La fisica del flavor nell'era dell'Higgs

Ayan Paul

ERC Ideas: NPFlavour

INFN, Sezione di Roma. Roma, Italy.

Università di Roma - La Sapienza. Roma, Italy.

SAPIENZA
UNIVERSITÀ DI ROMA

XII IFAE, Cittadella Universitaria di Monserrato, Cagliari. 3 – 5 Aprile 2013.

A Higgs and the World of Flavour

Ayan Paul

ERC Ideas: NPFlavour

INFN, Sezione di Roma. Roma, Italy.

Università di Roma - La Sapienza. Roma, Italy.

SAPIENZA
UNIVERSITÀ DI ROMA

XII IFAE, Cittadella Universitaria di Monserrato, Cagliari. 3rd – 5th April 2013.

A Higgs and the World of Charm

Ayan Paul

ERC Ideas: NPFlavour

INFN, Sezione di Roma. Roma, Italy.

Università di Roma - La Sapienza. Roma, Italy.

SAPIENZA
UNIVERSITÀ DI ROMA

XII IFAE, Cittadella Universitaria di Monserrato, Cagliari. 3rd – 5th April 2013.

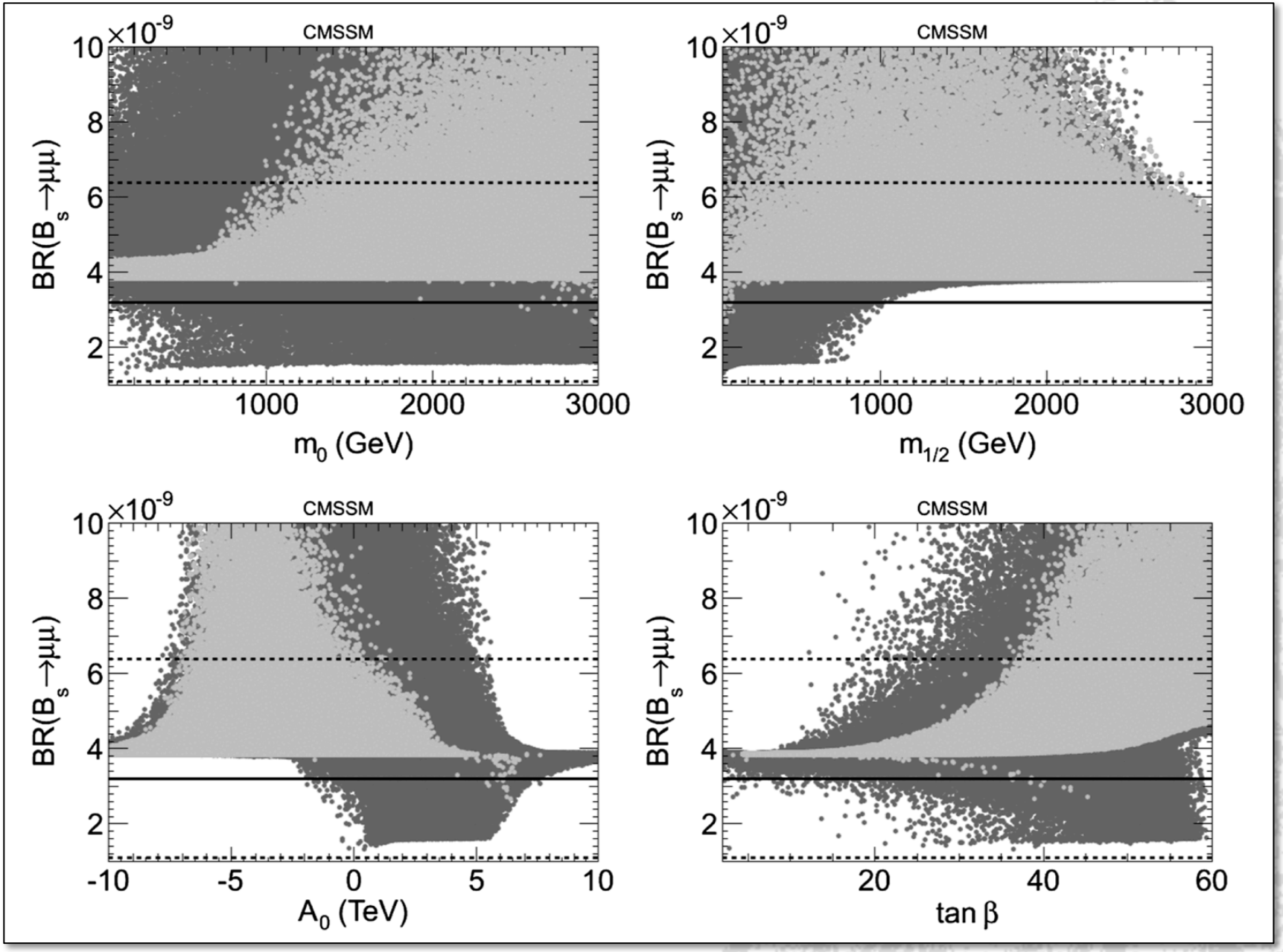
NEWS IN BRIEFS
The INDEPENDENT
EUREKA!
THE TIMES OF INDIA
Big bang moment: Scientists may finally have found 'God particle'
ARUBA DAILY
Eureka!
Physicists celebrate evidence of particle
Page 16
SVENSKA DAGBLADET
Cern har hittat spår av saknad partikel
Tampa Bay Times
Jutarnji LIST
gazeta WYBORCZA.PL
Cząstkę Higgsa fizycy najpierw wymyślili, potem szukali 40 lat
BOSKA MASA
EL PAÍS
Hallada "la más sólida evidencia" de la existencia del bosón de Higgs
UF physicists help find elusive particle
atomic key to reality
FILMOWY
MAGAZYN DO CZYTANIA

Higgs?

Yes…

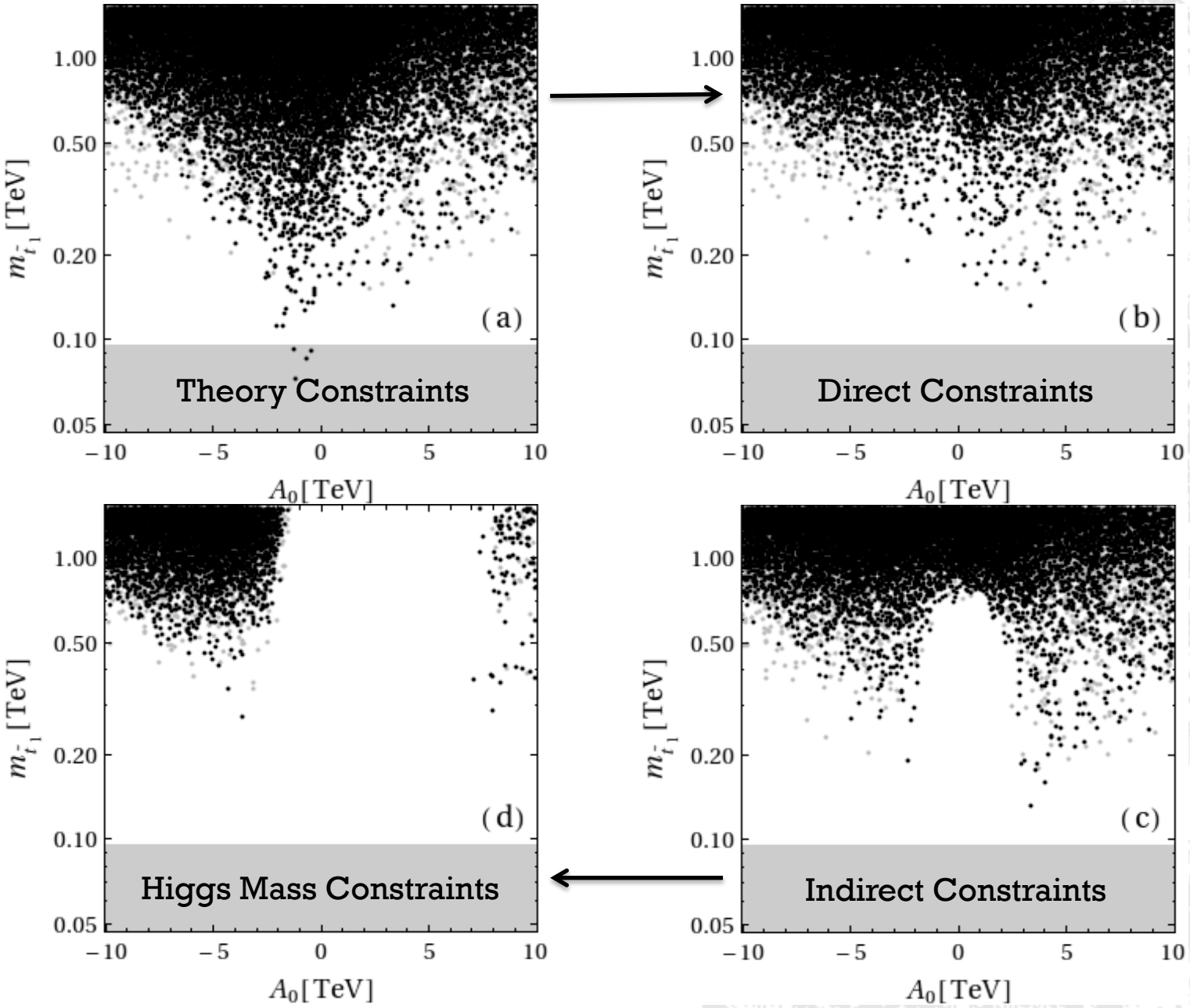
Now what…??

$B_s \to \mu^+\mu^-$ kills SUSY: Rumour Alert!



A. Arbey, M. Battaglia, F. Mahmoudi and D. M. Santos, arXiv:1212.4887

$B_s \to \mu^+\mu^-$ kills SUSY: Rumour Alert!



A. Dighe, D. Ghosh, K. M. Patel, and S. Raychaudhuri, "Testing Times for Supersymmetry: Looking Under the Lamp Post," arXiv:1303.0721 [hep-ph].

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

Ikaros I. Bigi

Why charm dynamics?

- ✓ The *ONLY* quark in the up quark sector that partakes in oscillations.
- ✓ The *ONLY* neutral meson system where direct CPV seems to 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.

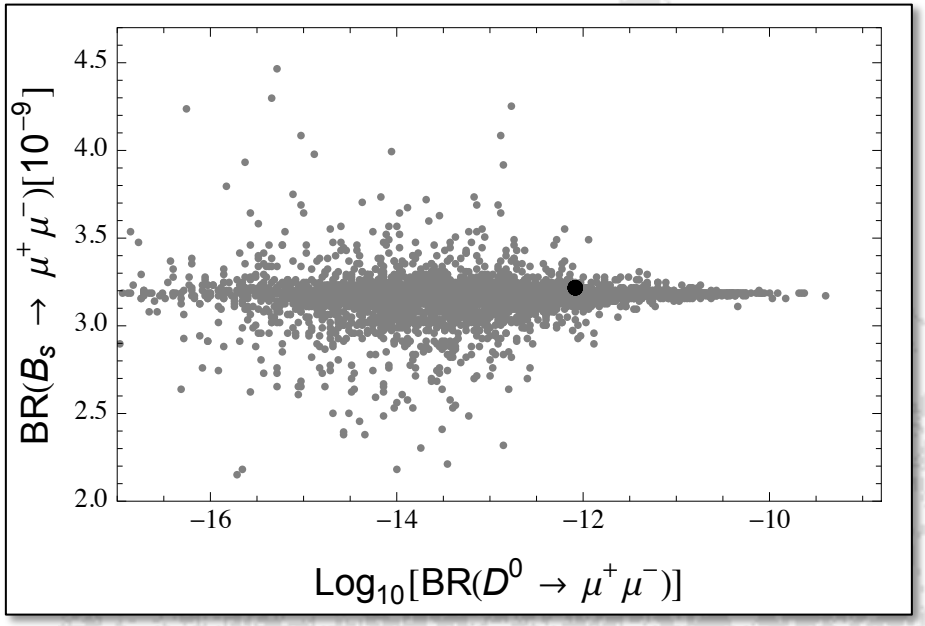
- o Charm is being produced in significantly large numbers, even in hadron machines: LHCb ~ 10^{13} charm pairs.
- o Extraction of charm signals from the background has significantly improved.
- o Beauty factories produce as much charm as beauty.
- o Dedicated charm threshold runs possible at super flavour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

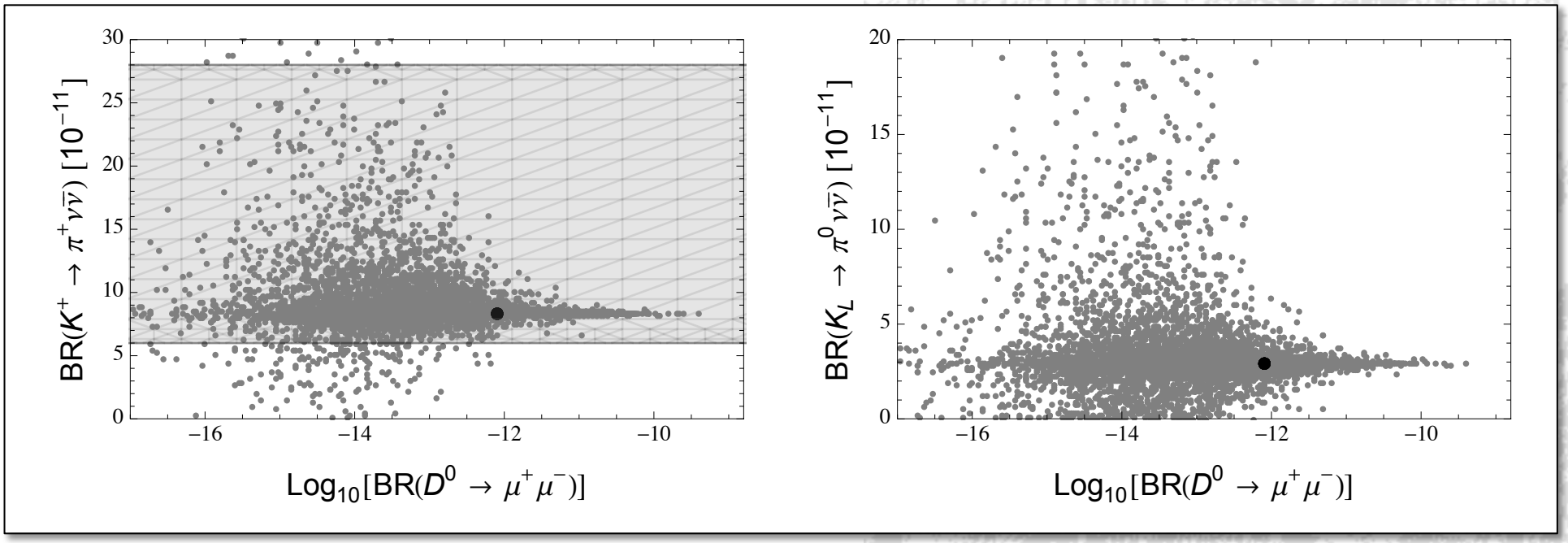
Why charm dynamics?

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].

Theoretical Hurdles

- All we can do is purturbation 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 does not work as it cannot consistently explain all decay channels (blame the SCS!)
- 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.

Non-Minimal Flavour Violation

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

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

minimal **non-minimal**

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 Changing Neutral Currents

OBSERVABLE	SM	ND Effects	EXPERIMENT
$\mathrm{BR}(D^0 \to \gamma\gamma)$	$(1-3)\times 10^{-8}$	SM LD Dominated	$< 2.4 \times 10^{-6}$
$\mathrm{BR}(D^0 \to \mu^+\mu^-)$	$(2.7-8)\times 10^{-13}$	$\sim \mathcal{O}(10^1) - \mathcal{O}(10^2) \Uparrow$	$< 1.3 \times 10^{-8}$
$\mathrm{BR}(D^\pm \to X_u l^+ l^-)$	$\sim \mathcal{O}(10^{-6})$	SM LD Dominated	$\sim \mathcal{O}(10^{-5})$
A_{FB}^c	$\sim 2 \times 10^{-6}$ †	$\sim \mathcal{O}(1\%)$	–
A_{CP}^c	$\sim 3 \times 10^{-4}$ †	$\sim \mathcal{O}(10\%) \Uparrow$	–
$A_{\mathrm{FB}}^{\mathrm{CP}}$	$\sim 3 \times 10^{-5}$ †	$\sim \mathcal{O}(10\%) - \mathcal{O}(100\%)$	–
$\mathrm{BR}(D \to X_u \nu\bar{\nu})$	$\sim \mathcal{O}(10^{-15}) - \mathcal{O}(10^{-16})$ †	$\mathcal{O}(10^3) - \mathcal{O}(10^4) \Uparrow$	–

†Estimates from our recent work on these decay channels.

A. Paul, I. I. Bigi and S. Recksiegel, *$D^0 \to \gamma\gamma$ and $D^0 \to \mu^+\mu^-$ rates on an unlikely impact of the littlest Higgs model with T parity*. Phys. Rev. **D 82** (2010) 094006. [arXiv:1008:3141].
A. Paul, I. I. Bigi and S. Recksiegel, *On $D \to X_u l^+ l^-$ within the Standard Model and Frameworks like the littlelest Higgs model with T Parity*. Phys. Rev. **D 83** (2011) 114006. [arXiv:1101.6053].
I. I. Bigi, A. Paul and S. Recksiegel, *Theoretical Conclusions from CDF Analyses of CP Violation in $D^0 \to \pi^+\pi^-, K^+K^-$ and Future Tasks*. JHEP**06** (2011) 089. [arXiv:1103.5785].

… and hadronic modes?

- x Factorization is not an option: corrections to factorization is too large.
- x FSI is very important: Input from rescattering data have to be implemented
- x SU(3) no longer holds as its breaking is of O(1).* However, one can continue to use SU(2) Isospin arguments.

So what can we expect?

- ✓ Only a downward fluctuation in the *central value* of ΔA_{CP} can bring it within reach of the SM. (even post-LHCb)
- ✓ An upward fluctuation of the *central value* will make an extremely strong case for New Dynamics. (even post-LHCb)
- ✓ A reduction of the error bars will increase the leaning towards New Dynamics, but life will remain complicated and it will not be business as usual.

* 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].

E. Franco, S. Mishima, A. Paul and L. Silvestrini, *Work in progress.*

Building on current Statistics.

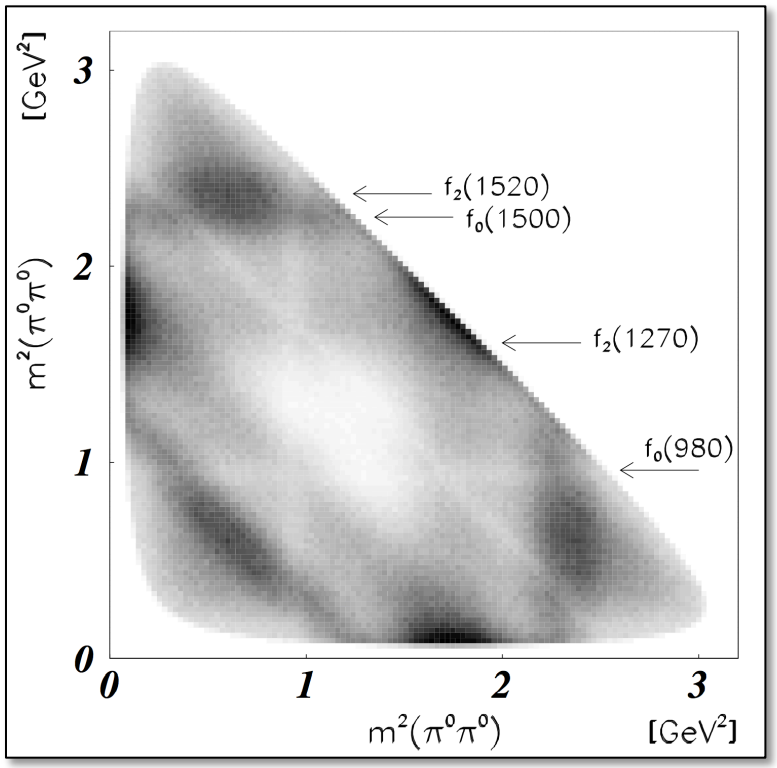
- Accessing charm dynamics was a challenge for one reason: Statistics.
- Recent bounty of statistics has enabled the study of not only rare decays but also high multiplicity final states.
- Since LHC is a *pp* collider, production asymmetries exist.
  Methods independent of production asymmetries become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

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

- Charm factories: Can they do better than the B factories?
  Super Tau-Charm Factory in Russia (BINP)
  Possibilities of one in Turkey.
  BES IV, V … etc.
  Can we *please* have one in Italy??

Reinventing the past…
or
Building the future…

A Ghost from the Past.



A $\bar{p}p \rightarrow 3\pi^0$ 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.

I. I. Bigi and A. Paul, *On CP Asymmetries in Two-, Three- and Four-Body D Decays.* **JHEP03** (2012) 021 [arXiv:1110.2862].

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.

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

$$D_L \xrightarrow{\cancel{CP}} h^+h^- \xrightarrow{\text{IB}} h^+h^-\gamma \text{ and } D_L \xrightarrow{\text{M1,E1}} h^+h^-\gamma$$

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

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

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

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

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

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

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.

Five body problems.

mamma mia...!!

basta...!!

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

Samuel Beckett
Worstward Ho!

Theatric rendition of:
Waiting for Godot.
Samuel Beckett.

We are all born mad.
Some remain so.*

Thank you…!!

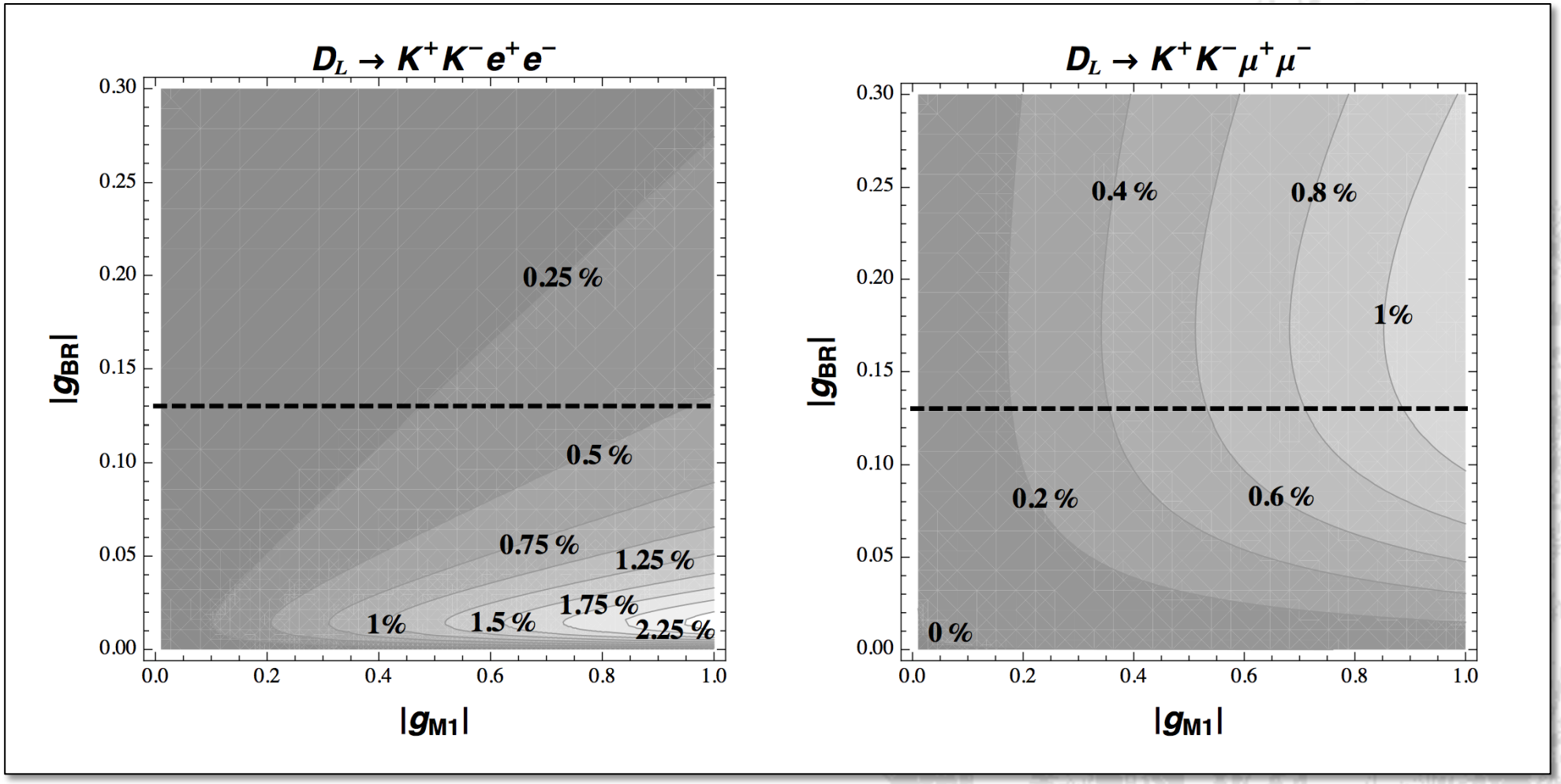
* Samuel Beckett. *Waiting for Godot.*

All I say cancels out. I'll have said nothing.*

* Samuel Beckett. *The Calmative.*

For the really curious…

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].

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].

The numbers we have

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

Oscillation have been observed:

$$x_D = \frac{\Delta M_D}{\Gamma_D} = \left(0.63^{+0.19}_{-0.20}\right)\% \quad , \quad y_D = \frac{\Delta\Gamma_D}{2\Gamma_D} = (0.75 \pm 0.12)\%$$

$$\left|\frac{q}{p}\right| = 0.88^{+0.18}_{-0.16} \quad , \quad \phi_D = \left(-10.1^{+9.5}_{-8.9}\right)^o .$$

$$x'^2 = (-0.9 \pm 1.3) \times 10^{-4}, \quad y' = (7.2 \pm 2.4) \times 10^{-3}, \quad R_D = (3.5 \pm 0.15) \times 10^{-3}.$$

$$\cancel{\text{CP invariance}} \rightarrow |q/p| \neq 1 \quad \phi_D \neq 0$$

The BABAR collaboration, B. Aubert et al., *Evidence for $D^0 - \bar{D}^0$ mixing*, Phys. Rev. Lett. **98** (2007) 211802. [hep-ex/0703020]

BELLE collaboration, M. Staric et al., *Evidence for $D^0 - \bar{D}^0$ mixing*, Phys. Rev. Lett. **98** (2007) 211803. [hep-ex/0703036]

BELLE collaboration, K. Abe et al., *Measurement of $D^0 - \bar{D}^0$ mixing in $D^0 \to K_s\pi^+\pi^-$ decays*, Phys. Rev. Lett. **99** (2007) 131803. [arXiv:0704.1000]

The LHCb Collaboration, *Observation of $D^0 - \bar{D}^0$ Oscillations,* [arXiv:1211.1230].

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.