Rare B and D decays, and supersymmetry

Gino Isidori
[*INFN, Frascati & CERN*]

- News from the high-energy frontier
- The role of $B_{s,d} \to \mu\mu$
- Shedding light on CPV in charm via radiative D decays
- Conclusions

News from the high-energy frontier (the "natural" SUSY spectrum)

The recent searches for new physics at the high-energy frontier can be (*roughly...*) summarized by two main messages:

- The Higgs boson is likely to be around 125 GeV (*in the "SUSY" region...*)
- No large signal of physics beyond the SM in pp collisions at 7 TeV.

News from the high-energy frontier (the "natural" SUSY spectrum)

The recent searches for new physics at the high-energy frontier can be (*roughly...*) summarized by two main messages:

- The Higgs boson is likely to be around 125 GeV (*in the "SUSY" region...*)
- No large signal of physics beyond the SM in pp collisions at 7 TeV.

⬇

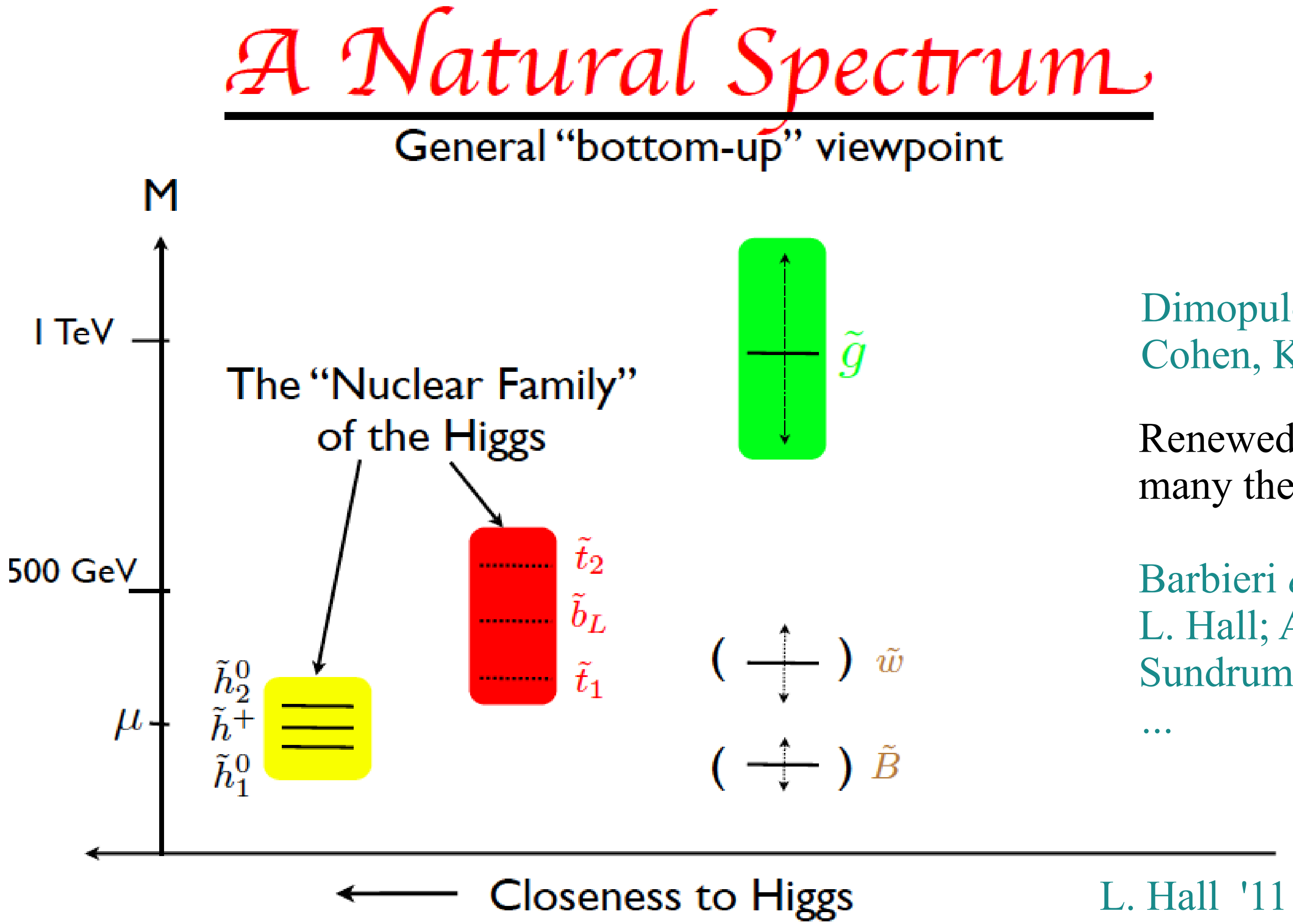
Supersymmetry remains a very good candidate (*shares of supersymmetry are definitely rising with respect to those of composite-Higgs models or extra-dimensions*): weakly coupled theory + light Higgs

But the SUSY spectrum cannot be (almost) degenerate, as in the most popular versions of the MSSM, and in MFV (otherwise too-large fine-tuning in m_h).

⬇

Supersymmetry with "split families" (3^{rd} gen. light, 1^{st} & 2^{nd} well above 1 TeV) is emerging as a very appealing possibility

▶ <u>*News from the high-energy frontier*</u> (the "natural" SUSY spectrum)



Dimopulos, Giudice, '95
Cohen, Kaplan, Nelson '96

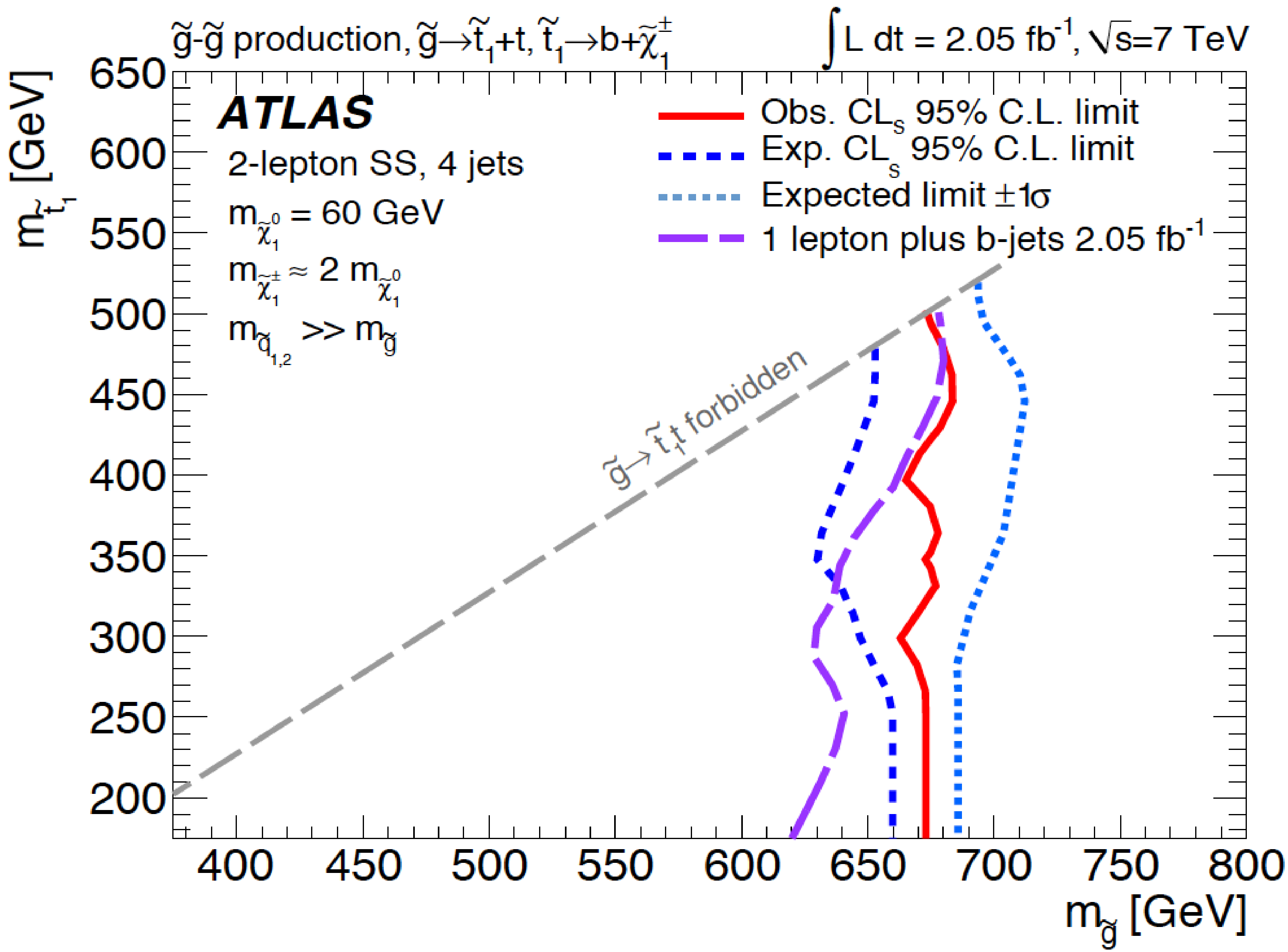
Renewed recent interest by many theorists:

Barbieri *et al.*,
L. Hall; Arkani-Hamed, Sundrum *et al.*
...

→ *Andi's talk*

- Only 3rd gen. squarks and Higgsinos need to be light to avoid tuning (in m_h)
- With heavy 1st & 2nd gen. squarks less "flavour problem" + easy to escape susy searches at LHC

▶ News from the high-energy frontier (the “natural” SUSY spectrum)



News from the high-energy frontier (the "natural" SUSY spectrum)

SUSY with split families does not fit well with the idea of MFV (at least in its minimal version), which would predict an almost degenerate squark spectrum (small splitting due to Yukawa couplings).

However, it offers an interesting prospects for

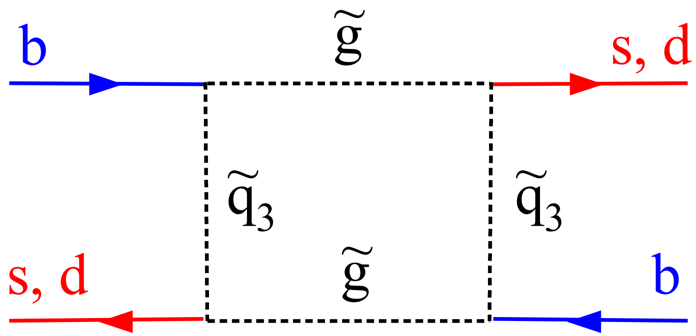
- solving some of the open problems of MFV
- addressing the existing anomalies in the quark sector (ε_K vs. $\sin(2\beta)$ tension & Δa_{CP})
- observing clear non-standard signals in other observables, such as $B\to\mu\mu$ and radiative D decays

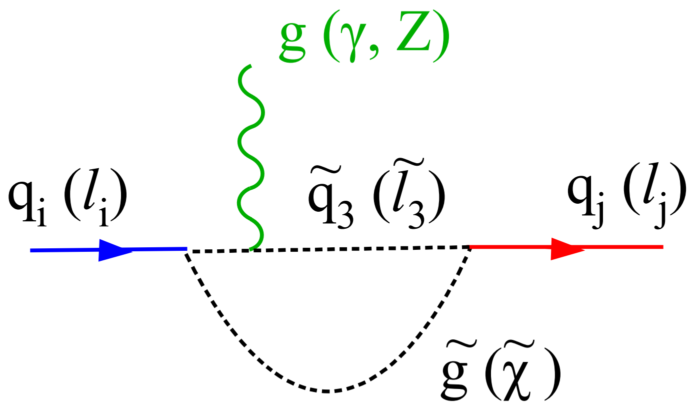
⬇

Low-energy flavor physics is definitely non trivial

Potentially visible non-standard effects mediated by the exchange of the 3rd generation of squarks (and possibly sleptons):

E.g.:



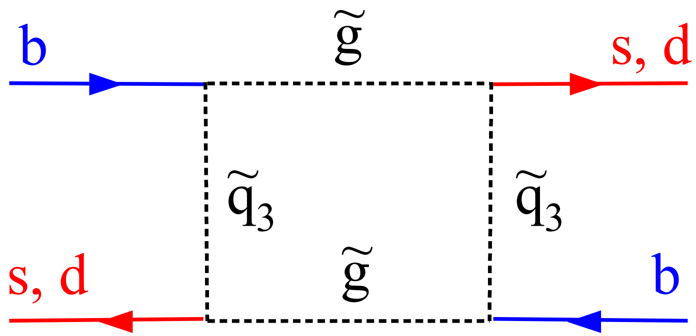


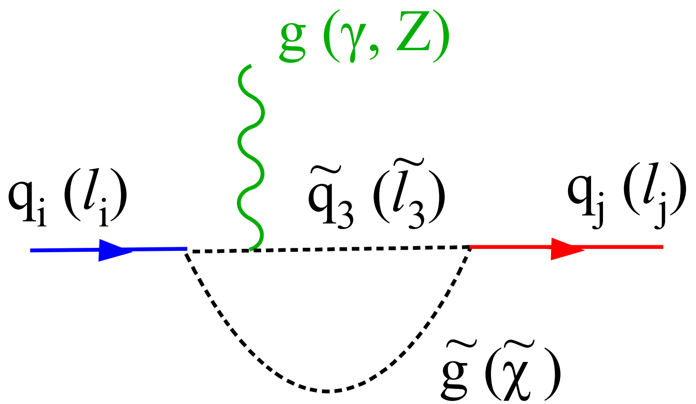
Possible solution of the "ε_K - sin(2β) tension"

Possible sizable contribution to Δa_{CP} but also rare B and D decays, LFV & edms

Potentially visible non-standard effects mediated by the exchange of the 3rd generation of squarks (and possibly sleptons):

E.g.:





Particularly interesting set-up provided by:

Giudice, G.I., Paradisi '12
Hiller, Hochberg, Nir '12
[Nomura, Stolarski, '08-'09]

$\boxed{\text{Split family SUSY with “disoriented A terms”}}$

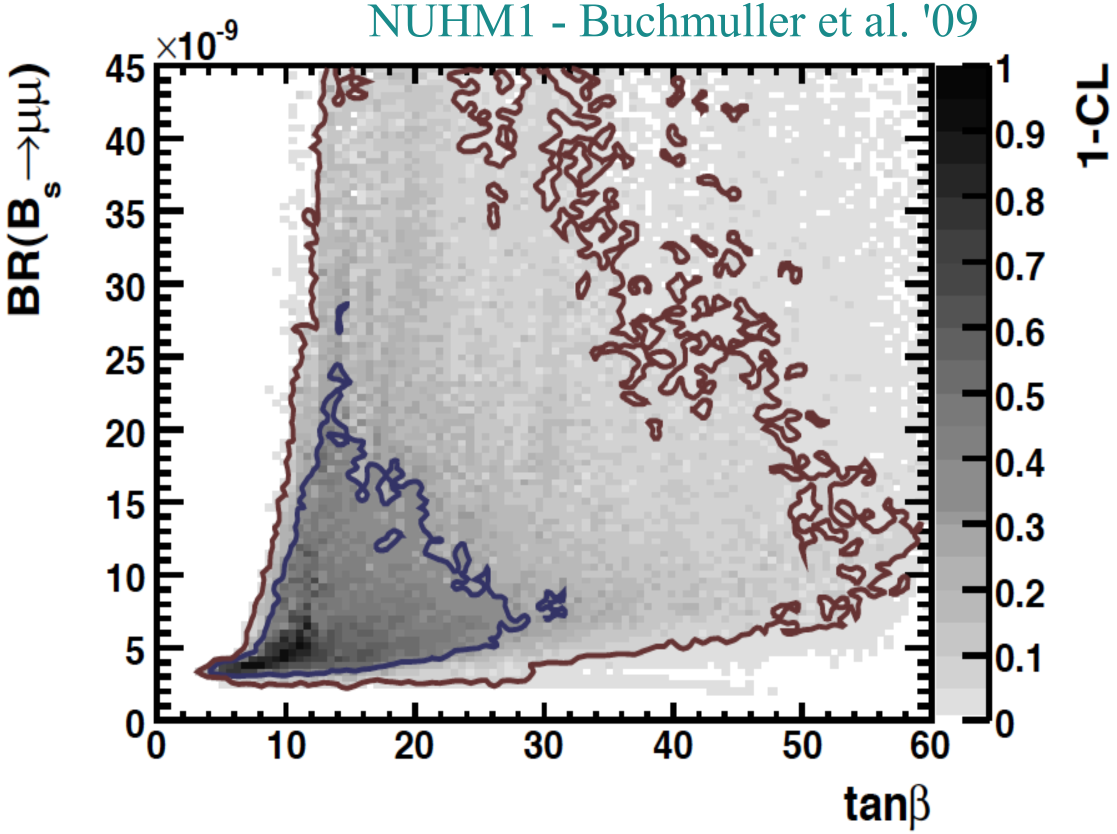
- The origin of flavor is all “confined” in the L-R mixing (Yukawas & A terms)
- Y & A are both proportional to quark & lepton masses, but are not aligned: large sources of flavor-symmetry break. compatible with existing bounds.

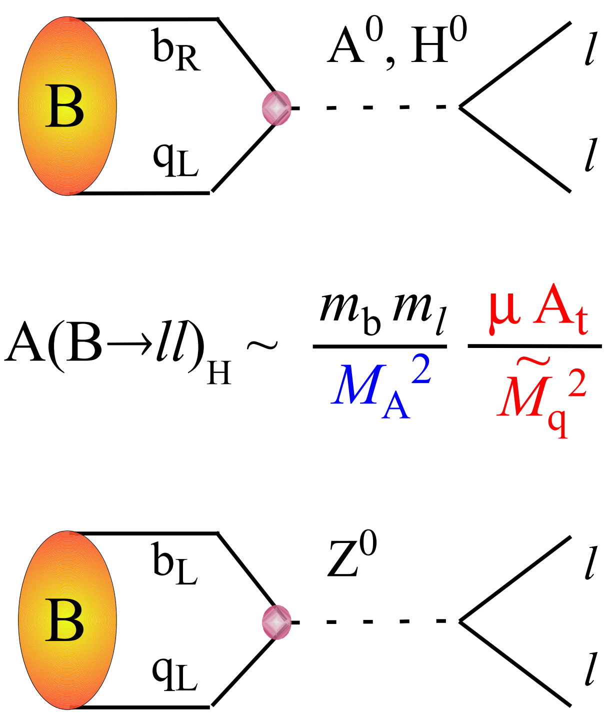
The role of $B_{s,d} \to \mu\mu$

This mode is a unique source of information about flavor physics beyond the SM:

- theoretically very clean (virtually no long-distance contributions)
- particularly sensitive to FCNC *scalar currents* and FCNC *Z penguins*

NUHM1 - Buchmuller et al. '09





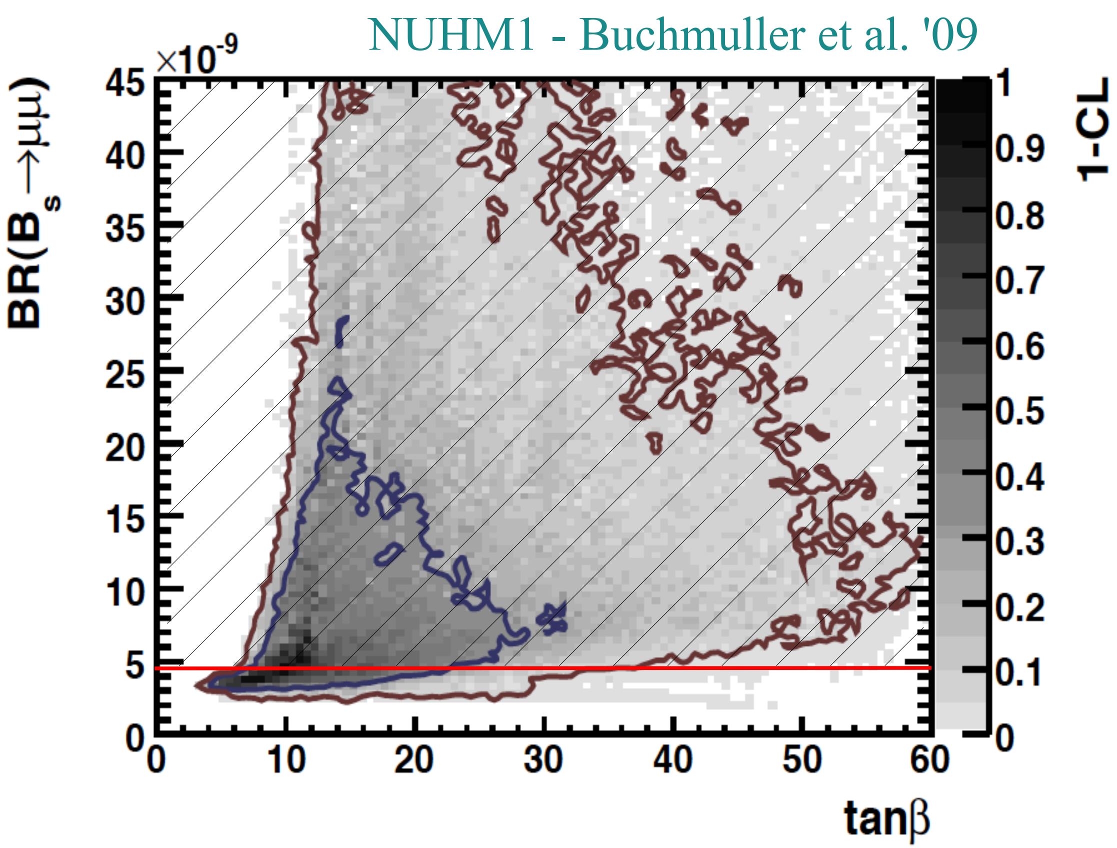
$$A(B\to ll)_H \sim \frac{m_b\, m_l}{M_A^2}\;\frac{\mu\, A_t}{\tilde{M}_q^2}\;\tan^3\beta$$

Relevant for $B(B\to ll) = O(SM)$

The role of $B_{s,d} \to \mu\mu$

This mode is a unique source of information about flavor physics beyond the SM:

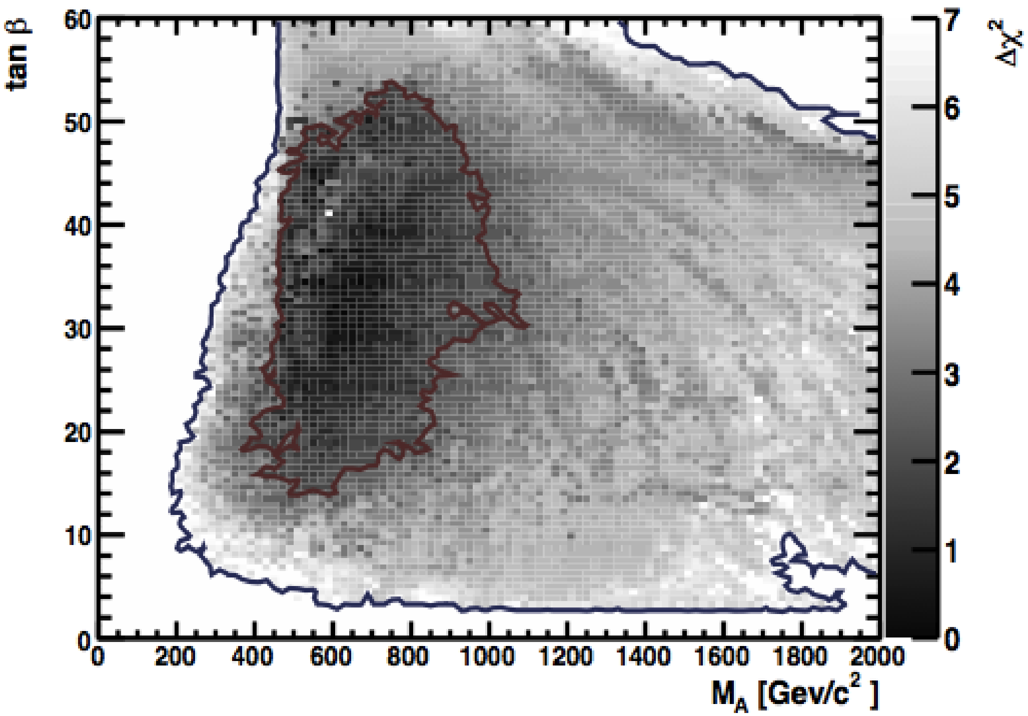
- theoretically very clean (virtually no long-distance contributions)
- particularly sensitive to FCNC *scalar currents* and FCNC *Z penguins*



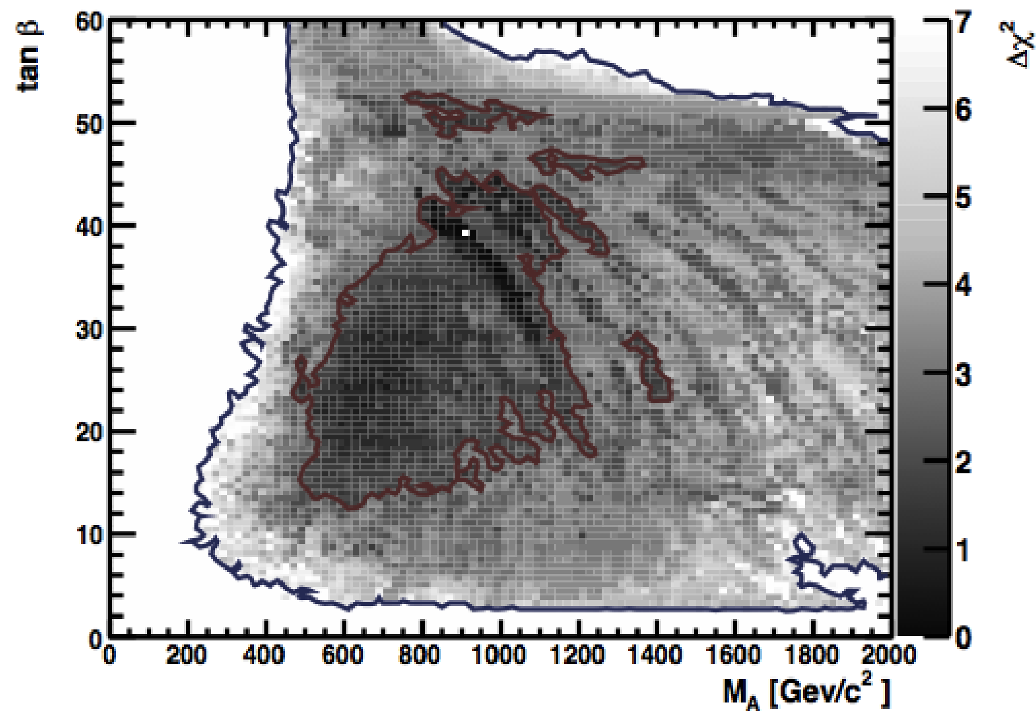
The possibility of large FCNC scalar currents (occurring in SUSY for low M_A and large $\tan\beta$) is essentially ruled out

The role of $B_{s,d} \to \mu\mu$

NUHM1 scenario within the MSSM:



Summer '11



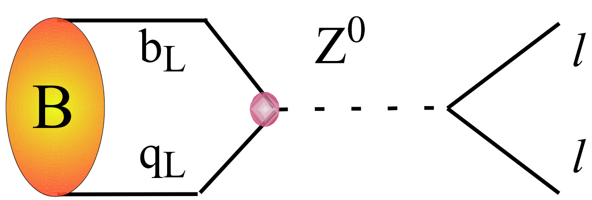
Inclusion of winter '12 results on $B_{s,d} \to \mu\mu$

The role of $B_{s,d} \to \mu\mu$

The fact we don't see large enhancements over the SM does not mean this decay mode is becoming less interesting.... !!

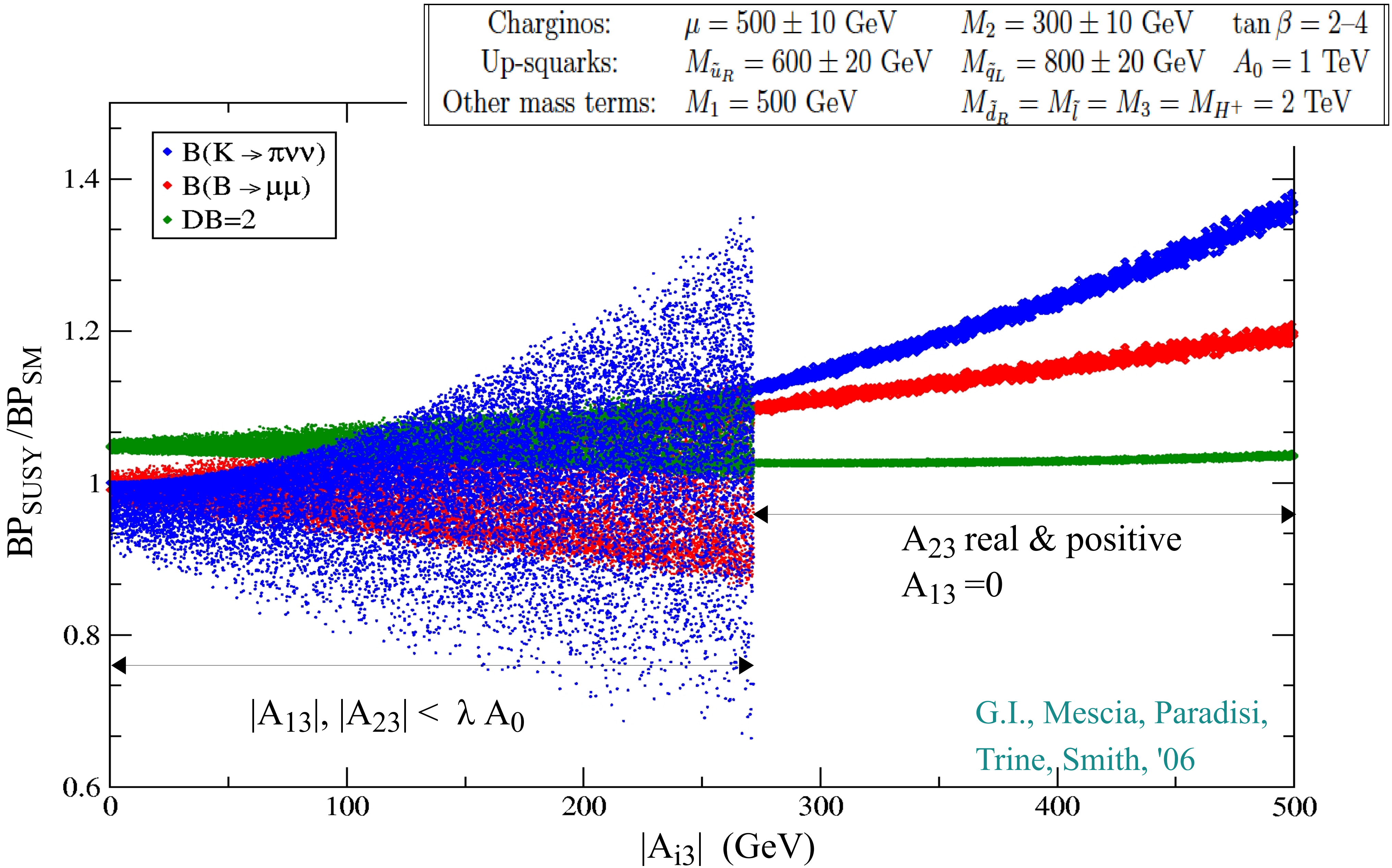
On the contrary, we are entering a regime where different type of amplitudes can affect the BR (not only scalar FCNC's)

E.g.: Split-SUSY with disoriented A terms



Relevant for $B(B\to ll) = O(SM)$

The role of $B_{s,d} \to \mu\mu$



The role of $B_{s,d} \to \mu\mu$

The fact we don't see large enhancements over the SM does not mean this decay mode is becoming less interesting.... !!

On the contrary, we are entering a regime where different type of amplitudes can affect the BR (not only scalar FCNC's).

⬇

Still a long way to go (and a lot to learn) before being saturated by the theory error

(which is likely to reach the 5% level with the help of Lattice)

Shedding light on CPV in charm via radiative D decays

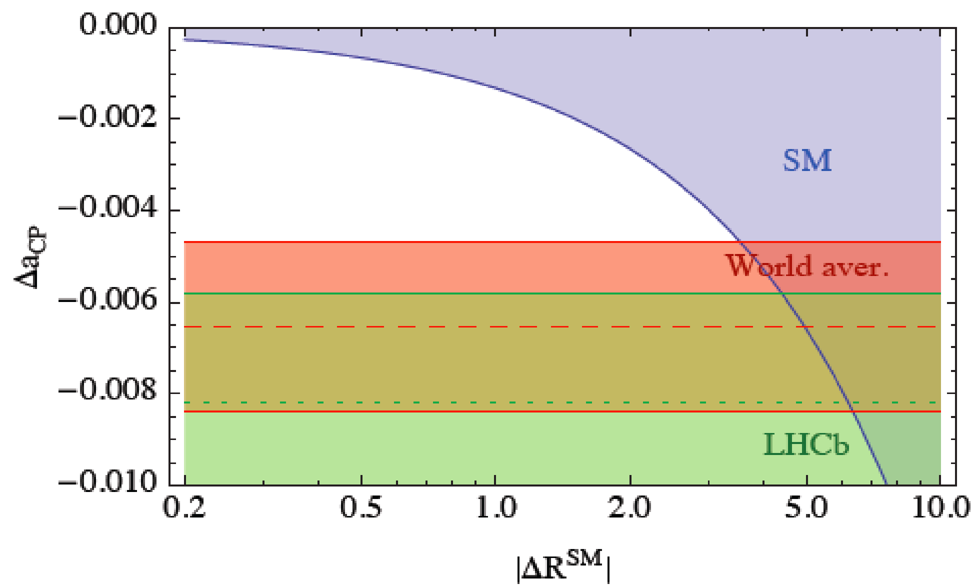
The recently observed direct CPV asymmetry in DPP decays (Δa_{CP}) is a "charming puzzle":

- It is too large compared to its naïve SM expectation, but is not large enough (compared to SM uncertainties) to be considered a clear signal of NP.

$$\Delta a_{CP} \approx (0.13\%)\mathrm{Im}(\Delta R^{\mathrm{SM}})$$

Model-independent suppression due to CKM structure

Ratio of "penguin" disconnedted/treel-level amplitudes (naivley expected < 1)



G.I., Kamenik, Ligeti, Perez '11

$$a_{CP}^{(\mathrm{dir})} = \frac{\Gamma(D\to PP) - \Gamma(\overline{D}\to PP)}{\Gamma(D\to PP) + \Gamma(\overline{D}\to PP)}$$

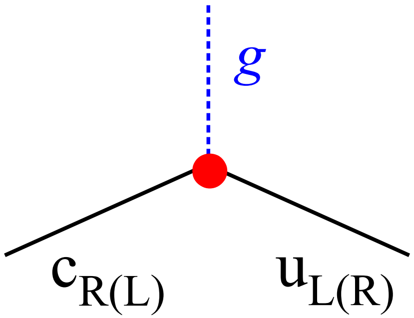
Shedding light on CPV in charm via radiative D decays

The recently observed direct CPV asymmetry in DPP decays (Δa_{CP}) is a "charming puzzle":

- It is too large compared to its naïve SM expectation, but is not large enough (compared to SM uncertainties) to be considered a clear signal of NP.

- It fits well in a wide class of NP models (including SUSY) predicting sizable CPV in *chromo-maganetic* operators (Q_8 & Q_8').

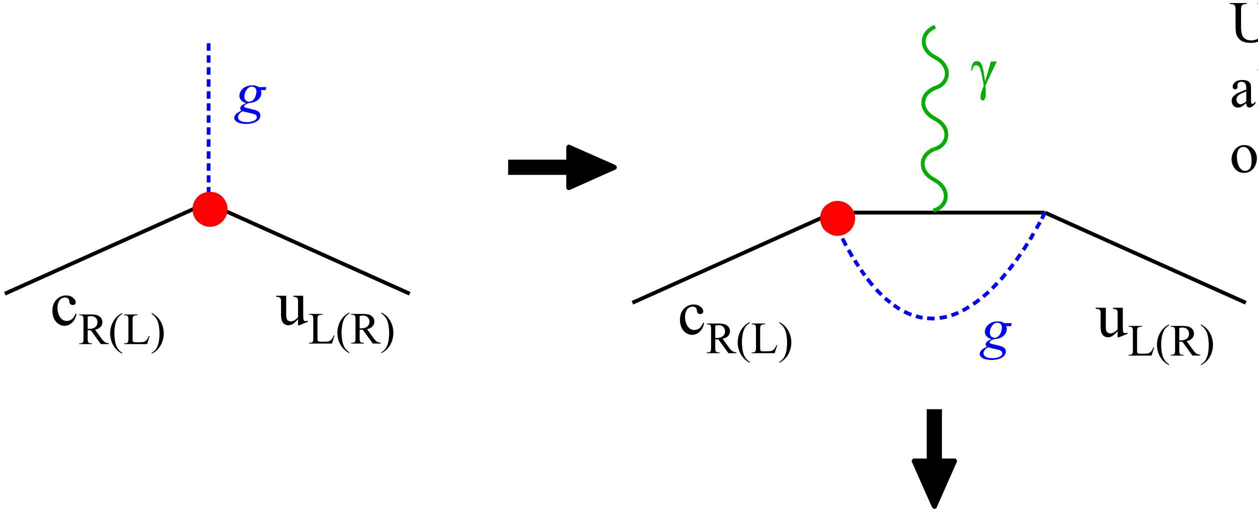
→ Riccardo's talk



Shedding light on CPV in charm via radiative D decays

The recently observed direct CPV asymmetry in DPP decays (Δa_{CP}) is a "charming puzzle":

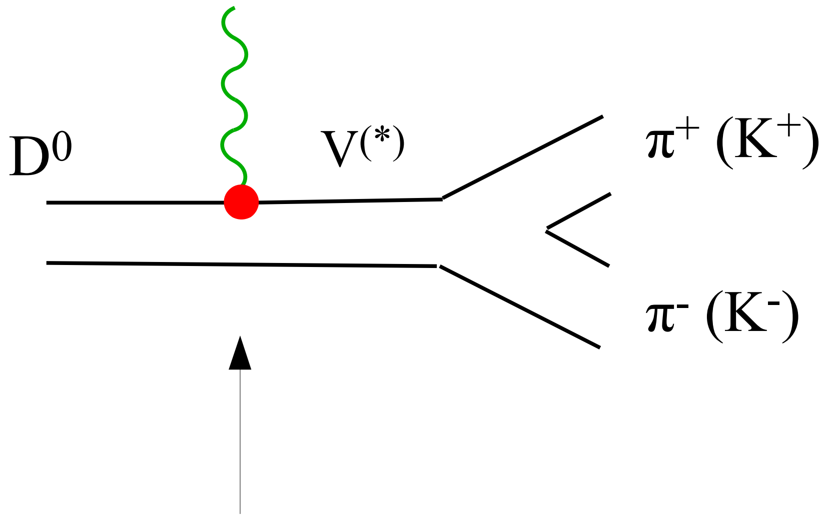
- It is too large compared to its naïve SM expectation, but is not large enough (compared to SM uncertainties) to be considered a clear signal of NP.
- It fits well in a wide class of NP models (including SUSY) predicting sizable CPV in *chromo-maganetic* operators (Q_8 & Q_8').



Unavoidable large CPV also in the *electric-dipole* operators (Q_7 & Q_7')

- Radiative SCS D decays, especially $D \to (P^+P^-)_V \gamma$, could help to shed light on the issue.

Shedding light on CPV in charm via radiative D decays



Relatively clean short-distance CPV amplitude due to $\langle Q_7 \rangle$:

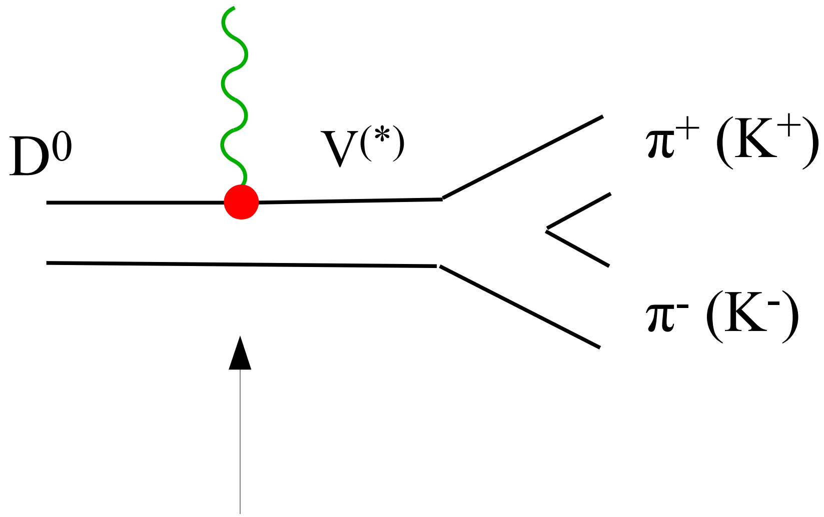
sub-leading in the rates (10^{-7}-10^{-8}), but large enough to generate O(few%) CPV asymmetry when interfering with the (approximately CPC) SM amplitude

SM amplitude dominated by long-distance VMD-type contributions:

$\rho^0\gamma$	< 2.4	$\times 10^{-4}$ CL=90%
$\omega\gamma$	< 2.4	$\times 10^{-4}$ CL=90%
$\phi\gamma$	$(2.69 \pm 0.35) \times 10^{-5}$	
$\overline{K}^*(892)^0\gamma$	$(3.27 \pm 0.34) \times 10^{-4}$	

$$\frac{\mathcal{B}(D^0 \to \phi\gamma)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma)} \approx \frac{\mathcal{B}(D^0 \to \phi\rho^0)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\rho^0)}$$

Shedding light on CPV in charm via radiative D decays



Relative weight of NP substantially higher than in D→PP
(*if NP appears mainly in Q_7 & Q_8*)

Relatively clean short-distance CPV amplitude due to $\langle Q_7 \rangle$:

sub-leading in the rates (10^{-7}-10^{-8}), but large enough to generate O(few%) CPV asymmetry when interfering with the (approximately CPC) SM amplitude

SM amplitude dominated by long-distance VMD-type contributions:

$\rho^0\gamma$	< 2.4	$\times 10^{-4}$ CL=90%
$\omega\gamma$	< 2.4	$\times 10^{-4}$ CL=90%
$\phi\gamma$	$(2.69 \pm 0.35) \times 10^{-5}$	
$\overline{K}^*(892)^0\gamma$	$(3.27 \pm 0.34) \times 10^{-4}$	

$$\frac{\mathcal{B}(D^0 \to \phi\gamma)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\gamma)} \approx \frac{\mathcal{B}(D^0 \to \phi\rho^0)}{\mathcal{B}(D^0 \to \bar{K}^{*0}\rho^0)}$$

Shedding light on CPV in charm via radiative D decays

Estimating $a_{CP}(D\to V\gamma)$ assuming $a_{CP}(D\to PP)$ is NP dominated via $\langle Q_8 \rangle$:

1) Extraction of $\mathrm{Im}C_8$ from $a_{CP}(D\to PP)$ [O(1) uncertainty because of $\langle Q_8 \rangle$]
2) RGE evolution to determine $\mathrm{Im}C_7$ [small uncertainty]
3) CPV short-distance amplitude due to $\langle Q_7 \rangle$ [O(30%) uncertainty]
4) Interference with the long-dist. amplitude [largest uncertainty: strong phases]

Shedding light on CPV in charm via radiative D decays

Estimating $a_{CP}(D\to V\gamma)$ assuming $a_{CP}(D\to PP)$ is NP dominated via $\langle Q_8\rangle$:

1) Extraction of $\mathrm{Im}C_8$ from $a_{CP}(D\to PP)$ [O(1) uncertainty because of $\langle Q_8\rangle$]
2) RGE evolution to determine $\mathrm{Im}C_7$ [small uncertainty]
3) CPV short-distance amplitude due to $\langle Q_7\rangle$ [O(30%) uncertainty]
4) Interference with the long-dist. amplitude [largest uncertainty: strong phases]

$\downarrow$

We can estimate reliable upper-bounds on
$\Delta a_{CP}(D\to V\gamma) = a_{CP}(D\to V\gamma) - a_{CP}(D\to K^{0*}\gamma)$

$\Delta a_{CP}(D\to \omega\gamma)^{max} \sim 10\%$

$\Delta a_{CP}(D\to \rho\gamma)^{max} \sim 5\%$

$\Delta a_{CP}(D\to "\phi"\gamma)^{max} \sim 3\%$

PRELIMINARY [work in prog.]

About 1 order of magnitude above $\Delta a_{CP}(D\to PP)$!

$\longrightarrow$ If these bounds were saturated, we would clearly establish NP and we would even (partly) understand its nature.

Shedding light on CPV in charm via radiative D decays

Estimating $a_{CP}(D\to V\gamma)$ assuming $a_{CP}(D\to PP)$ is NP dominated via $\langle Q_8\rangle$:

1) Extraction of $\mathrm{Im}C_8$ from $a_{CP}(D\to PP)$ [O(1) uncertainty because of $\langle Q_8\rangle$]
2) RGE evolution to determine $\mathrm{Im}C_7$ [small uncertainty]
3) CPV short-distance amplitude due to $\langle Q_7\rangle$ [O(30%) uncertainty]
4) Interference with the long-dist. amplitude [largest uncertainty: strong phases]

$\downarrow$

We can estimate reliable upper-bounds on
$\Delta a_{CP}(D\to V\gamma) = a_{CP}(D\to V\gamma) - a_{CP}(D\to K^{0*}\gamma)$

$\Delta a_{CP}(D\to \omega\gamma)^{max} \sim 10\%$

$\Delta a_{CP}(D\to \rho\gamma)^{max} \sim 5\%$

$\Delta a_{CP}(D\to "\phi"\gamma)^{max} \sim 3\%$

N.B.:

- The $|P^+P^-\gamma_{soft}\rangle$ final state could replace $|K^{0*}\gamma\rangle$ for the subtraction
- In the $|(K^+K^-)_\phi\gamma\rangle$ case the largest CP asym. is expected slightly above the ϕ peak
- In general, a full Dalitz plot analysis for M_{PP} = 0.7-1.2 GeV could help to maximize the CPV signal

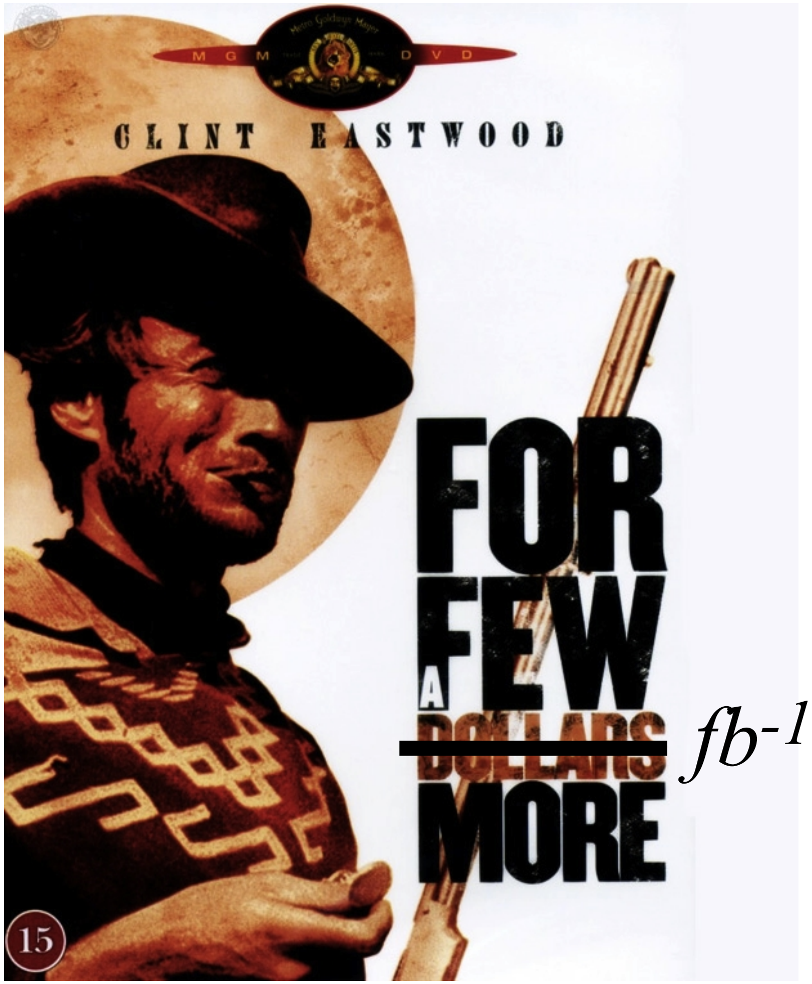
▶ *Conclusions* (following Tim's recommendation...):

news:
NP could hide in Δa_{CP} & $B \to \mu\mu$

news:
could all be SM...

news:
so far QCD and stat. errors prevent us to understand...

▶ *Conclusions* (following Tim's recommendation...):



fb^{-1}

news:
NP could hide in Δa_{CP} & $B\to\mu\mu$

news:
could all be SM...

news:
so far QCD and stat. errors prevent us to understand...

That's why we need the LHCb upgrade!