Main contributions to the discovery and comprehension of New Physics by

super B-Factories and the upgrade of the LHC experiments

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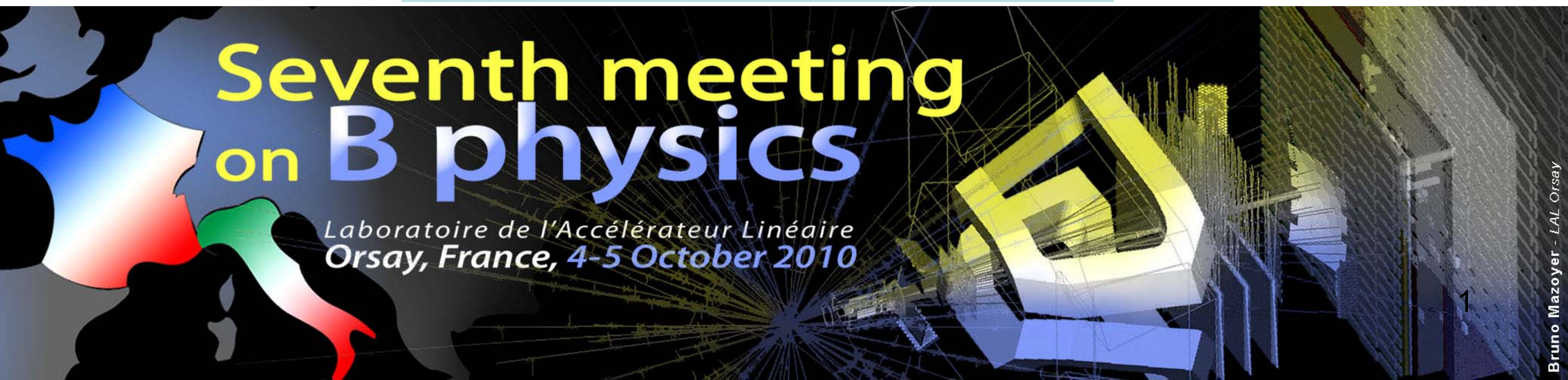

Beyond the Standard Model with flavour physics

$$\frac{|\delta_{bq}|}{\Lambda_{eff}}$$

The indirect searches look for "New Physics" through virtual effects from new particles in loop corrections

1. ~1970 charm quark from FCNC and GIM-mechanism $K^0 \rightarrow \mu\mu$
2. ~1973 3rd generation from CP violation in kaon (ε_K) KM-mechanism
3. ~1990 heavy top from B oscillations Δm_B
4. ~2000 success of the description of FCNC and CPV in SM

"Discoveries" and construction of the SM Lagrangian

- SM FCNCs and CP-violating (CPV) processes occur at the loop level
- SM quark Flavour Violation (FV) and CPV are governed by weak interactions and are suppressed by mixing angles.
- SM quark CPV comes from a single sources (if we neglect θ_{QCD})

New Physics does not necessarily share the SM behaviour of FV and CPV

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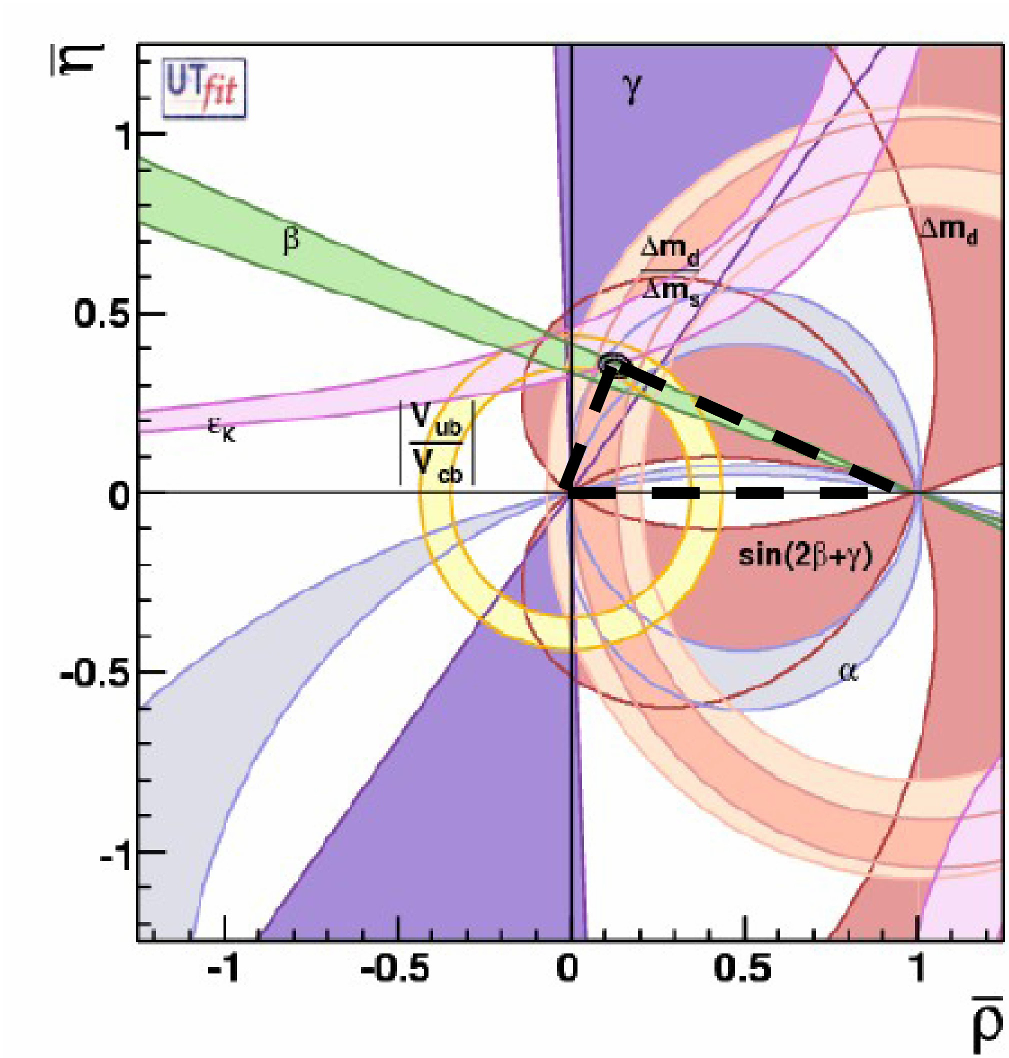
The test of the SM (in fermion sector)

..Or the « not discovery » of any new physics beyond the SM

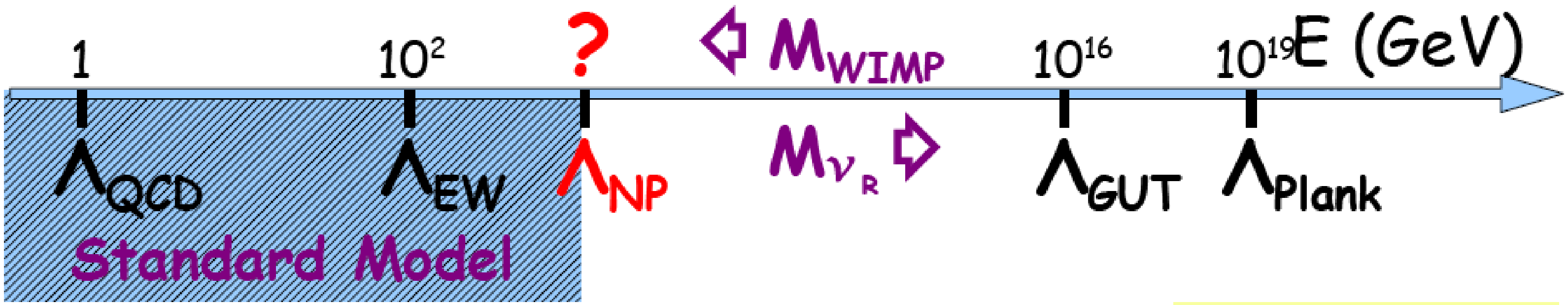
~1990-now → a huge number of precise measurements



Coherent picture of FCNC and CPV processes in SM

Discovery : absence of New Particles up to the ~2×Electroweak Scale !

The problem of particle physics today is : where is the NP scale $\Lambda \sim 0.5, 1 \ldots 10^{16}$ TeV

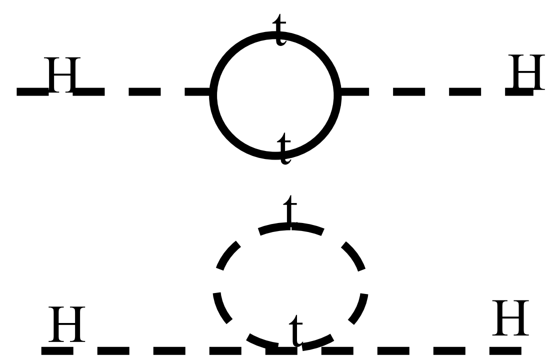


LHC will search on this range

The quantum stabilization of the Electroweak Scale suggests that $\Lambda \sim 1$TeV

$$m_H^2 \rightarrow m_{bare}^2 + \delta m_H^2$$

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



Those are arguments of fine tuning…if the NP scale is at 2-3..10 TeV …naturalness is not at loss yet…

Present and future goals of Flavour Physics

It is a game of couplings and scales

→ if NP particles are discovered at LHC we have to be able to study the flavour structure of the NP **("reconstructing" the NP Lagrangian)**

→ to have the capability to explore NP scale beyond the LHC reach

$$\propto \frac{|\delta_{bq}|}{\Lambda_{eff}}$$

Coupling δ	PRECISION 20% today	PRECISION ~10% Tomorrow (2010-2015) (LHCb,MEG,NA62…)	PRECISION 1% after tomorrow (>2015)
Order 1	$\Lambda_{eff} \sim 20$ TeV	$\Lambda_{eff} \sim 30$ TeV	$\Lambda_{eff} \sim 100$ TeV
MFV	$\Lambda_{eff} \sim 180$ GeV	$\Lambda_{eff} \sim 250$ GeV	$\Lambda_{eff} \sim 800$ GeV

B factories → SuperB

B factories have shown that a variety of measurements can be performed in the clean environment. → Asymmetric B factory

The systematic errors are very rarely irreducible and can almost on all cases be controlled with control samples. (up to..50-100ab^{-1}) → High luminosity

L= 10^{34} cm^{-2} s^{-1} → 150 fb^{-1} → 1.5 × 10^8 Υ(4s) produced by year

L= 10^{36} cm^{-2} s^{-1} → 15 ab^{-1} → 1.5 × 10^{10} Υ(4s) produced by year

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LHCb → SLHCb

LHCb will "collect" an even larger sample
~5 ×10^{11} bb/year
(10fb^{-1} by 2015 → 5 10^{12} bb)

However :
- Hadronic environment
- Trigger
- Cannot use rare channels
  - → with neutrinos
  - → without charged tracks

From 10fb^{-1} → 100fb^{-1}

Some of the golden LHCb measurements can be improved

The actors in the next decade

$Br(B \to X_s \gamma)$

$Br, ACP(B \to X_s\, l\, l)$

$Br(B_s \to \mu\mu)$

$Br(K^0 \to \pi^0 \nu\nu)$

β

$Br(\mu \to e\gamma)$

$Br(B \to \tau\nu, \mu\upsilon)$

$(g-2)_\mu$

$Br(K^+ \to \pi^+ \nu\nu)$

$Br(\tau \to \mu\mu\mu)$

$Br(B \to K\nu\nu)$

$A_{CP}(B \to X_s \gamma)$

$Br(B \to K_S \pi^0 \gamma)$

$Br(\tau \to \mu\gamma)$

$ACP(B_s \to J/\psi\, \phi)$

Which NP will be ??

NMFV (1-3)

MFV

MFV-GUT

RH-currents

NMFV (2-3)

H^+ - high $\tan\beta$

Z penguins

LHT Models

EXAMPLE

Let's consider (reductively) the GOLDEN MATRIX for B physics for channel feasible at SuperB

	H^+ high tanβ	Minimal FV	Non-Minimal FV (1-3)	Non-Minimal FV (2-3)	NP Z-penguins	Right-Handed currents
$\mathcal{B}(B \to X_s \gamma)$		X		O		O
$A_{CP}(B \to X_s \gamma)$				X		O
$\mathcal{B}(B \to \tau \nu)$	X- CKM					
$\mathcal{B}(B \to X_s l^+ l^-)$				O	O	O
$\mathcal{B}(B \to K \nu \overline{\nu})$				O	X	X
$S(K_S \pi^0 \gamma)$						X
β			X- CKM			

X The GOLDEN channel for the given scenario

○ Not the GOLDEN channel for the given scenario, but can show experimentally measurable deviations from SM.

« SuperB specifics »

- inclusive analyses
- channels with π^0, γ, ν, many Ks…

In the following some examples of ↓ →

Similar matrices should be constructed for SLHCb Physics case.

The Quantum path

The indirect searches
look for “New Physics”
through virtual effects from new particles in loop corrections

I’ll show

4

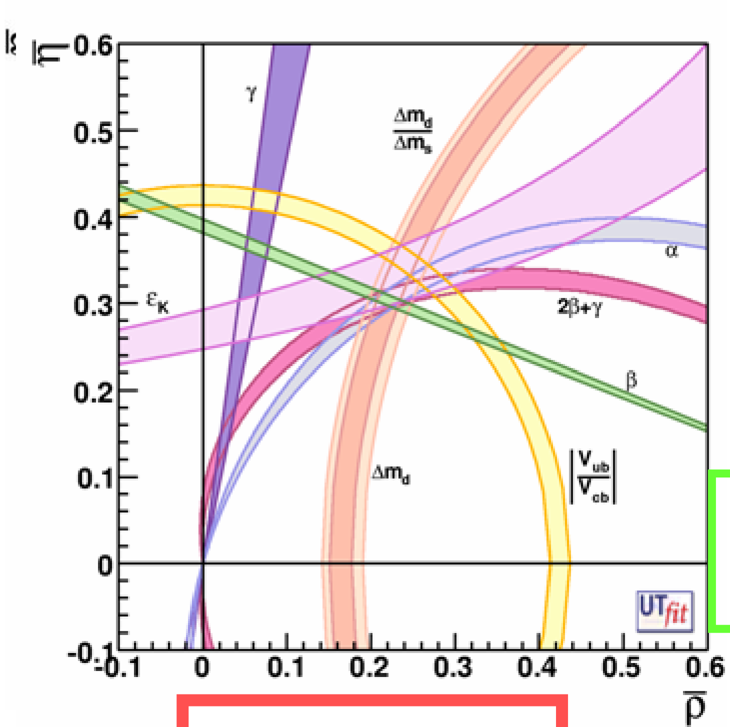
Examples of
golden measurements
for
possible discoveries

Key words :
Precise measurements
→ Luminosity

1

Determination of CKM parameters and New Physics

Future (SuperB) + Lattice improvements



players are :

$\gamma, \alpha, \beta.., V_{ub}$
and Lattice !

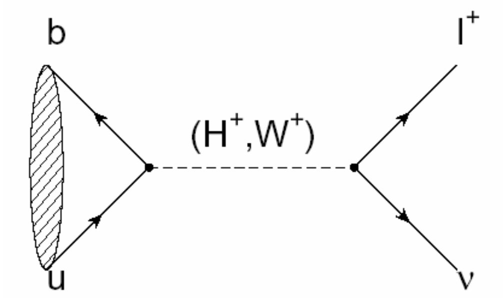
$\rho = \pm 0.0028$
$\eta = \pm 0.0024$

Improving CKM is crucial to look for NP

Important also in K physics :
$K \rightarrow \pi \nu \nu$, CKM errors dominated the error budget

2

Leptonic decay B → l ν

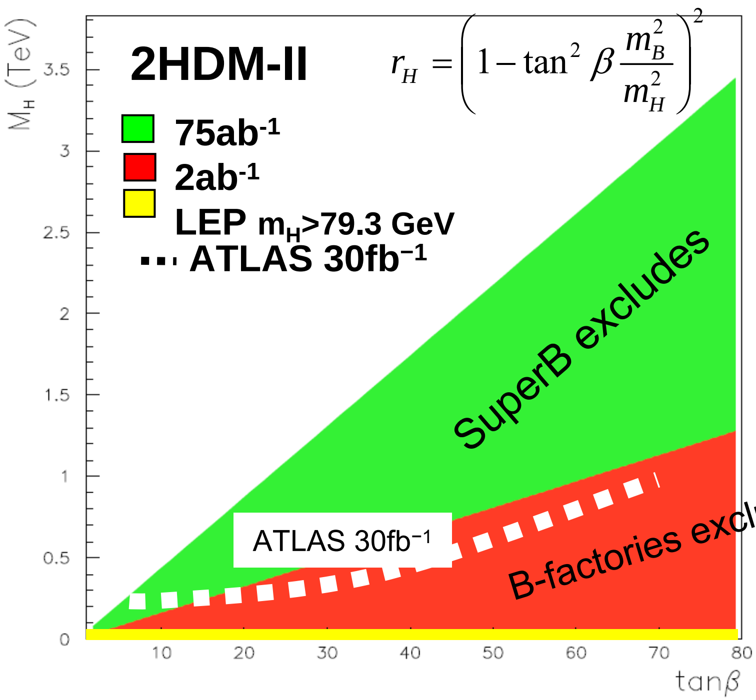


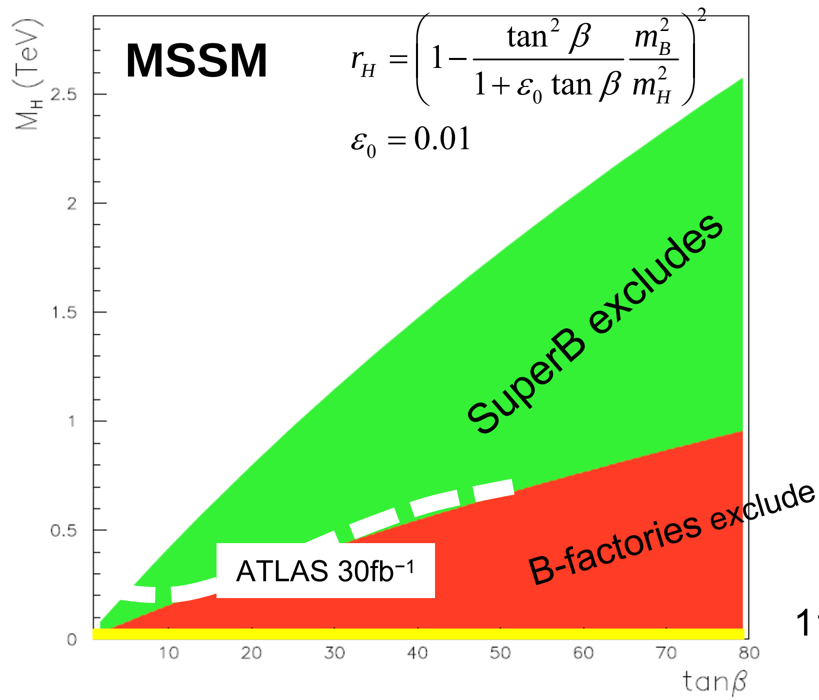
Observable	B Factories (2 ab^{-1})	**SuperB**
$\mathcal{B}(B \to \tau\nu)$	20%	4%
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%

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

SuperB -75ab^{-1}

M_H~1.2-2.5 TeV for tanβ~30-60





3

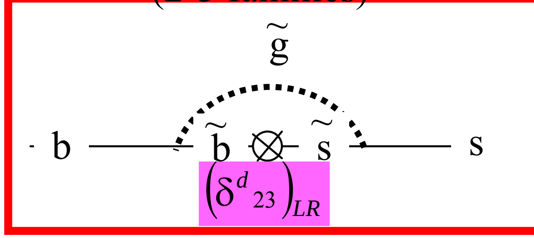
MSSM+generic soft SUSY breaking terms

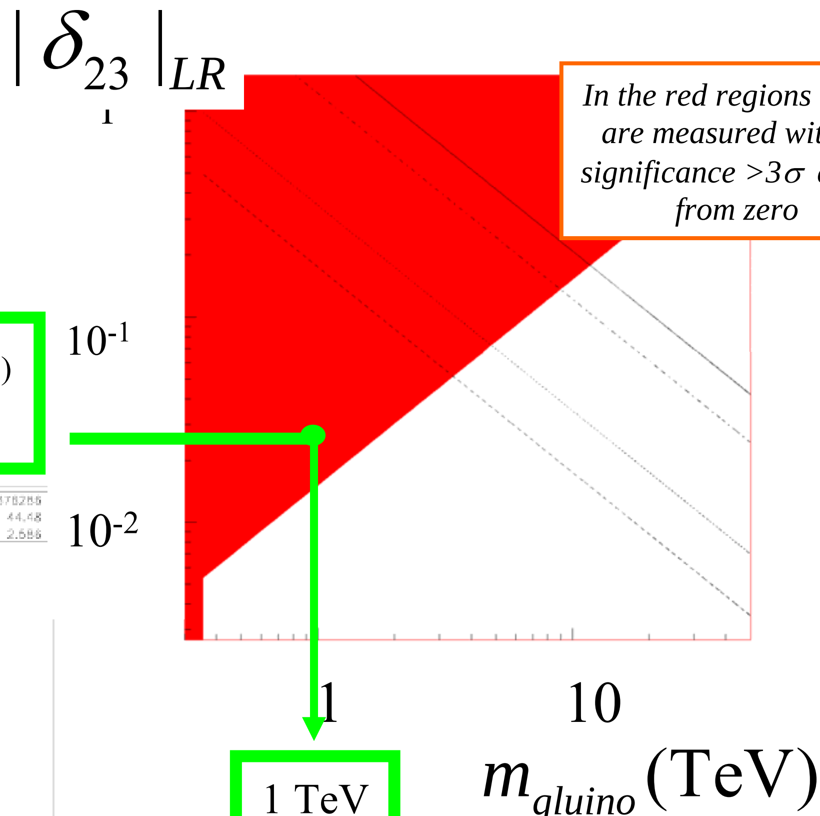
Flavour-changing NP effects in the squark propagator

→ NP scale SUSY mass $\tilde{m} \sim m_{\tilde{g}}$

→ flavour-violating coupling $(\delta^q_{ij})_{AB} \equiv \frac{(M^2_{ij})^q_{AB}}{\tilde{m}^2}$

New Physics contribution (2-3 families)

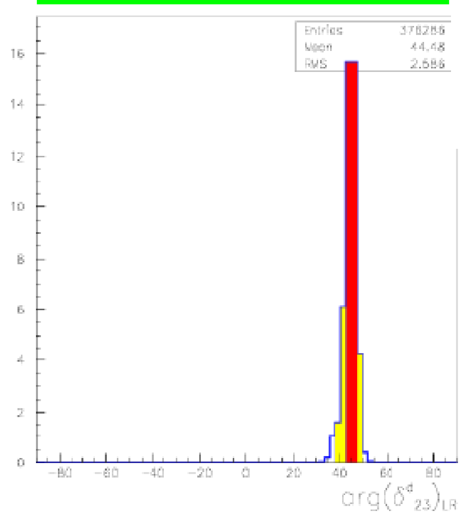




$|\delta_{23}|_{LR} = (0.026 \pm 0.005)$

$\mathrm{Arg}(\delta_{23})_{LR} = (44.5 \pm 2.6)^{o}$

1 TeV



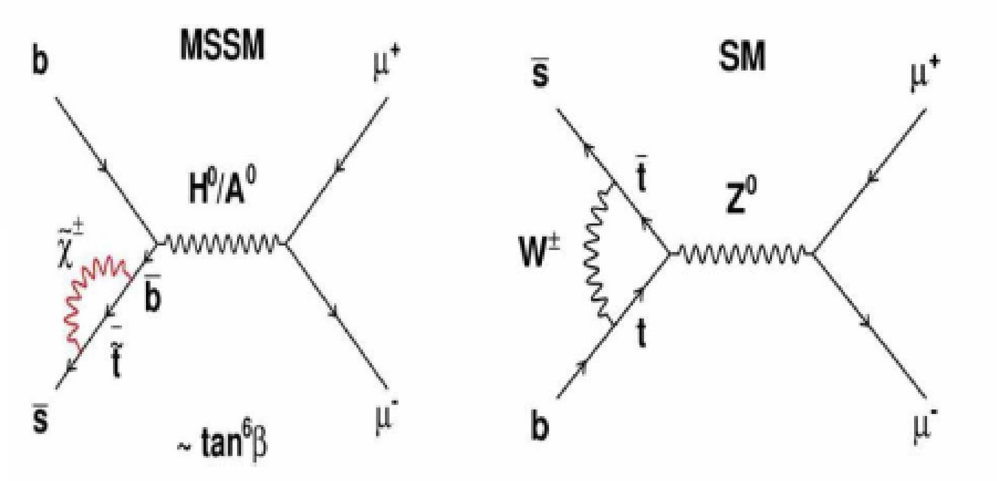
Here the players are :

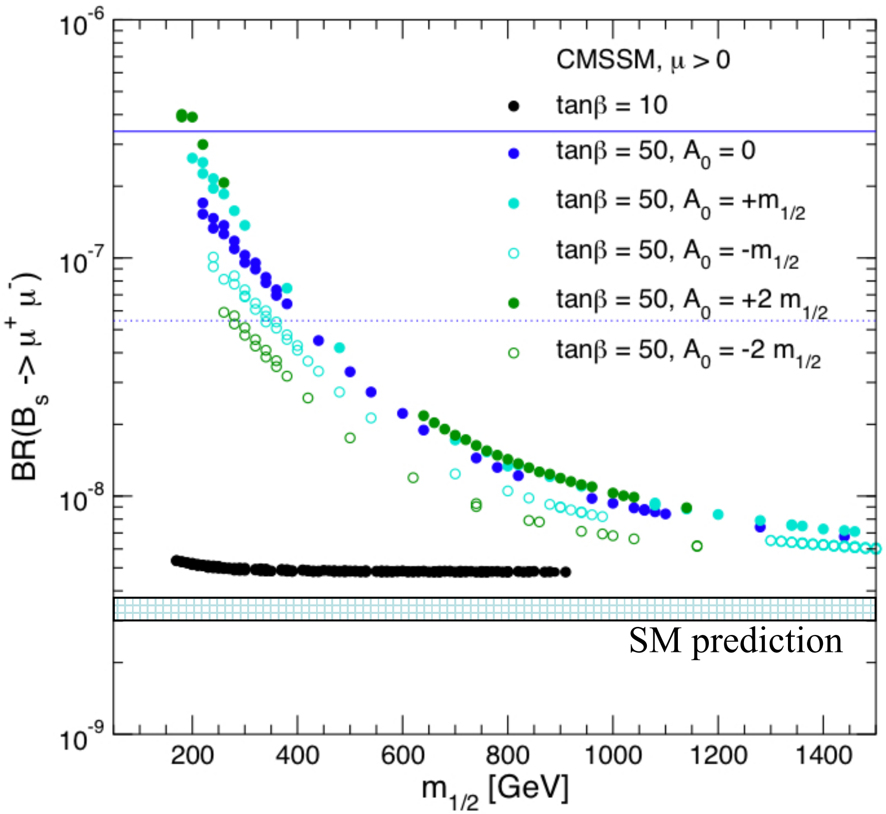
- $(B \to X_s\, \gamma)$
- $(B \to X_s\, l^+ l^-)$
- $A_{CP}(B \to X_s\, \gamma)$

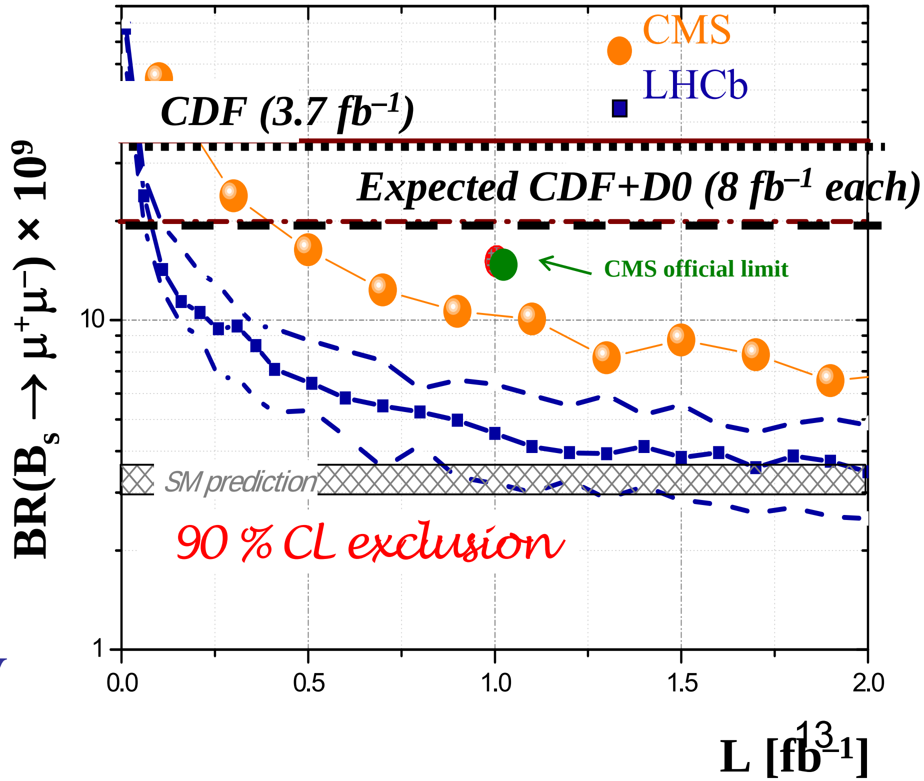
4

Br($B_s \rightarrow \mu\ \mu$)

40 years later .. $K^0 \rightarrow \mu^+ \mu^-$







Implications on $B_s \rightarrow \mu^+\mu^-$ CMSSM:

$250 < m_{1/2}$(gaugino mass) < 650 GeV

$\Rightarrow BR(B_s \rightarrow \mu+\mu-) = (5–100)\times10^{-9}$

Part of the program could be accomplished if SM theoretical predictions are @ 1%

Shown by Vittorio Lubicz at the SuperB Workshop LNF Dec2009

Hadronic matrix element	Lattice error in 2006	Lattice error in 2009	6 TFlop Year [2009]	60 TFlop Year [2011 LHCb]	1-10 PFlop Year [2015 SuperB]
$f_+^{K\pi}(0)$	0.9%	**0.5%**	0.7%	0.4%	**< 0.1%**
$\hat{B}_K$	11%	**5%**	5%	3%	**1%**
f_B	14%	**5%**	3.5 - 4.5%	2.5 - 4.0%	**1 – 1.5%**
$f_{Bs}B_{Bs}^{1/2}$	13%	**5%**	4 - 5%	3 - 4%	**1 – 1.5%**
ξ	5%	**2%**	3%	1.5 - 2 %	**0.5 – 0.8 %**
$\mathcal{F}_{B \to D/D^* l\nu}$	4%	**2%**	2%	1.2%	**0.5%**
$f_+^{B\pi}, \ldots$	11%	**11%**	5.5 - 6.5%	4 - 5%	**2 – 3%**
$T_1^{B \to K^*/\rho}$	13%	**13%**	----	----	**3 – 4%**

The expected accuracy has been reached! (except for Vub)

Some Golden Modes

No result (Red) | Moderate (Orange) | Precise (Yellow) | Very Precise (Green)

Observable	Babar/ Belle	LHCb ($10fb^{-1}$)	SLHCb ($100fb^{-1}$)	SuperB ($75ab^{-1}$)	Some Comment	Theo
γ	Orange	Yellow	Green	Green		Green
V_{ub}/V_{cb}	Yellow	Orange	Orange	Green	Excl. needs Lattice & Inclusive @ 2% ?	Yellow
β	Yellow	Green	Green	Green	Theo. error to be controlled on data (ex: $J/\psi\pi^0$)	Green
$S(J/\psi\phi)$	Red	Green	Green	Red	At 1° theo error controlled with data ?	Green
$B\rightarrow \tau\nu, \mu\nu$	Orange	Red	Red	Yellow	Very precise if detector is improved	Yellow
S-Penguins	Orange	Orange	Orange	Green	SLHCb (very) precise for $B\rightarrow\phi K$, $Bs\rightarrow\phi\phi$ Not possible for $Ks\pi^0$,ksksks,ηks, ωKs..	Orange
$A_{CP}(B\rightarrow X_s\gamma)$	Yellow	Orange	Orange	Green	Control syst. Is an issue	Green
$Br(B\rightarrow X_s\gamma)$	Yellow	Orange	Orange	Green	Syst. Controlled with data ?	Orange
$Br(B\rightarrow X_s\, l\, l)$ *Angular var.*	Orange	Red	Red	Green		Green
$Br(B\rightarrow K^* l\, l)$, Angular var.	Orange	Yellow	Green	Green	Could theory control @20%? Angular analysis are clean ? →	Orange
$Br(B\rightarrow K^{(*)}\nu\nu)$	Red	Red	Red	Yellow	Stat. limited. With more stat. angular analyses also possible	Green
$Br(B\rightarrow K_s\pi^0\gamma)$	Orange	Red	Red	Green		Green
$Br(B_s\rightarrow\phi\gamma)$	Red	Yellow	Green	Red	As precise as $Br\rightarrow K_s\pi^0\gamma$) ?	Green
$Br(B_s\rightarrow\mu\mu)$	Red	Yellow	Green	Red		Green
$\tau\rightarrow\mu\gamma$	Orange	Red	Red	Yellow	profit of polarized beams	Green
CPV charm	Red	Yellow	Green	Green	CPV in SM negligible. So clean NP probe	Green

THEORY

- Orange: Moderately Clean
- Yellow: Clean Need Lattice
- Green: Clean

Conclusions and perspectives

Flavour Physics with FCNC and CPV processes has played in the past a crucial role in constructing and testing the SM
Some observable are already precise.

Flavour Phyiscs is a major actor in NP search @ few-TeV range and a unique player in the reconstruction of the NP Lagrangian

Part of the program could be accomplished if SM theoretical predictions are @ 1%.

….
B-Factories today
LHCb (MEG, NA62..) tomorrow
And the day after tomorrow..?

SLHCb could improve some LHCb golden measurements γ, $B_s \rightarrow \mu\mu$, $B_s \rightarrow \phi\gamma$

SuperB factories have a much wider Physics Case,
which can naturally follow the B-factory+LHCb era.

BACKUP MATERIAL

B physics @ Υ(4S)

Variety of measurements for any observable

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
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° (*)
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°
$2\beta + \gamma$ $(D^{(*)\pm}\pi^\mp,\, D^\pm K^0_S\pi^\mp)$	20°	5°
$S(\phi K^0)$	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 (*)
$\|V_{cb}\|$ (exclusive)	4% (*)	1.0% (*)
$\|V_{cb}\|$ (inclusive)	1% (*)	0.5% (*)
$\|V_{ub}\|$ (exclusive)	8% (*)	3.0% (*)
$\|V_{ub}\|$ (inclusive)	8% (*)	2.0% (*)

Observable	B Factories (2 ab^{-1})	Super$B$ (75 ab
$\mathcal{B}(B \to \tau\nu)$	20%	4% (†)
$\mathcal{B}(B \to \mu\nu)$	visible	5%
$\mathcal{B}(B \to D\tau\nu)$	10%	2%
$\mathcal{B}(B \to \rho\gamma)$	15%	3% (†)
$\mathcal{B}(B \to \omega\gamma)$	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%
$\mathcal{B}(B \to K\nu\bar{\nu})$	visible	20%
$\mathcal{B}(B \to \pi\nu\bar{\nu})$	–	possible

Possible also at LHCb

Similar precision at LHCb

Example of « SuperB specifics »

- inclusive in addition to exclusive analyses
- channels with π^0, γ's, ν, many Ks…

τ physics (polarized beams)

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}

Charm at Υ(4S) and threshold

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}
$D^0 \to K^+\pi^-$	x'^2		3×10^{-5}
	y'		7×10^{-4}
$D^0 \to K^+K^-$	y_{CP}		5×10^{-4}
$D^0 \to K^0_S\pi^+\pi^-$	x		4.9×10^{-4}
	y		3.5×10^{-4}
	$\lvert q/p\rvert$		3×10^{-2}
	ϕ		$2°$

To be evaluated at LHCb

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

B_s at Υ(5S)

Observable	Error with 1 ab^{-1}	Error with 30 ab^{-1}
$\Delta\Gamma$	0.16 ps^{-1}	0.03 ps^{-1}
Γ	0.07 ps^{-1}	0.01 ps^{-1}
β_s from angular analysis	$20°$	$8°$
A^s_{SL}	0.006	0.004
A_{CH}	0.004	0.004
$\mathcal{B}(B_s \to \mu^+\mu^-)$	-	$< 8 \times 10^{-9}$
$\lvert V_{td}/V_{ts}\rvert$	0.08	0.017
$\mathcal{B}(B_s \to \gamma\gamma)$	38%	7%
β_s from $J/\psi\phi$	$16°$	$6°$
β_s from $B_s \to K^0\bar{K}^0$	$24°$	$11°$

Bs : Definitively better at LHCb

LHCb 10 fb^{-1} NP physics highlights

Upgrade

Santos

Rare decays: $B_s \rightarrow \mu\mu$
•Direct search for NP
•3σ measurement of SM prediction

Measure BR to ~5-10%, search for $B_d \rightarrow \mu\mu$

Leroy

Mixing phase in $B_s \rightarrow J/\psi\phi$ (tree)
•Sensitive to NP in mixing
•Measure $\sigma(\phi_s) \approx 0.01$

Improve by factor 3:
Level of indirect prediction

Leroy

Mixing phase in $B_s \rightarrow \phi\phi$ (penguin)
•Sensitive to NP in loops
•Measure phase ≠ 0 (=NP) with $\sigma \approx 0.03$

Measure to $\sigma \approx 0.01$, pin down NP

Ricciardi

CKM angle γ from $B_d \rightarrow D/DK$, $B_s \rightarrow D_sK$, B_d->$D\pi$ (tree)
•standard candle against which NP sensitive measurements can be compared
•measurements to ~ 2° degrees

sub-degree precision

Carson

•CKM angle γ from $B_{d(s)} \rightarrow \pi\pi$, KK (penguin), $B \rightarrow hhh$
•γ_NP vs γ_SM
•Sensitive to ≈ 3° degrees

Improve by factor 4-5

CPV in penguins $B_d \rightarrow \phi K_s$: β vs β_{eff}
•Sensitive to NP in loops
•Sensitive to ≈ 0.1

Comparison at 0.03° level

Reece, Belyaev

Search for RH currents in radiative decays $B_s \rightarrow \phi\gamma$; Asymmetry FB of $B_d \rightarrow K^* \mu\mu$
•(zero of $A_{FB}(s)$ to 7%)

New observables to improve NP sensitivty

Magnin

D meson physics
CP, D-D mixing, rare decays

Measure and characterise CPV