Summary of WG 3: Rare B, D, K & LFV decays

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12th September 2014

- Focus of WG 3 was $b \to s(d)$, $c \to u$ and $s \to d$ FCNC processes and null tests of the SM.
  - Rare top decays are covered by WG 6.

- Will attempt to summarise 5 sessions (and 25 talks):
  - $\rightsquigarrow$ Can't possibly cover everything and this summary is not a good replacement for looking through the slides from the session.

- We also had new results presented for the first time:
  1. Combination of CMS and LHCb results on $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$ [F. Archilli]
  2. First 100 hours of data taken by KOTO [K. Shiomi]

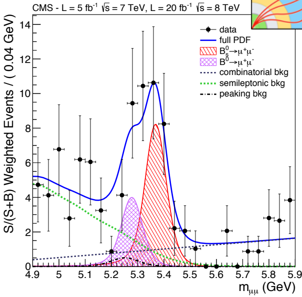
$$B_q^0 \to \mu^+\mu^-$$

EPS-HEP 2013

- During EPS-HEP 2013 CMS and LHCb collaborations presented their results based on 25fb^{-1} and 3fb^{-1} respectively

Nov. 2012: LHCb found the first evidence of the $\mathcal{B}(B^0{}_s \to \mu^+\mu^-)$ with 2.1fb^{-1}

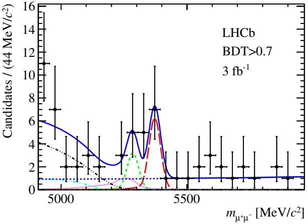
[PRL 111 (2013) 101804]



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 3.0^{+1.0}_{-0.9} \times 10^{-9} \quad (4.3\sigma)$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.5^{+2.1}_{-1.8} \times 10^{-10} \quad (2.0\sigma)$$

[PRL 111 (2013) 101805]



$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.9^{+1.1}_{-1.0} \times 10^{-9} \quad (4.0\sigma)$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.7^{+2.4}_{-2.1} \times 10^{-10} \quad (2.0\sigma)$$

Flavio Archilli

Fit result

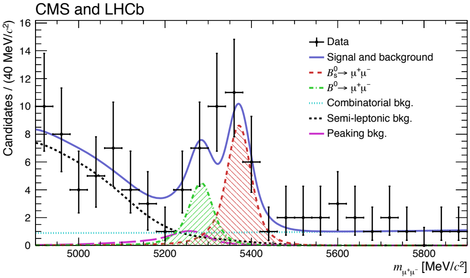
from the simultaneous fit we get:

$$\mathcal{B}(B_s^0 \to \mu^+\mu^-) = 2.8^{+0.7}_{-0.6} \times 10^{-9}$$

$$\mathcal{B}(B^0 \to \mu^+\mu^-) = 3.9^{+1.6}_{-1.4} \times 10^{-10}$$

Using the Wilks' theorem the statistical significance from the likelihood is:

- 6.2 σ for the $B^0_s \to \mu^+\mu^-$ (Expected SM 7.6 σ)
  - ✦ First **observation**
- 3.2 σ for the $B^0 \to \mu^+\mu^-$ (Expected SM 0.8 σ)

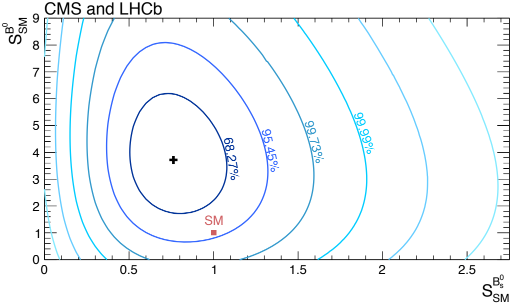


Flavio Archilli

projection of invariant mass of best 6 categories selected through S/(S+B) value

Wilks' theorem assumes asymptotic behaviour, Feldman-Cousin approach is used for $B^0 \to \mu^+\mu^-$

2D likelihood scan of $\mathcal{B}/\mathcal{B}^{\rm SM}$



Flavio Archilli

- fit and 2D LL scan also performed with the ratio of BF's over their SM expectation value:

$$\mathcal{S}_{\rm SM}^{B^0_{(s)}} = \frac{\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-)}{\mathcal{B}(B^0_{(s)} \to \mu^+\mu^-)^{\rm SM}}$$

- theoretical error included in the fit

$$\mathcal{S}_{\rm SM}^{B^0_s} = 0.76^{+0.20}_{-0.18} \qquad \mathcal{S}_{\rm SM}^{B^0} = 3.7^{+1.6}_{-1.4}$$

✳Compatibility with the SM: 2.2 σ for B^0 and 1.2 σ for $B^0{}_s$

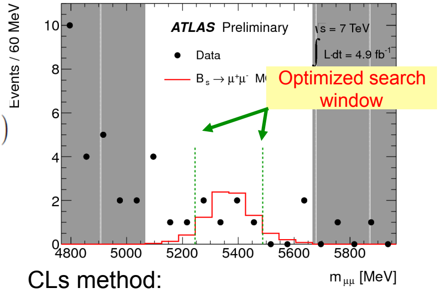
$B_s^0 \to \mu^+\mu^-$: Result on 4.9 fb^{-1} at 7 TeV

Single-event-sensitivity:

$$SES = \frac{1}{N_{J/\psi K^+}} \cdot \frac{\epsilon_{J/\psi K^+} A_{J/\psi K^+}}{\epsilon_{\mu\mu} A_{\mu\mu}} \cdot \frac{f_u}{f_s} \cdot BR(B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+)$$

$$= (2.07 +/- 0.26\,(\text{stat})) \cdot 10^{-9}$$

Main systematics (± 12.5%):
BR(B^+), f_u/f_s and $\varepsilon \cdot A$ ratio



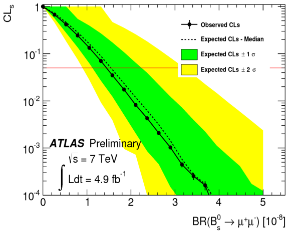
CLs method:

N_{bkg} expected in signal window: 6.75 events

BR($B_s^0 \to m^+m^-$) < 1.6 x 10^{-8}

N_{mm} observed in signal window: 6 events

BR($B_s^0 \to m^+m^-$) < 1.5 x 10^{-8}
(@ 95% CL)



S. Palestini - CKM 2014

[ATLAS-CONF-2013-076]

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Sandro Palestini

The new SM Prediction & Error Budget

$$\mathbf{BR}(B_s \to \mu^+\mu^-)^{\text{exp}} = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$$

[new average, see talk by F. Archilli]

$$\mathbf{BR}(B_s \to \mu^+\mu^-)^{\text{SM}} = (3.65 \pm 0.23) \times 10^{-9}$$

[Bobeth, Gorbahn, Hermann, Misiak, ES, Steinhauser '13, arXiv:1311.0903]

Emmanuel Stamou

Error Budget

f_{B_s}	CKM	τ_H^s	M_t	α_s	other param.	**non-param.**	$\sum$
4.0%	4.3%	1.3%	1.6%	0.1%	$< 0.1\%$	1.5%	6.4%

param.

- $f_{B_s} = 227.4(4.5)$ MeV

  [FLAG '13, arXiv:1310.8555]
- V_{cb} from recent inclusive fit

  [Gambino, Schwanda '13, arXiv:1307.4551]

  [Update! See talk by P. Gambino]

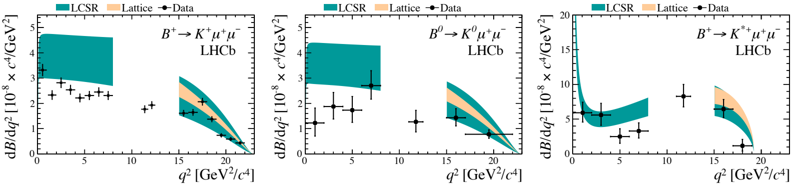
non param.

- 0.3% from $\mu_b \in [m_b/2, 2m_b]$
- $2 \times 0.3\%$ from $\mathcal{O}(\alpha_s^3, \alpha_{em}^2, \alpha_s\alpha_{em})$ for $\mu_0 \in [m_t/2, 2m_t]$
- 0.3% from top-mass conversion
- 0.5% additional uncertainties $(\mathcal{O}(m_b^2/M_W^2) + \ldots)$

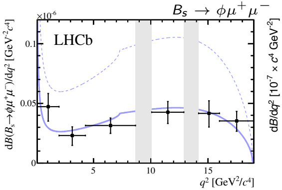
$$b \to s\ell^+\ell^-$$

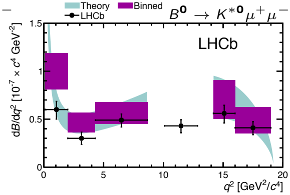
1. Decay rate measurements

- Large LHCb datasets allows for precision measurements
- Results hint towards lower rates than predicted
  → Could be explained with new physics in C_9 e.g Z'



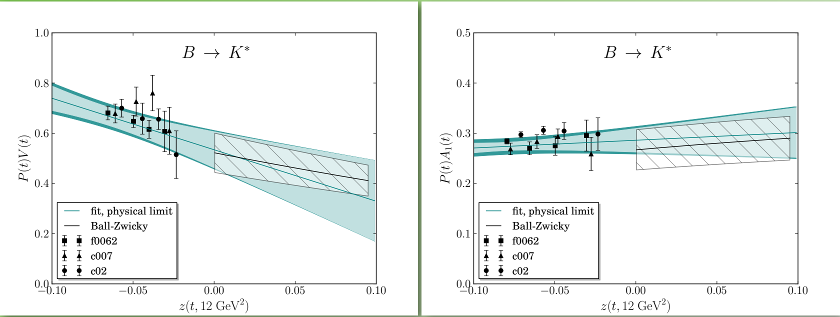
Kostas Petridis





$B^0 \to K^{*0}\mu^+\mu^-$: [JHEP08(2013)131]
$B_s \to \phi\mu^+\mu^-$: [JHEP07(2013)084]
$B^+ \to K^+\mu^+\mu^-$, $B^0 \to K^0\mu^+\mu^-$,
$B^+ \to K^{*+}\mu^+\mu^-$: [JHEP06(2014)133]
LCSR: Bobeth et al. [1111.2558],
[JHEP07(2011)067]
Lattice: Bouchard et al. [1310.3207]
missing 2-loop corrections to C_9^{eff}

$B \to K^*$ form factors



using NRQCD+asqtad valence on MILC n_f=2+1 asqtad

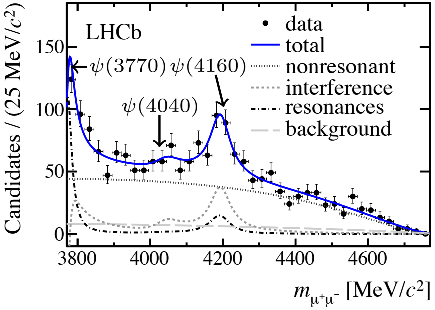
Horgan, Liu, Meinel, Wingate, arXiv:1310.3722

$$z = \frac{\sqrt{t_+ - t} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - t} + \sqrt{t_+ - t_0}} \qquad t = q^2 \qquad t_\pm = (m_B \pm m_F)^2 \qquad F(t) = \frac{1}{1 - t/m_{\mathrm{res}}^2} \sum_n a_n z^n$$

Matthew Wingate

What can $c\bar{c}$ say about this?

- For the first time $c\bar{c}$ resonances observed in high q^2 region of $B^+ \to K^+\mu^+\mu^-$ using full RunI data [PRL 111,112003 (2013)]



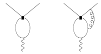
- Resonant contribution (including interference) at high q^2 amounts to $\sim 20\%$ of the $B^+ \to K^+\mu^+\mu^-$ rate in that region [PRL 111,112003 (2013)]
- How does this fit in with QCD treatment of high q^2?

Kostas Petridis

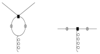
Local OPE for $q^2 \sim m_b$: Beylich, Buchalla, Feldman'2011, Grinstein, Pirjol'2004

$$\mathcal{K}^\mu(q^2) \sim \int dx^4 e^{iq.x}\, T\{j^\mu_{c\bar{c}}(x)\mathcal{H}^c(0)\} \xrightarrow{q^2\sim m_b^2} \sum_{n,d} C_{d,n}(q)\mathcal{O}^\mu_{d,n}$$

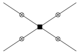
$$= \quad \mathcal{K}^\mu_3(q^2) \quad + \quad \mathcal{K}^\mu_5(q^2) \quad + \quad \mathcal{K}^\mu_6(q^2) \quad + \quad \mathcal{O}[(\Lambda/m_b)^3]$$



Usual FFs
NLO $\sim$ 10-15%



$\lesssim 1\%$



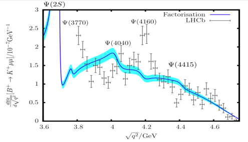
$\lesssim 1‰$

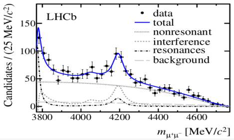
Duality violations: Beylich, Buchalla, Feldman'2011

From a model fitted to BES data: $\pm 2\%$ for *integrated BR over high-q^2 region.*

Non-fact. corrections:
Seem to be large

figures from Lyon,Zwicky'2014
and LHCb-1307.7595

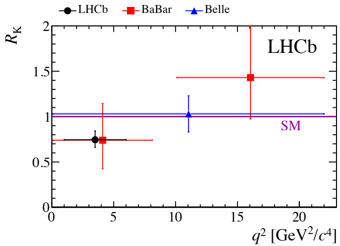




Javier Virto

2. Ratios of decay rates

- Recent measurement of: $R_K = \frac{\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{\mathcal{B}(B^+ \to K^+e^+e^-)}$ [1406.6482 accepted by PRL]
  - Precise theory prediction due to cancellation of hadronic form factor uncertainties
- Expected to be 1.000 in SM (Higgs contribution m_ℓ suppressed)
- Z' models with enhanced couplings to muons e.g [Altmannshofer et al 1403.1269]
  $\rightarrow$ Destructive interference with SM can lead to $R_K < 1$



- Measure for $1 < q^2 < 6\,\text{GeV}^2/c^4$
  $\rightarrow R_K = 0.745^{+0.090}_{-0.074}(\text{stat}) \pm 0.035(\text{syst})$
- R_K consistent at $\sim 2.6\sigma$

- Consistent with decay rate measurements assuming Z' does not couple to electrons

Kostas Petridis

$B^0 \to K^{*0}\mu^+\mu^-$ angular distribution

- Angular distribution depends on 11 angular terms:

$$\frac{\mathrm{d}^4\Gamma[B^0 \to K^{*0}\mu^+\mu^-]}{\mathrm{d}\cos\theta_\ell\,\mathrm{d}\cos\theta_K\,\mathrm{d}\phi\,\mathrm{d}q^2} = \frac{9}{32\pi}\Big[J_1^s \sin^2\theta_K + J_1^c \cos^2\theta_K + J_2^s \sin^2\theta_K \cos 2\theta_\ell + J_2^c \cos^2\theta_K \cos 2\theta_\ell + J_3 \sin^2\theta_K \sin^2\theta_\ell \cos 2\phi + J_4 \sin 2\theta_K \sin 2\theta_\ell \cos\phi + J_5 \sin 2\theta_K \sin\theta_\ell \cos\phi + J_6 \cos^2\theta_K \cos\theta_\ell + J_7 \sin 2\theta_K \sin\theta_\ell \sin\phi + J_8 \sin 2\theta_K \sin 2\theta_\ell \sin\phi + J_9 \sin^2\theta_K \sin^2\theta_\ell \sin 2\phi \Big]$$

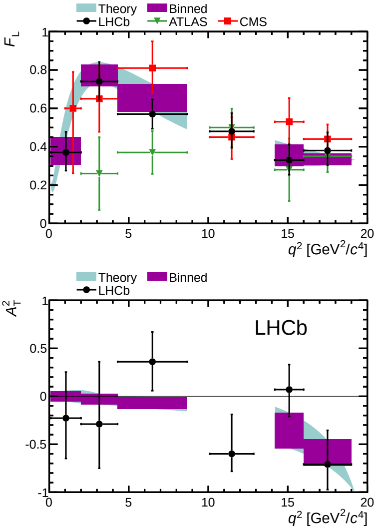
where the J_i's are bilinear combinations of seven decay amplitudes $A_\parallel^{L,R}$, $A_\perp^{L,R}$, $A_0^{L,R}$ & A_t (L/R for the chirality of the $\mu^+\mu^-$ system).

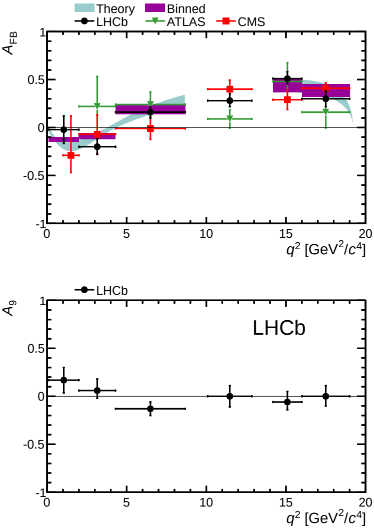
- Large number of terms, simplified by angular folding or by integrating over one or more angles.

See talks by S. Palestini, G. Mohanty and K. Petridis for details

$B^0 \to K^{*0}\mu^+\mu^-$ angular distribution

ATLAS (prelim.) [ATLAS-CONF-2013-038] , CMS 5.2 fb^{-1} [PLB 727 (2013) 77] , LHCb 1 fb^{-1} [JHEP 08 (2013) 131]

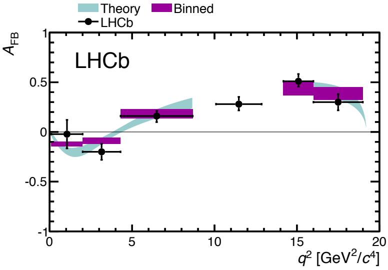


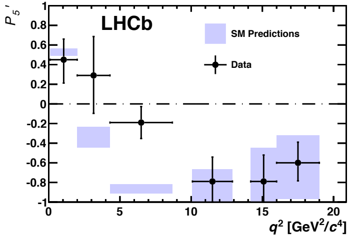


Theory prediction from Bobeth et al. [JHEP 07 (2011)] and references therein.

3. Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$

- Precision era in measurements of angular distribution
- LHCb published last year measurements both of "standard" and "optimised observables" with 1/3 of available statistics [JHEP08(2013)131], [PRL111,191801(2013)]





Kostas Petridis

- Large (3.7σ) local deviation in P_5' (measure of $L \leftrightarrow R$ asymmetry of interference between A_0 and $A_\perp$ [Descote-Genon et al. JHEP 1305(2013)137])

$B \to K^* \ell^+ \ell^-$: FF Correlations

Two ways to FF correlations:

1. "Munich" approach: Correlations from LCSRs (not public (yet)).
2. "Aachen" approach: Correlations from EFT symmetry relations.

Example SCET relation at large recoil

$$\frac{\epsilon_-^{*\mu} q^\nu \langle K_-^* | \bar{s} \sigma_{\mu\nu} P_R b | B \rangle}{i m_B \langle K_-^* | \bar{s} \not{\epsilon}_-^* P_L b | B \rangle} = 1 + \mathcal{O}(\alpha_s, \Lambda/m_b)$$

This allows to build observables with **reduced dependence on FFs**.

Optimized observables at large recoil

Matias, Mescia, Ramon, JV – 1202.4266
Descotes-Genon, Matias, Ramon, JV – 1207.2753

$$P_1 = \frac{J_3}{2J_{2s}} \qquad P_2 = \frac{J_{6s}}{8J_{2s}} \qquad P_4' = \frac{J_4}{\sqrt{-J_{2s}J_{2c}}}$$

$$P_5' = \frac{J_5}{2\sqrt{-J_{2s}J_{2c}}} \qquad P_6' = \frac{-J_7}{2\sqrt{-J_{2s}J_{2c}}} \qquad P_8' = \frac{-J_8}{\sqrt{-J_{2s}J_{2c}}}$$

Also: Kruger+Matias, Egede et.al. Becirevic+Schneider, etc.

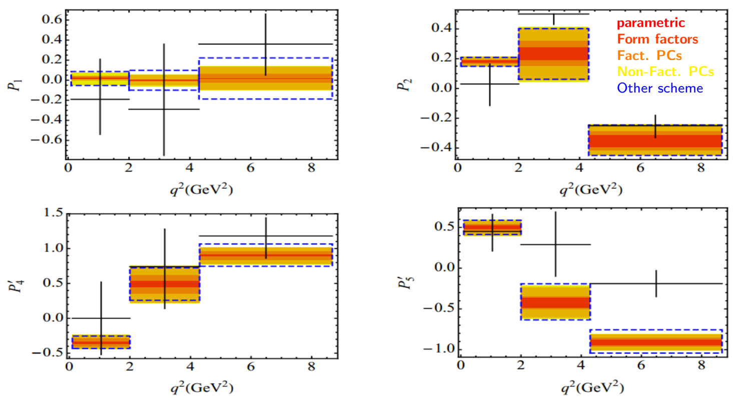
Javier Virto

Factorizable Power Corrections

Scheme 1:

$$V(s) = (1 + m_{K^*}/m_B)\,\xi_\perp$$

$$T_1(s) = \xi_\perp + \Delta T_1^{\alpha_s} + a_{T_1} + b_{T_1}(s/m_B) + c_{T_1}(s/m_B)^2$$



Conclusion: Factorisable PCs mostly under control.

Javier Virto

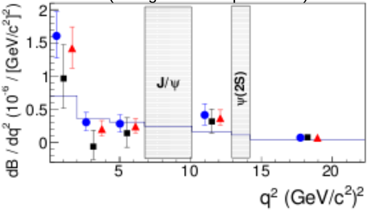
PRL 112 (2014) 211802

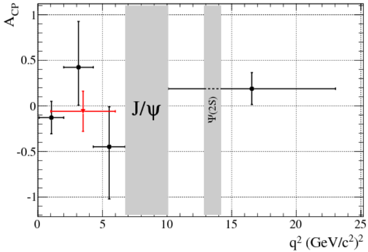
Differential branching fraction and CP asymmetries in $B \to X_s l^+l^-$

- Results

l^+l^- = e^+e^-, $\mu^+\mu^-$, combined

(histogram = SM prediction)





Tim Gershon

Differential branching fraction consistent with expectation.
Integrated value ($q^2 > 0.1\text{GeV}^2$)

$$\mathcal{B}(B \to X_s l^+l^-) = (6.73\ ^{+0.70}_{-0.64}\ ^{+0.34}_{-0.25} \pm 0.50) \times 10^{-6}$$

(stat) (syst) (model)

CP asymmetry consistent with zero.
Integrated value ($q^2 > 0.1\text{GeV}^2$)

$$A_{CP} = 0.04 \pm 0.11 \pm 0.01$$

THE UNIVERSITY OF WARWICK

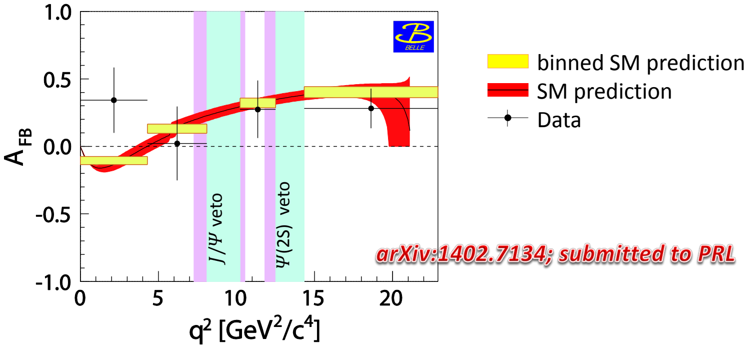
Tim Gershon

$b \to sl^+l^-$ & $b \to s\gamma$

Updated SM BF predictions were presented by T. Huber

Result of $A_{FB}(B \to X_s l^+ l^-)$

- A_{FB} are consistent with the SM.
  - The deviation of the 1st bin is 1.8σ.
  - Exclude $A_{FB} < 0$ at $q^2 > 10.2$ GeV²/c² at 2.3σ.
- First measurement of inclusive A_{FB} with sum-of-exclusives



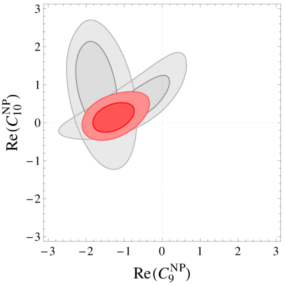
arXiv:1402.7134; submitted to PRL

Yutaro Sato

C_9 - C_{10} Plane

$O_9/O_{10} \propto (\bar{s}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu/\gamma^\mu\gamma_5\mu)$

left handed quark current



WA, Straub, preliminary

major update of WA, Straub 1308.1501

- branching ratios of: $B \to K^*\mu^+\mu^-$, $B \to K\mu^+\mu^-$, $B_s \to \phi\mu^+\mu^-$, $B \to X_s\mu^+\mu^-$, $B_s \to \mu^+\mu^-$
- $B \to K^*\mu^+\mu^-$ angular observables: A_{FB}, F_L, S_3, S_4, S_5

(bins with $q^2 < 6\text{GeV}^2$ and $q^2 > 15\text{GeV}^2$)

Wolfgang Altmannshofer

(see also: Descotes-Genon, Matias, Virto 1307.5683 and Beaujean, Bobeth, van Dyk 1310.2478 Hurth, Mahmoudi 1312.5267)

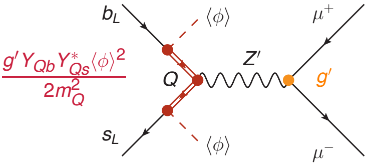
A Simple Z' Model Based on Gauged $L_\mu - L_\tau$

muon number - tau number
is anomaly free
gauging it leads to the wanted
vector couplings with muons

$$\mathcal{L} \supset g'(\bar{\mu}\gamma^\mu\mu - \bar{\tau}\gamma^\mu\tau)Z'_\mu$$

couple the Z' to quarks only
indirectly, by mixing with
heavy vector-like fermions
charged under $U(1)'$

e.g. Fox, Liu, Tucker-Smith, Weiner 1104.4127



contributions to $B \to K^* \mu^+\mu^-$ are
independent of the $U(1)'$ gauge
coupling and the Z' mass

$$C_9 \simeq \frac{Y_{Qb} Y^*_{Qs}}{2m_Q^2} \quad , \quad C'_9 \simeq -\frac{Y_{Db} Y^*_{Ds}}{2m_D^2}$$

(WA, Gori, Pospelov, Yavin 1403.1269)

Wolfgang Altmannshofer

No effect on electrons, $R_K \simeq 0.75$

$(g-2)$ of the muon

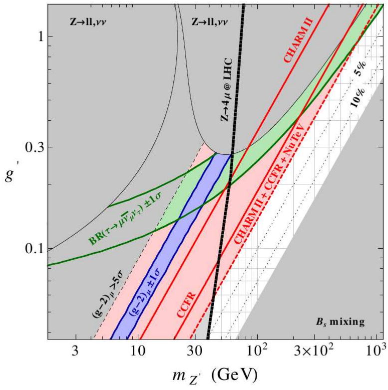
tau decays

Z couplings to leptons

$Z \to 4\mu$ @ LHC

B_s mixing

neutrino trident production



WA, Gori, Pospelov, Yavin 1403.1269

B_s mixing leads to an upper bound
on the $U(1)'$ breaking vev
neutrino tridents lead to a lower bound

750GeV $\lesssim \langle\phi\rangle \lesssim$ 1.8TeV

bound from neutrino tridents
can improve at LBNE
(WA, Gori, Pospelov, Yavin 1406.2332)

Wolfgang Altmannshofer

$b \to s\nu\bar{\nu}$

- Theoretically cleaner than $B \to K^{(*)}\mu^+\mu^-$ and complementary probe of new physics.
- Updated theory predictions of

$$\mathcal{B}(B \to K^+\nu\bar{\nu})_{\rm SM} = (4.20 \pm 0.33 \pm 0.15) \times 10^{-6}$$
$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu})_{\rm SM} = (9.93 \pm 0.74 \pm 0.35) \times 10^{-6}$$

[A. Buras, J. Girrbach-Noe, C. Niehoff & D. Straub in preparation]

- Experimental limit from BaBar [PRD 87, 112005 (2013)] of

$$\mathcal{B}(B \to K\nu\bar{\nu}) < 17 \times 10^{-6} \text{ at 90\% CL}$$

and from Belle [PRD 87, 111003 (2013)] of

$$\mathcal{B}(B^0 \to K^{*0}\nu\bar{\nu}) < 55 \times 10^{-6} \text{ at 90\% CL}$$

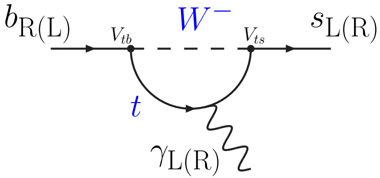
Jennifer Girrbach-Noe & Alberto Lusiani

$$b \to s\gamma$$

Photon polarisation in $b \to s\gamma$ decays

- $B^0 \to K^{*0}\gamma$ was the first penguin decay ever observed, by CLEO in 1992 .[PRL 71 (1993) 674]
- We already know from the B-factories that inclusive & exclusive $b \to s\gamma$ branching fractions are compatible with SM expectations.
- What else do we know?

⇝ In the SM, photons from $b \to s\gamma$ decays are predominantly left-handed ($C_7/C_7' \sim m_b/m_s$) due to the charged-current interaction.



- Can test C_7/C_7' using:

⇝ Mixing-induced CP violation [Atwood et al PRL 79 (1997) 185-188],

⇝ $B \to K^{**}\gamma$ decays such as $B^+ \to K_1(1270)\gamma$. [Gronau & Pirjol PRD 66 (2002) 054008]

How to measure the polarization?

proposed methods

▸ Method I: Time dependent CP asymmetry in $B_d \to K_S\pi^0\gamma$ $B_s \to K^+K^-\gamma$ (called $S_{K_S\pi^0\gamma}$, $S_{K^+K^-\gamma}$)

$$S_{K_S\pi^0\gamma} = \frac{2|C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime \rm NP}|}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime \rm NP}|^2} \sin(2\phi_1 - \phi_R) \qquad \phi_R = \arg\left[\frac{C_{7\gamma}^{\prime \rm NP}}{C_{7\gamma}^{\rm SM}}\right]$$

▸ Method II: Transverse asymmetry in $B_d \to K^* l^+ l^-$ (called $A_T^{(2)}$, $A_T^{(im)}$)

$$\mathcal{A}_T^{(2)}(q^2=0) = \frac{2Re[C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime \rm NP*}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime \rm NP}|^2} \qquad \mathcal{A}_T^{(im)}(q^2=0) = \frac{2Im[C_{7\gamma}^{\rm SM} C_{7\gamma}^{\prime \rm NP*}]}{|C_{7\gamma}^{\rm SM}|^2 + |C_{7\gamma}^{\prime \rm NP}|^2}$$

Assumption for γ^*/Z penguin (C_9, C_{10} contributions) necessary!

▸ Method III: $B \to K_1(\to K\pi\pi)\gamma$ (called λ_γ)

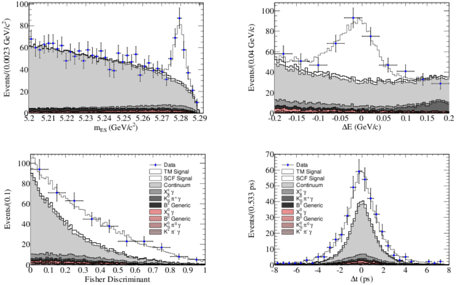
$$\lambda = \frac{|C_{7\gamma}^{\prime \rm NP}|^2 - |C_{7\gamma}^{\rm SM}|^2}{|C_{7\gamma}^{\prime \rm NP}|^2 + |C_{7\gamma}^{\rm SM}|^2}$$

Emi Kou

preliminary

Photon polarisation in B → Kππγ

- Fit to $B^0 \to K_S\pi^+\pi^-\gamma$ sample



$$\mathcal{S}_{K^0_S\pi^+\pi^-\gamma} = 0.137 \pm 0.249(\text{stat.})^{+0.042}_{-0.033}(\text{syst.})$$

$$\mathcal{C}_{K^0_S\pi^+\pi^-\gamma} = -0.390 \pm 0.204(\text{stat.})^{+0.045}_{-0.050}(\text{syst.})$$

$$+ \quad \mathcal{D}_{K^0_S\rho\gamma} = 0.549^{+0.096}_{-0.094}$$

$$\hookrightarrow \quad \mathcal{S}_{K^0_S\rho\gamma} = \frac{\mathcal{S}_{K^0_S\pi^+\pi^-\gamma}}{\mathcal{D}_{K^0_S\rho\gamma}} = 0.249 \pm 0.455^{+0.076}_{-0.060}$$

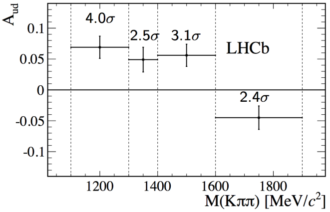
Tim Gershon

Tim Gershon
$b \to s l^+ l^-$ & $b \to s\gamma$

14

Angular analysis: Results and cross-checks

$\times 10^{-2}$	[1.1, 1.3]	[1.3, 1.4]	[1.4, 1.6]	[1.6, 1.9]
c_1	6.3 ± 1.7	5.4 ± 2.0	4.3 ± 1.9	-4.6 ± 1.8
c_2	31.6 ± 2.2	27.0 ± 2.6	43.1 ± 2.3	28.0 ± 2.3
c_3	-2.1 ± 2.6	2.0 ± 3.1	-5.2 ± 2.8	-0.6 ± 2.7
c_4	3.0 ± 3.0	6.8 ± 3.6	8.1 ± 3.1	-6.2 ± 3.2
$\mathcal{A}_{ud}$	6.9 ± 1.7	4.9 ± 2.0	5.6 ± 1.8	-4.5 ± 1.9



[PRL 112, 161801 (2014)]

Results

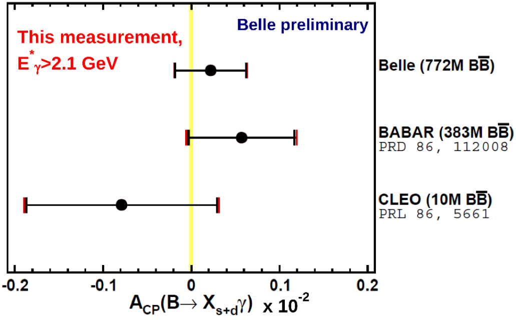
- Quoted uncertainties contain statistical and systematic contributions
- Combined significance determined from a χ^2 test where the null hypothesis is defined as $\lambda_\gamma = 0$, implying $\mathcal{A}_{up-down} = 0$ in each mass interval
- 5.2σ significance for non-zero up-down asymmetry
- **First observation of a parity-violating photon polarization different from 0**

Cross-checks

- Adding further orders in Legendre polynomials: negligible effect
- Further cross-checks performed with counting experiment and give:
  - Compatible up-down asymmetry
  - Lower significance (5.0σ) but in agreement with expectations from pseudo experiments

Jean-Francois Marchand

Result of $A_{CP}(B \to X_{s+d}\gamma)$



Yutaro Sato

- $A_{CP}(B \to X_{s+d}\gamma) = (2.23 \pm 4.02 \pm 0.78)\%$ ***Preliminary***
  - Consistent with SM.
  - Most precise measurement of A_{CP}.

arXiv:1406.0534

CP asymmetries in $B \to X_s \gamma$

- Results

$$A_{CP}(B^+ \to X_s^+\gamma) = (+4.23 \pm 2.93 \pm 0.95)\%$$

$$A_{CP}(B^0 \to X_s^0\gamma) = (-0.74 \pm 2.57 \pm 1.10)\%$$

→ Average

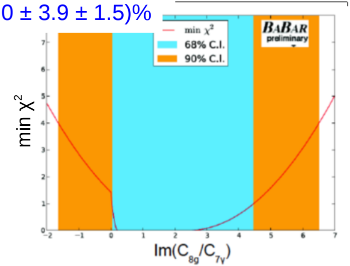
$$A_{CP}(B \to X_s\gamma) = (+1.7 \pm 1.9 \pm 1.0)\%$$

→ Difference

$$\Delta A_{CP}(B \to X_s\gamma) = (+5.0 \pm 3.9 \pm 1.5)\%$$

→ Constraint on Wilson coefficient C_8

  - consistent with SM
    - i.e. $\Delta A_{CP} \sim 0$; $\mathrm{Im}(C_8) \sim 0$



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Tim Gershon

Tim Gershon
b→sl+l− & b→sγ

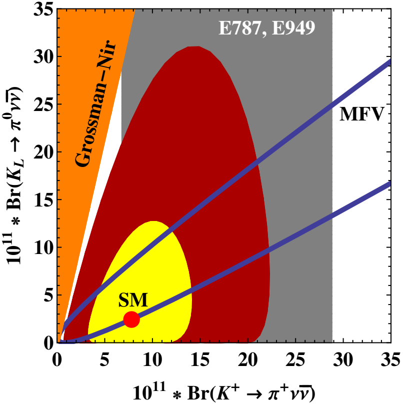
Rare kaon decays

Summary of SM rare kaon decay predictions

	SM	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}$	$7.81(75)(29) \times 10^{-11}$	$(1.73^{+1.15}_{-1.05}) \times 10^{-10}$ E787 E949
$K_L \to \pi^0 \nu\bar{\nu}$	$2.43(39)(6) \times 10^{-11}$	$< 2.6 \times 10^{-8}$ E391a
$K_L \to \pi^0 e^+ e^-$	$(3.23^{+0.91}_{-0.79}) \times 10^{-11}$	$< 28 \times 10^{-11}$ KTEV
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.29^{+0.24}_{-0.23}) \times 10^{-11}$	$< 38 \times 10^{-11}$ KTEV
$K_L \to \mu^+ \mu^-$	$< 2.5 \times 10^{-9}$(SD)	$(6.84 \pm 0.11) \times 10^{-9}$ PDG
ϵ_K	$1.81(28) \times 10^{-3}$	$2.228(11) \times 10^{-3}$ PDG
$K_L \to e^\pm \mu^\mp$	≈ 0	$< 4.7 \times 10^{-12}$ B871

Joachim Brod

NP in $K \to \pi\nu\bar{\nu}$ – Minimal Flavor Violation



- $C_{\rm NP} \leq 0.5|\lambda_t C_{\rm SM}|$
- $C_{\rm NP} \leq |\lambda_t C_{\rm SM}|$

Minimal flavor violation:

- $C_{\rm NP} \propto \lambda_t C_{\rm SM}$

Joachim Brod

KOTO experiment

- Study of $K_L \to \pi^0 \nu \bar{\nu}$ @J-PARC 30GeV Main Ring.
  - Successor to the E391a experiment
  - Goal is to observe few SM events.

J-PARC

Koji Shiomi

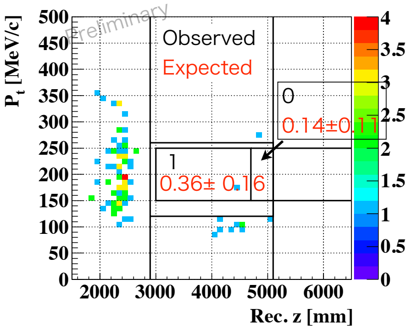
3

14年9月11日木曜日

Showed first results from 100 hours of data taking with similar SES to E391a

Opened the signal box

- One event was observed inside the signal box.
  - N_{obs} is consistent with N_{exp} statistically

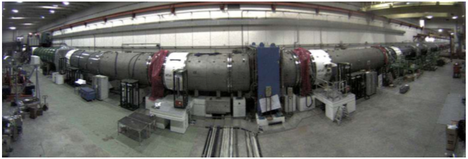


Koji Shiomi

14年9月11日木曜日

Conclusions

CERN Live NA62 CAM - May 2014



NA62 Beam line ready ✔

Detector installation completed by the end of September 2014

6 October 2014: start of pilot physics run (60 days) **!**

Goals:

✓ Commissioning of hardware and readout with particles at lower intensity

✓ Address SM sensitivity

Angela Romano

Nominal intensity beam in 2015-2017 for full physics runs (~100 days) officially scheduled by CERN **!**

Goals:

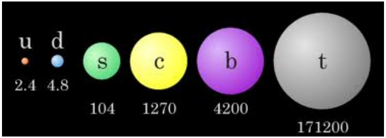
✓ collect O(100) SM $K^+ \to \pi^+ \nu \bar{\nu}$ events

✓ measure BR($K^+ \to \pi^+ \nu \bar{\nu}$) with ~10% accuracy

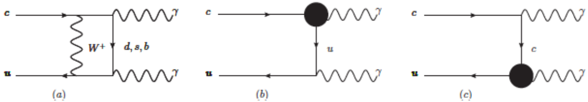
Rare charm decays

LD contributions in charm very difficult to calculate!

$$m_s(\Lambda_{QCD}) < m_c < m_b$$



$$D \to \gamma\gamma$$



- parity violating amplitude

- parity conserving amplitude

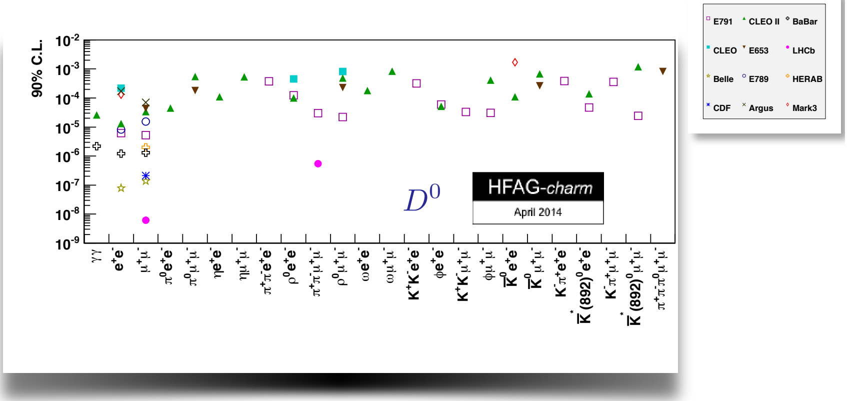
$$\mathrm{BR}^{\text{2-loop}}_{\text{SD}}(D^0 \to \gamma\gamma) \simeq (3.6\text{–}8.1) \times 10^{-12}$$

$$\mathrm{BR}^{\text{LD}}_{\text{SM}}(D^0 \to \gamma\gamma) \sim (1\text{–}3) \times 10^{-8}$$

Svjetlana Fajfer

+ Many more

- references and limits of all rare decay searches can be found at the HFAG web-page: http://www.slac.stanford.edu/xorg/hfag/charm/April14/Rare/rare_charm.html

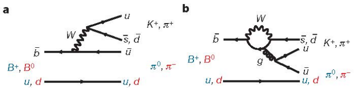


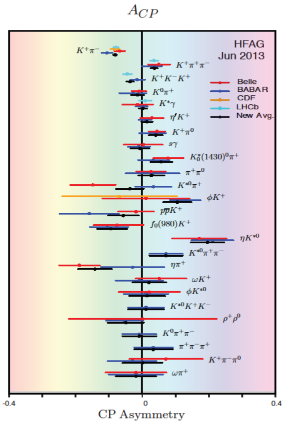
Anže Zupanc

Non-leptonic decays

Penguin Loops and Trees

- Contributions from both tree and penguins.
- Results from different flavour decays can help SM predictions.
- Three-body decays
  - 1 or 3 kaons: b→s penguin dominates
  - 2 kaons: b→u tree, b→d penguin
- New physics can affect loops:
  - Can enhance branching fractions
  - Changes in predicted CP asymmetries
  - Changes in predicted polarization
  - Changes in angular correlations
- Some overlap here with WG5.





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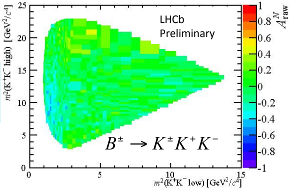
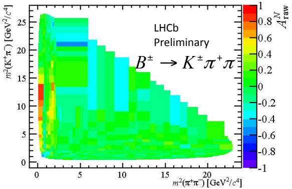
$B^+ \to h^+h^+h^-$ ($h=K,\pi$)

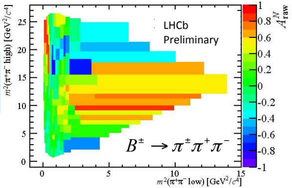
LHCb: PRL 111, 101801 (2013)
LHCb; PRL 112, 011801 (2012)
LHCb: arXiv:1408.5373

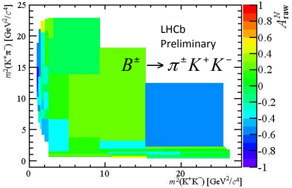
b→s penguin dominated





b→u tree,
b→d penguin





$$A_{CP}(B^\pm \to K^\pm \pi^+ \pi^-) = +0.025 \pm 0.004 \pm 0.004 \pm 0.007\ (2.8\sigma)$$
$$A_{CP}(B^\pm \to K^\pm K^+ K^-) = -0.036 \pm 0.004 \pm 0.002 \pm 0.007\ (4.3\sigma)$$
$$A_{CP}(B^\pm \to \pi^\pm \pi^+ \pi^-) = +0.058 \pm 0.008 \pm 0.009 \pm 0.007\ (4.2\sigma)$$
$$A_{CP}(B^\pm \to \pi^\pm K^+ K^-) = -0.123 \pm 0.017 \pm 0.012 \pm 0.007\ (5.6\sigma)$$

Fergus Wilson

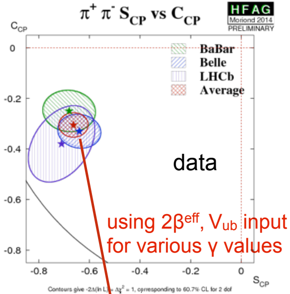
TDCPV in B➔ππ

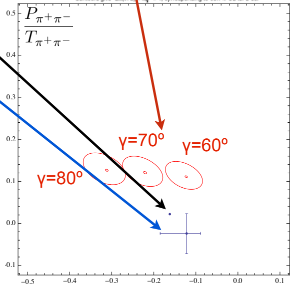
penguin-to-tree ratios: theory

Beneke, SJ 2006

choice of parameters (mainly small λ_B) to accommodate BF data

Ratio	Value/Range	Value G
$\frac{P_{\pi\pi}}{T_{\pi\pi}}$	$-0.122^{+0.033}_{-0.063} + (-0.024^{+0.047}_{-0.048})i$	$-0.162 + 0.022i$
$\frac{P_{\rho\rho}}{T_{\rho\rho}}$	$-0.036^{+0.006}_{-0.009} + (-0.009^{+0.007}_{-0.007})i$	$-0.037 - 0.009i$
$\frac{P_{\pi\rho}}{T_{\pi\rho}}$	$-0.037^{+0.015}_{-0.028} + (-0.005^{+0.024}_{-0.024})i$	$-0.070 + 0.006i$
$\frac{P_{\rho\pi}}{T_{\rho\pi}}$	$0.042^{+0.039}_{-0.023} + (0.004^{+0.030}_{-0.030})i$	$0.051 - 0.024i$
$\frac{C_{\pi\pi}}{T_{\pi\pi}}$	$0.363^{+0.277}_{-0.156} + (0.029^{+0.166}_{-0.103})i$	$0.691 + 0.165i$
$\frac{C_{\rho\rho}}{T_{\rho\rho}}$	$0.198^{+0.233}_{-0.150} + (-0.009^{+0.145}_{-0.097})i$	$0.344 + 0.042i$
$\frac{C_{\pi\rho}}{T_{\pi\rho}}$	$0.250^{+0.229}_{-0.143} + (-0.012^{+0.127}_{-0.090})i$	$0.467 + 0.071i$
$\frac{C_{\rho\pi}}{T_{\rho\pi}}$	$0.134^{+0.199}_{-0.156} + (-0.024^{+0.152}_{-0.117})i$	$0.283 + 0.138i$
$\frac{T_{\rho\pi}}{T_{\pi\rho}}$	$0.869^{+0.275}_{-0.207} + (0.014^{+0.058}_{-0.057})i$	$0.945 - 0.004i$





Sebastian Jäger

QCDF allows to make predictions for 2-body decays, some new puzzles appear

Null tests of the SM

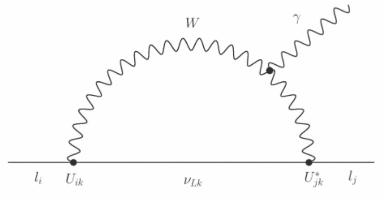
What about cLFV?

Note: LFV ≠ Lepton Flavor in Vienna

In conclusion, lepton flavor is **not** conserved: there is **lepton flavor violation (LFV)**

However... what about **charged lepton flavor violation (cLFV)**?

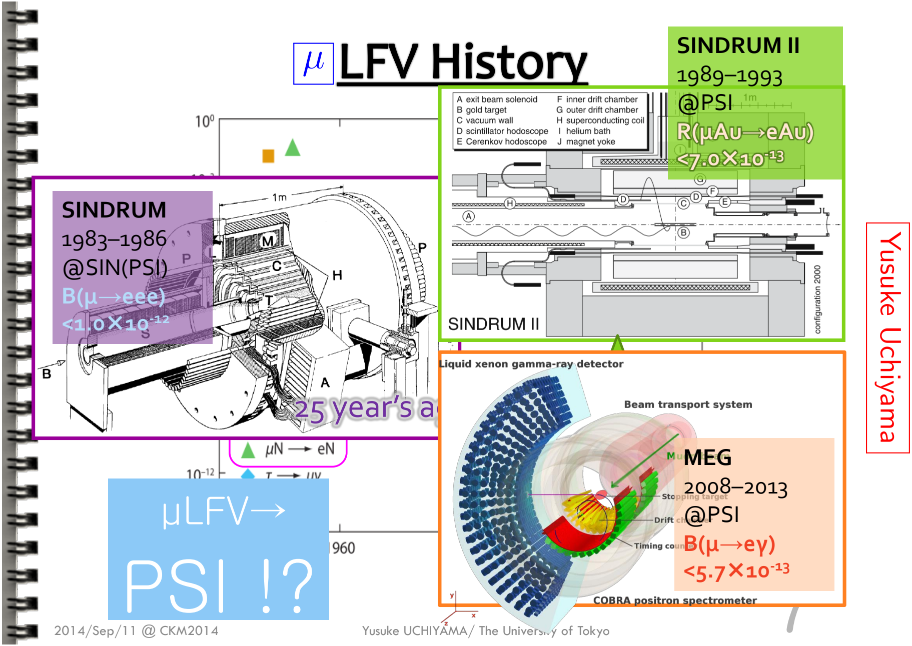
SM + neutrino masses



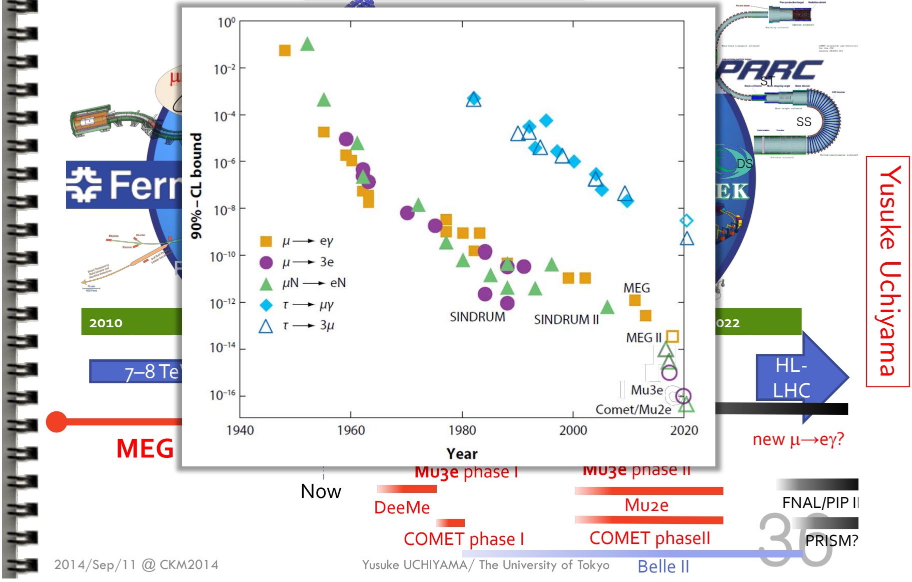
$$\mathrm{Br}(\mu \to e\gamma) = \frac{3\alpha}{32\pi} \left| \sum_k U_{ek} U^*_{\mu k} \frac{m^2_{\nu k}}{m^2_W} \right|^2 \lesssim 10^{-54}$$

Since neutrino masses are the only source of LFV, all cLFV amplitudes are strongly suppressed (in fact, GIM suppressed)

Avelino Vincente


μ LFV History
SINDRUM
1983–1986
@SIN(PSI)
B(μ→eee)
<1.0×10-12
SINDRUM II
1989–1993
@PSI
R(μAu→eAu)
<7.0×10-13
A exit beam solenoid
B gold target
C vacuum wall
D scintillator hodoscope
E Cerenkov hodoscope
F inner drift chamber
G outer drift chamber
H superconducting coil
I helium bath
J magnet yoke
SINDRUM II
configuration 2000
25 year's a
μN → eN
μLFV→
PSI !?
Liquid xenon gamma-ray detector
Beam transport system
MEG
2008–2013
@PSI
B(μ→eγ)
<5.7×10-13
COBRA positron spectrometer
Yusuke Uchiyama
2014/Sep/11 @ CKM2014
Yusuke UCHIYAMA/ The University of Tokyo

Next decade



PS
PRISM
ST
SS
DS
Fermilab
2010
2022
7–8 TeV
MEG
HL-LHC
new μ→eγ?
Now
Mu3e phase I
Mu3e phase II
DeeMe
Mu2e
COMET phase I
COMET phaseII
Belle II
FNAL/PIP II
PRISM?
Yusuke Uchiyama
90%–CL bound
Year
μ → eγ
μ → 3e
μN → eN
τ → μγ
τ → 3μ
SINDRUM
SINDRUM II
MEG
MEG II
Mu3e
Comet/Mu2e
2014/Sep/11 @ CKM2014
Yusuke UCHIYAMA/ The University of Tokyo
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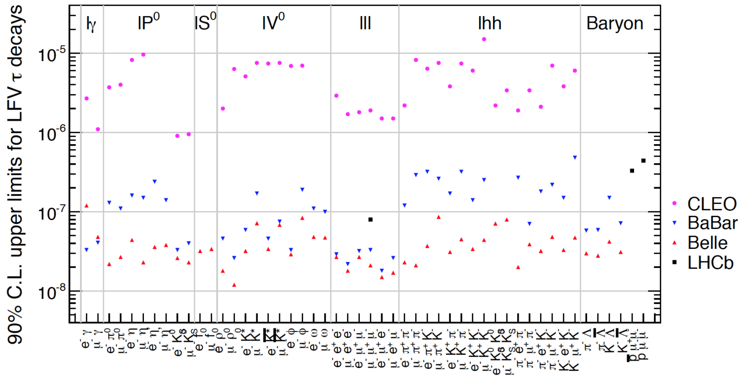
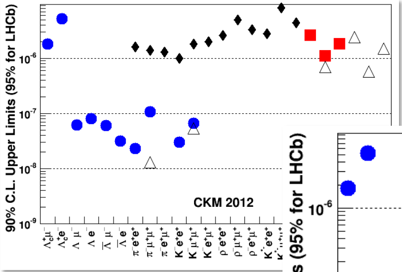
Summary of τ LFV

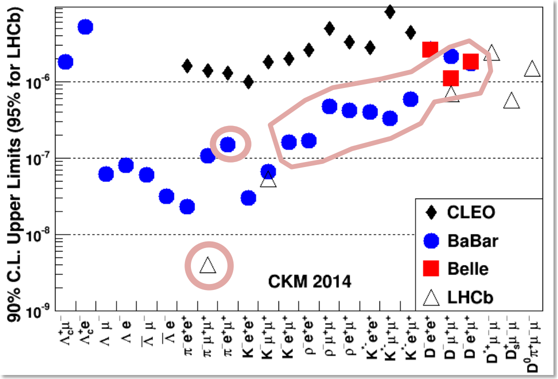


Toru Iijima

- 48 tau LFV modes have been searched for at B-factories.
  - Note: need theorists' help to relate them (other than lγ,lll) to NP
- Recently LHCb also made the search for $\tau^- \to \mu^-\mu^+\mu^-$, $\bar{p}\mu^+\mu^-$, $p\mu^-\mu^-$.

Summary of LNV results in B decays





CLEO: PRD 65, 111102 (2002)
Belle: PRD 84, 071106 (2011)
BaBar: PRD 85, 071102 (2012)
LHCb: PRL 108, 106601 (2012)
LHCb: PRD 85,112004 (2012)
BaBar: PRD 89, 011102 (2014)
LHCb: PRL 112, 131802 (2014)

Fergus Wilson

Summary (of the summary)

- Large amount of experimental progress since CKM 2012.
  - $\rightsquigarrow$ SM is still prevailing, but there are now a few interesting hints.
- There has also been impressive progress from theory (including new lattice results), challenge will be to keep pace with the measurements!
- There are still many opportunities to find "new physics"
  - New results from KOTO, MEG, NA62 and the LHC experiments and the final results from the B-factories are expected before CKM 2016.
- Finally, we would like to thank again all the speakers in WG 3 and everyone who participated in the discussion.