What we learned and what we expect after 2012 experimental achievements

Luca Silvestrini
INFN, Rome
UTfit

- Introduction
- The Higgs boson, EWSB and NP
- Quark flavour and CP violation
- Conclusions and Outlook

INFN Istituto Nazionale di Fisica Nucleare
erc European Research Council
Funding for top researchers from anywhere in the world

DISCLAIMER

- The title is very ambitious and would require a much much broader perspective than what I can possibly offer
- I will present a selection of topics based only on my knowledge, so I apologize in advance if I couldn't cover your favorite measurement or model...
- Similarly, the future perspective is just based on my personal opinions...

INTRODUCTION

The Standard Model works beautifully up to a few hundred GeV's, but it must be an effective theory valid up to a scale $\Lambda \leq M_{planck}$:

$$\mathcal{L}(M_W) = \Lambda^2 H^\dagger H + \lambda \left(H^\dagger H\right)^2 + \mathcal{L}_{\rm SM}^{\rm gauge} + \mathcal{L}_{\rm SM}^{\rm Yukawa} + \frac{1}{\Lambda}\mathcal{L}^5 + \frac{1}{\Lambda^2}\mathcal{L}^6 + \ldots$$

EW scale

Has accidental symmetries

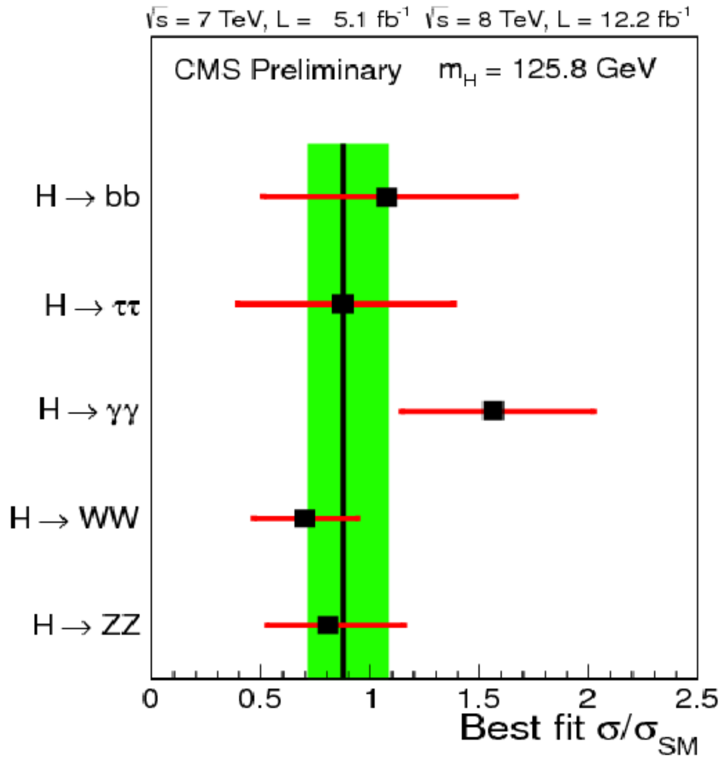
Violates accidental symmetries

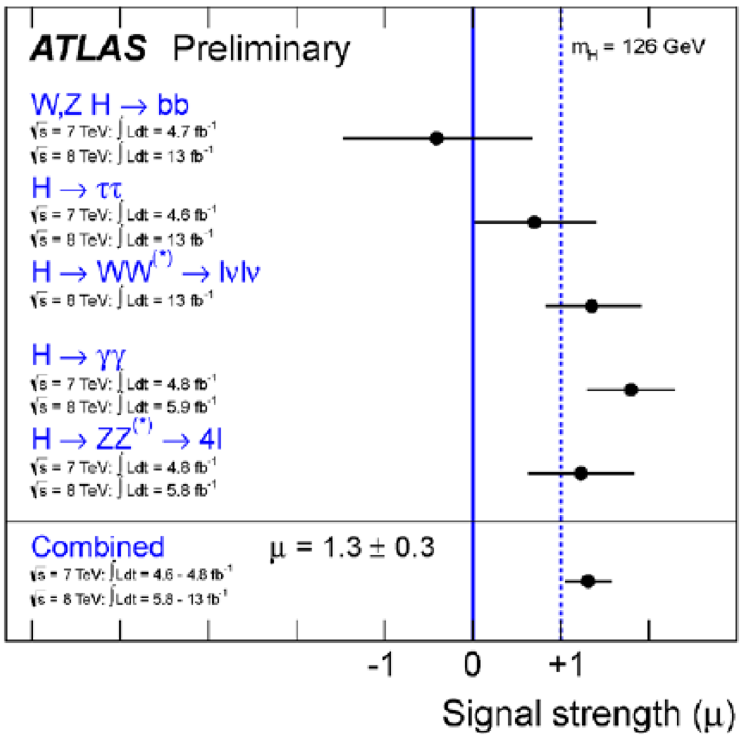
INTRODUCTION - II

- Scale separation requires symmetry to prevent EW scale from raising to the cutoff:
  - low-energy SUSY:
    - Pros: allows for large cutoff, favours gauge unification, perturbative, DM candidate
    - Cons: SUSY breaking mechanism, flavour & CP properties
  - composite Higgs / extra dims:
    - Pros: flavour origin
    - Cons: perturbative unification lost

The Nature of the Higgs Boson

- No doubt that the Higgs Boson discovery is the major experimental highlight of 2012:





Is this the SM Higgs?

Effective Lagrangian for the Higgs: $\mathcal{L} = -V(h) + \mathcal{L}^{(2)} + \mathcal{L}^{(4)} + \dots$

$$V(h) = \frac{1}{2} m_h^2 h^2 + d_3 \frac{1}{6} \left(\frac{3m_h^2}{v} \right) h^3 + d_4 \frac{1}{24} \left(\frac{3m_h^2}{v^2} \right) h^4 + \dots$$

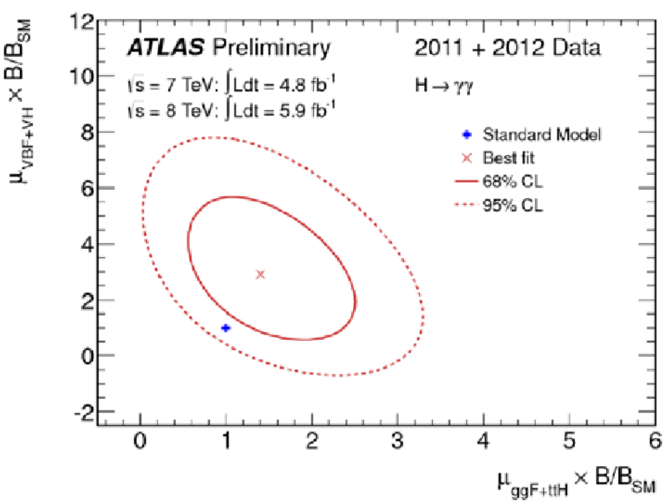
$$\begin{aligned}
\mathcal{L}^{(2)} = & \frac{1}{2}(\partial_\mu h)^2 + \frac{v^2}{4} \mathrm{Tr}\left(D_\mu \Sigma^\dagger D^\mu \Sigma \right) \left(1 + 2a \frac{h}{v} + b \frac{h^2}{v^2} + \cdots \right) \\
& - \frac{v}{\sqrt{2}} \lambda^u_{ij} \left(\bar{u}_L^{(i)}, \bar{d}_L^{(i)} \right) \Sigma \left(u_R^{(i)}, 0 \right)^T \left(1 + c_u \frac{h}{v} + c_{2u} \frac{h^2}{v^2} + \cdots \right) + h.c. \\
& - \frac{v}{\sqrt{2}} \lambda^d_{ij} \left(\bar{u}_L^{(i)}, \bar{d}_L^{(i)} \right) \Sigma \left(0, d_R^{(i)} \right)^T \left(1 + c_d \frac{h}{v} + c_{2d} \frac{h^2}{v^2} + \cdots \right) + h.c. \\
& - \frac{v}{\sqrt{2}} \lambda^l_{ij} \left(\bar{\nu}_L^{(i)}, \bar{l}_L^{(i)} \right) \Sigma \left(0, l_R^{(i)} \right)^T \left(1 + c_l \frac{h}{v} + c_{2l} \frac{h^2}{v^2} + \cdots \right) + h.c.
\end{aligned}$$

The SM corresponds to $a = b = c_u = c_d = c_e = d_3 = d_4 = 1$

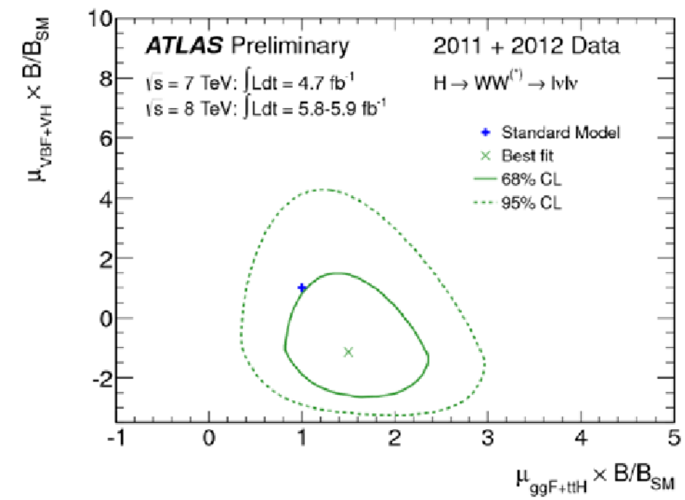
Contino et al '10; Azatov et al '12

SM Higgs Couplings

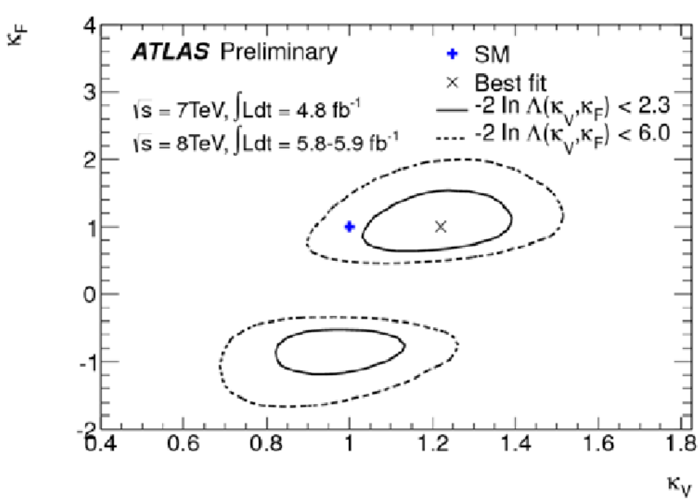
- ATLAS has performed a coupling analysis, using the recommended framework from the Higgs XSWG, based on effective field theory approach. [arXiv 1209.0040]
- This analysis was based on the data in the "Higgs Observation" paper, and has not yet been updated for HCP (only the signal strength plot was updated).



Signal strength fits for the $\gamma\gamma$ final state (left) and the WW final state (right).

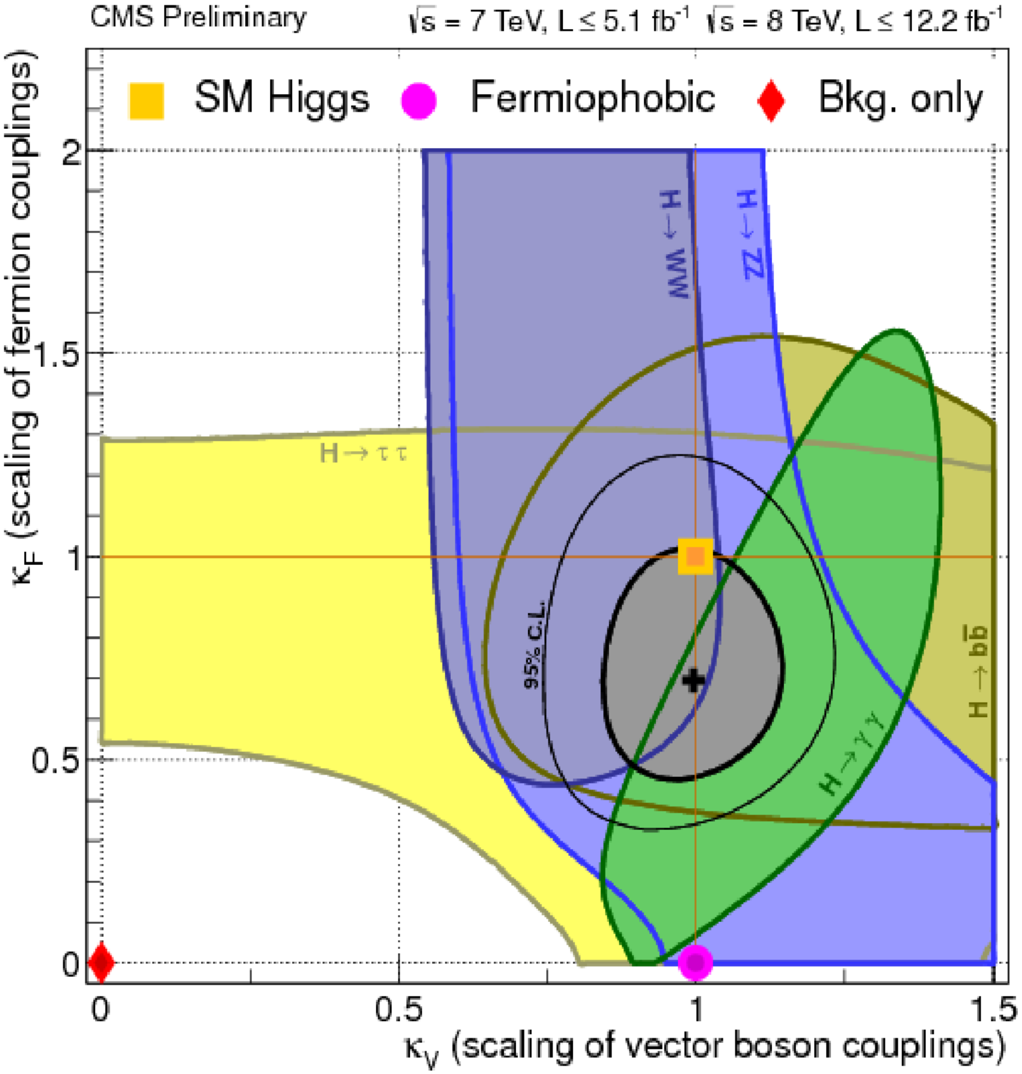


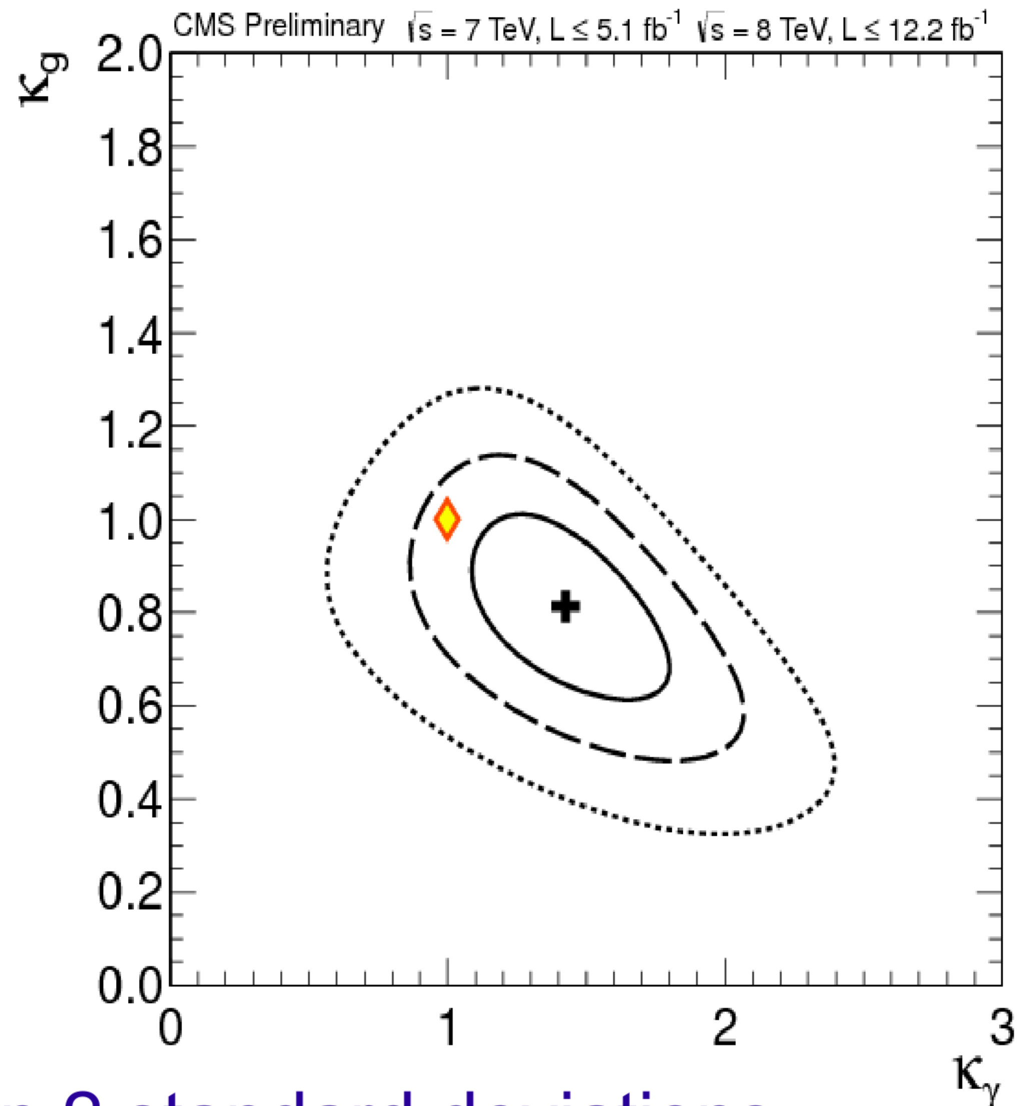
[ATLAS-CONF-2012-127]



- Fit for κ_V versus κ_F, assuming there is a single coupling for all fermions t, b, τ (κ_F) and a single coupling for vector bosons (κ_V).
- Sign comes from interference between t and W loops in $\gamma\gamma$ process.

Combination of Higgs Results





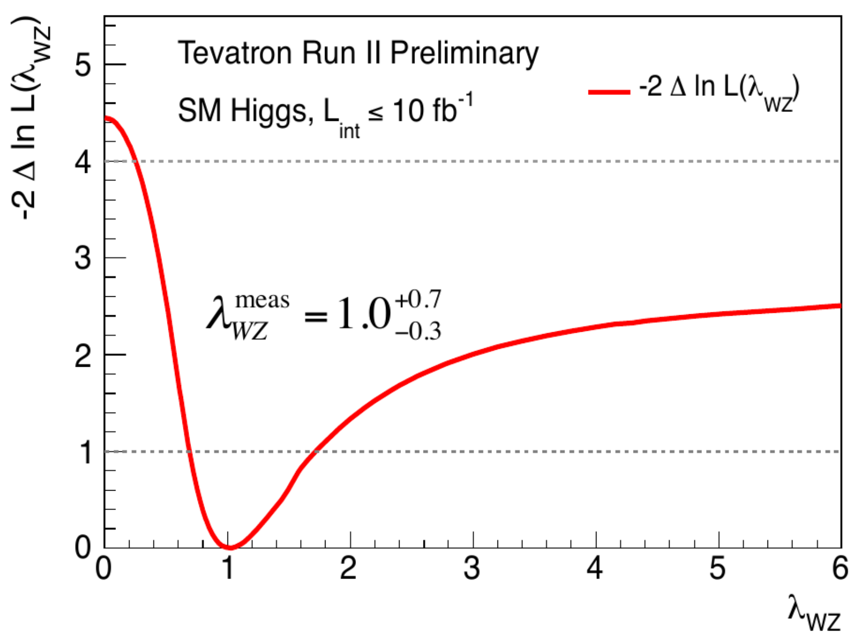
Couplings look consistent within 2 standard deviations

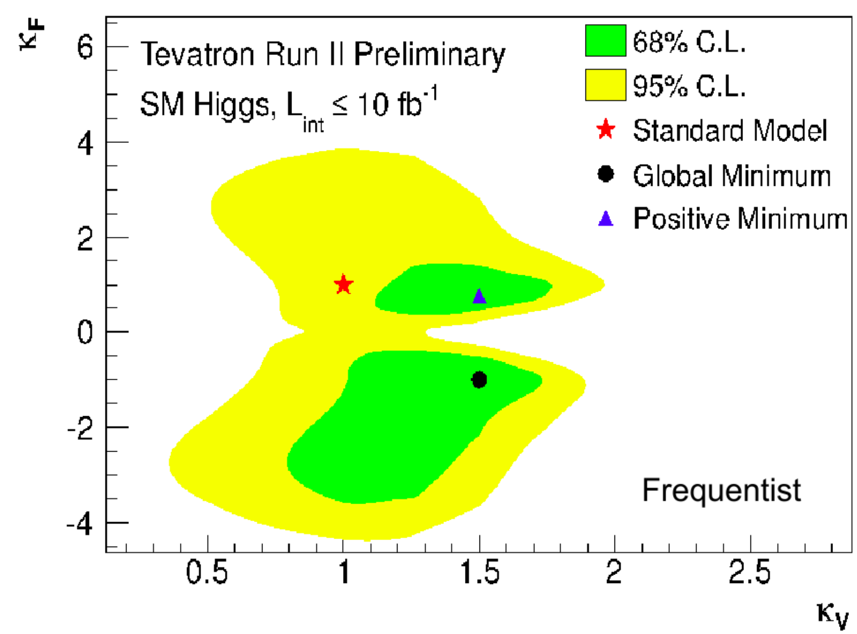
- Fermions versus vector bosons
- effective gluon versus photon couplings (loops)

Paus @ HCP2012

Probing Higgs Boson Couplings

- **Benchmark I:**
  - Probe $SU(2)_V$ custodial symmetry by measuring the ratio $\lambda_{WZ}=\kappa_W/\kappa_Z$. Assume all fermion couplings as predicted by the SM.
- **Benchmark II:**
  - Consider two independent multiplicative factors: common to all couplings to vector bosons (κ_V) and common to all couplings to fermions (κ_f). Assume λ_{WZ}=1.
  - Measure κ_f and κ_V simultaneously.





Measurements consistent with the SM prediction

Juste @ HCP2012

INDIRECT CONSTRAINTS

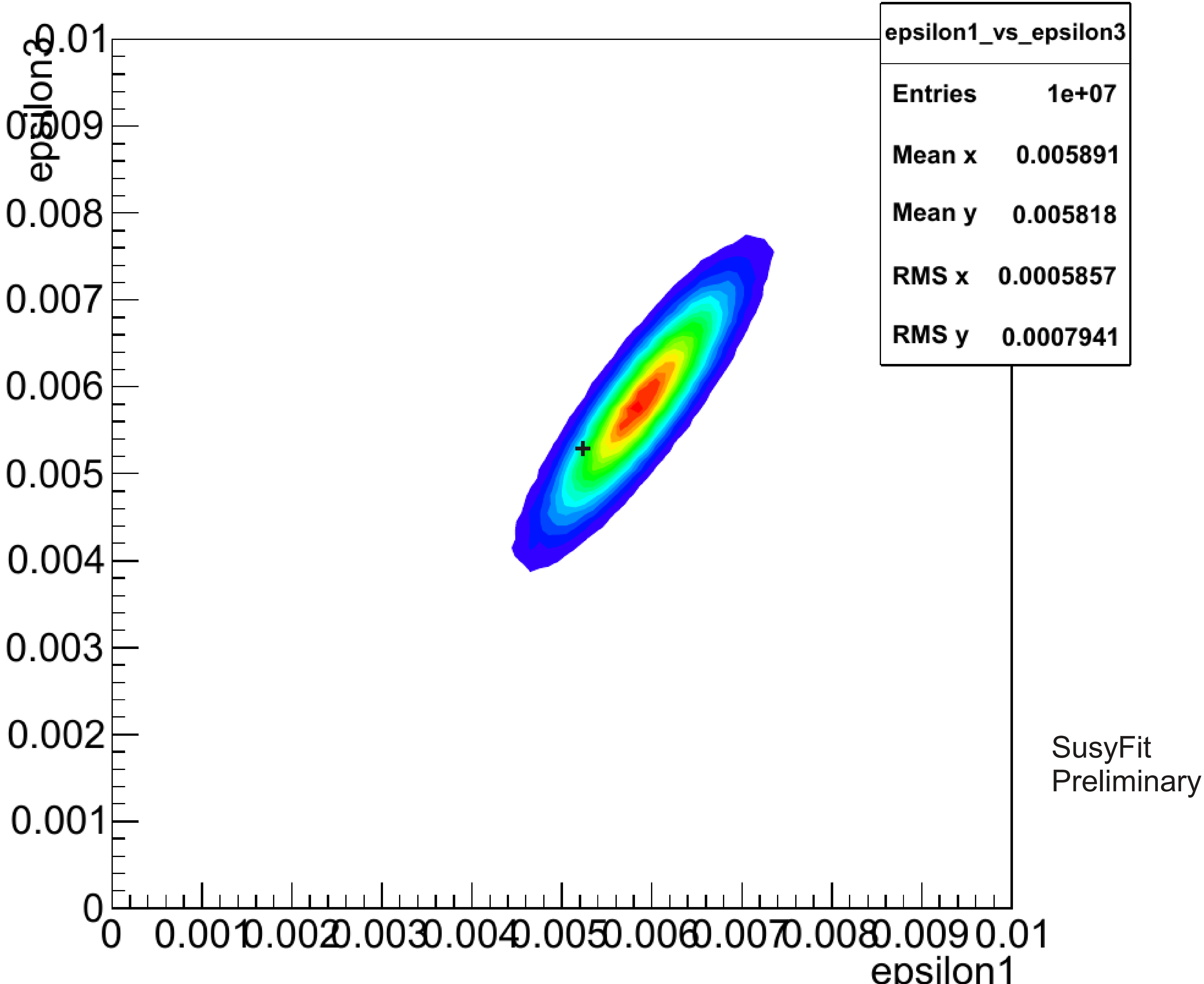
- Modified Higgs couplings affect LEP precision observables:

$$\Delta\epsilon_1 = -\frac{3}{16\pi}\,\frac{\alpha(m_Z)}{\cos^2\theta_W}\,(1-a^2)\log\left(\frac{\Lambda^2}{m_h^2}\right)$$

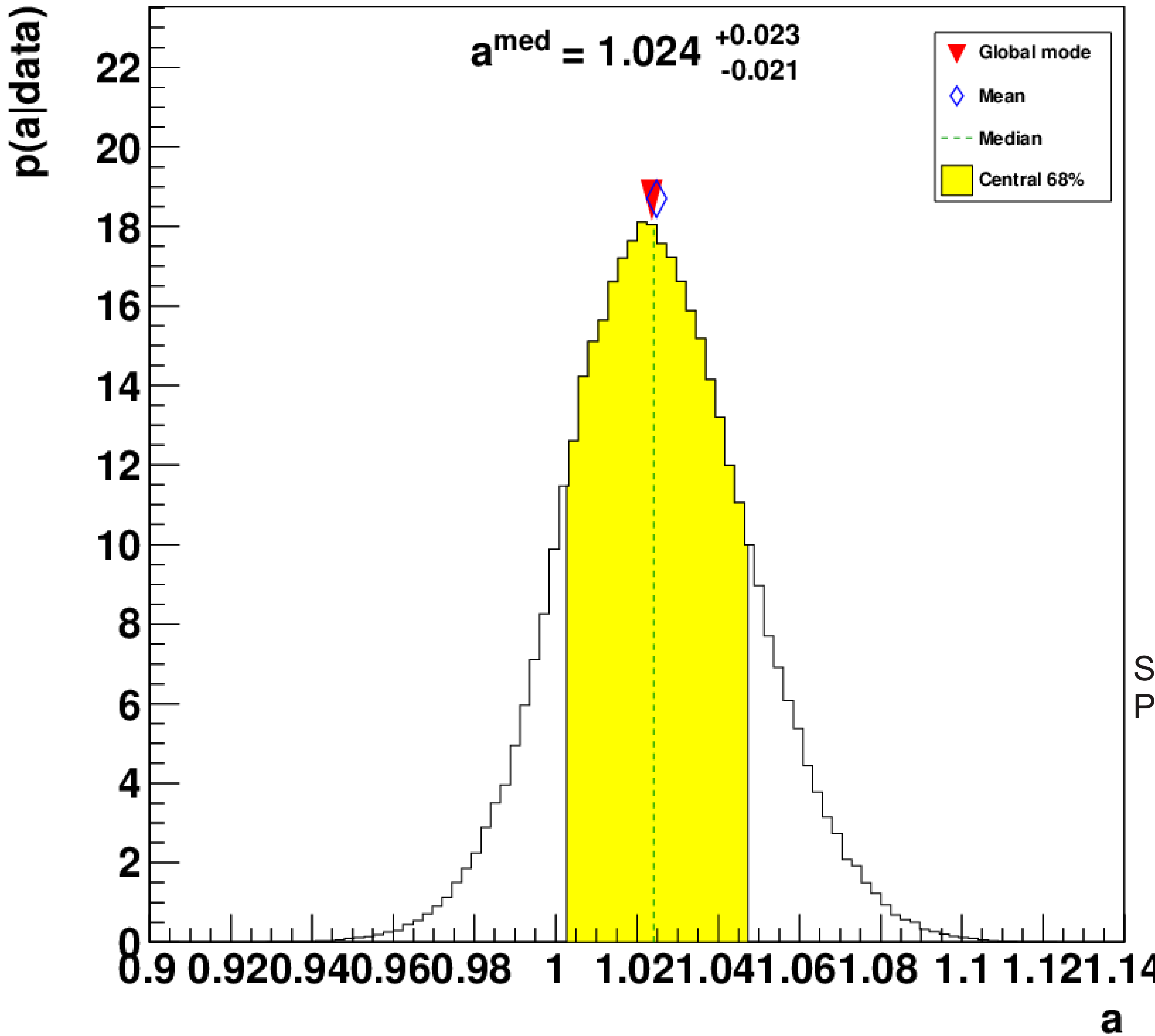
$$\Delta\epsilon_3 = +\frac{1}{48\pi}\,\frac{\alpha(m_Z)}{\sin^2\theta_W}\,(1-a^2)\log\left(\frac{\Lambda^2}{m_h^2}\right)$$

with $\Lambda = 4\pi v/\sqrt{1-a^2}$

Barbieri et al '07


epsilon1_vs_epsilon3
Entries 1e+07
Mean x 0.005891
Mean y 0.005818
RMS x 0.0005857
RMS y 0.0007941
epsilon3
epsilon1
SusyFit
Preliminary

Ro

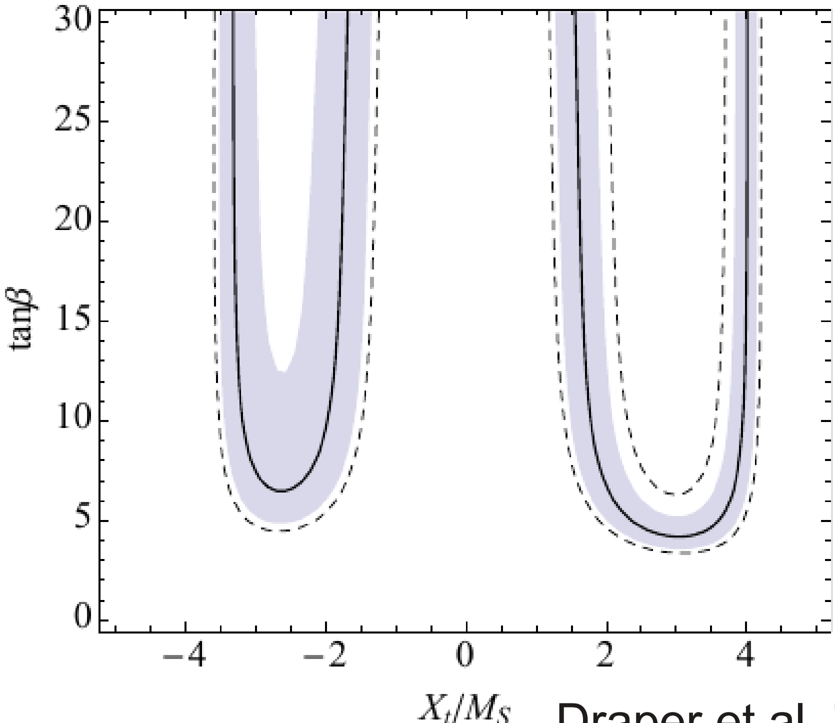


SusyFit Preliminary

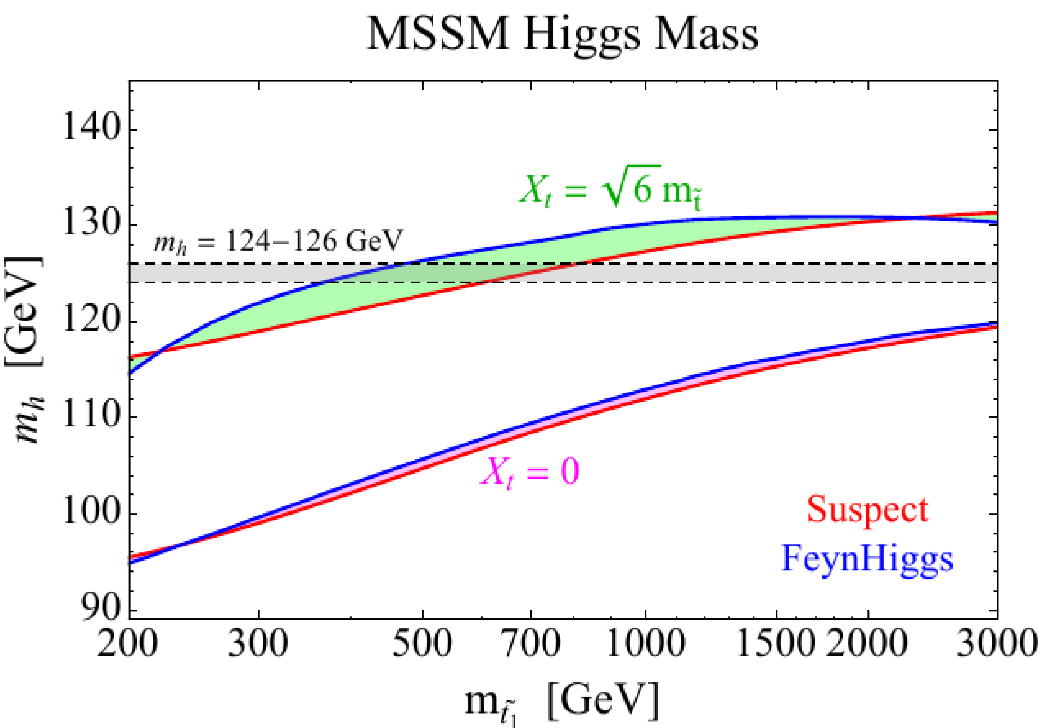
IMPACT ON NP MODELS

- One has in general $a<1$ unless $I=2$ resonances dominate WW scattering
- Composite Higgs models disfavoured **barring accidental cancellations**, i.e. unless other states contribute sizably to LEP observables and bring back the model into the eps1-eps3 ellipse

BACK TO SUSY



Draper et al. '12



Hall et al '12

Tuning well below the % level required in the MSSM, less tuned extensions possible

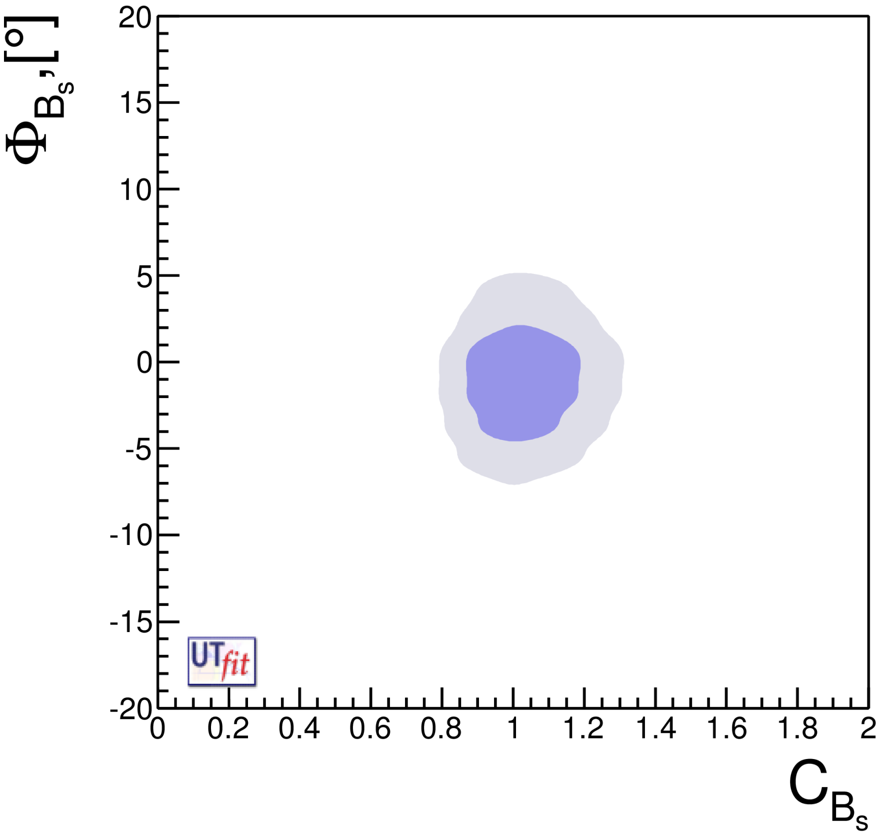
SUMMARY OF HIGH-pT

- We have seen a Higgs Boson well compatible with the SM one
- Models stabilizing the EW scale must be fine-tuned due to direct searches, the value of m_H and LEP data
- Consider NP in the multi-TeV region

FLAVOUR PHYSICS

- In the quark flavour sector, two major achievements in 2011/12:
  - ruling out order-of-magnitude effects in b-s transitions
  - pointing out possible NP in D decays

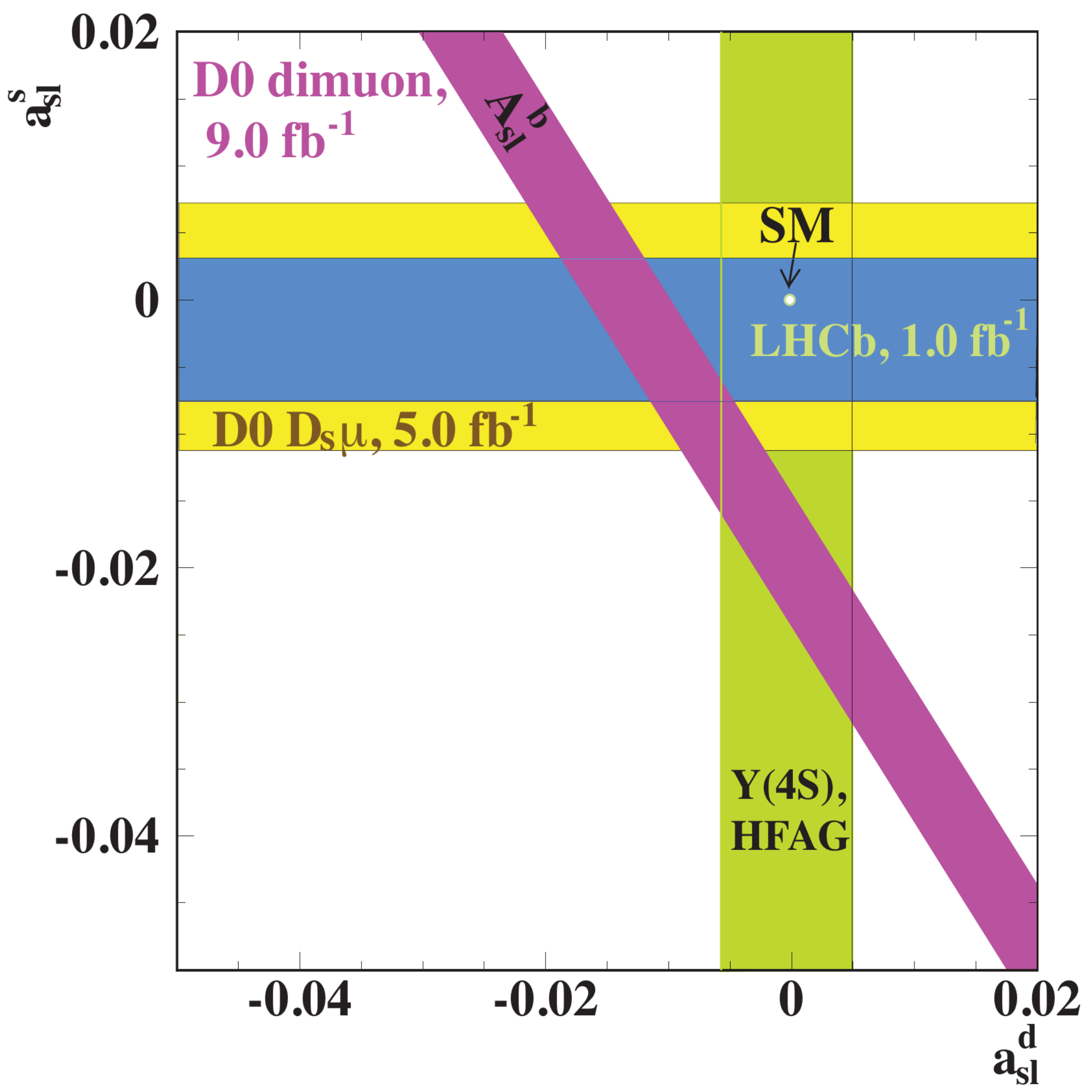
NP IN B_s MIXING



- $C_{Bs} = 1.02 \pm 0.10$ ([0.83,1.24] @ 95% probability)
- $\phi_{Bs} = (-1.1 \pm 2.2)°$ ([-6,3.6]° @ 95% probability)

The D0 dimuon asymmetry remains unexplained

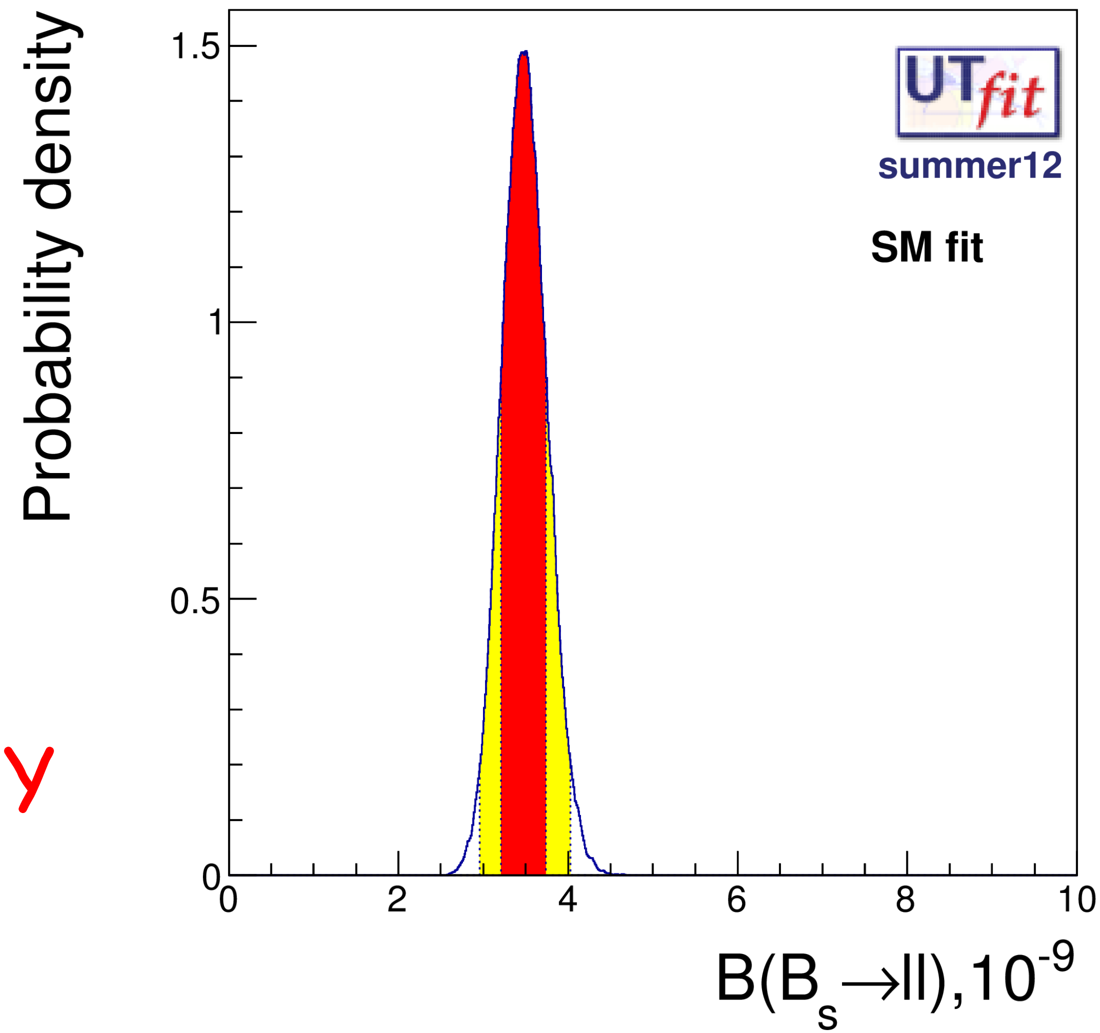
NEW LHCb RESULT ON A_{SL}^{s}



Maybe we should forget about the dimuon problem...

$B_s \to \mu\mu$

- SM prediction: $(3.47 \pm 0.27)10^{-9}$
- LHCb 2012 result: $(3.2+1.5-1.2)10^{-9}$
- Strong constraint on large tanβ SUSY



D-$\bar{D}$ MIXING

- Established experimentally only in 2007
- Great experimental progress recently
- SM long distance contributions difficult to estimate, but solid prediction: no CPV in mixing
- Direct CPV possible in SCS decays (and recently observed by LHCb and CDF)

BASIC FORMULAE

- All mixing-related observables can be expressed in terms of $x=\Delta m/\Gamma$, $y=\Delta\Gamma/2\Gamma$ and $|q/p|$, or better in terms of M_{12}, Γ_{12} and $\Phi_{12}=\arg(\Gamma_{12}/M_{12})$:

$$|M_{12}| = \frac{1}{\tau_D}\sqrt{\frac{x^2+\delta^2 y^2}{4(1-\delta^2)}}\,, \quad |\Gamma_{12}| = \frac{1}{\tau_D}\sqrt{\frac{y^2+\delta^2 x^2}{1-\delta^2}}\,, \quad \sin\Phi_{12} = \frac{|\Gamma_{12}|^2+4|M_{12}|^2-(x^2+y^2)|q/p|^2/\tau_D^2}{4|M_{12}\Gamma_{12}|}$$

$$\delta = \frac{1-|q/p|^2}{1+|q/p|^2}\,, \quad \phi = \arg(q/p) = \arg(y+i\delta x)\,, \quad A_M = \frac{|q/p|^4-1}{|q/p|^4+1}\,, \quad R_M = \frac{x^2+y^2}{2}\,, \qquad (1)$$

$$\begin{pmatrix} x'_f \\ y'_f \end{pmatrix} = \begin{pmatrix} \cos\delta_f & \sin\delta_f \\ -\sin\delta_f & \cos\delta_f \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}\,, \quad (x'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1}(x'_f\cos\phi \pm y'_f\sin\phi)\,, \quad (y'_\pm)_f = \left|\frac{q}{p}\right|^{\pm 1}(y'_f\cos\phi \mp x'_f\sin\phi)\,,$$

$$y_{\rm CP} = \left(\left|\frac{q}{p}\right|+\left|\frac{p}{q}\right|\right)\frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right|-\left|\frac{p}{q}\right|\right)\frac{x}{2}\sin\phi\,, \quad A_\Gamma = \left(\left|\frac{q}{p}\right|-\left|\frac{p}{q}\right|\right)\frac{y}{2}\cos\phi - \left(\left|\frac{q}{p}\right|+\left|\frac{p}{q}\right|\right)\frac{x}{2}\sin\phi\,,$$

$$R_D = \frac{\Gamma(D^0\to K^+\pi^-)+\Gamma(\bar{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^-\pi^+)+\Gamma(\bar{D}^0\to K^+\pi^-)}\,, \quad A_D = \frac{\Gamma(D^0\to K^+\pi^-)-\Gamma(\bar{D}^0\to K^-\pi^+)}{\Gamma(D^0\to K^+\pi^-)+\Gamma(\bar{D}^0\to K^-\pi^+)}\,,$$

FIT RESULTS

parameter	result @ 68% prob.	95% prob. range
$\|M_{12}\|$ [1/ps]	$(6.9 \pm 2.4) \cdot 10^{-3}$	$[2.1, 11.5] \cdot 10^{-3}$
$\|\Gamma_{12}\|$ [1/ps]	$(17.2 \pm 2.5) \cdot 10^{-3}$	$[12.3, 22.4] \cdot 10^{-3}$
Φ_{12} [°]	(-6 ± 9)	$[-37, 13]$
x	$(5.6 \pm 2.0) \cdot 10^{-3}$	$[1.4, 9.6] \cdot 10^{-3}$
y	$(7.0 \pm 1.0) \cdot 10^{-3}$	$[5.0, 9.1] \cdot 10^{-3}$
$\|q/p\| - 1$	$(5.3 \pm 7.7) \cdot 10^{-2}$	$[-8.5, 25.6] \cdot 10^{-2}$
ϕ [°]	(-2.4 ± 2.9)	$[-8.8, 3.7]$
A_Γ	$(0.7 \pm 0.8) \cdot 10^{-3}$	$[-0.9, 2.3] \cdot 10^{-3}$
A_M	$(11 \pm 14) \cdot 10^{-2}$	$[-15, 44] \cdot 10^{-2}$
R_M	$(4.0 \pm 1.4) \cdot 10^{-5}$	$[1.7, 7.2] \cdot 10^{-5}$
R_D	$(3.27 \pm 0.08) \cdot 10^{-3}$	$[3.10, 3.44] \cdot 10^{-3}$
$\delta_{K\pi}$ [°]	(18 ± 12)	$[-14, 40]$
$\delta_{K\pi\pi^0}$ [°]	(31 ± 20)	$[-11, 73]$
$a_{CP}^{dir}(D^0 \to K^+K^-)$	$(-2.6 \pm 2.2) \cdot 10^{-3}$	$[-7.1, 1.9] \cdot 10^{-3}$
$a_{CP}^{dir}(D^0 \to \pi^+\pi^-)$	$(4.1 \pm 2.4) \cdot 10^{-3}$	$[-0.8, 9.0] \cdot 10^{-3}$
Δa_{CP}^{dir}	$(6.6 \pm 1.6) \cdot 10^{-3}$	$[-9.8, 3.5] \cdot 10^{-3}$

UTfit '12

TABLE II. Results of the fit to D mixing data. $\Delta a_{CP}^{dir} = a_{CP}^{dir}(D^0 \to K^+K^-) - a_{CP}^{dir}(D^0 \to \pi^+\pi^-)$.

EFT analysis of ΔF=2 transitions

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

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

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

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

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

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

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

7 new operators beyond MFV involving quarks with different chiralities

H_{eff} can be recast in terms of the $C_i(\Lambda)$ computed at the NP scale

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

$$C_i(\Lambda) = \frac{L F_i}{\Lambda^2}$$

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

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

Flavour structures:

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

present lower bound on the NP scale for $L=1$ and $F_i = 1$:

from ε_K: 4.9 10^5 TeV

from D mixing: 1.3 10^4 TeV

from B_d mixing: 3 10^3 TeV

from B_s mixing: 8 10^2 TeV

* $\Delta F=2$ chirality-flipping operators are RG enhanced and thus probe larger NP scales
* typical RS models have $L*F_4 = m_i m_j/v^2$, so that ε_K implies $\Lambda > 17$ TeV
* suppression of the 1 <-> 2 transitions strongly weakens the lower bounds

DIRECT CPV IN CHARM DECAYS

- Some basic facts known for a long time:

1) To obtain a good description of SCS D BR's need:

   - final state interactions and corrections to factorization
   - sizable SU(3) breaking

2) The SM expectation for direct CPV is $\lesssim 10^{-3}$

See for example Buccella et al. '95

EXPERIMENTAL STATUS

- Very recently, LHCb and CDF provided evidence of $\Delta A_{CP}=A_{CP}(K^+K^-)-A_{CP}(\pi^+\pi^-)$
- Combining LHCb, CDF and B-factories:

$a_{\rm CP}^{\rm dir}(D^0 \to K^+K^-)$	$(-2.6 \pm 2.2) \cdot 10^{-3}$	$[-7.1, 1.9] \cdot 10^{-3}$
$a_{\rm CP}^{\rm dir}(D^0 \to \pi^+\pi^-)$	$(4.1 \pm 2.4) \cdot 10^{-3}$	$[-0.8, 9.0] \cdot 10^{-3}$
$\Delta a_{\rm CP}^{\rm dir}$	$(6.6 \pm 1.6) \cdot 10^{-3}$	$[-9.8, 3.5] \cdot 10^{-3}$

well above the 10^{-3} barrier...

THEORY QUESTIONS

- Can we envisage a mechanism to enhance the SM prediction for CPV by one order of magnitude to reproduce the exp result?

Brod, Kagan & Zupan '11; Pirtskhalava & Uttayarat '11; Bhattacharya, Gronau & Rosner '12; Cheng & Chiang '12; Brod, Grossman, Kagan & Zupan '12

- Can anything analogous to the $\Delta I=1/2$ rule take place in SCS charm decays?

Golden & Grinstein, '89

ISOSPIN & UNITARITY

- Let us start from the basic knowledge:
  - SU(3) breaking is large $\Rightarrow$ use only isospin
  - corrections to factorization are large $\Rightarrow$ use a general parameterization
  - final state interactions are important $\Rightarrow$ implement unitarity & external info on rescattering

Franco, Mishima & LS '12;
Franco, Mishima, Paul & LS, in progress

ISOSPIN AMPLITUDES

$$A(D^+ \to \pi^+\pi^0) = \frac{\sqrt{3}}{2}\mathcal{A}_2^\pi\,,$$

$r_{CKM}=6.4\ 10^{-4}$

$$A(D^0 \to \pi^+\pi^-) = \frac{\mathcal{A}_2^\pi - \sqrt{2}(\mathcal{A}_0^\pi + i r_{\rm CKM}\mathcal{B}_0^\pi)}{\sqrt{6}}\,,$$

$$A(D^0 \to \pi^0\pi^0) = \frac{\sqrt{2}\mathcal{A}_2^\pi + \mathcal{A}_0^\pi + i r_{\rm CKM}\mathcal{B}_0^\pi}{\sqrt{3}}\,,$$

A CP-even

B CP-odd

$$A(D^+ \to K^+\bar{K}^0) = \frac{\mathcal{A}_{13}^K}{2} + \mathcal{A}_{11}^K + i r_{\rm CKM}\mathcal{B}_{11}^K\,,$$

$$A(D^0 \to K^+K^-) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K - \mathcal{A}_0^K + i r_{\rm CKM}\mathcal{B}_{11}^K - i r_{\rm CKM}\mathcal{B}_0^K}{2}\,,$$

$$A(D^0 \to K^0\bar{K}^0) = \frac{-\mathcal{A}_{13}^K + \mathcal{A}_{11}^K + \mathcal{A}_0^K + i r_{\rm CKM}\mathcal{B}_{11}^K + i r_{\rm CKM}\mathcal{B}_0^K}{2}\,.$$

NUMERICAL RESULTS FROM BR's

$$|\mathcal{A}_2^\pi| = (3.08 \pm 0.08) \times 10^{-7}\ \mathrm{GeV}\,,$$
$$|\mathcal{A}_0^\pi| = (7.6 \pm 0.1) \times 10^{-7}\ \mathrm{GeV}\,,$$
$$\arg(\mathcal{A}_2^\pi/\mathcal{A}_0^\pi) = (\pm 93 \pm 3)^\circ\,.$$

No ΔI=1/2 rule for D decays, large strong phases

$$|\mathcal{A}_{13}^K - \mathcal{A}_{11}^K - \mathcal{A}_0^K| = (5.0 \pm 0.4) \times 10^{-7}\ \mathrm{GeV}$$

Should vanish in the SU(3) limit, but is O(1)!!

UNITARITY CONSTRAINTS

$$S = \left(\begin{array}{c|cccc} D \to D & D \to \pi\pi & D \to KK & \cdots \\ \hline \pi\pi \to D & \pi\pi \to \pi\pi & \pi\pi \to KK & \cdots \\ KK \to D & KK \to \pi\pi & KK \to KK & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{array}\right) \equiv \begin{pmatrix} 1 & -i(T)^T \\ -i\,\mathrm{CP}(T) & S_S \end{pmatrix}$$

implies

$$T^R = S_S (T^R)^*, \qquad T^I = S_S (T^I)^*$$

Elastic case: $S = e^{2i\delta} \Rightarrow$ Watson theorem:

$T^R = |T^R| e^{i\delta}$, $T^I = |T^I| e^{i\delta}$

5-CHANNEL UNITARITY

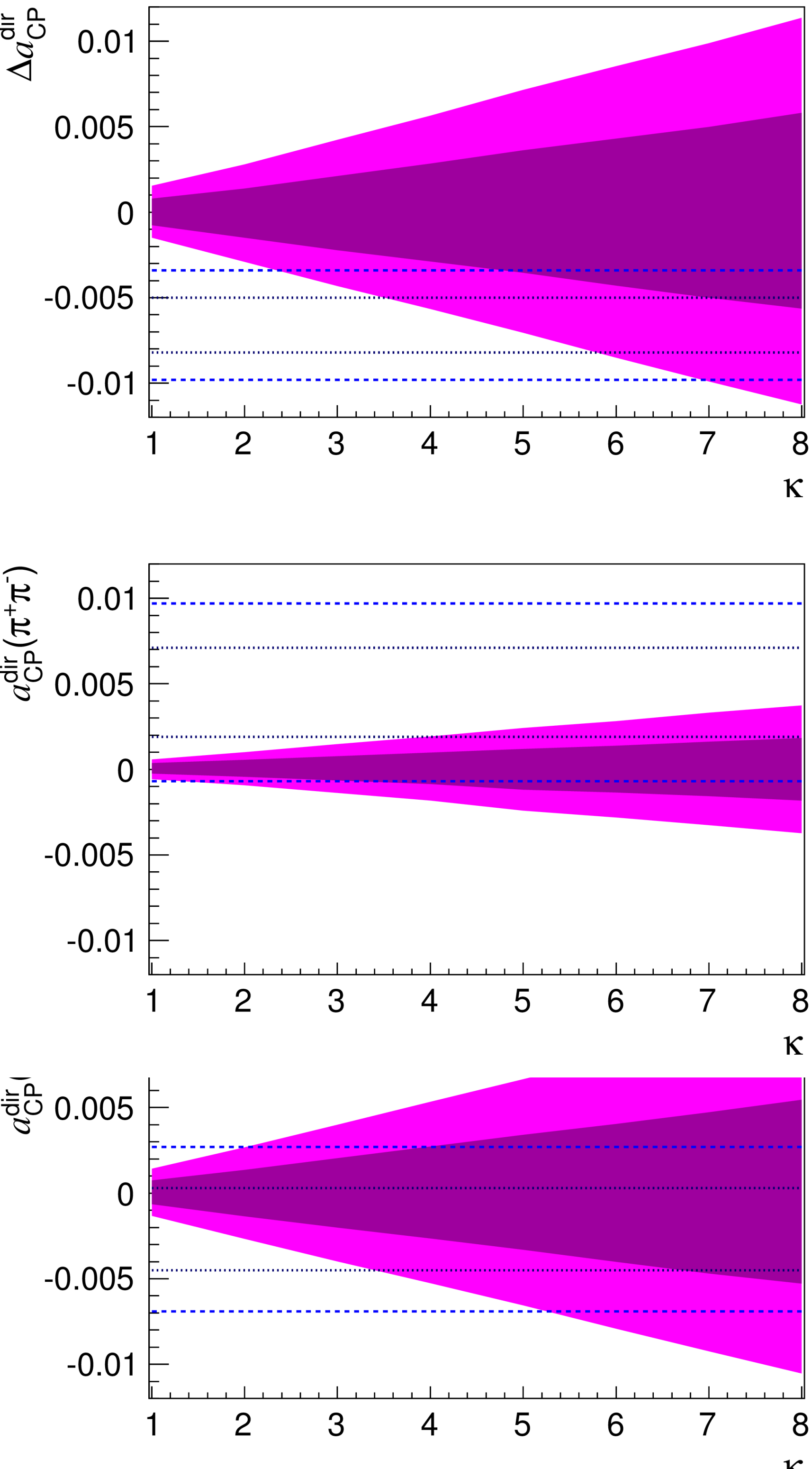
- Global fits of pion-nucleon scattering data provide the strong interaction S-matrix in the I=0 cannel for energies up to the D mass
- A five-channel unitary S matrix is obtained including $\pi\pi$, KK, $\eta\eta$, $\eta\eta'$ and 4π states
- Implementing unitarity constraints strongly the phase of the I=0 $\pi\pi$ amplitude

CP ASYMMETRIES

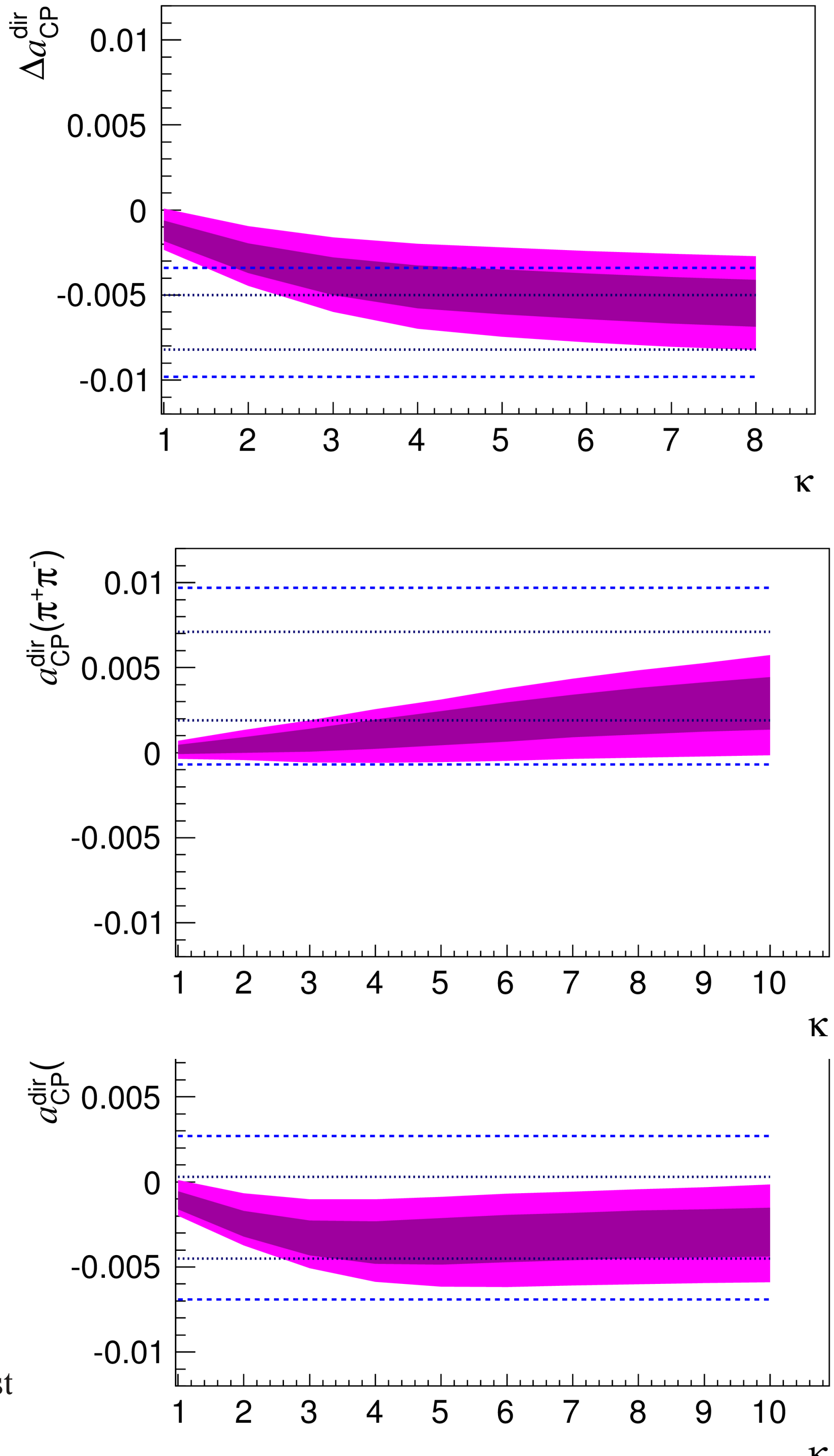
- One can study the CP asymmetries as a function of the upper bound on the size of CPV contributions. We write

$$
\begin{aligned}
|\mathcal{B}_0^\pi| &< \kappa |\mathcal{A}_0^\pi| \,, \\
|\mathcal{B}_0^K - \mathcal{A}_0^K| &< \kappa |\mathcal{A}_0^K| \,, \\
|\mathcal{B}_{11}^K - (\mathcal{A}_{11}^K - \mathcal{A}_{13}^K)| &< \kappa |\mathcal{A}_{11}^K - \mathcal{A}_{13}^K| \,,
\end{aligned}
$$

and consider predictions and fit results for CP asymmetries


Δa_{CP}^{dir}
0.01
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8
κ
$a_{CP}^{dir}(\pi^+\pi^-)$
0.01
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8
κ
a_{CP}^{dir}
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8

L. Silvest


Δa_{CP}^{dir}
0.01
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8
κ
$a_{CP}^{dir}(\pi^+\pi^-)$
0.01
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8 9 10
κ
$a_{CP}^{dir}($
0.005
0
-0.005
-0.01
1 2 3 4 5 6 7 8 9 10

CONCLUSIONS FROM UNITARITY

- The prediction reaches the exp value at the 2σ level for $\kappa\sim5$, but even for $\kappa=8$ it is still 1σ below
- ΔA_{CP} is fully driven by the KK channel: more precise individual measurements crucial to validate the model
- How large can κ be?
  - translate fit results into RGI parameters
  - compare with K and B

FROM ISOSPIN AMPLITUDES TO RGI PARAMETERS

- The BR fit results can be translated into results for RGI parameters (aka topologies). Neglecting for simplicity $O(1/N_c^2)$ terms:

$$E_1(\pi) + E_2(\pi) = (1.72 \pm 0.04) \times 10^{-6}\, e^{i\delta}\ \mathrm{GeV}\,,$$

$$E_1(\pi) + A_2(\pi) - P_1^{\mathrm{GIM}}(\pi) = (2.10 \pm 0.02) \times 10^{-6}\, e^{i(\delta \pm (71\pm 3)^\circ)}\ \mathrm{GeV}\,,$$

$$E_2(\pi) - A_2(\pi) + P_1^{\mathrm{GIM}}(\pi) = (2.25 \pm 0.07) \times 10^{-6}\, e^{i(\delta \mp (62\pm 2)^\circ)}\ \mathrm{GeV}$$

- E_1 does not dominate the amplitudes $\Rightarrow$ we are away from the infinite mass limit

- All amplitudes of same size, w. large phases

THE MEANING OF κ

- The condition $|\mathcal{B}_0^\pi| < \kappa |\mathcal{A}_0^\pi|\,,$ means

$$|P_1(\pi)| \leq \kappa \left| \frac{2}{3} E_1(\pi) - \frac{1}{3} E_2(\pi) + A_2(\pi) - P_1^{\rm GIM}(\pi) \right|$$

- κ is the ratio of $|P_1|$ over all other topologies
- Notice that $P_1 \sim P_b - P_s$ while $P_1^{GIM} \sim P_d - P_s$

DYNAMICAL ARGUMENTS

- The amplitudes for K, D and B $\to \pi\pi$ are formally the same, with the obvious flavour and CKM replacements.
- In the Kaon system, one has

$$(P_u - P_c) \sim 3\,(P_t - P_c) \sim 25\,(E_1 + E_2)$$

- No enhancement expected for P_u (will be checked on the lattice soon), while P_c and P_t generate local operators with chirally enhanced matrix elements (SVZ)

DYNAMICAL ARGUMENTS II

- In charm decays, no chiral enhancement is present, so that one expects

$$|P_1| = |P_b - P_s| \leq |E_1|, |E_2|, |A_1|, |A_2|, |P_1^{GIM}|$$

i.e. $\kappa \leq 1$.

- In B decays one is much closer to the infinite mass limit so that $|E_1|$ and $|E_2|$ dominate, with all other contractions power suppressed.

OUTLOOK: WHERE IS Λ ?

- Scale separation requires $\Lambda \sim \langle H_0 \rangle$
- Direct searches say $\Lambda \gtrsim$ TeV
- Indirect searches (Flavour) say
  $\Lambda \gtrsim 10^5$ TeV * √(Flavour coupling*Loop factor)
- Three options left:
  - Λ is just around the corner, visible at 13 TeV
  - Λ is above the LHC reach but within the indirect searches reach
  - Someone up there is tuning the EW scale

MY PERSONAL VIEW

- Not willing to give up the idea of scale separation, and considering that:
  - m_H and direct searches require some level of tuning, and NP at the multi-TeV level
  - this remains fully consistent with effects in flavour observables at the 10% level with some flavour symmetry for NP
- my expectation is for NP showing up in the next LHC run directly and/or indirectly