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Flavor Physics - IV

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New Physics searches within Flavour Physics

The SM turns out to be very successful
in describing essentially all processes
But
It is expecetd to be an effective theory valid up to a cutoff scale
as it has some important limits

- The SM is a quantum theory for strong and electroweak interactions but NOT for gravitation (quantum effecs in gravitation are expected to become important at very high energies (M_{Pl}~10^{23} GeV))
- There is cosmological evidence of Dark Matter (not made up of SM particles) in the Universe
- …

•...

•In order to explain the dominance of matter over anti-matter in the Universe it is crucial to have CP-violation: the phase in the CKM matrix is not enough to explain the required amount for baryogenesis

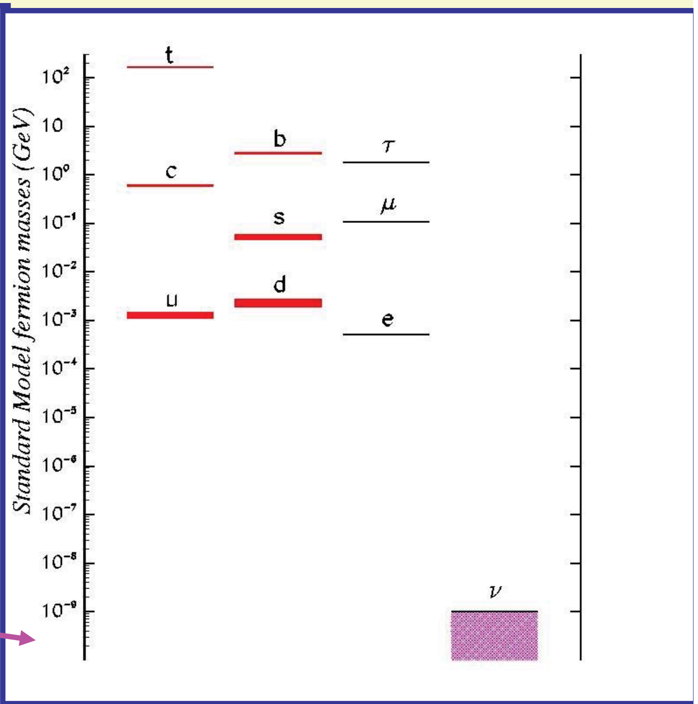
•In the SM the Higgs mass receives large radiative corrections, quadratic in the cutoff $\Lambda \sim M_{Pl} \sim 10^{23}$ GeV (energy scale where the SM fails).
In order to have a Higgs mass of O(100 GeV) as known indirectly from electroweak precision tests, an innatural fine-tuning is required (hierarchy problem)

•In the SM neutrinos (ν) are assumed massless while the evidence of oscillations shows that they are massive. The most credited mechanism to generate ν masses is the so called SEE-SAW, where ν masses are small because inversely proportional to a large scale.
It is reasonable to identify this scale with a NP scale where strong and electroweak interactions unify (GRAND-UNIFICATION)

•...

And, in particular, our understanding of flavour is UNSATISFACTORY

- The SM has too many unpredicted parameters to be fundamental (10 only in the quark sector)
- The CKM matrix turns out to be very hierarchical (while this is not the case for the PMNS matrix in the lepton sector)
- The quark masses have a very peculiar pattern (over 5 orders of magnitude)
- The number of families (3) remains unexplained



It is reasonable and desirable to think that an explanation is provided by New Physics (NP) beyond the SM!

Moreover, the solution doesn't seem to be trivial:
the FLAVOUR PROBLEM

"NP is expected at the TeV scale
(in order to solve the hierarchy problem)
but in flavour processes NP effects are not observed
(hinting for NP at higher scales)"

$\Downarrow$

The flavour structure of the NP model
cannot be generic

The most appealing and studied NP Models

(the elegant) SuperSymmetry (SUSY)

- It is a symmetry that relates the SM elementary particles to other particles that differ by half a unit of spin (known as superpartners)
- If SUSY were exact partners and superpartners would have the same mass, but superpartners have never been observed, then SUSY has to be broken
- The presence of superpartners solves the hierarchy problem by canceling quadratic radiative corrections to the Higgs mass
- The lightest superpartner can be a candidate for dark matter
- SUSY improves the unification of the strong and electroweak couplings w.r.t. the SM, providing a framework where Grand-Unification works well
- Susy is required in String Theory

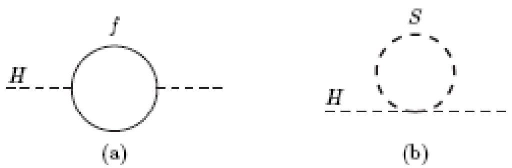
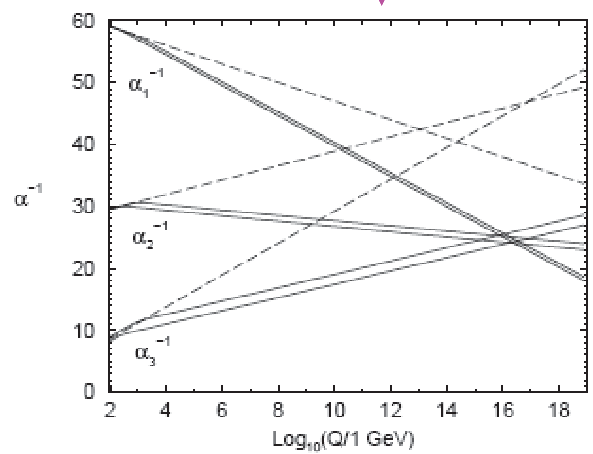
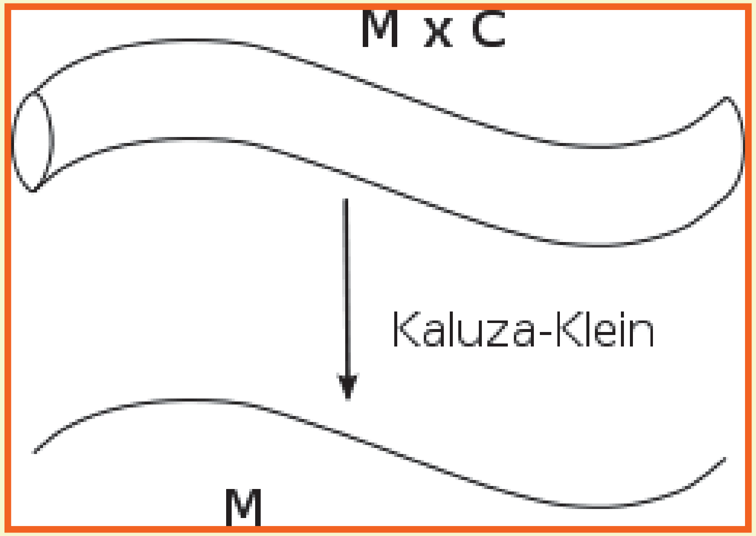


Figure 1.1: One-loop quantum corrections to the Higgs squared mass parameter m_H^2, due to (a) a Dirac fermion f, and (b) a scalar S.

Figure 5.8: RG evolution of the inverse gauge couplings $\alpha_a^{-1}(Q)$ in the Standard Model (dashed lines) and the MSSM (solid lines). In the MSSM case, the sparticle mass thresholds are varied between 250 GeV and 1 TeV, and $\alpha_3(m_Z)$ between 0.113 and 0.123. Two-loop effects are included.



(the revolutionary)
Extra-Dimensions (ED)



- It is based on the idea of having more than 3 spatial dimensions, with the additional dimensions being compactified

- It allows to describe gravity together with electroweak and strong interactions, in spite of the surprising weakness of gravity.

Gravity is the only interaction to live in the extra-dimensions. Gravity could then be equally strong as the other three forces, but thinly spread throughout many dimensions

- In the 3 spatial dimensions that we experience, the ED effectively manifest with new particles (Kaluza-Klein)

- The lightest Kaluza-Klein can be a candidate for dark matter

- ED are required in String Theory

(the strong)

Technicolor

1. There is not the SM Higgs (which has the hierarchy problem)

2. There is a new (higher scale) strong interaction similar to QCD

3. the new TechniPions generate masses

- EWPT and even more Flavour constraints put the Technicolor in troubles

- Modern version of TC:
  walking TC (nearly-conformal 4d strongly coupled theory AdS/CFT
  corresponding to a weakly coupled 5d theory,
  having peculiar anomalous dimension of techni-operators
  that suppresses NP effects in Flavour)

(the focused)

Little Higgs Models

1. The light Higgs is interpreted as a pseudoGoldstone boson of a spontaneously broken global symmetry (G)

2. Gauge and Yukawa couplings of the Higgs are introduced by gauging a subgroup of G

3. ``Dangerous´´ quadratic corrections are avoided at one-loop through Collective Symmetry Breaking
(the Higgs becomes massive only when two couplings are non-vanishing)

- The Higgs dynamics is described (similarly to ChPT) by a non-linear sigma model up to Λ ~10TeV
- The UV completion is unknown (another LH?,SUSY?,ED?)

(the extended)
Z' Models

1. The gauge symmetry is extended (e.g. a further SU(2), U(1),…)
2. New heavy gauge bosons appear
3. They mix with the SM gauge bosons, thus modifying couplings
4. Extra fermions and scalars might also exist
5. Several NP Models predict new heavy gauge bosons

- Tevatron has set the lower bound $M_{Z'} \geq 600\text{-}700$ GeV (for Z' which couple to leptons too)

(the why-not?)
Fourth Generation

•It is based on the idea of having a 4° generation of quarks (and leptons):
(t'_L, b'_L), t'_R, b'_R , with $m_{t'} \approx 300\text{-}600$ GeV, $m_{b'} \approx m_{t'} - 50$ GeV (from EWPT)

•The CKM matrix is 4x4, with 3 new mixing angles and 2 new phases

•It would remove the tension in the Higgs mass between direct lower bound and indirect constraints

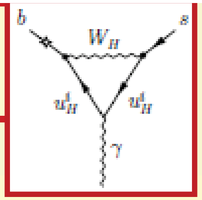
•It would help gauge coupling unification

•It would introduce new sources of CP-violation for barygenesis

The NP (classes of) models
I have mentioned are probably
the most studied
but other NP models exist…

How to search for NP effects within Flavour Phsycs: an effective theory approach

Beyond the SM



within MFV

$$H_{eff}^{NP} = \frac{G_F}{\sqrt{2}} \bullet [V_i^{CKM} \left(C_i^{NEW}(\mu) Q_i(\mu) + C_i^{MFV}(\mu) Q_i^{MFV}(\mu) \right)$$

$$+ V_i^{non\text{-}MFV} C_i^{non\text{-}MFV}(\mu) Q_i^{non\text{-}MFV}(\mu)]$$

beyond MFV

Minimal Flavour Violation (MFV): supported by the great success of the SM in Flavour Physics!

the SM Yukawa couplings are the only *building-blocks* of flavour violation

[G.D´Ambrosio et al., hep-ph/0207036], [A.J. Buras et al., hep-ph/0007085]

MFV models can also contain flavour blind CP-violating phases (FBPs) which make the C^i complex, with significant implications for phenomenology (interplay between FBPs and the CKM phase, e.g. in Flavour Blind MSSM)

Beyond MFV:

New sources of flavour violation ($V_i^{non\text{-}MFV}$) can appear

New operators (Q_i^{MFV}, $Q_i^{non\text{-}MFV}$) can appear

Classification of some appealing NP Models
(where extensive analyses have been performed, with Wilson coefficients calculated at LO in QCD)

MFV

- MSSM with MFV
- Appelquist-Cheng-Dobrescu (ACD) Model
- Littlest Higgs model without T-parity
- ...

MFV+FBPs

- Flavour blind MSSM (FBMSSM)
- 2Higgs doublet model with FBPs ($2HDM_{\overline{MFV}}$)
- ...

Beyond MFV

- SUSY flavour models (δLL, AC, RVV2, AKM)
- SUSY-GUTs ($SSU(5)_{RN}$, SO(10) CMM)
- SUSY with effective MFV
- Littlest Higgs with T-Parity (LHT)
- Z'-models
- Randall-Sundrum model with custodial protection
- SM with a 4th generation (SM4)
- Composite Higgs models
- RHMFV
- Left-right symmetric models
- ...

Theorist's Golden Modes

Suppression within the SM $\Rightarrow$ Sensitivity to NP

- FCNCs forbidden at tree-level in the SM
(radiative and rare decays: $b \to (s,d)\,\gamma$, $b \to (s,d)\, l^+ l^-$, $b \to s\nu\bar{\nu}$, $B_{d,s} \to l^+ l^-$, $s \to d\,\gamma$, $s \to d\, l^+ l^-$, $s \to d\,\nu\bar{\nu}$, $l_i \to l_j\,\gamma$, $l_i \to 3 l_j$, …)

- CKM-, helicity-suppression
(semileptonic CP-asymmetry: A^s_{SL}…, t-dep. CP-asymmetries: $A_{CP}(B \to K^*\gamma)$, and CP-asymmetries in D^0-$\bar{D}^0$ system)

	$K^+ \to \pi^+\nu\bar{\nu}$	$K_L \to \pi^0\nu\bar{\nu}$	$B \to X_s\nu\bar{\nu}$ $B_s \to l^+l^-$	$B \to X_d\nu\bar{\nu}$ $B_d \to l^+l^-$
λ_c	$\sim \lambda$	$(\mathrm{Im}\lambda_c \sim \lambda^5)$	$\sim \lambda^2$	$\sim \lambda^3$
λ_t	$\sim \lambda^5$	$(\mathrm{Im}\lambda_t \sim \lambda^5)$	$\sim \lambda^2$	$\sim \lambda^3$

Small hadronic uncertainties $\Rightarrow$ **Theoretically clean**

•At most one hadron in the final state

(leptonic and semileptonic decays: $B\to \tau\nu$, $B_{d,s}\to l^+ l^-$, $b\to (s,d)\, l^+l^-$, $b\to s\nu\bar{\nu}$, $s\to d\, l^+ l^-$, $s\to d\,\nu\bar{\nu}$, $l_i\to l_j\gamma$, $l_i\to 3l_j$,...)

•Smearing of bound-effects in the final state

(Inclusive quantities: lifetimes, ΔM_q, $\Delta\Gamma_q/\Gamma_q$, A^q_{SL}, ϕ_s,...)

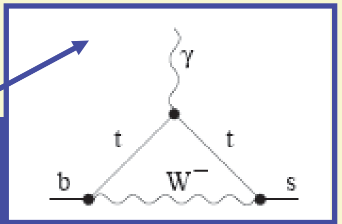
•Suppression/cancellation of some hadronic uncertainties

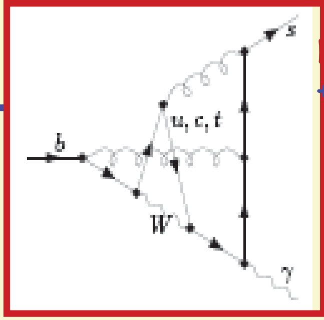
(clean dominant contributions, peculiar ratios/correlations: $A_{CP}(B\to J_\psi K_S)$, $\Delta M_s/\Delta M_d$,...)

Some Golden Modes from a closer look

$b \to s\gamma$ (inclusive)

- highly sensitive to NP (loop FCNC)
- theoretically well under control
- with a small experimental error





$$Br(B \to X_s\gamma)^{exp}_{E_\gamma > 1.6\,GeV} = (3.55 \pm 0.24 \pm 0.09)10^{-4}$$

[HFAG, 2010]

NNLO QCD correct. to Wilson coefficients
+ RG resummation of large logs $\ln(M_W^2/m_b^2)$
[M.Misiak et al., hep-ph/0609232]

$$Br(B \to X_s\gamma)^{SM}_{E_\gamma > 1.6\,GeV} = (3.15 \pm 0.23)10^{-4}$$

Benzke, Lee, Neubert, Paz (1003.5012):
there are $1/m_b$ effects beyond OPE
(photon conversion into light partons),
which imply a 4% irreducible uncertainty)

$b \to s\gamma$ (exclusive)

Theoretical predictions require QCD factorization:

$Br(B \to K^*\gamma)$ is theoretically cleaner than $Br(B \to \rho\gamma)$,
where $O(\Lambda_{QCD}/m_b)$ corrections turn out to be relevant

Interesting exclusive observables
are the t-dep. CP-asymmetries $A_{CP}(B \to V\gamma)$:
- they are (helicity) suppressed within the SM ~O(1%)
- their observation would be a clear signal of NP

$B_q \to l^+ l^-$

$$Br(B_s \to l^+l^-) = \tau(B_s)\frac{G_F^2}{\pi}\left(\frac{\alpha}{4\pi \sin^2\Theta_W}\right)^2 F_{B_s}^2 m_l^2 m_{B_s}\sqrt{1-4\frac{m_l^2}{m_{B_s}^2}}|V_{tb}^*V_{ts}|^2 Y^2(x_t)$$

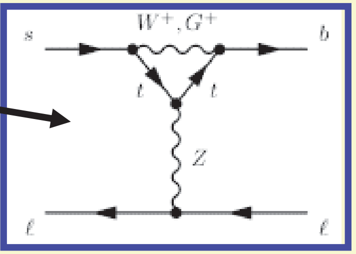
The $\mu^+\mu^-$ modes are experimentally the best:
- e^+e^- is m_e^2/m_μ^2 suppressed
- $\tau^+\tau^-$ has at least other two missing ν from decaying τ's

Upper bounds have been recently improved

$Br(B_d \to \mu^+\mu^-) < 7.6\cdot 10^{-9}$ (95% C.L)

$Br(B_s \to \mu^+\mu^-) < 4.3\cdot 10^{-8}$ [CDF, summer 2010]

- Highly sensitive to NP
  (loop FCNC: Z-penguin dominated)
- Theoretically clean (purely leptonic)



$$\Rightarrow \boxed{Q_A = (\bar{b}_L\gamma^\mu q_L)\ (\bar{l}\gamma^\mu\gamma^5 l)}$$

Wilson coeff. at NLO in QCD
[Misiak, J.Urban hep-ph/9901278,
G.Buchalla, A.J.Buras hep-ph/9901288]

$Br(B_d \to \mu^+\mu^-)^{SM} = (1.0\pm 0.1)\cdot 10^{-10}$

$Br(B_s \to \mu^+\mu^-)^{SM} = (3.2\pm 0.2)\cdot 10^{-9}$

There is still a lot of room for NP

$b \to (s,d)\ \ell^+\ell^-$

- Highly sensitive to NP (loop FCNC)
- Main SM contribution from em dipole operator (Q_7^γ), and ew penguin operators (Q^9, Q^{10})
- Close to the charm threshold (long-distance) $c\bar{c}$ resonances appear

Inclusive: $B \to X_s\ \ell^+\ell^-$

- Wilson coefficients at NNLO in QCD [C.Bobeth et al., hep-ph/0312090, M.Gorban, U. Haisch, hep-ph/0411071]
- HQE at $O(\Lambda^2_{QCD}/m_c^2)$, $O(\Lambda^2_{QCD}/m_b^2)$, $O(\Lambda^3_{QCD}/m_b^3)$
- QED corrections
- bremmstrahlung effects

[T.Huber at al., hep-ph/0512066]

$$\mathrm{Br}(\bar{B} \to X_s \mu^+\mu^-)^{SM} = (1.59 \pm 0.11)\cdot 10^{-6} \quad 1\,\mathrm{GeV}^2 < m^2_{ll} < 6\,\mathrm{GeV}^2$$

$$\mathrm{Br}(\bar{B} \to X_s e^+e^-)^{SM} = (1.64 \pm 0.11)\cdot 10^{-6}$$

Sensitive to the interference of the Wilson coefficients C_7 and C_9

The forward-backward asymmetry (A_{FB}) is sensitive to C_7C_{10} and C_9C_{10}

Exclusive: $B \to K^*\ \ell^+\ell^-$

The most interesting observables are:

- $d\Gamma^2 / (dq^2\, d\cos\theta_l)$ $\to$ extraction of C_9/C_7 and C_{10}/C_7 sensitive to NP in $C_{9,10}$
- A_{FB} and its zero q_0^2: main source of uncertainty $\to$ hadronic inputs
- A_I (isospin asymmetry between neutral and charged B): Small within the SM
- Muon to electron ratio: $R_H \equiv \int_{q_1}^{q_2} dq^2 \frac{d\Gamma(B \to H\mu^+\mu^-)}{dq^2} \Big/ \int_{q_1}^{q_2} dq^2 \frac{d\Gamma(B \to He^+e^-)}{dq^2}, \qquad H = \{K, K^*\}$

Inclusive: $B \to X_s \nu \bar{\nu}$

- Highly sensitive to NP
  (loop FCNC: Z-penguin and box dominated)
- Theoretically very clean
- It could provide the cleanest determination of $|V_{td}/V_{ts}|$

$$\frac{Br(B \to X_s \nu \bar{\nu})}{Br(B \to X_c e \bar{\nu})} = \frac{3\alpha^2}{4\pi^2 \sin^4 \Theta_{\mathrm{W}}} \frac{|V_{ts}|^2}{|V_{cb}|^2} \frac{X^2(x_t)}{f(z)} \frac{\bar{\eta}}{\kappa(z)}$$

$$\boxed{\frac{Br(B \to X_d \nu \bar{\nu})}{Br(B \to X_s \nu \bar{\nu})} = \frac{|V_{td}|^2}{|V_{ts}|^2}}$$

…and D-Physics…

W.r.t. B-Physics, long-distance contributions can be important.
Within the OPE: the expansion parameter Λ_{QCD}/m_c is not as small as Λ_{QCD}/m_b
and $\alpha_s(m_c) > \alpha_s(m_b)$

$$x_D = \frac{\Delta M_D}{\Gamma}, \quad y_D = \frac{\Delta\Gamma_D}{2\Gamma}$$

$x_D \sim y_D \sim$ (0.5-1)% (BaBar+Belle)
Is it compatible with the SM?
Difficult answer due to large uncertainties
(long-distance contributions)

…but, there is a corner to search for NP: CP-violation

- No sign of CP-violation has been observed yet
- Within the SM it is expected to be very small (M_{12}^D, Γ_{12}^D real to a good approx.)
  (mixing induced CP-asymmetry (rough estimate):~ $x_D \sin \phi_f$)
- A measured value larger than 1% would be a NP signal

$\phi_f \rightarrow \arg\frac{q}{p}$

Rare Kaon Decays

$K_L \to \pi^0 \nu \bar{\nu}$ and $K^+ \to \pi^+ \nu \bar{\nu}$

Golden modes (Short-distance dominated)
[intrinsic theoretical uncertainty <5%]

$K_L \to \pi^0 e^+ e^-$ and $K_L \to \pi^0 \mu^+ \mu^-$

Promising modes (not as clean as the previous decays, interesting for their sensitivity to new operators w.r.t. the SM)

$$Br(K_\mathrm{L} \to \pi^0 \nu\bar{\nu}) = \kappa_\mathrm{L} \cdot \left(\frac{\mathrm{Im}\lambda_t}{\lambda^5} X(x_t) \right)^2$$

$$\kappa_\mathrm{L} = \frac{r_{K_\mathrm{L}}}{r_{K^+}} \frac{\tau(K_\mathrm{L})}{\tau(K^+)} \kappa_+ = 1.80 \cdot 10^{-10}$$

$$Br(K^+ \to \pi^+ \nu\bar{\nu}) = \kappa_+ \cdot \left[\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5} X(x_t) \right)^2 + \left(\frac{\mathrm{Re}\lambda_c}{\lambda} P_0(X) + \frac{\mathrm{Re}\lambda_t}{\lambda^5} X(x_t) \right)^2 \right] ,$$

$$\kappa_+ = r_{K^+} \frac{3\alpha^2 Br(K^+ \to \pi^0 e^+ \nu)}{2\pi^2 \sin^4 \Theta_\mathrm{W}} \lambda^8 = 4.11 \cdot 10^{-11} ,$$

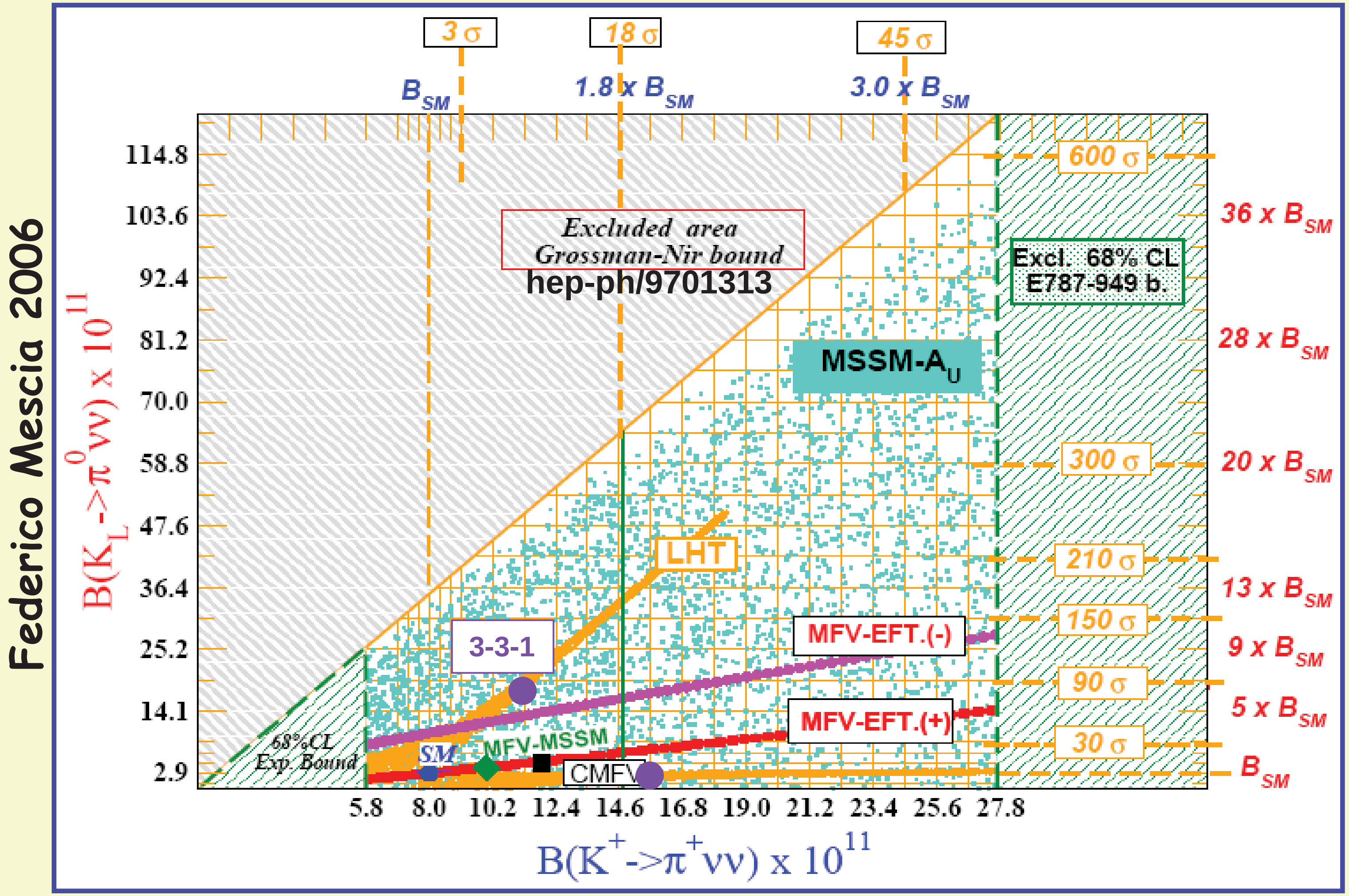
	$K^+ \to \pi^+ \nu\bar{\nu}$	$K_\mathrm{L} \to \pi^0 \nu\bar{\nu}$	$B \to X_s \nu\bar{\nu}$ $B_s \to l^+ l^-$	$B \to X_d \nu\bar{\nu}$ $B_d \to l^+ l^-$
λ_c	$\sim \lambda$	$(\mathrm{Im}\lambda_c \sim \lambda^5)$	$\sim \lambda^2$	$\sim \lambda^3$
λ_t	$\sim \lambda^5$	$(\mathrm{Im}\lambda_t \sim \lambda^5)$	$\sim \lambda^2$	$\sim \lambda^3$

Golden Modes	SM	Experiment	
$K^+ \to \pi^+ \nu \bar{\nu}$	$(7.8 \pm 0.8) \cdot 10^{-11}$	$\left(17^{+12}_{-11}\right) \cdot 10^{-11}$ E949	→ NA62 at CERN
$K_L \to \pi^0 \nu \bar{\nu}$	$(2.4 \pm 0.4) \cdot 10^{-11}$	$< 6.7 \cdot 10^{-8}$ E391a	→ KOTO at JPARC
$K_L \to \pi^0 e^+ e^-$	$\left(3.5^{+1.0}_{-0.9}\right) \cdot 10^{-11}$	$< 2.8 \cdot 10^{-10}$ KTeV	
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.4 \pm 0.3) \cdot 10^{-11}$	$< 3.8 \cdot 10^{-10}$ KTeV	

Next future improvements from:

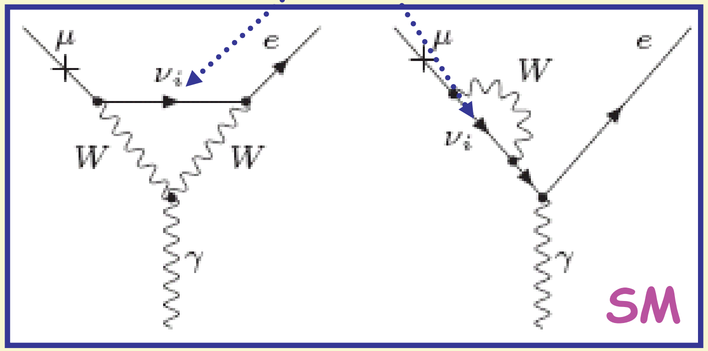
Still a lot of room for NP!

Spectacular effects are expected in several NP models



Lepton Flavour Violating Decays

LFV decays are strongly suppressed in the SM,
due to tiny neutrino masses



E.g.

$$\boxed{Br(\mu \to e\gamma)_{SM} < 10^{-54}}$$

$\wedge\wedge$

10^{-11} – 10^{-14}

present (MEGA) – near future (MEG)

experimental upper bounds

In NP models, new heavy masses can run in loops
yielding spectacular enhancements
(up to present exp. bounds)

There are several interesting Lepton Flavour Violating Decays

$\mu \to e\gamma$ → From 10^{-11} to 10^{-14} [MEG]

$\tau \to \mu\gamma$ → From 10^{-8} to $<10^{-9}$ [SuperB]

$\tau \to e\gamma$

$\mu^- \to e^- e^+ e^-$

$\tau^- \to \mu^- \mu^+ \mu^-$

$\tau^- \to e^- e^+ e^-$

$K_{L,S} \to \mu e$

$B_{d,s} \to \mu e$

$B_{d,s} \to \tau e$

$B_{d,s} \to \tau \mu$

$K_{L,S} \to \pi^0 \mu e$

$\tau \to \mu\pi$

$\tau \to e\pi$

$\tau \to \mu\eta$

$\tau \to e\eta$

$\tau \to \mu\eta'$

$\tau \to e\eta'$

$\tau^- \to e^- \mu^+ e^-$

$\tau^- \to \mu^- e^+ \mu^-$

$\tau^- \to \mu^- e^+ e^-$

$\tau^- \to e^- \mu^+ \mu^-$

$\mu\,\mathrm{Ti} \to e\,\mathrm{Ti}$ → From 10^{-12} to 10^{-18} [PRISM/PRIME]

DNA of Flavour Physics
by Andrzej Buras (1012.1447)

★★★ Large NP effects

★★ Small-moderate NP effects

★ Invisible NP effects

SUSY models

	AC	RVV2	AKM	δLL	FBMSSM	$SSU(5)_{\rm RN}$
$D^0-\bar{D}^0$	★★★	★	★	★	★	★
ϵ_K	★	★★★	★★★	★	★	★★★
$S_{\psi\phi}$	★★★	★★★	★★★	★	★	★★★
$S_{\phi K_S}$	★★★	★★	★	★★★	★★★	★★
$A_{\rm CP}(B\to X_s\gamma)$	★	★	★	★★★	★★★	★
$A_{7,8}(K^*\mu^+\mu^-)$	★	★	★	★★★	★★★	★
$B_s\to\mu^+\mu^-$	★★★	★★★	★★★	★★★	★★★	★★★
$K^+\to\pi^+\nu\bar{\nu}$	★	★	★	★	★	★
$K_L\to\pi^0\nu\bar{\nu}$	★	★	★	★	★	★
$\mu\to e\gamma$	★★★	★★★	★★★	★★★	★★★	★★★
$\tau\to\mu\gamma$	★★★	★★★	★	★★★	★★★	★★★
$\mu+N\to e+N$	★★★	★★★	★★★	★★★	★★★	★★★

Non-SUSY models

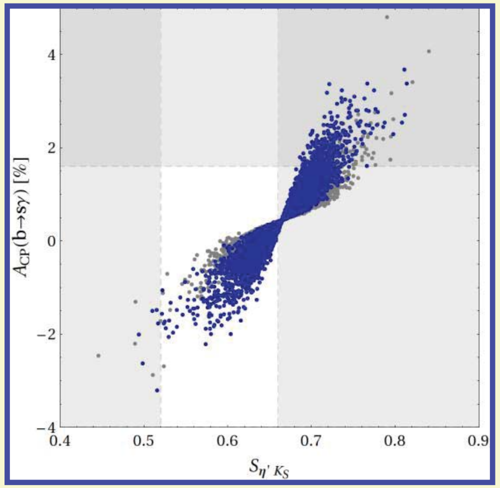
	LHT	RSc	4G	2HDM	RHMFV
$D^0-\bar{D}^0$ (CPV)	★★★	★★★	★★	★★	
ϵ_K	★★	★★★	★★	★★	★★
$S_{\psi\phi}$	★★★	★★★	★★★	★★★	★★★
$S_{\phi K_S}$	★	★	★★		
$A_{\rm CP}(B\to X_s\gamma)$	★		★		
$A_{7,8}(K^*\mu^+\mu^-)$	★★	★	★★		
$B_s\to\mu^+\mu^-$	★	★	★★★	★★★	★★
$K^+\to\pi^+\nu\bar{\nu}$	★★★	★★★	★★★		★★
$K_L\to\pi^0\nu\bar{\nu}$	★★★	★★★	★★★		★★
$\mu\to e\gamma$	★★★	★★★	★★★		
$\tau\to\mu\gamma$	★★★	★★★	★★★		
$\mu+N\to e+N$	★★★	★★★	★★★		

Even more important are correlations

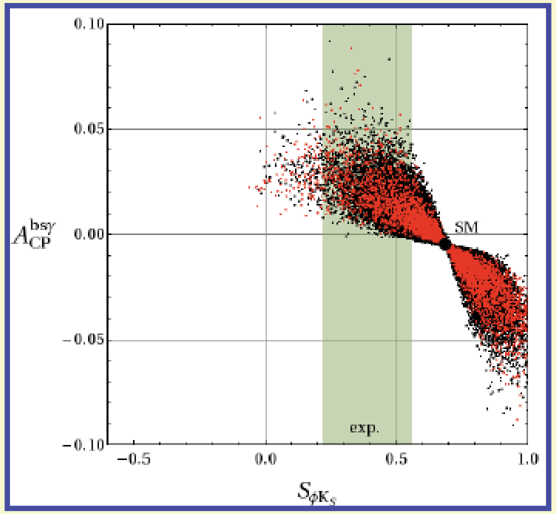
- less sensitive to model parameters
- useful to discriminate different models

Some examples:

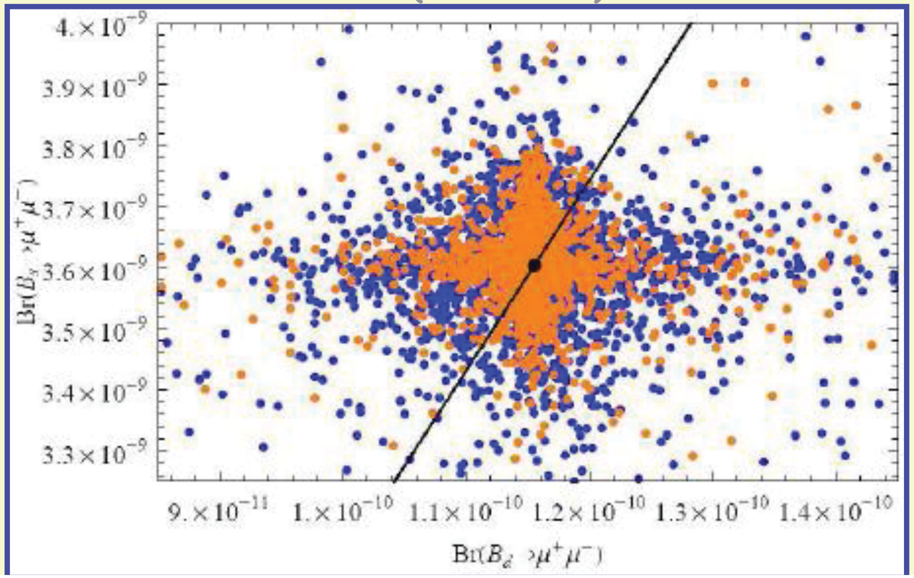
SUSY with Effective MFV
R. Barbieri et al. (1102.0726)



Flavor Blind MSSM
W. Almannshofer et al. (0808.0707)



Randall Sundrum with custodial protection
M. Blanke et al. (0812.3803)



...

Useful Correlations between LFV Br's could help in discriminating between different NP models

M.Blanke, A.J.Buras, B.Duling
A.Poschenrieder, C.T.,
0906.5454

ratio	LHT	MSSM (dipole)	MSSM (Higgs)
$\frac{Br(\mu^- \to e^- e^+ e^-)}{Br(\mu \to e\gamma)}$	$0.02 \ldots 1$	$\sim 6 \cdot 10^{-3}$	$\sim 6 \cdot 10^{-3}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.4$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.4$	$\sim 2 \cdot 10^{-3}$	$0.06 \ldots 0.1$
$\frac{Br(\tau^- \to e^- \mu^+ \mu^-)}{Br(\tau \to e\gamma)}$	$0.04 \ldots 0.3$	$\sim 2 \cdot 10^{-3}$	$0.02 \ldots 0.04$
$\frac{Br(\tau^- \to \mu^- e^+ e^-)}{Br(\tau \to \mu\gamma)}$	$0.04 \ldots 0.3$	$\sim 1 \cdot 10^{-2}$	$\sim 1 \cdot 10^{-2}$
$\frac{Br(\tau^- \to e^- e^+ e^-)}{Br(\tau^- \to e^- \mu^+ \mu^-)}$	$0.8 \ldots 2.0$	~ 5	$0.3 \ldots 0.5$
$\frac{Br(\tau^- \to \mu^- \mu^+ \mu^-)}{Br(\tau^- \to \mu^- e^+ e^-)}$	$0.7 \ldots 1.6$	~ 0.2	$5 \ldots 10$
$\frac{R(\mu\mathrm{Ti} \to e\mathrm{Ti})}{Br(\mu \to e\gamma)}$	$10^{-3} \ldots 10^{2}$	$\sim 5 \cdot 10^{-3}$	$0.08 \ldots 0.15$

Littlest Higgs Model
with T-parity

Minimal Supersymmetric
Standard Model with
a small or big Higgs contribution

…further interesting observables in searching NP…

□ε'/ε: direct CP-violation in the Kaon system
(lattice calculation of matrix elements suffers from great difficulties
(power divergences and disconnected contributions in $\Delta I=1/2$ operators)
Preliminary promising results have been recenlty obtained

•Two body non-leptonic decays of B mesons information on CP-violation
(e.g. $B\to \pi\pi$, $B\to \pi K$, LHCb will extend this study to B_s and B_c decays)

•CP-violation in D-mesons (i.e., mesons wih a charm quark)
(SuperB will produce a huge amount of D-mesons)

And some crucial flavour conserving observables that would deserve a separate talk

•Electric dipole moments (CP-violating flavour conserving quantities, very strongly suppressed in the SM)

•Muon anomalous magnetic moment, for which both very accurate theoretical prediction and measurement exist and deviate by ~3 σ

In order to reveal NP and understand its nature
Flavour Physics has a fundamental role
besides the direct production at LHC

The next decades will see a great
experimental activity,
not only in the direct NP search at LHC,
but also in the Flavour Sector

We briefly go through present and
next future experiments in Flavour Physics:

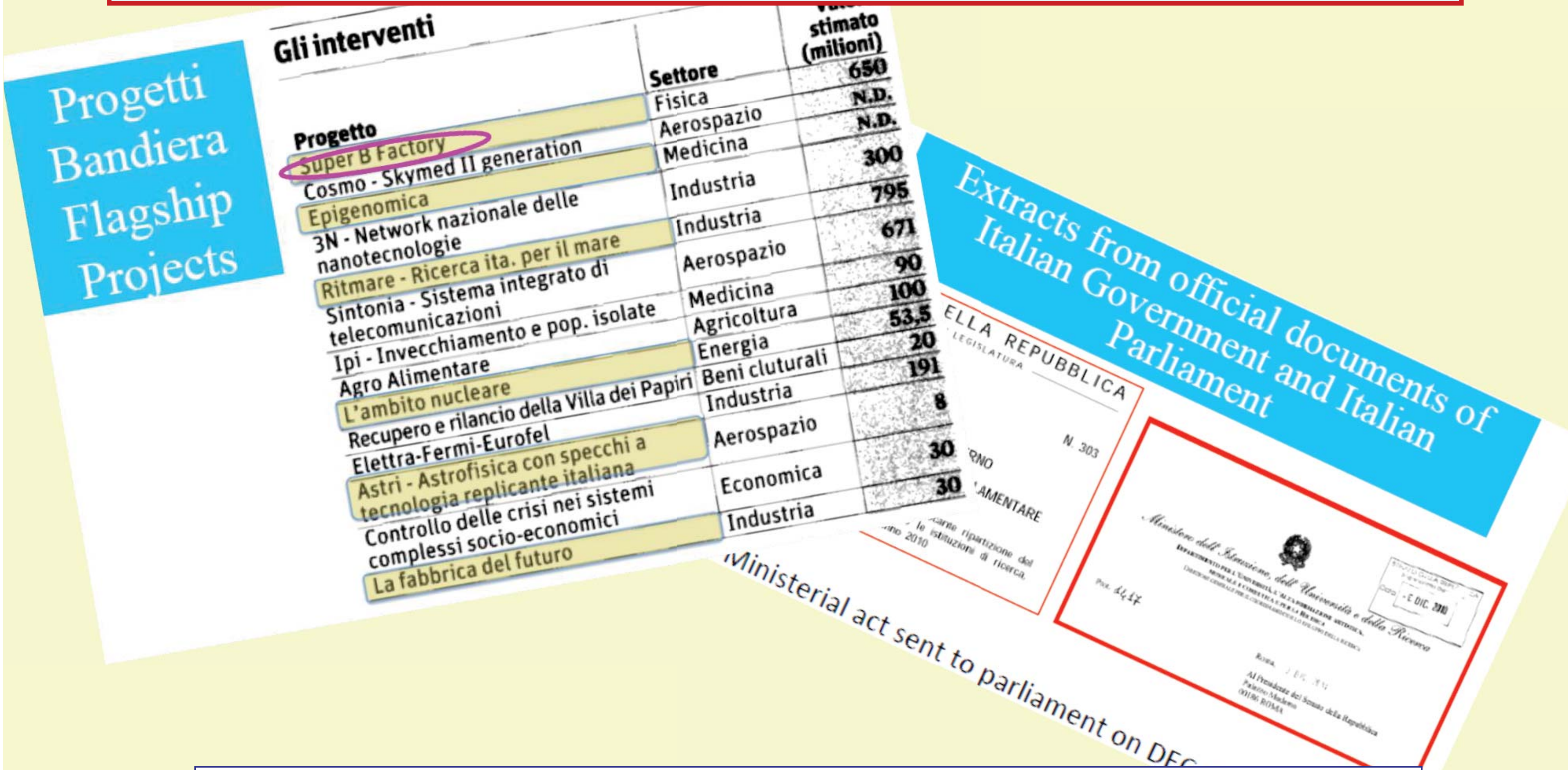
LHCb
SuperB-Factory
NA62
MEG
J-PARC
...

LHCb:
The LHC will study also the flavour structure of NP

- LHCb is one of the 6 experiments at LHC
- LHCb stands for LHCbeauty
- It is dedicated to the study of b-physics (all kinds of b-hadrons are produced)
- @LHC (p-p collider with 7 TeV for each beam) a huge amount of b-$\bar{b}$ couples (10^{12}/year) is produced but with a high background
- It is crucial to detect vertices and identify particles with great accuracy
- First, very promising, results have been obtained

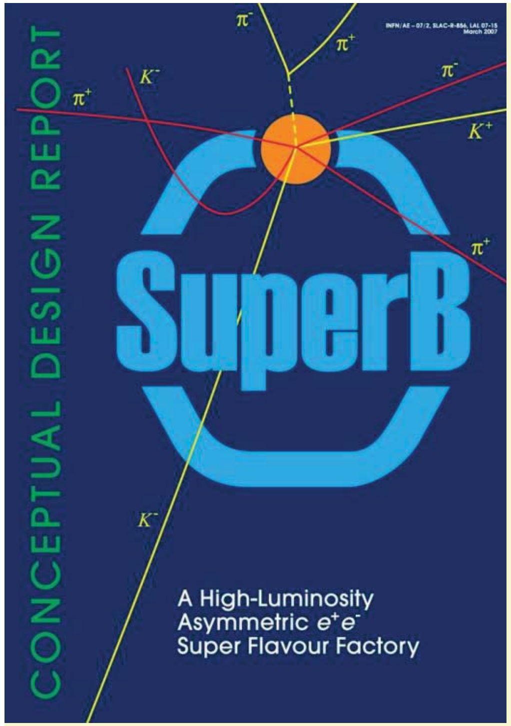
The SuperB project has been approved!

(the Super KEKB project has been approved as well in Japan)



Progetto	Settore	stimato (milioni)
Super B Factory	Fisica	650
Cosmo - Skymed II generation	Aerospazio	N.D.
Epigenomica	Medicina	N.D.
3N - Network nazionale delle nanotecnologie	Industria	300
Ritmare - Ricerca ita. per il mare	Industria	795
Sintonia - Sistema integrato di telecomunicazioni	Aerospazio	671
Ipi - Invecchiamento e pop. isolate	Medicina	90
Agro Alimentare	Agricoltura	100
L'ambito nucleare	Energia	53,5
Recupero e rilancio della Villa dei Papiri	Beni cluturali	20
Elettra-Fermi-Eurofel	Industria	191
Astri - Astrofisica con specchi a tecnologia replicante italiana	Aerospazio	8
Controllo delle crisi nei sistemi complessi socio-economici	Economica	30
La fabbrica del futuro	Industria	30

- The SuperB is an international project (~80 Institutions)
- It will be realized in Italy, (probable site: TorVergata area)
- It will reuse hardware from PEP-II (BaBar) and probably pre-existing infrastructures at the LNF
- The Technical-Design-Report will be ready in 2012

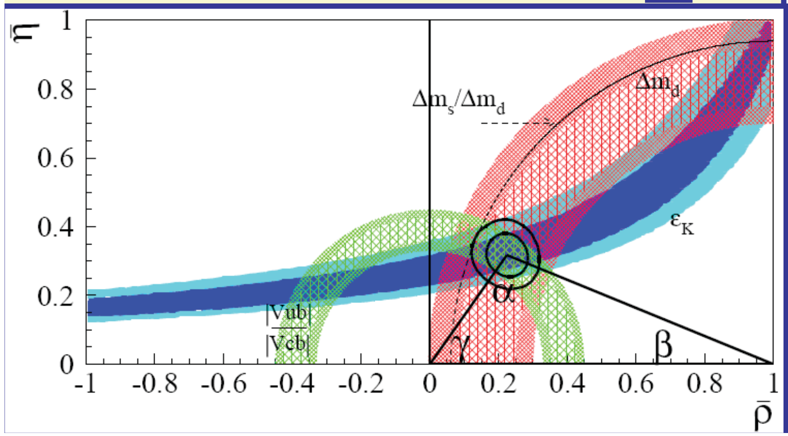


SuperB

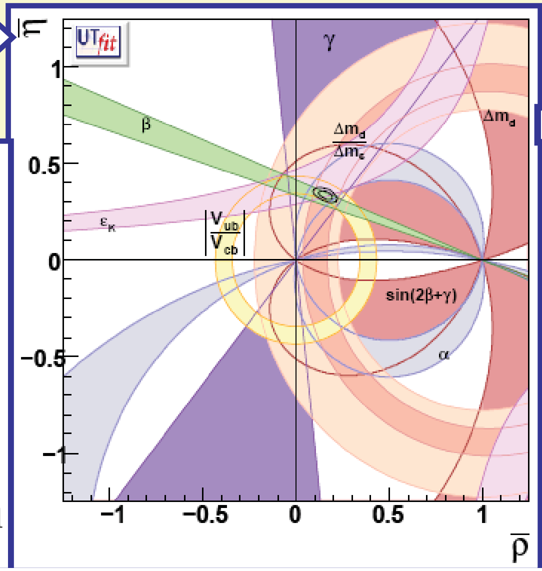
- e^+-e^- collider with the appropriate energy to **produce couples of B and anti-B mesons, in a clean environment** (like BaBar and Belle, but with ~100 times higher luminosity)
- it aims at **improving** the **accuracy** of the **B-factories** by a factor 5-10
- It will **test** the **CKM** matrix at 1% level
- It will **increase** the **sensitivity** for several channels sensitive to **NP** by one order of magnitude (e.g. $B \to \tau\nu$, but **also beyond B-physics**: τ decays which violate lepton flavour, CP-violation in the D-sector,…)

Role of B-factories in constraining the UT

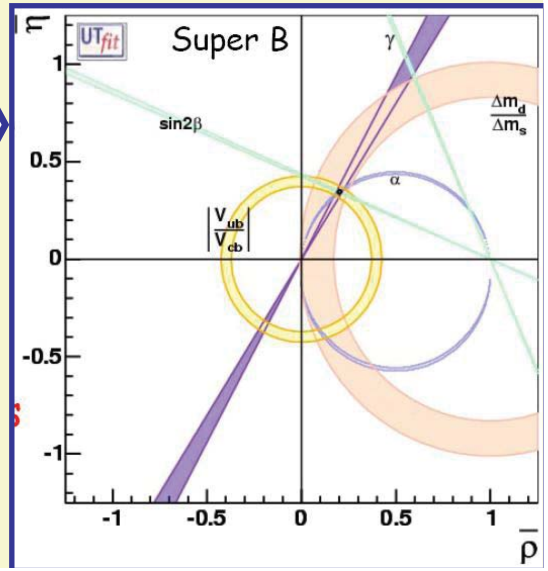
Before B-factories



After B-factories

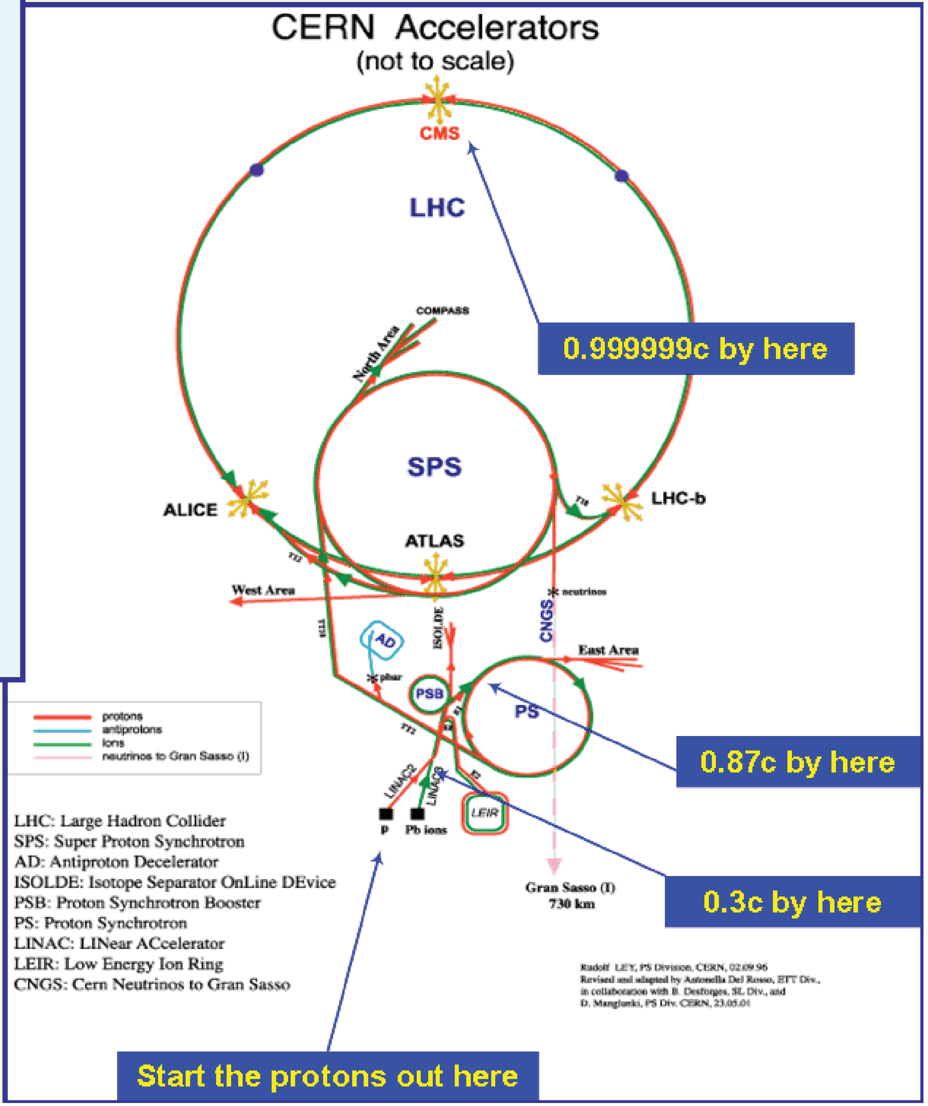


After SuperB-factories?



NA62

- The NA62 experiment at the CERN Super Proton Synchrotron (SPS) aims to collect about 100 $K^+ \to \pi^+ \nu \bar{\nu}$ events in two years of data taking
- The kaons are produced by protons from the CERN SPS hitting a fixed target
- $K^+ \to \pi^+ \nu \bar{\nu}$ is a very rare decay, theoretically clean, thus highly sensitive to NP
- The NA62 Experiment is a successor of the NA48 Experiment (1997-2004)
- Most detector parts will be newly built in order to achieve a significant improvement



MEG μ e γ

- 590MeV proton cyclotron facility of the Paul Scherrer Institut (PSI), Switzerland

- Dedicated to the lepton flavour violating decay $\mu \to e\,\gamma$, strongly suppressed in the SM and highly sensitive to NP

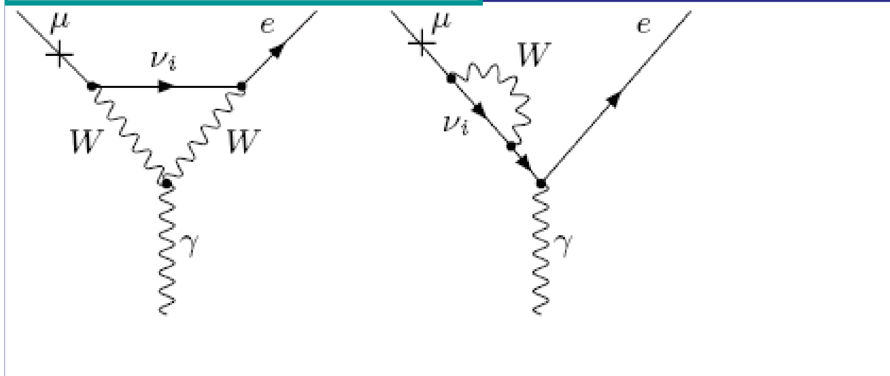
- It started in 2009

- It is expected to reduce the upper bound on Br($\mu \to e\,\gamma$) from 10^{-11} to 10^{-14}

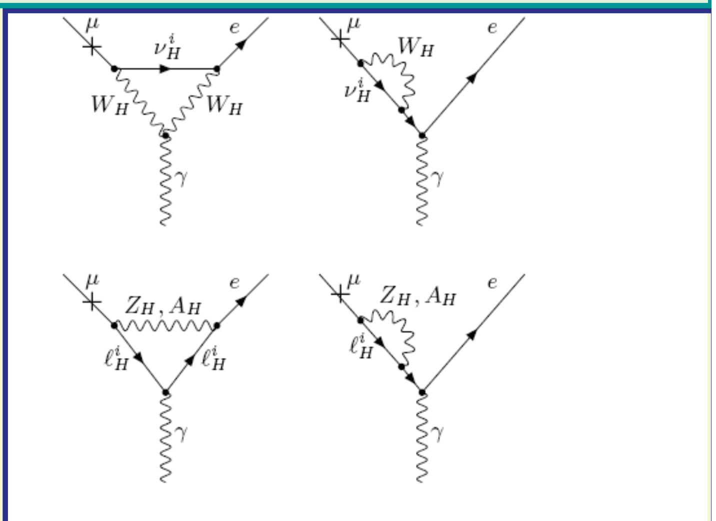
From the MEGA exp. at Los Alamos, 1999

E.g., in the Littlest Higgs Model with T-parity Br~10^{-11}, i.e. of the order of present exp. bounds is allowed (similarly in MSSM and ED)

In the SM Br~10^{-54} due to tiny ν masses



Diagrams contributing to $\mu \to e\gamma$ in the SM.



Diagrams contributing to $\mu \to e\gamma$ in the LHT model.

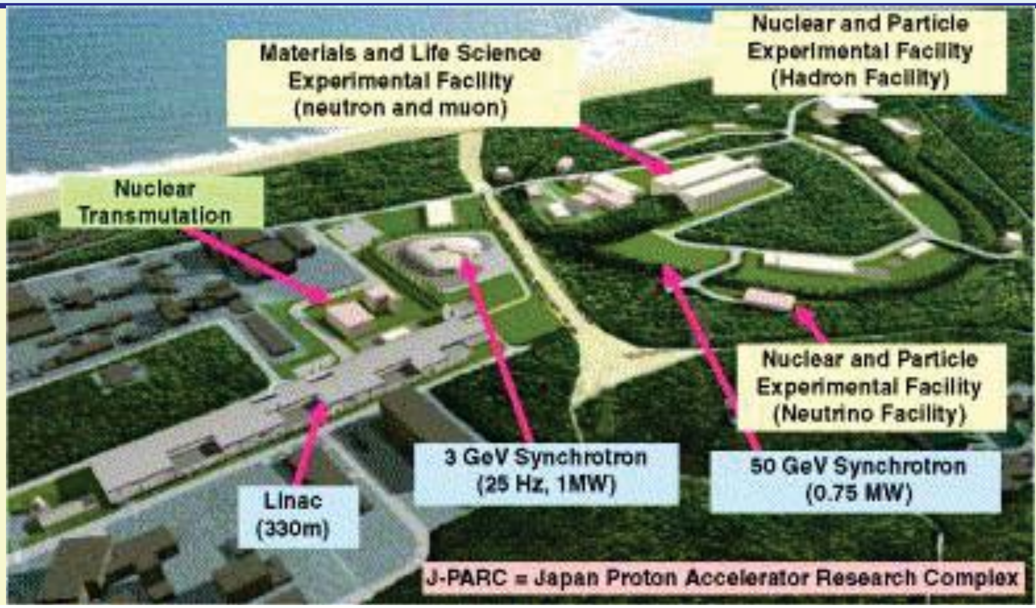
J-PARC

- The High Intensity Proton Accelerator Project, named as J-PARC, has been realized at Tokai (Japan)

- It consists of three accelerators: 400 MeV Linac, 3 GeV rapid cycle synchrotron and 50 GeV synchrotron

- It includes four major experimental facilities: Material and Life Science Facility, Nuclear and Particle Physics Facility, Nuclear Transmutation Experiment Facility and Neutrino Facility

- Its important role in Flavour Physics is due to the measurement of:
  - the (flavour-violating) μ-e transition in Nuclei, improving the present sensitivity by 6 orders of magnitude [PRISM/PRIME experiment],
  - the rare decay $K_L \to \pi^0 \nu \bar{\nu}$ [KOTO experiment]



Conclusions

- There are several Flavour Physics observables that are highly sensitive to NP (theoretically clean and accurately measurable in the next decade)

- With present experimental bounds there is room for significant NP effects in many flavour physics observables

- Important experiments dedicated to Flavour Physics have started or are in program for the next decade, together with a great theoretical activity

- The complementarity between direct production of new particles at LHC and indirect NP search in the flavour sector will be crucial to reveal the nature of NP


THANKS....