The Charm of the Future

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ERC Ideas: NPFlavour

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The landscape of Flavour Physics towards the high intensity era.

Pisa. 9th – 10th Dec 2014.

I know she invented fire, but what has she done recently?

Ikaros I.
Bigi

LHCb is a MONSTER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2013-199
LHCb-PAPER-2013-057
29 October 2013

Search for *CP* violation in the decay $D^+ \to \pi^-\pi^+\pi^+$

The LHCb collaboration†

LHCb is a MONSTER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-125
LHCb-PAPER-2014-018
10 June 2014

Search for CP violation in $D^{\pm} \to K^0_S K^{\pm}$ and $D^{\pm}_s \to K^0_S \pi^{\pm}$ decays

The LHCb collaboration[†]

LHCb is a MONSTER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-082
LHCb-PAPER-2014-013
June 11, 2014

Measurement of CP asymmetry in $D^0 \to K^- K^+$ and $D^0 \to \pi^- \pi^+$ decays

The LHCb collaboration†

LHCb is a MONSTER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-251
LHCb-PAPER-2014-054
14 October 2014

Search for CP violation in $D^0 \to \pi^-\pi^+\pi^0$ decays with the energy test

The LHCb collaboration†

LHCb is a MONSTER

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-PH-EP-2014-194
LHCb-PAPER-2014-046
October 1, 2014

Search for *CP* violation using *T*-odd correlations in $D^0 \to K^+K^-\pi^+\pi^-$ decays

The LHCb collaboration[†]

Why charm dynamics?

- ✓ The *ONLY* quark in the up quark sector that partakes in oscillations.
- ✓ The *ONLY* neutral meson system where direct CPV can possibly overcome indirect CPV.
- ✓ The *ONLY* quark that does not distinctly lie in the non-perturbative or the perturbative regime.
- ✓ The *ONLY* quark dynamics that SM has chosen to leave tiny signatures in.

- o Charm is being produced in significantly large numbers, even in hadron machines: LHCb ~ 10^{13} charm pairs and the future holds promises of much more.
- o Extraction of charm signals from the background has significantly improved.
- o A Beauty factory can produce as much charm as beauty.
- o Dedicated charm threshold runs possible at super flavour factories.

Theoretical Hurdles

- All we can do is perturbation theory.
- Traditional techniques for heavy quarks: Factorization, pQCD etc. do not work, even conceptually.
- Attempts have been made to use hybrid forms of chiral perturbation theory but charm is way too massive for that.
- Attempts have been made to use SU(3) breaking arguments in the (u, d, s) multiplets to extract reduced matrix elements, analyze tree and penguin contributions etc.
- Traditional SU(3) breaking through the strange quark mass insertion lies on shaky ground as too many assumptions have to be made.
- When one uses the OPE approach, there is no clear distinction between the long distance and the short distance due to the dominance of light quark operators.
- Charm hadrons are heavy enough to decay into high multiplicity states, a bane and a boon.

As charm never ages…

The agelessness of charm.

The First Time

Discovery of charm as a J/ψ bound state in 1974

The Second Time

Observation of X, Y, Z states and D_{sJ}

The Third Time

Observation of oscillation in neutral charm meson system in 2007

The Fourth Time

CP violation in charm and a hope of New Dynamics in 2011

The Fifth Time

???

CP Violation: References

Y. Grossman *et al.*, *New physics and CP violation in singly Cabibbo suppressed D decays,* Phys. Rev. **D 75** (2007) 036008. [hep-ph/0609178].

T. Feldmann, S. Nandi and A. Soni,*Repercussions of Flavour Symmetry Breaking on CP Violation in D-Meson Decays,* JHEP**06** (2012) 007. [arXiv:1202.3795].

H. -Y. Cheng and C. -W. Chiang, *SU(3) symmetry breaking and CP violation in* $D \to PP$ *decays*, Phys. Rev **D 86** (2012) 014014. [arXiv:1205.0580].

S. Nandi and A. Soni, *Constraining the mixing matrix for Standard Model with four generations: time dependent and semi-leptonic CP asymmetries in* B_d^0, B_s *and* D^0, Phys. Rev. **D 83**, (2011) 114510. [arXiv:1011.6091].

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W. Altmannshofer, R. Primulando, C. -T. Yu and F. Yu, *New Physics Models of Direct CP Violation in Charm Decays.* JHEP**04** (2012) 049. [arXiv:1202.2866].

T. Mannel and N. Uraltsev, *Charm CP Violation and the Electric Dipole Moments from the Charm Scale,* [arXiv:1205.0233].

C. -H. Chen, C. -Q. Geng and W. Wang, *Direct CP Violation in Charm Decays due to Left-Right Mixing,* [arXiv:1206.5158].

E. Franco, S. Mishima and L. Silvestrini,*The Standard Model confronts CP violation in* $D^0 \to \pi^+\pi^-$ *and* $D^0 \to K^+K^-$, JHEP**05** (2012) 140. [arXiv:1203.3131].

B. Bhattacharya, M. Gronau and J. L. Rosner, *CP asymmetries in singly-Cabibbo-suppressed D decays to two pseudoscalar mesons,* Phys. Rev. **D 85** (2012) 054014. [arXiv:1201.2351].

J. Brod, Y. Grossman, A. L. Kagan and J. Zupan, *A Consistent Picture for Large Penguins in* $D \to \pi^+\pi^-, K^+K^-$, JHEP**10**, 161 (2012). [arXiv:1203.6659].

Y. Grossman, A. L. Kagan and J. Zupan, *Testing for new physics in singly Cabibbo suppressed D decays,* Phys. Rev. **D 85** (2012) 114036. [arXiv:1204.3557].

H. -n. Li, C. -D. Lu and F. -S. Yu, *Branching ratios and direct CP asymmetries in* $D \to PP$ *decays,* Phys. Rev. **D 86** (2012) 036012. [arXiv:1203.3120].

Building on current Statistics.

- Accessing charm dynamics was a challenge for one reason: STATISTICS.
- Recent bounty of statistics has enabled the study of not only rare decays but also high multiplicity final states.
- Since LHC is a *pp* collider, production asymmetries exist.
  Methods independent of production asymmetries become important.
- Correlation is an important tool.
  Possible dedicated runs at the charm threshold at B super-factory(ies)

$$e^+e^- \to \psi''(3770) \to D^0\bar{D}^0/D_+D_-/D_1D_2 \to f_af_b$$

- Charm factories: Can they do better than the B factories?

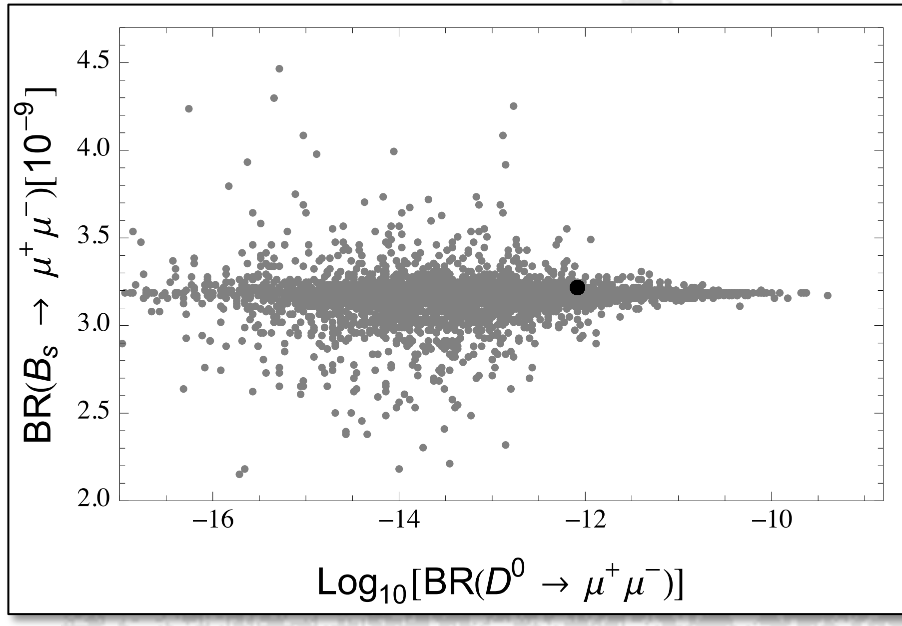
  YES… but who will build one…??

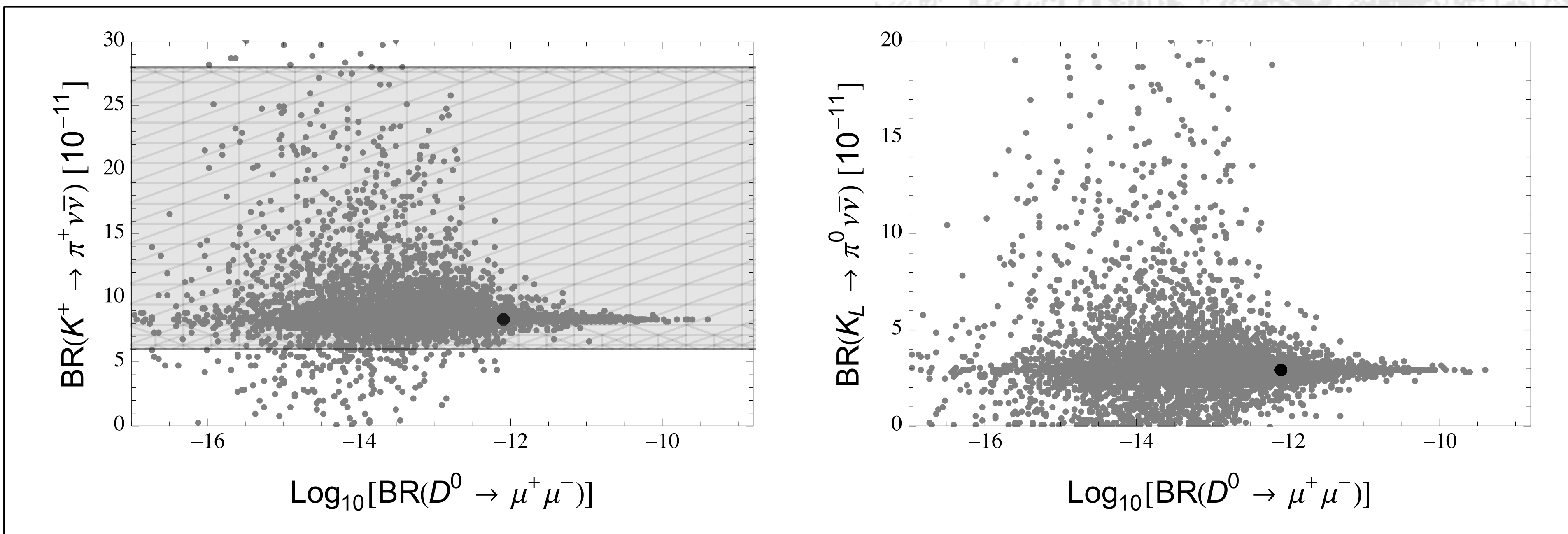
Again... why charm dynamics?

Unlike beauty and strange dynamics the SM signature in charm dynamics is tiny.

ND can make its effects felt by orders of magnitude.

(shown here for WED with custodial protection.)





A. Paul, A. de La Puente and I. I. Bigi, *Manifestations of Warped Extra Dimension in Rare Charm Decays and Asymmetries.* [arXiv:1212.4849].

NP model building

Do we care if there are specific models that predict large effects?

NO

- Still, it is nice that we have nice models that predict large effects
- In particular, given the bounds on the down sector, alignment requires some NP in the up sector

Non-Minimal Flavour Violation

A side-effect of many models built to address the problem of scale separations a.k.a Hierarchy Challenge.*

$$A(decay) = \sum_i B_i \eta^i_{QCD} V^i_{CKM} \left[F^i_{SM} + F^i_{ND}\right] + \sum_k B_k^{ND} \eta^k_{QCD} V^k_{ND} \left[G^k_{ND}\right]$$

minimal (↑ under V^i_{CKM}) **non-minimal** (↑ under V^k_{ND})

Non-Minimal dynamics can come from:

- An entirely new fermion-boson sector: LHT
- Delocalization of the SM states from the brane of our 4D universe: WED
- Compositeness of the SM states to varying degrees: Composite Dynamics
- …

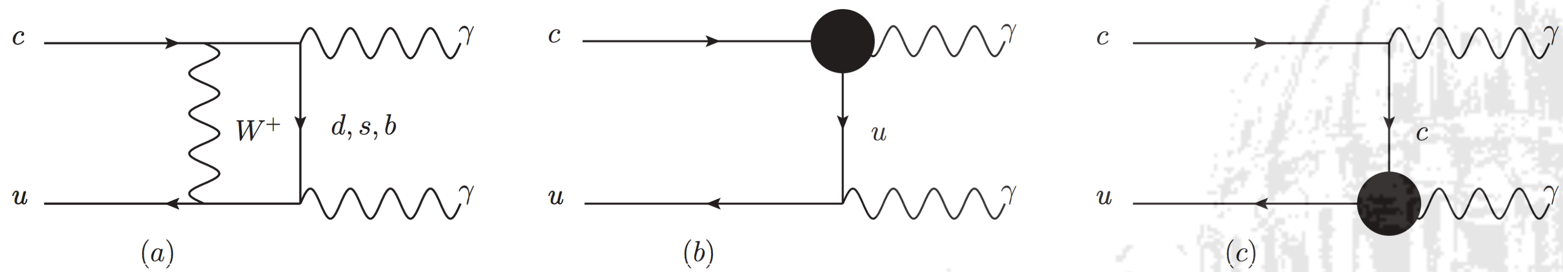
Of course there are others that are "flavour - tuned".

* Why have minimal when we can have non-minimal?

Charm as a portal into QCD

unusual places to look for QCD

$D^0 \to \gamma\gamma$



$$\mathrm{BR}_{SD}(D^0 \to \gamma\gamma) = \frac{m_M^3}{64\pi}\left(\left|A^{SD}([Q\bar{q}])\right|^2 + \left|B^{SD}([Q\bar{q}])\right|^2\right)$$

- LO QCD corrections to the 2PR.
- NLO QCD corrections to the 1PR.
- After including QCD corrections 1PR dominates.

- Generic ND does not enhance this channel much.
- Dominated by SM LD rates. ($\sim 10^{-8}$)
- BES III will get quite close but not there.

unusual places to look for QCD

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

$$\mathrm{BR}^{\mathrm{SD}}_{\mathrm{SM}}(D^0 \to \mu^+\mu^-) \approx 6 \times 10^{-19},$$
$$\mathrm{BR}^{\mathrm{LD}}_{\mathrm{SM}}(D^0 \to \mu^+\mu^-) = 2.7 \times 10^{-5} \times \mathrm{BR}(D^0 \to \gamma\gamma) \simeq 2.7 - 8 \times 10^{-13}$$

- LHCb now at 10^{-9}
- ND effects here correlated with *D* mixing.
- Dominant contribution comes from two photon unitary contribution.*

* an update can be expected soon from Healy and Petrov.

questioning our knowledge of QCD

$$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 7.3\,(8.3) \times 10^{-8},$$
$$\mathcal{B}(D_s^+ \to \pi^+\mu^+\mu^-) < 4.1\,(4.8) \times 10^{-7},$$
$$\mathcal{B}(D^+ \to \pi^-\mu^+\mu^+) < 2.2\,(2.5) \times 10^{-8},$$
$$\mathcal{B}(D_s^+ \to \pi^-\mu^+\mu^+) < 1.2\,(1.4) \times 10^{-7}.$$

LHCb limits April 2013

Best Theoretical Prediction of SM LD contribution: $O(10^{-6})$

- Hope: We are overestimating LD effects and really its more closer to SD estimates: $\mathrm{BR}^{\mathrm{SD}}_{\mathrm{SM}}(D \to X_u l^+ l^-) \simeq 3 \times 10^{-9}$
- Not so much Hope: We do not understand our QCD technologies.

Three body modes: Look into the distributions for asymmetries (CP and FB)

the SU(3) analysis

1. Choose you favourite set of singlet/octet final states and triplet initial state.
2. Construct your Hamiltonian from the triplet of quarks.

$$\begin{pmatrix} \mathcal{A}(D_s^+ \to \pi^+\pi^0) \\ \mathcal{A}(D^+ \to \pi^+\bar{K}^0) \\ \mathcal{A}(D^0 \to \pi^+K^-) \\ \mathcal{A}(D_s^+ \to \pi^+\eta_8) \\ \mathcal{A}(D^0 \to \pi^0\bar{K}^0) \\ \mathcal{A}(D_s^+ \to K^+\bar{K}^0) \\ \mathcal{A}(D^0 \to \bar{K}^0\eta_8) \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & \sqrt{\frac{2}{3}} & 0 & 0 & \frac{1}{\sqrt{3}} \\ 0 & 0 & -\frac{\sqrt{5}}{6} & -\frac{1}{2\sqrt{3}} & \frac{\sqrt{5}}{3} & -\frac{1}{3\sqrt{2}} & \frac{1}{\sqrt{6}} \\ \sqrt{\frac{3}{10}} & -\sqrt{\frac{3}{10}} & \frac{1}{6\sqrt{5}} & \frac{1}{2\sqrt{3}} & \frac{2}{3\sqrt{5}} & -\frac{1}{3\sqrt{2}} & -\frac{1}{\sqrt{6}} \\ \frac{1}{\sqrt{5}} & \frac{1}{\sqrt{5}} & \sqrt{\frac{2}{15}} & 0 & \sqrt{\frac{2}{15}} & \frac{1}{\sqrt{3}} & 0 \\ -\frac{\sqrt{\frac{3}{5}}}{2} & \frac{\sqrt{\frac{3}{5}}}{2} & -\frac{1}{\sqrt{10}} & \frac{1}{\sqrt{6}} & \frac{1}{\sqrt{10}} & 0 & -\frac{1}{\sqrt{3}} \\ -\sqrt{\frac{3}{10}} & -\sqrt{\frac{3}{10}} & \frac{2}{3\sqrt{5}} & 0 & \frac{2}{3\sqrt{5}} & \frac{\sqrt{2}}{3} & 0 \\ -\frac{1}{2\sqrt{5}} & \frac{1}{2\sqrt{5}} & 2\sqrt{\frac{2}{15}} & 0 & \frac{1}{\sqrt{30}} & -\frac{1}{\sqrt{3}} & 0 \end{pmatrix} \begin{pmatrix} \langle 8||\bar{6}_1||\bar{3}\rangle \\ \langle 8||15_1||\bar{3}\rangle \\ \langle 27||\overline{24}_1||\bar{3}\rangle \\ \langle 27||\overline{24}_2||\bar{3}\rangle \\ \langle 27||15_1||\bar{3}\rangle \\ \langle 27||42_1||\bar{3}\rangle \\ \langle 27||42_2||\bar{3}\rangle \end{pmatrix}$$

decay amplitudes

Clebsch-Gordon coefficients

reduced matrix elements

$$\begin{pmatrix} \mathcal{A}(D_s^+ \to \pi^+\eta_1) \\ \mathcal{A}(D^0 \to \bar{K}^0\eta_1) \end{pmatrix} = \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \end{pmatrix} \begin{pmatrix} \langle 8'||\bar{6}_1||\bar{3}\rangle \\ \langle 8'||15_1||\bar{3}\rangle \end{pmatrix}$$

singlet-octet final state different from octet-octet final state

Now you are ready to do some serious fitting…!!

$\eta - \eta'$ mixing

- ✓ Complete set of measurements of branching fraction available.
- ✓ The mixing angle is well measured.
- ✓ Previously left unconsidered in analyses based on the complete SU(3) framework.
- ✓ The singlet-octet mixing is a consequence of broken SU(3)
- ✓ There are convincing theoretical arguments and experimental hints that the states have not only quark content but also a gluonic component.

$$\begin{pmatrix} \eta \\ \eta' \end{pmatrix} = \begin{pmatrix} -\cos\theta & +\sin\theta \\ -\sin\theta & -\cos\theta \end{pmatrix} \begin{pmatrix} \eta_8 \\ \eta_1 \end{pmatrix}$$

C. Di Donato et al., Phys. Rev. D **85**, 013016 (2012).

S. V. Donskov, V. N. Kolosov, A. A. Lednev, Yu. V. Mikhailov, V. A. Polyakov, V. D. Samoylenko, G. V. Khaustov, IHEP 2012-22, arXiv:1301.6987

in the limit of SU(3) conservation

$$\mathcal{H} = \frac{V_{cd}^* V_{us}}{\sqrt{2}} \mathcal{H}_0^6 + \frac{(V_{cd}^* V_{ud} - V_{cs}^* V_{us})}{2} \mathcal{H}_{1/2}^6 - \frac{V_{cs}^* V_{ud}}{\sqrt{2}} \mathcal{H}_1^6 - \frac{(V_{cd}^* V_{ud} - 3V_{cs}^* V_{us})}{2\sqrt{6}} \mathcal{H}_{1/2}^{15} + \frac{(V_{cd}^* V_{us} + V_{cs}^* V_{ud})}{\sqrt{2}} \mathcal{H}_1^{15} + \frac{V_{cd}^* V_{ud}}{\sqrt{3}} \mathcal{H}_{3/2}^{15}$$

Grinstein-Lebed Relations

$$\frac{\langle f||6_{I=1/2}||i\rangle}{\langle f||6_{I=0}||i\rangle} = \frac{V_{cd}^* V_{ud} - V_{cs}^* V_{us}}{\sqrt{2} V_{cd}^* V_{us}}, \quad \frac{\langle f||6_{I=1}||i\rangle}{\langle f||6_{I=0}||i\rangle} = -\frac{V_{cs}^* V_{ud}}{V_{cd}^* V_{us}}$$

$$\frac{\langle f||6_{I=1}||i\rangle}{\langle f||6_{I=1/2}||i\rangle} = -\frac{\sqrt{2} V_{cs}^* V_{ud}}{V_{cd}^* V_{ud} - V_{cs}^* V_{us}}, \quad \frac{\langle f||15_{I=1}||i\rangle}{\langle f||15_{I=1/2}||i\rangle} = -\frac{2\sqrt{3}(V_{cs}^* V_{ud} + V_{cd}^* V_{us})}{V_{cd}^* V_{ud} - 3V_{cs}^* V_{us}}$$

$$\frac{\langle f||15_{I=3/2}||i\rangle}{\langle f||15_{I=1/2}||i\rangle} = -\frac{2\sqrt{2} V_{cd}^* V_{ud}}{V_{cd}^* V_{ud} - 3V_{cs}^* V_{us}}, \quad \frac{\langle f||15_{I=3/2}||i\rangle}{\langle f||15_{I=1}||i\rangle} = \sqrt{\frac{2}{3}} \frac{V_{cd}^* V_{ud}}{V_{cs}^* V_{ud} + V_{cd}^* V_{us}}$$

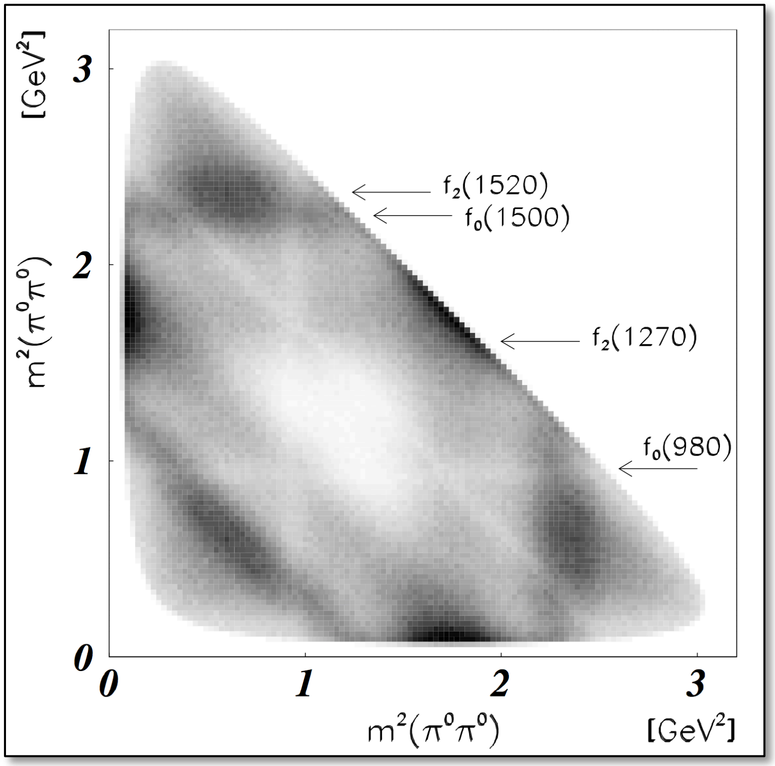
"The ratios of pieces of the Hamiltonian of the same representation are independent of isospin and depend only on the Clebsch-Gordon coefficients and CKM elements for a fixed pair of initial and final state representations."

the SU(3) framework for hadronic decays

- ✓ The SU(3) framework requires that the hadronic final states be identified and there be no variation in the reduced matrix elements due to just the final states. (FSI?)
- ✓ Not making this assumption renders the SU(3) framework completely useless.
- ✓ Identifying the charm meson as a triplet of SU(3) and the pseudoscalars as an octet of SU(3) allows for the set up of the SU(3) framework
- ✓ However, the strength of the SU(3) framework like in its dynamical constructions, i.e. , the Hamiltonian.
- ✓ While we know how to deal with the weak part of the Hamiltonian, we depend solely on motivated arguments and data for the QCD part.

Reinventing the past…
or
Building the future…

A Ghost from the Past.



A $\bar{p}p \longrightarrow 3\pi^0$ Dalitz plot from the Crystal Barrel.

Dalitz analysis is a powerful tool to extract resonances and separating weak and strong phases.

Both model dependent and model independent analysis possible.

Production asymmetries do not matter.

Ideal for CPV studies.

The les Nabis* Project:

A consortium of theorists and experimentalist set up to specialize in Dalitz plot analyses.

The talisman, Paul Serusier, 1888

* les Nabis: 'The Prophets' who defined French art in the 1890s.

Three body problems.

$D^{\pm}_{(s)} \to h_1 h_2 h_3$

- Separation of weak and strong phase possible.

- CP asymmetry does not depend on relative production of CP conjugate states.

$D^0/\bar{D}^0 \to K_S K^+ K^-$ $D^0/\bar{D}^0 \to K_S \pi\pi$

- Possible intervention of ND.

- SM cannot generate direct CP violation.

✓ 2D Dalitz Plot analysis needs to be done.
✓ CP asymmetry does not depend on relative production of CP conjugate states.
✓ More data necessary but more information can be gleaned.

Four body problems.

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

- ✓ Time dependent CP analysis can be done.
- ✓ T odd correlation can be probed.
- × Theoretically more challenging.

$D^\pm \to K_S K^\pm l^+ l^-$: CP violation from FSI, none from ND.

$D^\pm \to K_S \pi^\pm l^+ l^-$ $\quad \frac{\Gamma(D^+ \to K_S\pi^+) - \Gamma(D^- \to K_S\pi^-)}{\Gamma(D^+ \to K_S\pi^+) + \Gamma(D^- \to K_S\pi^-)} \simeq 2\mathrm{Re}(\epsilon_K) \simeq 3.3 \times 10^{-3}$

- ✓ CA mode, CP violation possible within SM through interference with DCSD.
- ✓ ND contribution possible.
- ✓ T odd correlation can be probed.

I. I. Bigi and A. Paul, *On CP Asymmetries in Two-, Three- and Four-Body D Decays*, JHEP**03** (2012) 021. [arXiv:1110.2862].

L. Cappiello, O. Cata and G. D'Ambrosio, *Standard Model prediction and new physics tests for $D^0 \to h^+h^-l^+l^-(h = \pi, K : l = e, \mu)$*. [arXiv:1209.4235].

Four body problems.

$$\boldsymbol{D_L \to h^+h^-l^+l^-}$$

$$D_L \xrightarrow{\not{CP}} h^+h^- \xrightarrow{\text{IB}} h^+h^-\gamma \text{ and } D_L \xrightarrow{\text{M1,E1}} h^+h^-\gamma.$$

$$D_L \to h^+h^-\gamma^* \to h^+h^-l^+l^-$$

$\mathrm{BR}(D \to \pi^+\pi^-l^+l^-) \sim 10^{-9}$
$\mathrm{BR}(D \to K^+K^-l^+l^-) \sim 10^{-10} - 10^{-9}$

$$\frac{\mathrm{d}}{\mathrm{d}\Phi}\Gamma(D_L \to h^+h^-l^+l^-) = \Gamma_1 \cos^2\Phi + \Gamma_2 \sin^2\Phi + \Gamma_3 \cos\Phi \sin\Phi.$$

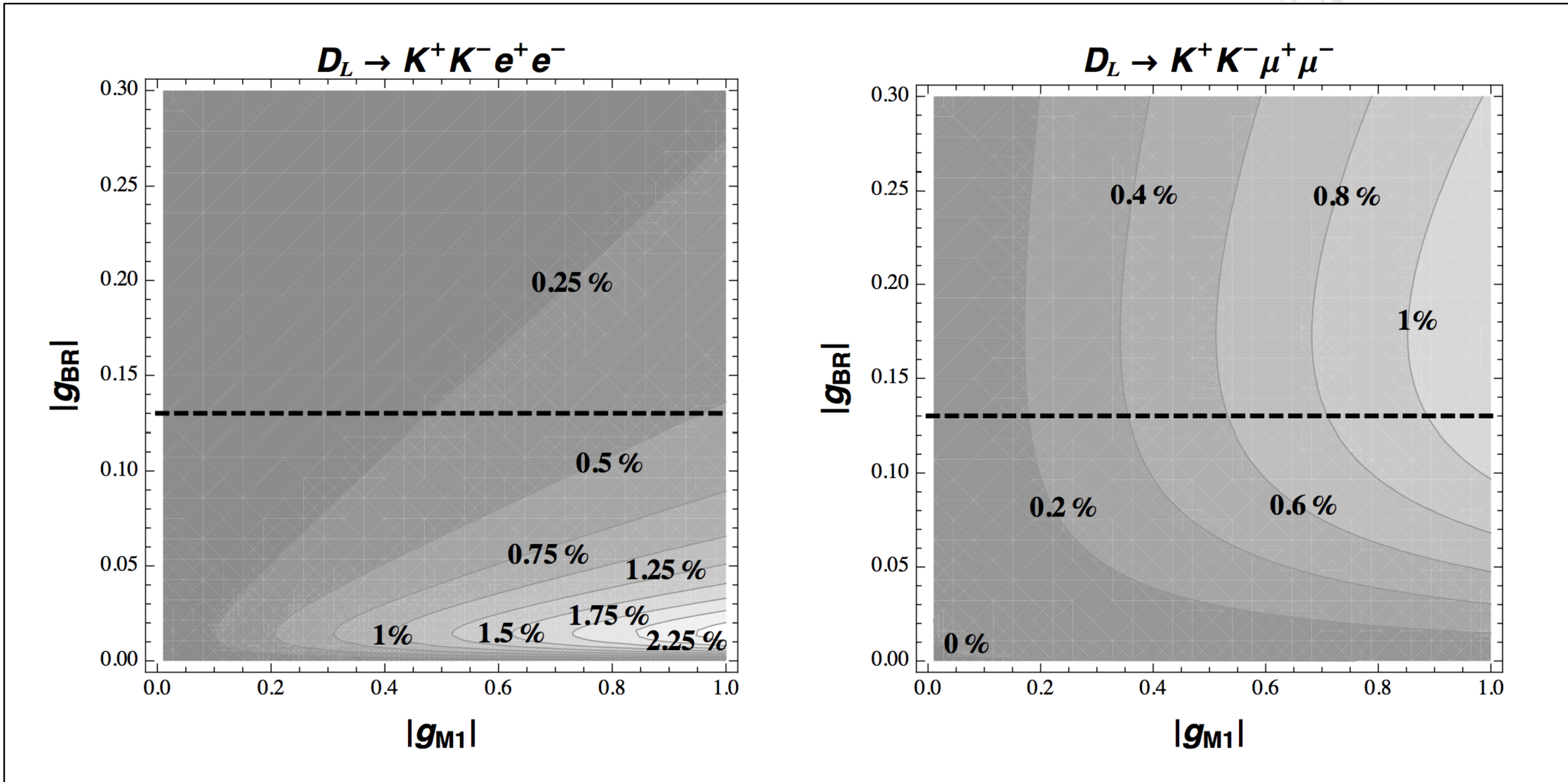
$$A_{\mathrm{T}}^{D} = \frac{\left[\left(\int_0^{\frac{\pi}{2}} + \int_{\pi}^{\frac{3\pi}{2}}\right) - \left(\int_{\frac{\pi}{2}}^{\pi} + \int_{\frac{3\pi}{2}}^{2\pi}\right)\right] \frac{d\Gamma}{d\Phi} d\Phi}{\int_0^{2\pi} \frac{d\Gamma}{d\Phi} d\Phi} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)}.$$

$$\eta_{h^+h^-}^{D(h)} \equiv \frac{\langle h^+h^-|H_W|D_L\rangle}{\langle h^+h^-|H_W|D_S\rangle} = \epsilon_D + \epsilon'_D, \quad \arg\left(\eta_{h^+h^-}^{D(h)}\right) \equiv \Phi_{\pm}^{D(h)}$$

$$K_L \to e^+e^-\pi^+\pi^-$$
$$A_{\mathrm{T}}|_{\text{theory}} = (14.3 \pm 1.3)\%$$
$$A_{\mathrm{T}}|_{exp} = (13.7 \pm 1.5)\%$$

L. M. Sehgal, M. Wanninger, *CP Violation in the Decay $K_L \to \pi^+\pi^-e^+e^-$*. Phys. Rev. **D 46** (1992) 1035; *Erratum:* Phys. Rev. **D 46** (1992) 5209.

CPV in 4 body modes



I. I. Bigi and A. Paul, *On CP Asymmetries in Two-, Three- and Four-Body D Decays*, JHEP**03** (2012) 021. [arXiv:1110.2862].

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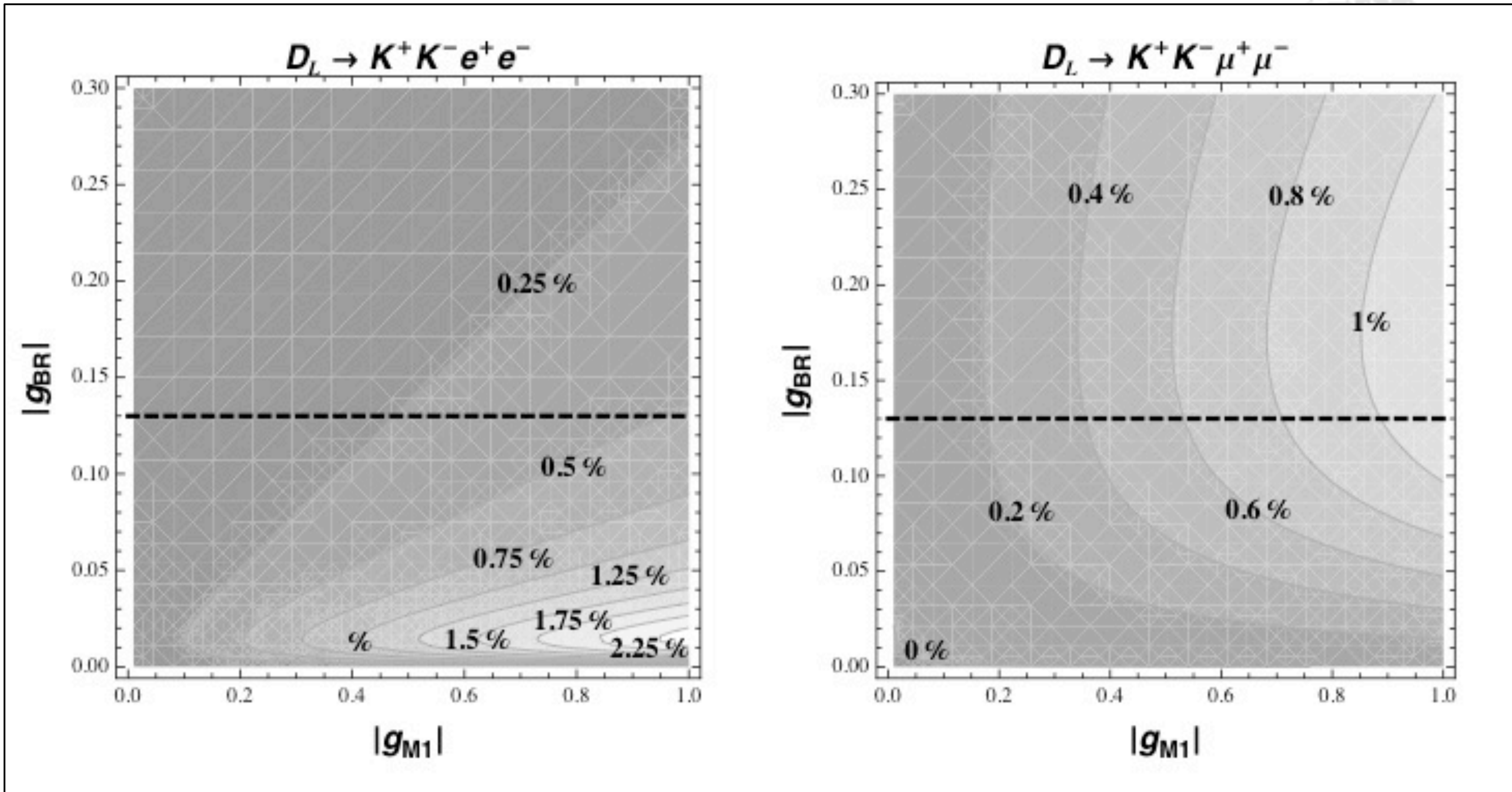
CPV in 4 body modes



Similar analysis for $D^0 \to K^+\pi^-l^+l^-$ vs. $\bar{D}^0 \to K^-\pi^+l^+l^-$

I. I. Bigi and A. Paul, *On CP Asymmetries in Two-, Three- and Four-Body D Decays*, JHEP**03** (2012) 021. [arXiv:1110.2862].

L. Cappiello, O. Cata and G. D'Ambrosio, *Standard Model prediction and new physics tests for* $D^0 \to h^+h^-l^+l^-(h = \pi, K : l = e, \mu)$. [arXiv:1209.4235].

Take Home Snacks

$$\delta(\varepsilon)$$

what we have produced in charm dynamics → δ

our understanding of charm dynamics → ε

THE PLAN

LHCb has to (and hopefully will) keep on pushing harder…

experiments in charm already has and will continue to question our understanding of nature…

at the theoretical end we need to come up with better technologies to understand QCD…

Charm Factory

$$e^+e^- \to \psi''(3770) \to D^0\bar{D}^0/D_+D_-/D_1D_2 \to f_a f_b$$

$$\mathrm{BR}(\psi''(3770) \to D^0\bar{D}^0/D_+D_-/D_1D_2 \to f_a f_b) \simeq$$
$$\mathrm{BR}(D \to f_a)\mathrm{BR}(D \to f_b) \times \left[(2 - x_D^2 + y_D^2)\left|\bar{\rho}(f_a) - \bar{\rho}(f_b)\right|^2 + (x_D^2 + y_D^2)\left|\frac{p}{q}\right|^2 \left|1 - \frac{q}{p}\bar{\rho}(f_a)\frac{q}{p}\bar{\rho}(f_b)\right|^2 \right]$$

- The meson pair is produced in a C odd P wave.
- EPR Correlations comes to the rescue.
- CP violation implied by mere existence of certain final states.
- Both direct and indirect CPV can be probed.
- Sensitivity to mass eigenstates?

Lessons from Charm

- ✓ **the Expected:**
  - ✓ To theorists, all models look promising (*even* the Standard Model).
  - ✓ FCNCs and CP Violation provides a good testing ground for these models.
  - ✓ SM has blessed (cursed) charm physics with tiny effects.
  - ✓ Any self-respecting ND should come in with a bang!

- ✓ **the Unexpected:**
  - ✓ We do not live in a theorists' world. (a.k.a. Nature does not care about us.)
  - ✓ Experimental constraints come in all flavours.
  - ✓ SM effects can be overcome but not overruled! "that's life"

- ✓ **the Gamble:**
  - ✓ Even theorists can be enterprising and innovative.
  - ✓ "Leave no stone unturned" is a "good policy"!

- ✓ **the Real Analysis or how to find a Bookworm:**
  - ✓ Probing with specific models can lead to model independent results too. Generalization is the only weapon theorists have against Nature's contempt for our favourite models!

Hence: **KEEP EXPERIMENTING**

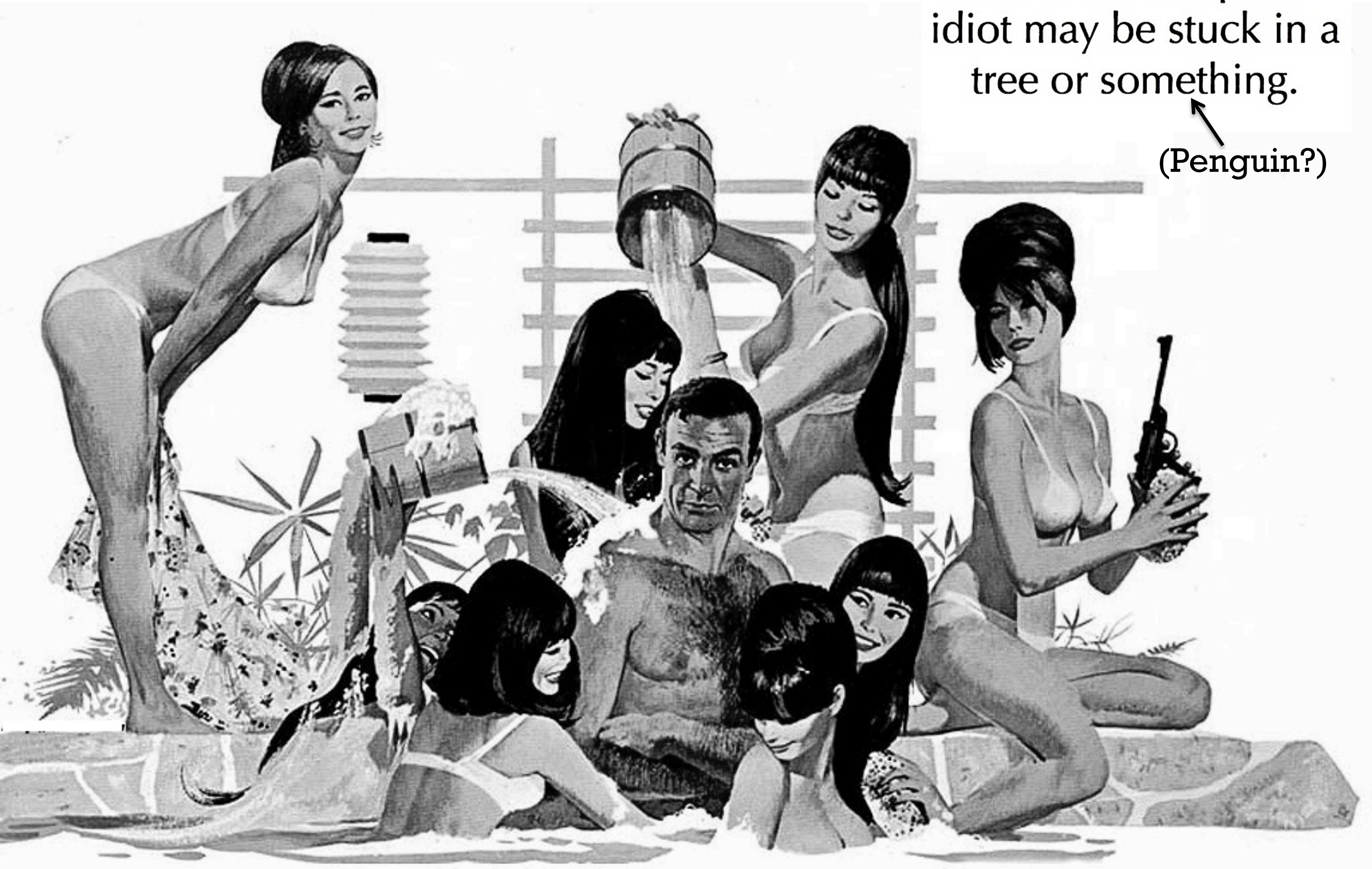
Ever tried. Ever failed. No matter.
Try again. Fail again. Fail better.

Samuel Beckett
Worstward Ho!

Theatric rendition of:
Waiting for Godot.
Samuel Beckett.

Stop waiting for Prince Charming. Get up and find him. The poor idiot may be stuck in a tree or something.

(Penguin?)



Thank you…!!

("… Best of Luck, you will need it!!")

To my Mother and Father, who showed me what I could do,

and to Ikaros, who showed me what I could not.

“To know what no one else does, what a pleasure it can be!”

– adopted from the words of

Eugene Wigner.