Flavours of New Physics

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* Flavour physics beyond the Standard Model
  - motivations, EFT, flavour symmetry
  - NP scale from $\Delta F=2$ transitions
* Evidence for new physics (?)
  - CP asymmetries $A_{CP}(K\pi)$
  - D_s leptonic decays
  - B_s mixing phase $\varphi_s \neq -\beta_s$ and its implications
* Outlook: TeVatron, LHCb and SuperB

UTfit collaboration

Bologna – CERN - Genova – Orsay - Rome

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SUSY + A. Masiero
+ P. Paradisi

Thanks to everybody

Why flavour physics?

Indirect searches look for NP through the virtual effects of new particles in loop corrections

* SM flavour-changing neutral currents (FCNCs) and CP-violating processes occur at the loop level thus they potentially receive O(1) NP corrections

* SM quark FV and CPV are governed by the weak interactions and suppressed by the mixing angles

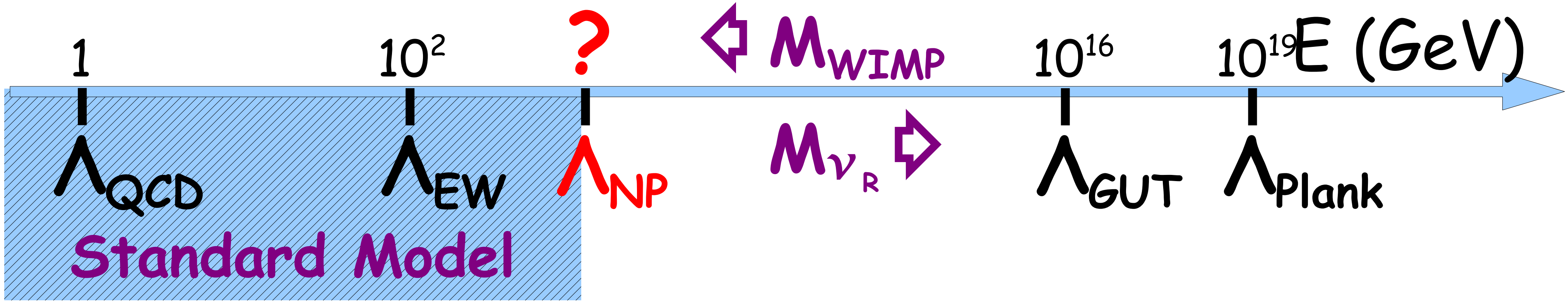
* SM has a single source of CPV (neglecting θ_{QCD})

NP not necessarily shares the SM pattern of FV and CPV: very large contributions are possible

Flavour physics confronts NP searches

The problem of today particle physics:

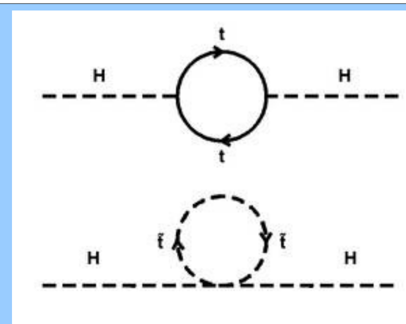
where is the NP scale Λ_{NP}? 0.5, 1, 10, 10^{13}, 10^{16} TeV?



The quantum stabilization of the weak scale suggests ≤ 1 TeV (naturalness argument)

$$m_H^2 \rightarrow m_H^2 + \delta m_H^2$$

$$\delta m_H^2 = \frac{3 G_F}{\sqrt{2}\pi^2} m_t^2 \Lambda_{NP}^2 \sim \left(0.3\,\Lambda_{NP}\right)^2$$



*** LHC searches in this range...**

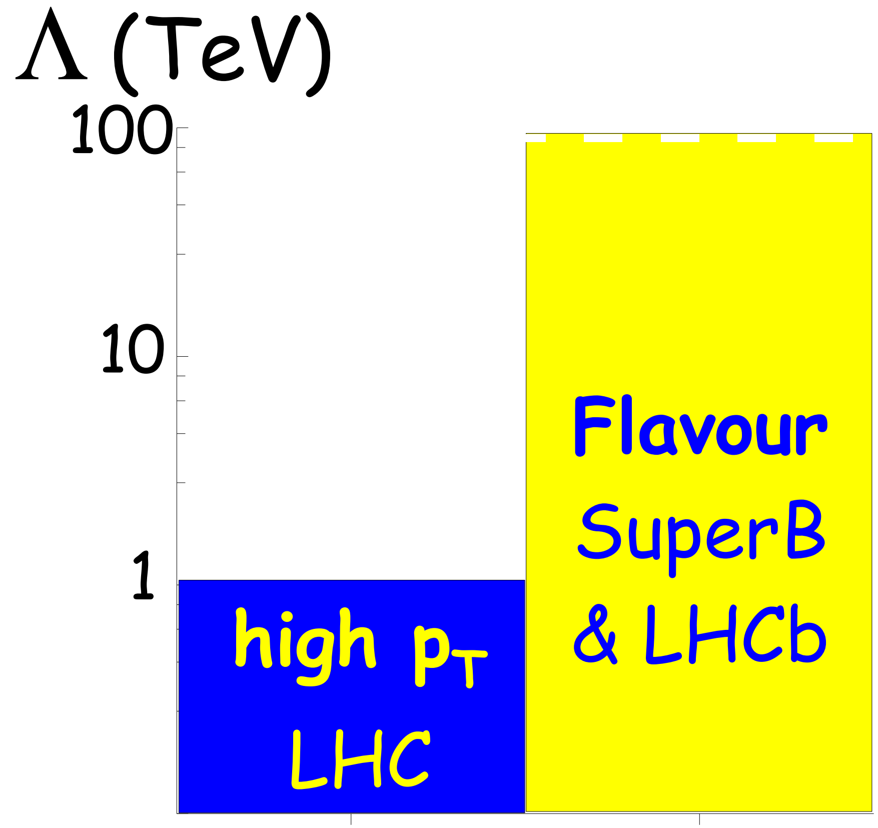
What if the scale is just above 1 TeV, say in the 1-100 TeV range?

naturalness is not at loss yet

(redefining tolerance to fine tuning)

The bright side of the "flavour problem":

flavour physics can probe NP scales beyond the LHC reach



MSSM@LHC: reconstructing the Lagrangian

Parameters	MSSM		SM	
gauge+Higgs	14		6	
masses	30	(36)	9	(12)
mixing angles	39	(54)	3	(6)
phases	41	(56)	1	(2)
Total	124	(160)	19	(26)

SM parameters match: FC vs FV&CPV 17-9

MSSM parameters match: FC vs FV&CPV 50-110

* fast increase of the # of FV&CPV parameters

* FV&CPV are related to basic properties of the NP Lagrangian (e.g. SUSY breaking in the MSSM)

EFT approach to New Flavour Physics a game of scale and couplings

$$\mathscr{L}_{eff} = \mathscr{L}_{SM} + \sum_{k=1} \left(\sum_i C_i^k \, Q_i^{(k+4)} \right) / \Lambda^k$$

NP flavour effects are governed by two players:

i) **the value of the new physics scale Λ**

ii) **the effective flavour-violating couplings C's**

In explict models:

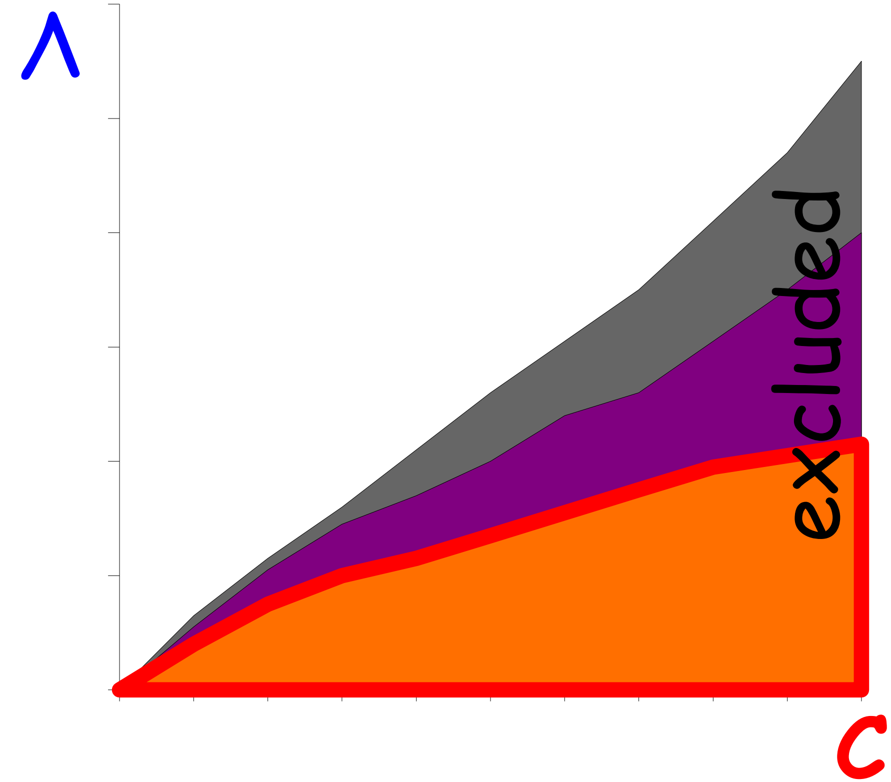
Λ ~ mass of virtual particles (Fermi th.: M_W)

C ~ loop coupling × flavour coupling

(SM/MFV: α_w × CKM)

Pictorially :

- exp. constraints give a bound on Λ for any given C and vice-versa
- curves correspond to different model classes



Let's see what we know today about the NP scale making different assumptions for the FV couplings

New physics in $\Delta F=2$ processes

New Physics in the mixing amplitudes

1. find out how much room is left for NP in $\Delta F=2$ transitions
   - add most general NP to all sectors
   - use all available experimental info
   - fit simultaneously for the CKM and the NP parameters (generalized UT fit)
2. perform an EFT analysis to put bounds on the NP scale
   - consider different choices of the FV and CPV couplings

UTfit collaboration
hep-ph/0509219, arXiv:0707.0636

1. parameterization of NP contributions to the mixing amplitudes

K mixing amplitude (2 real parameter):

$$\mathrm{Re}\,A_K = C_{\Delta m_K}\,\mathrm{Re}\,A_K^{SM} \qquad \mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$

B_d and B_s mixing amplitudes (2+2 real parameters):

$$A_q e^{2i\phi_q} = C_{B_q} e^{2i\phi_{B_q}} A_q^{SM} e^{2i\phi_q^{SM}} = \left(1 + \frac{A_q^{NP}}{A_q^{SM}} e^{2i(\phi_q^{NP} - \phi_q^{SM})}\right) A_q^{SM} e^{2i\phi_q^{SM}}$$

Observables:

$$\Delta m_{q/K} = C_{B_q/\Delta m_K} (\Delta m_{q/K})^{SM} \qquad \varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

$$A_{CP}^{B_d \to J/\psi K_S} = \sin 2(\beta + \phi_{B_d}) \qquad A_{CP}^{B_s \to \phi K_S} = \sin 2(-\beta_s + \phi_{B_s})$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right) \qquad \Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$

UT parameters in the presence of NP

Model-independent fit of the CKM parameters

(neglecting NP in tree decays)

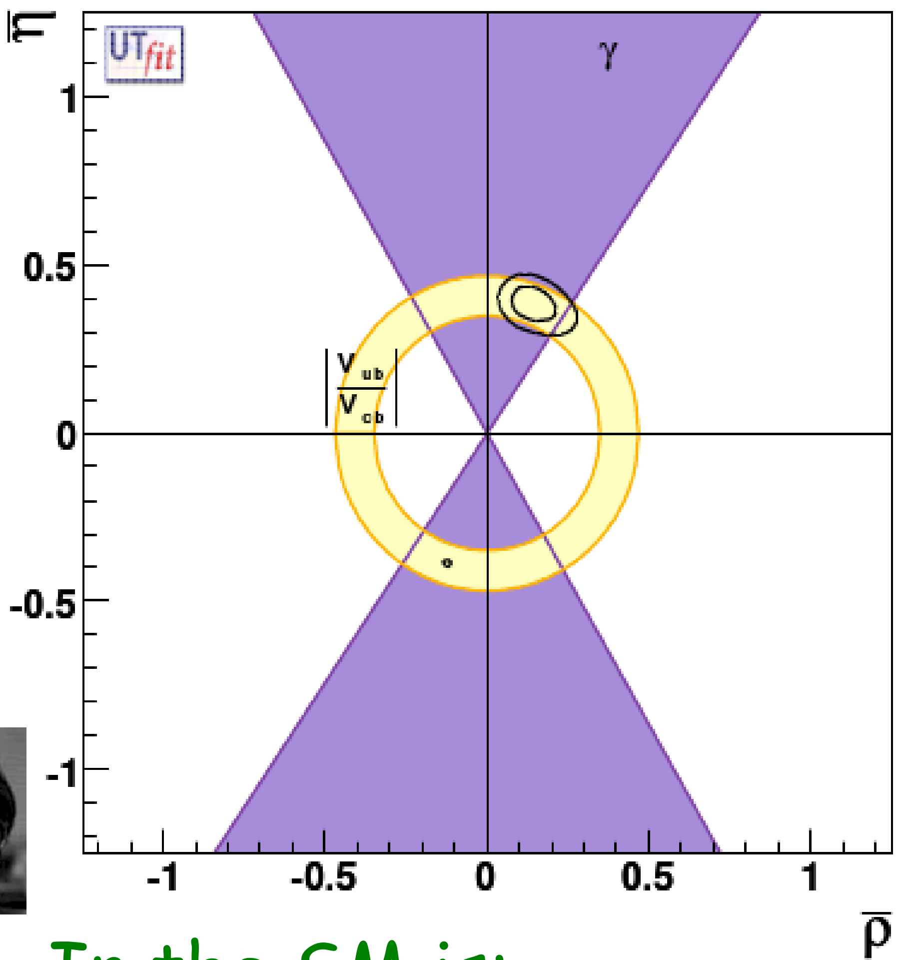
$$V_{CKM} = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2 & 1 \end{pmatrix}$$

$\lambda = 0.2258 \pm 0.0014$

$A = 0.804 \pm 0.001$

$\bar{\rho} = 0.140 \pm 0.046$

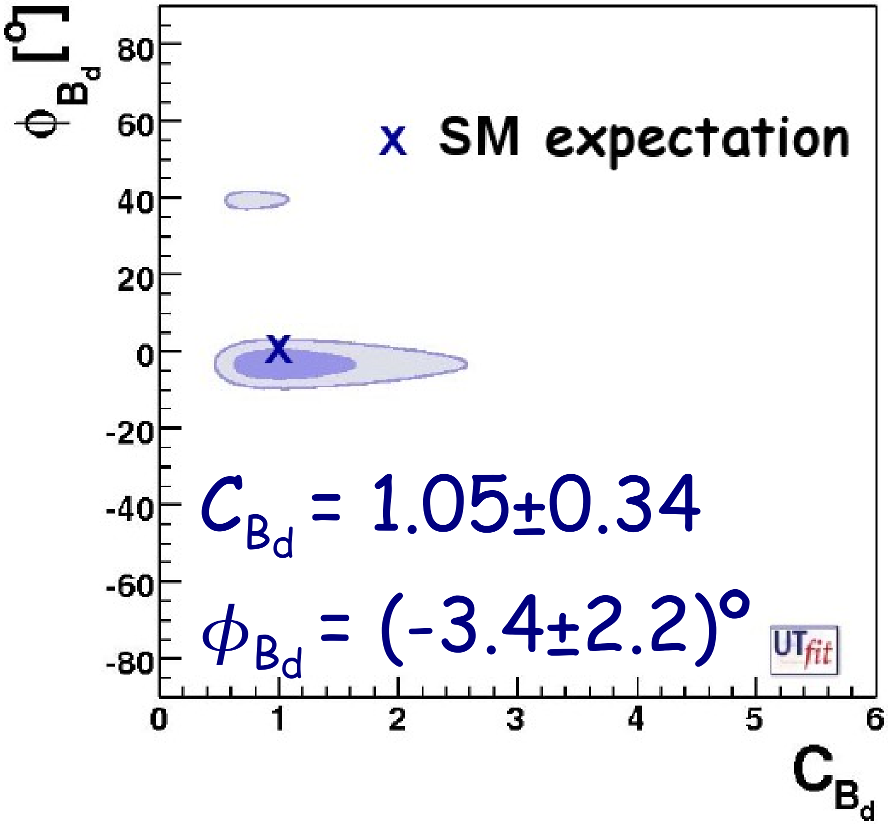
$\bar{\eta} = 0.384 \pm 0.035$

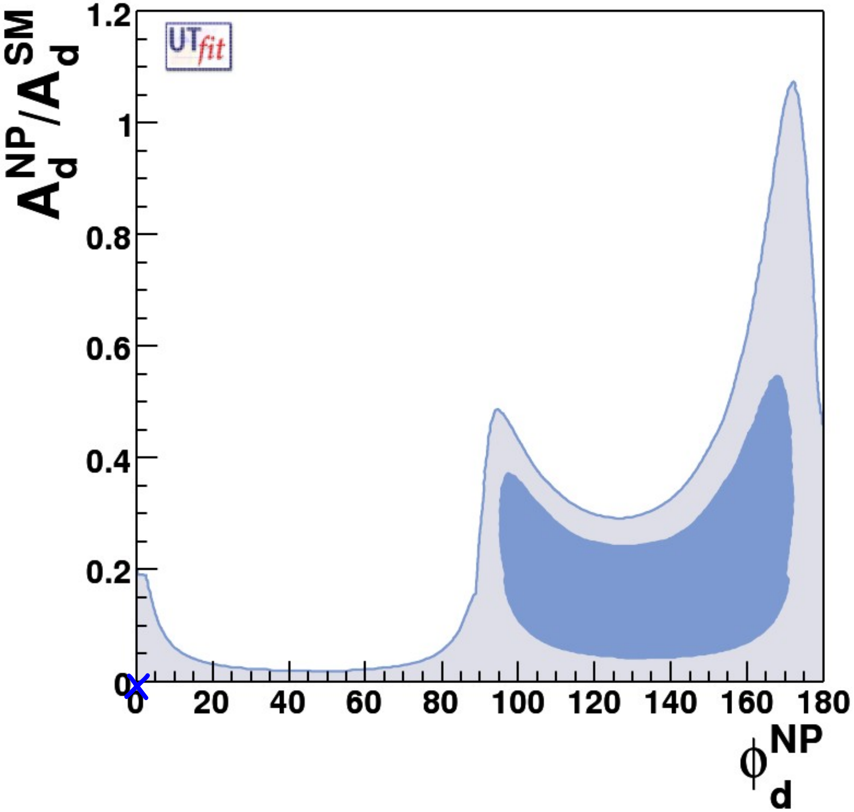


In the SM is:

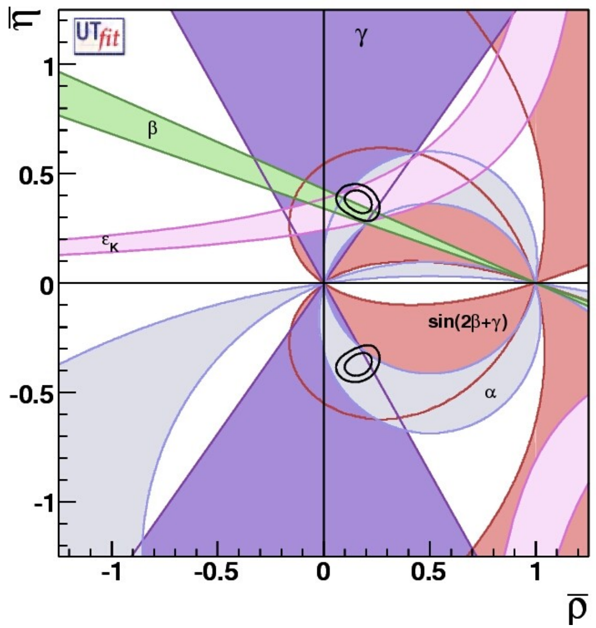
$\bar{\rho} = 0.147 \pm 0.029$

$\bar{\eta} = 0.342 \pm 0.012$





* the sin2β tension produces the 1.5σ effect of ϕ_{B_d} and the asymmetry in $(A^{NP}/A^{SM},\ \phi_d{}^{NP})$
* up to ~20% NP amplitude is allowed for generic NP phase



2. the ΔF=2 effective Hamiltonian

The mixing amplitudes $A_q e^{2i\phi_q} = \langle \bar{M}_q | H_{eff}^{\Delta F=2} | M_q \rangle$

$$H_{eff}^{\Delta B=2} = \sum_{i=1}^{5} C_i(\mu) Q_i(\mu) + \sum_{i=1}^{3} \tilde{C}_i(\mu) \tilde{Q}_i(\mu)$$

$$Q_1 = \bar{q}_L^\alpha \gamma_\mu b_L^\alpha \, \bar{q}_L^\beta \gamma^\mu b_L^\beta \qquad \text{(SM/MFV)}$$

$$Q_2 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_R^\beta b_L^\beta \qquad Q_3 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_R^\beta b_L^\beta$$

$$Q_4 = \bar{q}_R^\alpha b_L^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad Q_5 = \bar{q}_R^\alpha b_L^\beta \, \bar{q}_L^\beta b_R^\beta$$

$$\tilde{Q}_1 = \bar{q}_R^\alpha \gamma_\mu b_R^\alpha \, \bar{q}_R^\beta \gamma^\mu b_R^\beta$$

$$\tilde{Q}_2 = \bar{q}_L^\alpha b_R^\alpha \, \bar{q}_L^\beta b_R^\beta \qquad \tilde{Q}_3 = \bar{q}_L^\alpha b_R^\beta \, \bar{q}_L^\beta b_R^\beta$$

7 new operators beyond SM/CMFV involving quarks with different chiralities

H_{eff} can be recast in terms of the high-scale $C_i(\Lambda)$

- $C_i(\Lambda)$ can be extracted from the data (one by one)
- the associated NP scale Λ can be defined as

$$\Lambda = \sqrt{\frac{L F_i}{C_i(\Lambda)}}$$

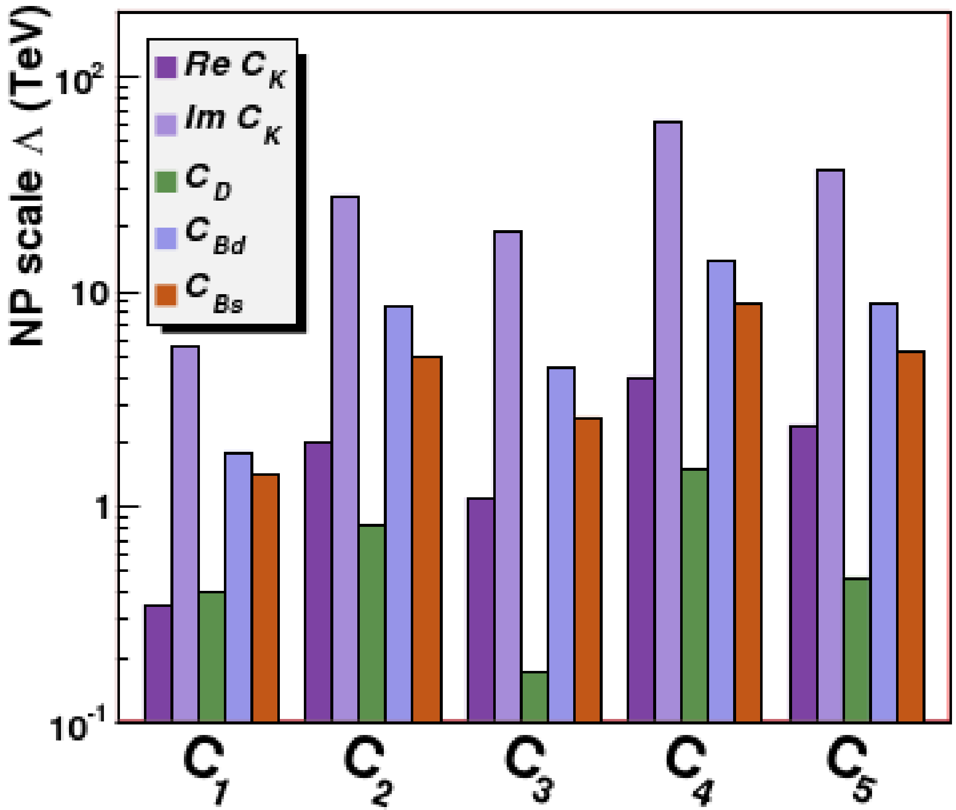
tree/strong interact. NP: $L \sim 1$

perturbative NP: $L \sim \alpha_s^2, \alpha_W^2$

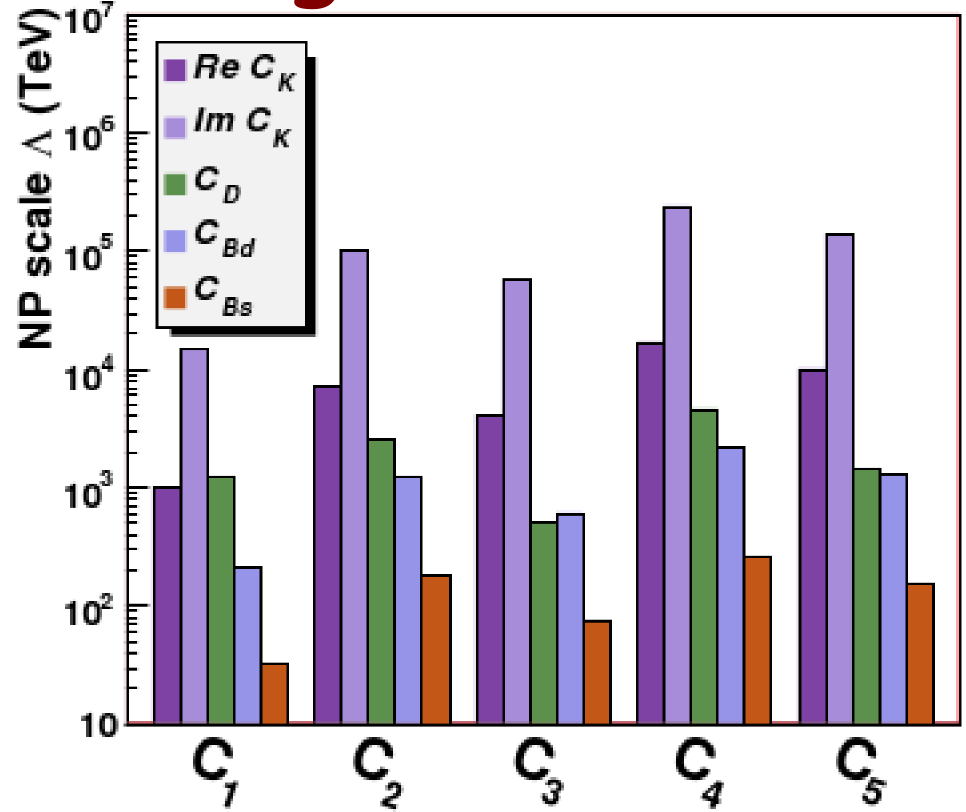
Flavour structures:

MFV	next-to-MFV	generic
- $F_1 = F_{SM} \sim (V_{tq} V_{tb}^*)^2$	- $\lvert F_i \rvert \sim F_{SM}$	- $\lvert F_i \rvert \sim 1$
- $F_{i \neq 1} = 0$	- arbitrary phases	- arbitrary phases

MFV



generic FV



Contributions of the ΔF=2 operators to the lower bound on the NP scale in the tree/strong interacting case

present lower bound on the NP scale (TeV @95%)

B + K

Scenario	strong/tree	α_s loop	α_W loop
MFV	5.5	0.5	0.2
NMFV	62	6.2	2
General	24000	2400	800

B only

strong/tree	α_s loop	α_W loop
–	–	–
14	1.4	0.4
2200	220	66

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scales
* when these operators are allowed, the NP scale is easily pushed beyond the LHC reach (manifestation of the flavour problem)
* suppression of the 1 <-> 2 transitions strongly weakens the lower bound on the NP scale

ΔF=2 processes occur at the loop level, thus could receive O(1) NP corrections but effects > ~20% are excluded

common misconception: this result points to MFV (or even establishes MFV)

if NP < 1 TeV

* suppression of flavour-violating couplings required in all sectors *possibly* pointing to MFV

* SUSY can stabilize the Fermi scale with "mild" fine-tuning

if 1< NP < 10-100 TeV

* suppression of flavour-violating couplings needed in sector 1-2 only. No indication of MFV

* SUSY can still stabilize the Fermi scale with "moderate" fine-tuning

Evidence for physics beyond the SM

Great potential of flavour physics to display large deviations from the Standard Model but not a single evidence in >20 years

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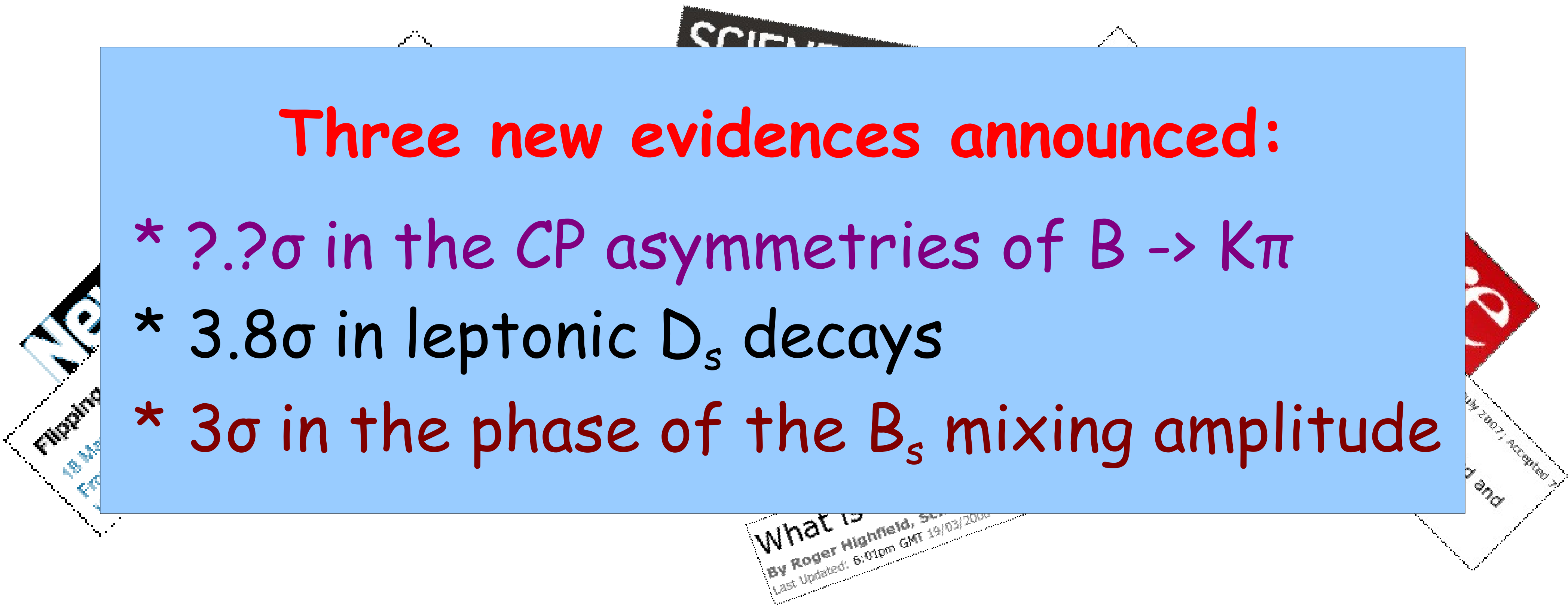


Three new evidences announced:

* ?.?σ in the CP asymmetries of B -> Kπ
* 3.8σ in leptonic D_s decays
* 3σ in the phase of the B_s mixing amplitude

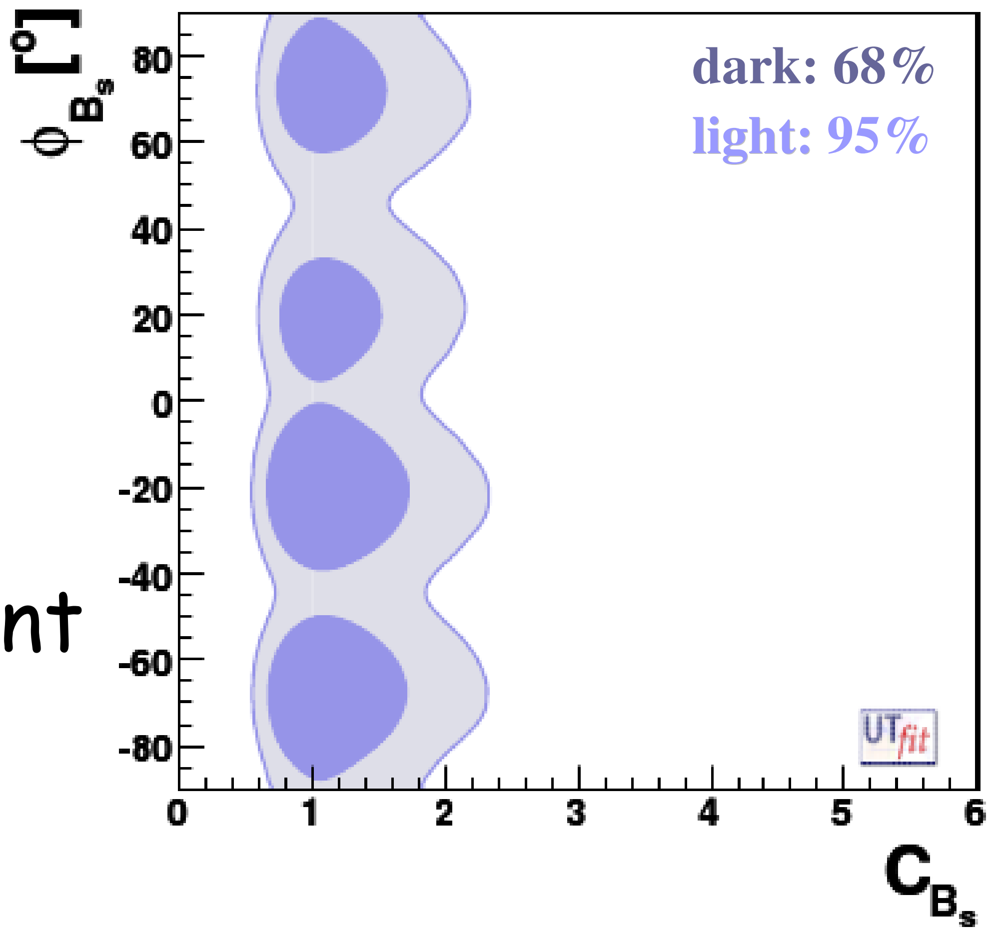
3. new physics in B_s mixing

the TeVatron realm

$C_{B_s} = 1.11 \pm 0.32$

$\phi_{B_s} = (-69\pm14)° \cup (-20\pm14)° \cup (20\pm5)° \cup (72\pm8)°$

- Δm_s
- $\tau_{B_s}^{FS} = \frac{1}{\Gamma_s} \frac{1+\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}{1-\left(\frac{\Delta\Gamma_s}{2\Gamma_s}\right)^2}$
- $A_{\rm SL}^s$
- $A_{\rm SL}^{\mu\mu} = \frac{f_d \chi_{d0} A_{\rm SL}^d + f_s \chi_{s0} A_{\rm SL}^s}{f_d \chi_{d0} + f_s \chi_{s0}}$
- $\Delta\Gamma_s$ and ϕ_s from the untagged time-dependent angular analysis of $B_s \to J/\Psi\ \phi$



Time-dependent angular analysis

TAGGED	UNTAGGED
2-fold ambiguity	4-fold ambiguity
($\pi-\phi$, $-\Delta\Gamma_s$, $\pi-\delta_{1,2}$)	($\pi+\phi$, $-\Delta\Gamma_s$, $\pm\delta_{1,2}$)
	($-\phi$, $\Delta\Gamma_s$, $\pm(\pi-\delta_{1,2})$)
$\phi = 2\phi_s$	($\pi-\phi$, $-\Delta\Gamma_s$, $\pm(\pi-\delta_{1,2})$)

Dunietz, Fleischer, Nierste
hep-ph/0012219

$$\frac{d^4\Gamma}{dt\,d\cos\theta\,d\varphi\,d\cos\psi} \propto$$
$$2\cos^2\psi(1-\sin^2\theta\cos^2\varphi)|A_0(t)|^2$$
$$+\sin^2\psi(1-\sin^2\theta\sin^2\varphi)|A_\parallel(t)|^2$$
$$+\sin^2\psi\sin^2\theta|A_\perp(t)|^2$$
$$+(1/\sqrt{2})\sin 2\psi\sin^2\theta\sin 2\varphi\,\mathrm{Re}(A_0^*(t)A_\parallel(t))$$
$$+\ (1/\sqrt{2})\sin 2\psi\sin 2\theta\cos\varphi\,\mathrm{Im}(A_0^*(t)A_\perp(t))$$
$$-\ \sin^2\psi\sin 2\theta\sin\varphi\,\mathrm{Im}(A_\parallel^*(t)A_\perp(t)).$$

$$|A_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\,t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\,t}{2} + \sin\phi\,\sin(\Delta m\,t)\right]$$

$$|\overline{A}_0(t)|^2 = |A_0(0)|^2 e^{-\Gamma t}\left[\cosh\frac{\Delta\Gamma\,t}{2} - |\cos\phi|\sinh\frac{|\Delta\Gamma|\,t}{2} - \sin\phi\,\sin(\Delta m\,t)\right]$$

$$\mathrm{Im}\{A_0^*(t)A_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[\sin\delta_2\,\cos(\Delta m\,t) - \cos\delta_2\,\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

$$\mathrm{Im}\{\overline{A}_0^*(t)\overline{A}_\perp(t)\} = |A_0(0)|\,|A_\perp(0)|\,e^{-\Gamma t}$$
$$\times\left[-\sin\delta_2\,\cos(\Delta m\,t) + \cos\delta_2\,\cos\phi\,\sin(\Delta m\,t) - \cos\delta_2\,\sin\phi\,\sinh\frac{\Delta\Gamma\,t}{2}\right]$$

Recently both CDF and DØ published the tagged time-dependent angular analysis of $B_s \to J/\Psi\ \phi$

2D likelihood ratio for $\Delta\Gamma$ and ϕ_s

2-fold ambiguity present, no assumption on the strong phases

arXiv:0712.2397

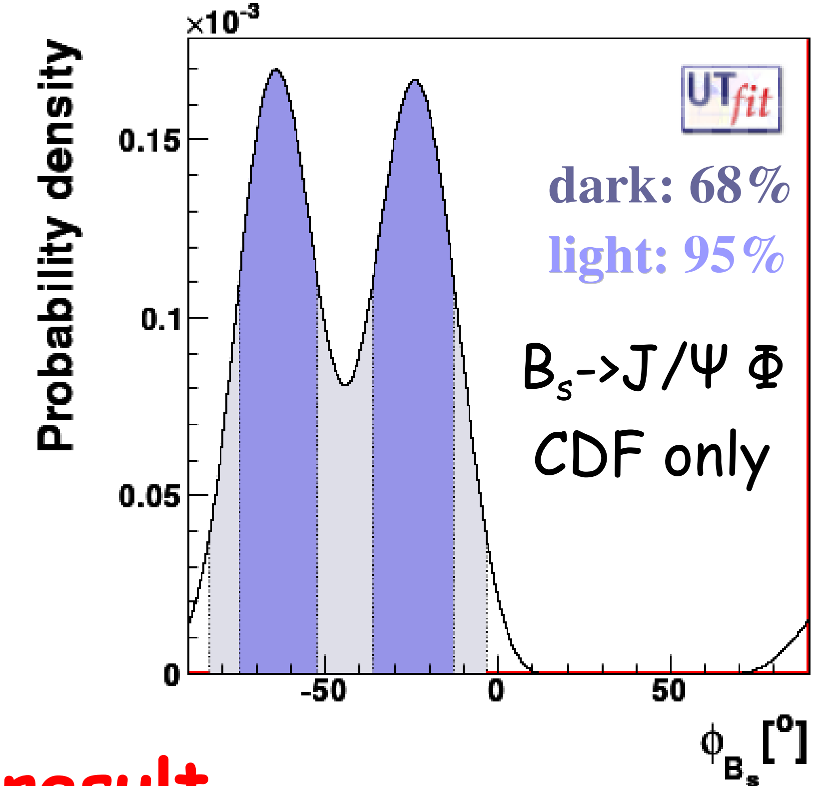
7-parameter fit + correlation matrix or 1D likelihood profiles of $\Delta\Gamma$ and ϕ_s

2-fold ambiguity removed using strong phases from $B \to J/\Psi\ K^*$ + SU(3) + ?

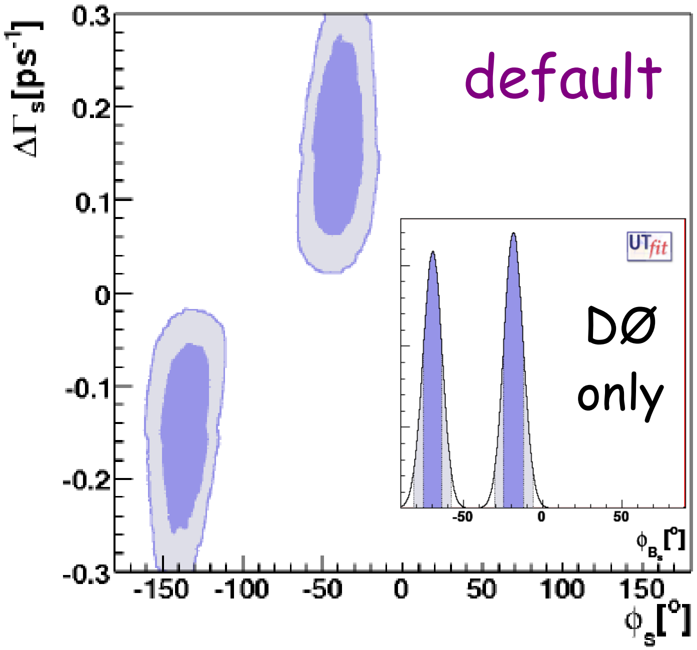
arXiv:0802.2255

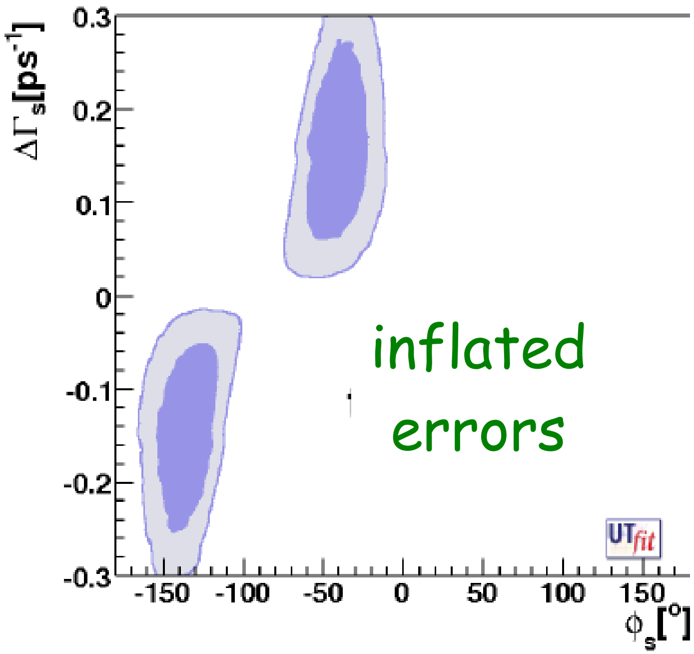
Combining the two measurements requires some gymnastic with the DØ results...

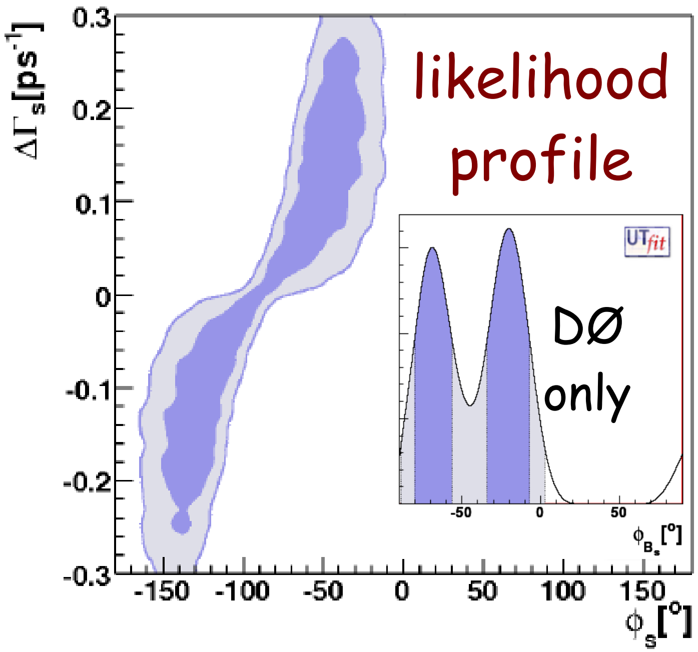
* <u>default</u>: CDF likelihood+Gaussian DØ result with 2x2 corr. matrix
* <u>inflated error</u>: as above, but with error inflated to reproduce the 2σ range computed by DØ
* <u>likelihood profile</u>: using the 1D likelihood profiles for ϕ_s and $\Delta\Gamma_s$

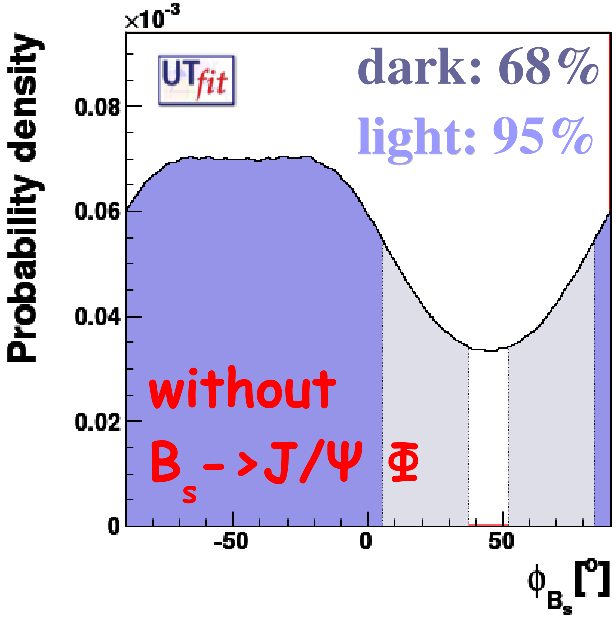


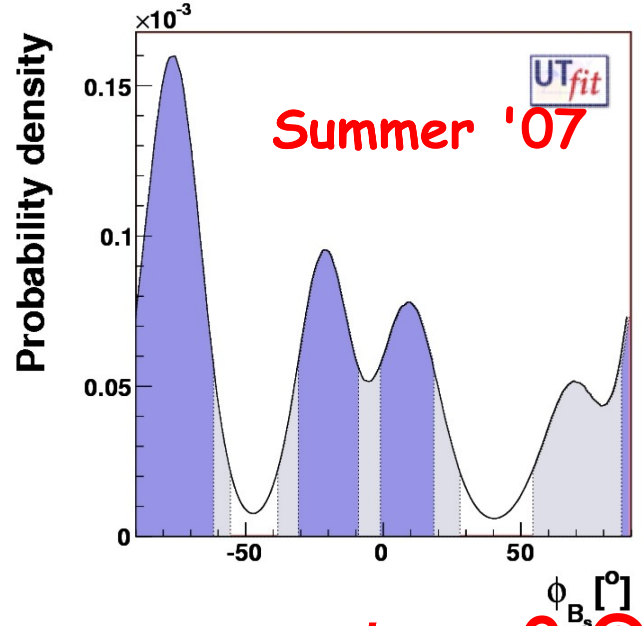
ambiguity reintroduced in the DØ result

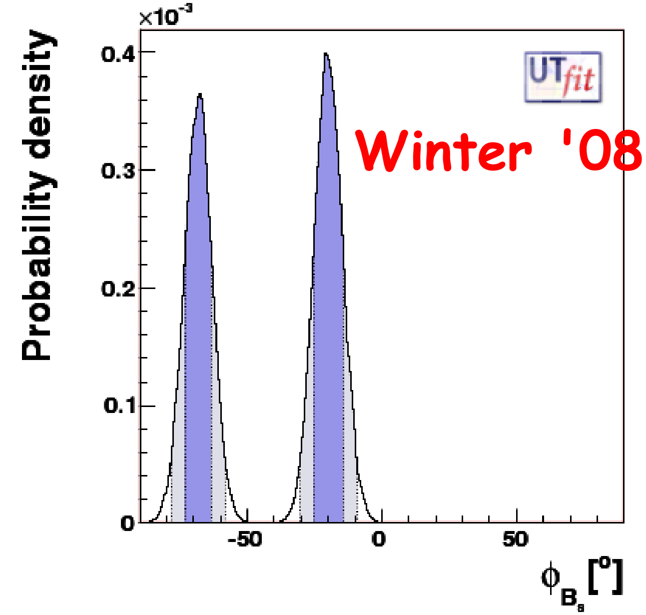




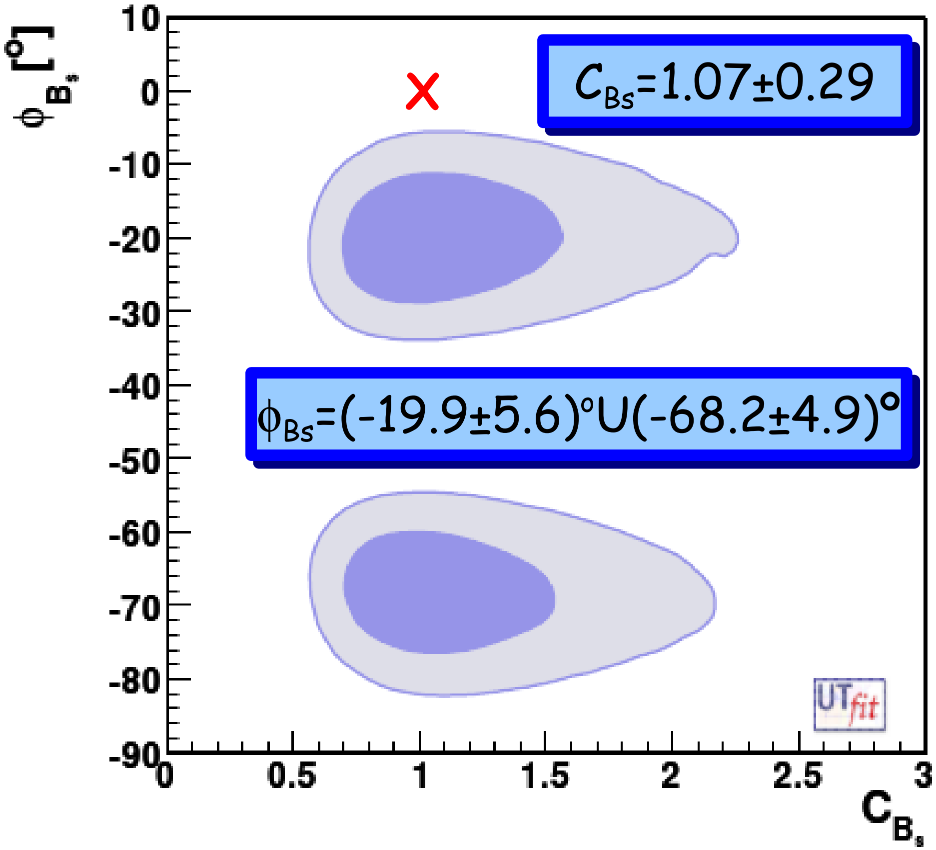




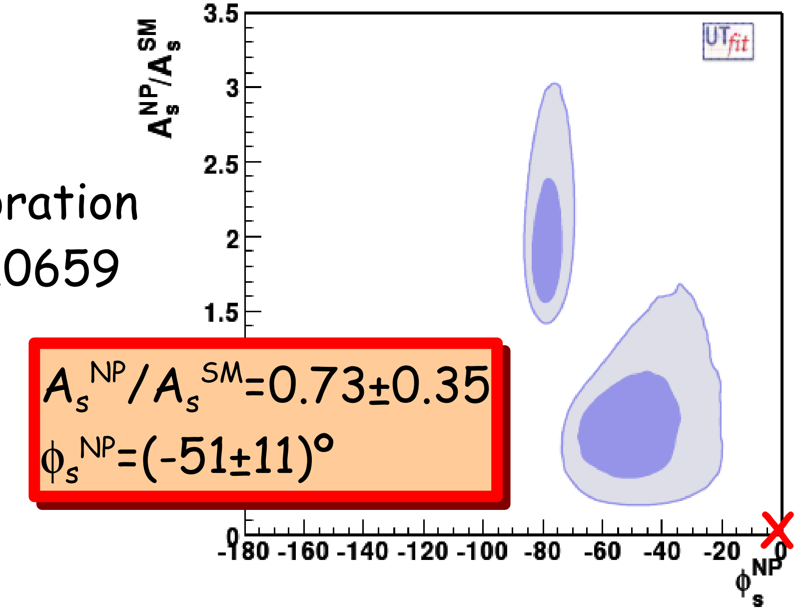




$\phi_{B_s} < 0$ @99.7% probability (equivalent to the Gaussian 3σ level) for any treatment of the DØ data



UTfit collaboration
arXiv:0803.0659



If this evidence is confirmed...

* MFV models are ruled out, including the simplest realizations of the MSSM
* the following pattern of flavour violation in NP emerges:

  1 <-> 2: strong suppression

  1 <-> 3: $\lesssim$ O(10%)

  2 <-> 3: O(1)

  this pattern is not unexpected in flavour models and in SUSY-GUTs
* In progress: (i) update of the $\Delta F=2$ operator analysis, (ii) correlations with $\Delta F=1$ in the MSSM

preliminary

Upper bound on the NP scale

In the presence of a NP evidence the EFT analysis also gives an UPPER bound on the NP scale (TeV @95%)

Scenario	strong/tree	α_s loop	α_W loop
NMFV	35	4	2
General	800	80	30

upper bound < lower bound !!!

the pattern of the flavour couplings cannot be general nor SM-like

MSSM + generic soft SUSY-breaking terms

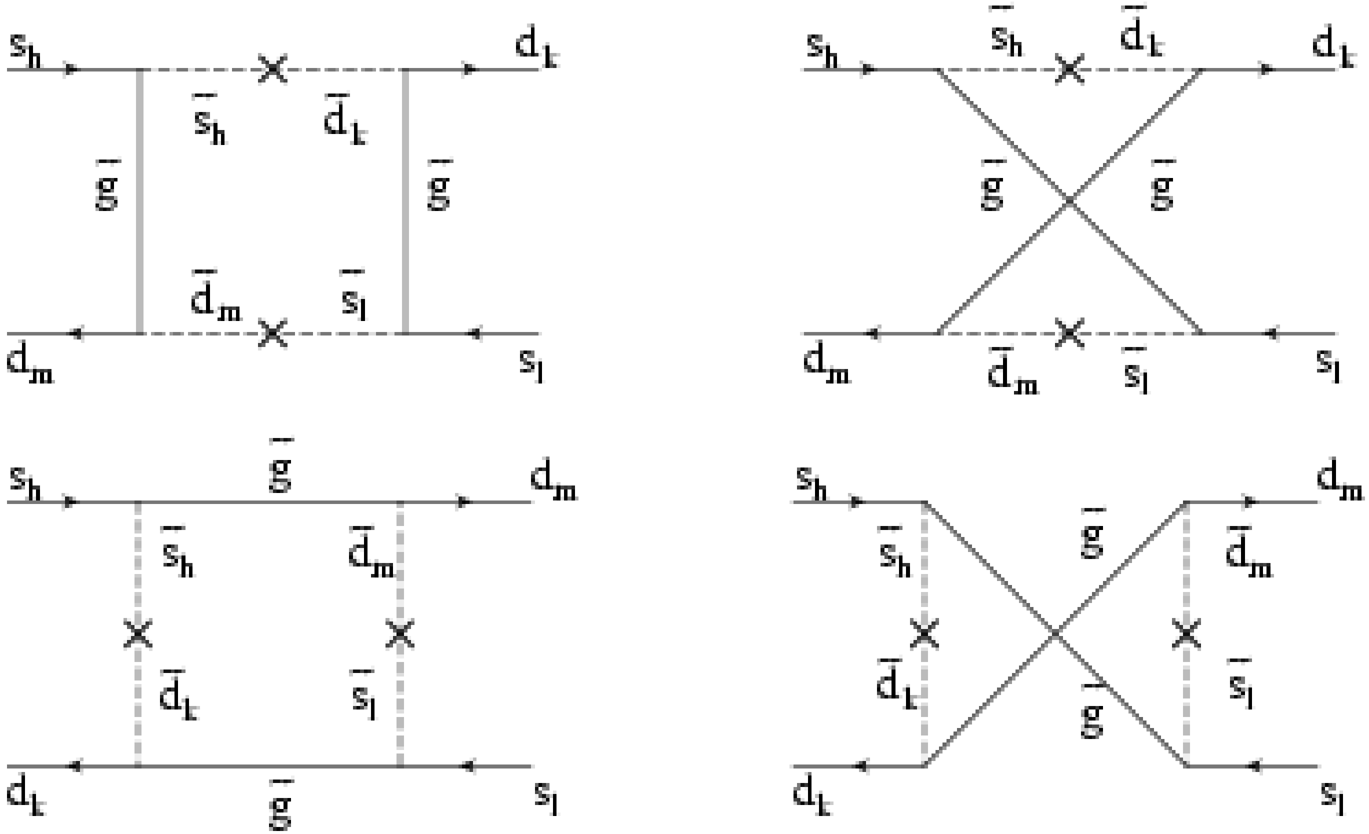
All flavour-changing NP effects in the squark propagators

$$(\tilde{q}_i)_A - - - \times - - - (\tilde{q}_j)_B \qquad (\delta^q_{ij})_{AB}$$

$$q = \{u, d\}, \quad (A, B) = \{L, R\}$$
$$(i, j) = \{1, 2, 3\}$$

- NP scale: SUSY masses $\widetilde{m} \sim m_{\tilde{g}}$
- flavour-violating couplings: $(\delta^q_{ij})_{AB} \equiv \dfrac{(M^2_{ij})^q_{AB}}{\widetilde{m}^2}$

$$(M^2)^{\tilde{d}} = \begin{pmatrix} m^2_{\tilde{d}_L} & m_d(A_d \;\; \mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde{d}_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde{s}_L} & m_s(A_s - \mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde{s}_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde{b}_L} & m_b(A_b - \mu\tan\beta) \\ & & & & & m^2_{\tilde{b}_R} \end{pmatrix}$$



trivial changes in the case ΔB=2

dominant gluino-squark contributions to the Wilson coefficients

$$C_1 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LL}^2 f_1(x) \quad C_2 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RL}^2 f_2(x) \quad C_3 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RL}^2 f_3(x)$$

$$\tilde{C}_1 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{RR}^2 f_1(x) \quad \tilde{C}_2 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LR}^2 f_2(x) \quad \tilde{C}_3 = \frac{\alpha_s^2}{\tilde{m}^2}(\delta_{12}^d)_{LR}^2 f_3(x)$$

$$C_4 = \frac{\alpha_s^2}{\tilde{m}^2}\left[(\delta_{12}^d)_{LL}(\delta_{12}^d)_{RR} f_4(x) + (\delta_{12}^d)_{LR}(\delta_{12}^d)_{RL} \tilde{f}_4(x)\right]$$

$$C_5 = \frac{\alpha_s^2}{\tilde{m}^2}\left[(\delta_{12}^d)_{LL}(\delta_{12}^d)_{RR} f_5(x) + (\delta_{12}^d)_{LR}(\delta_{12}^d)_{RL} \tilde{f}_5(x)\right]$$

Gabbiani et al., hep-ph/9604387

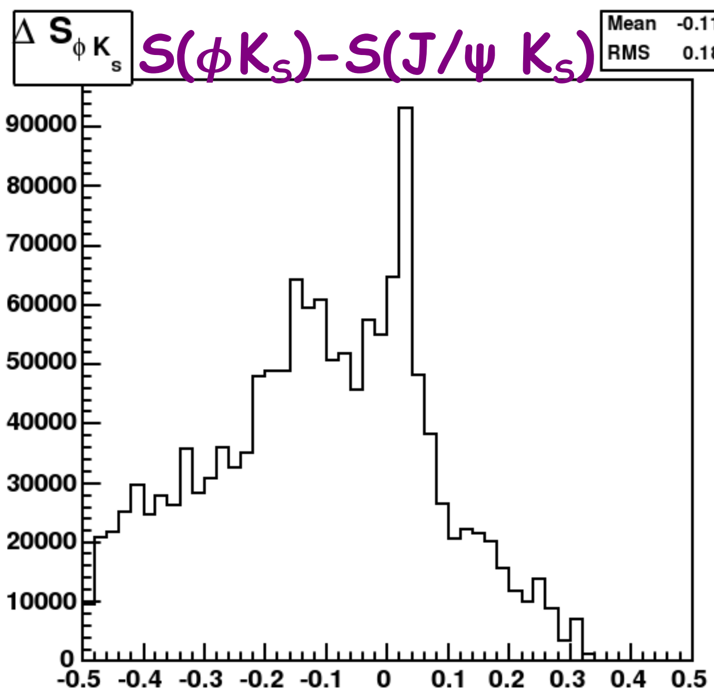
* chirality-flipping mass insertions are strongly bounded by $b \to s \gamma$: they are too small to produce the measured ϕ_s

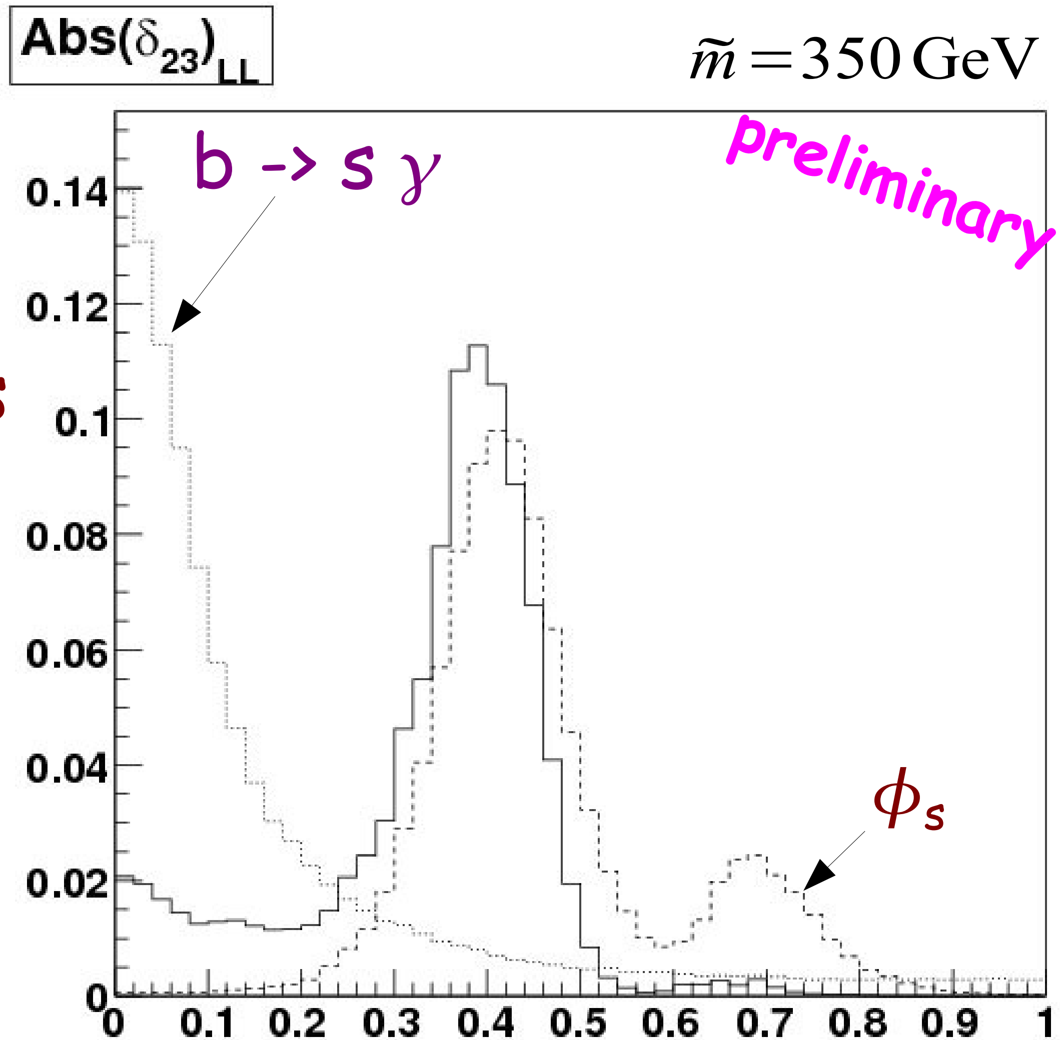
<u>case #1</u>: single mass insertion, e.g. $(\delta_{23})_{LL}$

* large MI needed for ϕ_s: tension with $b \to s \gamma$

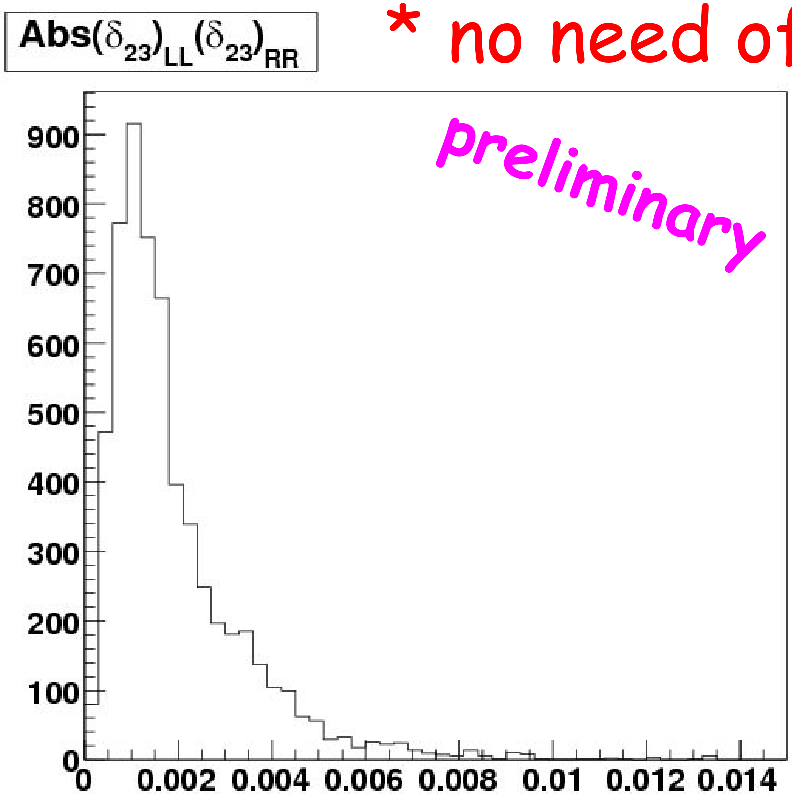
* MI saturates at 1: upper bound $\tilde{m}$ < O(1 TeV)

* huge effect in b->s penguins



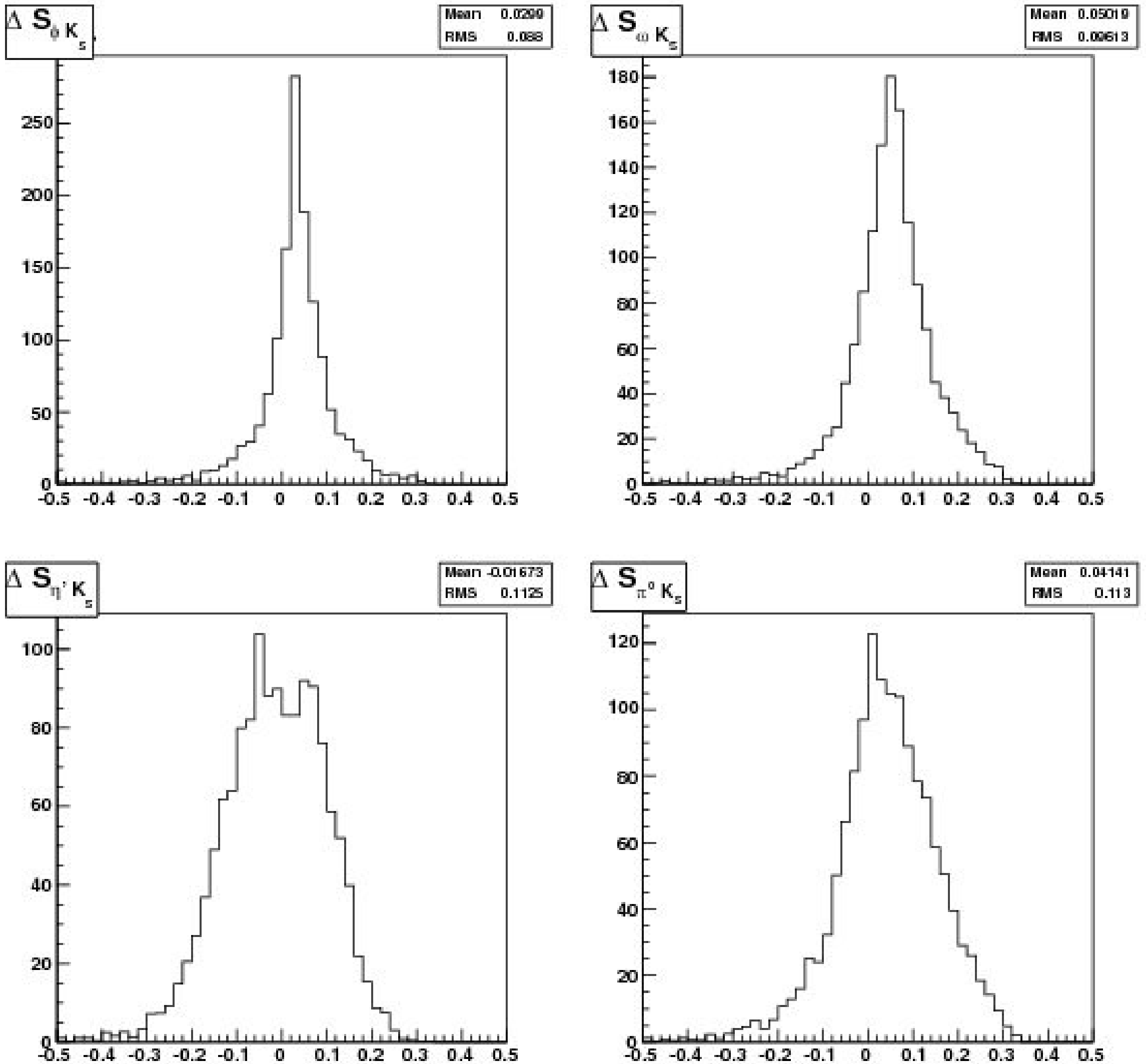


case #2: double mass insertion, $(\delta_{23})_{LL}$ & $(\delta_{23})_{RR}$



* no need of large MIs: $(\delta_{23})_{LL} \sim (\delta_{23})_{RR} \sim 3\text{-}4 \cdot 10^{-2}$

b -> s γ is no longer a problem



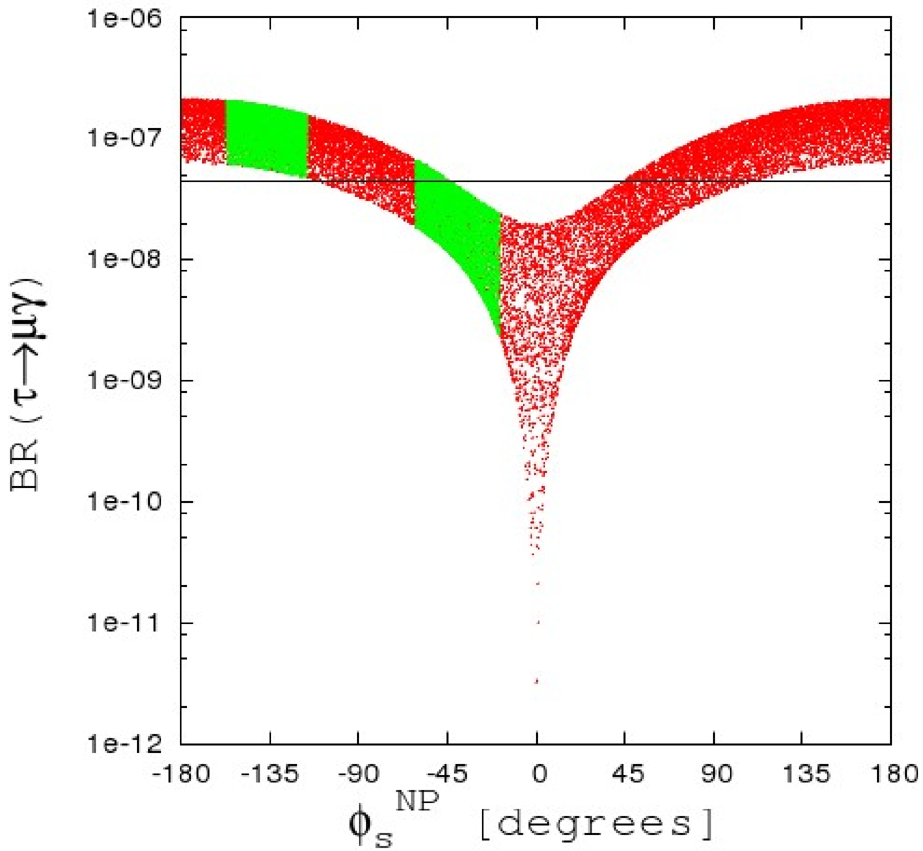
* large effects in b->s penguins still possible (larger if LR MIs are also switched on)

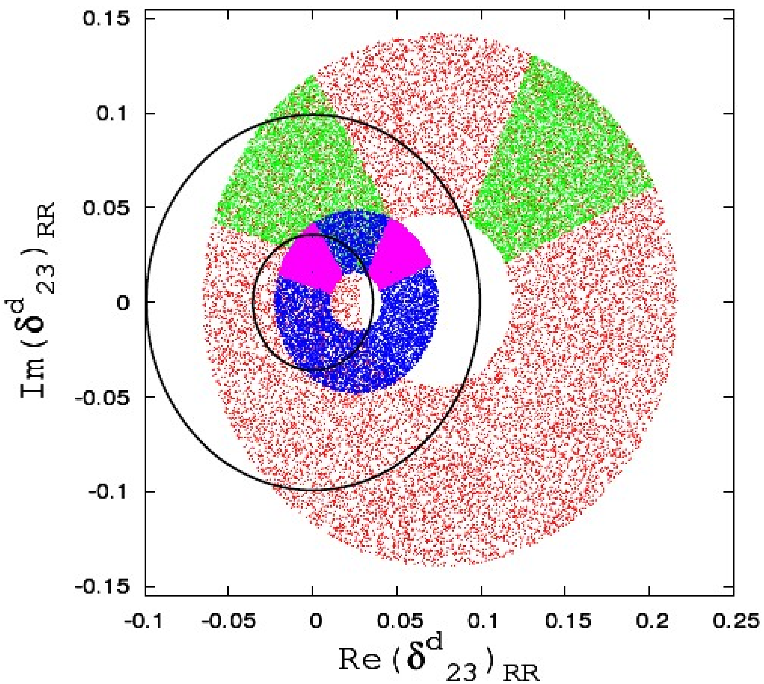
Lower bound on FV in SUSY-GUT's

Parry, Zhang, arXiv:0710.5443v2

mass insertion analysis in a SUSY-GUT scheme

- RG-induced $(\delta_{23})_{LL}$
- explicit $(\delta_{23})_{RR}$

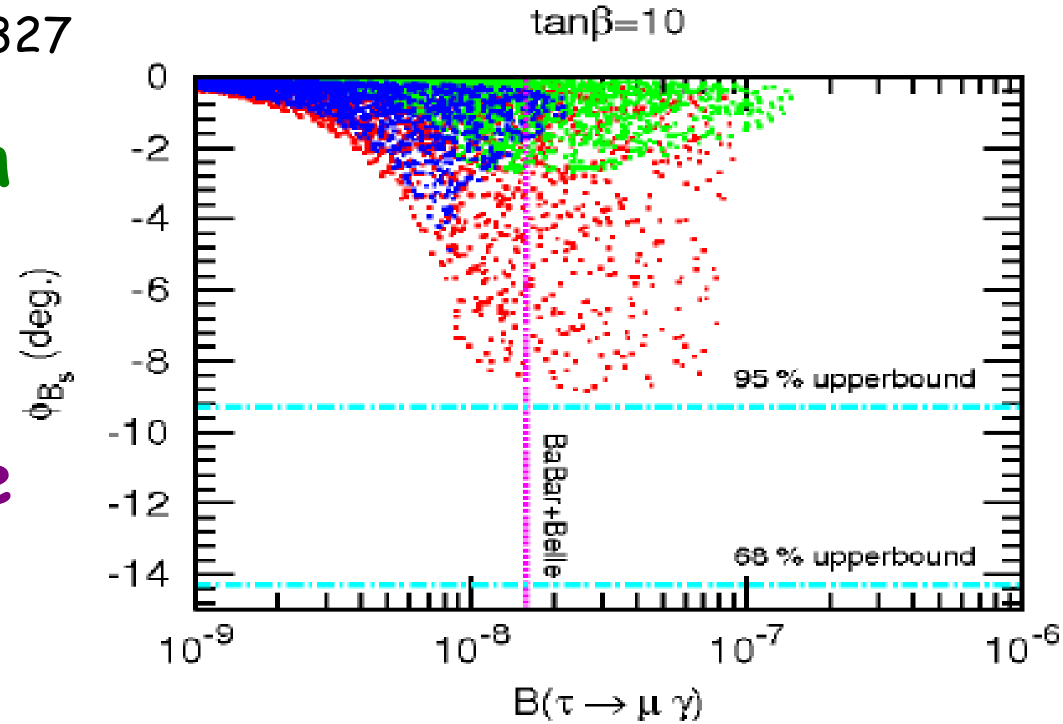




In the UTfit range for the B_s mixing phase:

$$BR(\tau\rightarrow\mu\gamma) > 3 \times 10^{-9} \text{ !!}$$

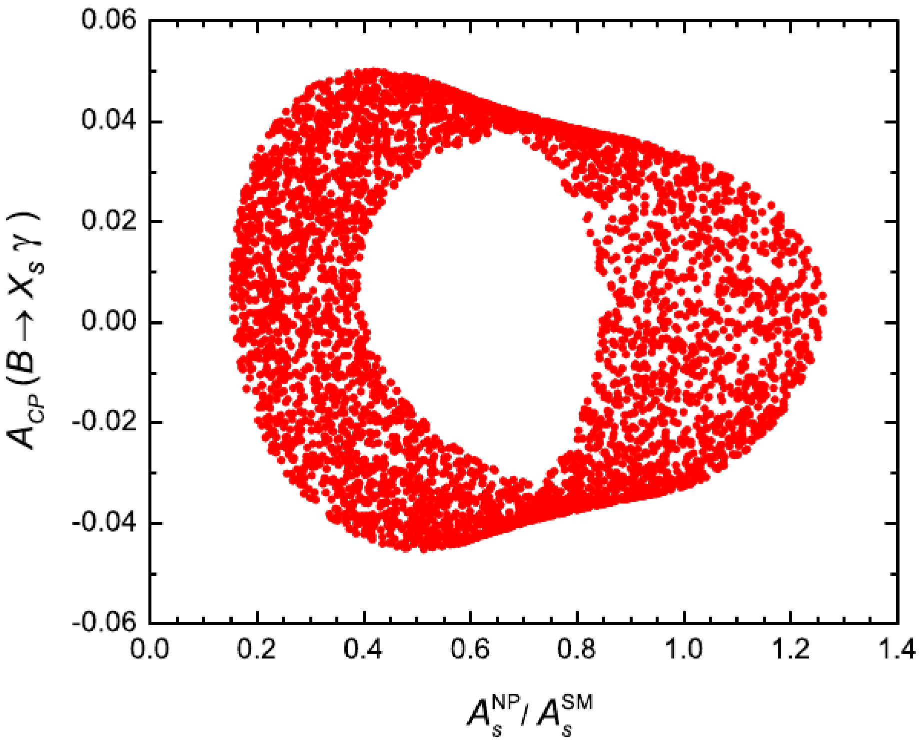
Hisano, Shimizu, arXiv:0805.3327



In a SU(5) SUSY-GUT with ν_R and supergravity-like boundary conditions:

large φ_s requires too large BR($\tau \to \mu\gamma$): marginal !!!

Dutta, Mimura, arXiv:0805.2988



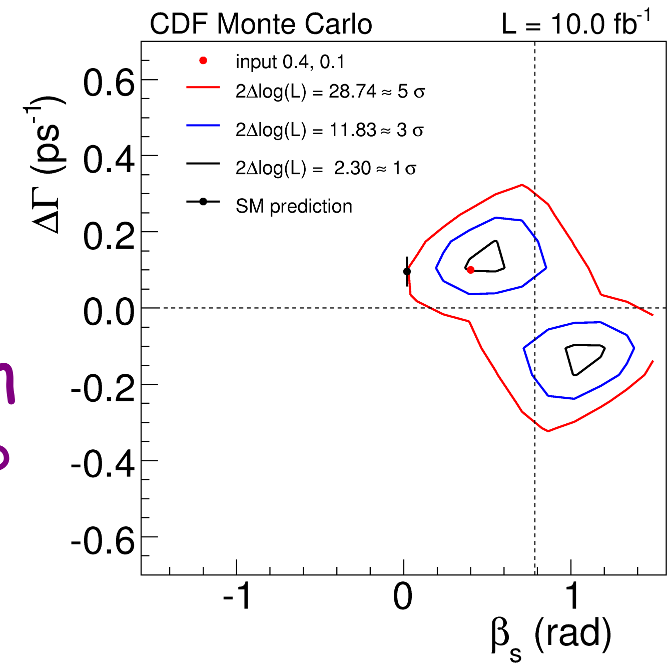
Enlarging the GUT group to SO(10), the correlation φ_s-BR($\tau \to \mu\gamma$) can be relaxed

large φ_s correspond to large CP asymmetries in B → X_s γ

Flavour Physics Roadmap

now-2009: TeVatron

observation of $\phi_s \sim -20°$



2009-2015: LHC

+MEG
+JPARC

- ϕ_s down to the SM value
- BR($B_s \to \mu\,\mu$) down to SM value
- UT angle γ with $\delta\gamma \sim 2$-$3°$

2015-2020: TOV?

EVERYTHING ELSE!!! (but K)

τFV, $A_{CP}(b \to s)$, $b \to s$ penguins, CKM at 1% (with LQCD help), $B \to l\nu$, $S(K^*\gamma)$, $B \to K\nu\nu$, D CPV, ...

Spare Slides

1. new physics in Kπ CP asymmetries?

$$\mathcal{A}_{K^\pm\pi^\mp} \equiv \frac{N(\bar{B}^0 \to K^-\pi^+) - N(B^0 - K^+\pi^-)}{N(\bar{B}^0 \to K^-\pi^+) + N(B^0 \to K^+\pi^-)} = -0.094 \pm 0.018 \pm 0.008$$

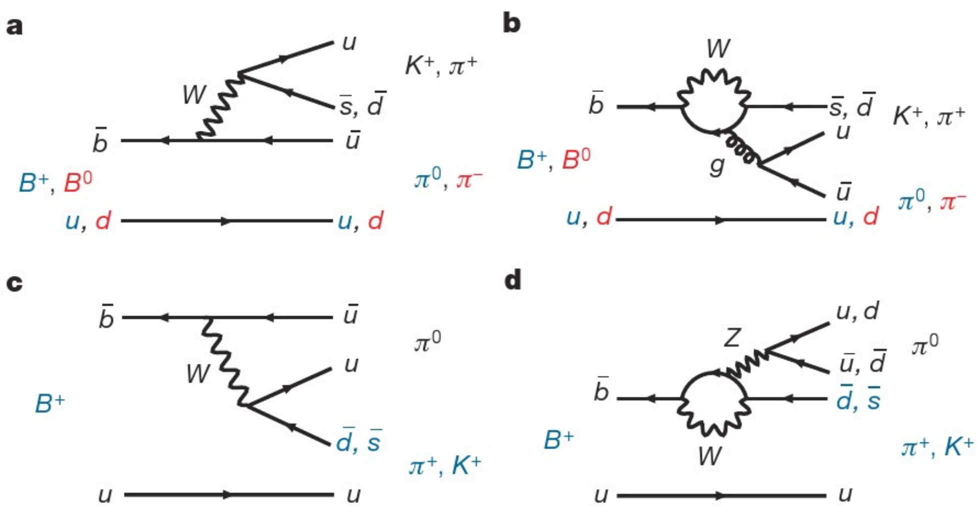
$$\mathcal{A}_{K^\pm\pi^0} = +0.07 \pm 0.03 \pm 0.01$$

Belle collaboration
Nature 452,2008

$$\Delta\mathcal{A} \equiv \mathcal{A}_{K^\pm\pi^0} - \mathcal{A}_{K^\pm\pi^\mp} = +0.164 \pm 0.037$$

difference: 4.4σ

Is this new physics?
It could be but SM predictions depend on hadronic models



Silvestrini
arXiv:0705.1624

	QCDF [50]	PQCD [54, 55]	SCET [58]	GP [92]
$A_{CP}(\pi^0 K^-)$	$7.1\,^{+1.7\,+2.0\,+0.8\,+9.0}_{-1.8\,-2.0\,-0.6\,-9.7}$	-1^{+3}_{-5}	$-11 \pm 9 \pm 11 \pm 2$	3.4 ± 2.4
$A_{CP}(\pi^+ K^-)$	$4.5\,^{+1.1\,+2.2\,+0.5\,+8.7}_{-1.1\,-2.5\,-0.6\,-9.5}$	-9^{+6}_{-8}	$-6 \pm 5 \pm 6 \pm 2$	-8.9 ± 1.6

GP: general parametrization

preliminary

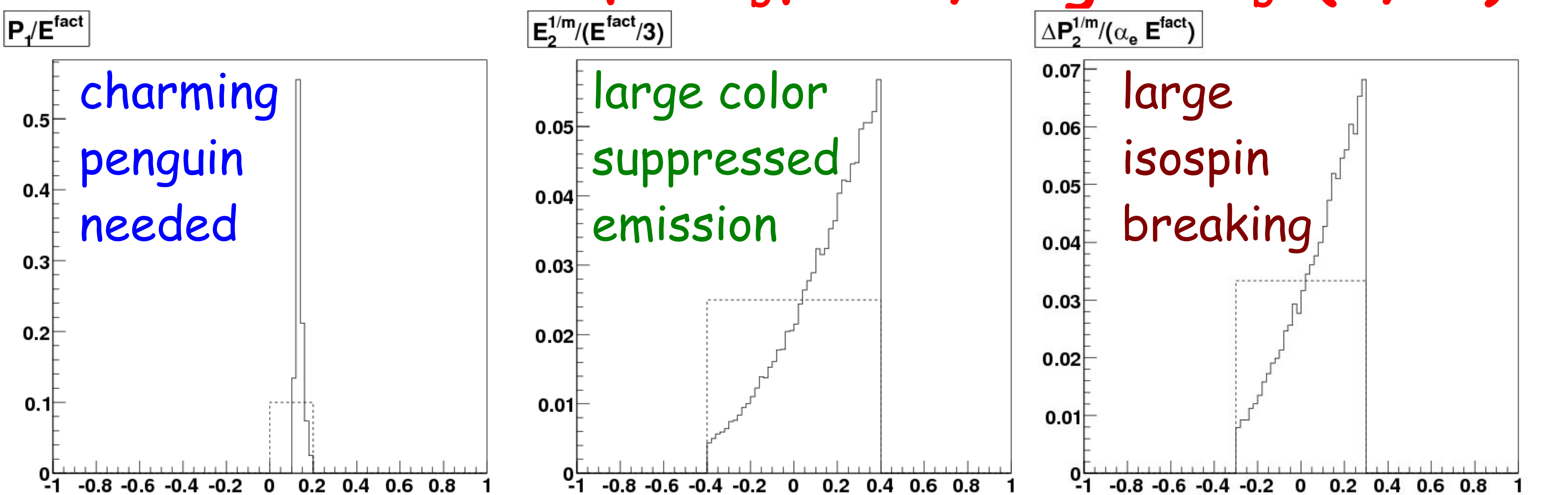
$$A(K^+\pi^-) = V_{ts}V_{tb}^* (P_1+\Delta P_1) - V_{us}V_{ub}^* E_1$$

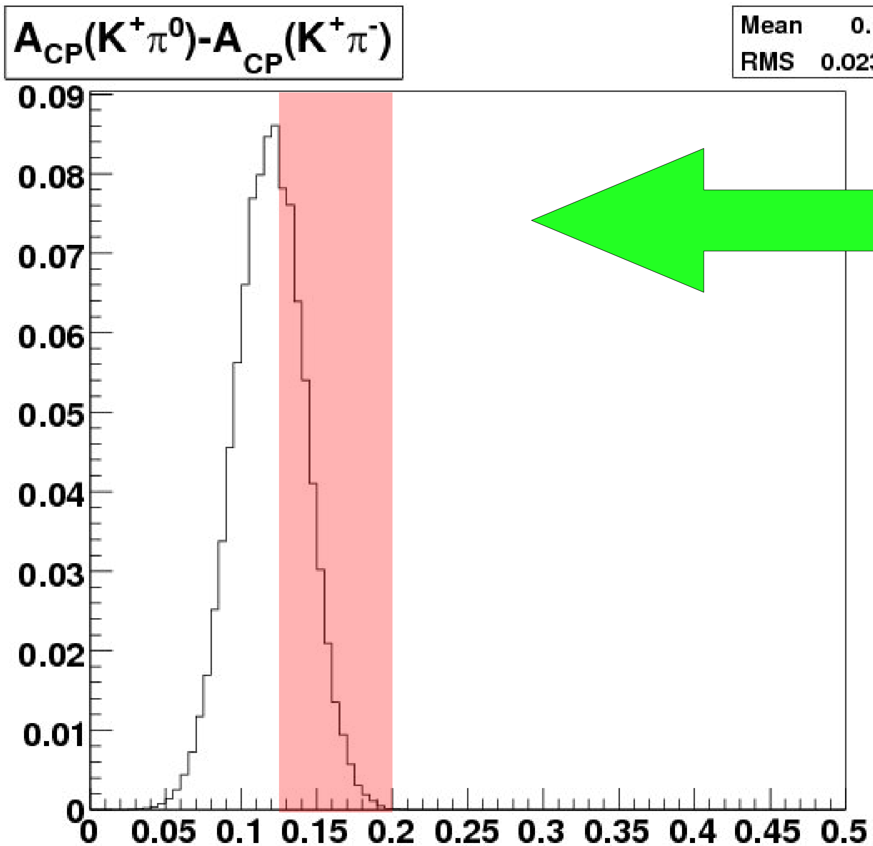
$$\sqrt{2}\, A(K^+\pi^0) = V_{ts}V_{tb}^* (P_1+\Delta P_1+\Delta P_2) - V_{us}V_{ub}^* (E_1+E_2+A_1)$$

$E_1 \sim E^{fact}+E_1^{1/m}$, $E_2 \sim E^{fact}/3+E_2^{1/m}$, $P_1 \sim E^{fact}\Lambda/m_b$

$A_1 \sim E^{fact}\Lambda/m_b$, $\Delta P_1 \sim \alpha_e E^{fact}/3+\Delta P_1^{1/m}$, $\Delta P_2 \sim \alpha_e E^{fact}+\Delta P_2^{1/m}$

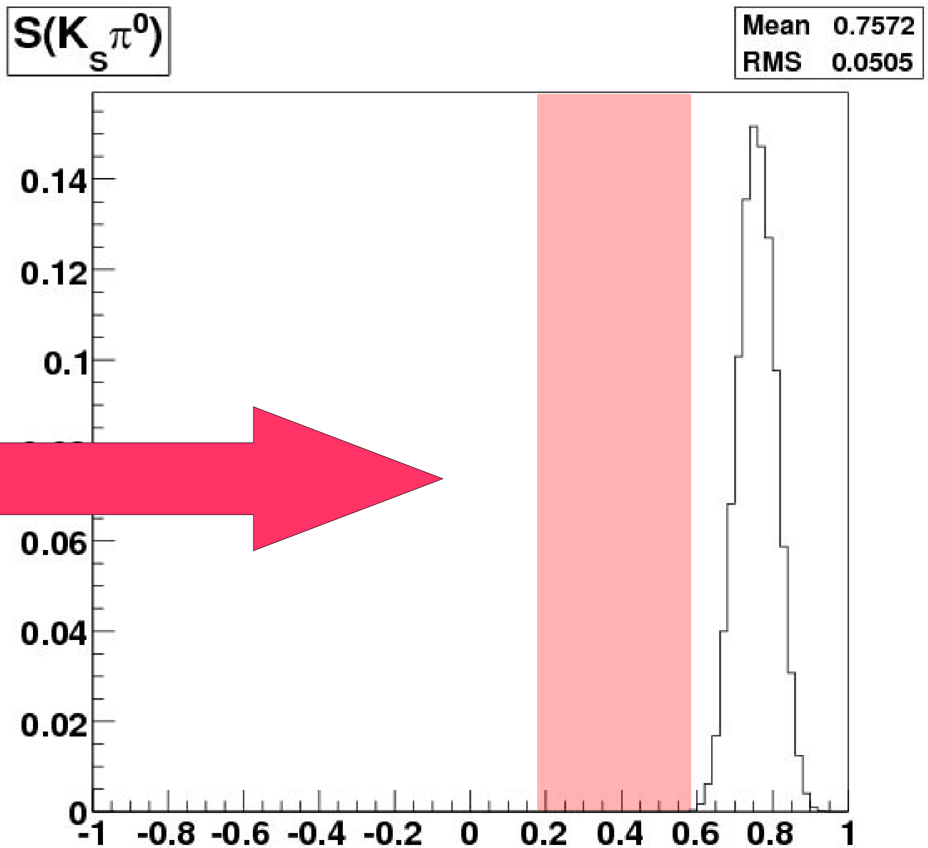
Fit Kπ data with $|\Lambda/m_b|<0.4$, arg $\Lambda/m_b=(0,2\pi)$





preliminary

No clash with the Belle measurement of the *CP* asymmetries



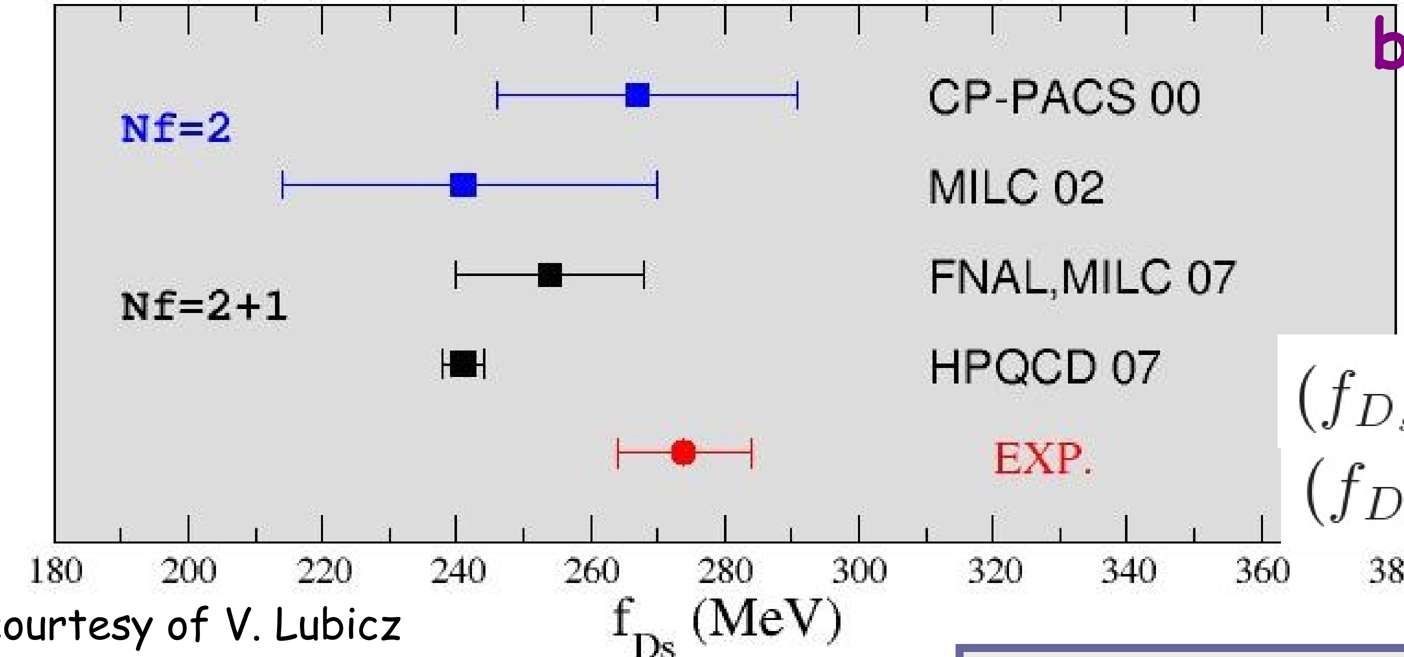
However...

$$S(K_S\pi^0)_{exp}=0.38 \pm 0.19$$

2. Evidence for non-standard leptonic decays of D_s mesons

Dobrescu, Kronfeld
arXiv:0803.0512

$$B(D_s \to \ell\nu) = \frac{m_{D_s}}{8\pi} \tau_{D_s} f_{D_s}^2 \, |G_F V_{cs}^* m_\ell|^2 \left(1 - \frac{m_\ell^2}{m_{D_s}^2}\right)^2$$



courtesy of V. Lubicz

based on the latest lattice result only

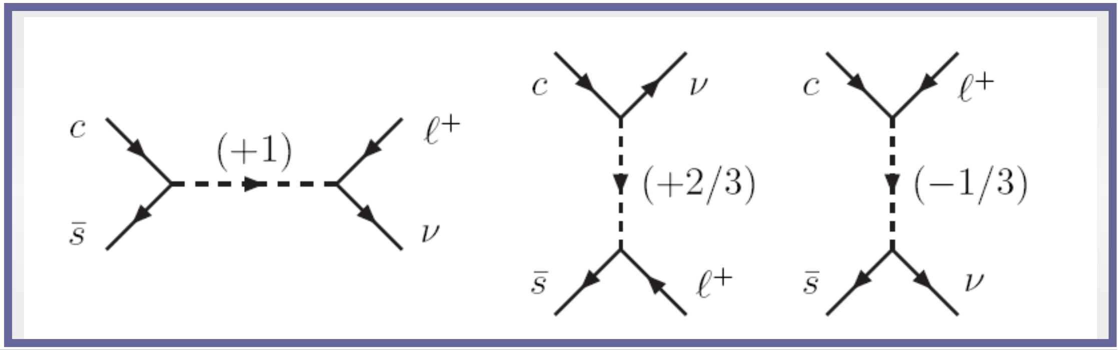
Follana et al.
arXiv:0706.1726

$$(f_{D_s})_{\rm QCD} = 241 \pm 3 \text{ MeV}$$
$$(f_{D_s})_{\rm expt} = 277 \pm 9 \text{ MeV}$$

difference: 3.8σ

"exotic" new physics:

- leptoquarks
- exotic charged Higgs



Conclusions

Flavour physics is a unique tool for searching and studying NP complementary to the LHC

There is a first evidence for NP in b<->s transitions. Confirmation in Summer

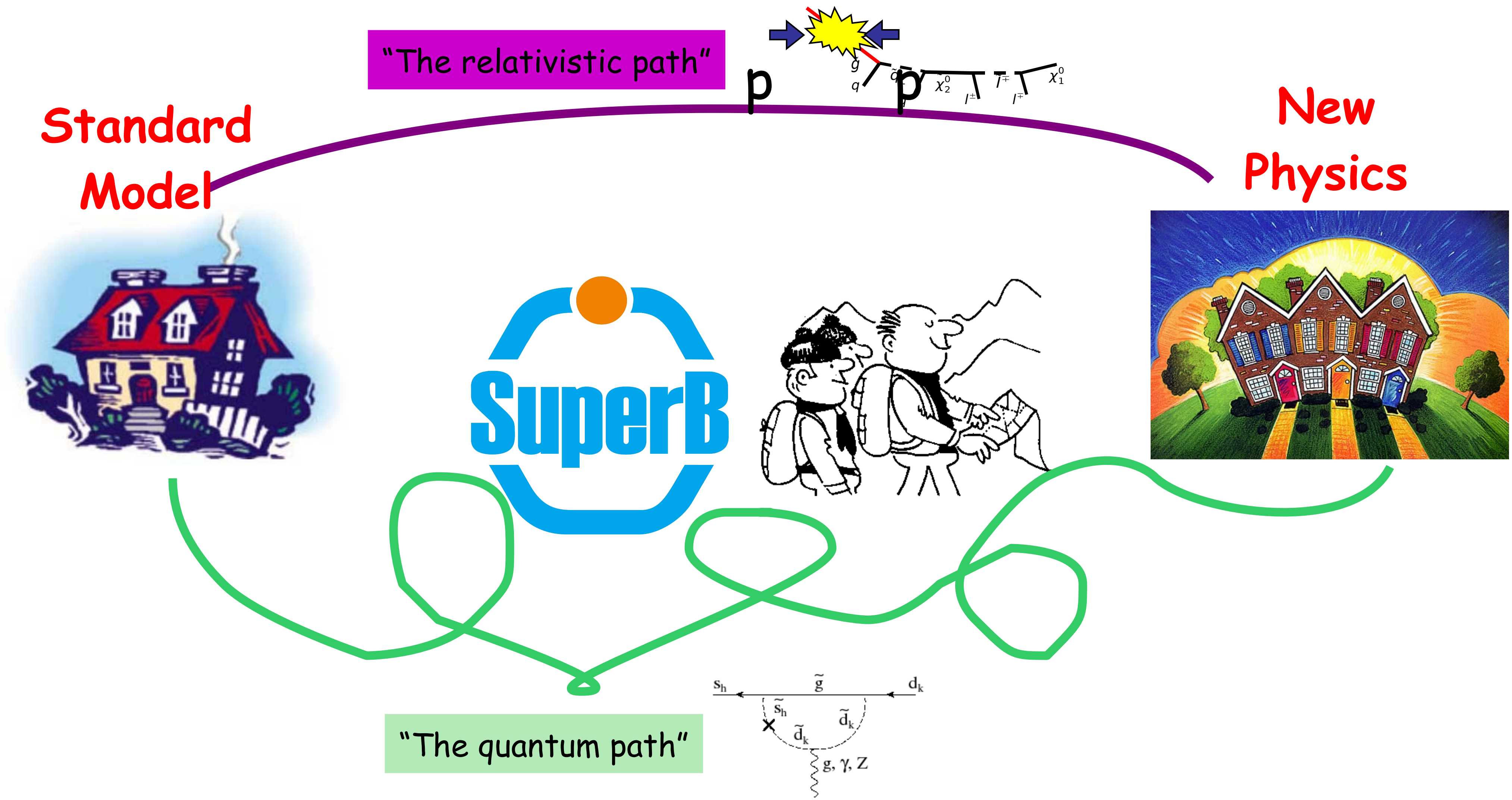
From $\Delta F=2$ transitions, a pattern of flavour violation in NP emerges:

2<->3: O(1), 1<->3: < O(0.1), 1<->2 strong suppr.

The next 15 years of flavour physics are well motivated and clearly planned: exciting times ahead

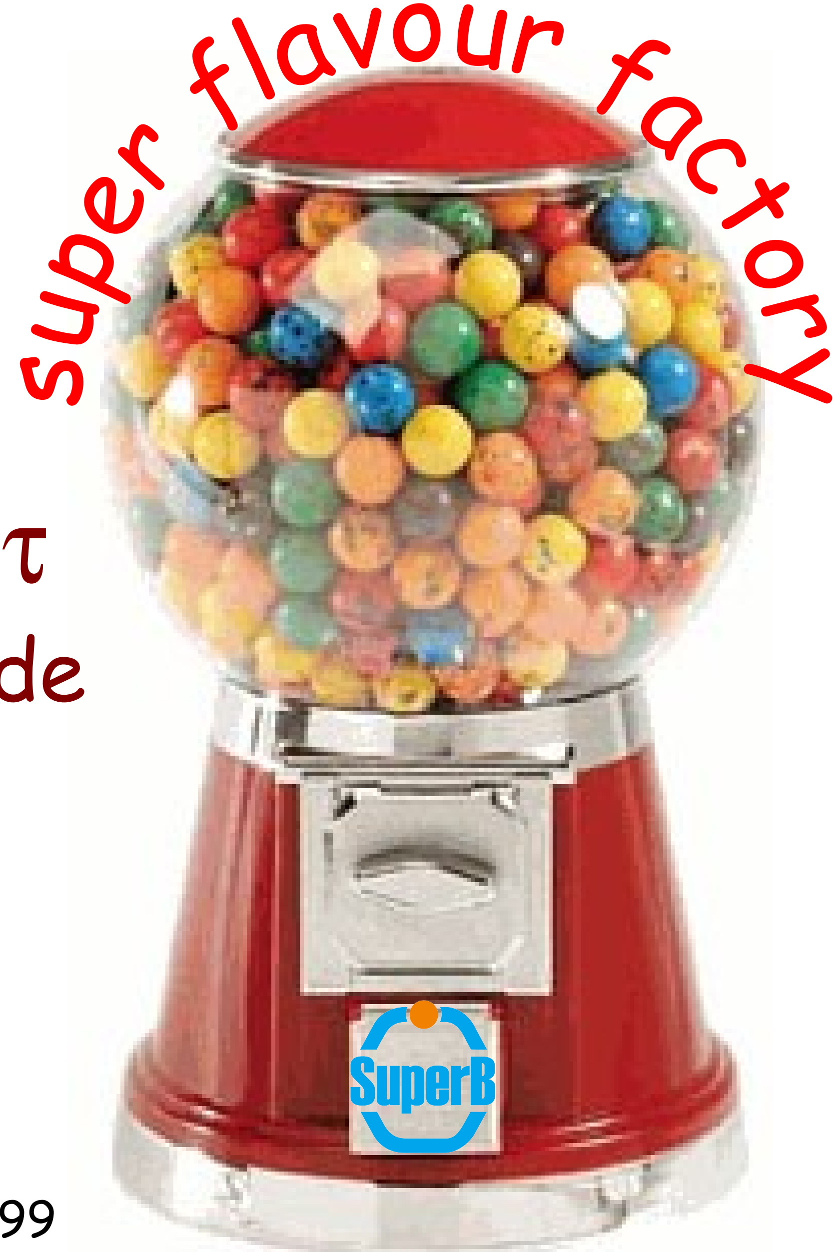
SuperB New Physics

Marco Ciuchini - INFN



What is SuperB?

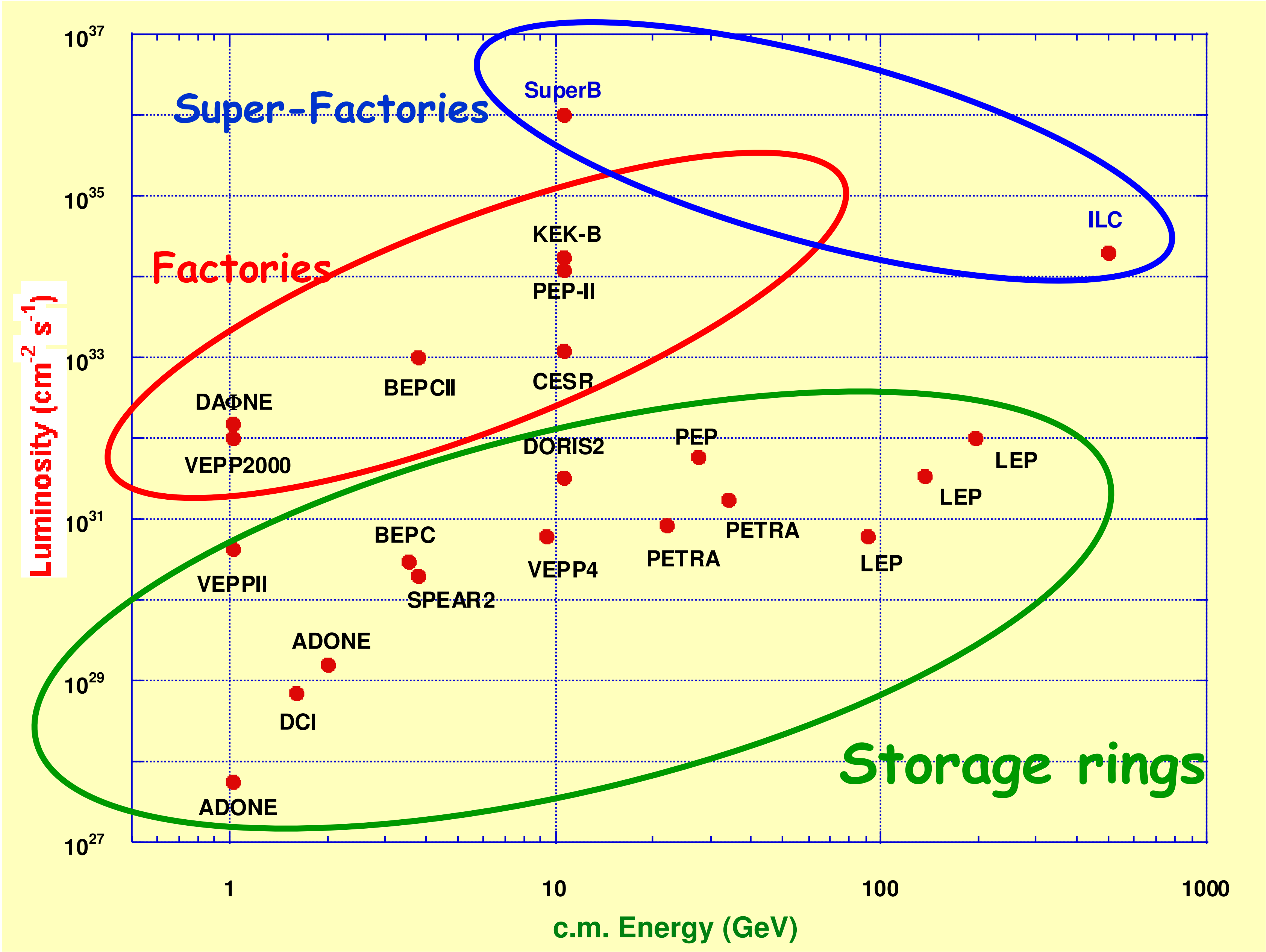
- improve precision/sensitivity of B-factories x5-10
- test the CKM paradigm and determine V_{CKM} at 1% level
- increase sensitivity to LFV in τ decays by 1 order of magnitude
- explore CPV with charm



feasible with 75 ab^{-1} collected at the $\Upsilon(4S)$

SuperB CDR, arXiv:0709.0451
T. Browder at al., arXiv:0710.3799

$e^+ e^-$ colliders



SuperB physics in tables

Observable	B factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$\sin(2\beta)$ $(J/\psi\, K^0)$	0.018	0.005 (†)
$\cos(2\beta)$ $(J/\psi\, K^{*0})$	0.30	0.05
$\sin(2\beta)$ (Dh^0)	0.10	0.02
$\cos(2\beta)$ (Dh^0)	0.20	0.04
$S(J/\psi\,\pi^0)$	0.10	0.02
$S(D^+D^-)$	0.20	0.03
$S(\phi K^0)$	0.13	0.02 (∗)
$S(\eta' K^0)$	0.05	0.01 (∗)
$S(K^0_S K^0_S K^0_S)$	0.15	0.02 (∗)
$S(K^0_S \pi^0)$	0.15	0.02 (∗)
$S(\omega K^0_S)$	0.17	0.03 (∗)
$S(f_0 K^0_S)$	0.12	0.02 (∗)
γ $(B \to DK,\, D \to CP$ eigenstates)	$\sim 15^\circ$	2.5°
γ $(B \to DK,\, D \to$ suppressed states)	$\sim 12^\circ$	2.0°
γ $(B \to DK,\, D \to$ multibody states)	$\sim 9^\circ$	1.5°
γ $(B \to DK$, combined)	$\sim 6^\circ$	1–2°
α $(B \to \pi\pi)$	$\sim 16^\circ$	3°
α $(B \to \rho\rho)$	$\sim 7^\circ$	1–2° (∗)
α $(B \to \rho\pi)$	$\sim 12^\circ$	2°
α (combined)	$\sim 6^\circ$	1–2° (∗)
$2\beta + \gamma$ $(D^{(*)\pm}\pi^\mp,\, D^\pm K^0_S \pi^\mp)$	20°	5°
$\lvert V_{cb}\rvert$ (exclusive)	4% (∗)	1.0% (∗)
$\lvert V_{cb}\rvert$ (inclusive)	1% (∗)	0.5% (∗)
$\lvert V_{ub}\rvert$ (exclusive)	8% (∗)	3.0% (∗)
$\lvert V_{ub}\rvert$ (inclusive)	8% (∗)	2.0% (∗)
$BR(B \to \tau\nu)$	20%	4% (†)
$BR(B \to \mu\nu)$	visible	5%
$BR(B \to D\tau\nu)$	10%	2%
$BR(B \to \rho\gamma)$	15%	3% (†)
$BR(B \to \omega\gamma)$	30%	5%
$A_{CP}(B \to K^*\gamma)$	0.007 (†)	0.004 († ∗)
$A_{CP}(B \to \rho\gamma)$	~ 0.20	0.05
$A_{CP}(b \to s\gamma)$	0.012 (†)	0.004 (†)
$A_{CP}(b \to (s+d)\gamma)$	0.03	0.006 (†)
$S(K^0_S \pi^0 \gamma)$	0.15	0.02 (∗)
$S(\rho^0\gamma)$	possible	0.10
$A_{CP}(B \to K^*\ell\ell)$	7%	1%
$A^{FB}(B \to K^*\ell\ell)s_0$	25%	9%
$A^{FB}(B \to X_s\ell\ell)s_0$	35%	5%
$BR(B \to K\nu\overline{\nu})$	visible	20%
$BR(B \to \pi\nu\bar{\nu})$	–	possible

Mode	Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab^{-1})
$D^0 \to K^+K^-$	y_{CP}	2–3×10^{-3}	5×10^{-4}
$D^0 \to K^+\pi^-$	y'_D	2–3×10^{-3}	7×10^{-4}
	x'^2_D	1–2×10^{-4}	3×10^{-5}
$D^0 \to K^0_S\pi^+\pi^-$	y_D	2–3×10^{-3}	5×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}
Average	y_D	1–2×10^{-3}	3×10^{-4}
	x_D	2–3×10^{-3}	5×10^{-4}

	Sensitivity
$D^0 \to e^+e^-$, $D^0 \to \mu^+\mu^-$	1×10^{-8}
$D^0 \to \pi^0 e^+e^-$, $D^0 \to \pi^0\mu^+\mu^-$	2×10^{-8}
$D^0 \to \eta e^+e^-$, $D^0 \to \eta\mu^+\mu^-$	3×10^{-8}
$D^0 \to K^0_S e^+e^-$, $D^0 \to K^0_S\mu^+\mu^-$	3×10^{-8}
$D^+ \to \pi^+ e^+e^-$, $D^+ \to \pi^+\mu^+\mu^-$	1×10^{-8}
$D^0 \to e^\pm\mu^\mp$	1×10^{-8}
$D^+ \to \pi^+ e^\pm\mu^\mp$	1×10^{-8}
$D^0 \to \pi^0 e^\pm\mu^\mp$	2×10^{-8}
$D^0 \to \eta e^\pm\mu^\mp$	3×10^{-8}
$D^0 \to K^0_S e^\pm\mu^\mp$	3×10^{-8}
$D^+ \to \pi^- e^+e^+$, $D^+ \to K^- e^+e^+$	1×10^{-8}
$D^+ \to \pi^-\mu^+\mu^+$, $D^+ \to K^-\mu^+\mu^+$	1×10^{-8}
$D^+ \to \pi^- e^\pm\mu^\mp$, $D^+ \to K^- e^\pm\mu^\mp$	1×10^{-8}

5-10x improvement

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\,\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\,\mu\,\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K^0_S)$	2×10^{-10}

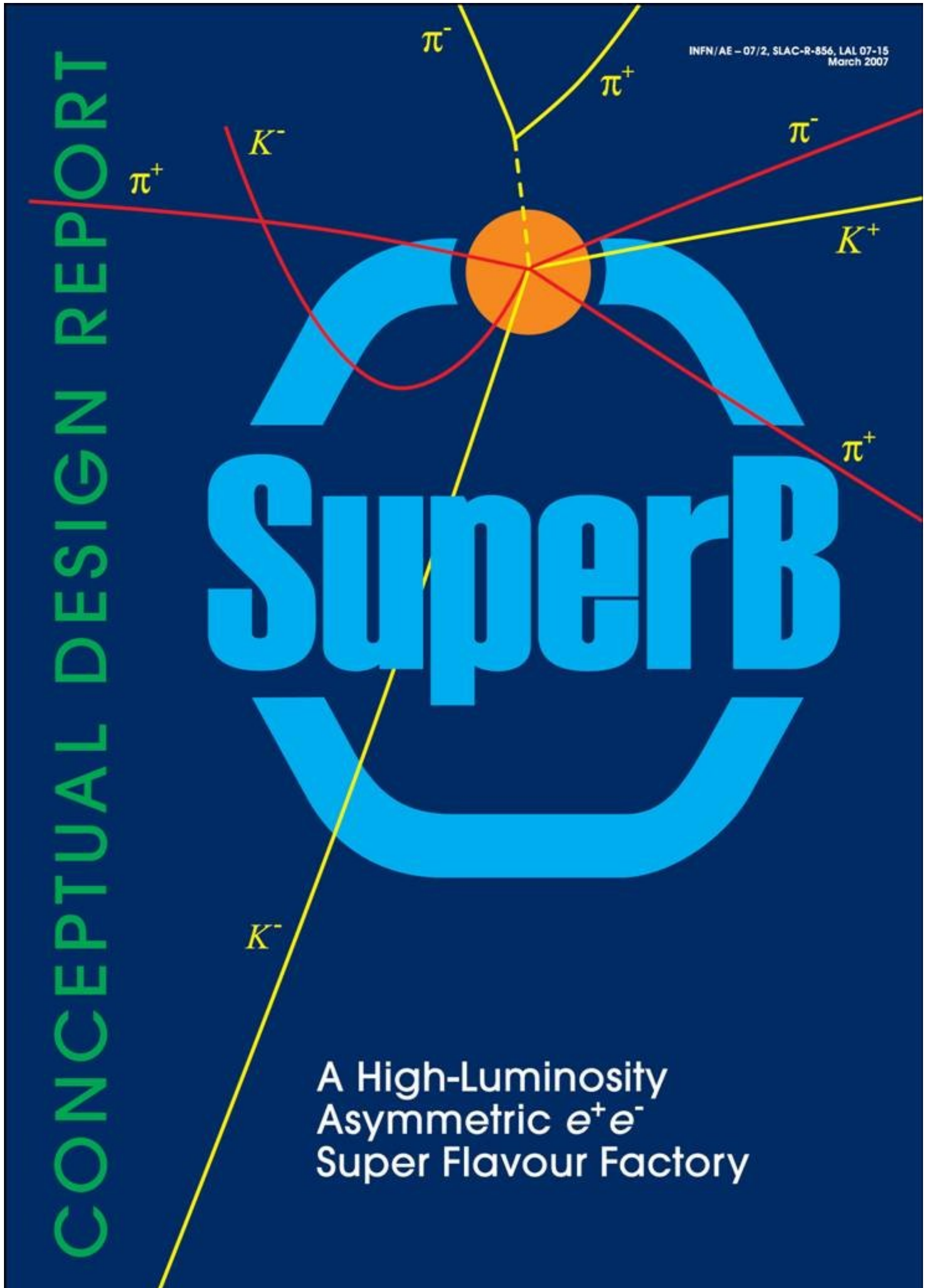
+ τ FC physics (CPV, ...)

Super Flavour Factory

a "treasure chest" of new physics-sensitive observables

Observable	Error with 1 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}
Γ	0.07 ps^{-1}
β_s from angular analysis	20°
A^s_{SL}	0.006
[illegible]	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-
$\lvert V_{td}/V_{ts}\rvert$	0.08
$\mathcal{B}(B_s \to \gamma\gamma)$	38%
β_s from $J/\psi\phi$	10°

Bible of SuperB: Conceptual Design Report



The CDR of SuperB is ready!

476 pages (~130 about physics)

INFN/AE-07/02, SLAC-R-856, LAL 07-15, arXiv:0709.0451

Also available at:

www.pi.infn.it/SuperB

copies can be requested from Lucia.Lilli@pi.infn.it

<u>next meeting</u>:

SuperB Workshop VII

La Biodola, Isola d'Elba (IT)

May 31st – June 3rd, 2008

www.pi.infn.it/bfactory/SuperB_elba2008

SuperB physics goals

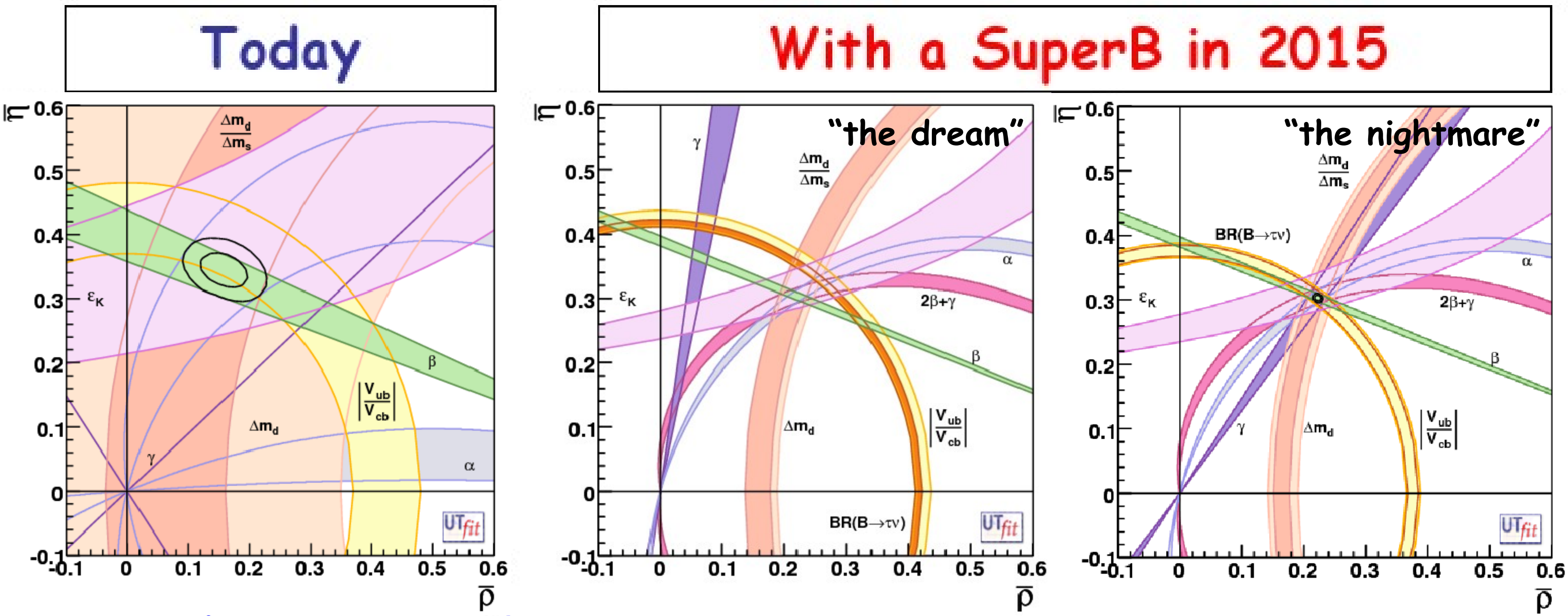
NP found at LHC

* determine the flavour- and CP-violating couplings the NP Lagrangian
* look for the effects of heavier states beyond the LHC discovery reach

NP not found at LHC

* look for indirect NP signals coming from the 1-100 TeV energy range
* exclude regions of the NP parameter space

Overture: CKM matrix at 1%

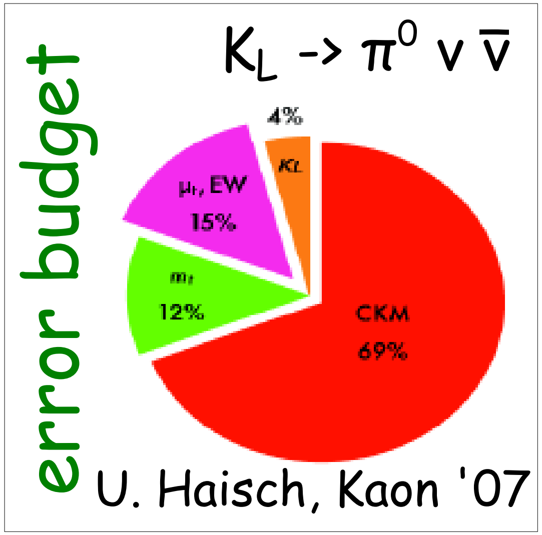


Generalized UT fits:

CKM at 1% in the presence of NP!

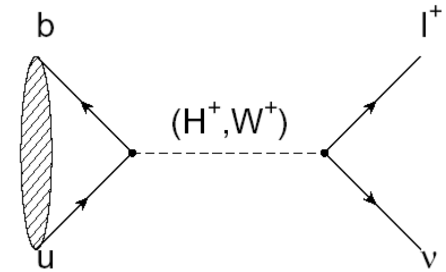
	today	SuperB
$\bar\rho$	0.187±0.056	±0.005
$\bar\eta$	0.370±0.036	±0.005

- crucial for many NP searches with flavour (not only for B decays!)



Higgs-mediated NP in MFV at large tanβ

$$\mathrm{BR}(B^+ \to l^+ \nu) = \mathrm{BR}_{\mathrm{SM}}(B^+ \to l^+ \nu)\left(1 - \frac{m_B^2}{M_H^2}\tan^2\beta\right)^2$$

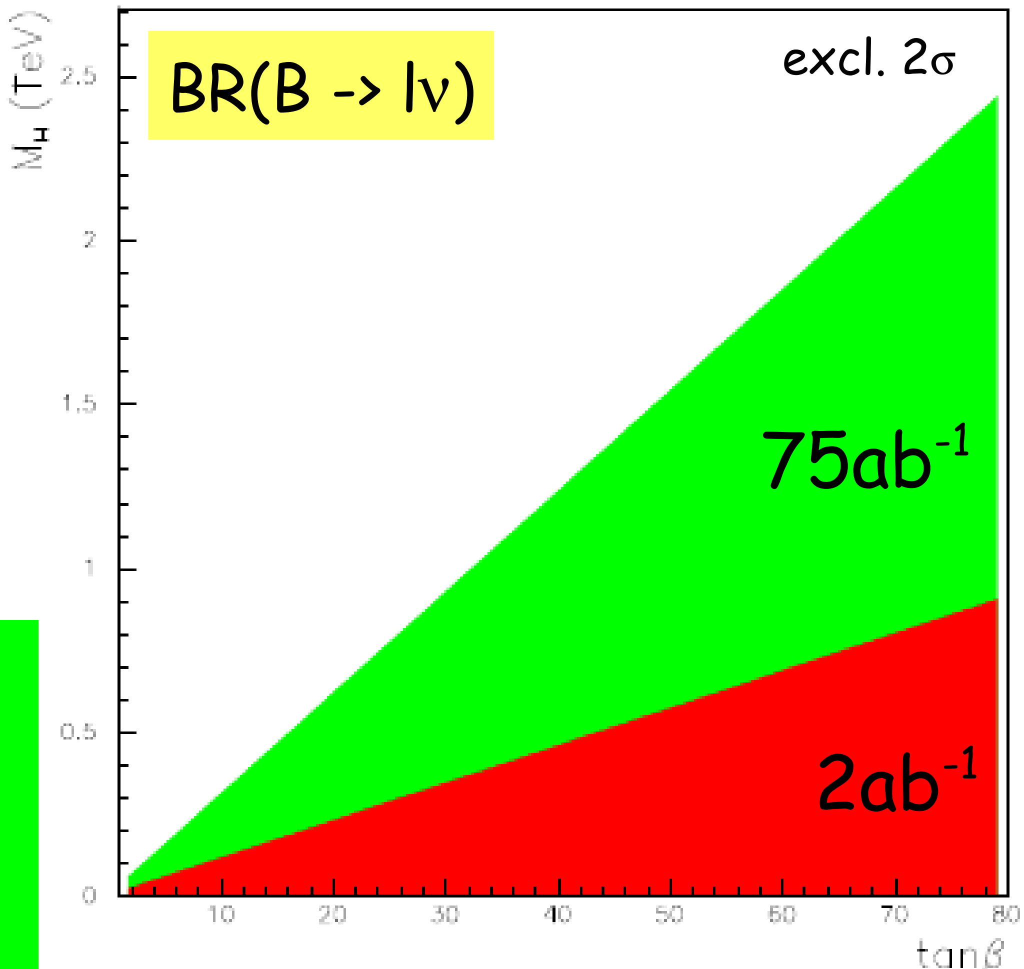


formula and plot for 2HDM
similar results for MSSM

sensitivity:

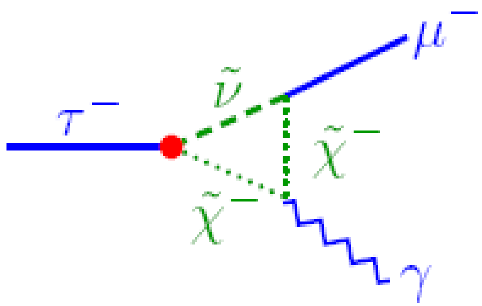
B factories (2/ab)
$M_H \sim 0.4$ TeV
for tanβ ~ 50

SuperB (75/ab)
$M_H \sim 1.5$ TeV
for tanβ ~ 50



τ flavour violation

Process	Sensitivity
$\mathcal{B}(\tau \to \mu\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to e\gamma)$	2×10^{-9}
$\mathcal{B}(\tau \to \mu\mu\mu)$	2×10^{-10}
$\mathcal{B}(\tau \to eee)$	2×10^{-10}
$\mathcal{B}(\tau \to \mu\eta)$	4×10^{-10}
$\mathcal{B}(\tau \to e\eta)$	6×10^{-10}
$\mathcal{B}(\tau \to \ell K_s^0)$	2×10^{-10}



not just yet-another order of magnitude: start probing the interesting region

- help disentangle SUSY and LHT models

see Hitlin's talk

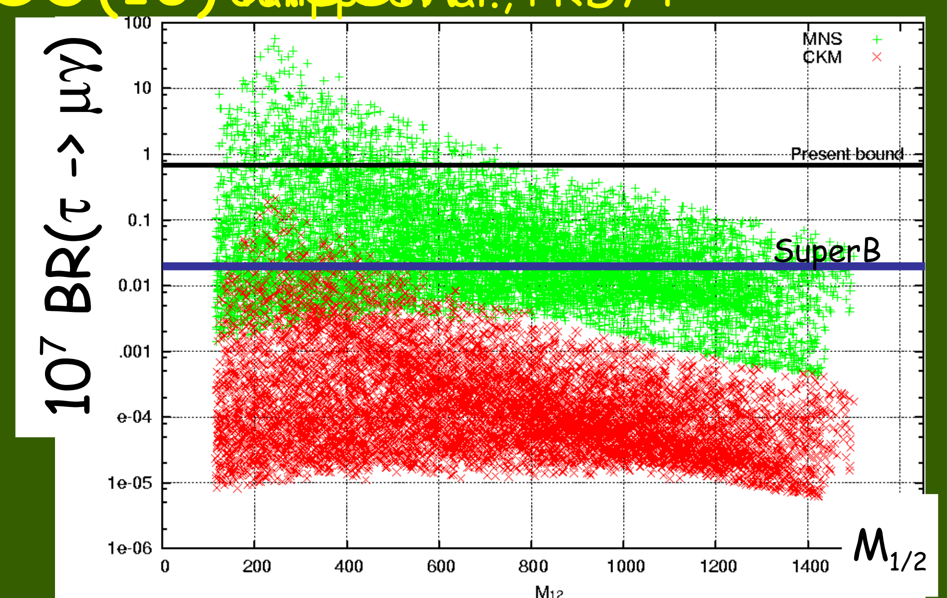
- in Grand-Unified models:

* can identify the origin of LFV (CKM or PMNS);

* is complementary to the MEG sensitivity to BR(μ->eγ) ~10^{-13}

SO(10) MSSM

Calibbi et al., PRD74



Lepton MFV GUT models

Isidori, 4th SuperB workshop

$B(\tau\to\mu\gamma):B(\tau\to e\gamma):B(\mu\to e\gamma) \sim \lambda^{-6}:\lambda^{-4}:1 \sim 10^4:500:1$ ← **LFV from CKM**

$B(\tau\to\mu\gamma):B(\tau\to e\gamma):B(\mu\to e\gamma) \sim [500\text{–}10]:1:1$ ← **LFV from PMNS**

Explicit model: MSSM

$M^2_{\tilde d} =$

SuperB

$$\begin{pmatrix} m^2_{\tilde d_L} & m_d(A_d-\mu\tan\beta) & (\Delta^d_{12})_{LL} & (\Delta^d_{12})_{LR} & (\Delta^d_{13})_{LL} & (\Delta^d_{13})_{LR} \\ & m^2_{\tilde d_R} & (\Delta^d_{12})_{RL} & (\Delta^d_{12})_{RR} & (\Delta^d_{13})_{RL} & (\Delta^d_{13})_{RR} \\ & & m^2_{\tilde s_L} & m_s(A_s-\mu\tan\beta) & (\Delta^d_{23})_{LL} & (\Delta^d_{23})_{LR} \\ & & & m^2_{\tilde s_R} & (\Delta^d_{23})_{RL} & (\Delta^d_{23})_{RR} \\ & & & & m^2_{\tilde b_L} & m_b(A_b-\mu\tan\beta) \\ & & & & & m^2_{\tilde b_R} \end{pmatrix}$$

LHC, ILC - HE frontier

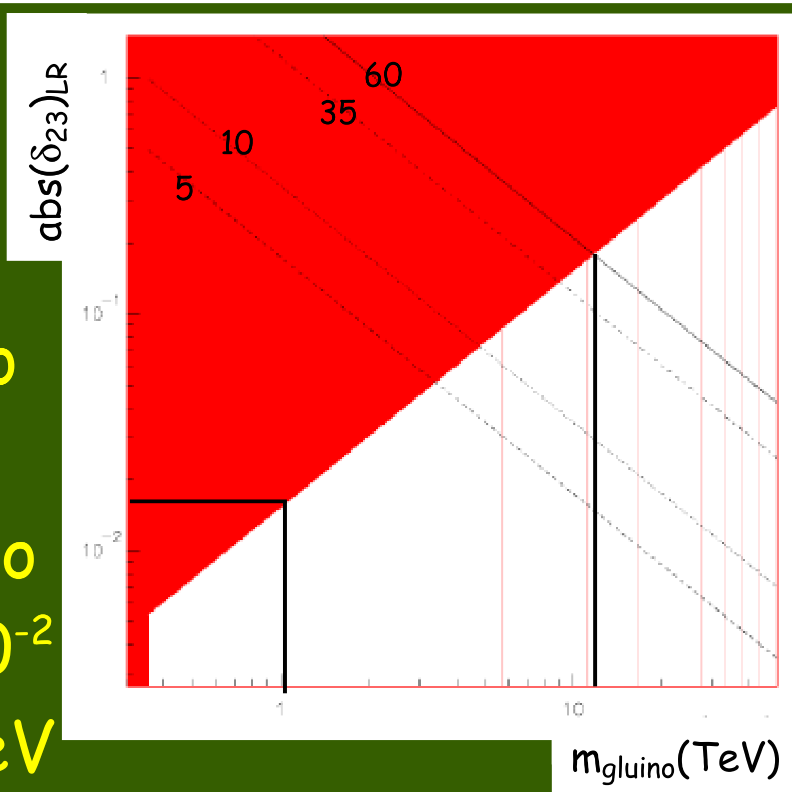
Mass Insertions

$(\delta^d_{ij})_{AB} = (\Delta^d_{ij})_{AB}/m_{\tilde q}^2$

3σ from 0 sensitivity plot

i) sensit. to $\Lambda<20$ TeV

ii) sensit. to $|(\delta^d_{23})_{LR}|>10^{-2}$ for $\Lambda<1$ TeV

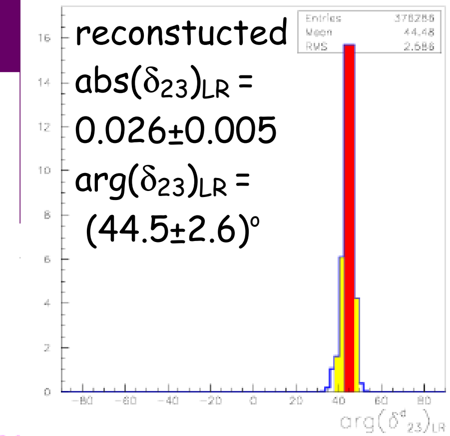


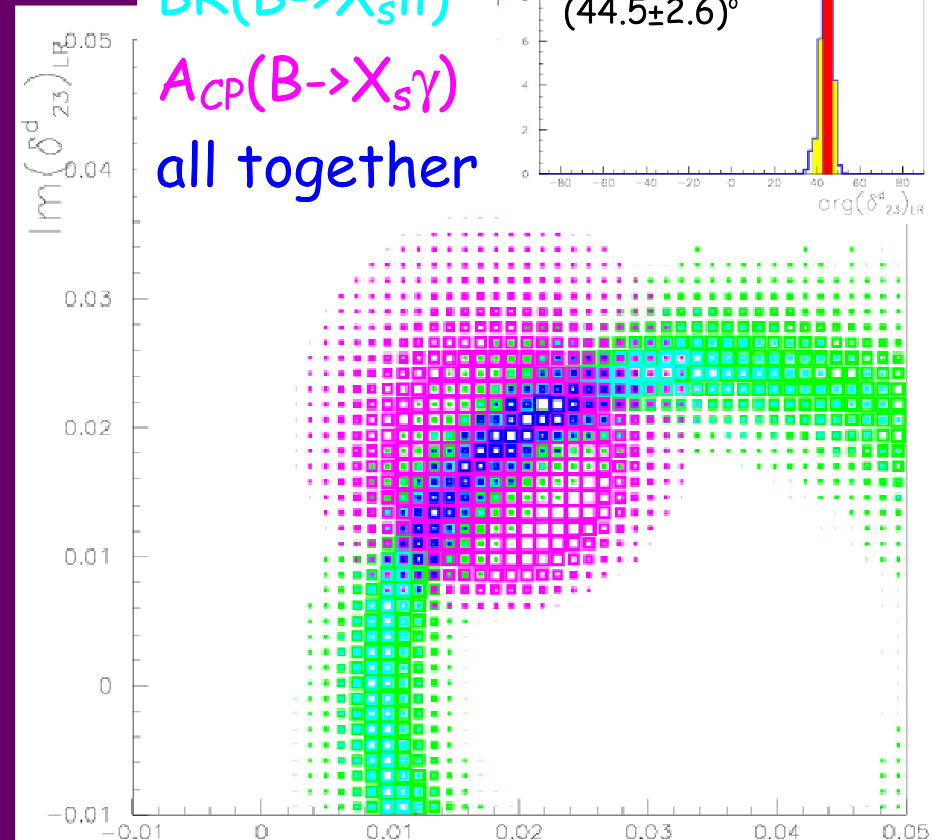
BR(B->Xsγ)

BR(B->Xsll)

ACP(B->Xsγ)

all together





$Im(\delta^d_{23})_{LR}$ vs $Re(\delta^d_{23})_{LR}$

Reconstruction of $(\delta^d_{23})_{LR}=0.028\ e^{i\pi/4}$ for $\Lambda = m_{\tilde g} = m_{\tilde q} = 1$ TeV

Theory keeps up...

- lattice QCD can reach the O(1%) precision goal in time
- some progress for inclusive techniques for SL B decays
- non-leptonic B decays more problematic

Measurement	Hadronic Parameter	Present Error	6 TFlops	60 TFlops	1-10 PFlops (Year 2015)
$K \to \pi l \nu$	$f_+^{K\pi}(0)$	0.9 %	0.7 %	0.4 %	< 0.1 %
ε_K	$\hat{B}_K$	11 %	5 %	3 %	1 %
$B \to l \nu$	f_B	14 %	3.5-4.5 %	2.5-4.0 %	1.0-1.5 %
Δm_d	$f_{Bs}\sqrt{B_{B_s}}$	13 %	4-5 %	3-4 %	1-1.5 %
$\Delta m_d/\Delta m_s$	ξ	5 %	3 %	1.5-2 %	0.5-0.8 %
$B \to D/D^* l \nu$	$\mathcal{F}_{B\to D/D^*}$	4 %	2 %	1.2 %	0.5 %
$B \to \pi/\rho l \nu$	$f_+^{B\pi}, \dots$	11 %	5.5-6.5 %	4-5 %	2-3 %
$B \to K^*/\rho (\gamma, l^+ l^-)$	$T_1^{B\to K^*/\rho}$	13 %	——	——	3-4 %

V. Lubicz, 4th SuperB Workshop and SuperB CDR

Conclusions (ii)

Only part of the SuperB physics program relies on theory upgrades. For this part, theoretical errors of O(1-2%) are needed: feasible for LQCD; challenging but possibly reachable in inclusive measurements; factorization needs checking on channel basis

SuperB and S-LHCb physics programs are largely complementary. As for the part in common, they are competitive but SuperB can measure more and th. cleaner channels

An issue to debate: 10^{36} vs 10^{35}

we plan to complete the exercise for B physics during this week. Yet O(1) differences on accessible scales and couplings can be anticipated

although any such difference could be crucial, they are likely not very impressive to present and difficult to defend, given the intrinsic uncertainty of the EFT approach which was heavily used

we should look for qualitative differences in the physics that can be done with 75/ab vs the physics possible with say 10-15/ab

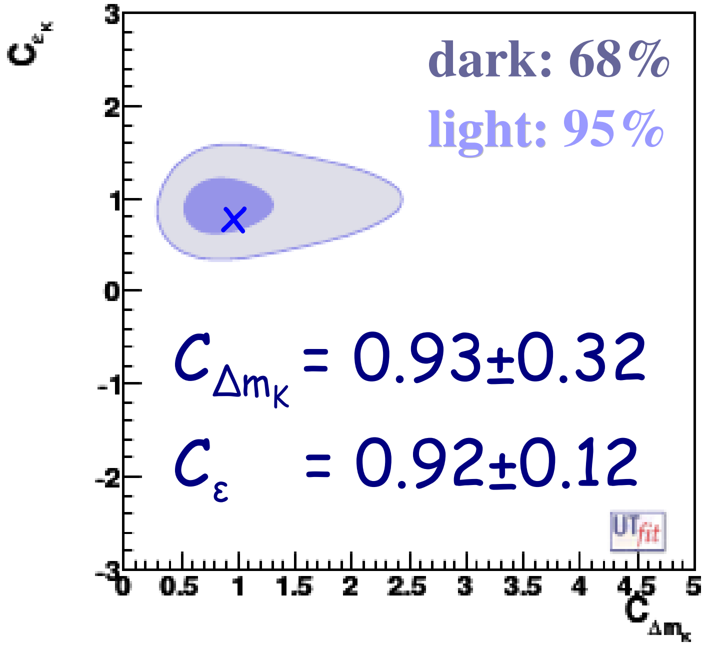
This means that we have to look at qualifying points which are difficult to achieve even at 10^{36}!

A couple comes to my mind:

i) the "full LHC" label, i.e. the possibility to to measure flavour effects in the whole LHC discovery energy range, fully playing the complementarity game with high-pT searches

ii) the possibility of measuring theoretically interesting values of LFV BRs and of being complementary with the MEG measurement

These goals are not attainable with 10^{35} but we have to clearly show that they are at SuperB



dark: 68%
light: 95%
$C_{\Delta m_K} = 0.93 \pm 0.32$
$C_{\varepsilon} = 0.92 \pm 0.12$
C_{ε_K}
$C_{\Delta m_K}$
UTfit

Minimal Flavour Violation (i)

$$\mathcal{L}_{\mathrm{SM}} = \mathcal{L}_{\mathrm{gauge}} + \mathcal{L}_{\mathrm{Higgs}} + \mathcal{L}_{\mathrm{Yukawa}}$$

$\mathcal{L}_{\mathrm{gauge}} + \mathcal{L}_{\mathrm{Higgs}}$ invariant under the global symmetry

$$U(3)^5 = SU(3)_{Q_L} \times SU(3)_{U_R} \times SU(3)_{D_R} \times \ldots$$

$\mathcal{L}_{\mathrm{Yukawa}} = \bar{Q}_L\, Y_U\, U_R \tilde{\varphi} + \bar{Q}_L\, Y_D\, D_R \varphi + \ldots$ is formally invariant if $Y_U = (3,\bar{3},1)$ and $Y_D = (3,1,\bar{3})$ (spurions)

MFV hypothesis: NP operators (built out of the SM and spurion fields) must be invariant under the global symmetry

D'Ambrosio et al., NPB645 (2002)

Minimal Flavour Violation (ii)

Chivukula,Giorgi,PLB188(1987)
Hall,Randall,PRL65 (1990)
Gabrielli,Giudice,NPB433 (1995)
Gabrielli,MC,Giudice, PLB388 (1998)
Buras et al., NPB500 (2001)

No new sources of flavour and CP violation beyond the SM

- NP contributions governed by SM Yukawa couplings
  ex.: small-tanβ CMSSM and mSUGRA, Universal χDim, LHM
- NP only modifies SM top contribution to FCNC & CPV
  unless other Yukawa couplings are enhanced; for example large tanβ in 2HDM enhances bottom contributions

1HDM/2HDM at small tanβ	2HDM at large tanβ
same operators as in H_{eff}^{SM}	new operators wrt H_{eff}^{SM}
NP in K and B correlated	NP in K and B uncorrelated