EFT, global analyses, model (in)dependence, and all that

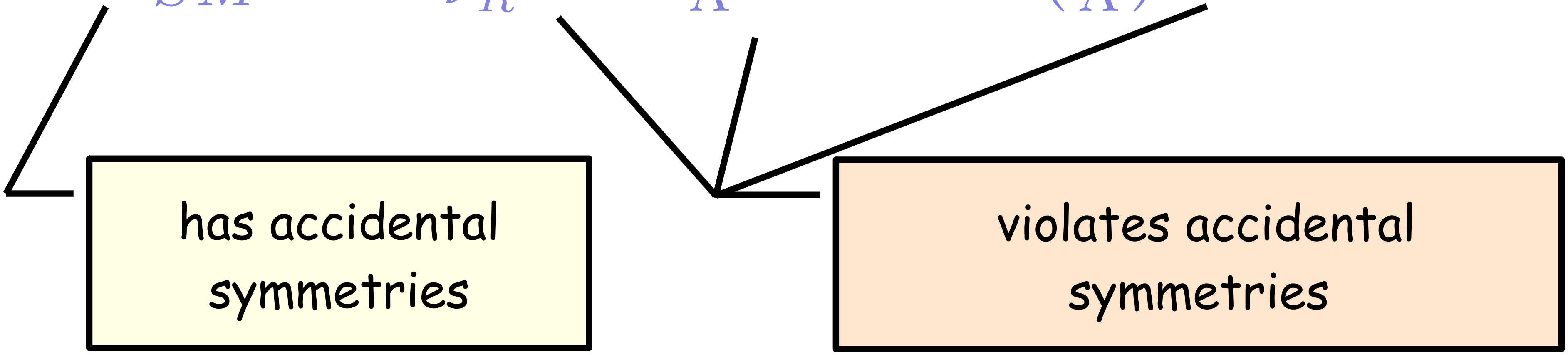
Marco Ciuchini INFN Roma Tre

- EFT vs NP models: the UTA example
- From H_{eff} to SMEFT: C_7-$C_{9/10}$ global analysis
- HEP*fit*: a tool for combining direct and indirect constraints on HEP models

TUM LMU ESO
Excellence Cluster Universe

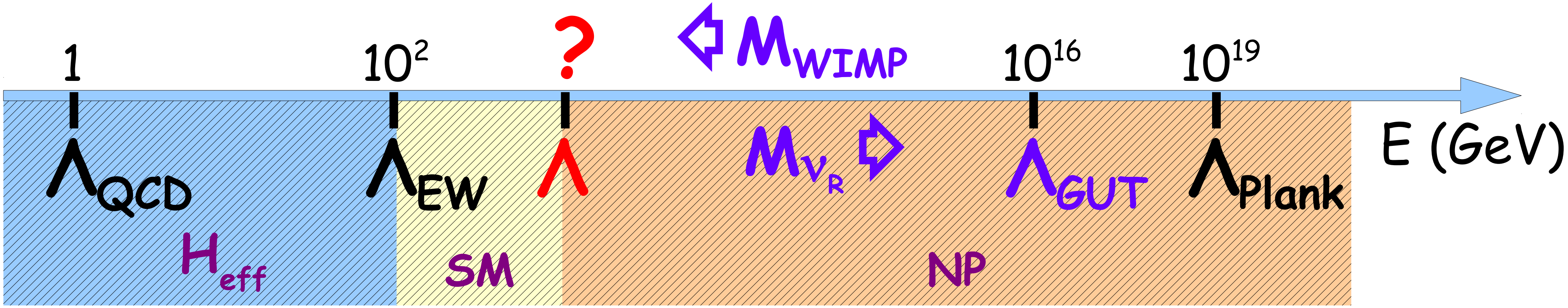
Standard Model as an EFT

$$\mathcal{L} = \mathcal{L}_{SM}^{D=4} + \mathcal{L}_{\nu_R}^{D=4} + \frac{1}{\Lambda}\mathcal{L}^{D=5} + \left(\frac{1}{\Lambda}\right)^2 \mathcal{L}^{D=6} + \ldots$$



has accidental symmetries

violates accidental symmetries



$$\underset{E \ll \Lambda_{\rm EW}}{\longrightarrow} \mathcal{H}_{\rm eff}^{\rm SM} + \mathcal{H}_{\rm eff}^{\rm NP}$$

$SU(3)_c \times U(1)_q$
-invariant, i.e.
low-energy symmetries

When does this construction work?

i) Scale separation

There must be a NP scale much larger than the EW scale (and of the scale of the process)

👍 at least one scale is there: the Plank scale

challenged: e.g. Salvio, Strumia, 1403.4226

ii) Full knowledge of the low-energy physics

The particle content below the NP scale is known, i.e. all low-energy d.o.f.'s are included in the EFT

challenged: feebly coupled light particles
(dark sectors, portal, etc.)

Top-down or bottom-up?

$$\mathcal{H}_{\rm eff}^{\rm NP} = \frac{1}{\Lambda^2}\sum_i C_i Q_i$$

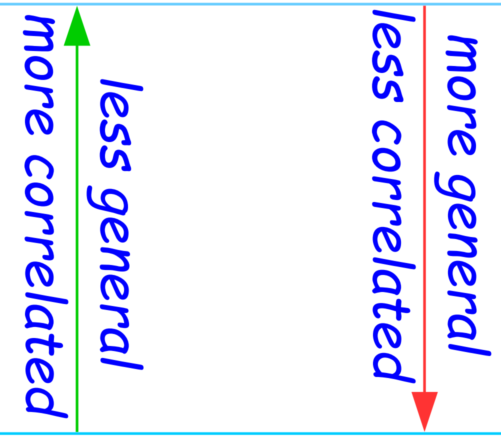
Top-down: a NP correlation pattern in enforced on the WC's and then looked for in the data

Bottom-up: only low-energy correlations are enforced, data fix WCs', hopefully showing additional patterns

Both approaches require the effective theory

Specific NP model

- C_i and Λ are fully calculable in terms of the model parameters



more correlated

less general

less correlated

more general

Model-independent analysis

- the free parameters are C_i/Λ^2
- Λ cannot be determined

A well-known example: NP in the UT

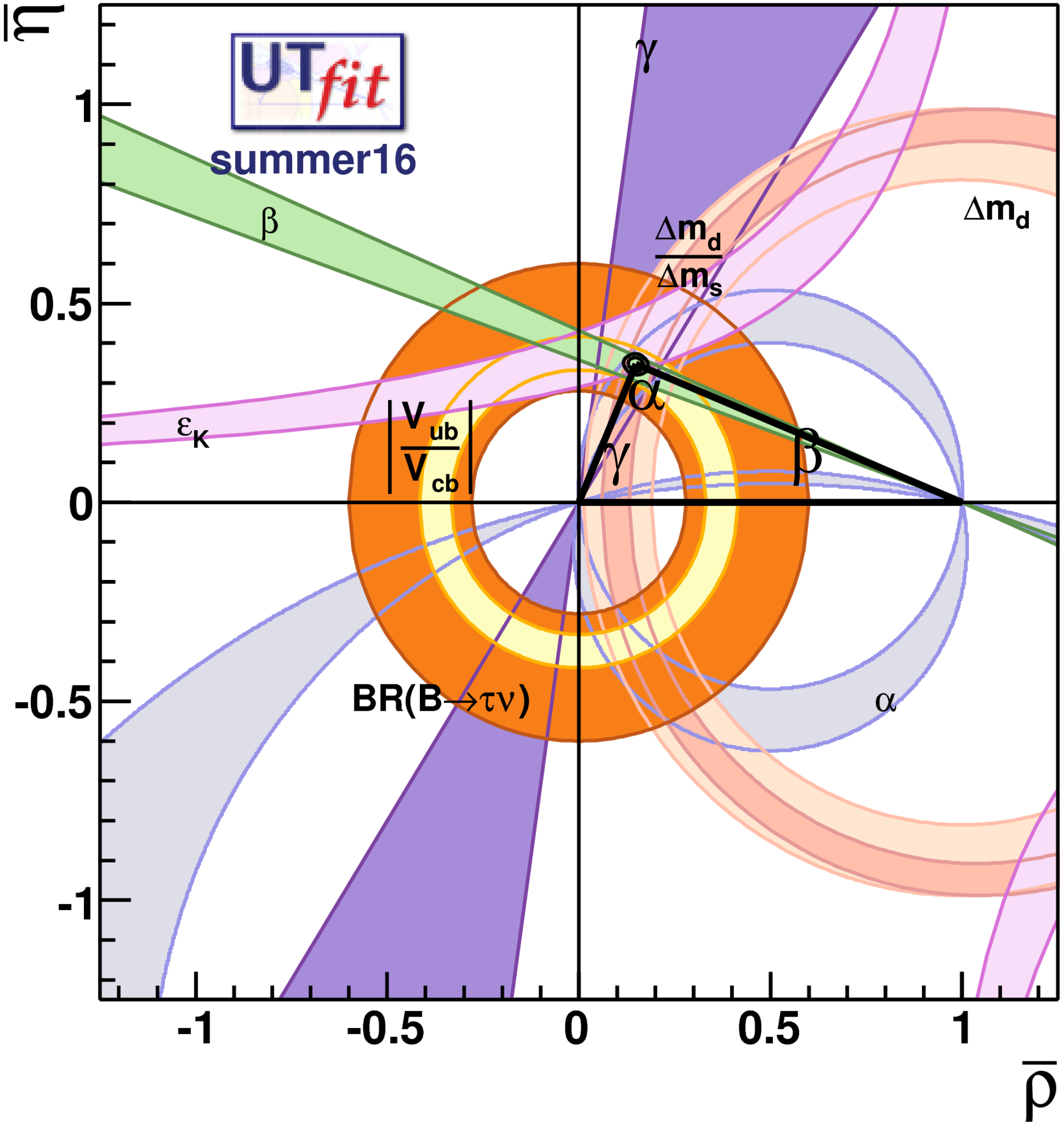
The UT analysis is mainly driven by ΔF=2 transitions and usually done using SM amplitudes

NP can be include with an increasing degree of model-dependence:

Step 0: Phenomenological parametrization

Step 1: EFT analysis

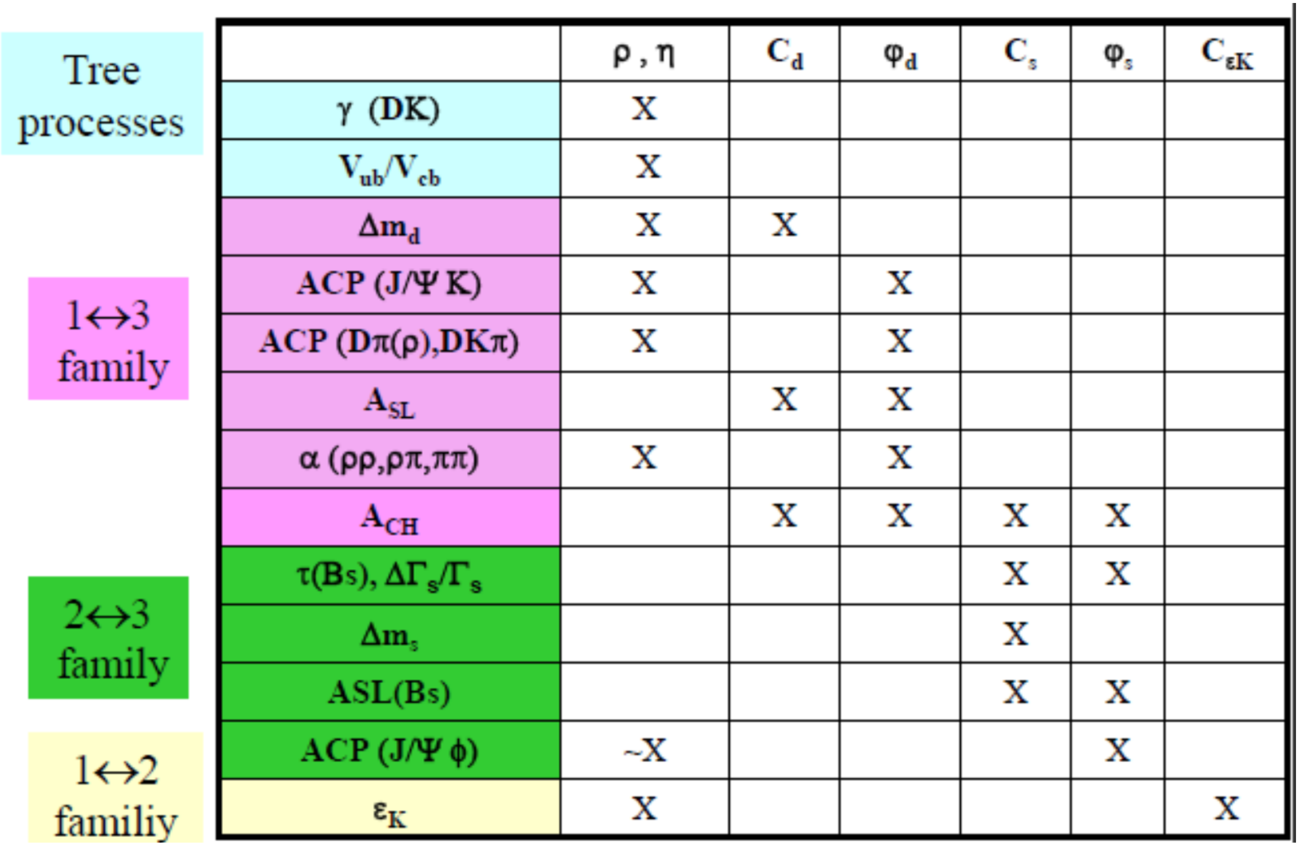
Step 2: Explict model (MSSM)



0- Phenomenological parametrization(s)

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

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



		ρ , η	C_d	φ_d	C_s	φ_s	$C_{\varepsilon K}$
Tree processes	γ (DK)	X					
	V_{ub}/V_{cb}	X					
1↔3 family	Δm_d	X	X				
	ACP (J/Ψ K)	X		X			
	ACP (Dπ(ρ),DKπ)	X		X			
	A_{SL}		X	X			
	α (ρρ,ρπ,ππ)	X		X			
	A_{CH}		X	X	X	X	
2↔3 family	τ(Bs), $\Delta\Gamma_s/\Gamma_s$				X	X	
	Δm_s				X		
	ASL(Bs)				X	X	
	ACP (J/Ψ φ)	~X				X	
1↔2 familiy	ε_K	X					X

$$q=d,s,\ \ \phi_d^{SM}=\beta,\ \ \phi_s^{SM}=-\beta_s$$

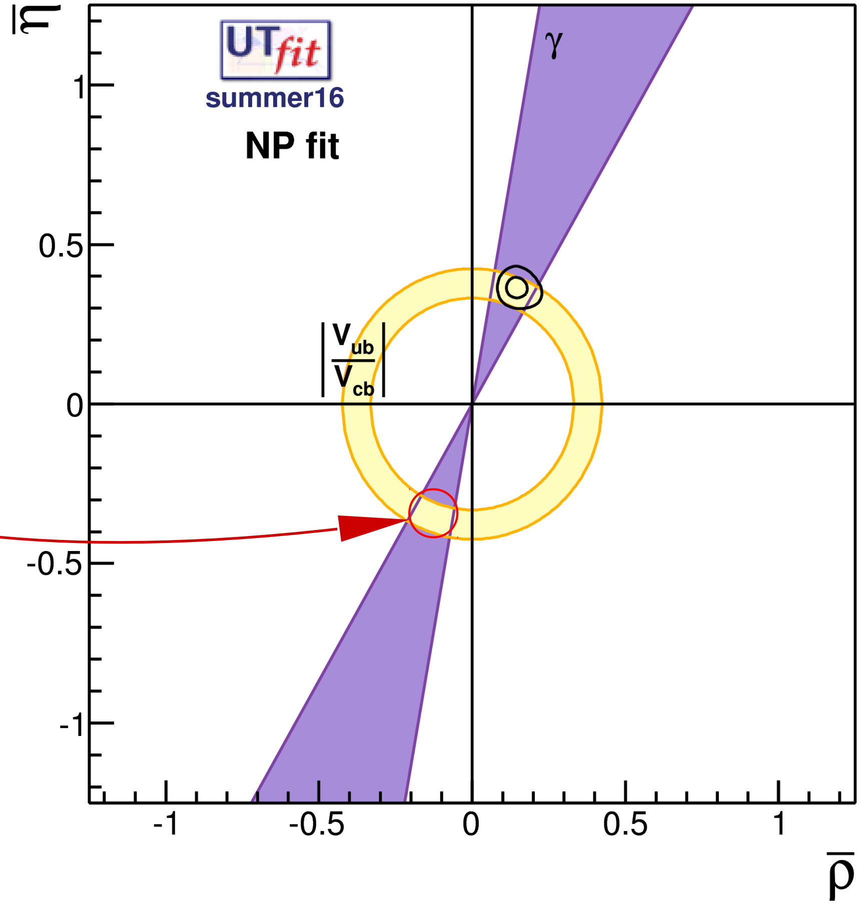
+

K mixing amplitude (1 real param):

$$\mathrm{Im}\,A_K = C_\varepsilon\,\mathrm{Im}\,A_K^{SM}$$

Correlations at work

assumption: negligible NP in tree decays



excluded by correlations

$\bar{\rho}$ = 0.147 ± 0.043

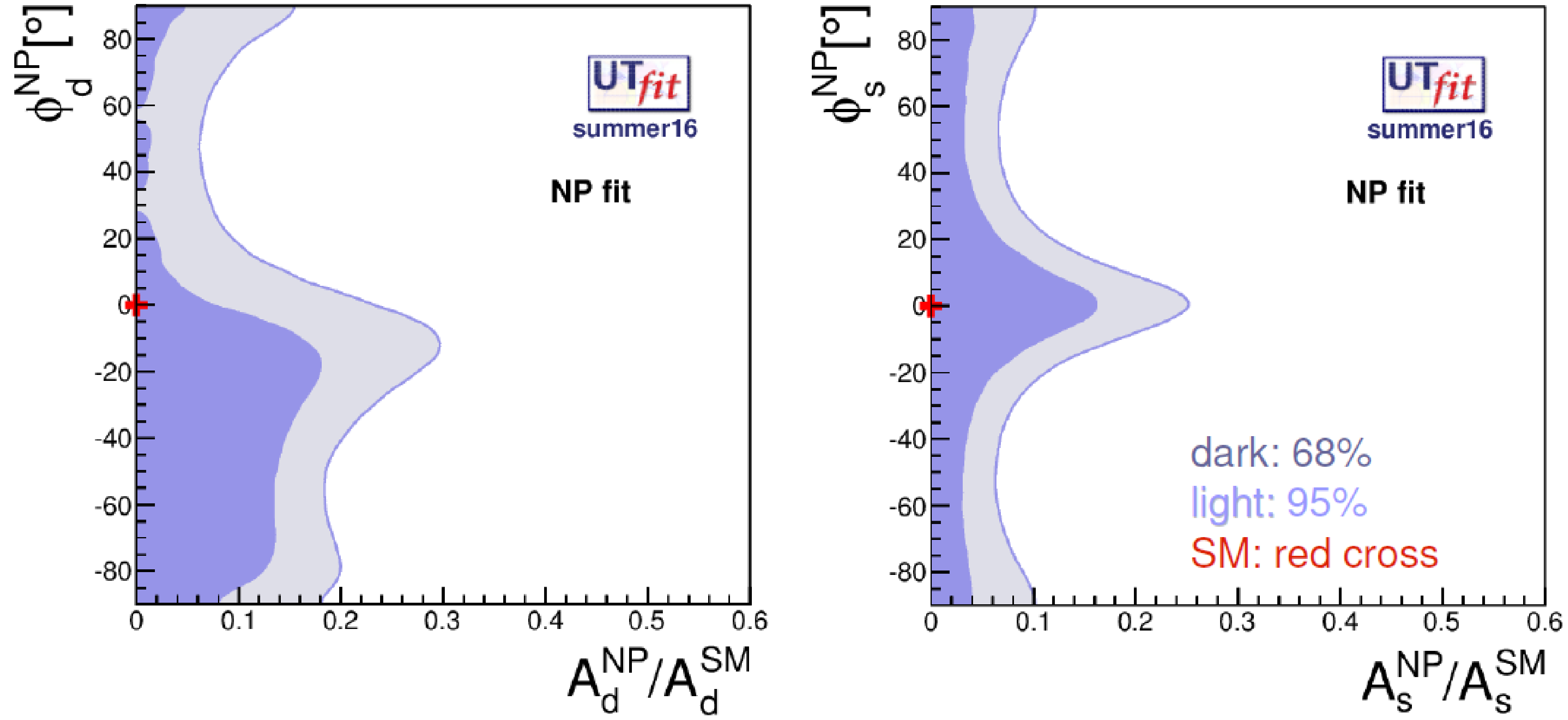
$\bar{\eta}$ = 0.384 ± 0.044

in the SM fit is:

$\bar{\rho}$ = 0.142 ± 0.018

$\bar{\eta}$ = 0.357 ± 0.013

Implications for the NP amplitudes



The ratio of NP/SM amplitudes is:

< ~1-20% @68% prob. (5-30% @95%) in B_d mixing

< ~3-15% @68% prob. (5-25% @95%) in B_s mixing

1- EFT analysis of ΔF=2 transitions

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

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

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

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

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

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

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

$C_i(\Lambda)$ are extracted from data:

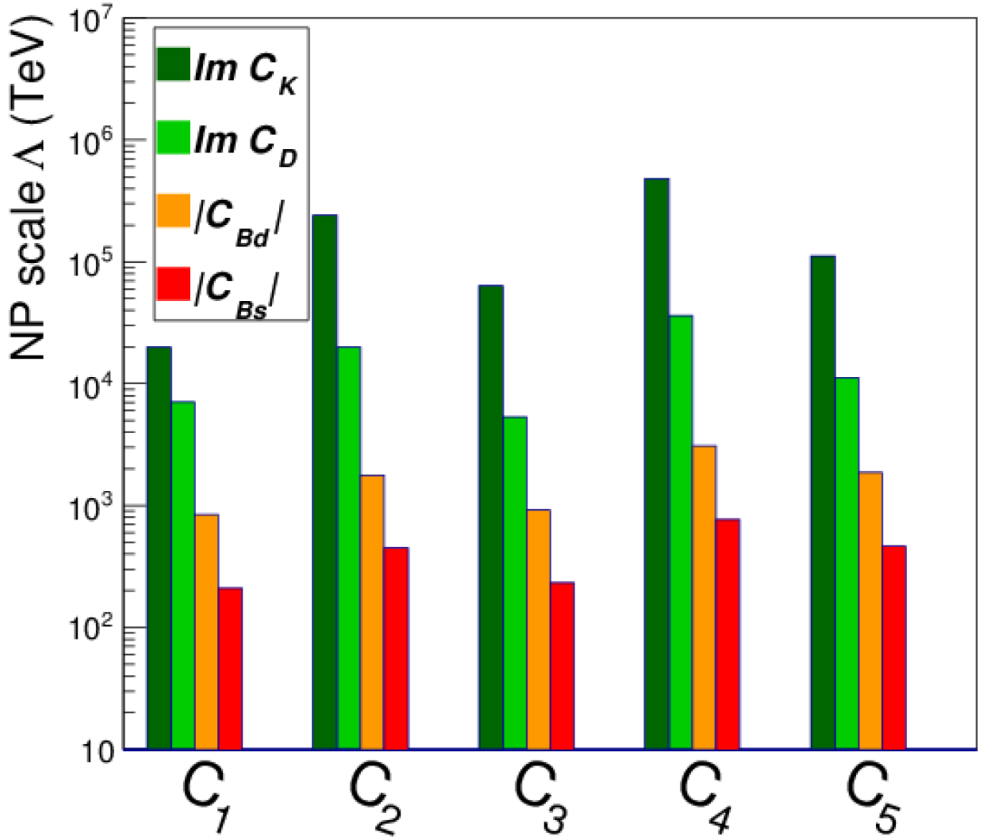
- one by one, "barring accidental cancellations"
- all together, safer but trickier

Parameter	95% allowed range (GeV^{-2})
$\mathrm{Im}C_K^1$	$[-1.8, 2.5] \cdot 10^{-15}$
$\mathrm{Im}C_K^2$	$[-1.7, 1.2] \cdot 10^{-17}$
$\mathrm{Im}C_K^3$	$[-1.7, 2.5] \cdot 10^{-16}$
$\mathrm{Im}C_K^4$	$[-3.0, 4.3] \cdot 10^{-18}$
$\mathrm{Im}C_K^5$	$[-5.5, 8.1] \cdot 10^{-17}$
$\mathrm{Im}C_D^1$	$[-1.4, 2.0] \cdot 10^{-14}$
$\mathrm{Im}C_D^2$	$[-2.5, 1.7] \cdot 10^{-15}$
$\mathrm{Im}C_D^3$	$[-2.4, 3.5] \cdot 10^{-14}$
$\mathrm{Im}C_D^4$	$[-5.2, 7.7] \cdot 10^{-16}$
$\mathrm{Im}C_D^5$	$[-5.3, 7.9] \cdot 10^{-15}$
$\lvert C_{B_d}^1 \rvert$	$< 1.4 \cdot 10^{-12}$
$\lvert C_{B_d}^2 \rvert$	$< 3.2 \cdot 10^{-13}$
$\lvert C_{B_d}^3 \rvert$	$< 1.2 \cdot 10^{-12}$
$\lvert C_{B_d}^4 \rvert$	$< 1.0 \cdot 10^{-13}$
$\lvert C_{B_d}^5 \rvert$	$< 2.9 \cdot 10^{-13}$
$\lvert C_{B_s}^1 \rvert$	$< 2.3 \cdot 10^{-11}$
$\lvert C_{B_s}^2 \rvert$	$< 5.0 \cdot 10^{-12}$
$\lvert C_{B_s}^3 \rvert$	$< 1.9 \cdot 10^{-11}$
$\lvert C_{B_s}^4 \rvert$	$< 1.7 \cdot 10^{-12}$
$\lvert C_{B_s}^5 \rvert$	$< 4.6 \cdot 10^{-12}$

Lower bound on the NP scale Λ from ΔF=2 transitions (TeV @95% prob.)

Already beyond the EFT: it needs assumptions on the UV structure

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



Loop factor L:

- tree/strong interact. NP, L ~ 1
- if perturbative: L ~ α_s^2, α_W^2

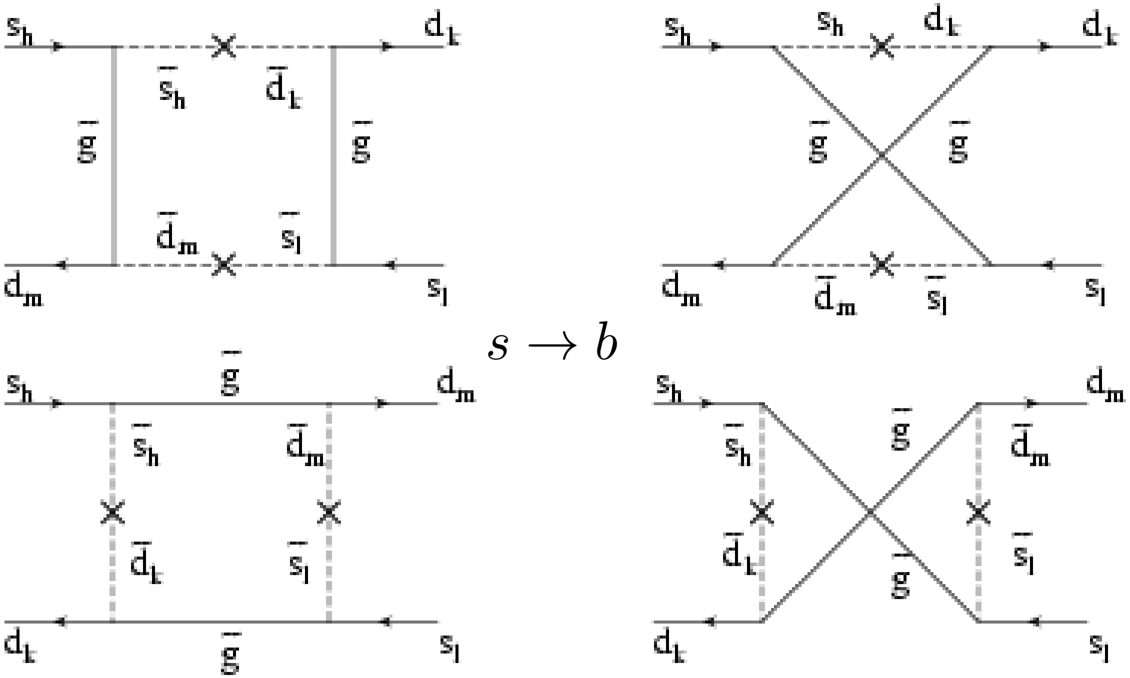
Flavor couplings FC:

- |FC| ~ 1, arbitrary phases; …

Λ (TeV)	K CPV	D CPV	B_d CPC	B_s CPC
lower bound	4.8×10^5	3.6×10^4	3.1×10^3	760

for the case of loop and flavour NP couplings equal to 1

2- MSSM: gluino-squark contributions



$s \to b$

Gabbiani et al.,
hep-ph/9604387

$$C_1=\alpha_s^2\boxed{\frac{(\delta_{13}^d)_{LL}^2}{\tilde{m}^2}}f_1(x) \quad C_2=\alpha_s^2\frac{(\delta_{13}^d)_{RL}^2}{\tilde{m}^2}f_2(x) \quad C_3=\alpha_s^2\frac{(\delta_{13}^d)_{RL}^2}{\tilde{m}^2}f_3(x)$$

$$x=\frac{m_{\tilde{g}}^2}{\tilde{m}}$$

$$\tilde{C}_1=\alpha_s^2\boxed{\frac{(\delta_{13}^d)_{RR}^2}{\tilde{m}^2}}f_1(x) \quad \tilde{C}_2=\alpha_s^2\frac{(\delta_{13}^d)_{LR}^2}{\tilde{m}^2}f_2(x) \quad \tilde{C}_3=\alpha_s^2\frac{(\delta_{13}^d)_{LR}^2}{\tilde{m}^2}f_3(x)$$

$$C_4=\alpha_s^2\left[\boxed{\frac{(\delta_{13}^d)_{LL}(\delta_{13}^d)_{RR}}{\tilde{m}^2}}f_4(x)+\frac{(\delta_{13}^d)_{LR}(\delta_{13}^d)_{RL}}{\tilde{m}^2}\tilde{f}_4(x)\right]$$

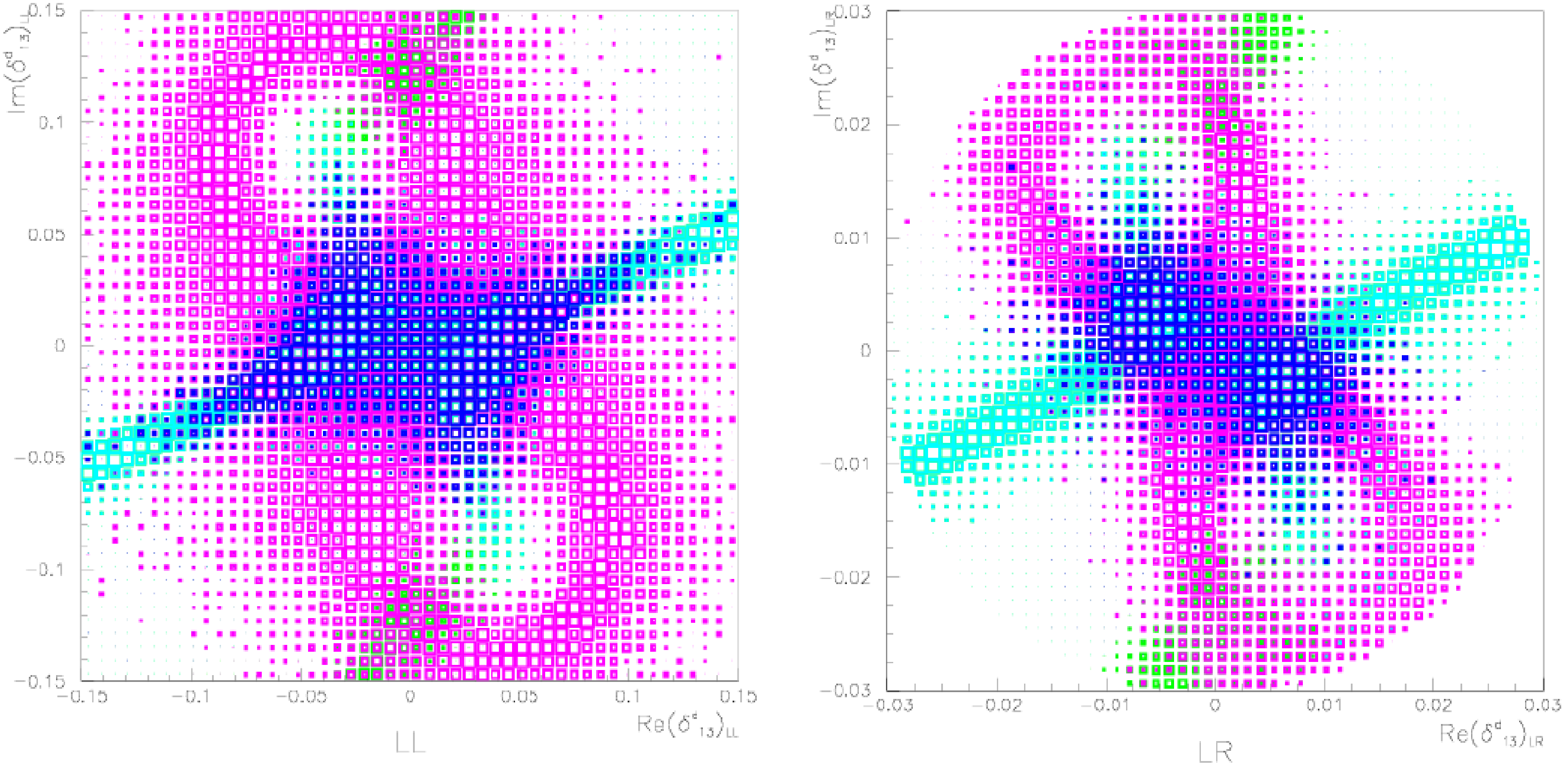
$$C_5=\alpha_s^2\left[\frac{(\delta_{13}^d)_{LL}(\delta_{13}^d)_{RR}}{\tilde{m}^2}f_5(x)+\frac{(\delta_{13}^d)_{LR}(\delta_{13}^d)_{RL}}{\tilde{m}^2}\tilde{f}_5(x)\right]$$

NP model:

→ less parameters

→ more correlations

Δm_{Bd} sin2β sin2β and cos2β all



$\mathrm{Re}\,(\delta^d_{13})_{LL,RR}$ vs $\mathrm{Im}\,(\delta^d_{13})_{LL,RR}$ $\mathrm{Re}\,(\delta^d_{13})_{LR,RL}$ vs $\mathrm{Im}\,(\delta^d_{13})_{LR,RL}$

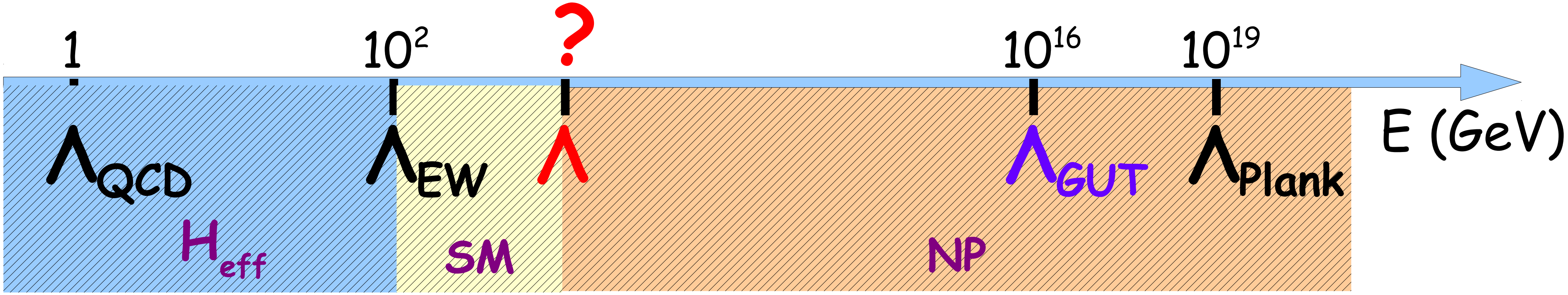
MC et al, hep-ph/9808328 + updates

$m_{sq}=m_g= -\mu = 350$ GeV (!!!), scale as $m_{sq}/350$ GeV

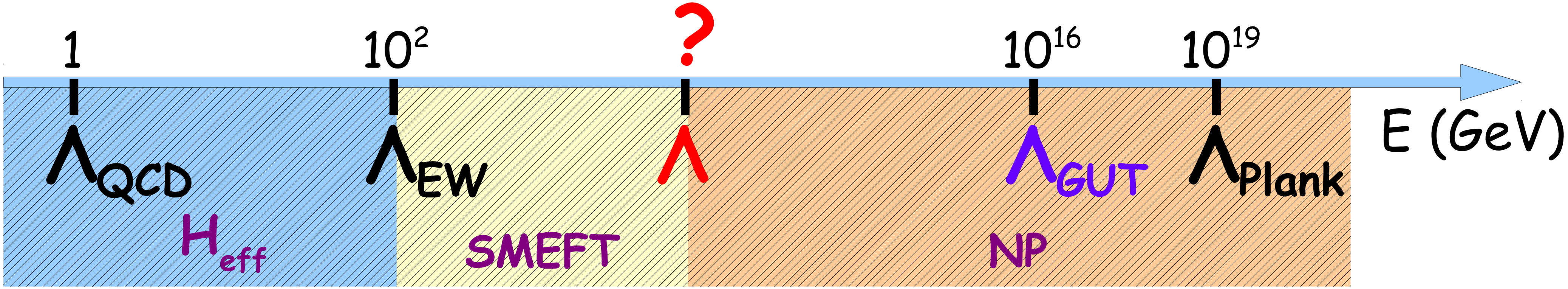
$\left\|\left(\delta^d_{13}\right)_{LL,RR}\right\|$	$\left\|\left(\delta^d_{13}\right)_{LL=RR}\right\|$	$\left\|\left(\delta^d_{13}\right)_{LR}\right\|$	$\left\|\left(\delta^d_{13}\right)_{RL}\right\|$
$7 \cdot 10^{-2}$	$5 \cdot 10^{-3}$	$1 \cdot 10^{-2}$	$1 \cdot 10^{-2}$

A step upward: SMEFT

$$\mathcal{L} = \mathcal{L}_{SM}^{D=4} + \mathcal{L}_{\nu_R}^{D=4} + \frac{1}{\Lambda}\mathcal{L}^{D=5} + \left(\frac{1}{\Lambda}\right)^2 \mathcal{L}^{D=6} + \ldots$$



If $\Lambda \gg \Lambda_{EW}$ (as LHC data might suggest):



$$\underset{E \ll \Lambda}{\rightarrow} SU(3)_c \times SU(2)_L \times U(1)_Y \text{ EFT} \underset{E \ll \Lambda_{\text{EW}}}{\rightarrow} SU(3)_c \times U(1)_q \text{ EFT}$$

Facts about the SMEFT

see talks by Bobeth, Gonzalez-Alonso, and Straub

- 2499 operators (59 operators considering only flavour-diagonal and family-universal) built out of SU(2)xU(1) multiplets (including the Higgs doublet)
- It allows for studying SM processes at large (e.g. EWPO, Higgs couplings, flavour, …)

Buchmuller & Wyler;
Grzadkowski et al;

- Once matched onto the usual weak H_{eff}, it induces additional contraints and correlations on the WC's

CAVEAT:

- LHC may still prove that Λ is <u>not</u> much larger than Λ_{EW}
- No additional constraint on the H_{eff} WC's if the EWSB is not linearly realized

Catà, Jung

EWSB and low-energy processes

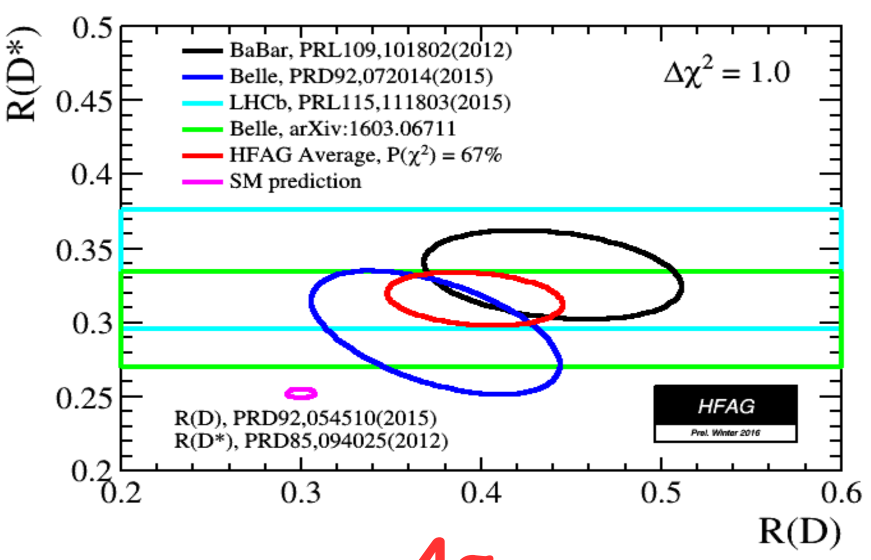
It is another floor added to the tower of EFT's built going from low to high energies (or vice versa).
As energy much larger than the EW scale, the EW symmetry is restored.

It is found that low-energy processes are sensitive to the details of EWSB (!!!)

Catà, Jung,
arXiv:1505.05804

For instance, if studying b → s ℓ ℓ transitions, it is found that the Wilson coefficient of the operator $(\bar{s}\sigma_{\mu\nu}b)\ \bar{l}\sigma^{\mu\nu}l$ is non-vanishing, then not only the presence of NP is established, but also the non-standard character of the EWSB is ascertained

SMEFT & flavour anomalies



4σ

$$R(X) = \frac{\Gamma(B \to X\tau\nu)}{\Gamma(B \to X\ell\nu)}$$

$$R(D) =$$

-1.9σ

$$0.397 \pm 0.040 \pm 0.028$$

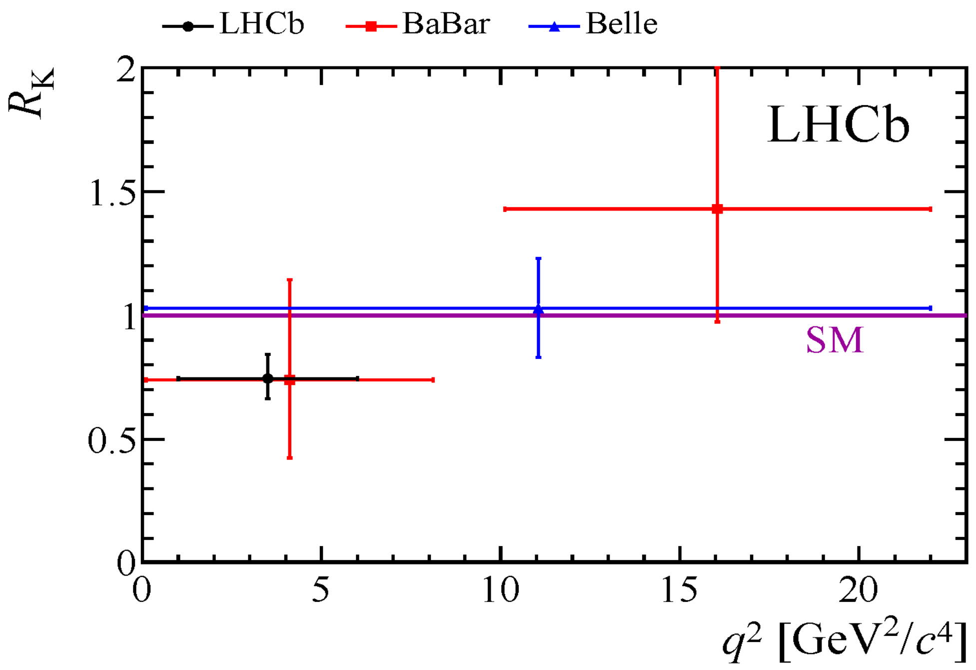
$$R(D)_{\rm SM} = 0.300 \pm 0.008$$

$$R(D^*) =$$

-3.3σ

$$0.316 \pm 0.016 \pm 0.010$$

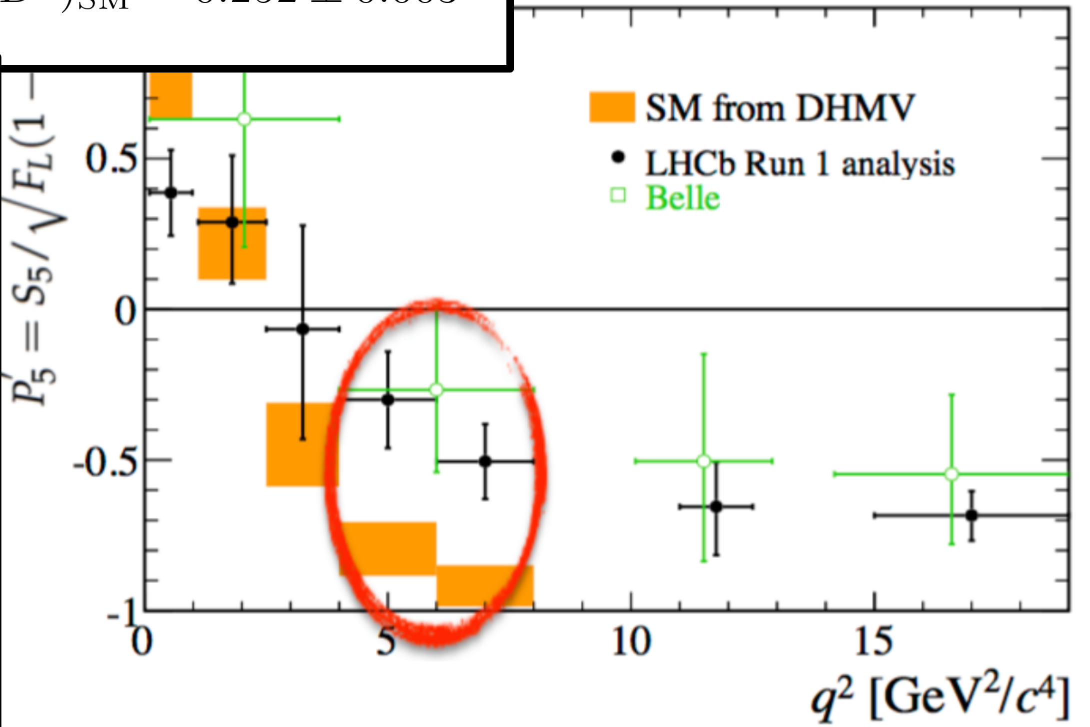
$$R(D^*)_{\rm SM} = 0.252 \pm 0.003$$



$$0.745^{+0.090}_{-0.074}\,({\rm stat}) \pm 0.036\,({\rm syst})$$

2.6σ

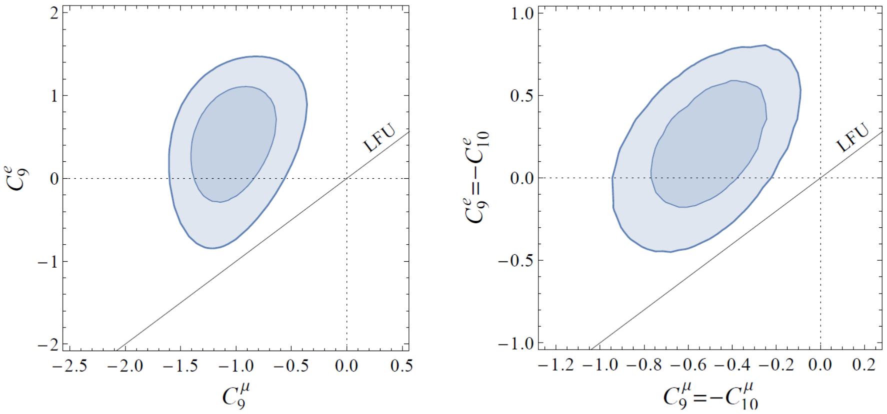
V.Vaanoni. ICHEP



SM predictions from Descotes-Genon et al., arXiv:1407.8526

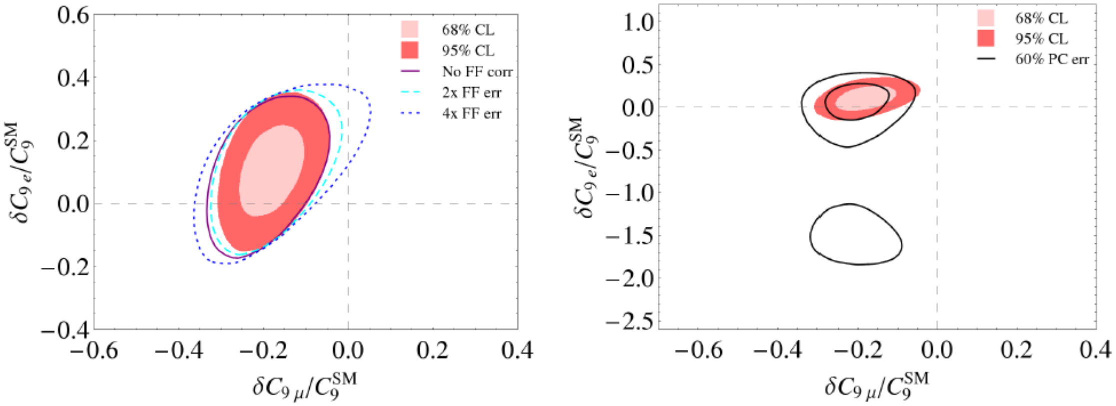
EFT global analysis

Altmannshofer, Straub., arXiv:1411.3161

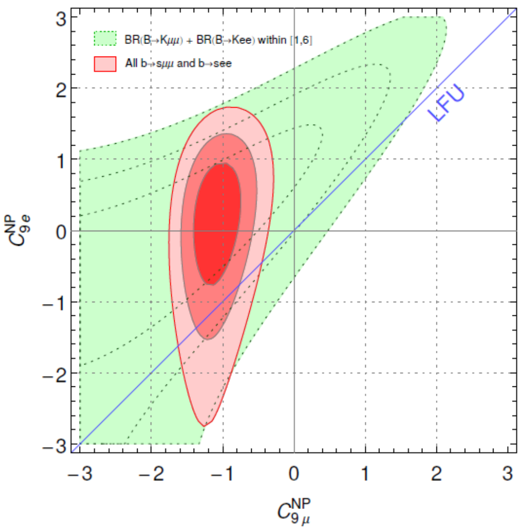


- $B \to K^{(*)} \mu\mu$
- $B_s \to \phi\, \mu\mu$
- $B \to K^* \gamma$
- $B \to X_s \gamma$
- R_K

Hurth et al., arXiv:1603.00865



Descotes-Genon et al., arXiv:1605.06059



point to an O(1) correction to the WC of $Q_9^\mu = \bar{s}_L \gamma_\alpha b_L \bar{\mu} \gamma^\alpha \mu$

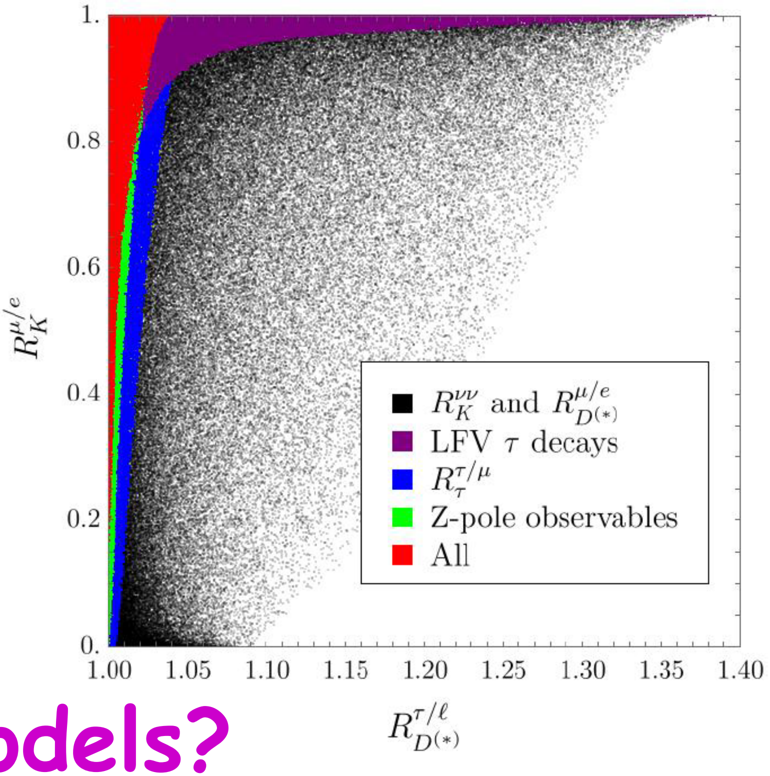
If LFU is induced by NP coupled to the 3rd generation at a scale much larger than the weak scale, in the SMEFT there are 2 four-fermion operator candidates:

$$Q'_{L,3}\gamma_\mu Q'_{L,3} L'_{L,3}\gamma^\mu L'_{L,3}, \quad Q'_{L,3}\gamma_\mu\sigma^i Q'_{L,3} L'_{L,3}\gamma^\mu\sigma^i L'_{L,3}$$

i) give typically rise to large LFV Glashow et al, arXiv:1411.0565

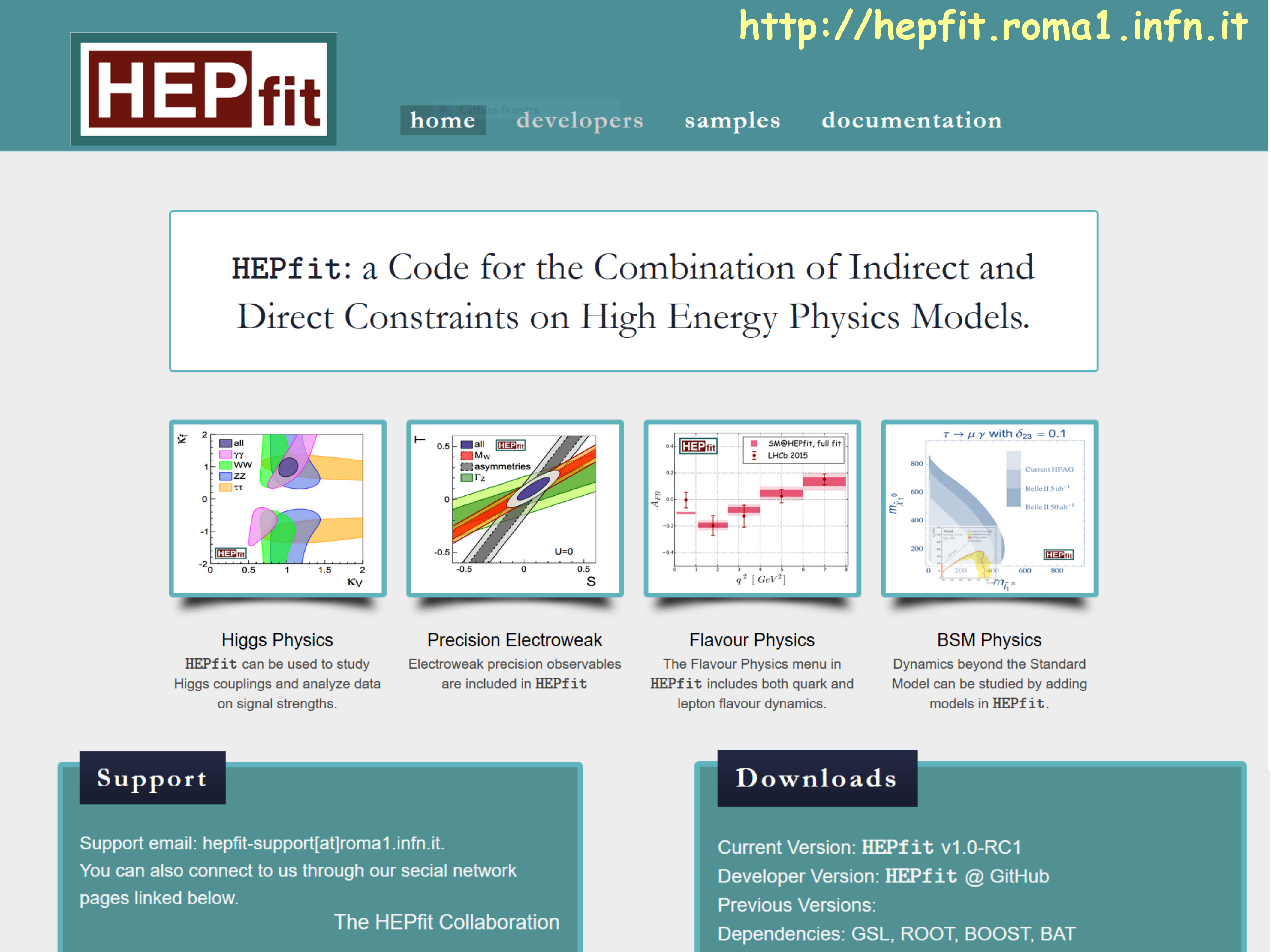
ii) can account for the anomalies in R_K, R(D)&R(D*) Bhattacharya et al, arXiv:1412.7164

iii) RGE running in SMEFT produces LFV corrections to the Vℓℓ vertices and induces large purely leptonic FV transitions, which disfavour a common explanation of the anomalies Feruglio et al, arXiv:1606.00524



what about RGE effects in models?

http://hepfit.roma1.infn.it



HEPfit: a Code for the Combination of Indirect and Direct Constraints on High Energy Physics Models.

Higgs Physics

HEPfit can be used to study Higgs couplings and analyze data on signal strengths.

Precision Electroweak

Electroweak precision observables are included in **HEPfit**

Flavour Physics

The Flavour Physics menu in **HEPfit** includes both quark and lepton flavour dynamics.

BSM Physics

Dynamics beyond the Standard Model can be studied by adding models in **HEPfit**.

Support

Support email: hepfit-support[at]roma1.infn.it.
You can also connect to us through our secial network pages linked below.

The HEPfit Collaboration

Downloads

Current Version: **HEPfit** v1.0-RC1
Developer Version: **HEPfit** @ GitHub
Previous Versions:
Dependencies: GSL, ROOT, BOOST, BAT

The HEPfit team

HEPfit

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+ you!

The HEPfit philosophy

- **Open source**
  - C++ source released under GPL available on github

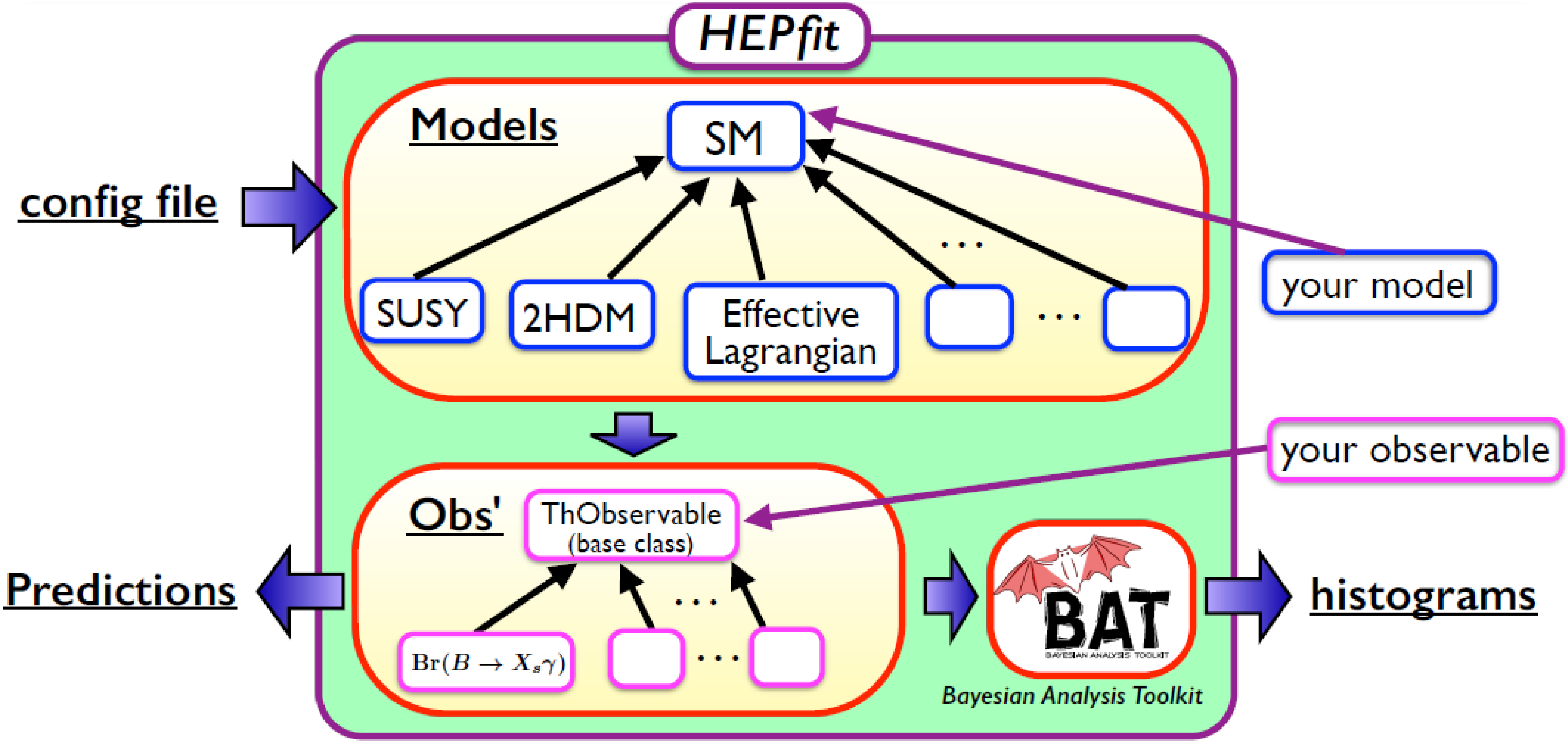
- **Easy to use**
  - CMake installation, optionally include external libraries
  - configurable with few human-readable config files
  - fully doxygen-ed

- **Highly flexible and customizable**
  - includes an expanding set of models and observables
  - provides interfaces to add new models and observables
  - can be used for quick estimate as well as global analyses
  - interfaces to the Bayesian Analysis Tools based on MCMC

Caldwell et al, arXiv:0808.2552
http://mpp.mpg.de/bat

- **Fast**
  - optional support for MPI parallelization

The HEPfit structure



HEPfit

config file

Models

SM

SUSY

2HDM

Effective Lagrangian

. . .

your model

Obs'

ThObservable (base class)

$\mathrm{Br}(B \to X_s\gamma)$

. . .

your observable

Predictions

BAT

Bayesian Analysis Toolkit

histograms

courtesy of S. Mishima

Installation and usage

Download HEPfit-x.x.tar.gz from the HEPfit website - http://hepfit.roma1.infn.it, then

```
tar zxvf HEPfit-x.x.tar.gz
cd HEPfit-x.x
cmake . -DLOCAL_INSTALL_ALL=ON -DMPIBAT=ON
make
make install
```

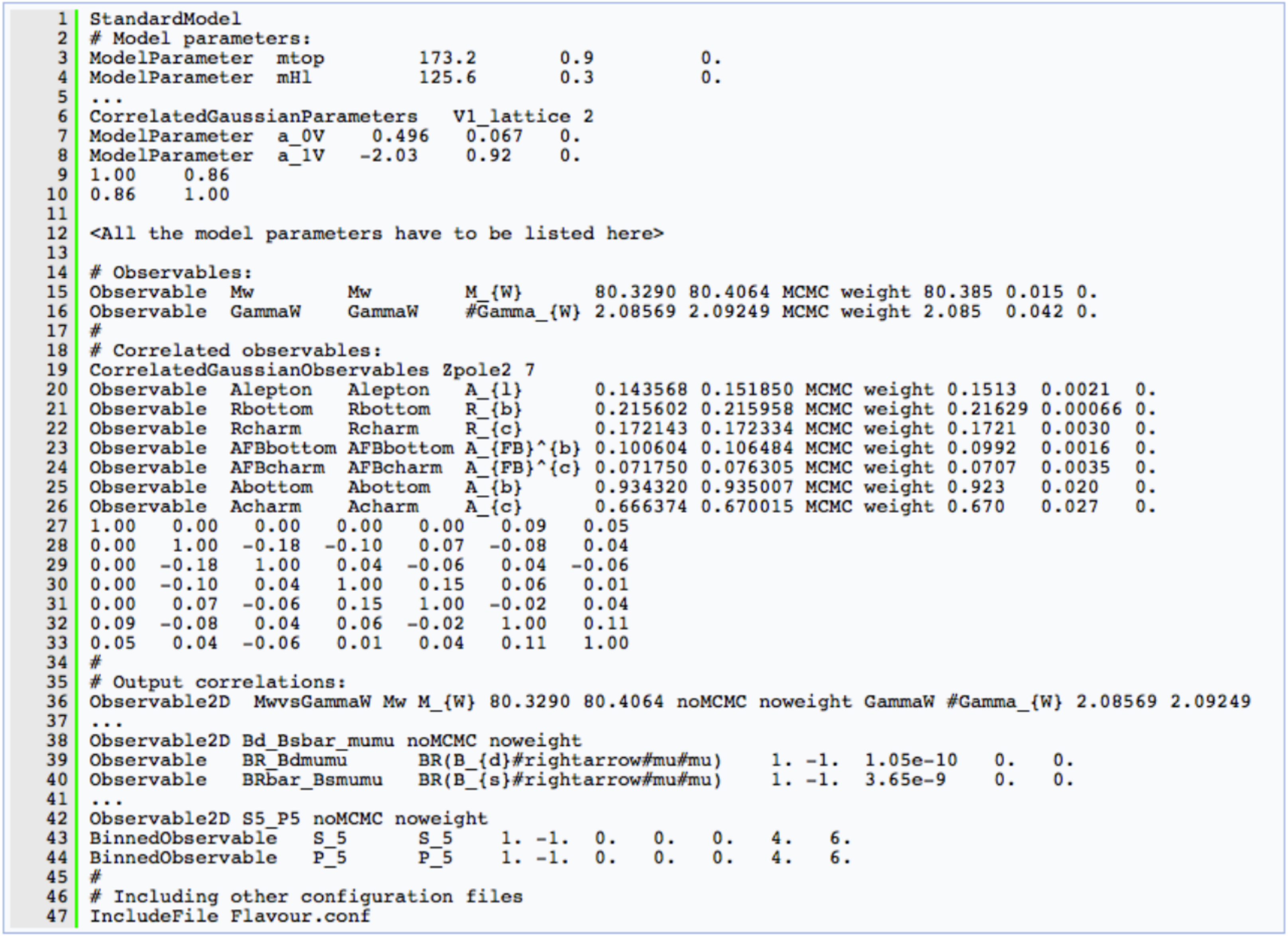
this will also download, compile and install the required and optional libraries (ROOT, BAT, gsl, BOOST, MPI), if needed. Then, it is ready to run:

```
./analysis StandardModel.conf MonteCarlo.conf
```

getting in input two config files (or just one if you do not wish to do the MCMC statistical analysis)

The config file

StandardModel.conf



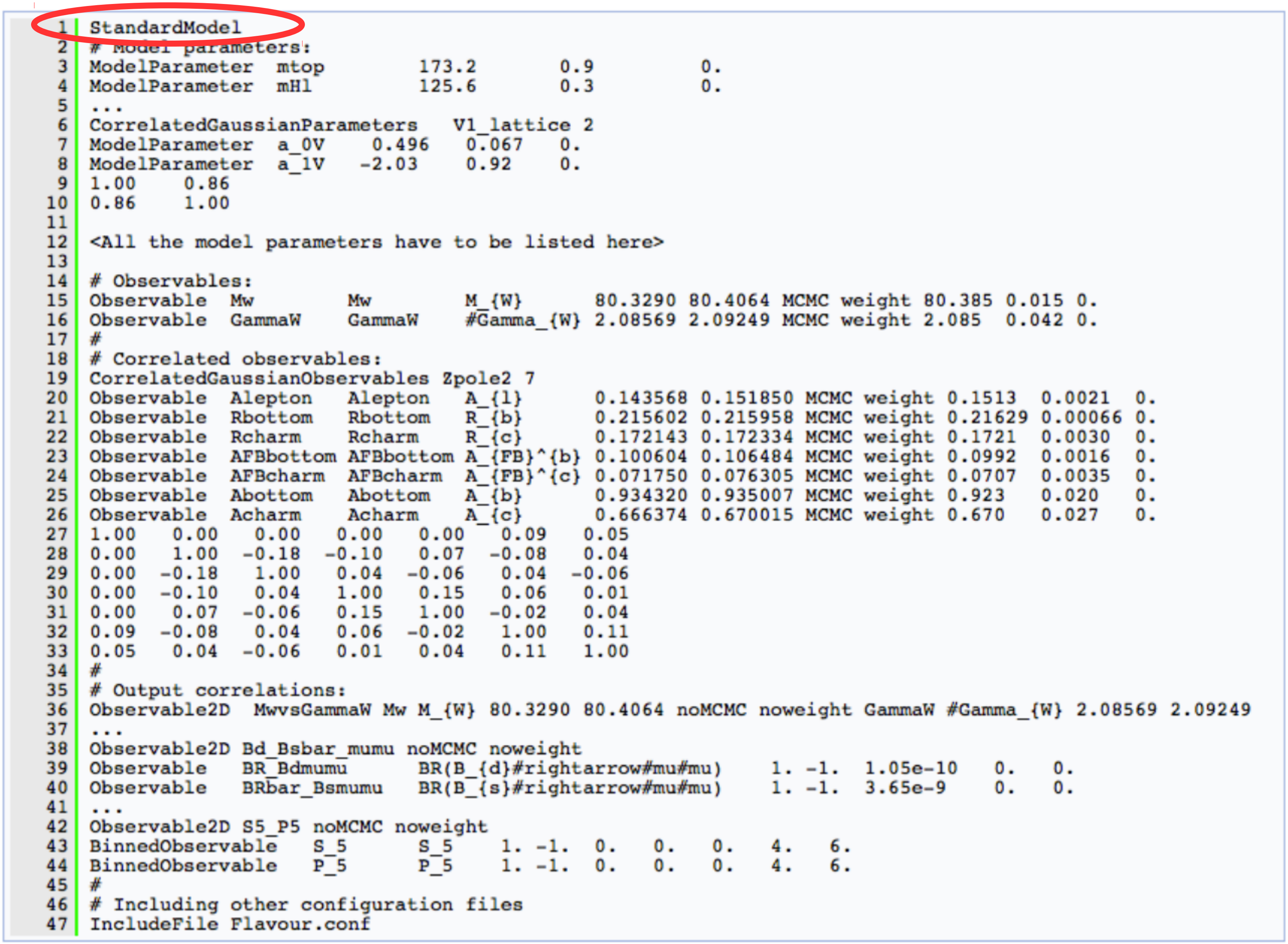
```
StandardModel
# Model parameters:
ModelParameter  mtop        173.2       0.9         0.
ModelParameter  mHl         125.6       0.3         0.
...
CorrelatedGaussianParameters   V1_lattice 2
ModelParameter  a_0V    0.496   0.067   0.
ModelParameter  a_1V   -2.03    0.92    0.
1.00    0.86
0.86    1.00

<All the model parameters have to be listed here>

# Observables:
Observable  Mw        Mw        M_{W}      80.3290 80.4064 MCMC weight 80.385 0.015 0.
Observable  GammaW    GammaW    #Gamma_{W} 2.08569 2.09249 MCMC weight 2.085  0.042 0.
#
# Correlated observables:
CorrelatedGaussianObservables Zpole2 7
Observable  Alepton   Alepton   A_{l}      0.143568 0.151850 MCMC weight 0.1513  0.0021  0.
Observable  Rbottom   Rbottom   R_{b}      0.215602 0.215958 MCMC weight 0.21629 0.00066 0.
Observable  Rcharm    Rcharm    R_{c}      0.172143 0.172334 MCMC weight 0.1721  0.0030  0.
Observable  AFBbottom AFBbottom A_{FB}^{b} 0.100604 0.106484 MCMC weight 0.0992  0.0016  0.
Observable  AFBcharm  AFBcharm  A_{FB}^{c} 0.071750 0.076305 MCMC weight 0.0707  0.0035  0.
Observable  Abottom   Abottom   A_{b}      0.934320 0.935007 MCMC weight 0.923   0.020   0.
Observable  Acharm    Acharm    A_{c}      0.666374 0.670015 MCMC weight 0.670   0.027   0.
1.00   0.00   0.00   0.00   0.00   0.09   0.05
0.00   1.00  -0.18  -0.10   0.07  -0.08   0.04
0.00  -0.18   1.00   0.04  -0.06   0.04  -0.06
0.00  -0.10   0.04   1.00   0.15   0.06   0.01
0.00   0.07  -0.06   0.15   1.00  -0.02   0.04
0.09  -0.08   0.04   0.06  -0.02   1.00   0.11
0.05   0.04  -0.06   0.01   0.04   0.11   1.00
#
# Output correlations:
Observable2D  MwvsGammaW Mw M_{W} 80.3290 80.4064 noMCMC noweight GammaW #Gamma_{W} 2.08569 2.09249
...
Observable2D Bd_Bsbar_mumu noMCMC noweight
Observable   BR_Bdmumu      BR(B_{d}#rightarrow#mu#mu)    1. -1.  1.05e-10   0.   0.
Observable   BRbar_Bsmumu   BR(B_{s}#rightarrow#mu#mu)    1. -1.  3.65e-9    0.   0.
...
Observable2D S5_P5 noMCMC noweight
BinnedObservable   S_5      S_5    1. -1.  0.   0.   0.   4.   6.
BinnedObservable   P_5      P_5    1. -1.  0.   0.   0.   4.   6.
#
# Including other configuration files
IncludeFile Flavour.conf
```

The config file

StandardModel.conf



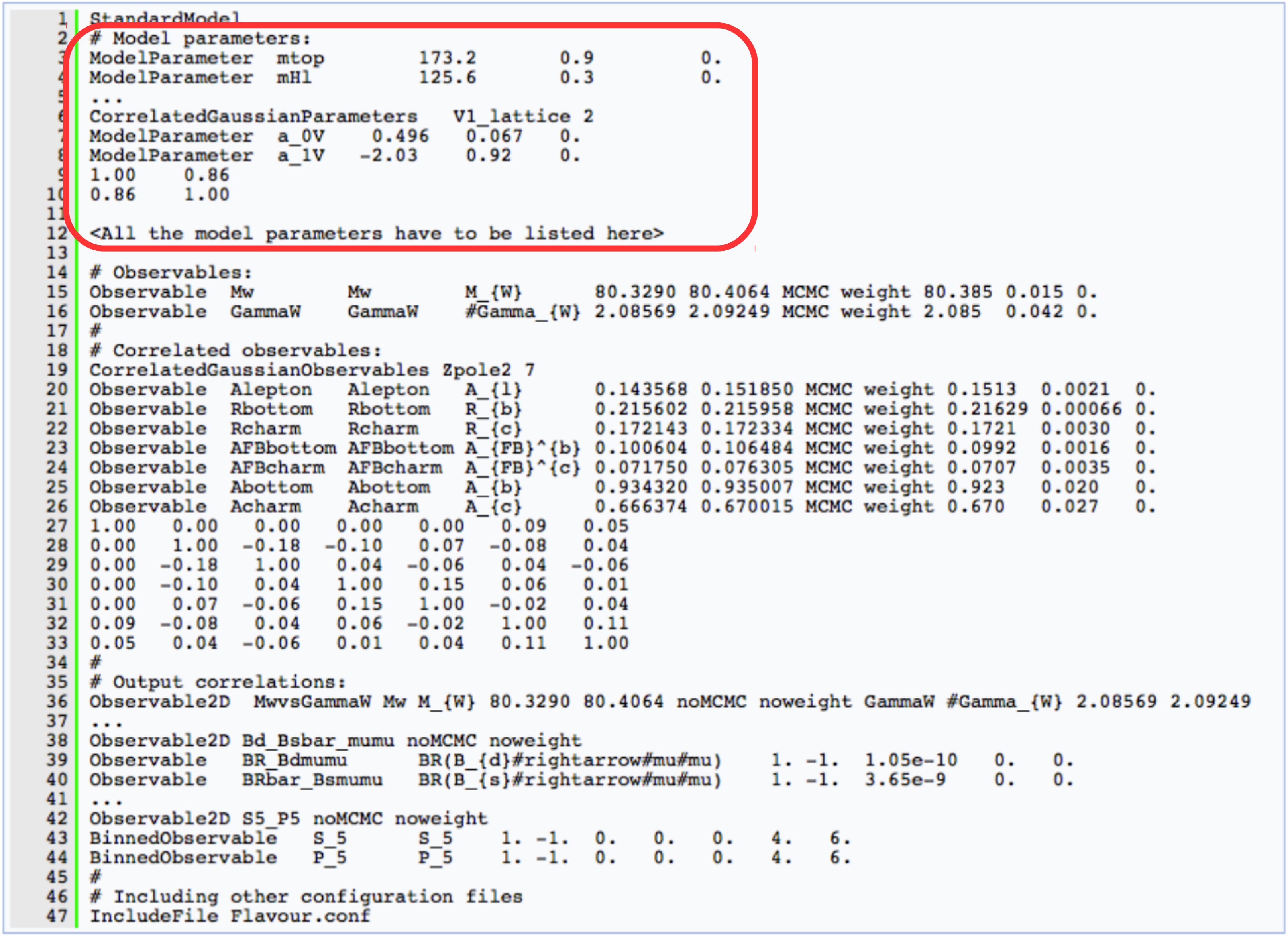
```
StandardModel
# Model parameters:
ModelParameter  mtop        173.2       0.9         0.
ModelParameter  mHl         125.6       0.3         0.
...
CorrelatedGaussianParameters   V1_lattice 2
ModelParameter  a_0V    0.496   0.067   0.
ModelParameter  a_1V   -2.03    0.92    0.
1.00    0.86
0.86    1.00

<All the model parameters have to be listed here>

# Observables:
Observable  Mw        Mw        M_{W}      80.3290 80.4064 MCMC weight 80.385 0.015 0.
Observable  GammaW    GammaW    #Gamma_{W} 2.08569 2.09249 MCMC weight 2.085  0.042 0.
#
# Correlated observables:
CorrelatedGaussianObservables Zpole2 7
Observable  Alepton   Alepton   A_{l}      0.143568 0.151850 MCMC weight 0.1513  0.0021  0.
Observable  Rbottom   Rbottom   R_{b}      0.215602 0.215958 MCMC weight 0.21629 0.00066 0.
Observable  Rcharm    Rcharm    R_{c}      0.172143 0.172334 MCMC weight 0.1721  0.0030  0.
Observable  AFBbottom AFBbottom A_{FB}^{b} 0.100604 0.106484 MCMC weight 0.0992  0.0016  0.
Observable  AFBcharm  AFBcharm  A_{FB}^{c} 0.071750 0.076305 MCMC weight 0.0707  0.0035  0.
Observable  Abottom   Abottom   A_{b}      0.934320 0.935007 MCMC weight 0.923   0.020   0.
Observable  Acharm    Acharm    A_{c}      0.666374 0.670015 MCMC weight 0.670   0.027   0.
1.00   0.00   0.00   0.00   0.00   0.09   0.05
0.00   1.00  -0.18  -0.10   0.07  -0.08   0.04
0.00  -0.18   1.00   0.04  -0.06   0.04  -0.06
0.00  -0.10   0.04   1.00   0.15   0.06   0.01
0.00   0.07  -0.06   0.15   1.00  -0.02   0.04
0.09  -0.08   0.04   0.06  -0.02   1.00   0.11
0.05   0.04  -0.06   0.01   0.04   0.11   1.00
#
# Output correlations:
Observable2D  MwvsGammaW Mw M_{W} 80.3290 80.4064 noMCMC noweight GammaW #Gamma_{W} 2.08569 2.09249
...
Observable2D Bd_Bsbar_mumu noMCMC noweight
Observable   BR_Bdmumu      BR(B_{d}#rightarrow#mu#mu)    1. -1.  1.05e-10   0.    0.
Observable   BRbar_Bsmumu   BR(B_{s}#rightarrow#mu#mu)    1. -1.  3.65e-9    0.    0.
...
Observable2D S5_P5 noMCMC noweight
BinnedObservable   S_5      S_5    1. -1.  0.    0.    0.    4.    6.
BinnedObservable   P_5      P_5    1. -1.  0.    0.    0.    4.    6.
#
# Including other configuration files
IncludeFile Flavour.conf
```

The config file

StandardModel.conf



```
StandardModel
# Model parameters:
ModelParameter  mtop        173.2       0.9         0.
ModelParameter  mHl         125.6       0.3         0.
...
CorrelatedGaussianParameters   V1_lattice 2
ModelParameter  a_0V    0.496   0.067   0.
ModelParameter  a_1V   -2.03    0.92    0.
1.00    0.86
0.86    1.00

<All the model parameters have to be listed here>

# Observables:
Observable  Mw        Mw        M_{W}      80.3290 80.4064 MCMC weight 80.385 0.015 0.
Observable  GammaW    GammaW    #Gamma_{W} 2.08569 2.09249 MCMC weight 2.085  0.042 0.
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Observable  Rbottom   Rbottom   R_{b}      0.215602 0.215958 MCMC weight 0.21629 0.00066 0.
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Observable  AFBcharm  AFBcharm  A_{FB}^{c} 0.071750 0.076305 MCMC weight 0.0707  0.0035  0.
Observable  Abottom   Abottom   A_{b}      0.934320 0.935007 MCMC weight 0.923   0.020   0.
Observable  Acharm    Acharm    A_{c}      0.666374 0.670015 MCMC weight 0.670   0.027   0.
1.00   0.00   0.00   0.00   0.00   0.09   0.05
0.00   1.00  -0.18  -0.10   0.07  -0.08   0.04
0.00  -0.18   1.00   0.04  -0.06   0.04  -0.06
0.00  -0.10   0.04   1.00   0.15   0.06   0.01
0.00   0.07  -0.06   0.15   1.00  -0.02   0.04
0.09  -0.08   0.04   0.06  -0.02   1.00   0.11
0.05   0.04  -0.06   0.01   0.04   0.11   1.00
#
# Output correlations:
Observable2D  MwvsGammaW Mw M_{W} 80.3290 80.4064 noMCMC noweight GammaW #Gamma_{W} 2.08569 2.09249
...
Observable2D Bd_Bsbar_mumu noMCMC noweight
Observable   BR_Bdmumu      BR(B_{d}#rightarrow#mu#mu)    1. -1.  1.05e-10   0.   0.
Observable   BRbar_Bsmumu   BR(B_{s}#rightarrow#mu#mu)    1. -1.  3.65e-9    0.   0.
...
Observable2D S5_P5 noMCMC noweight
BinnedObservable   S_5      S_5    1. -1.  0.   0.   0.   4.   6.
BinnedObservable   P_5      P_5    1. -1.  0.   0.   0.   4.   6.
#
# Including other configuration files
IncludeFile Flavour.conf
```
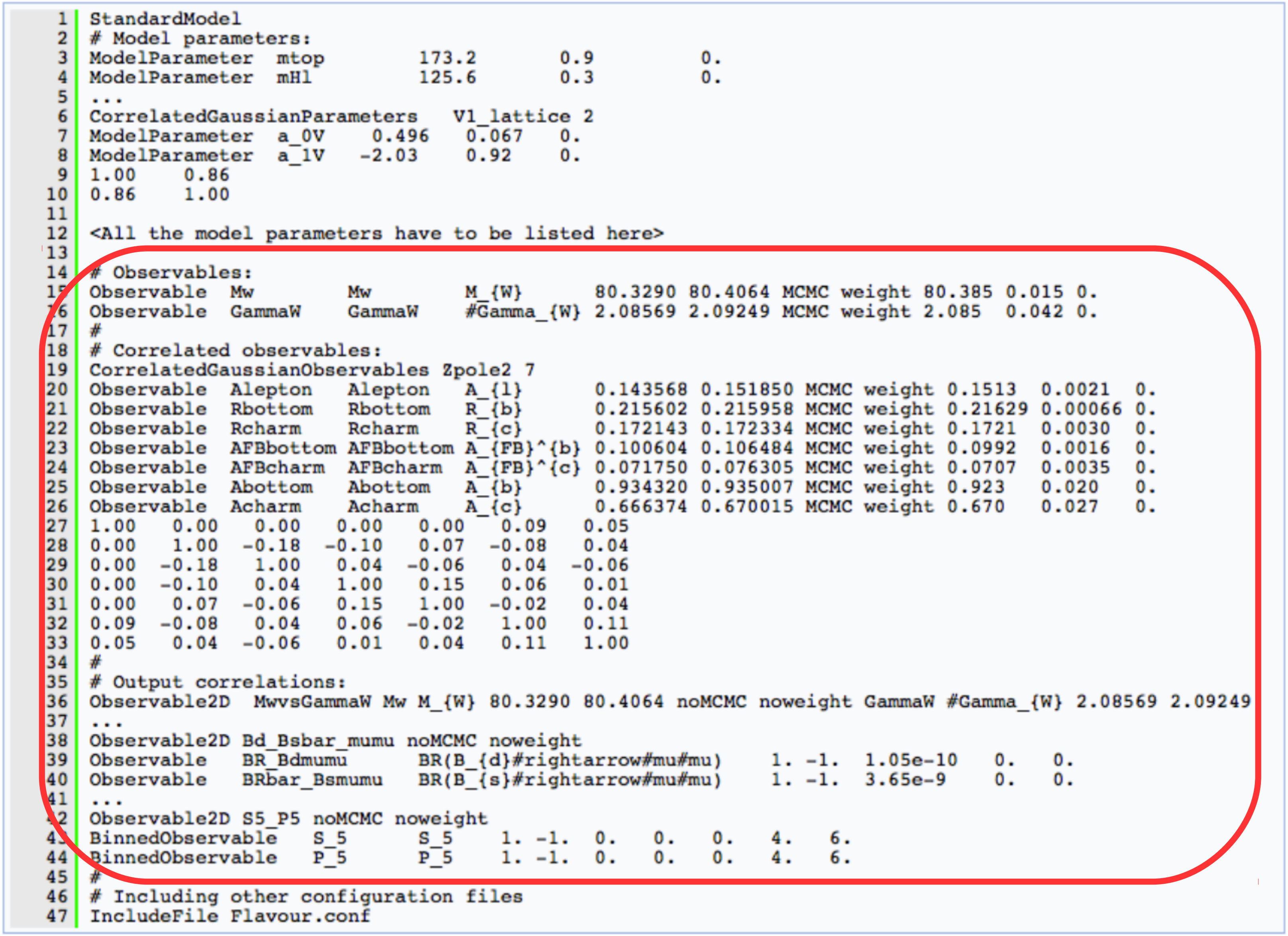

The config file

StandardModel.conf



```
StandardModel
# Model parameters:
ModelParameter  mtop        173.2       0.9         0.
ModelParameter  mHl         125.6       0.3         0.
...
CorrelatedGaussianParameters   V1_lattice 2
ModelParameter  a_0V    0.496   0.067   0.
ModelParameter  a_1V   -2.03    0.92    0.
1.00    0.86
0.86    1.00

<All the model parameters have to be listed here>

# Observables:
Observable  Mw        Mw        M_{W}      80.3290 80.4064 MCMC weight 80.385 0.015 0.
Observable  GammaW    GammaW    #Gamma_{W} 2.08569 2.09249 MCMC weight 2.085  0.042 0.
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1.00   0.00   0.00   0.00   0.00   0.09   0.05
0.00   1.00  -0.18  -0.10   0.07  -0.08   0.04
0.00  -0.18   1.00   0.04  -0.06   0.04  -0.06
0.00  -0.10   0.04   1.00   0.15   0.06   0.01
0.00   0.07  -0.06   0.15   1.00  -0.02   0.04
0.09  -0.08   0.04   0.06  -0.02   1.00   0.11
0.05   0.04  -0.06   0.01   0.04   0.11   1.00
#
# Output correlations:
Observable2D  MwvsGammaW Mw M_{W} 80.3290 80.4064 noMCMC noweight GammaW #Gamma_{W} 2.08569 2.09249
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Observable   BRbar_Bsmumu   BR(B_{s}#rightarrow#mu#mu)    1. -1.  3.65e-9    0.   0.
...
Observable2D S5_P5 noMCMC noweight
BinnedObservable   S_5      S_5    1. -1.  0.   0.   0.   4.   6.
BinnedObservable   P_5      P_5    1. -1.  0.   0.   0.   4.   6.
#
# Including other configuration files
IncludeFile Flavour.conf
```
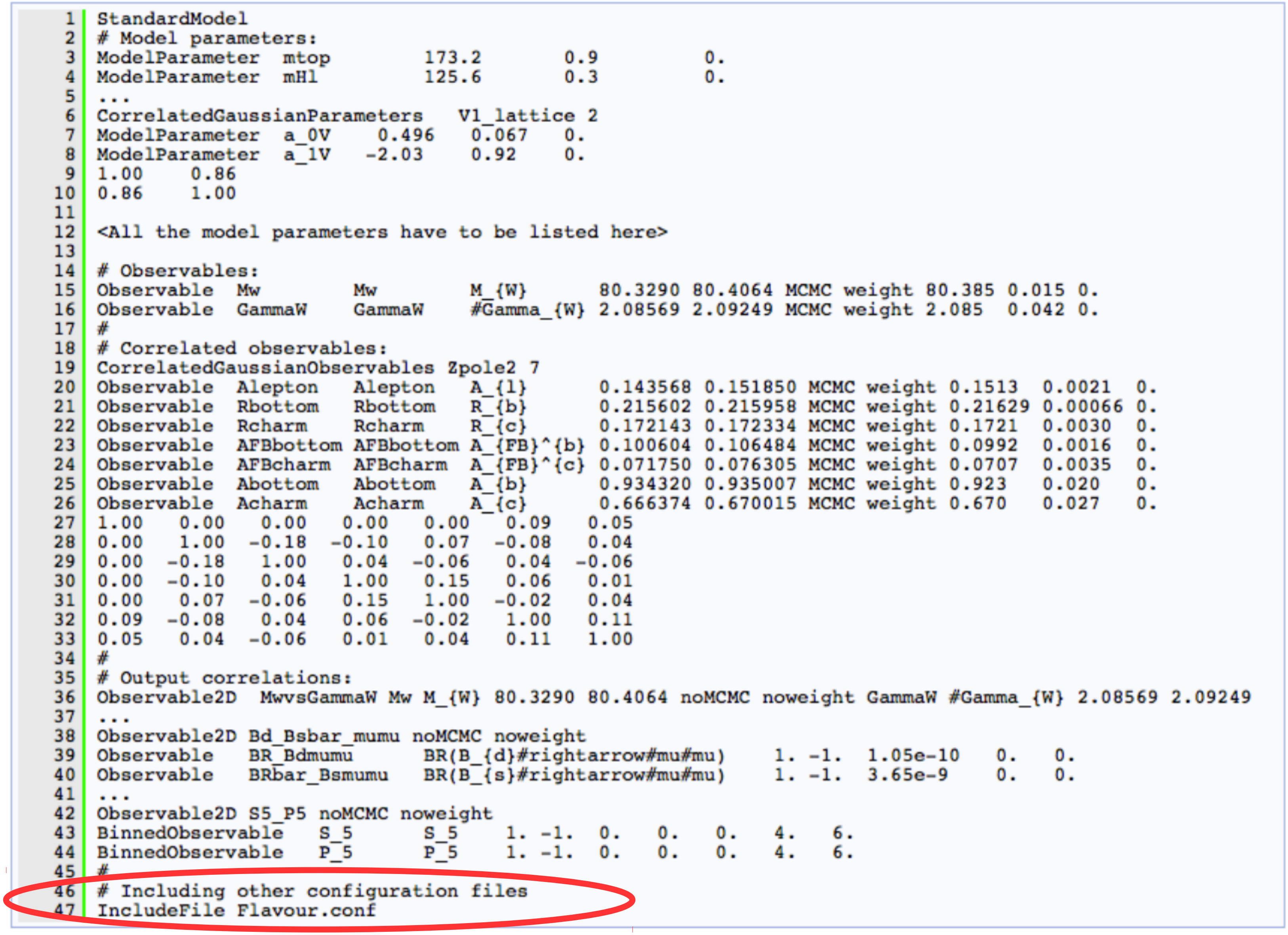

The config file

StandardModel.conf



```
StandardModel
# Model parameters:
ModelParameter  mtop        173.2       0.9         0.
ModelParameter  mHl         125.6       0.3         0.
...
CorrelatedGaussianParameters   V1_lattice 2
ModelParameter  a_0V    0.496   0.067   0.
ModelParameter  a_1V   -2.03    0.92    0.
1.00    0.86
0.86    1.00

<All the model parameters have to be listed here>

# Observables:
Observable  Mw        Mw        M_{W}      80.3290 80.4064 MCMC weight 80.385 0.015 0.
Observable  GammaW    GammaW    #Gamma_{W} 2.08569 2.09249 MCMC weight 2.085  0.042 0.
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Observable  Rbottom   Rbottom   R_{b}      0.215602 0.215958 MCMC weight 0.21629 0.00066 0.
Observable  Rcharm    Rcharm    R_{c}      0.172143 0.172334 MCMC weight 0.1721  0.0030  0.
Observable  AFBbottom AFBbottom A_{FB}^{b} 0.100604 0.106484 MCMC weight 0.0992  0.0016  0.
Observable  AFBcharm  AFBcharm  A_{FB}^{c} 0.071750 0.076305 MCMC weight 0.0707  0.0035  0.
Observable  Abottom   Abottom   A_{b}      0.934320 0.935007 MCMC weight 0.923   0.020   0.
Observable  Acharm    Acharm    A_{c}      0.666374 0.670015 MCMC weight 0.670   0.027   0.
1.00   0.00   0.00   0.00   0.00   0.09   0.05
0.00   1.00  -0.18  -0.10   0.07  -0.08   0.04
0.00  -0.18   1.00   0.04  -0.06   0.04  -0.06
0.00  -0.10   0.04   1.00   0.15   0.06   0.01
0.00   0.07  -0.06   0.15   1.00  -0.02   0.04
0.09  -0.08   0.04   0.06  -0.02   1.00   0.11
0.05   0.04  -0.06   0.01   0.04   0.11   1.00
#
# Output correlations:
Observable2D  MwvsGammaW Mw M_{W} 80.3290 80.4064 noMCMC noweight GammaW #Gamma_{W} 2.08569 2.09249
...
Observable2D Bd_Bsbar_mumu noMCMC noweight
Observable   BR_Bdmumu      BR(B_{d}#rightarrow#mu#mu)    1. -1.  1.05e-10   0.    0.
Observable   BRbar_Bsmumu   BR(B_{s}#rightarrow#mu#mu)    1. -1.  3.65e-9    0.    0.
...
Observable2D S5_P5 noMCMC noweight
BinnedObservable   S_5      S_5      1. -1.  0.    0.    0.    4.    6.
BinnedObservable   P_5      P_5      1. -1.  0.    0.    0.    4.    6.
#
# Including other configuration files
IncludeFile Flavour.conf
```

HEPfit model-observable matrix

	SM	THDM	MSSM	H_{eff}
$\Delta F=2$ amp's	X	O	O	O
$B \to \tau\nu$	X	X	O	O
$B_{s/d} \to \mu\mu$	O	O	O	O
rare K decays	O			O
$B \to X_s \gamma$	X	X	O	O
$B \to V\gamma$ $B \to P/V\ell\ell$	X			O
$B \to X_s\ell\ell$	O			O
$B \to PP, PV$	O			O

	SM	THDM	MSSM	L_{EWSB}	SMEFT
EWPO + LEP2	X	X		X	X
$H \to VV$, $H \to ff$ μ's	X	X	O		X
direct searches		X	O		
LFV $\ell_i \to \ell_j\gamma$, $3\ell_j$			X		

X: done

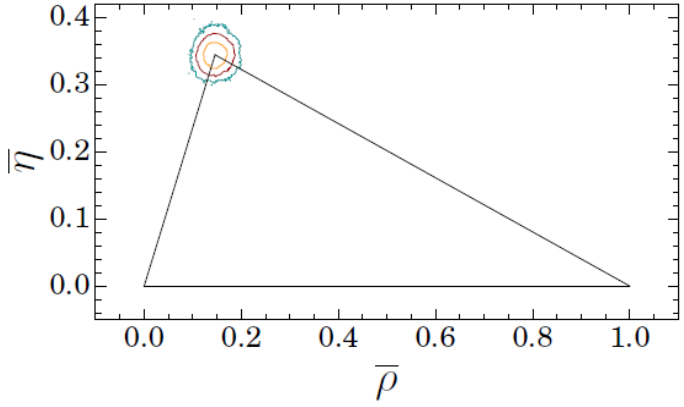
O: in progress

more to come

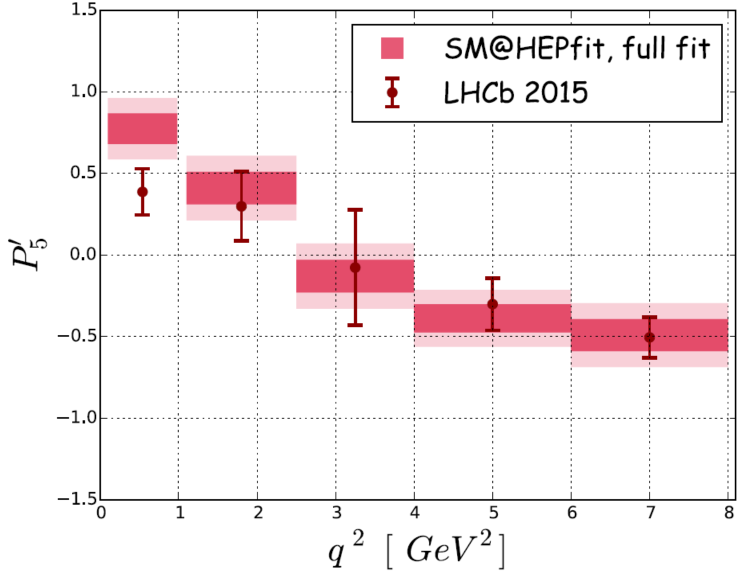
(L-R model, aligned THDM,…)

Here's what you get

HEPfit UTA, soon adopted by UTfit

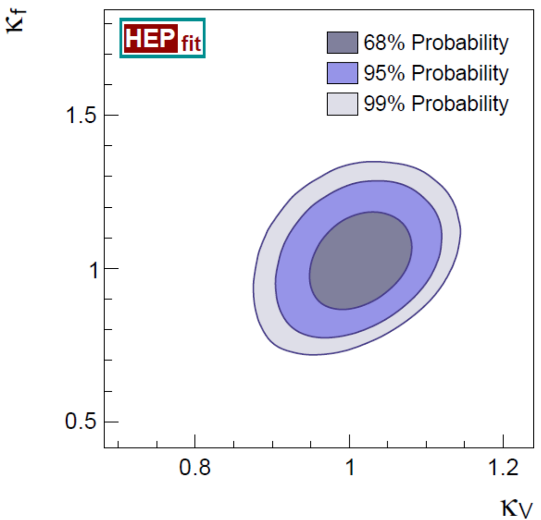


M.C. et al, arXiv:1512.07157

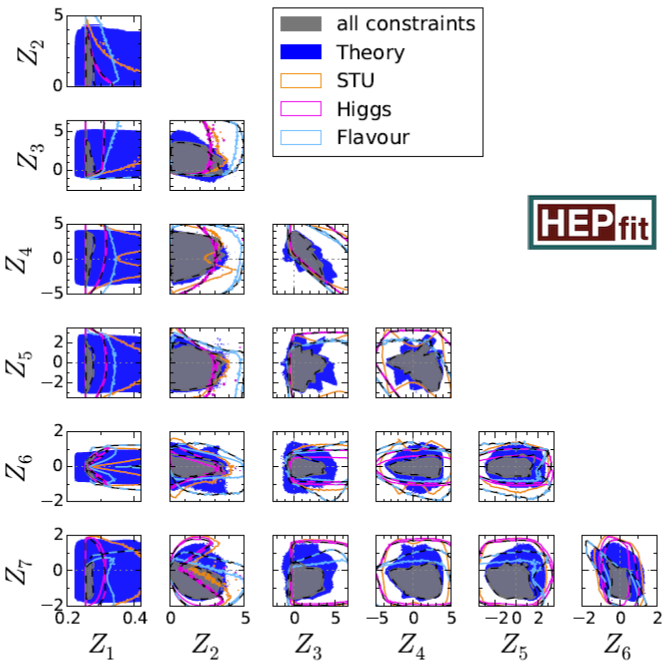


SM flavour

Fits to EWPO



De Blas et al.,
arXiv:1608.01509



2HDM with Z_2 soft symmetry breaking

Cacchio et al.,
arXiv:1609.01290

More studies with HEPfit on the way

* SMEFT analysis of EWPO and Higgs μ's
* global EFT analysis of radiative B decays
* analysis of MSSM with generic flavour structure
* phenomenological study of the aligned THDM
* full-fledged NP UTA and $\Delta F=2$ EFT analysis
* …

What about your next phenomenological analysis?
And your next background study?

Give HEPfit a try!

http://hepfit.roma1.infn.it

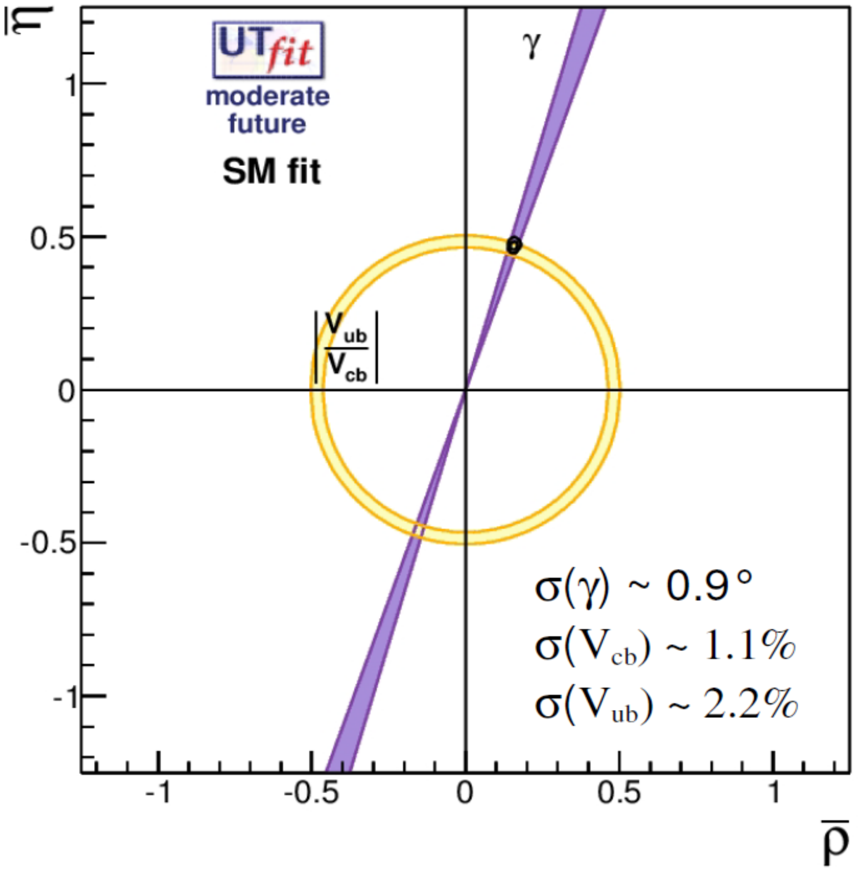
Backup

Outlook

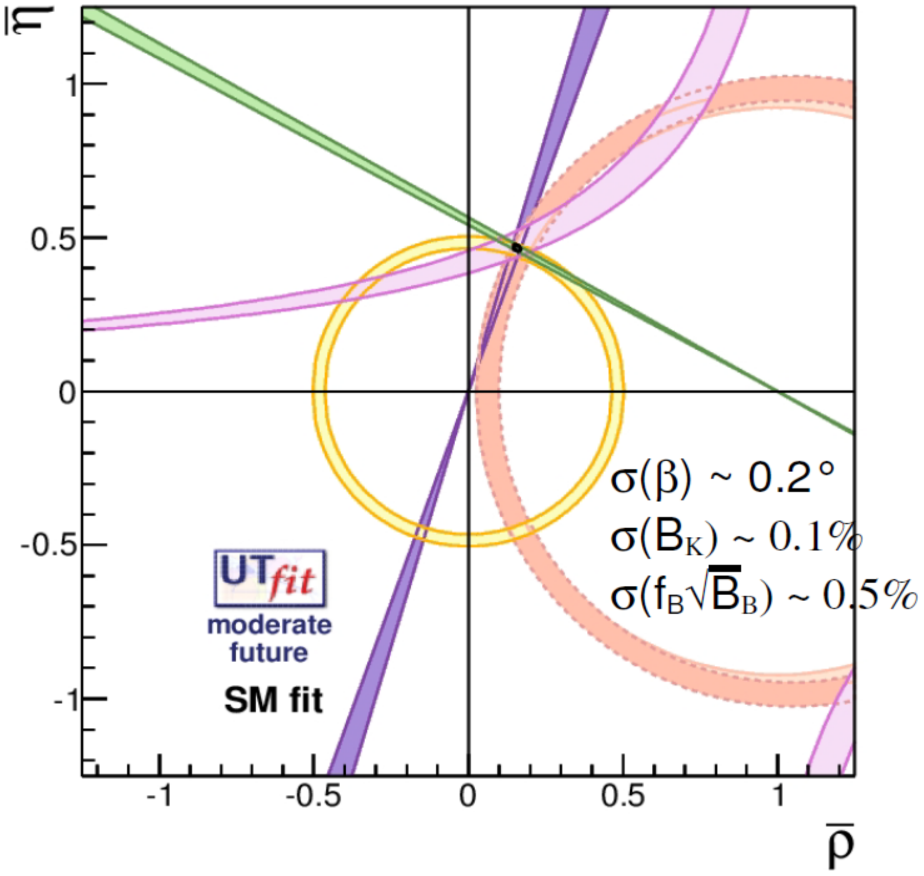
Look at the future

errors predicted from
Belle II + LHCb upgrade

M. Bona, ICHEP 2016



$\sigma(\gamma) \sim 0.9°$
$\sigma(V_{cb}) \sim 1.1\%$
$\sigma(V_{ub}) \sim 2.2\%$

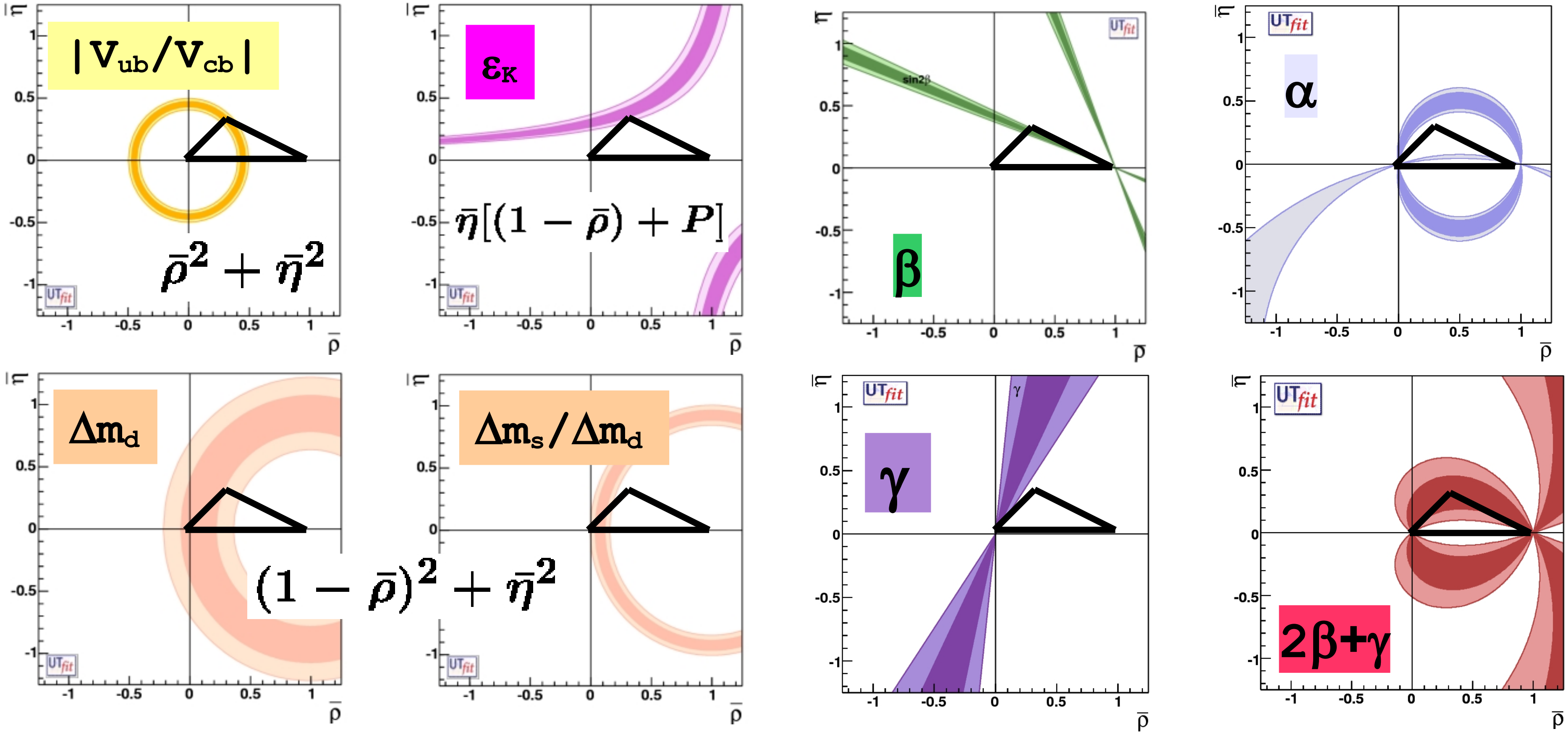


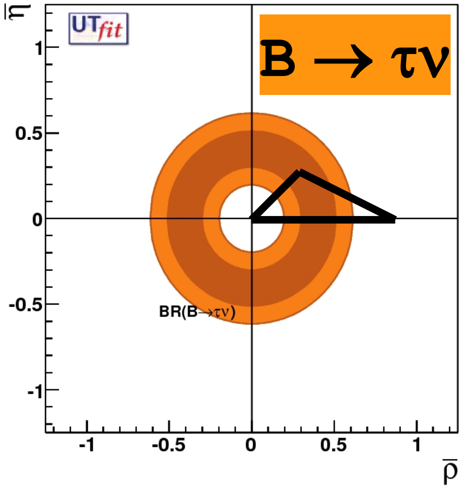
$\sigma(\beta) \sim 0.2°$
$\sigma(B_K) \sim 0.1\%$
$\sigma(f_B\sqrt{\bar{B}_B}) \sim 0.5\%$

errors from tree-only fit on ρ and η:
$\sigma(\rho) = 0.008$ *[currently 0.050]*
$\sigma(\eta) = 0.010$ *[currently 0.035]*

errors from 5-constraint fit on ρ and η:
$\sigma(\rho) = 0.005$ *[currently 0.015]*
$\sigma(\eta) = 0.004$ *[currently 0.013]*

Unitarity Triangle analysis: $V_{ub}^{*}V_{ud}+V_{cb}^{*}V_{cd}+V_{tb}^{*}V_{td}=0$





Original goal:

- determine the UT apex and the CKM matrix parameters

Overconstrained fit:

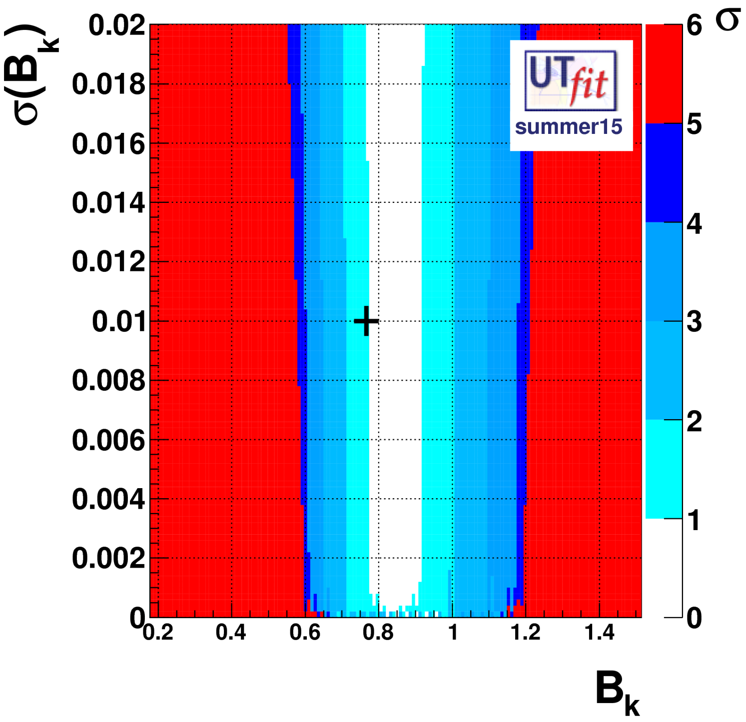
- predict observables, hadronic parameters and constrain NP

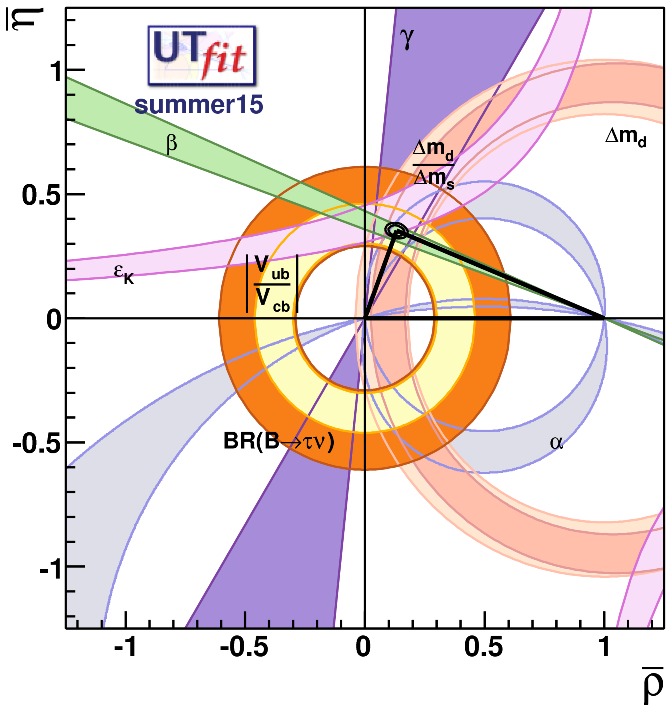
ε_K & B_K

$B_K^{lattice} = 0.766 \pm 0.010$

$B_k^{prediction} = 0.845 \pm 0.074$

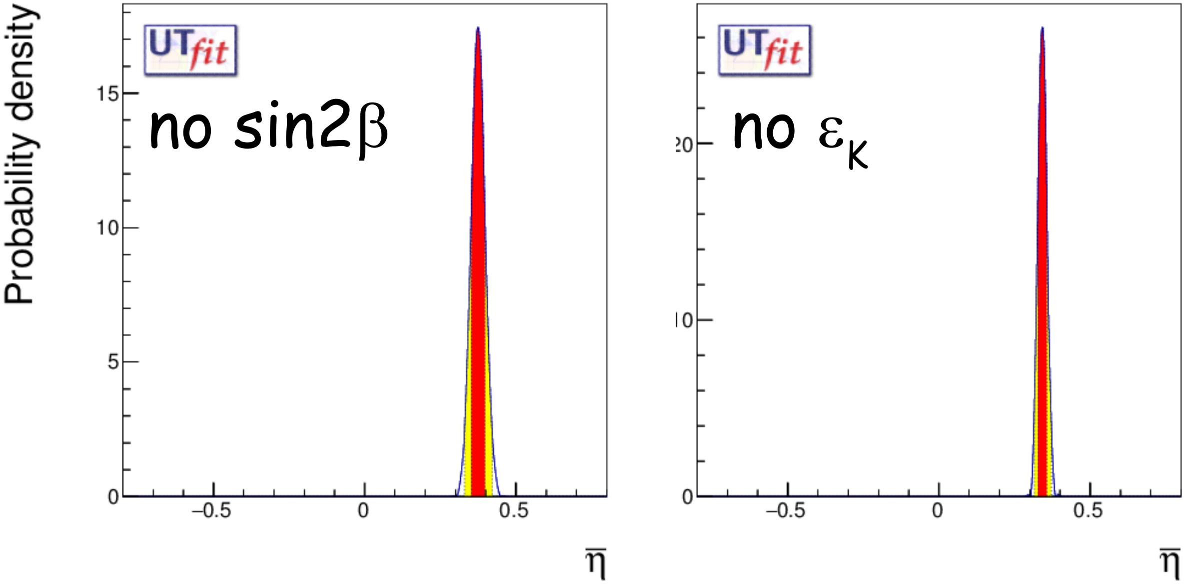
~1σ





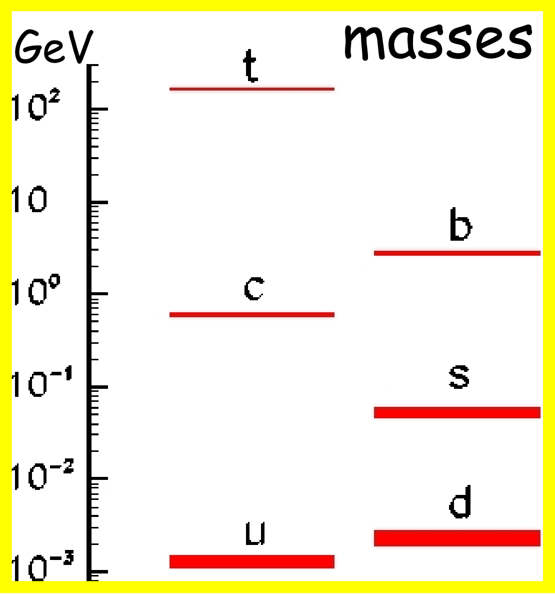
$\bar{\eta} = 0.375 \pm 0.023$

$\bar{\eta} = 0.343 \pm 0.015$



given $B_K^{lattice}$, ε_K calls for large A or η

Flavour physics in the SM: rich phenomenology (FCNC suppression, mixing, CP violation, …) but little understanding of the "why" and the "how"

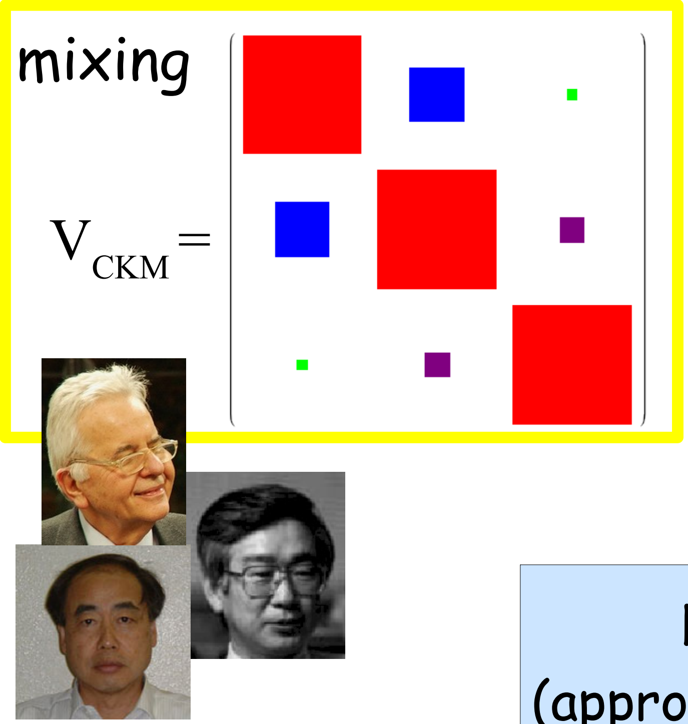


$$\mathcal{L}_{\rm SM} = \mathcal{L}_{\rm EWSB} + \mathcal{L}_{\rm kin} + \mathcal{L}_{\rm gauge} + \mathcal{L}_{\rm Y}$$

The Yukawa Lagrangian describes quark flavour physics in terms of 10 physical parameters:

6 masses, 3 mixing angles + 1 CPV phase

the Cabibbo-Kobayashi-Maskawa matrix



Beyond the SM: a powerful indirect probe of the New Physics scale Λ

$$\mathcal{L}_{\rm eff} = \mathcal{L}_{\rm SM} + \frac{\mathcal{L}_5}{\Lambda} + \frac{\mathcal{L}_6}{\Lambda^2} + \ldots$$

has accidental (approximate) symmetries

may violate accidental symmetries

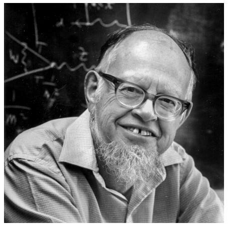
The CKM matrix in the SM

$$V_{\rm CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Standard parametrization (PDG): s_{12}, s_{13}, s_{23}, δ

$$\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$

Wolfenstein parametrization: λ, A, ρ, η



$$\begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

The CKM matrix in the SM

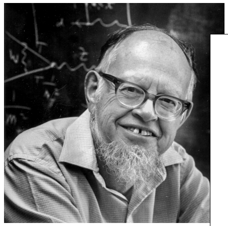
$$\begin{array}{c|ccc} & \text{d} & \text{s} & \text{b} \\ \hline \text{u} & 0.9743(2) & 0.2251(7) & 3.7(1)\cdot 10^{-3}e^{-i66(2)^\circ} \\ \text{c} & -0.2250(7)e^{i0.035(1)^\circ} & 0.9734(2)e^{-i0.0019(1)^\circ} & 4.26(7)\cdot 10^{-2} \\ \text{t} & 8.7(1)\cdot 10^{-3}e^{-i22(1)^\circ} & -4.16(6)\cdot 10^{-2}e^{i1.04(4)^\circ} & 0.99910(2) \end{array}$$

Standard parametrization (PDG): s_{12}, s_{13}, s_{23}, δ

$s_{12} = 0.2250 \pm 0.0007$ $\quad$ $s_{23} = (4.229 \pm 0.057)\times 10^{-2}$

$s_{13} = (3.68 \pm 0.10)\times 10^{-3}$ $\quad$ $\delta = (65.9 \pm 2.0)^\circ$

Wolfenstein parametrization: λ, A, ρ, η



$\lambda = 0.2250 \pm 0.0007$ $\quad$ $A = 0.833 \pm 0.012$

$\rho = 0.157 \pm 0.014$ $\quad$ $\eta = 0.352 \pm 0.011$

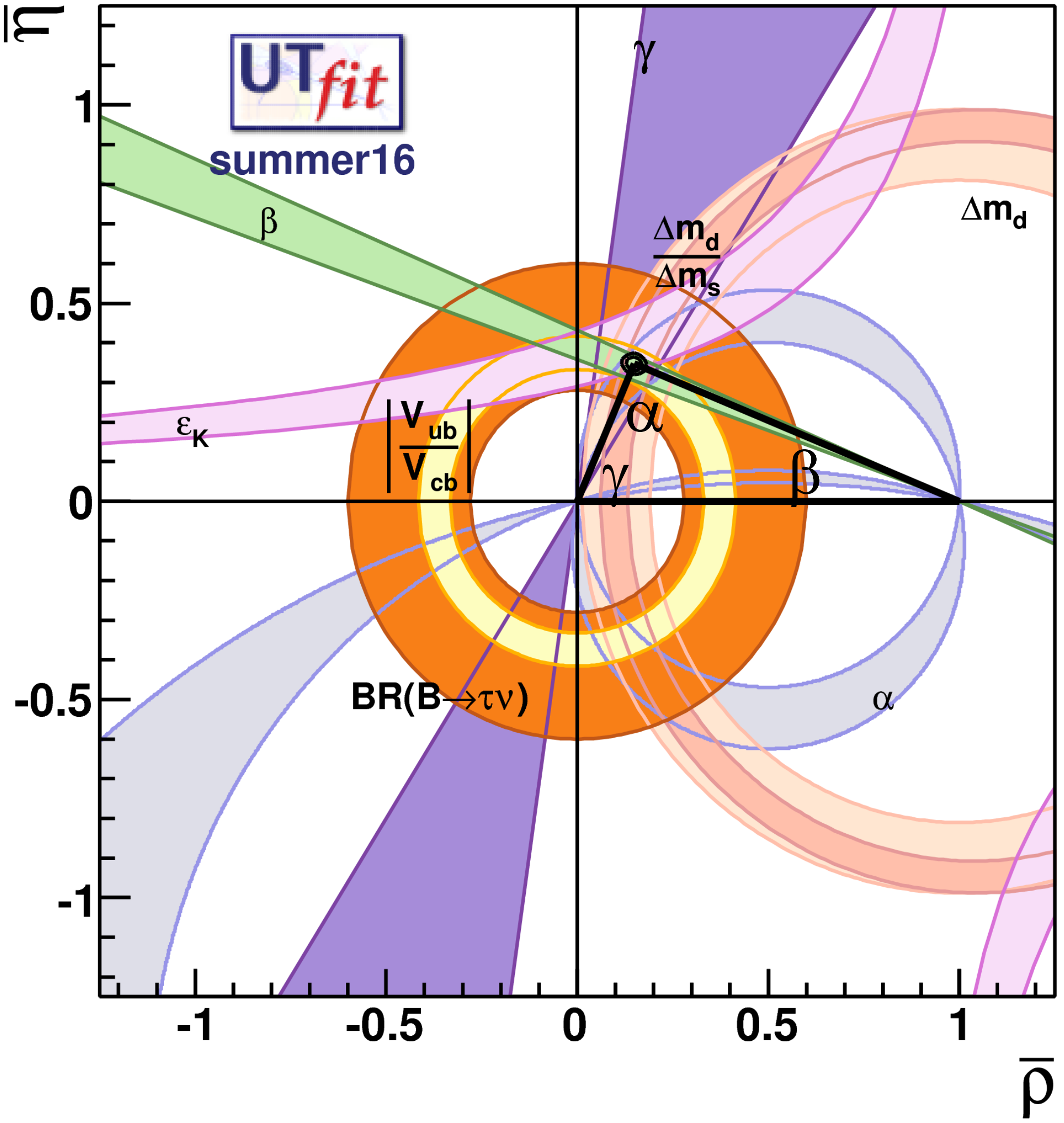
SM results

Summer 2016

SM determination of the Unitarity Triangle

$$V_{ub}^*V_{ud}+V_{cb}^*V_{cd}+V_{tb}^*V_{td}=0$$

$$R_u\ e^{i\gamma}+R_t\ e^{-i\beta}=1$$



$R_u = 0.372 \pm 0.013$

$R_t = 0.917 \pm 0.022$

$\gamma = (65.8 \pm 1.9)^\circ$

$\beta = (22.11 \pm 0.76)^\circ$

$\alpha = (92.0 \pm 2.0)^\circ$

apex coordinates

$\bar{\rho} = 0.153 \pm 0.013$

$\bar{\eta} = 0.343 \pm 0.011$

SM predictions: B_d & K

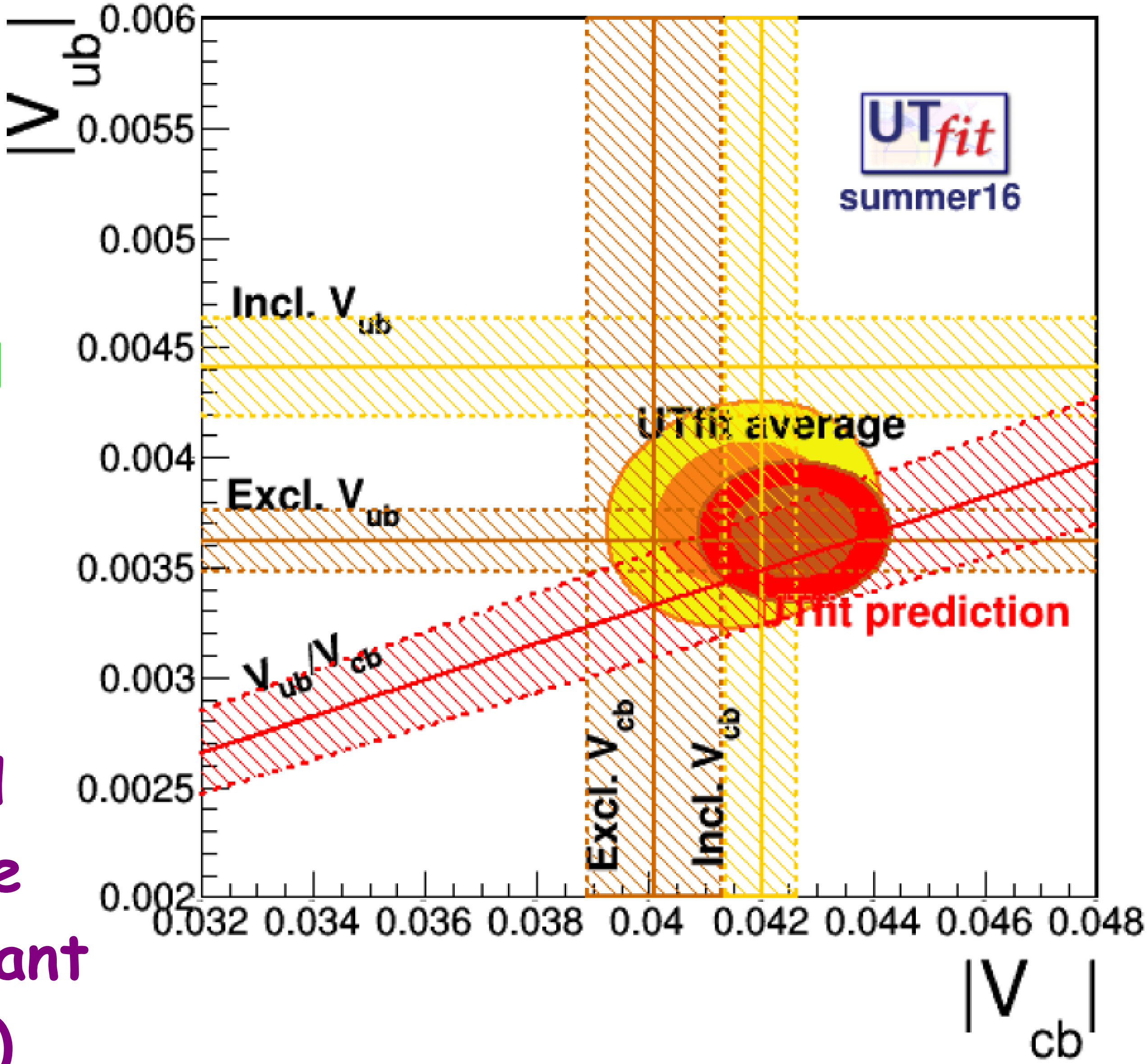
	Measurement	%	Prediction	Pull(σ)
$\sin 2\beta$	0.680±0.023	3.4	0.724±0.028	+1.2
γ [°]	70.5±5.7	8	65.3±2.0	< 1
α[°]	94.2±5.0	5	91.0±2.5	< 1
$\|V_{cb}\|\cdot 10^3$	41.7±1.0	2	42.6±0.7	< 1
$\|V_{cb}\|_{incl}\cdot 10^3$	42.0±0.6	1	" "	< 1
$\|V_{cb}\|_{excl}\cdot 10^3$	40.0±1.1	3	" "	+1.7
$\|V_{ub}\|\cdot 10^3$	3.73±0.21	6	3.66±0.12	< 1
$\|V_{ub}\|_{incl}\cdot 10^3$	4.40±0.22	5	" "	-3.0
$\|V_{ub}\|_{excl}\cdot 10^3$	3.61±0.13	4	" "	< 1
$\varepsilon_K\cdot 10^3$	2.228±0.011	0.5	2.03±0.18	-1.1
$BR(B\to\tau\nu)\cdot 10^{-4}$	1.06±0.20	20	0.81±0.06	-1.3

V_{cb} & V_{ub}

- * data favour inclusive V_{cb} and exclusive V_{ub}

- * no clear evidence to inculpate a theoretical method (a suspect: V_{ub} inclusive)

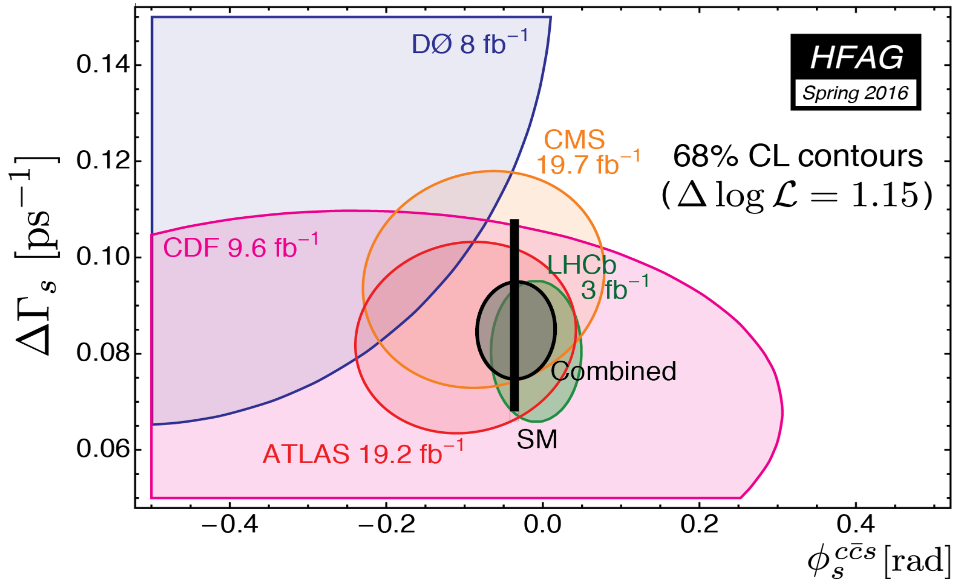
- * difficult to explain with NP (right-handed currents are not viable in a SU(2)xU(1) invariant effective field theory)

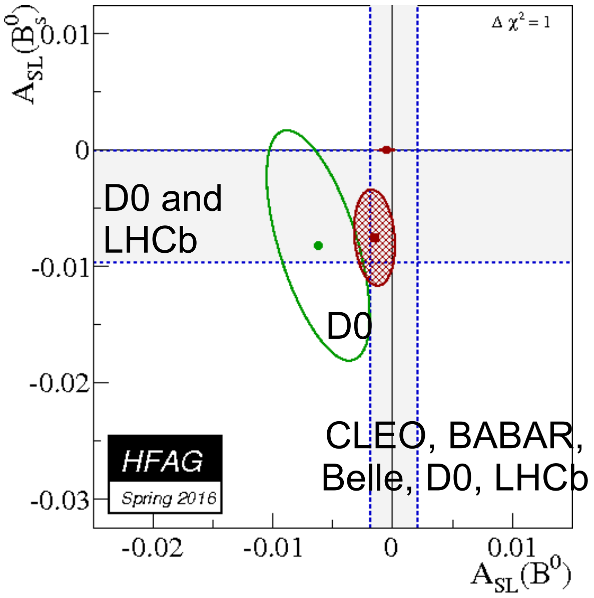


Crivellin, Pokorski, arXiv:1407.1320

SM predictions: B_s

	Measurement	%	Prediction	Pull (σ)
Δm_s [ps^{-1}]	17.757±0.021	0.1	17.7±0.9	< 1
β_s[°]	0.94±0.94	100	1.04±0.03	< 1
$\Delta\Gamma_s/\Gamma_s$	0.124±0.009	7.2	0.154±0.012	+1.9
$A_{SL}^{s}\cdot 10^4$	-75±41	57	0.13±0.01	+1.8





Deviations from the SM to keep an eye on

- ε'/ε
- $BR(B_s \to \mu\mu)$, $BR(B \to \mu\mu)$
- $R(D)$, $R(D^*)$
- R_K
- q^2 spectrum of $B \to K^*\mu\mu$

Deviations from the SM to keep an eye on

- ε′/ε
- **BR(B_s → μμ), BR(B → μμ)**

$$\mathrm{BR}(\mathrm{B}_s \to \mu^+\mu^-) = (2.8^{+0.7}_{-0.6}) \times 10^{-9}$$

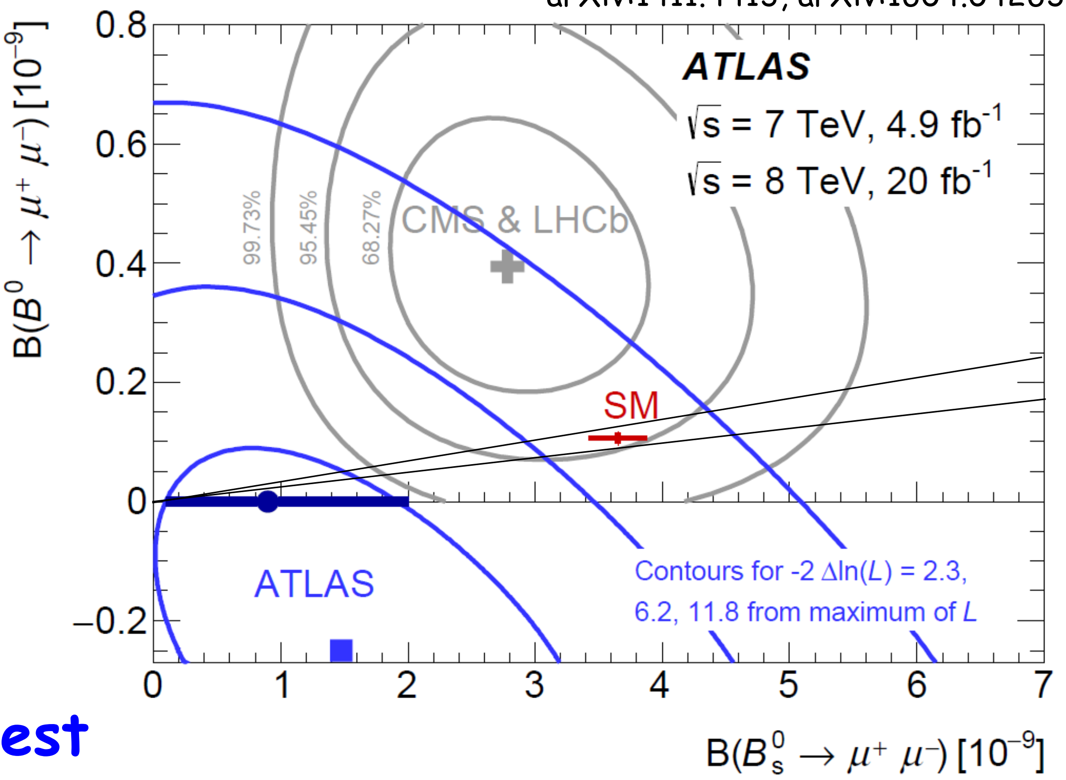
$$\mathrm{BR}(\mathrm{B}_s \to \mu^+\mu^-)_{SM} = (3.65 \pm 0.23) \times 10^{-9} \quad +1.2\sigma$$

$$\mathrm{BR}(\mathrm{B} \to \mu^+\mu^-) = (3.9^{+1.6}_{-1.4}) \times 10^{-10}$$

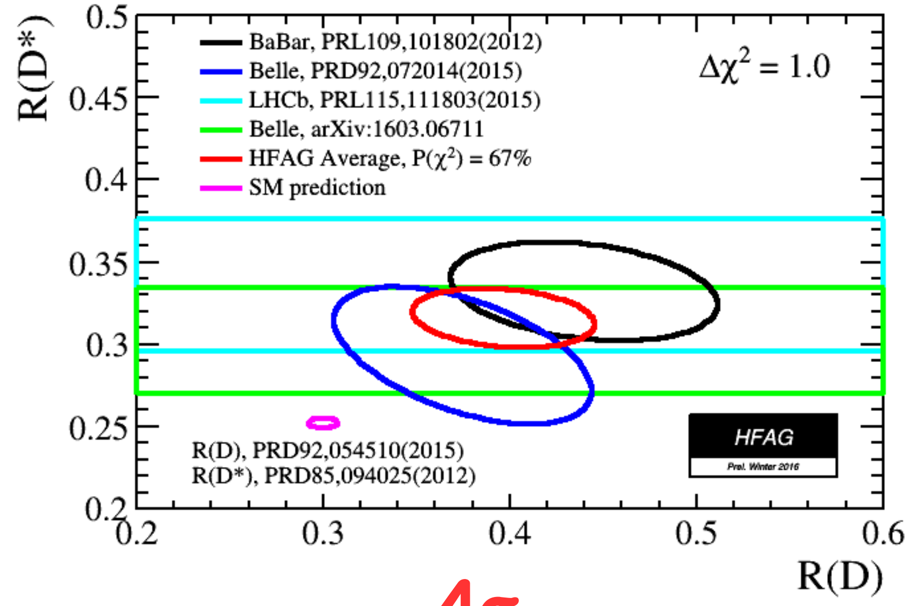
$$\mathrm{BR}(\mathrm{B} \to \mu^+\mu^-)_{SM} = (1.06 \pm 0.09) \times 10^{-10} \quad -2.2\sigma$$

SM predictions from
Bobeth et al., arXiv:1311.0903

arXiv:1411.4413, arXiv:1604.04263



Minimal Flavour Violation test



4σ

$$R(X) = \frac{\Gamma(B \to X\tau\nu)}{\Gamma(B \to X\ell\nu)}$$

$$R(D) =$$

-1.9σ

$$0.397 \pm 0.040 \pm 0.028$$

$$R(D)_{\rm SM} = 0.300 \pm 0.008$$

Na et al., arXiv:1505.03925

$$R(D^*) =$$

-3.3σ

$$0.316 \pm 0.016 \pm 0.010$$

$$R(D^*)_{\rm SM} = 0.252 \pm 0.003$$

Fajfer et al., arXiv:1203.2654

an eye on

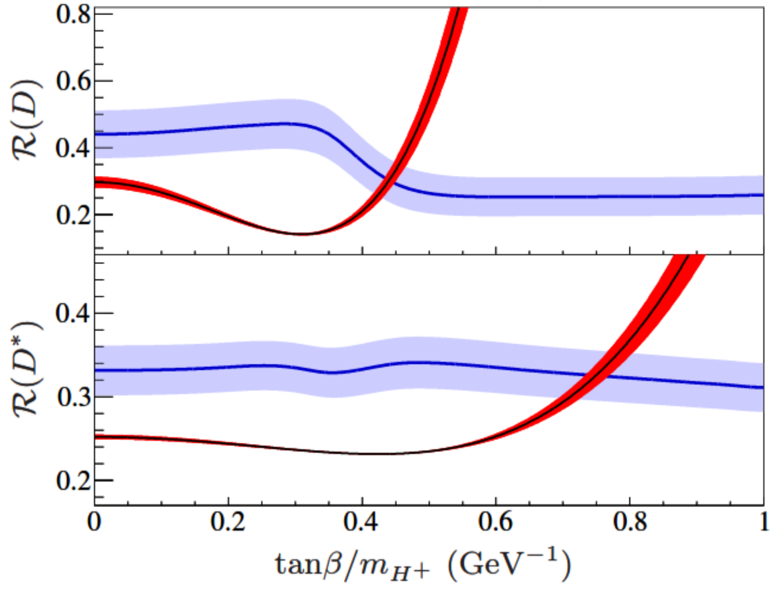
)

- R(D), R(D*)
- Γ(B
- q^2 s

simplest realizations of 2HDM cannot explain the excess in the two channels simultaneously

more exotic NP required, e.g. 2HDM-type III, leptoquarks, compositeness, …

BaBar coll., arXiv:1205.5442



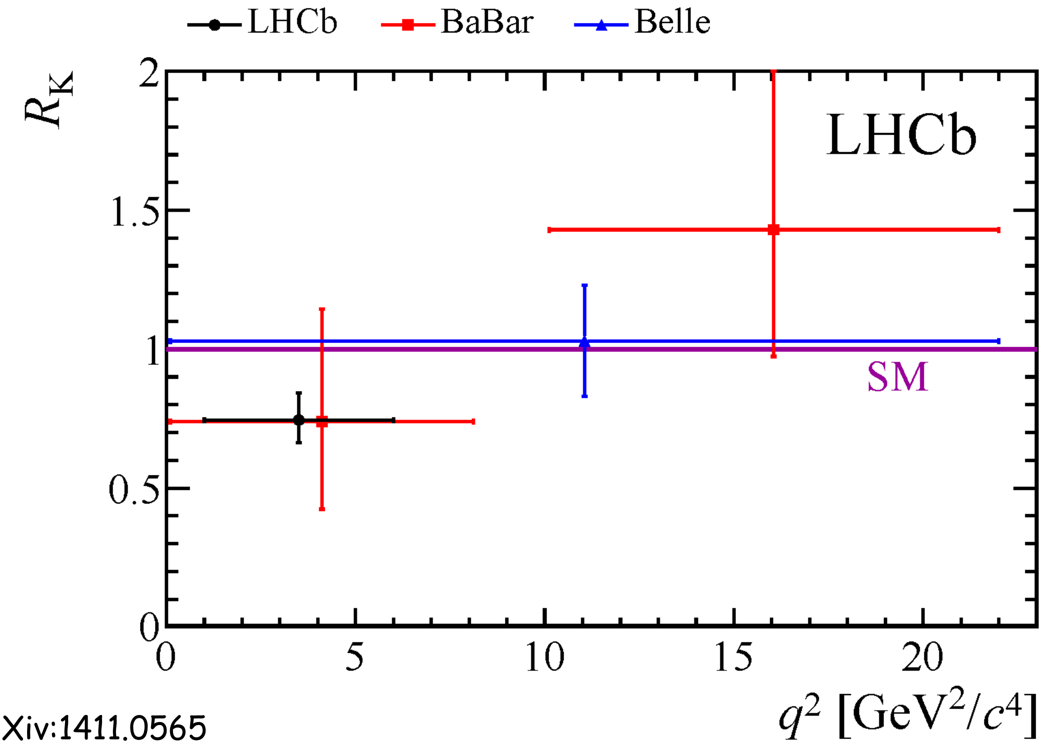
Deviati

Also beyond the SM, such a large violation of lepton universality is not easily obtained (e.g. leptoquarks)

it may be correlated to large LFV in B decays

$b \to s\, \ell_i^+ \ell_j^-$

Glashow et al., arXiv:1411.0565



- R_K

LHCb Collaboration, arXiv:1406.6482

$$R_K = \frac{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+\mu^+\mu^-]}{\mathrm{d}q^2}\mathrm{d}q^2}{\int_{q^2_{\min}}^{q^2_{\max}} \frac{\mathrm{d}\Gamma[B^+ \to K^+e^+e^-]}{\mathrm{d}q^2}\mathrm{d}q^2} = 0.745^{+0.090}_{-0.074}\,(\mathrm{stat}) \pm 0.036\,(\mathrm{syst})$$

+2.6σ

$$R_K^{\mathrm{SM}} = 1.0003 \pm 0.0001$$

Bobeth et al., arXiv:0709.4174

If LFU is induced by NP coupled to the 3rd generation at a scale much larger than the weak scale, in the effective theory, one gets

$$Q'_{L,3}\gamma_\mu Q'_{L,3} L'_L \gamma^\mu L'_L, \quad Q'_{L,3}\gamma_\mu \sigma^i Q'_{L,3} L'_L \gamma^\mu \sigma^i L'_L,$$

i) can account for the anomalies in R_K, R(D)/R(D*)

ii) give typically rise to large LFV

Glashow et al., arXiv:1411.0565
Bhattacharya et al., arXiv:1412.7164

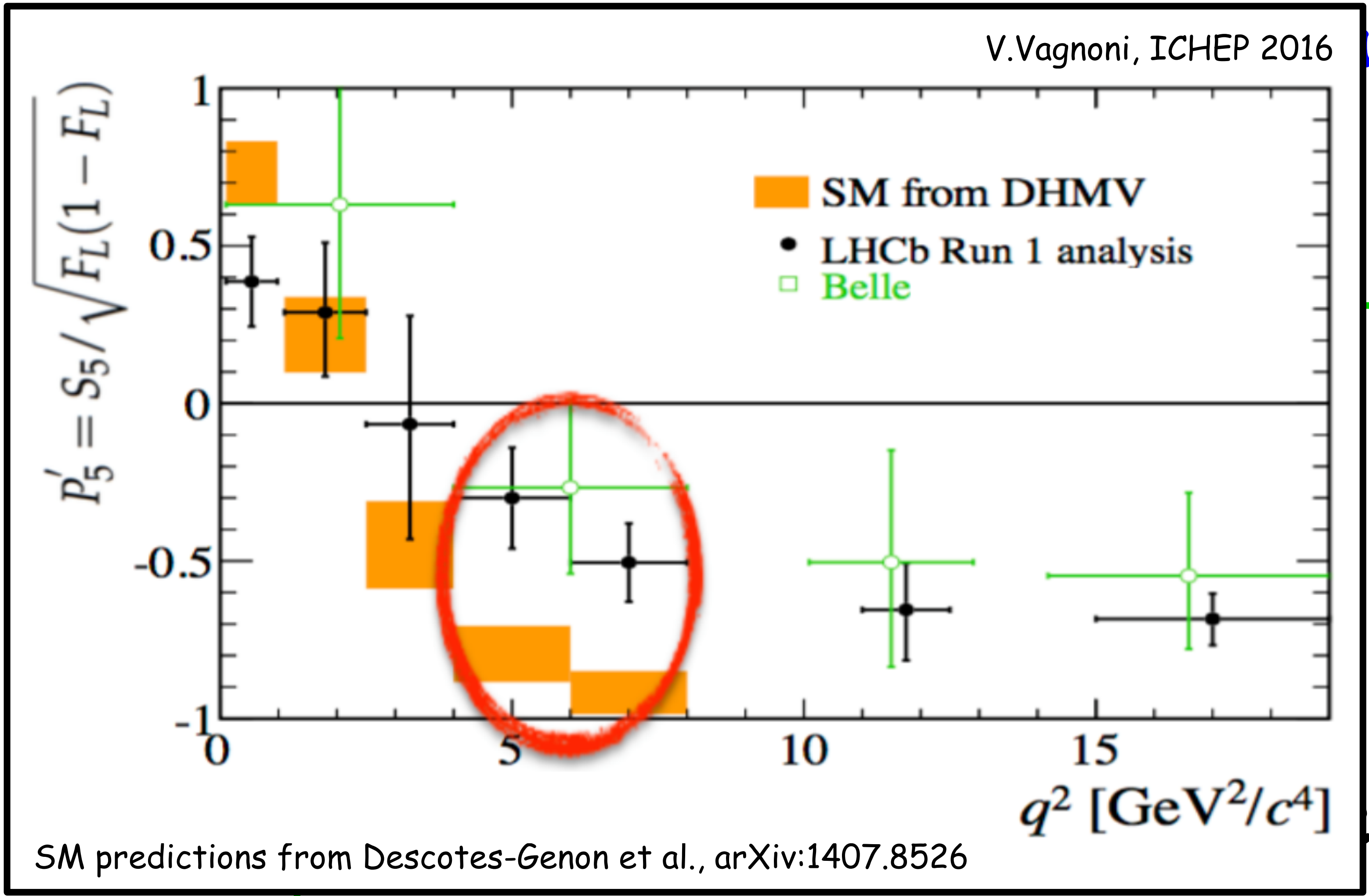
iii) running effects produce large corrections to the $V\ell\ell$ vertices and induce purely leptonic LFV transitions

Feruglio et al., arXiv:1606.00524

Explicit models face more severe contraints, still there are viable proposals:

- **non-minimal scalar leptoquarks** Becirevic et al., arXiv:1608.08501
- triplet heavy gauge bosons Greljo et al., arXiv:1506.01705
- …

n eye on



V.Vagnoni, ICHEP 2016

SM predictions from Descotes-Genon et al., arXiv:1407.8526

- q^2 spectrum of B → K*μμ

$$\frac{d^{(4)}\Gamma}{dq^2\, d(\cos\theta_l)\, d(\cos\theta_k)\, d\phi} = \frac{9}{32\pi}\Big(I_1^s \sin^2\theta_k + I_1^c \cos^2\theta_k + (I_2^s \sin^2\theta_k + I_2^c \cos^2\theta_k)\cos 2\theta_l$$
$$+ I_3 \sin^2\theta_k \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_k \sin 2\theta_l \cos\phi$$
$$+ I_5 \sin 2\theta_k \sin\theta_l \cos\phi + (I_6^s \sin^2\theta_k + I_6^c \cos^2\theta_K)\cos\theta_l$$
$$+ I_7 \sin 2\theta_k \sin\theta_l \sin\phi + I_8 \sin 2\theta_k \sin 2\theta_l \sin\phi$$
$$+ I_9 \sin^2\theta_k \sin^2\theta_l \sin 2\phi\Big)$$

angular analysis

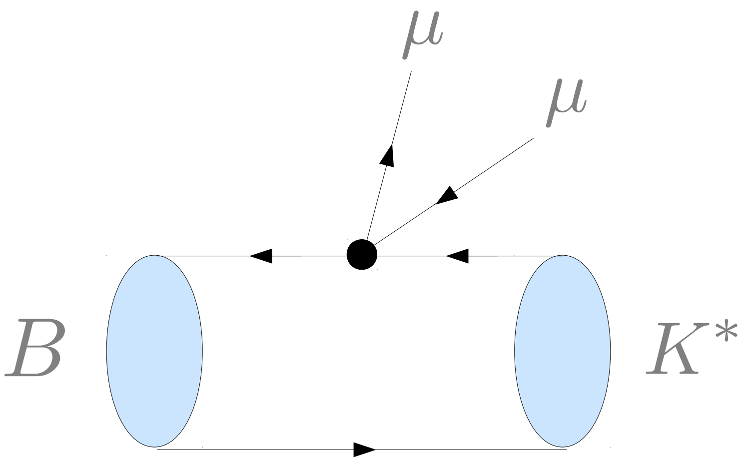
$$S_i = \left(I_i^{(s,c)} + \bar{I}_i^{(s,c)}\right) / \Gamma'$$
$$(2\,\Gamma' \equiv d\Gamma/dq^2 + d\bar{\Gamma}/dq^2)$$

8 CP-AVERAGED OBSERVABLES

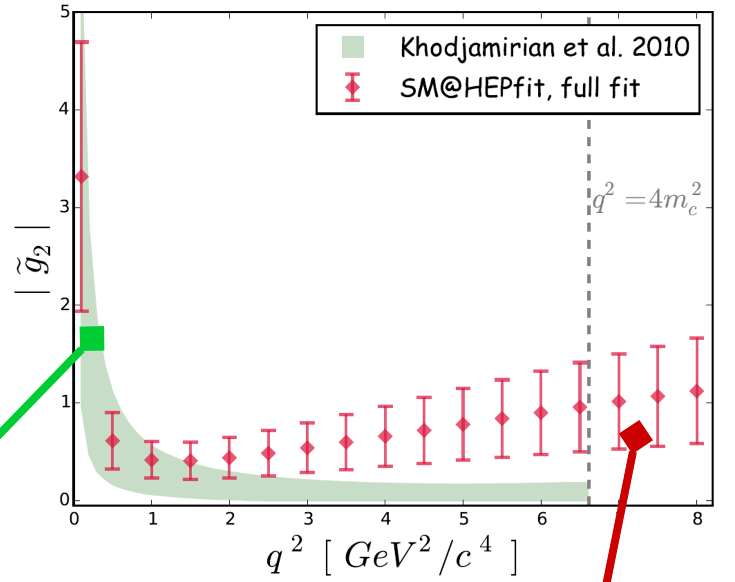
$$\boxed{F_L, A_{FB}, S_{3,4,5,7,8,9}}$$

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

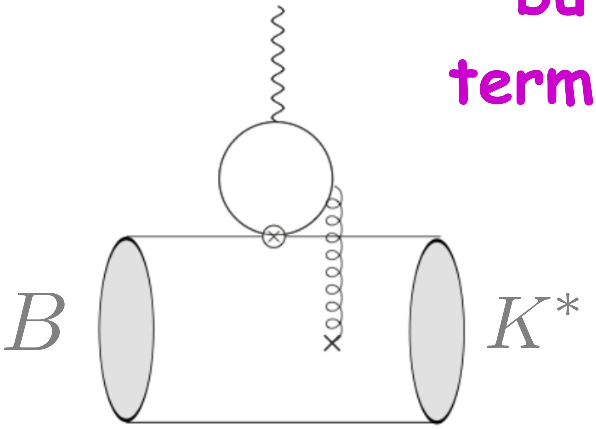
The leading amplitude is factorizable

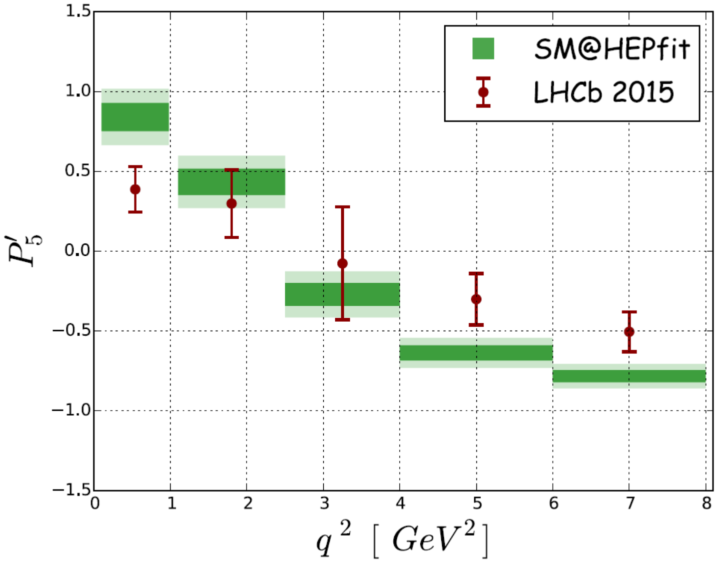


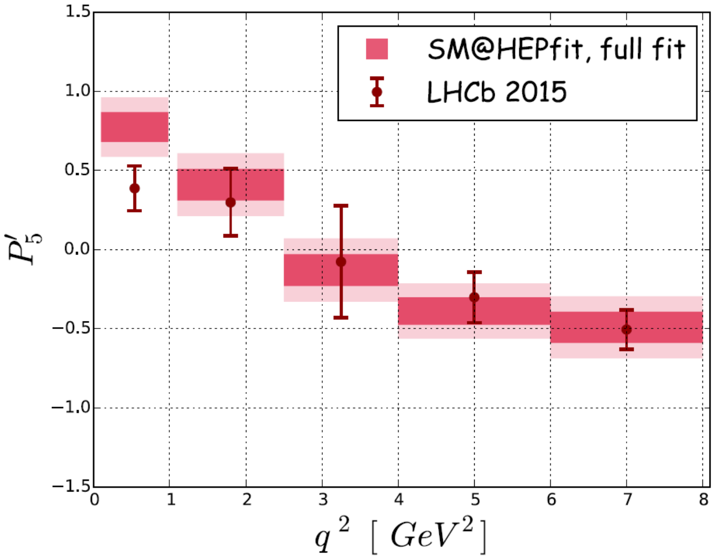
MC, Fedele, Franco, Paul, Silvestrini, Valli, 1512.07157



but non-factorizable terms may be important:

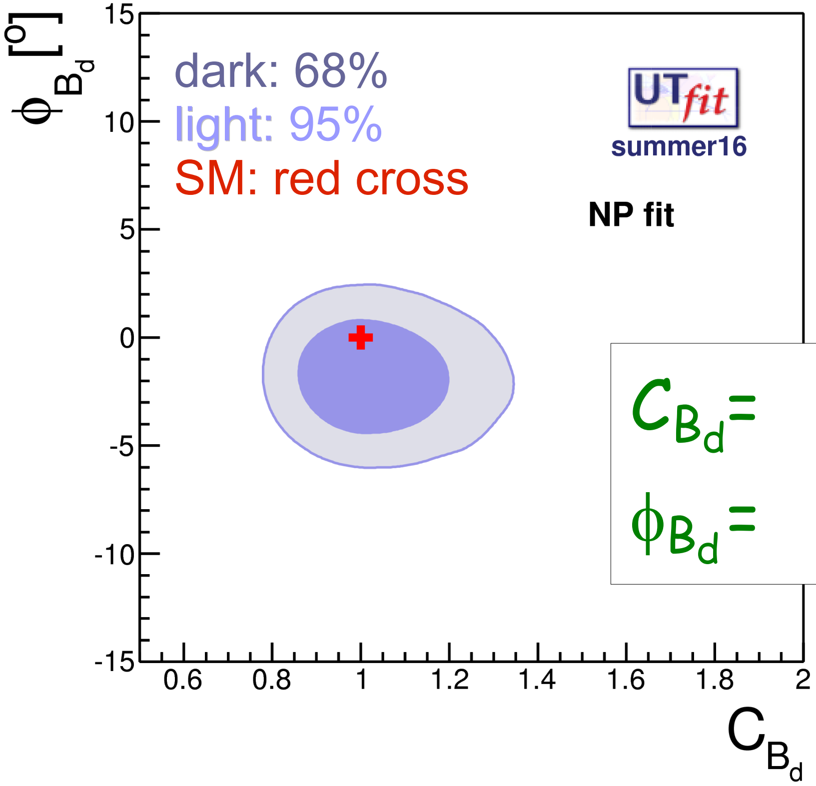






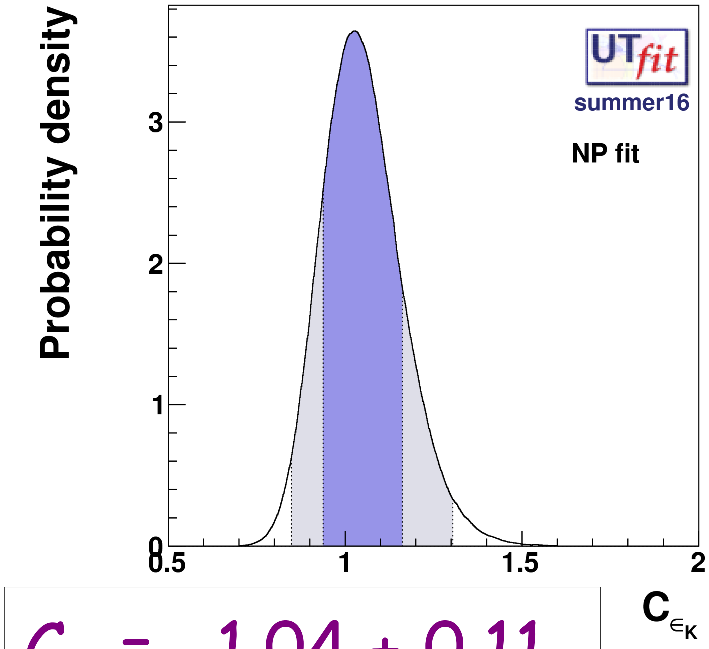
BSM sensitivity could be hindered by hadronic uncertainties

New Physics parameters



C_{B_d}= 1.03 ± 0.11

ϕ_{B_d}= (-1.8 ± 1.7)°



$C_{\varepsilon K}$= 1.04 ± 0.11

$$\varepsilon_K = C_\varepsilon \varepsilon_K^{SM}$$

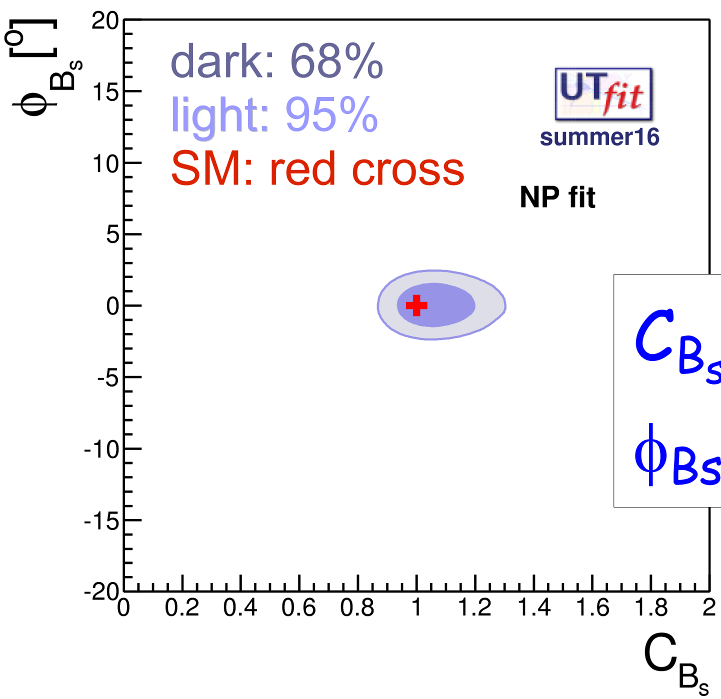
$$\Delta m_q = C_{B_q} (\Delta m_q)^{SM}$$

$$a_{CP}^{B_d \to J/\psi K_s} \to \sin 2(\beta + \phi_{B_d})$$

$$a_{CP}^{B_s \to J/\psi \phi} \to -\beta_s + \phi_{B_s}$$

$$A_{SL}^q = \mathrm{Im}\left(\Gamma_{12}^q / A_q\right)$$

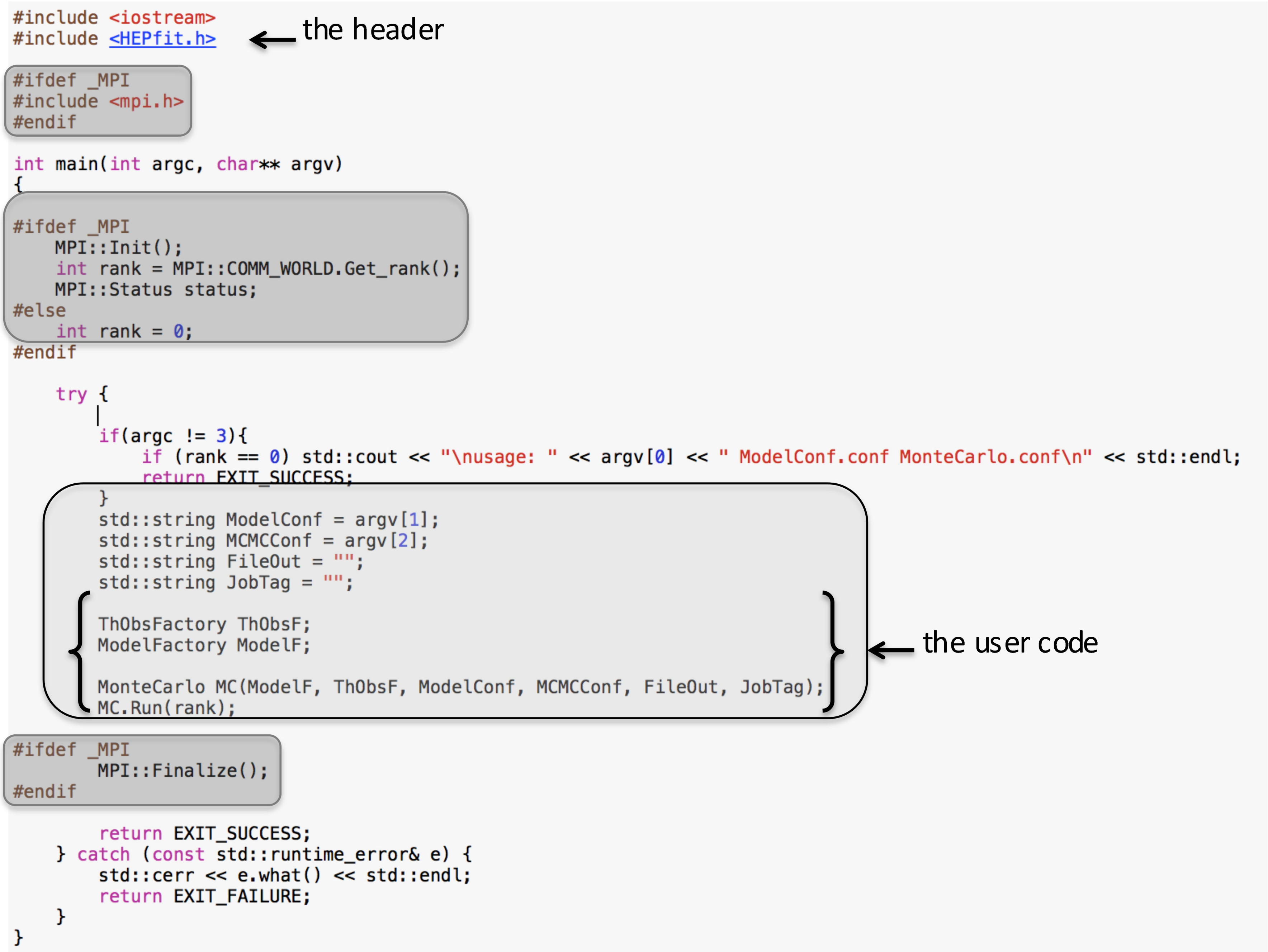
$$\Delta\Gamma^q / \Delta m_q = \mathrm{Re}\left(\Gamma_{12}^q / A_q\right)$$



C_{B_s}= 1.07 ± 0.09

ϕ_{B_s}= (-0.05 ± 0.95)°

sample user codes for MCMC

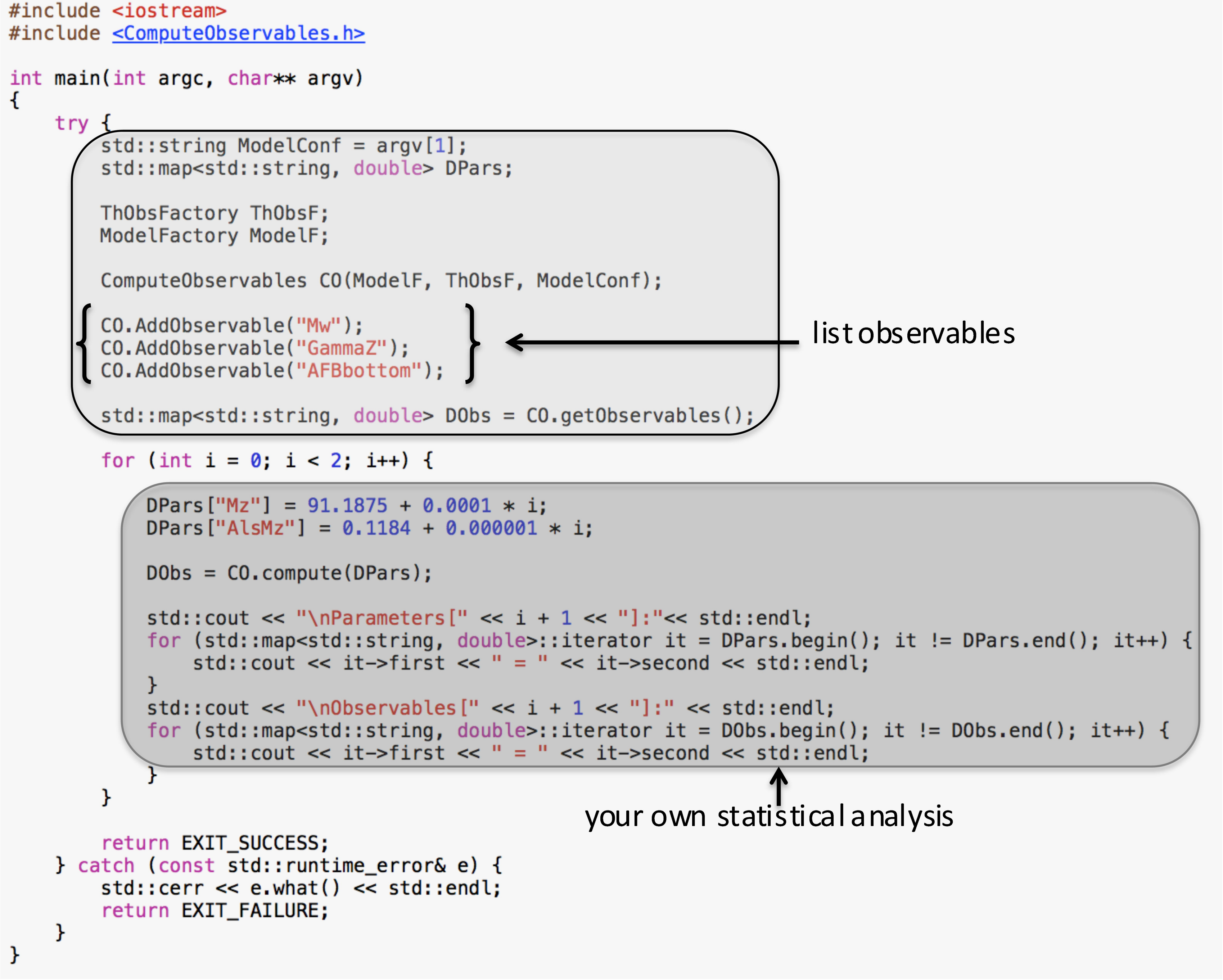


```
#include <iostream>
#include <HEPfit.h>

#ifdef _MPI
#include <mpi.h>
#endif

int main(int argc, char** argv)
{

#ifdef _MPI
    MPI::Init();
    int rank = MPI::COMM_WORLD.Get_rank();
    MPI::Status status;
#else
    int rank = 0;
#endif

    try {

        if(argc != 3){
            if (rank == 0) std::cout << "\nusage: " << argv[0] << " ModelConf.conf MonteCarlo.conf\n" << std::endl;
            return EXIT_SUCCESS;
        }
        std::string ModelConf = argv[1];
        std::string MCMCConf = argv[2];
        std::string FileOut = "";
        std::string JobTag = "";

        ThObsFactory ThObsF;
        ModelFactory ModelF;

        MonteCarlo MC(ModelF, ThObsF, ModelConf, MCMCConf, FileOut, JobTag);
        MC.Run(rank);

#ifdef _MPI
        MPI::Finalize();
#endif

        return EXIT_SUCCESS;
    } catch (const std::runtime_error& e) {
        std::cerr << e.what() << std::endl;
        return EXIT_FAILURE;
    }
}
```

the header

the user code

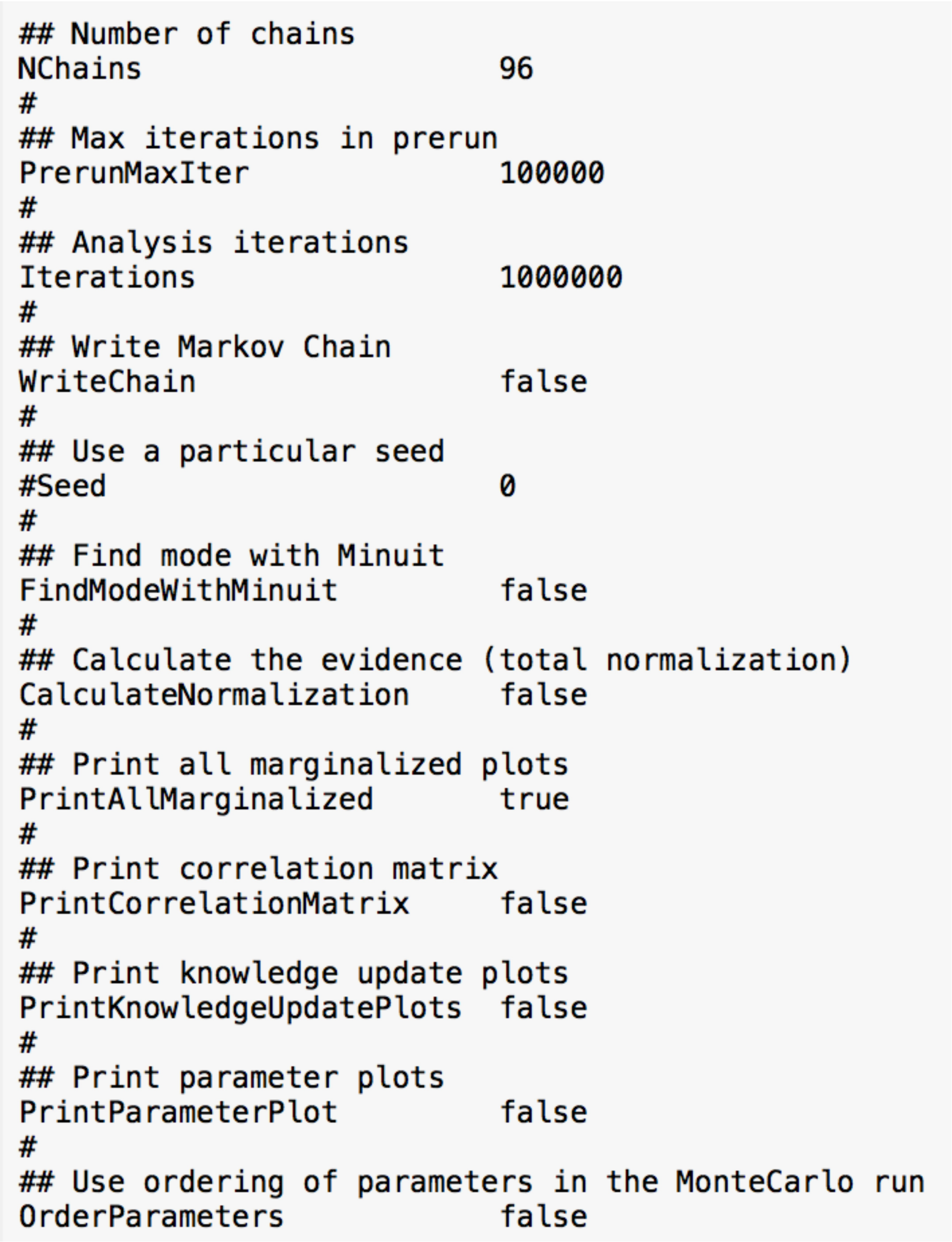
to implement your own statistical analysis



```
#include <iostream>
#include <ComputeObservables.h>

int main(int argc, char** argv)
{
    try {
        std::string ModelConf = argv[1];
        std::map<std::string, double> DPars;

        ThObsFactory ThObsF;
        ModelFactory ModelF;

        ComputeObservables CO(ModelF, ThObsF, ModelConf);

        CO.AddObservable("Mw");
        CO.AddObservable("GammaZ");
        CO.AddObservable("AFBbottom");

        std::map<std::string, double> DObs = CO.getObservables();

        for (int i = 0; i < 2; i++) {

            DPars["Mz"] = 91.1875 + 0.0001 * i;
            DPars["AlsMz"] = 0.1184 + 0.000001 * i;

            DObs = CO.compute(DPars);

            std::cout << "\nParameters[" << i + 1 << "]:"<< std::endl;
            for (std::map<std::string, double>::iterator it = DPars.begin(); it != DPars.end(); it++) {
                std::cout << it->first << " = " << it->second << std::endl;
            }
            std::cout << "\nObservables[" << i + 1 << "]:" << std::endl;
            for (std::map<std::string, double>::iterator it = DObs.begin(); it != DObs.end(); it++) {
                std::cout << it->first << " = " << it->second << std::endl;
            }
        }

        return EXIT_SUCCESS;
    } catch (const std::runtime_error& e) {
        std::cerr << e.what() << std::endl;
        return EXIT_FAILURE;
    }
}
```

list observables

your own statistical analysis



```
## Number of chains
NChains                    96
#
## Max iterations in prerun
PrerunMaxIter              100000
#
## Analysis iterations
Iterations                 1000000
#
## Write Markov Chain
WriteChain                 false
#
## Use a particular seed
#Seed                      0
#
## Find mode with Minuit
FindModeWithMinuit         false
#
## Calculate the evidence (total normalization)
CalculateNormalization     false
#
## Print all marginalized plots
PrintAllMarginalized       true
#
## Print correlation matrix
PrintCorrelationMatrix     false
#
## Print knowledge update plots
PrintKnowledgeUpdatePlots  false
#
## Print parameter plots
PrintParameterPlot         false
#
## Use ordering of parameters in the MonteCarlo run
OrderParameters            false
```