Frascati, 30th May 2013

(Personal) Perspectives in Flavour physics
Interacting with Juliet and Paolo

Giancarlo D'Ambrosio

INFN Sezione di Napoli

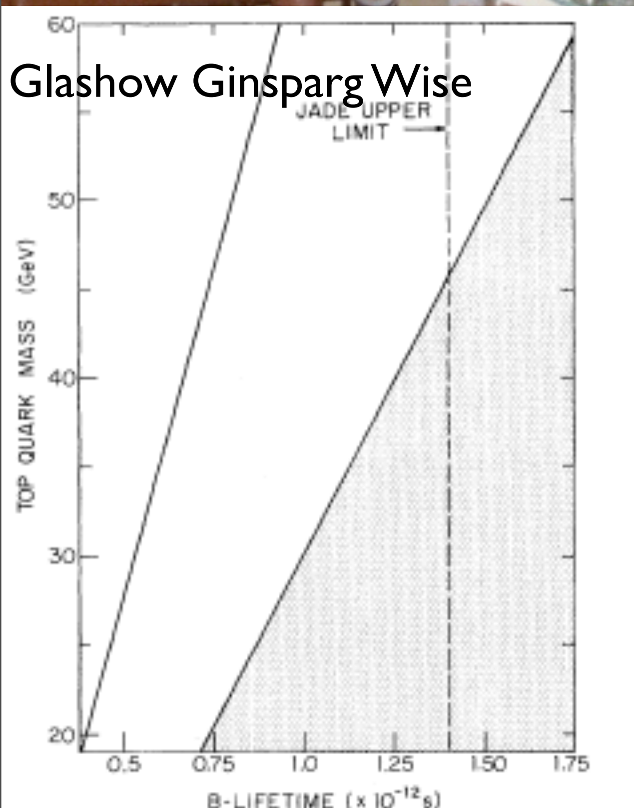
Latest work in collaboration with Luigi Cappiello and Oscar Catà

Outline

- Cargese 1983, Summer 1984 Stanford
- Fall 1989 Pisa Presidenza INFN
- Geneva 1991(Lepton –Photon +ECHEP)
- Bell Steinberger relations
- (g-2)_muon
- Rare Kaon and D-decays

Cargese July 1983

- Juliet and Paolo were there along with Carlo (first W's and Z's), Glashow, Giorgio, Charpak..



Possibility of a long B-lifetime

Bounds from the observed ϵ_K

mt> 40 GeV

Paolo: very good determination of the CKM matrix

Juliet QCD potentials

Amusing Glashow's remark

Cargese 1983

- Einstein's problem No role of nuclear forces in unification
- Dirac's problem No large adimensional numbers, large #'s related to universe lifetime
- Rabi's problem Anthropic principle Nanopoulos: 3 families to explain matter antimatter asymm.
- Cabibbo's problem Universality of couplings reduction of couplings

Slac, summer 1984

- Slac Summer school, sixth quark, workshop : Great Harari lectures
- Juliet and Paolo are there! Great results discussed (Flavour and spectroscopy) Pief fest, Carlo comes! Also Nicola: first trip as INFN President
- I share the office with Gabriele Veneziano: an interesting remark in preon theory (MFV ?) Chivukula and Georgi

Fall 1989, INFN Pisa + Presidenza

- After Pisa (October, Nello invited me to come) we meet in Presidenza (7th December) to discuss physics at the phi factory
- Incidentally also Paolo and Carlo come
- Nicola very positive on the impact of the phi factory
- Luciano the 23rd of December chairs the DAFNE working group (after one month or so Luciano invites Nello and me to meet Gino and discuss their work)

Geneva 1991(Lepton –Photon +ECHEP)

- Paolo and Nicola (honoured by EPS prize) are there: they discuss of important issues

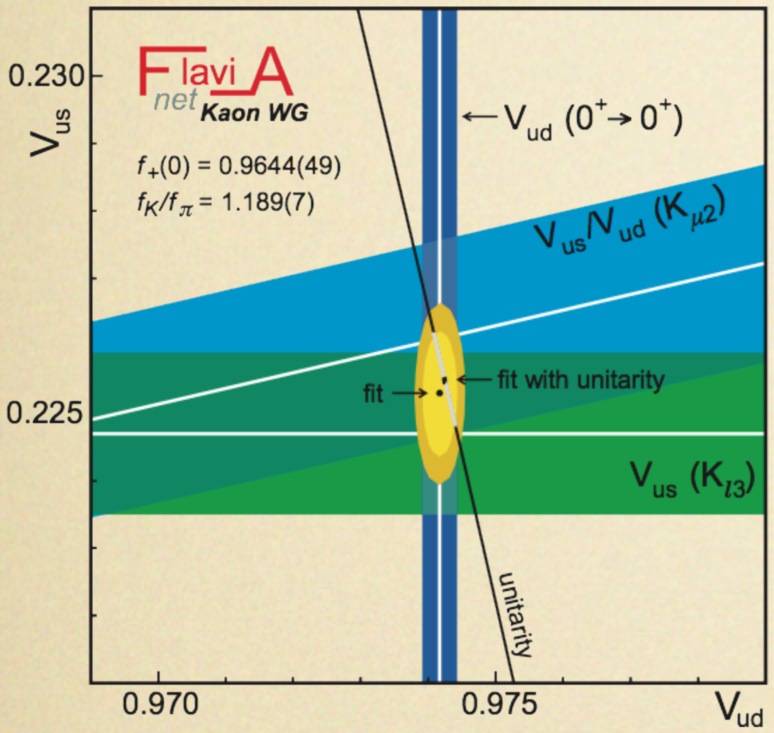
Always interacting with Juliet and Paolo

- PDG activity
- g-2_muon: light by light, pi0 pole
- Flavour physics, rare K and D decays

Activity PDG G. D'Ambrosio

Responsabilities:

Kaon physics, CPT tests



M. Antonelli, GD

$\Re(\epsilon)$ $\Im(\delta)$

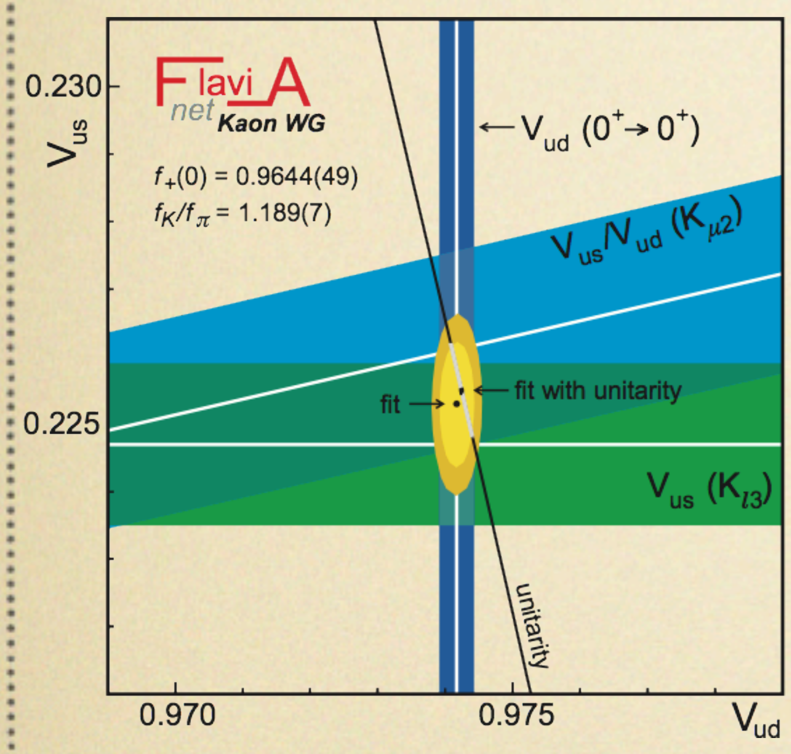
Review Bell-Steinberger relations: unitarity determines CP and CPT violating in terms of $A_L(f)A_S^*(f)$

$$\left[\frac{\Gamma_S+\Gamma_L}{\Gamma_S-\Gamma_L}+i\tan\phi_{\rm SW}\right]\left[\frac{\Re(\epsilon)}{1+|\epsilon|^2}-i\Im(\delta)\right]=\frac{1}{\Gamma_S-\Gamma_L}\sum_f A_L(f)A_S^*(f)$$

CPLEAR, NA48, KLOE, PDGfit, KTEV

Activity PDG G. D'Ambrosio

Responsabilities:
Kaon physics, CPT tests



Cabibbo's angle
Vus at 0.5 %

M. Antonelli, GD

Review Bell-Steinberger relations: unitarity determines CP and CPT violating in terms of $A_L(f)A_S^*(f)$

$\Re(\epsilon)$ $\Im(\delta)$

$$\left[\frac{\Gamma_S+\Gamma_L}{\Gamma_S-\Gamma_L}+i\tan\phi_{SW}\right]\left[\frac{\Re(\epsilon)}{1+|\epsilon|^2}-i\Im(\delta)\right]=\frac{1}{\Gamma_S-\Gamma_L}\sum_f A_L(f)A_S^*(f)$$

CPLEAR, NA48, KLOE, PDGfit, KTEV

Determinations for Bell Steinberger relations

M. Antonelli, GD

$$
\begin{aligned}
\alpha_{\pi^+\pi^-} &= ((1.112 \pm 0.013) + i(1.061 \pm 0.014)) \times 10^{-3} \\
\alpha_{\pi^0\pi^0} &= ((0.493 \pm 0.007) + i(0.471 \pm 0.007)) \times 10^{-3} \\
\alpha_{\pi^+\pi^-\pi^0} &= ((0 \pm 2) + i(0 \pm 2)) \times 10^{-6}
\end{aligned}
$$

from CPLEAR, NA48,
KLOE KTeV

Matter antimatter limit

M. Antonelli, GD

$$\Re(\epsilon) = (161.1 \pm 0.5) \times 10^{-5}, \qquad \Im(\Delta) = (-0.7 \pm 1.4) \times 10^{-5}$$

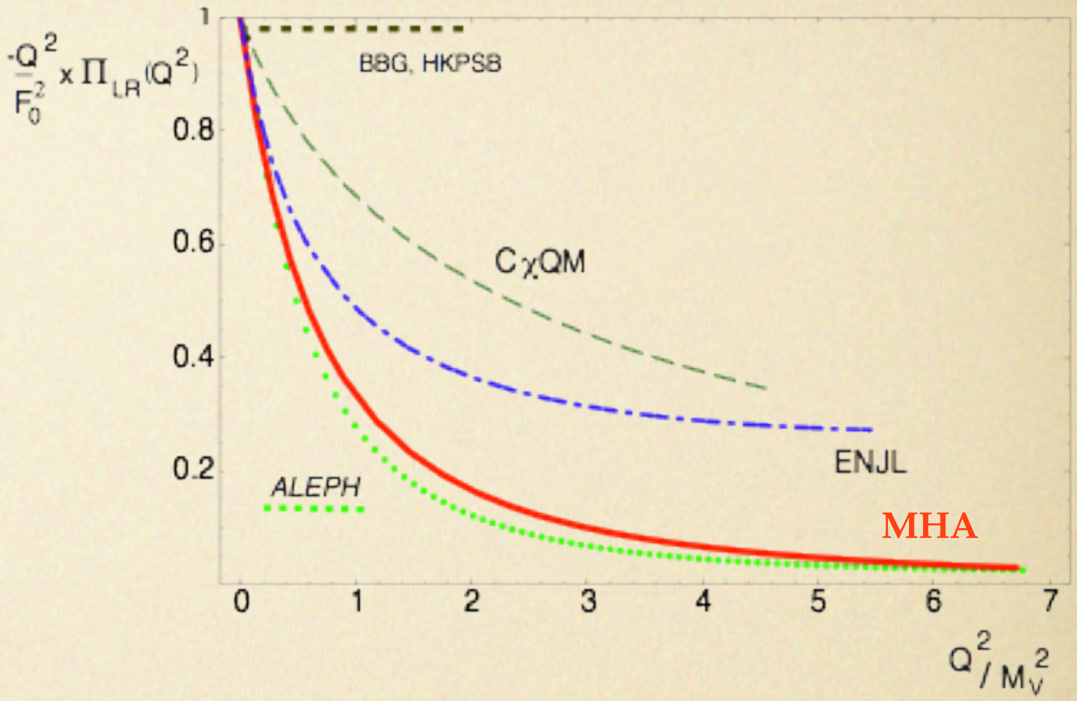
$$-4.0 \times 10^{-19}\ \text{GeV} < m_{K^0} - m_{\bar{K^0}} < 4.0 \times 10^{-19}\ \text{GeV} \quad \text{at } 95\%\ \text{CL}$$

- g-2 requires solid QCD estimate
- few words about the holographic approach

Holographic QCD: activity L. Cappiello, O. Cata, G.D.

Traditional approach to evaluate QCD correlators:

- Large Q^2 : perturb. QCD
- low Q^2 : chiral sym.,VMD



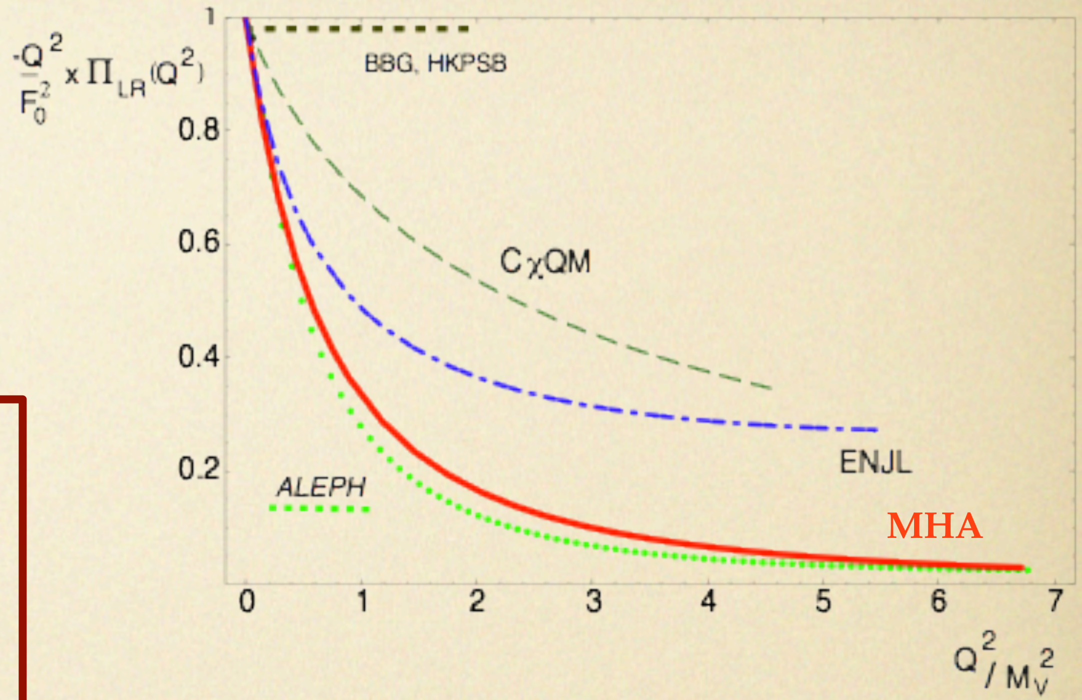
Holographic QCD: activity L. Cappiello, O. Cata, G.D.

Traditional approach to evaluate QCD correlators:

- Large Q^2 : perturb. QCD
- low Q^2 : chiral sym.,VMD

Holographic approach to evaluate QCD correlators:

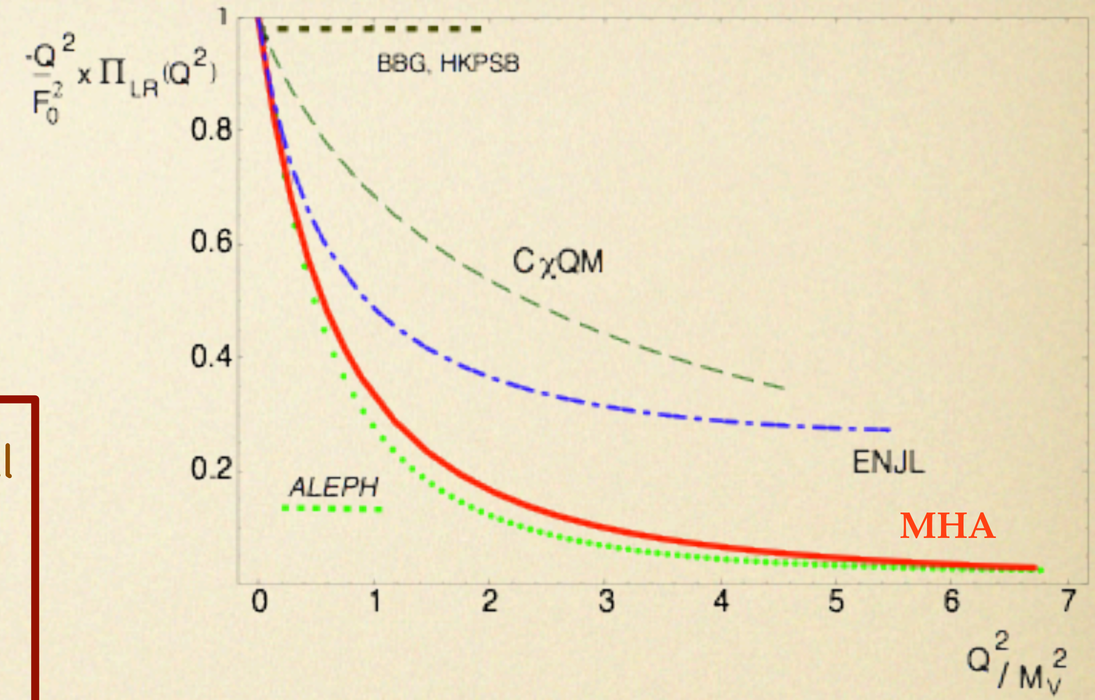
- Large Q^2 , perturb. QCD → Conformal symm-
- 4D gauge (conformal) dual 5D ADS



Holographic QCD: activity L. Cappiello, O. Cata, G.D.

Traditional approach to evaluate QCD correlators:

- Large Q^2 : perturb. QCD
- low Q^2 : chiral sym., VMD



Holographic approach to evaluate QCD correlators:

- Large Q^2 , perturb. QCD → Conformal symm-
- 4D gauge (conformal) dual 5D ADS

Strong and weak chiral lagrangian

$\langle \alpha_s G_{\mu\nu} G^{\mu\nu} \rangle$

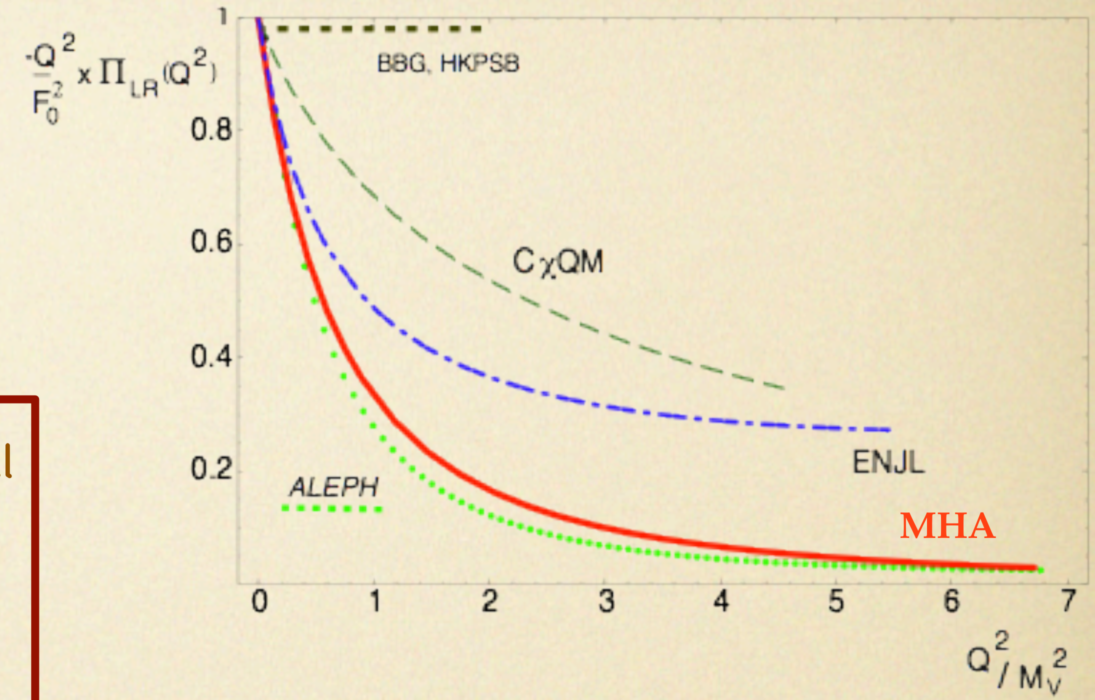
$$\mathcal{L} = \frac{F_\pi^{\,2}}{4} \overbrace{\langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + U \chi^\dagger \rangle}^{\pi \to l\nu,\ \pi\pi \to \pi\pi,\ K \to \pi..} + \overbrace{\sum_i L_i O_i}^{K \to \pi..} + \cdots$$

$$\mathcal{L}_{\Delta S=1} = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K \to 2\pi/3\pi} + \underbrace{G_8 F^2 \sum_i N_i W_i}_{K^+ \to \pi^+ \gamma\gamma,\, K \to \pi l^+ l^-} + \cdots$$

VMD: success 5D. not in 4D

Holographic QCD: activity L. Cappiello, O. Cata, G.D.

Traditional approach to evaluate QCD correlators:
- Large Q^2 : perturb. QCD
- low Q^2 : chiral sym.,VMD



Holographic approach to evaluate QCD correlators:
- Large Q^2 , perturb. QCD → Conformal symm-
- 4D gauge (conformal) dual 5D ADS

Strong and weak chiral lagrangian

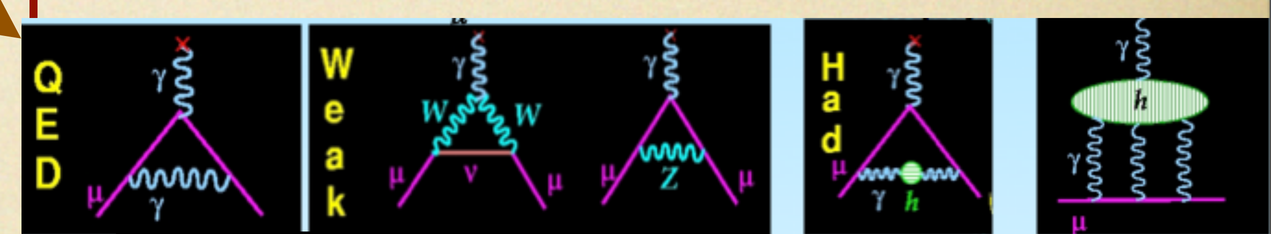
$\langle \alpha_s G_{\mu\nu} G^{\mu\nu} \rangle$

$$\mathcal{L} = \frac{F_\pi{}^2}{4} \overbrace{\langle D_\mu U D^\mu U^\dagger + \chi U^\dagger + U \chi^\dagger \rangle}^{\pi \to l\nu,\ \pi\pi \to \pi\pi,\ K \to \pi..} + \overbrace{\sum_i L_i O_i}^{K \to \pi..} + \cdots$$

$$\mathcal{L}_{\Delta S=1} = G_8 F^4 \underbrace{\langle \lambda_6 D_\mu U^\dagger D^\mu U \rangle}_{K \to 2\pi/3\pi} + \underbrace{G_8 F^2 \sum_i N_i W_i}_{K^+ \to \pi^+ \gamma\gamma,\ K \to \pi l^+ l^-} + \cdots$$

VMD: success 5D. not in 4D

Hadronic contribution to g-2 muon

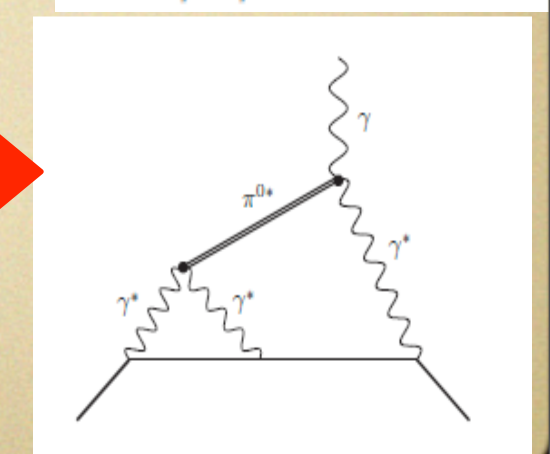


3 σ's discrepancy TH vs EXP

Pion Form Factor

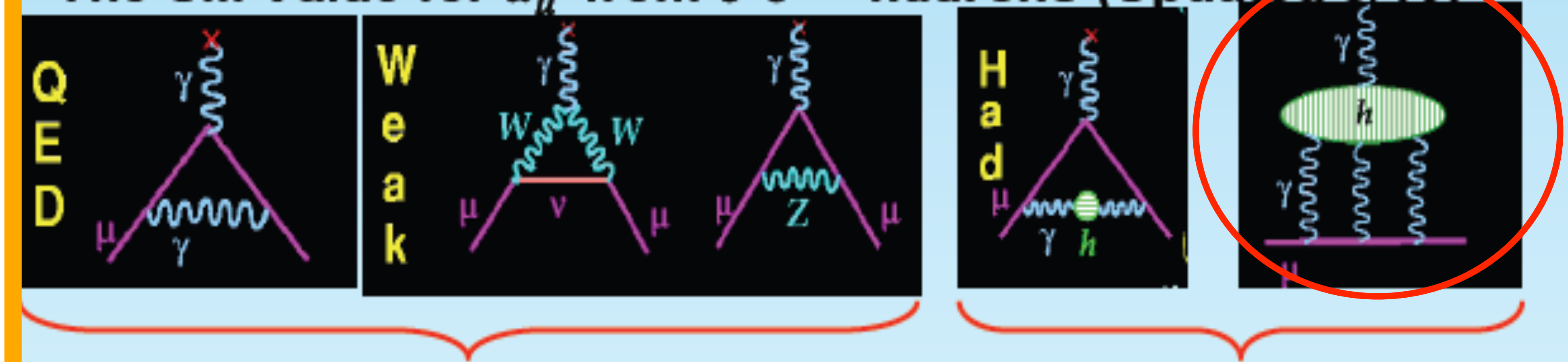
$F_{\pi^0 \gamma^* \gamma^*}(Q_1^2, Q_2^2)$

Comparison Th vs Exp requires accuracy $1/10^{10}$!



Holographic QCD and Hadronic Light-by-Light Scattering Contribution to Muon g-2

The SM Value for a_μ from $e^+e^- \rightarrow$ *hadrons* (Updated 9/10)



CONTRIBUTION	RESULT ($\times 10^{-11}$) UNITS
QED (leptons)	$116\,584\,718.09 \pm 0.14 \pm 0.04_\alpha$
HVP(lo)	$6\,914 \pm 42_{\rm exp} \pm 14_{\rm rad} \pm 7_{\rm pQCD}$
HVP(ho)	$-98 \pm 1_{\rm exp} \pm 0.3_{\rm rad}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\,591\,793 \pm 51$

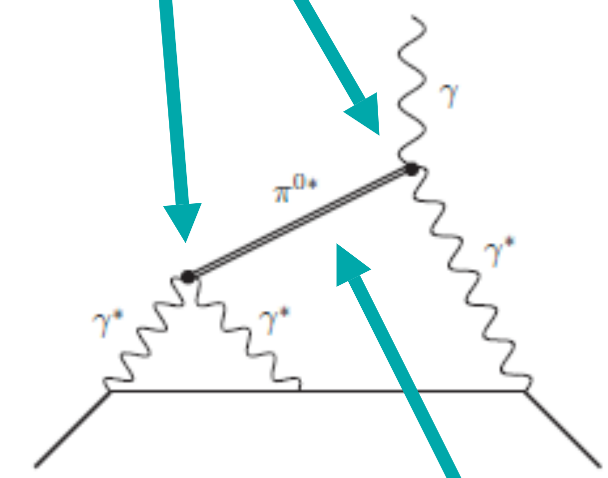
A. Höcker Tau 2010, U. Manchester September 2010 **116 592 089 +- 63**

EXP

Pion exchange diagram dominates HLbL

Pion Form Factor

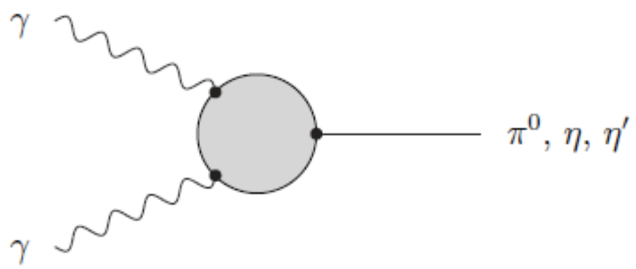
$F_{\pi^0\gamma^*\gamma^*}(Q_1^2, Q_2^2)$



Off-Shell Pion

Anomalous AdS/CFT three point function

Cappiello Cata G.D.



Grigoryan and A.V. Radyushkin

- From CS

$$K(Q_1^2, Q_2^2) = -\int_0^{z_0} \mathcal{J}(Q_1, z)\mathcal{J}(Q_2, z)\, \partial_z \Psi(z)\, dz$$

$$\mathcal{J}(Q, z) = Qz\left[K_1(Qz) + I_1(Qz)\frac{K_0(Qz_0)}{I_0(Qz_0)}\right] .$$

- short distance naturally implemented

- low energy, various models discriminated:

  acceptable phenom. linear slope measured

$$F_{\pi^0\gamma^*\gamma^*}(Q_1^2, Q_2^2) \simeq -\frac{N_C}{12\pi^2 f_\pi}\left[1 + \hat{\alpha}\,(Q_1^2 + Q_2^2) + \hat{\beta}\; Q_1^2 Q_2^2 + \hat{\gamma}\;(Q_1^4 + Q_2^4)\right]$$

fixed !

Pseudoscalar exchanges

Our result

Model for $\mathcal{F}_{P^{(*)}\gamma^*\gamma^*}$	$a_\mu(\pi^0) \times 10^{11}$	$a_\mu(\pi^0, \eta, \eta') \times 10^{11}$
modified ENJL (off-shell) [BPP]	59(9)	85(13)
VMD / HLS (off-shell) [HKS,HK]	57(4)	83(6)
LMD+V (on-shell, $h_2 = 0$) [KN]	58(10)	83(12)
LMD+V (on-shell, $h_2 = -10$ GeV^2) [KN]	63(10)	88(12)
LMD+V (on-shell, constant FF at ext. vertex) [MV]	77(7)	114(10)
nonlocal χQM (off-shell) [DB]	65(2)	—
LMD+V (off-shell) [N]	72(12)	99(16)
AdS/QCD (off-shell ?) [HoK]	69	107
AdS/QCD/DIP (off-shell) [CCD]	65.4(2.5)	—
DSE (off-shell) [FGW]	58(7)	84(13)
[PdRV]	—	114(13)
[JN]	72(12)	99(16)

BPP = Bijnens, Pallante, Prades '95, '96, '02 (ENJL = Extended Nambu-Jona-Lasinio model); HK(S) = Hayakawa, Kinoshita, Sanda '95, '96; Hayakawa, Kinoshita '98, '02 (HLS = Hidden Local Symmetry model); KN = Knecht, Nyffeler '02; MV = Melnikov, Vainshtein '04; DB = Dorokhov, Broniowski '08 (χQM = Chiral Quark Model); N = Nyffeler '09; HoK = Hong, Kim '09; CCD = Cappiello, Catà, D'Ambrosio '10 (used AdS/QCD to fix parameters in DIP (D'Ambrosio, Isidori, Portolés) ansatz); FGW = Fischer, Goecke, Williams '10, '11 (Dyson-Schwinger equation)
Reviews on LbyL: PdRV = Prades, de Rafael, Vainshtein '09; JN = Jegerlehner, Nyffeler '09

A. Nyffeler Seattle 2011

There are many competing models:
ENJL
(Chiral quark model)
Lowest Meson Dominance
Hidden Symmetry
Non-Local ChQM
Bethe-Salpeter
Holographic QCD
Lattice QCD

A theoretical effort should be done to make them talk to each other

Uncertainty can increase of 10-15 % due to poor knowledge of the parameter χ_0 which we used to encode the pion off-shellness by the high-Q^2 constraint

$$\lim_{Q^2\to\infty} F_{\pi^{0*}\gamma^*\gamma^*}(Q^2, Q^2, 0) = -\frac{f_\pi}{3}\chi_0 + \cdots$$

Notice that the low-Q^2 predictions for PFF of the holographic models could be tested at KLOE-2

$$\lim_{Q_1^2, Q_2^2 \to 0} F_{\pi^0\gamma^*\gamma^*}(Q_1^2, Q_2^2) \simeq -\frac{N_C}{12\pi^2 f_\pi} \times \left[1 + \hat\alpha\,(Q_1^2 + Q_2^2) + \hat\beta\, Q_1^2 Q_2^2 + \hat\gamma\,(Q_1^4 + Q_2^4)\right]$$

Exp.

$$\hat\alpha = -1.76(22)\ \mathrm{GeV}^{-2}$$

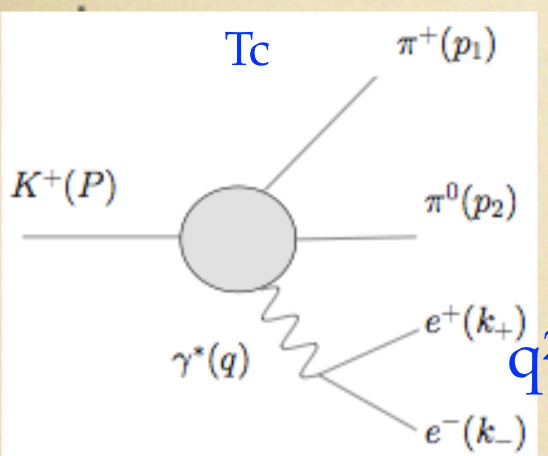
$$\hat\beta = 3.33(32)\ \mathrm{GeV}^{-4}, \quad \hat\gamma = 2.84(21)\ \mathrm{GeV}^{-4}.$$

Flavour physics

Cappiello Catà G.D.

3 reasons to study flavour physics NOW:

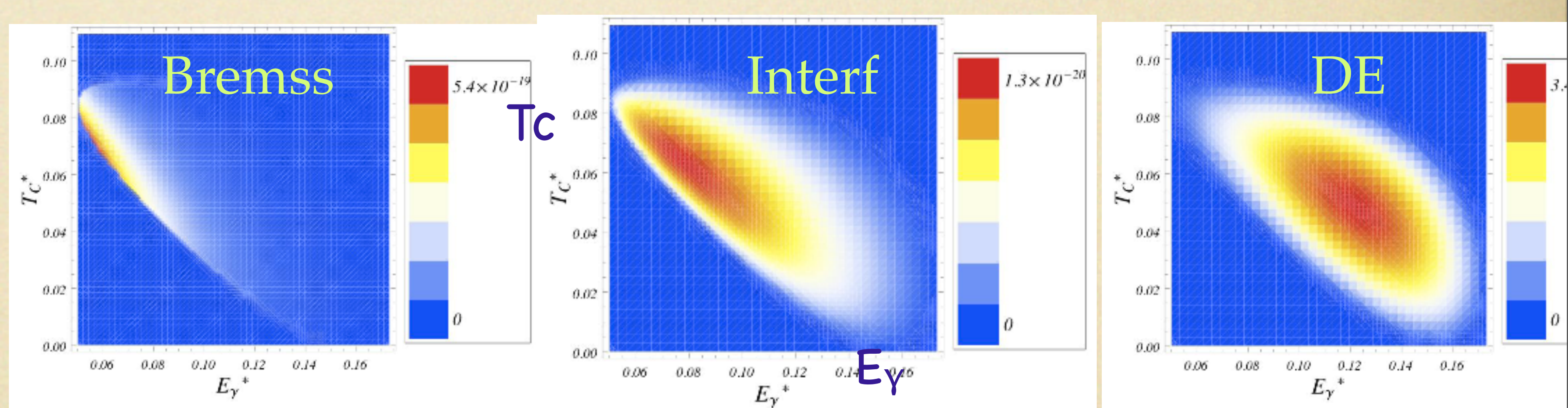
- beautiful LHCb results
- INFN experience in the field thanks also to Paolo is superb
- If Higgs confirmed: deviations from SM **tiny** to be tested by precision flavour physics (Minimal Flavour violation)



$$K^+ \to \pi^+\pi^0 e^+ e^-$$

Tc, q^2, E_γ - kinematical analysis useful to pin down the most interesting physics distributions

Bremss 10^-6
DE 10^-8



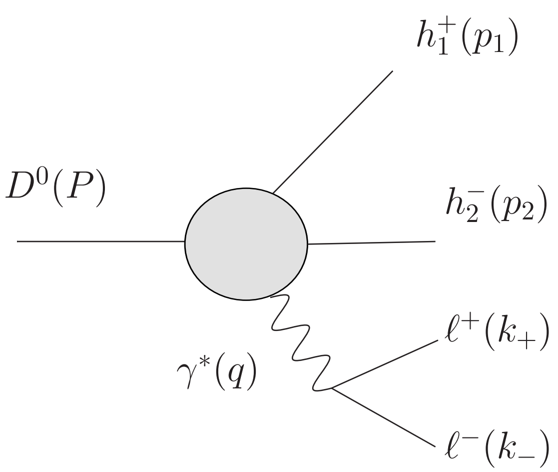
$$A_{CP} = \frac{\Gamma(K^+\to\pi^+\pi^0e^+e^-)-\Gamma(K^-\to\pi^-\pi^0e^+e^-)}{\Gamma(K^+\to\pi^+\pi^0e^+e^-)+\Gamma(K^-\to\pi^-\pi^0e^+e^-)}$$

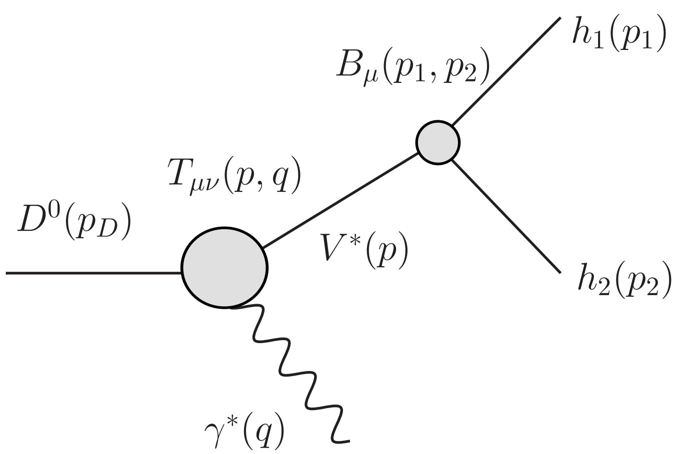
NA48 NA62 analysis in progress

$$D^0 \to h^+h^-l^+l^- \quad (h^+h^- = \pi\pi, \pi K, K\pi, KK)$$

Cappiello Catà G.D.

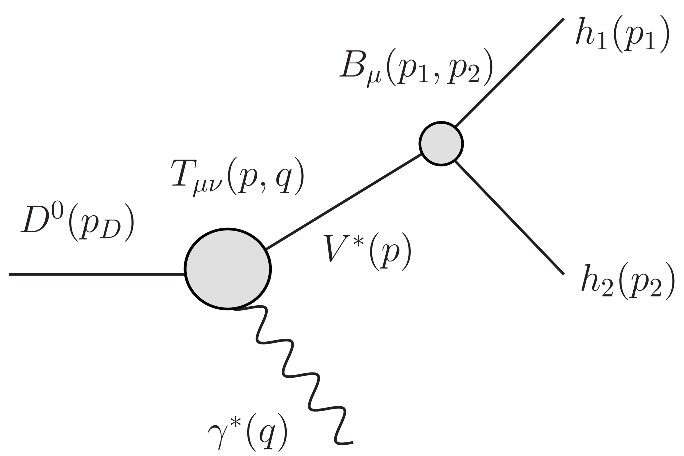
- LHCb is going to measure them
- competitive with $D \to V\gamma$
- SM: LD (IB +DE) and short distance, NP





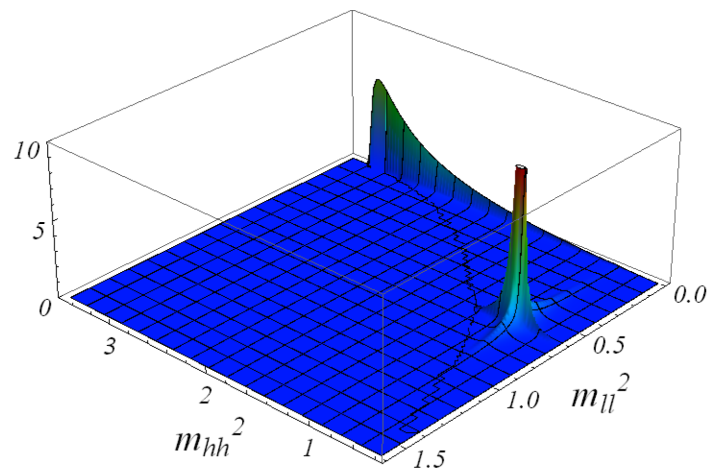
DE: form factor generated from $D \to VV$

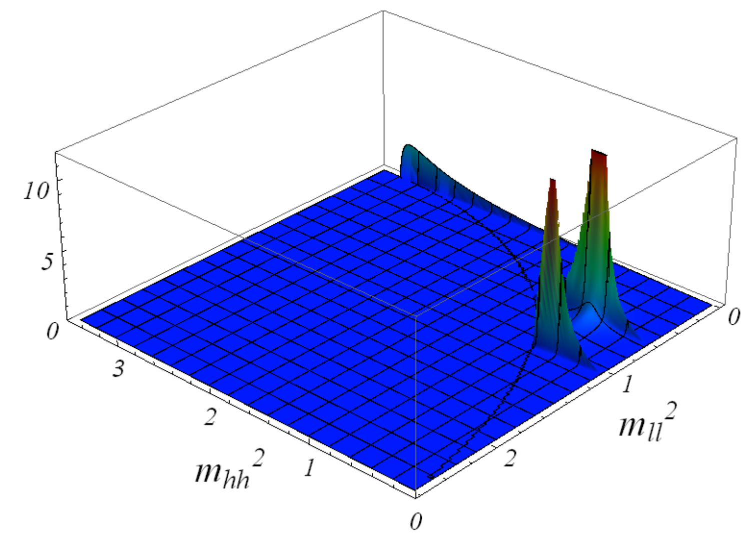
$$\frac{e}{q^2} \;\; \bar{l}\gamma^\mu l \; H_\mu(p_1, p_2, q) \qquad\qquad H^\mu = F_1 p_1^\mu + F_2 p_2^\mu + F_3 \; \varepsilon^{\mu\nu\alpha\beta} p_{1\nu} p_{2\alpha} q_\beta$$

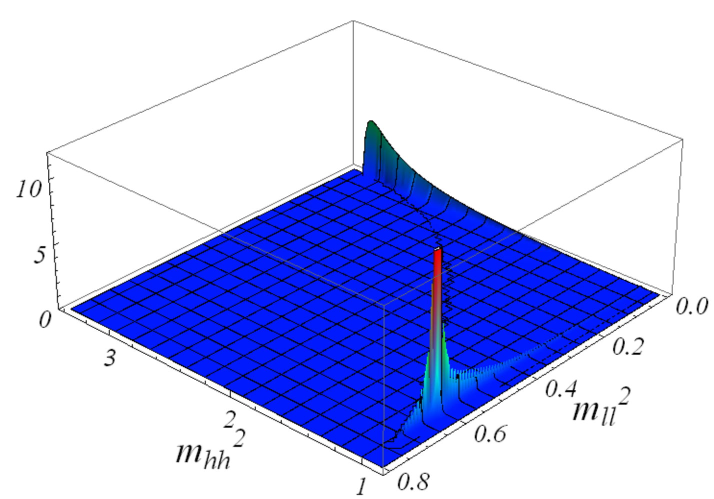


- general ff then VMD + Factorization Bauer,Stech,Wirbel
- We use D_l4 data from Focus Babar

(m_{ll}^2, m_{hh}^2) plane $\quad K^\mp\pi^\pm(K^*)$, $\quad \pi^+\pi^-(\rho) \quad K^+K^-(\phi), e^+e^-$







Decay mode	Bremss	(E)	(M)
$D^0 \to K^-\pi^+e^+e^-$	$9.9 \cdot 10^{-6}$	$6.2 \cdot 10^{-6}$	$4.8 \cdot 10^{-7}$
$D^0 \to \pi^+\pi^-e^+e^-$	$5.3 \cdot 10^{-7}$	$1.3 \cdot 10^{-6}$	$1.3 \cdot 10^{-7}$
$D^0 \to K^+K^-e^+e^-$	$5.4 \cdot 10^{-7}$	$1.1 \cdot 10^{-7}$	$5.0 \cdot 10^{-9}$
$D^0 \to K^+\pi^-e^+e^-$	$3.7 \cdot 10^{-8}$	$1.7 \cdot 10^{-8}$	$1.3 \cdot 10^{-9}$
$D^0 \to K^-\pi^+\mu^+\mu^-$	$8.6 \cdot 10^{-8}$	$6.2 \cdot 10^{-6}$	$4.8 \cdot 10^{-7}$
$D^0 \to \pi^+\pi^-\mu^+\mu^-$	$5.6 \cdot 10^{-9}$	$1.3 \cdot 10^{-6}$	$1.3 \cdot 10^{-7}$
$D^0 \to K^+K^-\mu^+\mu^-$	$3.3 \cdot 10^{-9}$	$1.1 \cdot 10^{-7}$	$5.0 \cdot 10^{-9}$
$D^0 \to K^+\pi^-\mu^+\mu^-$	$3.3 \cdot 10^{-10}$	$1.7 \cdot 10^{-8}$	$1.3 \cdot 10^{-9}$

Good News

- I just realized: 30 years I know Paolo!
- I tend always to make SM prediction more solid, I have difficulties with NP scenarios. SM always WINS: HOWEVER people DO NOT get depressed, they try harder!!! I find it amazing
- LHCb is fantastic, NA62, KOTO, BELLE, BES great perspectives! LNF has to match up, Orka good luck!