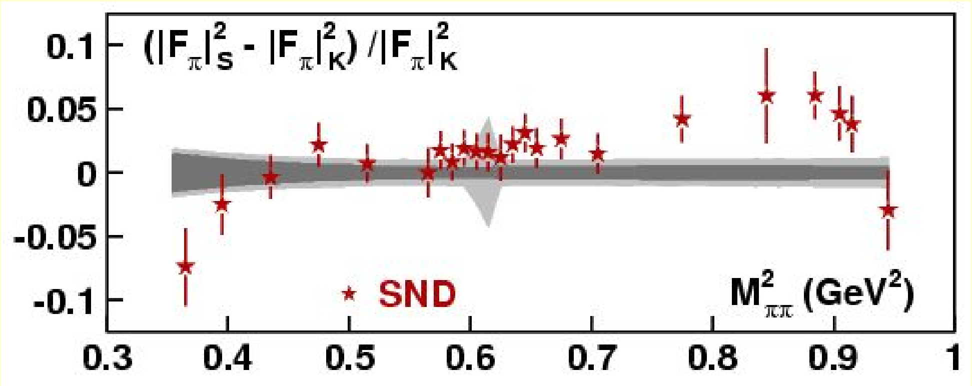
$$L_{peak} = 1.3\times10^{32}\ cm^{-2}\ s^{-1}$$

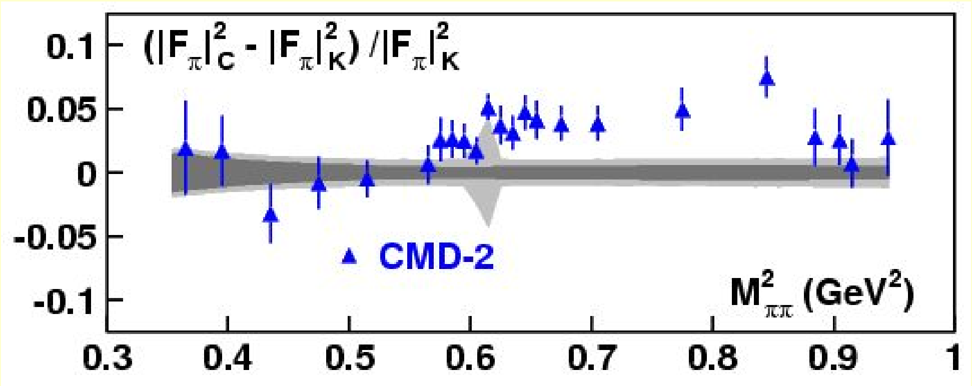


Results from KLOE







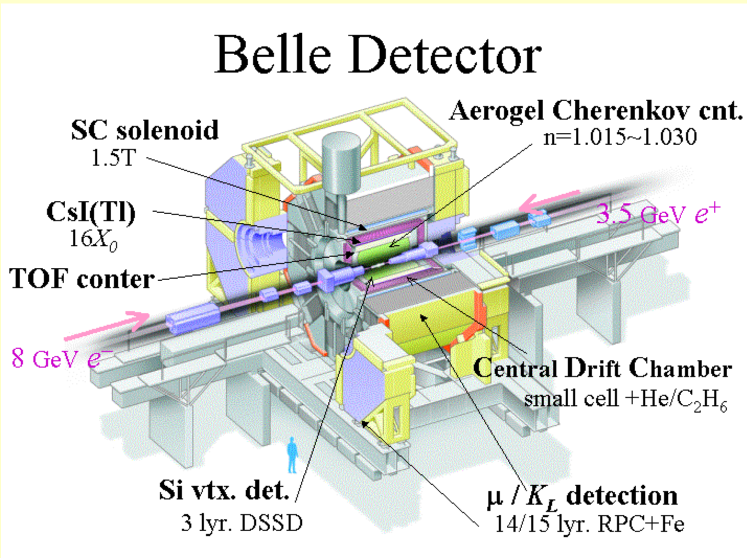


KLOE strengthens the discrepancy ~ 3.4 σ between the SM prediction and the BNL measurements

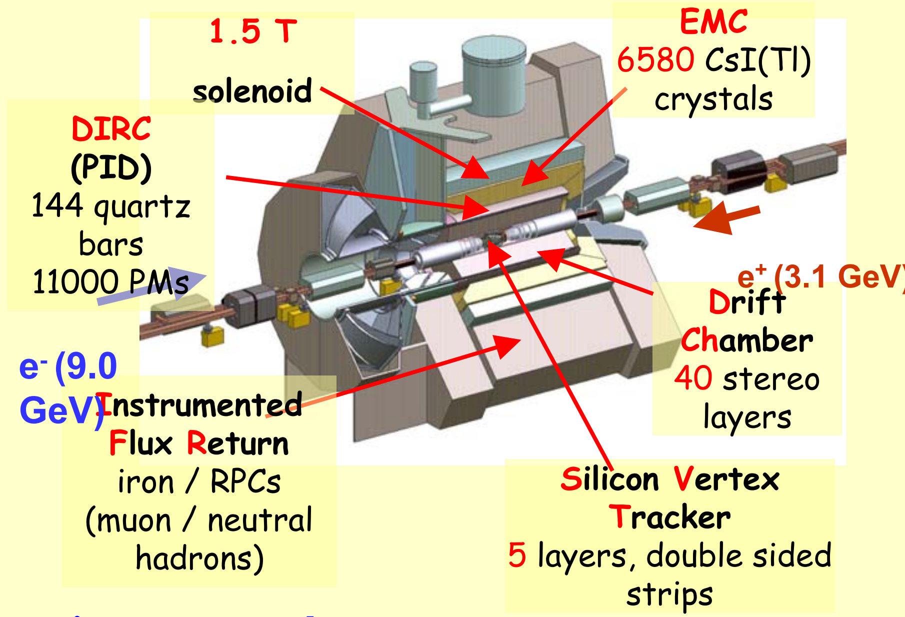
Tau decays study - last years the main contributions came from two B-factories – Belle and BaBar

F/B asymmetric detectors

High vertex resolution, magnetic spectrometry, excellent calorimetry and sophisticated particle ID ability



BaBar detector



$$\sum_{BaBar}^{Belle} \int_{1999}^{2006} Ldt \approx 1.5ab^{-1}$$

Clear environment!

→ $\approx 1\,400\,000\,000\ \tau^+\tau^-$

Decay Mode	Experiment	Reference	Result
$(\tau^- \to K^- \nu_\tau)/(\tau^- \to e^- \bar{\nu}\nu)$	BaBar	arXiv:0811.1429 [hep-ex]	(0.03882 +- 0.00032 +- 0.00056)
		$|g_{tau}/g_{mu}|$ = (0.9836 +- 0.0087)	
$\tau^- \to K^- \pi^0 \nu_\tau$	BaBar	Phys.Rev.D76:051104,2007	(0.416 +- 0.003 +- 0.018)x 10^{-2}
tau- -> K0bar pi- nu	BaBar	arXiv:0808.1121 [hep-ex]	(0.840 +- 0.004 +- 0.023)x 10^{-2}
	Belle	Phys.Lett.B654:65-73,2007	(0.808 +- 0.004 +- 0.026)x 10^{-2}
tau- -> K- pi- pi+ nu	BaBar	Phys.Rev.Lett.100:011801,2008	(0.273 +- 0.002 +- 0.009)x 10^{-2}
(excl. KS0)	Belle	arXiv:0812.0480 [hep-ex]	(0.325 +- 0.002 $^{+0.016}_{-0.015}$)x 10^{-2}
tau- -> K- pi- K+ nu	BaBar	Phys.Rev.Lett.100:011801,2008	(1.346 +- 0.010 +- 0.036)x 10^{-3}
	Belle	arXiv:0812.0480 [hep-ex]	(1.53 +- 0.01 $^{+0.06}_{-0.06}$)x 10^{-3}
tau- -> K- K- K+ nu	BaBar	Phys.Rev.Lett.100:011801,2008	(1.58 +- 0.13 +- 0.12)x 10^{-5}
	Belle	arXiv:0812.0480 [hep-ex]	(2.60 +- 0.23 $^{+0.10}_{-0.10}$)x 10^{-5}
tau- -> K- phi nu	BaBar	Phys.Rev.Lett.100:011801,2008	(3.39 +- 0.20 +- 0.28) x 10^{-5}
	Belle	Phys.Lett.B643:5-10,2006	(4.05 +- 0.25 +- 0.26) x 10^{-5}
tau- -> K* K- nu	Belle	arXiv:0808.1059 [hep-ex]	(1.56 +- 0.02 +- 0.09) x 10^{-3}
tau- -> K* K- pi0 nu	Belle	arXiv:0808.1059 [hep-ex]	(2.39 +- 0.46 +- 0.26) x 10^{-5}
tau- -> K- eta nu	Belle	Phys.Lett.B672:209-218,2009	(1.58 +- 0.05 +- 0.09) x 10^{-4}
tau- -> K- pi0 eta nu	Belle	Phys.Lett.B672:209-218,2009	(4.6 +- 1.1 +- 0.4) x 10^{-5}
tau- -> KS0 pi- eta nu	Belle	Phys.Lett.B672:209-218,2009	(4.4 +- 0.7 +- 0.2) x 10^{-5}
tau- -> K*- eta nu	Belle	Phys.Lett.B672:209-218,2009	(1.34 +- 0.12 +- 0.09) x 10^{-4}

(tau- -> pi- nu)/(tau- -> e- nubar nu)	BaBar	arXiv:0811.1429 [hep-ex]	(0.5945 +- 0.0014 +- 0.006[illegible]
		$|g_{tau}/g_{mu}|$ = (0.9859 +- 0.0057)	
tau- -> pi- pi0 nu	Belle	Phys.Rev.D78:072006,2008	(25.24 +- 0.01 +- 0.39) X 10^{-2}
tau- -> pi- pi- pi+ nu	BaBar	Phys.Rev.Lett.100:011801,2008	(8.83 +- 0.01 +- 0.13) x 10^{-2}
(excl. KS0)	Belle	arXiv:0812.0480 [hep-ex]	(8.41 +- 0.00 $^{+0.34}_{-0.33}$) x 10^{-2}
tau- -> pi- pi0 eta nu	Belle	Phys.Lett.B672:209-,2009	(1.35 +- 0.03 +- 0.07) x 10^{-3}
tau- -> pi- phi nu	BaBar	Phys.Rev.Lett.100:011801,2008	(3.42 +- 0.55 +- 0.25) x 10^{-5}

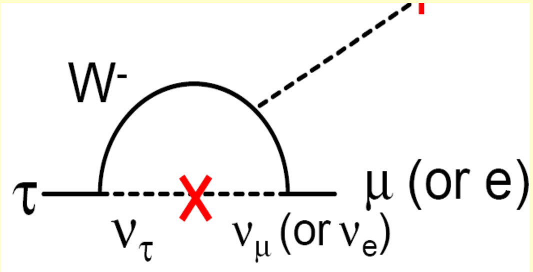
Compilation of HFAG-tau group

Searches for lepton flavour violation in tau decays

In the SM the lepton flavour violation decays are extremely small:

$Br(\tau \to l\gamma) \sim 10^{-54}$

$Br(\tau \to 3\ leptons) \sim 10^{-14}$



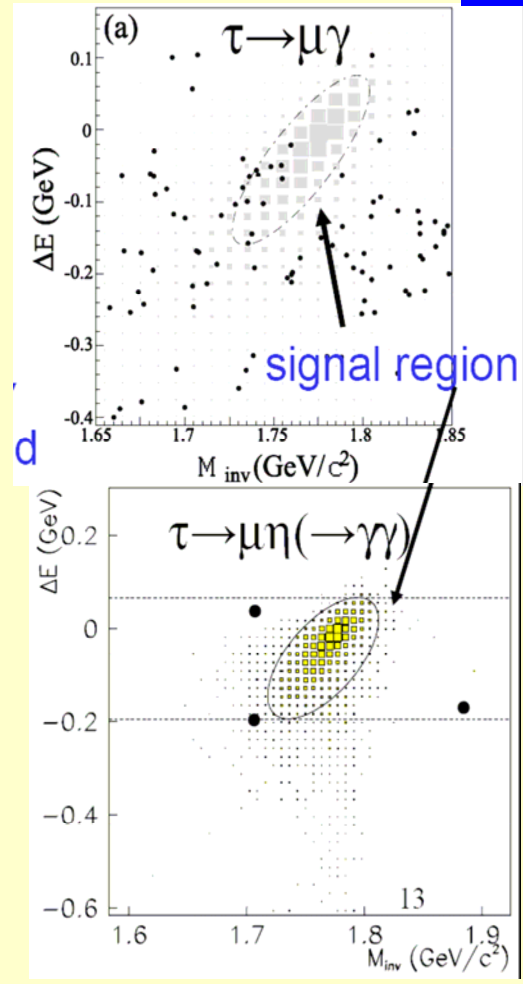
Observation of LFV decays would be a clear signal of New Physics

- **Searches for μ - e LFV: μ - e conversion, $\mu^- \to e^-\gamma$ ($B < 1.2 \times 10^{-11}$), $\mu^- \to e^-e^+e^-$ ($B < 1.0 \times 10^{-12}$) MEG, PRISM prepared.**
- **Many models consider extensions of the Standard Model with enhanced LFV. Particularly popular are SUSY models, e.g. MSSM extension of SM, also discussed SUGRA, GUT, Higgs, little Higgs.** Predicted $B(\tau^- \to \mu^-\gamma)$ reach 10^{-8} - 10^{-7}
- **At Belle and BaBar 44 different modes studied. The most stringent limit is $B(\tau^- \to \mu^+ e^- e^-) < 1.5 \times 10^{-8}$. The sensitivity is limited by background suppression/statistics.**

Example - results from Belle

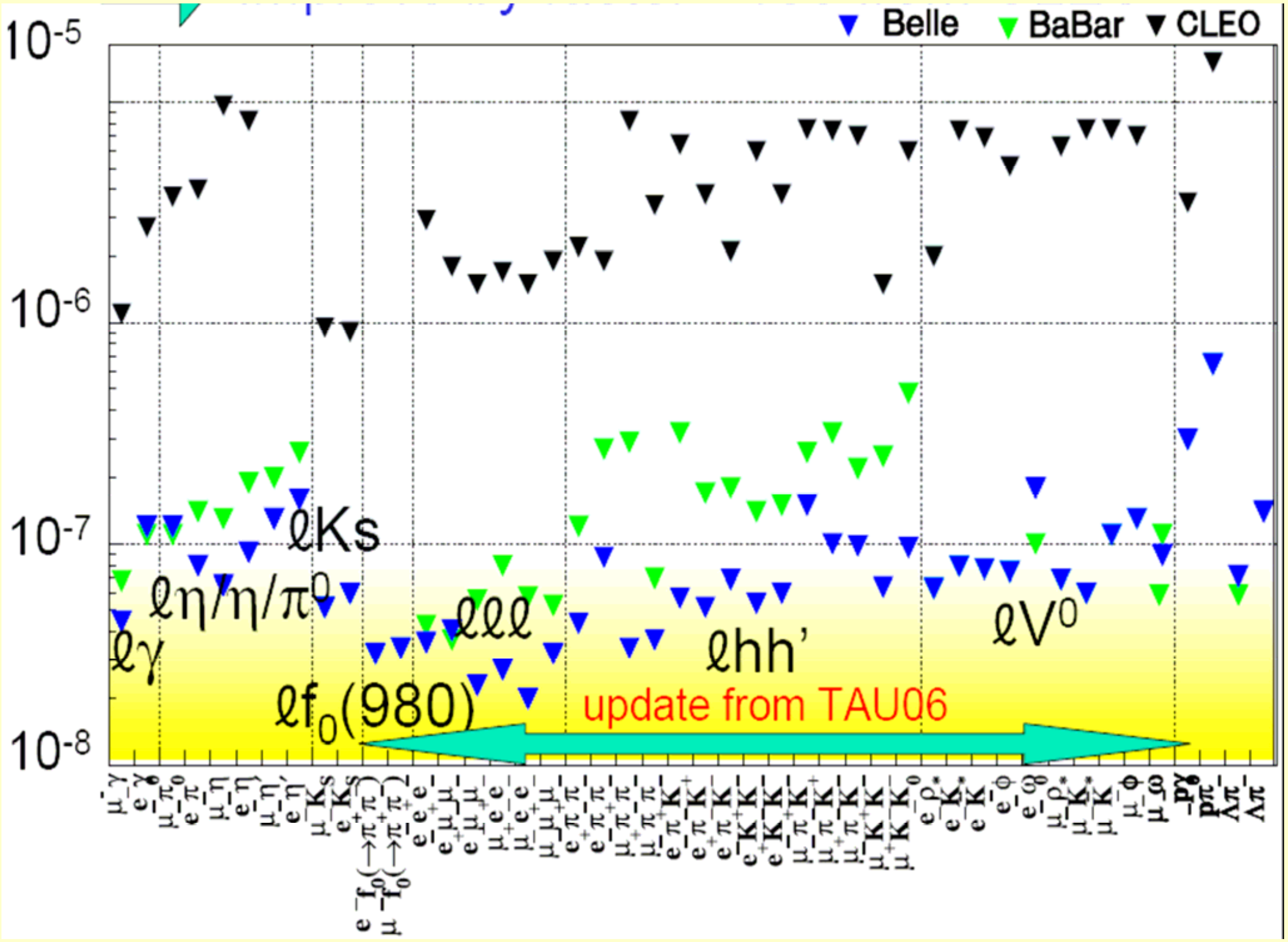
$\tau^- \to \mu^-\gamma$, $e\gamma$ (PLB666,16(2008))
Final state: 1-prong decays and others
Data: 535fb-1
$Br(\tau^- \to \mu^-\gamma)$ < 4.5x10-8 at 90%C.L.
$Br(\tau^- \to e^-\gamma)$ < 1.2x10-7 at 90%C.L.
sensitivity is limited by the remaining background from $e^+e^- \to \tau^+\tau^-\gamma$

$\tau \to e/\mu(\eta, \eta', \pi^0)$ (PLB648, 341 2007))
Data:401fb^{-1}
Expected BG : (0.0-0.6) events
Nobs : 1 event
$Br(\tau \to \mu\eta, \mu\eta', \mu\pi^0)$ < (6.5-13)x10^{-8}
$Br(\tau \to e\eta, e\eta', e\pi^0)$ < (8.0-16)x10^{-8}



Points - data

Recent Upper limits on LFV τ decays



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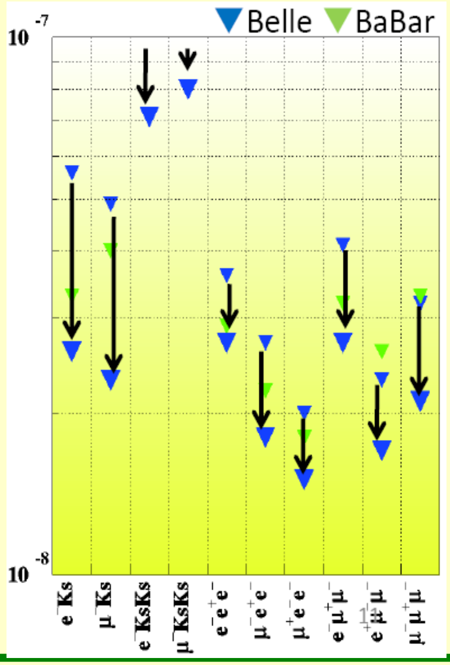
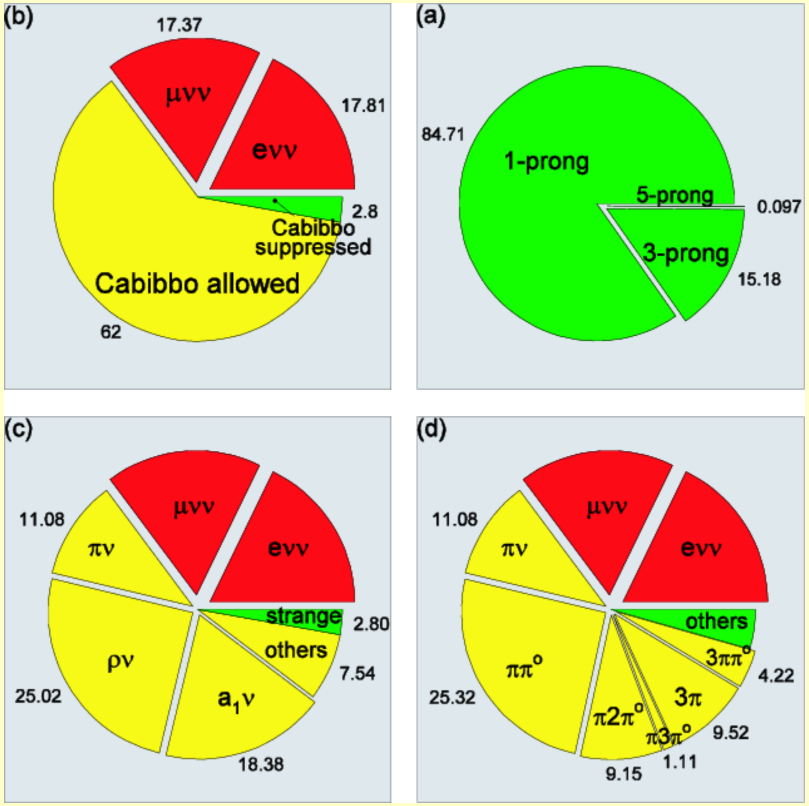


Improvement by factor ~ 100 from CLEO

Main motivations to study tau hadronic decays



✓τ-lepton decays provide an excellent laboratory to study hadron physics up to 1.8 GeV. The main attraction is quite clear initial state.

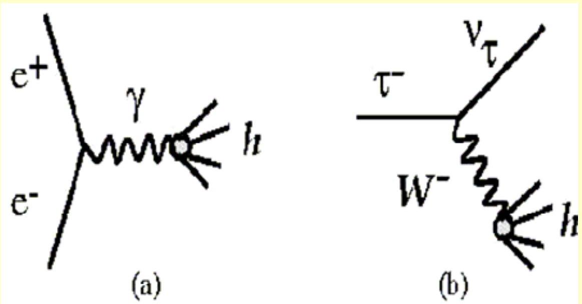
✓Tests of CVC and evaluation of the a_μ from spectral functions.

✓ Search for CP violation effects in the hadronic decays in hope to find new physics.

✓Improvement of the limits on the neutrino mass.

$\tau^- \to \pi^- \pi^0 \nu_\tau$ decay – important features:

- **Largest branching fraction**
- **Connection to e^+e^- via CVC**



$$\frac{1}{N_{\pi\pi}}\frac{dN_{\pi\pi}}{ds} = \frac{6\pi |V_{ud}|^2 S_{EW}}{m_\tau^2} \times \frac{B_e}{B_{\pi\pi}}\left[\left(1-\frac{s}{m_\tau^2}\right)^2\left(1+\frac{2s}{m_\tau^2}\right)\right] v^{\pi\pi}(s)$$

$$v^{\pi\pi^0}(s) = \frac{\beta^3(s)}{12\pi}\left|F_\pi(s)\right|^2$$

$e^+e^- \to h^0$ and $\tau^- \to h^-$,

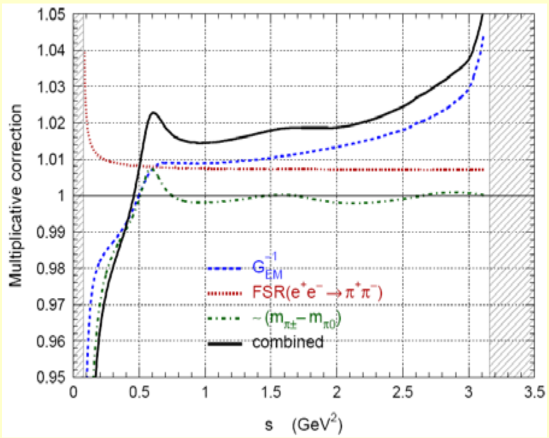
h: $I^G J^P = 1^+ 1^-$

Corrections to the Spectral Functions

- $S_{EW} = 1.0233 \pm 0.0006$
- Real photons, loops
- FSR
- $m_{\pi\pm} \neq m_{\pi 0}$ (phase space, $\Gamma\rho$)
- $m_{\rho\pm} \neq m_{\rho 0}$
- $\rho - \omega$ interference
- Radiative decays ($\pi\pi\gamma$, $\pi(\eta)\gamma$, l^+l^-)
- $m_u \neq m_d$
- and 2 class currents

V. Cirigliano, G. Ecker, H. Neufeld, 2002

M.Davier et al., 2002



$\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ – recent results from Belle : Branching Fraction

updated results from Belle experiment based on 5.6×10^6 $\tau^- \rightarrow \pi^- \pi^0 \nu_\tau$ decays (72.2/fb). Presented at Tau-08.

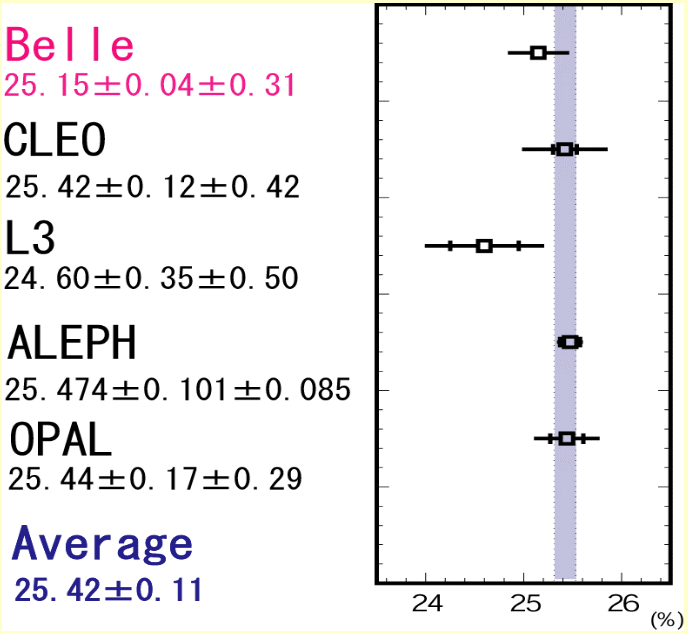
$$Br_{2\pi} = (25.24 \pm 0.01(stat) \pm 0.39(sys))\%$$

Systematic uncertainties Source	$\Delta B/B$, %
Tracking efficiency	0.47
π^0 efficiency	1.3
Background in τ-pair	0.59
Feed down background	0.16
Continuum background	0.20
γ veto	0.20
Trigger	0.32
MC statistics	0.08
Total	1.52

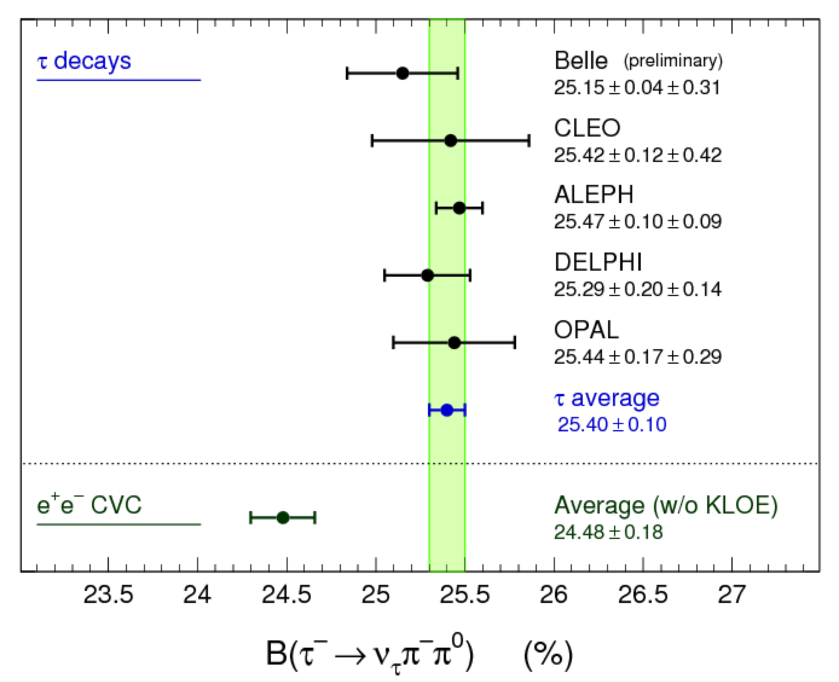
Systematic is dominated by the uncertainty of the π^0 efficiency and the BG in τ-pair

π^0 Calibrated by η signals ($\eta \rightarrow \pi^0\pi^0\pi^0 / \eta \rightarrow \gamma\gamma$).

Checked by using electron tracks.



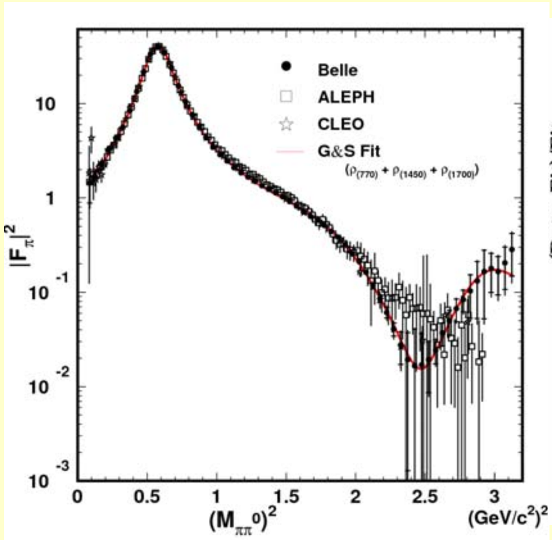
CVC in the 2π channel. e^+e^- vs. τ

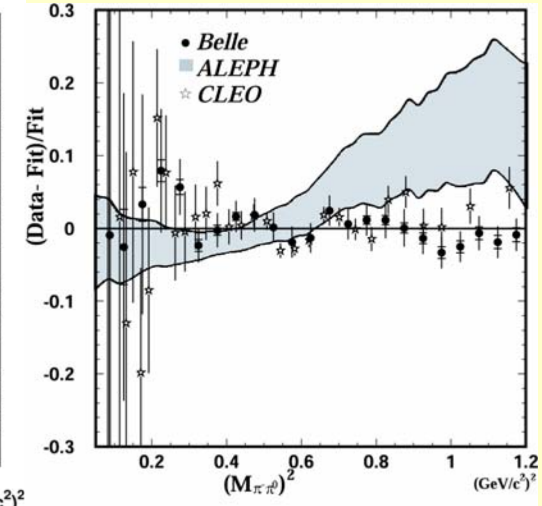


The branching from all groups is systematically higher than the CVC prediction:

B - Bee = (0.92 ± 0.21)% or 4.5σ from 0. The discrepancy is a 3.6% effect, about twice the SU(2) correction.

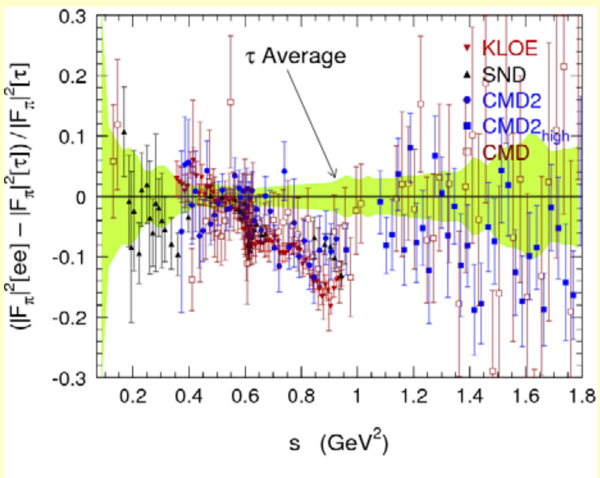
$\tau^- \to \pi^-\pi^0\nu_\tau$ – recent results from Belle





Systematics, %

$M^2_{\pi\pi}$	threshold	ρ region	ρ'	ρ"
Total	**5.3**	**0.7**	**1.8**	**11.4**



- Belle(τ)

$$a_\mu^{\pi\pi} = (523.5 \pm 1.5(exp.) \pm 2.6(Br) \pm 2.5(isospin))x10^{-10}$$

- ALEPH, CLEO, OPAL (τ) Ref. Eur. Phys. J. C27, 497 (2003)

$$a_\mu^{\pi\pi} = (520.1 \pm 2.4(exp.) \pm 2.7(Br) \pm 2.5(isospin))x10^{-10}$$

- CMD2,SND (e^+e^-) Ref. Nucl. Phys. Proc. Suppl. 169, 288 (2007)

$$a_\mu^{\pi\pi} = (504.6 \pm 3.1(exp.) \pm 0.9(rad.))x10^{-10}$$

Search for 2nd Class Currents

1CC – $PG(-1)^J = +1$: $J^{PG} = 0^{-}(\pi)$, $1^{-+}(\rho)$, $1^{+-}(a_1)$, …

2CC – $PG(-1)^J = -1$: $J^{PG} = 0^{+-}(a_0)$, $1^{++}(b_1)$, ….

S. Weinberg (Phys. Rev. **112**, 1375 (1958))

Experiment	$B(\tau^- \to \eta\pi^-\nu_\tau)$, 10^{-4}
HRS, 1987	$510 \pm 100 \pm 120$
CLEO, 1987	< 100
ARGUS, 1988	< 90
CLEO, 1992	< 3.4
CLEO, 1996	< 1.4
ALEPH, 1997	< 6.2
experiment	**$B(\tau^- \to \eta'\pi^-\nu_\tau)$, 10^{-5}**
CLEO, 1997	< 7.4
BaBar, 2006	< 1:2

2nd class currents suppressed

in SM: $\propto (m_u - m_d)$

$\tau^- \to \eta\pi^-\nu_\tau$ has $J^{PG} = 0^{+-}$

Theory prediction:

$B(\tau^- \to \eta\pi^-\nu_\tau) \sim 10^{-6} - 10^{-5}$.

Large BG from $\tau^- \to \eta\pi^-\pi^0\nu_\tau$

with $B = (1.77 \pm 0.24) \cdot 10^{-3}$

Up to now no SCC were not found in experiment

Recent results of a search for $\tau^- \to \eta\pi^-\nu_\tau$ at Belle

Studied sample contained 6.2×10^8 τ pairs

(EPS –09)

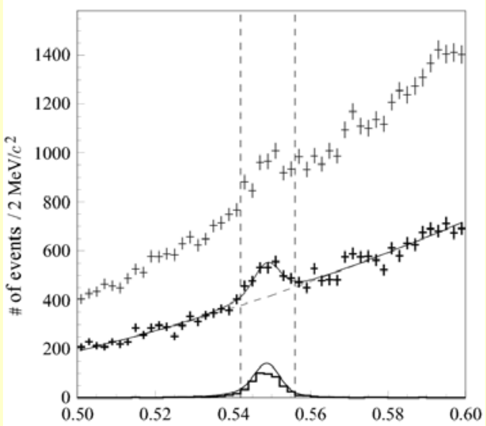
$$e^+ + e^- \to \tau^- + \tau^+$$

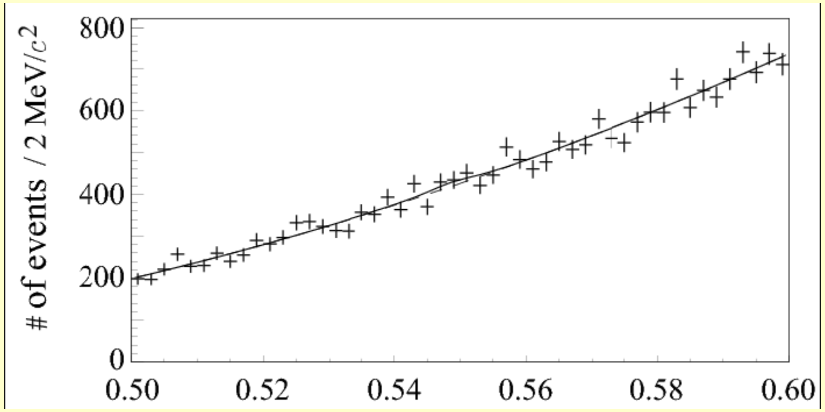
$\tau^- \to \pi^- + \eta + \nu_\tau$ **signal side**

$\eta \to \pi^+ + \pi^- + \pi^0 (\to \gamma\gamma)$

$\tau^- \to l^+ + \nu_\tau + \nu_\lambda + n\gamma$ **tag side**

Additional condition – $M(4\pi) < 1.2$ GeV





After BG subtraction $N_{\eta,sig} = N_{\eta,fit} - N_{\eta,BG} = 190.9 \pm 68.6$

$B(\tau^- \to \eta\pi^-\nu_\tau) = (4.4 \pm 1.6 \pm 0.8) \times 10^{-5}$

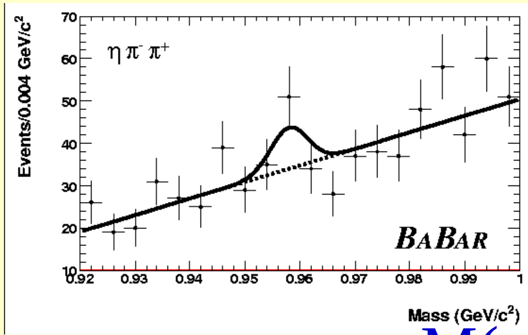
$B(\tau^- \to \eta\pi^-\nu_\tau) < 7.3 \times 10^{-5}$ @90%CL

$B(\tau^- \to \eta'\pi^-\nu_\tau) < 4.6 \times 10^{-6}$ @90%CL

BaBar searches for SCC

$\tau^- \to \eta' \pi^- \nu_\tau$

Integrated luminosity of 384 fb̃1 (706 million τ-decays)

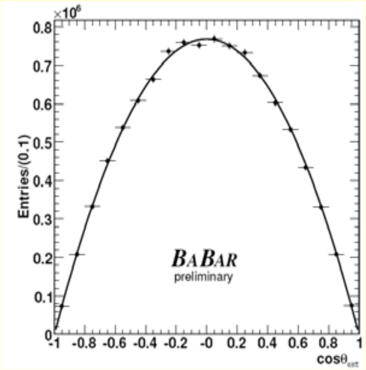


Fit gives 19 ± 13 events

$B(\tau^- \to \eta'(958)\pi^- \nu_\tau) < 7.2 \times 10^{-6}$
at 90% confidence level

M(ηππ)

omega pi nu ⇒ vector (FCC) + axial-vector (SCC)



Integrated luminosity of 347 fb̃1 (319 million τ-pairs)

$\frac{N^{\omega\pi}(\text{non-vector})}{N^{\omega\pi}(\text{vector})}$ **< 0.69% at 90% C.L. and 0.85% at 95% CL**

arXiv:0807.4900 [hep-ex].

- **CLEO: < 6.4% at the 95% CL**

K. E. Edwards et. al., Phys. Rev. D61, 072003 (2000),

- **ALEPH: < 8.6% at the 95% CL**

D. Buskulic et. al. , Zeit. Phys. C74, 263 (1997).

|Vus| from Tau Decays

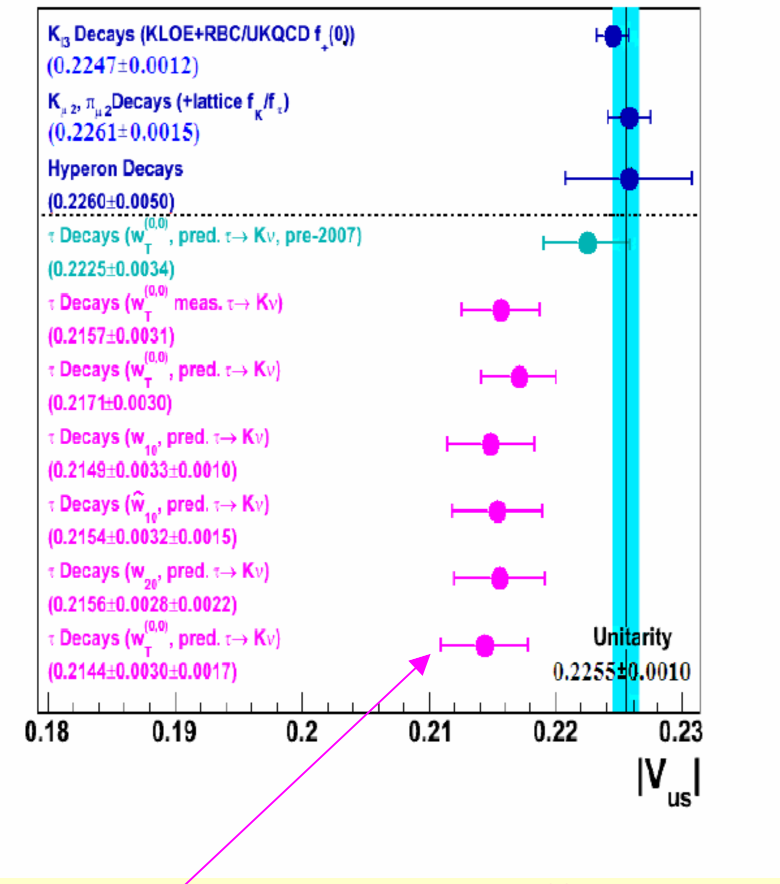
$$R_\tau = \frac{\Gamma(\tau^- \to h^- \nu_\tau)}{\Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)} = R_s + R_{ns}$$

$$|V_{us}|^2 = \frac{R_s}{R_{ns}/|V_{ud}|^2 - \delta R_\tau}$$

The branching fractions and invariant mass distributions are the experimental input to determine |Vus| well measured from superallowed beta decays

The is determined from Finite Energy Sum Rules and is relatively small, so that even a large relative error can yield a precise measurement

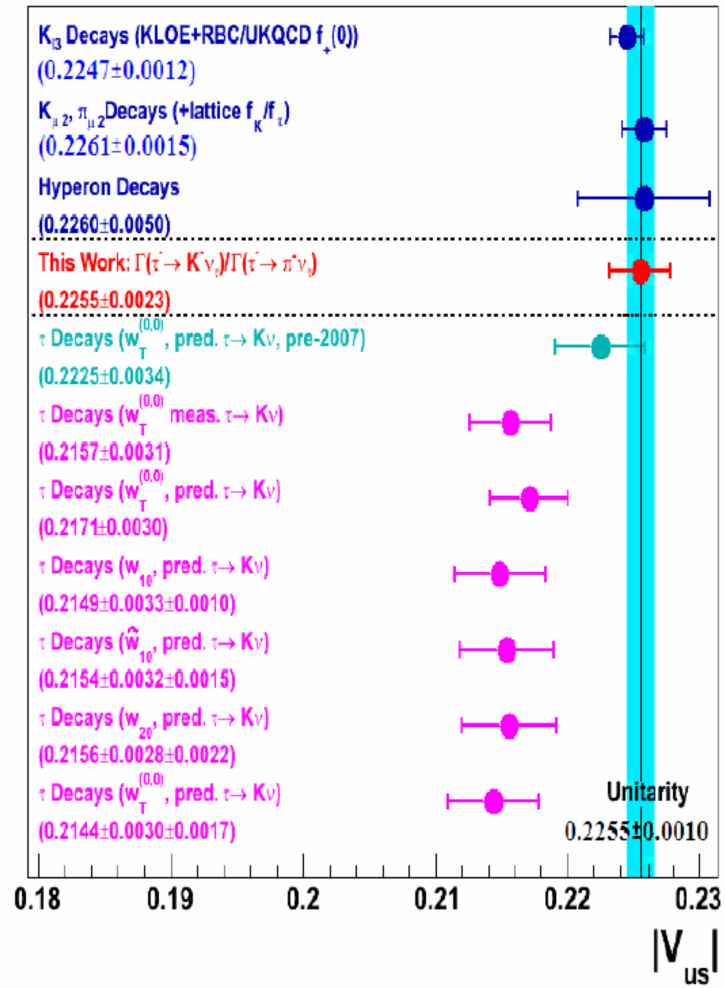
of |Vus| (e.g. ~6% of Rnon-strange/|Vud|2 and known to better than10%)



these points use same data, different weight functions in FESR

Independent determination of |Vus| in Tau Decays by Babar

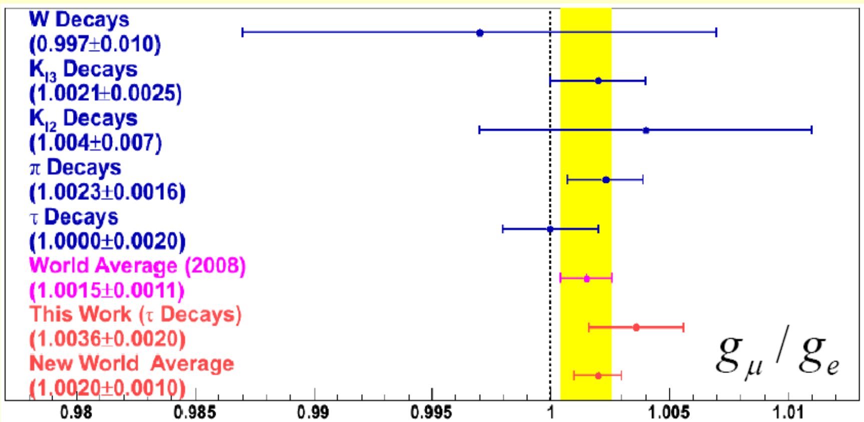
$$\frac{\Gamma(\tau \to K\nu_\tau)}{\Gamma(\tau \to \pi\nu_\tau)} = \left|\frac{V_{us}}{V_{ud}}\right|^2 \frac{f_K^2}{f_\pi^2} \left(\frac{1-m_K^2/m_\tau^2}{1-m_\pi^2/m_\tau^2}\right)^2 (1+\delta_{RC}^\tau)$$

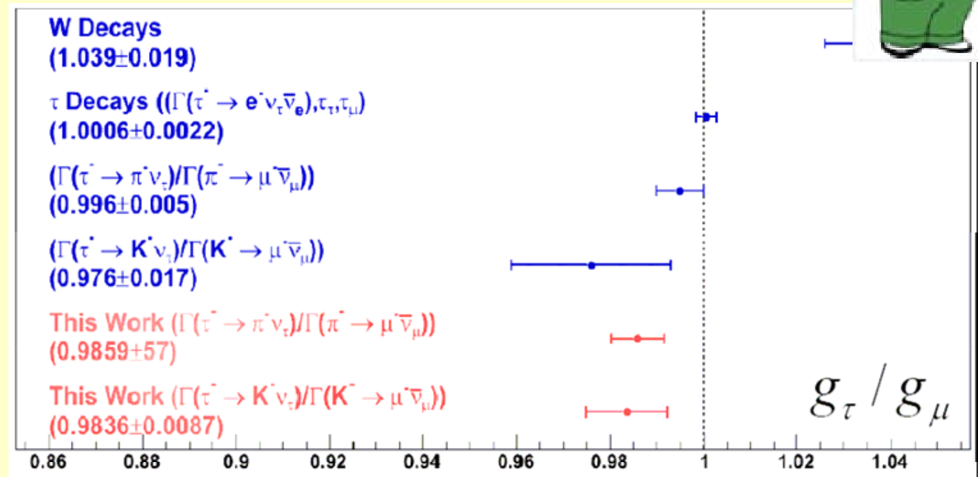


Measure $B(\tau\to K\nu_\tau)/B(\tau\to \pi\nu_\tau)$

- **Take f_K/f_π =1.189±0.007 from Lattice QCD (E. Follana, et al. PRL 100, 062002 (2008))**
- **δτRC =0.03%**
- **|Vud|= 0.97408±0.00026 from superallowed beta decays**

Lepton universality and tau mass





From Standard Model

$$G_F = \frac{g^2}{4\sqrt{2}M_W^2}, \quad g = g_e = g_\mu = g_\tau$$

Experimental Measurements

W Decays:
- ALEPH, DELPHI, L3, and OPAL

τ Decays:
- ALEPH, DELPHI, L3, OPAL, and CLEO

Kaon Decays:
- KLOE

Pion Decays:
- TRIUMF and PSI

$$r = \left(\frac{g_\tau}{g_\mu}\right)^2 = \left(\frac{m_\mu}{m_\tau}\right)^5 \left(\frac{\tau_\mu}{\tau_\tau}\right) B(\tau \to e\nu_\tau \bar{\nu}_e) \frac{F_{cor}(m_\mu, m_e)}{F_{cor}(m_\tau, m_e)}$$

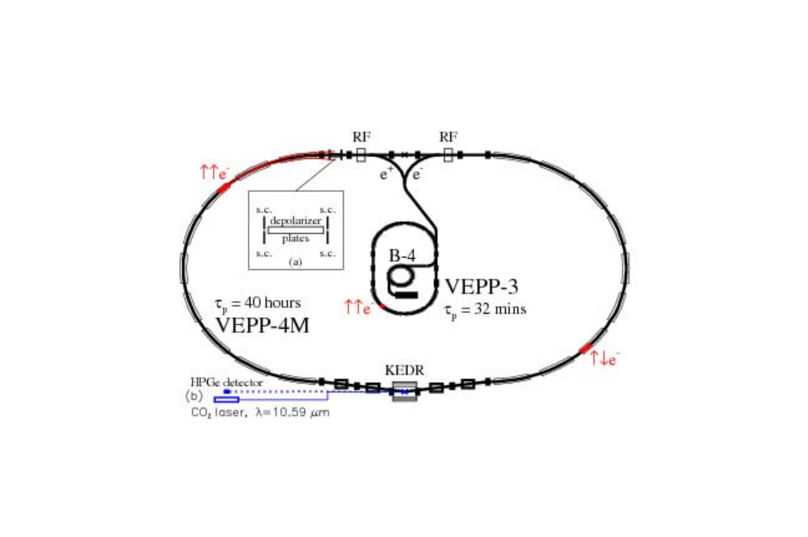
r	τ , fs	$B(\tau \to e\nu_\tau\nu_e)$, %	m_τ ,MeV
1.0020 ± 0.0051	290.6 ± 1.1 0.0038	17.84 ± 0.06 0.0034	$1776.99^{+0.29}_{-0.26}$ 0.0008

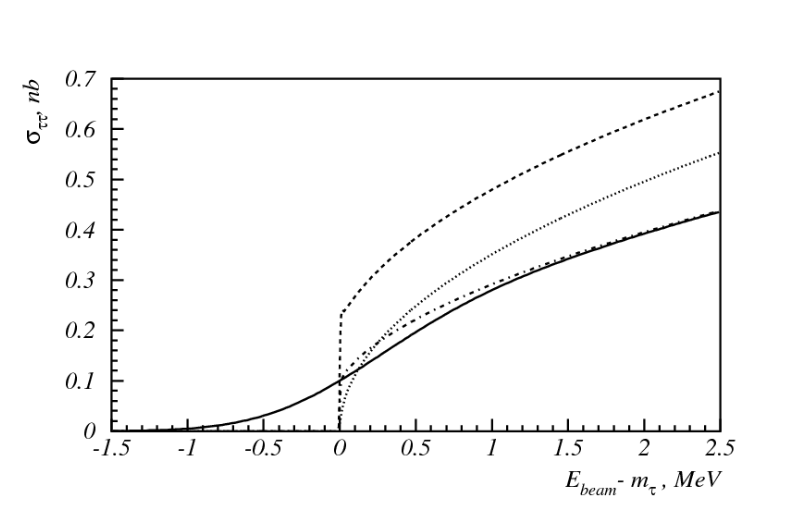
M_τ = (1776.69+0.17-0.19+-0.15) MeV PDG 2004

Mass m_μ = 105.658367 ± 0.000004 MeV

Mass m_e = 0.510998910 ± 0.000000013 MeV

M_τ at KEDR: $\tau^+\tau^-$ cross section near threshold





Lmax = $2{\cdot}10^{30}$ cm^{-2} s^{-1} at 1.78 GeV/beam

Two independent methods of energy measurement

Resonant depolarization for absolute calibration (slow):

$\Omega/\omega = 1 + \gamma{\cdot}\mu/\mu_0$,

Ω - spin precession frequency,

ω - revolution frequency,

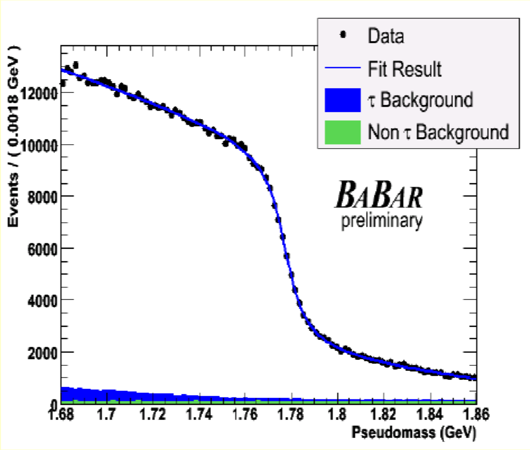
μ (μ_0) - anomalous (normal) emm

Compton backscattering of laser 0.12 MeV photons (fast)

M_τ at Belle and BaBar: analysys of the hadronic decays by Pseudomass method

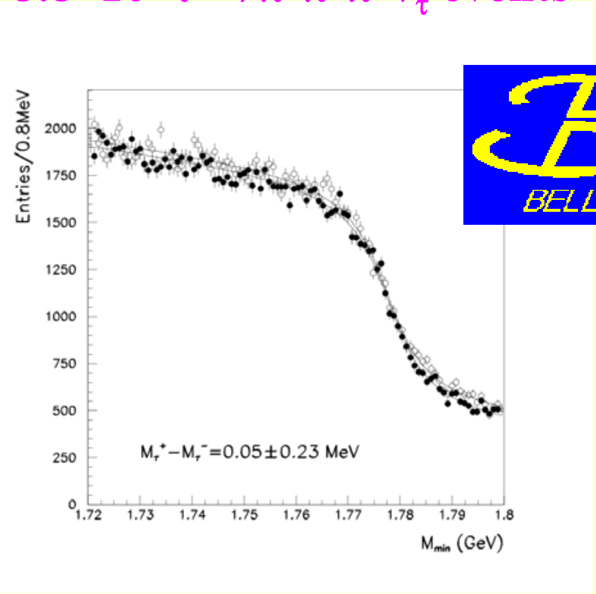
$$M_\tau^2 = (E_h + E_\nu)^2 - (\vec{p}_h + \vec{p}_\nu)^2 = M_h^2 + 2(E_\tau - E_h)(E_h - p_h \cos\theta)$$
$$\geq M_p^2 = M_h^2 + 2(E_{beam} - E_h)(E_h - p_h)$$

BaBar: ~389 million τ+τ- pairs



Belle: 414 fb^{-1} or 370×10^6 $\tau^+\tau^-$ pairs

~ 5.8×10^5 $\tau^- \to \pi^+\pi^-\pi^-\nu_\tau$ events



$\Delta m = m_{\tau+} - m_{\tau-}$

Group	OPAL, 2000	Belle, 2007	BaBar, 2008
$N_{\tau+\tau-}, 10^6$	0.16	370	389
$\Delta m/m_\tau, 10^{-4}$	0.0 ± 18.0	0.3 ± 1.5	-3.5 ± 1.3
$\Delta m/m_\tau, 10^{-4}$ 90%CL	< 30.0	$< 2.8 \times 10^{-4}$	$-5.6 < \ldots < -1.4$

Group	M_τ, MeV
BES, 1996	1776.96+0.18-021+0.25-0.17
PDG, 2006	1776.99+0.29-0.26
KEDR, 2007	1776.81+0.25-0.23±0.15
Belle, 2007	1776.61 ±0.13 ± 0.35
PDG, 2008	1776.83 ± 0.18
KEDR, 2008	1776.68+0.17-0.19±0.15
BaBar, 2008	1776.68 ± 0.12 ± 0.41

What is next?

Next 3 – 5 - …. years:

Intensive analysis of the ~1.5 ab-1 data sample harvested by both B-factories;

New results from KLOE and KEDR;

First results from BES-III;

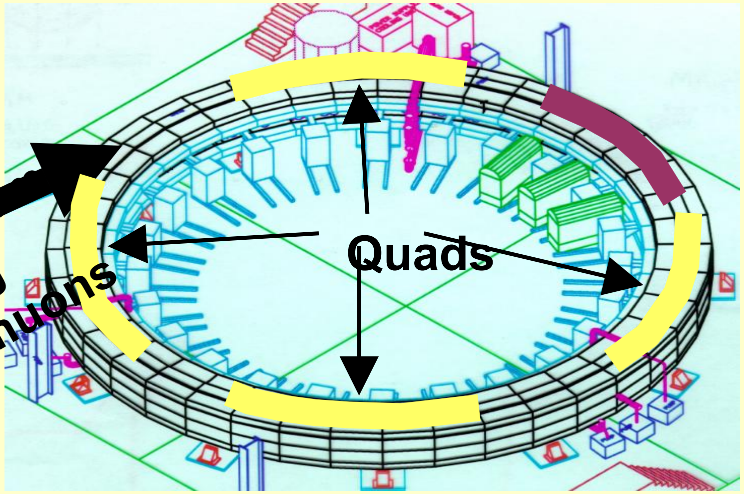
First results from LHC

…………………………………

What's then? ⇒

Successor of the BNL E821

- **Experimental uncertainty = 63 x 10^{-11} (0.54 ppm)**
  - **0.46 ppm statistical**
  - **0.28 ppm systematic**

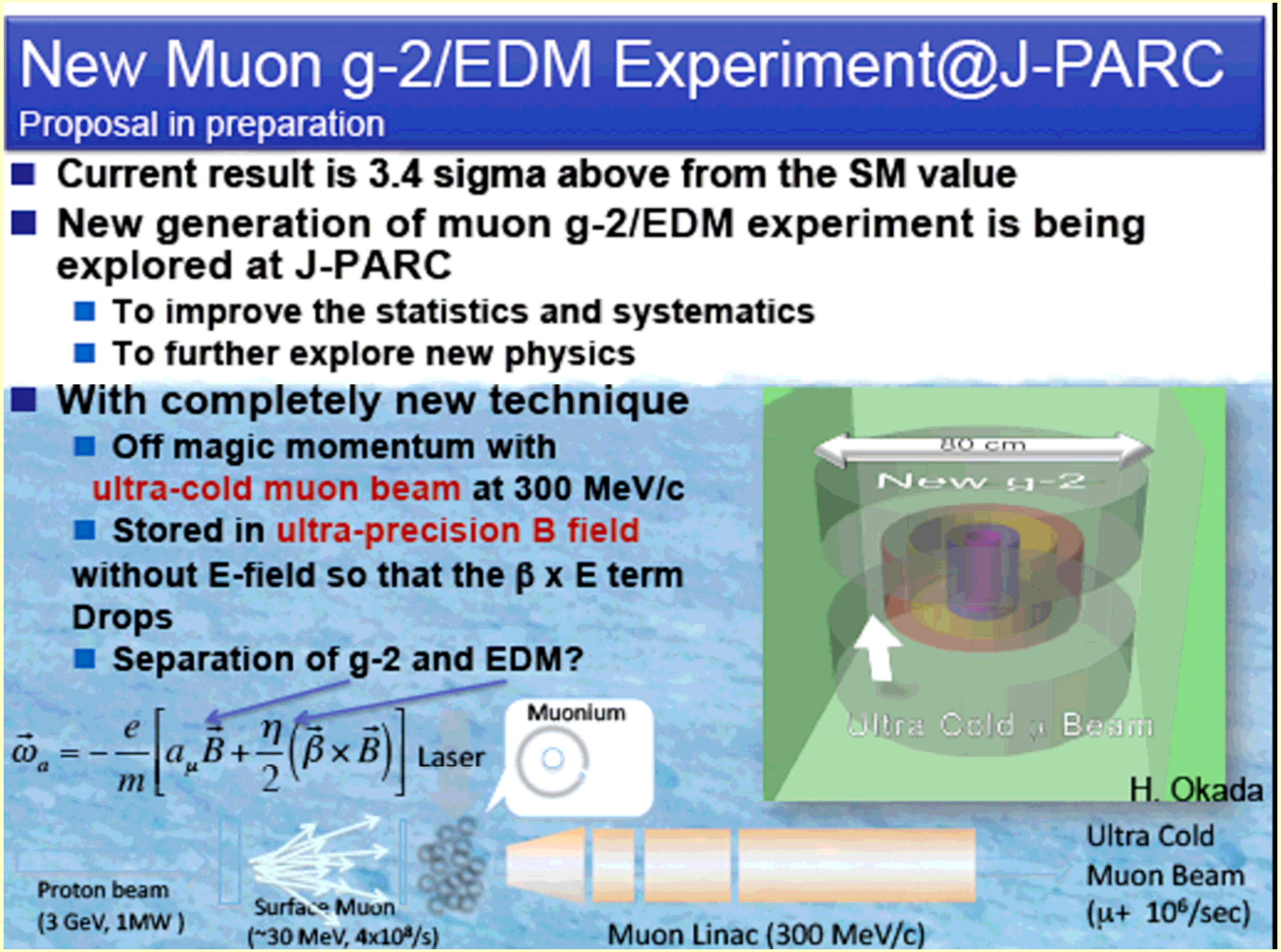


The New $(g-2)$ Experiment:
A Proposal to Measure the Muon Anomalous Magnetic Moment
to ± 0.14 ppm Precision

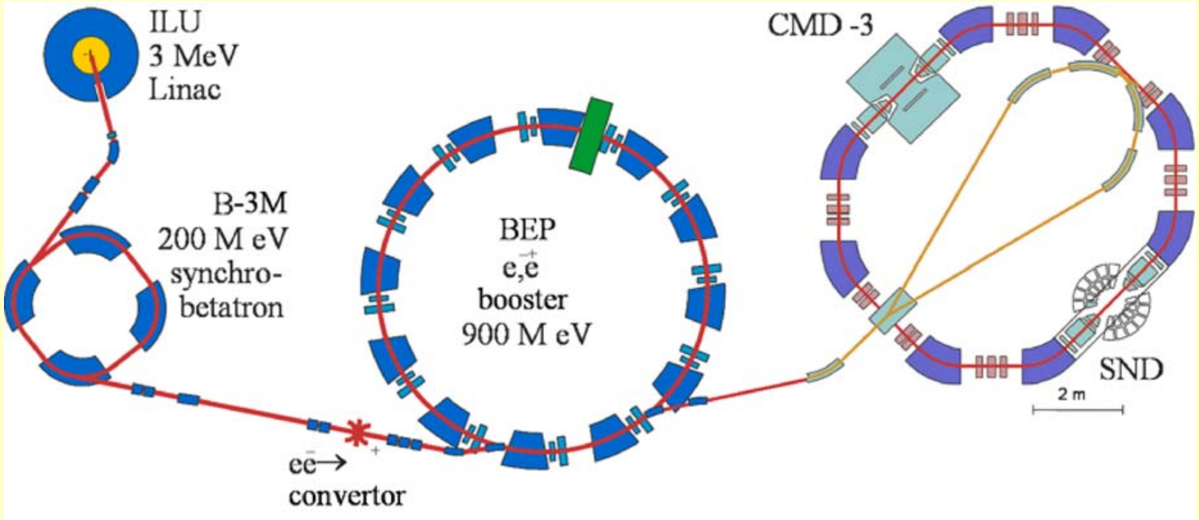
New $(g-2)$ Collaboration: R.M. Carey[1], K.R. Lynch[1], J.P. Miller[1], B.L. Roberts[1], W.M. Morse[2], Y.K. Semertzidis[2], V.P. Druzhinin[3], B.I. Khazin[3], I.A. Koop[3], I. Logashenko[3], S.I. Redin[3], Y.M. Shatunov[3], Y. Orlov[4], R.M. Talman[4], B. Casey[5], J. Johnstone[5], D. Harding[5], A. Klebaner[5], A. Leveling[5], J-F. Ostiguy[5], N. Mokhov[5], D. Neuffer[5], M. Popovic[5], S. Strigonov[5], M. Syphers[5], G. Velev[5], S. Werkema[5], F. Happacher[6], G. Venanzoni[6], P. Debevec[7], M. Grosse-Perdekamp[7], D.W. Hertzog[7], P. Kammel[7], C. Polly[7], K.L. Giovanetti[8], K. Jungmann[9], C.J.G. Onderwater[9], N. Saito[10], C. Crawford[11], R. Fatemi[11], T.P. Gorringe[11], W. Korsch[11], B. Plaster[11], V. Tishchenko[11], D. Kawall[12], T. Chupp[13], C. Ankenbrandt[14], M.A Cummings[14], R.P. Johnson[14], C. Yoshikawa[14], André de Gouvêa[15], T. Itahashi[16], Y. Kuno[16], G.D. Alkhazov[17], V.L. Golovtsov[17], P.V. Neustroev[17], L.N. Uvarov[17], A.A. Vasilyev[17], A.A. Vorobyov[17], M.B. Zhalov[17], F. Gray[18], D. Stöckinger[19], S. Baeßler[20], M. Bychkov[20], E. Frlež[20], and D. Počanić[20]

parameter	BNL	FNAL	gain factor FNAL/BNL
Y_π pion/p into channel acceptance	$\approx$ 2.7E-5	$\approx$ 1.1E-5	0.4
L decay channel length	88 m	900 m	2
decay angle in lab system	3.8 $\pm$ 0.5 mr	forward	3
$\delta p_\pi / p_\pi$ pion momentum band	$\pm$0.5%	$\pm$2%	1.33
FODO lattice spacing	6.2 m	3.25 m	1.8
inflector	closed end	open end	2
total			11.5

Proposal for J-PARC experiment



VEPP-2000 storage ring at BINP



≈100 1/pb per detector per year

- Up to 2 GeV c.m. energy
- Factor >10 in luminosity

  $L=10^{31}\ cm^{-2}c^{-1}$, $\sqrt{s}=1.0$ GeV

  $L=10^{32}\ cm^{-2}c^{-1}$, $\sqrt{s}=2.0$ GeV

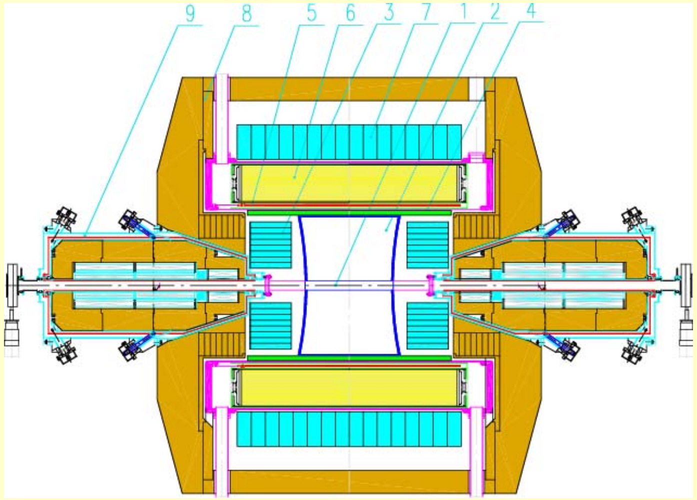
Status:

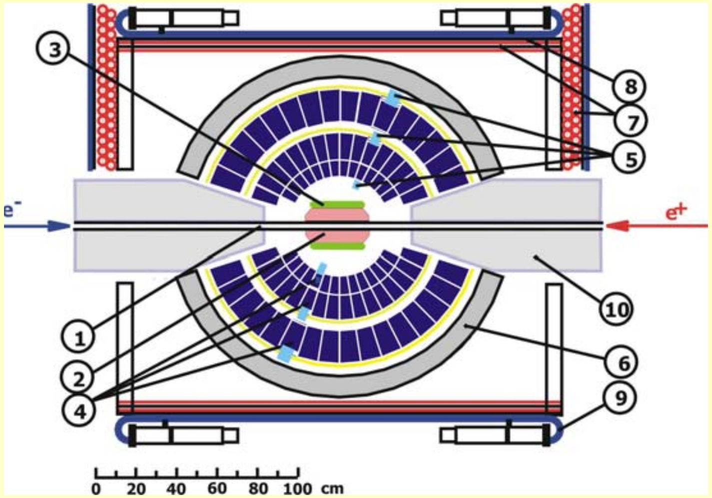
construction is finished

had first beams and collisions

2009 – start of experiments

Detectors for VEPP-2000





Advantages compared to CMD-2:

- new drift chamber with x2 better resolution - better tracking
- thicker barrel calorimeter
  better separation
- LXe calorimeter
  - much better spatial resolution for γ's
  - shower profile

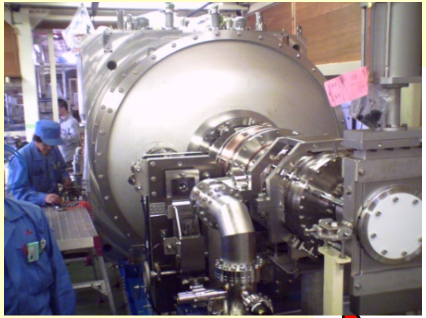
Advantages compared to "old" SND:

new system - cherenkov counter (n=1.05, 1.13)
  e/π separation E<450 MeV
  π/K separation E<1 GeV

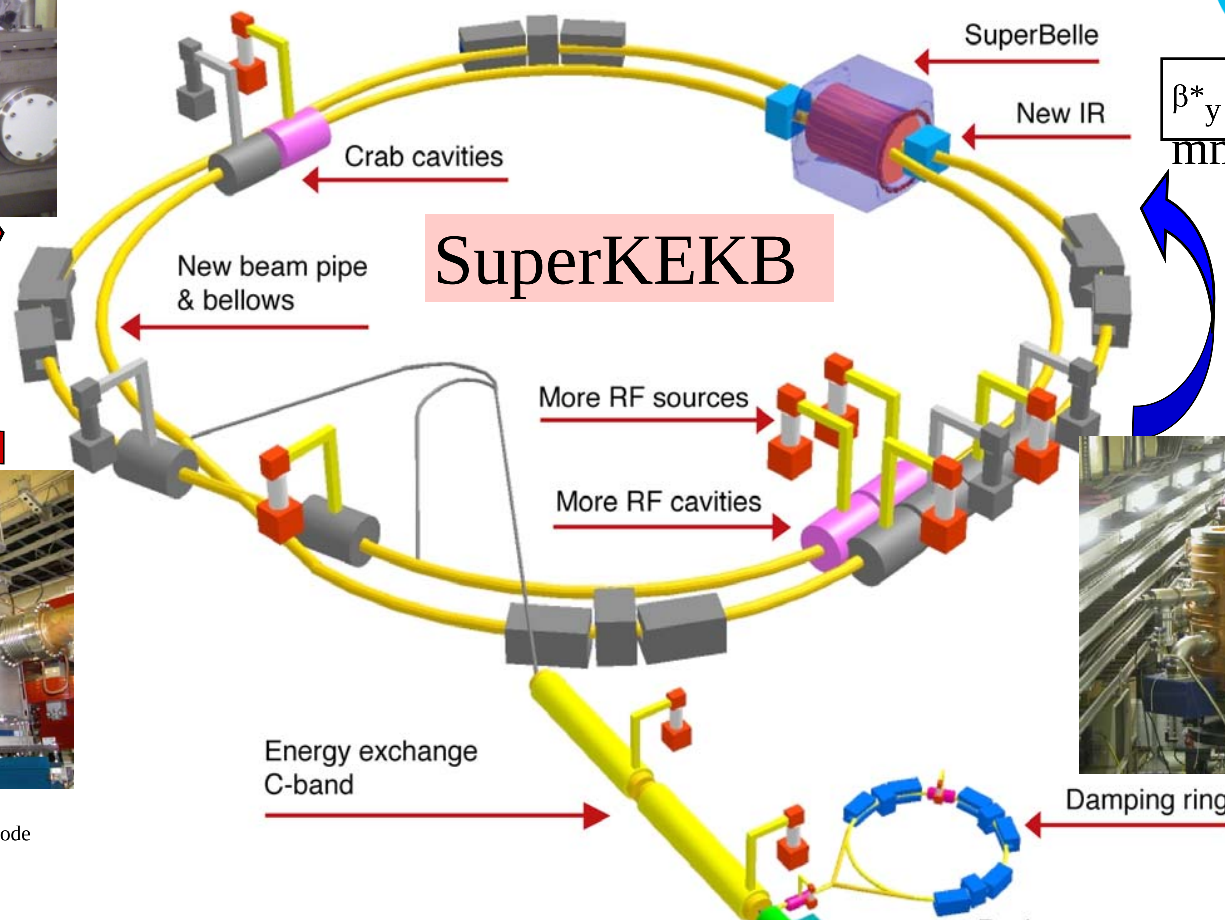
- new drift chamber
  better tracking
  better determination of solid angle

We expect to:

- measure 2π mode to 0.3-0.4%, 4π mode to 2%
- overall improvement in R precision by factor 2-3
- Efforts of theorists are highly needed!



Crab cavities will be installed and tested with beam in 2006.



SuperKEKB

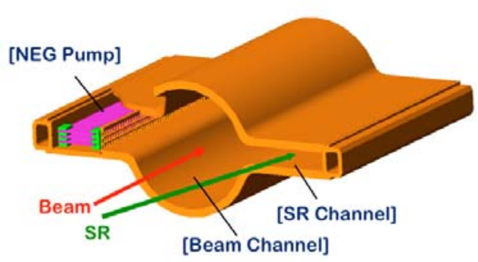
$\beta^*_y = \sigma_z = 3$ mm

e- 9.4 A

e+ 4.1 A

The superconducting cavities will be upgraded to absorb more higher-order mode power up to 50 kW.

The state-of-art ARES copper cavities will be upgraded with higher energy storage ratio to support higher current.



The beam pipes and all vacuum components will be replaced with higher-current-proof design.

$$L = \frac{\gamma_{\pm}}{2er_e}\left(1+\frac{\sigma_y^*}{\sigma_x^*}\right)\left(\frac{I_{\pm}\xi_{\pm y}}{\beta_y^*}\right)\left(\frac{R_L}{R_y}\right)$$

will reach 8 × 10^{35} $cm^{-2}s^{-1}$.

Super B-factory

Super (KEK)B-factory:(10~50) ab^{-1}

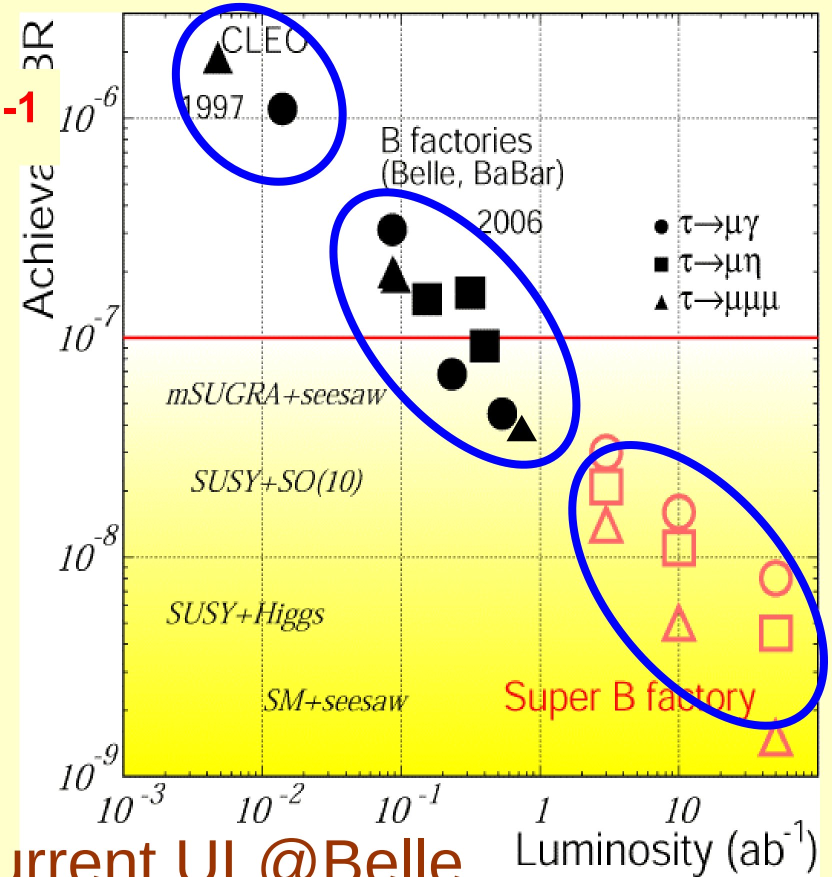
Expected sensitivity

$\tau \rightarrow \ell\gamma$ Br~O($10^{-8\sim9}$)

$\tau \rightarrow \ell\ell\ell$, l+meson Br~O($10^{-9\sim10}$)

- **Super (KEK) B GOAL:**

Improve the sensitivity by additional factor of 100 and achieve 10^{-10}



Current UL@Belle

Br($\tau \rightarrow \mu\mu\mu$) <3.2x$10^{-8}$@543$fb^{-1}$

Br($\tau \rightarrow \mu\mu\mu$)<3x$10^{-10}$@50$ab^{-1}$

- **$\tau \rightarrow \mu\gamma$ and $\tau \rightarrow e\gamma$:**

Background dominated

Conclusion

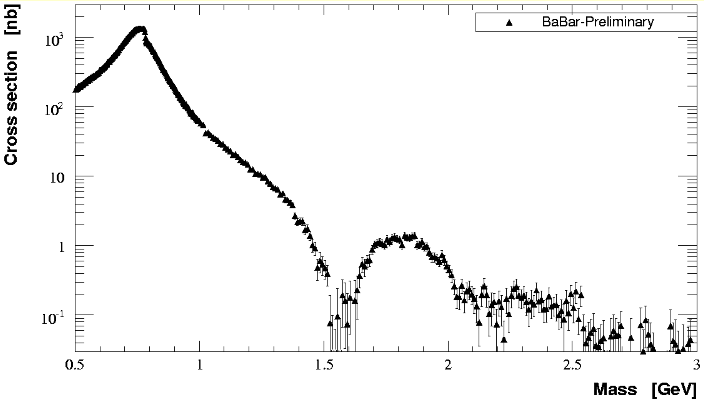
In the last three decades the Standard Model (SM) was successfully used to describe variety of physical phenomena in the wide energy range – from atomic transitions to the hundreds GeV scale. On the other hand, a word "model" in the title reflects the common feeling that some more fundamental theory can be hidden behind SM. At present many experiments are aimed to search for the SM boundaries.

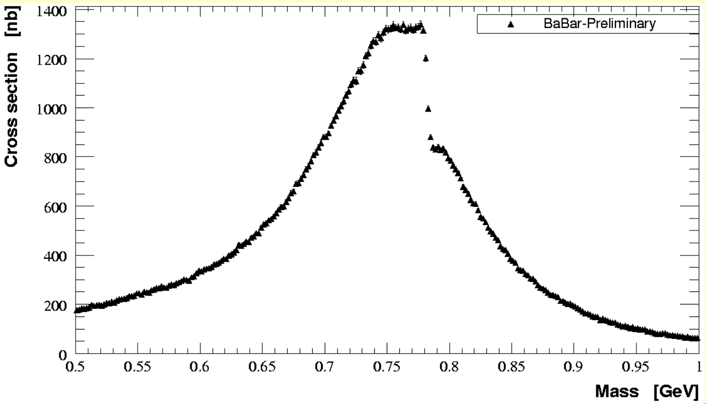
In the considered class of experiments at low energies we can see some (illusive? real?) discrepancies with the calculations based on the SM. These can be barely taken as the indications of a NP, however, we have to apply new efforts to clarify this phenomena.

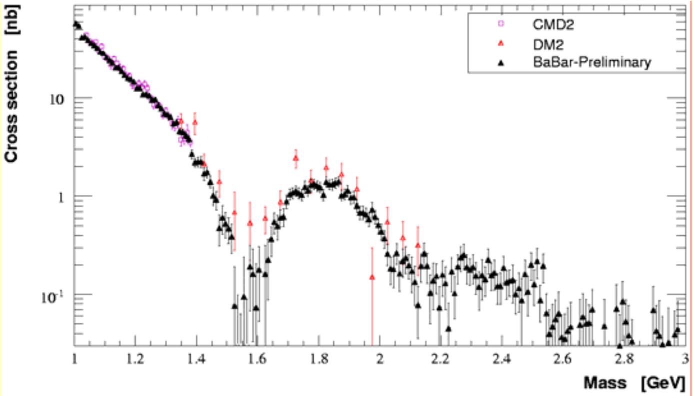
Hopefully, in the next 5-10 years we'll receive answers from new experiments and advanced theoretical approaches.

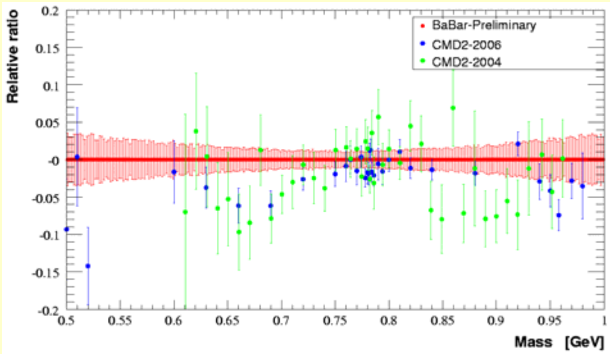
Back up

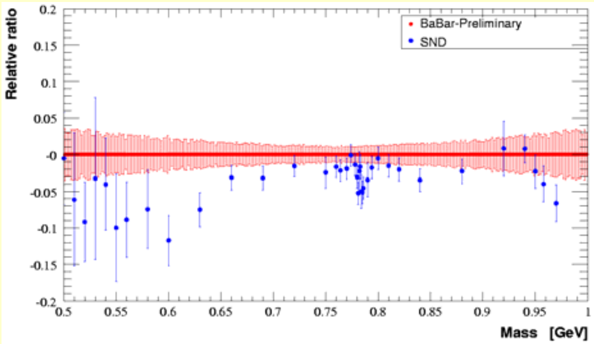
BaBar – $\pi^+\pi^-$, Tau-08

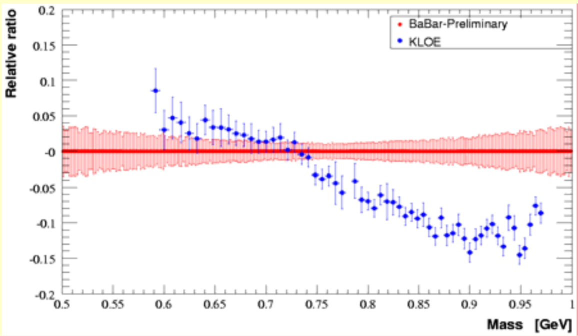




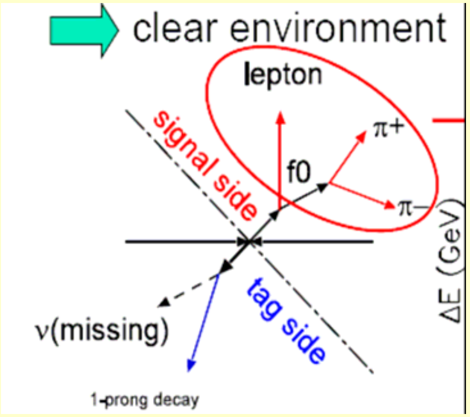








Analysis method



✓At Υ(4S) (10.58 GeV) $\sigma(e^+e^- \to \tau^+\tau^-) = 0.92$ nb $\Rightarrow$ 100 fb^{-1} provides $N = 92 \times 10^6$.

✓ We divide the event space by the plane perpendicular to the thrust axis into two hemispheres { "tag" side , in which some ordinary decay (usually

✓1-prong modes are selected) is observed and "signal" side , in which we try to completely reconstruct a neutrinoless LFV decay.

✓ Decays we are searching for are very rare ($P < 10^{-7}$) $\Rightarrow$ mostly background (BG) is detected in the "signal" side. We apply various kinematical, topological and PID cuts to suppress BG.

✓ We compare various distributions in data with MC to be sure that we completely understand BG.

✓ We calculate the branching ratio or place an upper limit:
$B = N_{sig}/2N_{\tau+\tau-}\varepsilon$, where N_{sig} - signal yield, ε - acceptance

$$M_{inv} = \sqrt{E_{sig}^2 - p_{sig}^2}$$

$$\Delta E = E_{sig}^{CM} - E_{beam}^{CM}$$

Blind analysis:

Blind signal region in the Minv-ΔE plain

number of BG is estimated

using sideband data

	Belle		BaBar		CLEO	
	B, 10^{-8}	$\int Ldt$, fb^{-1}	B, 10^{-8}	$\int Ldt$, fb^{-1}	B, 10^{-8}	$\int Ldt$, fb^{-1}
$\mu^-\gamma$	4.5	535	6.8	232	110	13.8
$e^-\gamma$	12	535	11	232	270	4.68
$e^-e^-e^+$	3.6	535	4.9	376	290	4.79
$e^-\mu^-\mu^+$	4.3	535	6.6	376	180	4.79
$e^+\mu^-\mu^-$	2.4	535	4.6	376	150	4.79
$\mu^-e^-e^+$	2.8	535	5.0	376	170	4.79
$\mu^-\mu^-\mu^+$	3.4	535	6.7	376	190	4.79
$\mu^+e^-e^-$	2.1	535	2.7	376	150	4.79
$e^-\pi^0$	8.0	401	13	339	370	4.68
$e^-\eta$	9.2	401	16	339	820	4.68
$e^-\eta'$	16	401	24	339	-	-
$\mu^-\pi^0$	12	401	11	339	400	4.68
$\mu^-\eta$	6.5	401	15	339	960	4.68
$\mu^-\eta'$	13	401	14	339	-	-