

Status of CKM fits



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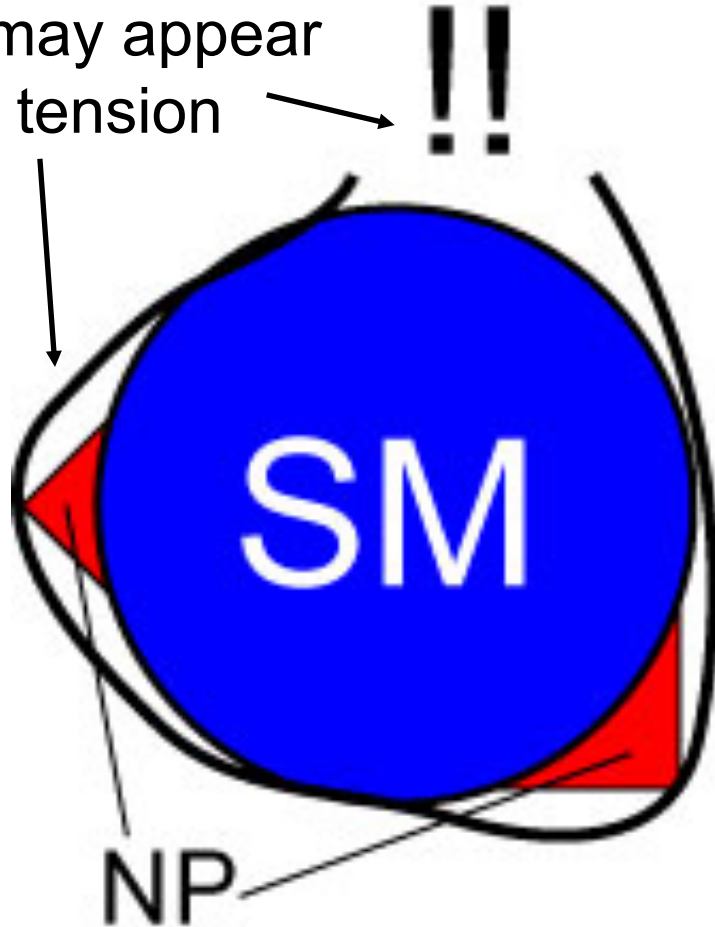
FPCP 2020

A non-fit-expert physicist's view

- Many still unresolved questions.
- Standard Model (SM) is not an ultimate theory.
- New Physics (NP) must be there.
- It is difficult to predict where the NP appears.
- Need to align many relevant measurements with the guiding principle based on the appropriate symmetries, conservations, i.e. unitarity, sum rule and so on → Global fit

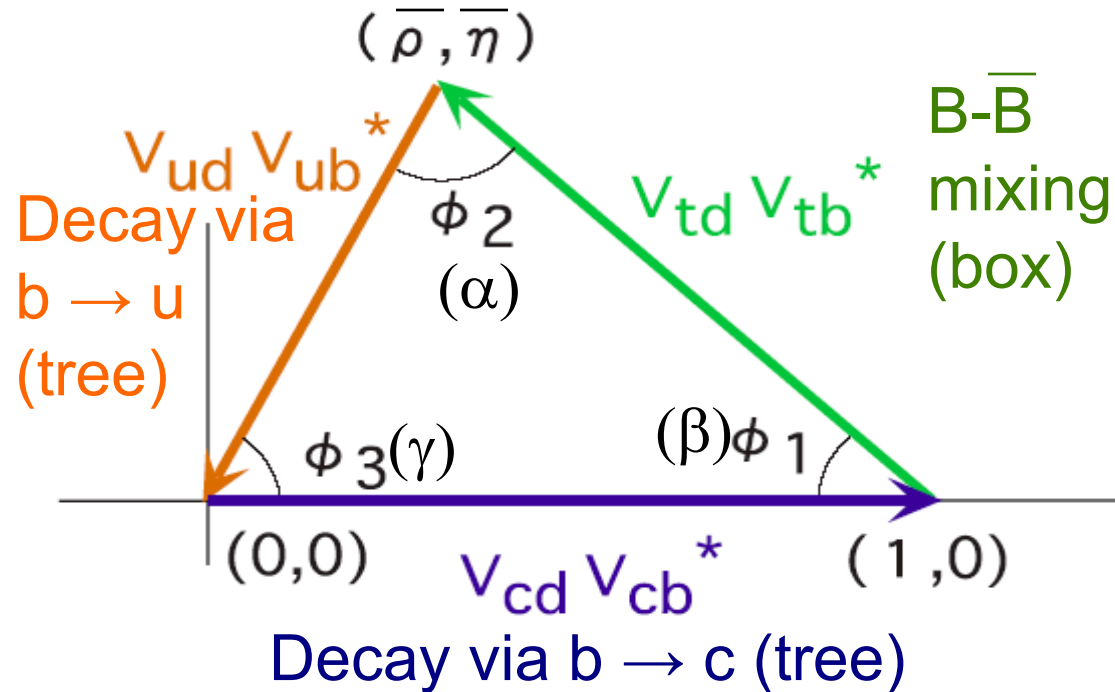
Speaking in my personal image

NP may appear
as a tension



- If the object (Physics) is perfectly a ball (SM), the bag having superficial area of $4\pi r^2$ (unitarity hypothesis) should fit to close to wrap it. Otherwise, something there.

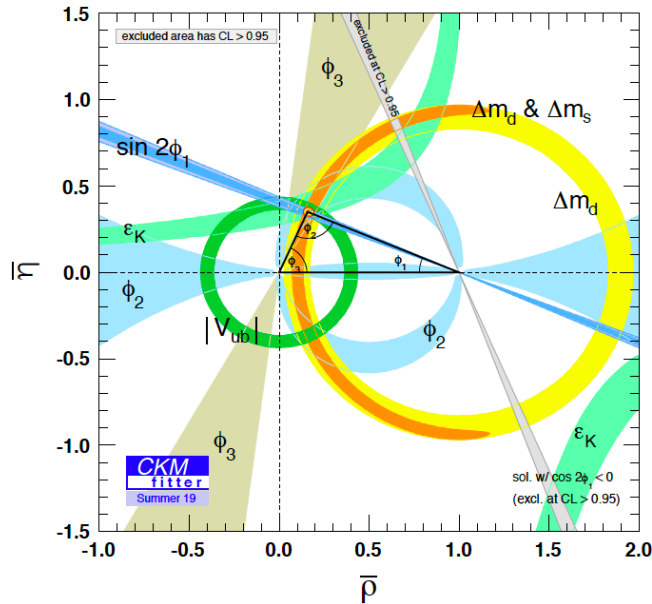
Unitarity triangle for B_d (and B^\pm)



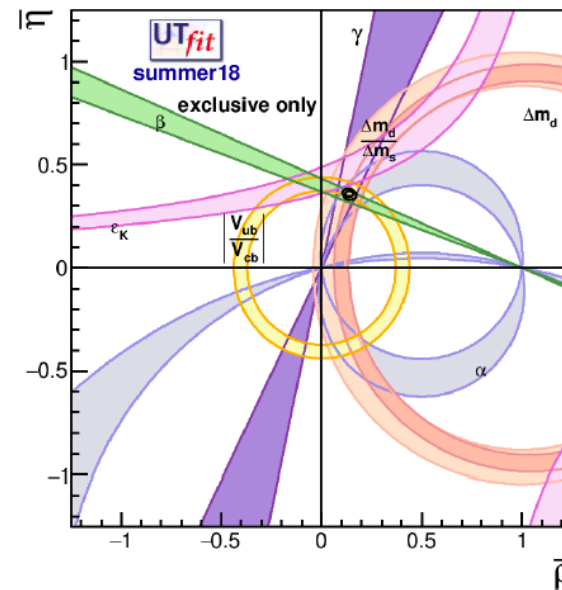
$$V_{\text{CKM}} = \begin{pmatrix} 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda + \frac{1}{2}A^2\lambda^5[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}\lambda^2 - \frac{1}{8}\lambda^4(1 + 4A^2) & A\lambda^2 \\ A\lambda^3[1 - (1 - \frac{1}{2}\lambda^2)(\rho + i\eta)] & -A\lambda^2 + \frac{1}{2}A\lambda^4[1 - 2(\rho + i\eta)] & 1 - \frac{1}{2}A^2\lambda^4 \end{pmatrix}$$

Two teams in the world

- CKMfitter 
 - Frequentist approach

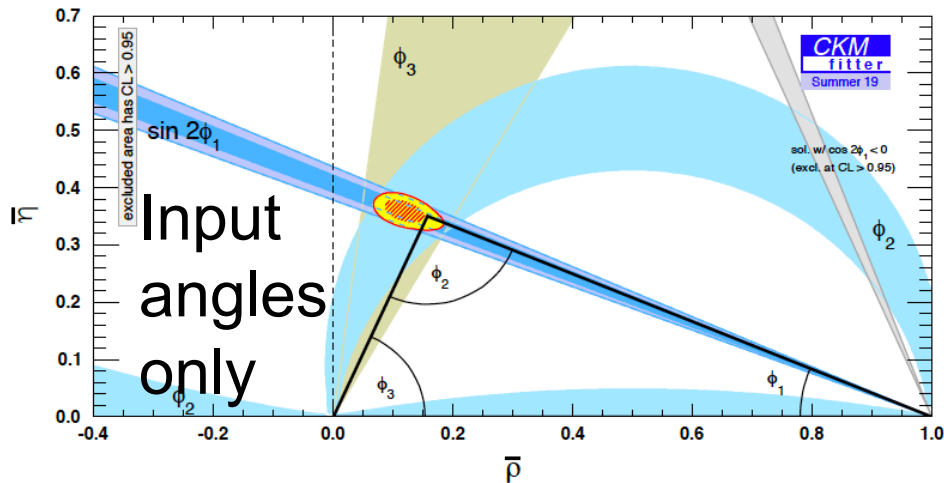
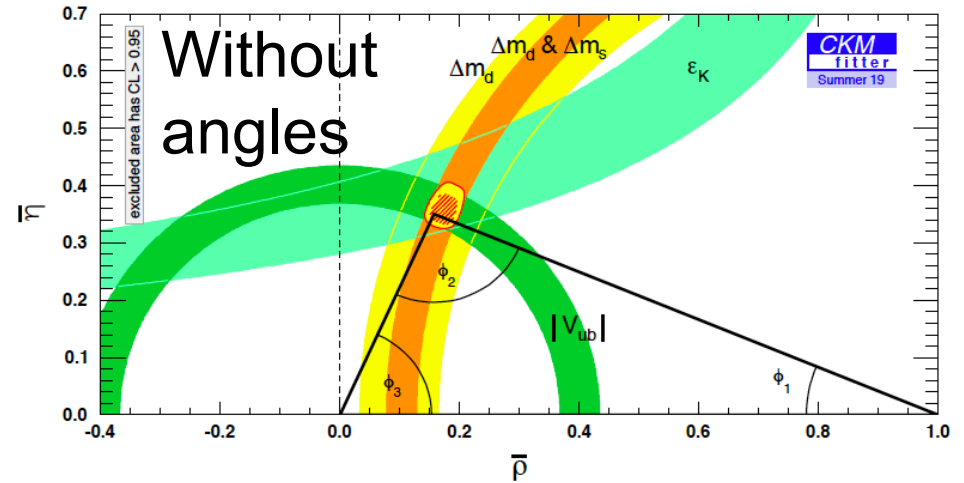
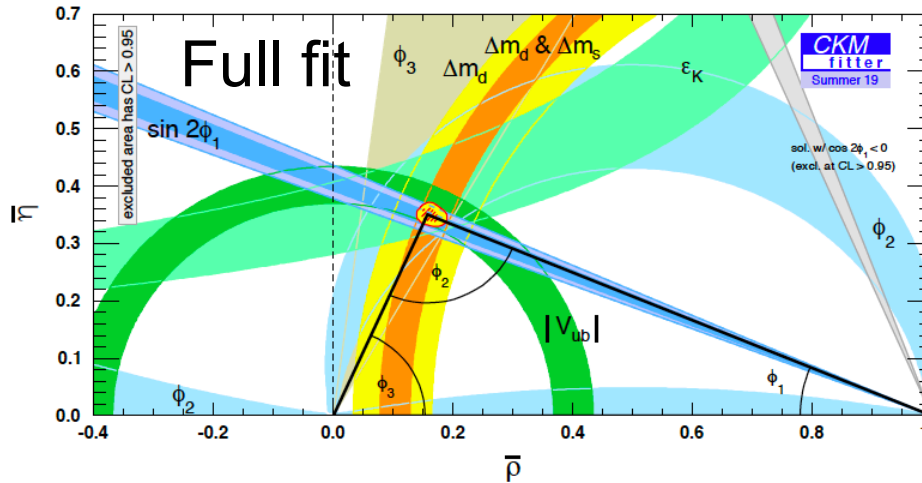


- UTfit 
 - Bayesian approach



Co-existence is a scientific merit in our research community.
 For some constraints, comparison with HFLAV also possible. 5

CKMfitter three cases

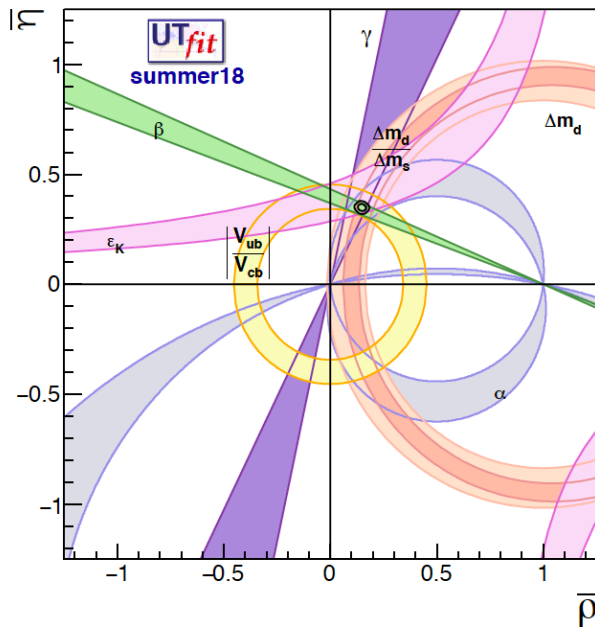


The apex $(\bar{\rho}, \bar{\eta})$ found to be compatible each other for these cases.
More pattern can be found:

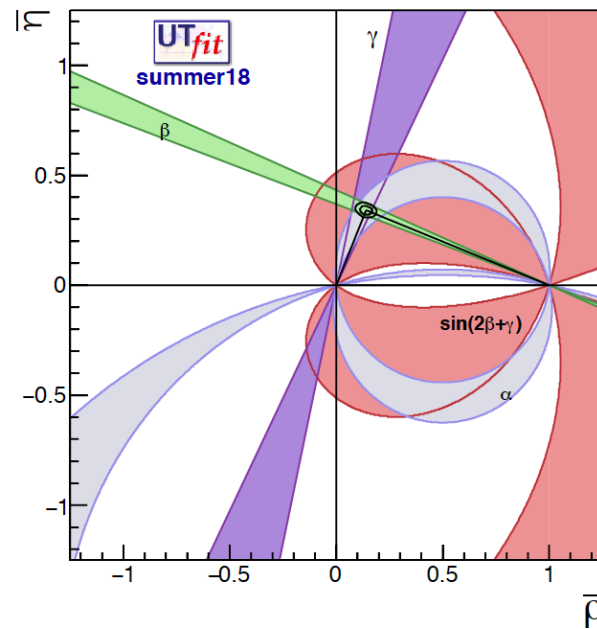
http://ckmfitter.in2p3.fr/www/results/plots_summer19/ckm_res_summer19.html

UTfit three cases

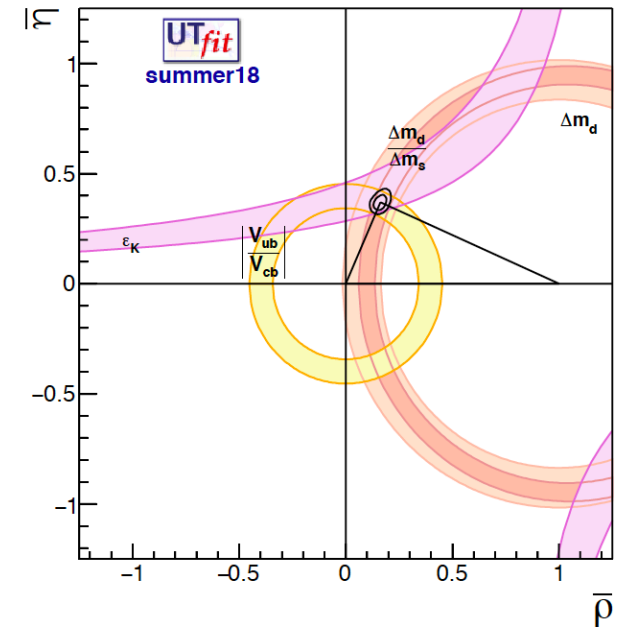
Full fit



Input angles only

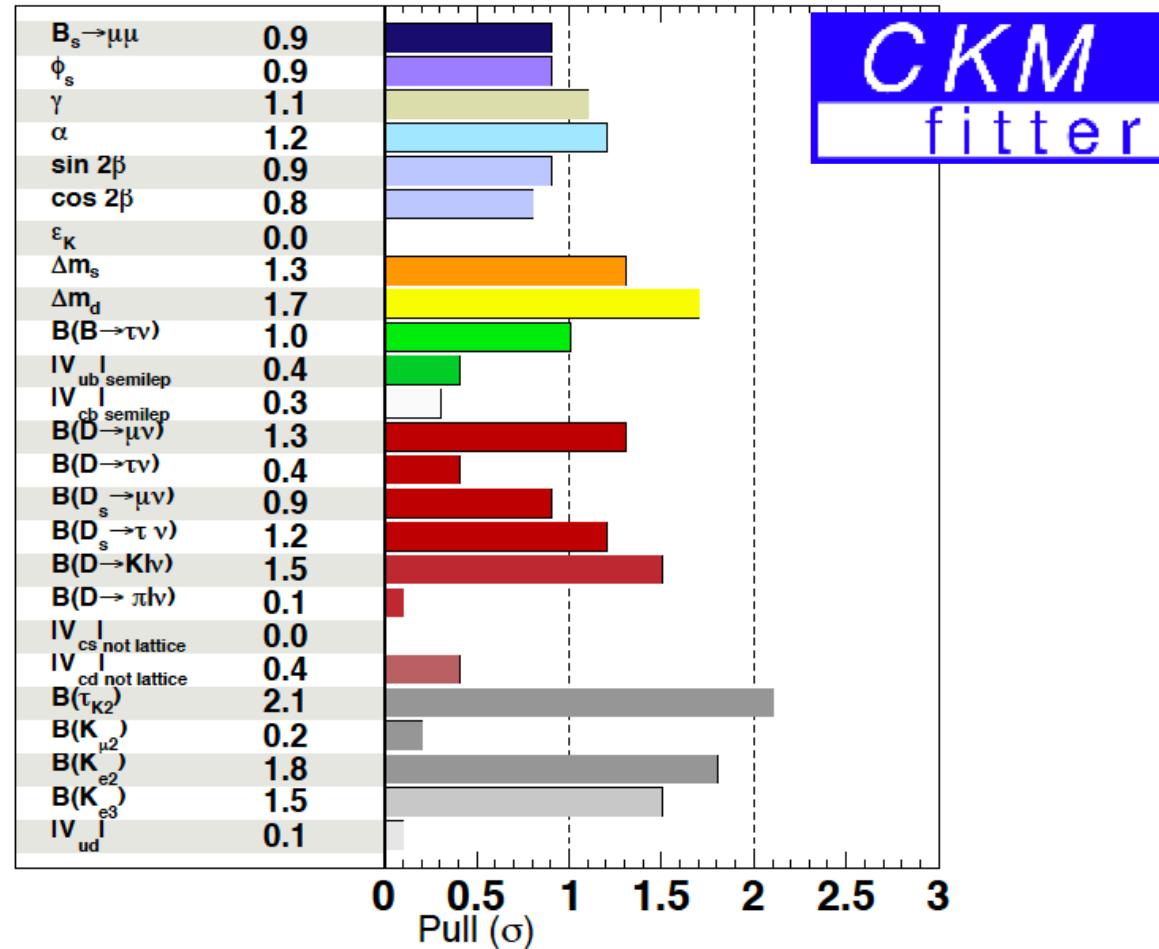


Input sides only



In all these cases, the found apex $(\bar{\rho}, \bar{\eta})$ compatible each other.
Taken from <http://www.utfit.org/UTfit/ResultsSummer2018SM>

Visiting each observable



Looking at pull values, currently no observable showing the tension above 3σ .

Visiting each observable



2018 SM fit results

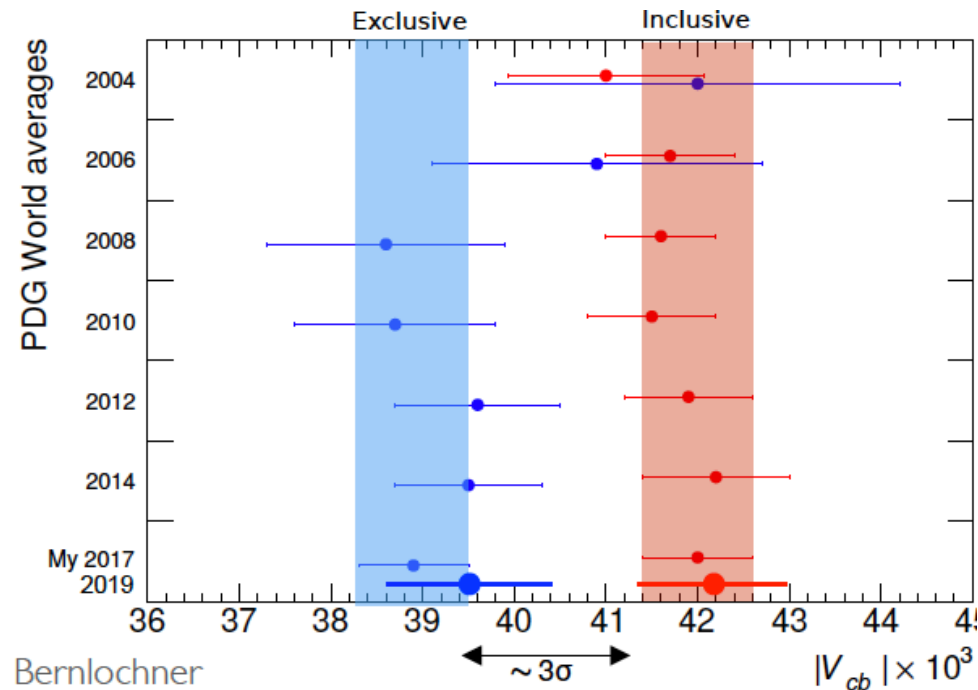
<http://www.utfit.org/UTfit/ResultsSummer2018SM>

Parameter	Input value	Full fit	SM Prediction	Pull
$\bar{\rho}$	—	—	0.148 ± 0.013	—
$\bar{\eta}$	—	—	0.348 ± 0.010	—
ρ	—	—	0.152 ± 0.014	—
η	—	—	0.357 ± 0.010	—
A	—	—	0.826 ± 0.012	—
λ	0.22574 ± 0.00089	—	0.22500 ± 0.00100	-0.6
$ V_{ub} $	0.00372 ± 0.00023	0.003675 ± 0.000095	0.00366 ± 0.00011	-0.3
$ V_{ub} (\text{excl})$	0.00365 ± 0.00013	—	—	0.0
$ V_{ub} (\text{incl})$	0.00449 ± 0.00020	—	—	-3.8
$ V_{cb} $	0.0405 ± 0.0011	0.04200 ± 0.00059	0.04240 ± 0.00070	+1.4
$ V_{cb} (\text{excl})$	0.03887 ± 0.00059	—	—	+3.9
$ V_{cb} (\text{incl})$	0.04218 ± 0.00077	—	—	+0.2

As of 2018, semileptonic decays exhibit pulls larger than 3σ , but it looks excl. vs incl. consistency question.

Paolo Gambino discussed more recent situation on Tuesday. 9

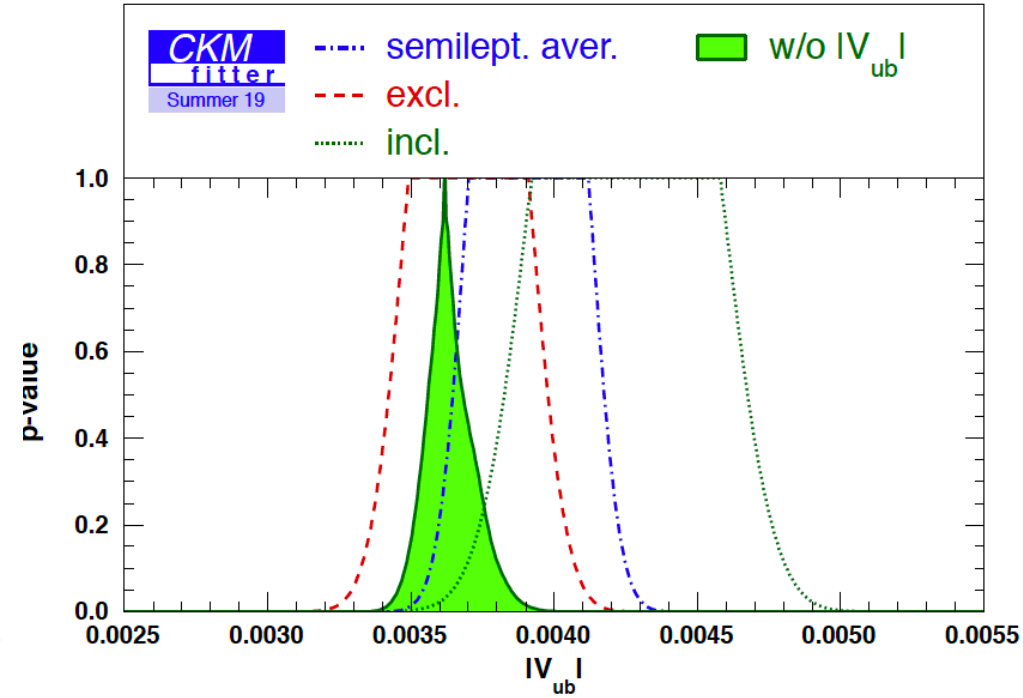
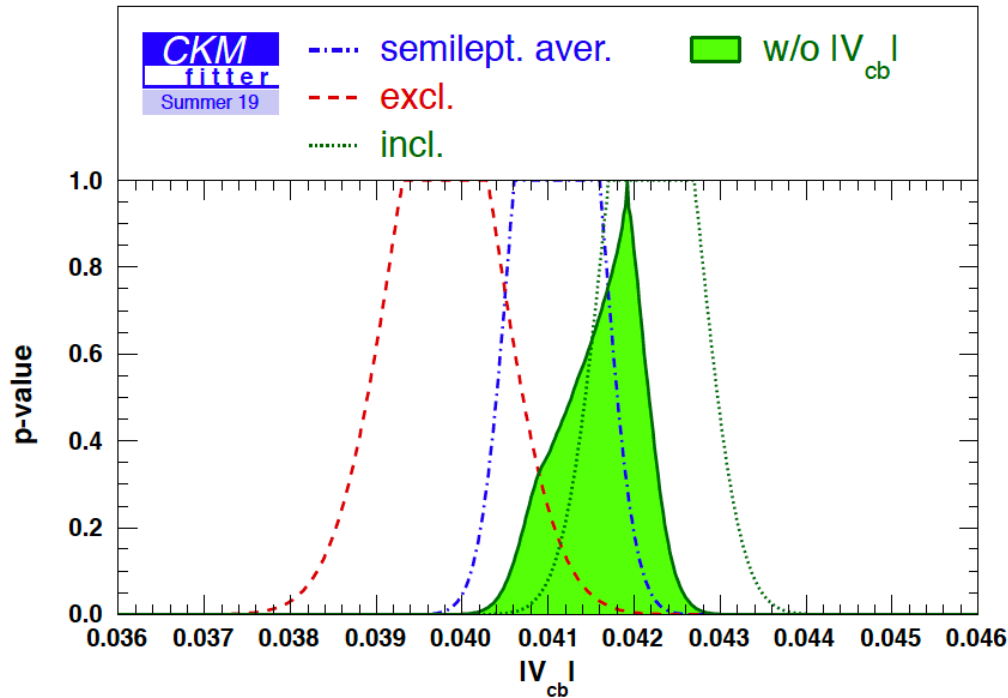
According to the already given talk



Taken from Paolo Gambino's talk on Tuesday

- **Inclusive/Exclusive tensions remain, but weaker, still puzzling.**
- Inclusive decays: ongoing effort to improve theory, promising progress on the lattice.
- Exclusive $b \rightarrow c$ decays have been revisited: uncertainties were underestimated. Several lattice groups are computing all necessary FFs at non-zero recoil.

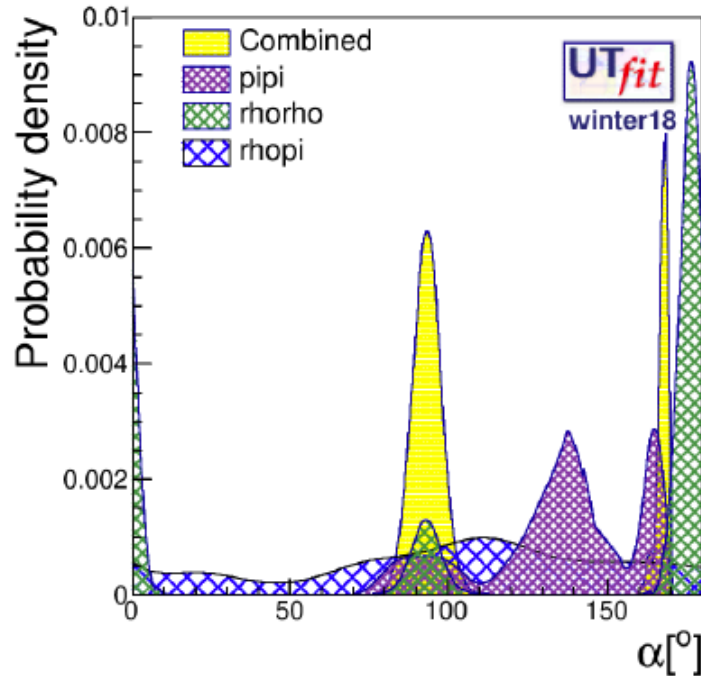
More on $|V_{cb}|$ and $|V_{ub}|$



Indirect determination (w/o $|V_{xb}|$) looks between excl. and incl. measurements, i.e. compatible with the semileptonic average.

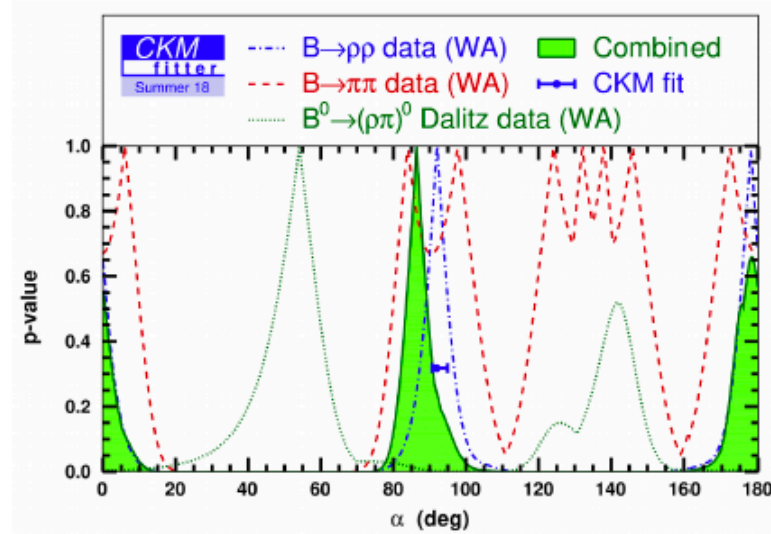
As for angles

$\phi_2 = \alpha$, given by Marcella Bona at CKM2018



combined SM: $(93.3 \pm 5.6)^\circ$

UTfit prediction: $(90.1 \pm 2.2)^\circ$



[dir.] $(86.4 +4.5)^\circ \cup (-1.8 +4.3)^\circ$

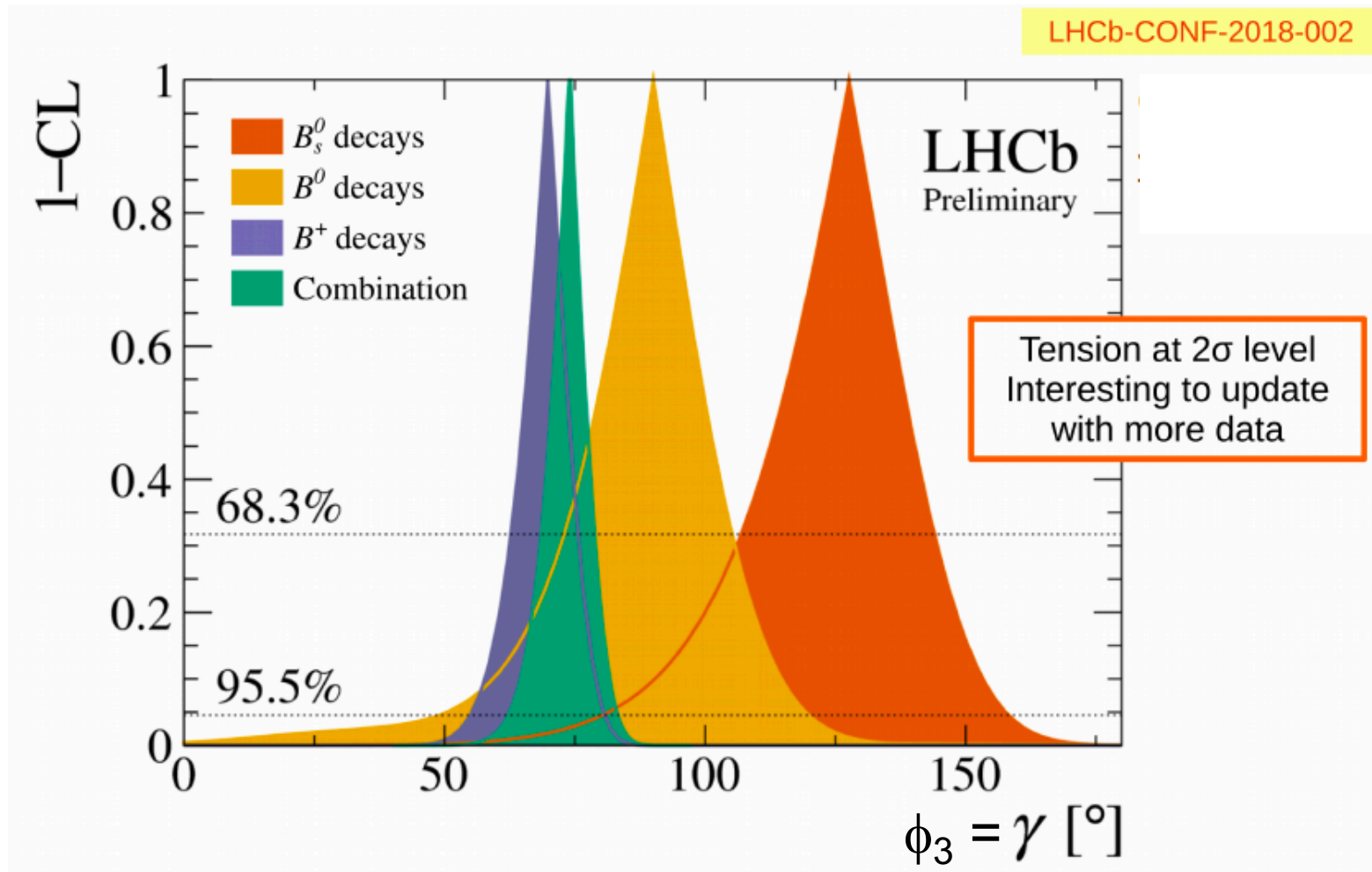
[indir.] $(91.9 +3.0)^\circ$

[comb.] $(91.6 +1.7)^\circ$

Compatibility between direct and indirect determinations looks OK. Similar situation for other angles except for $\phi_3 = \gamma$ B meson dep.¹²

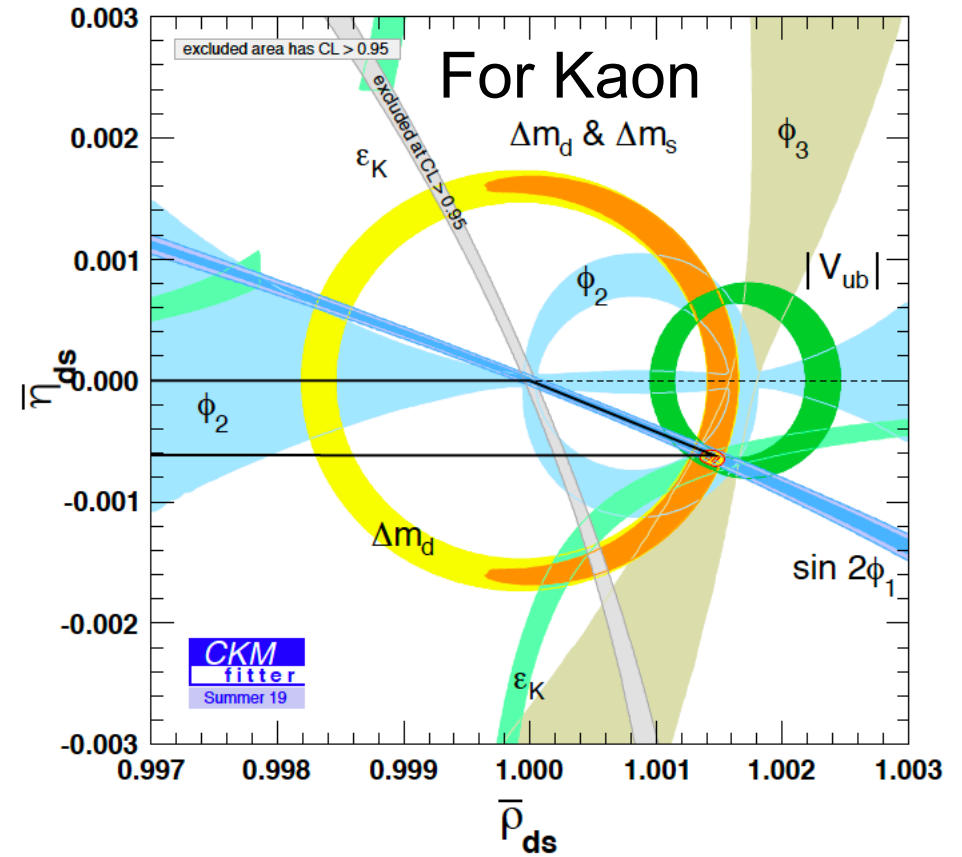
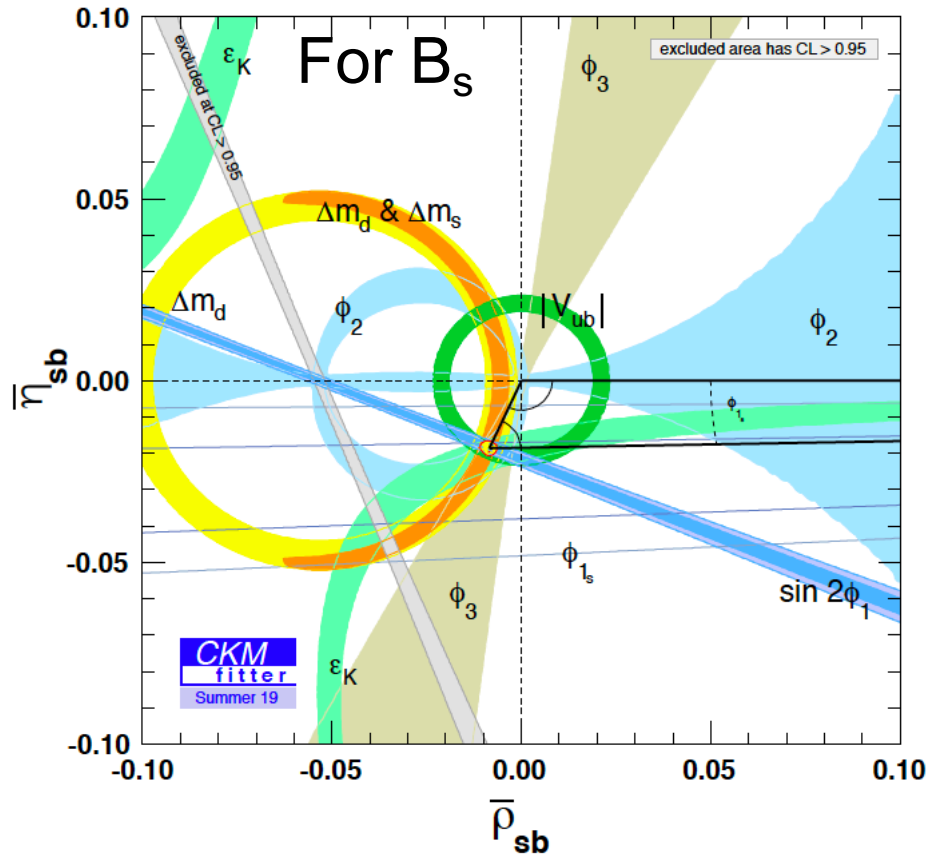
As for angles (cont.)

given by Marcella Bona at CKM2018



$\phi_3 - 2\phi_s$ converted to ϕ_3 using $-2\phi_s$ from $B_s \rightarrow J/\psi\phi$

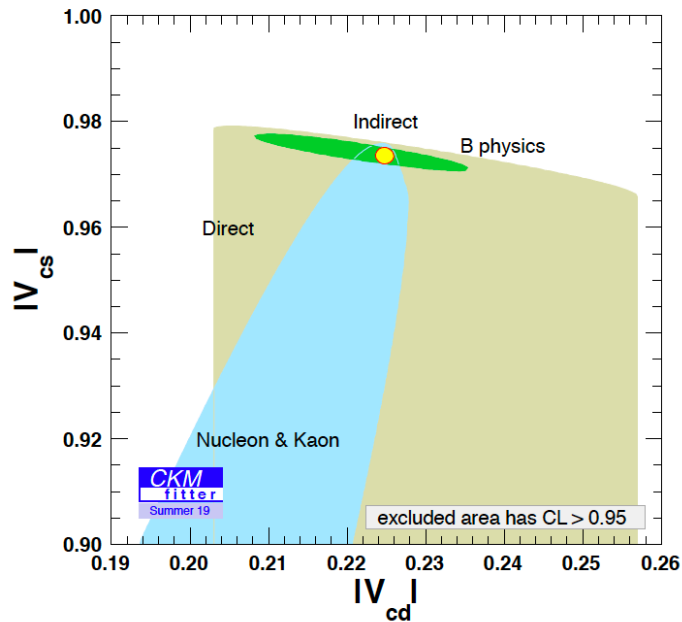
Visiting other triangles



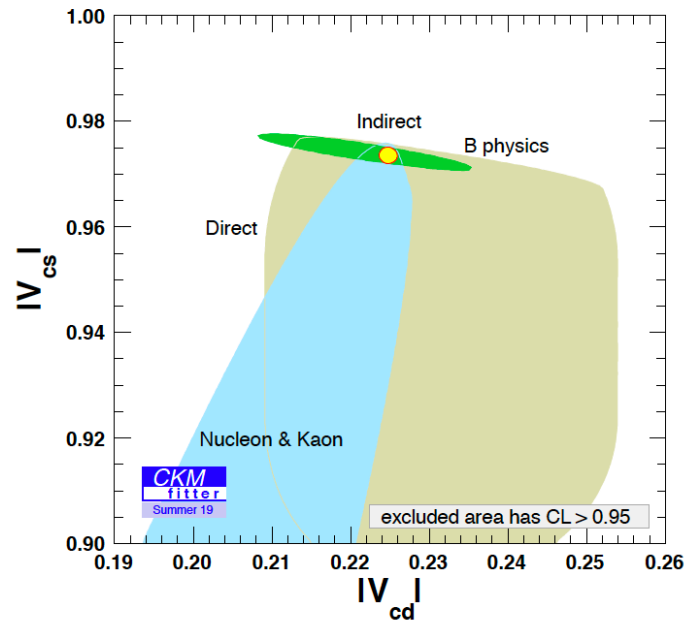
Both compatible triangle apex seen.

$|V_{cs}|$ and $|V_{cd}|$ from charm

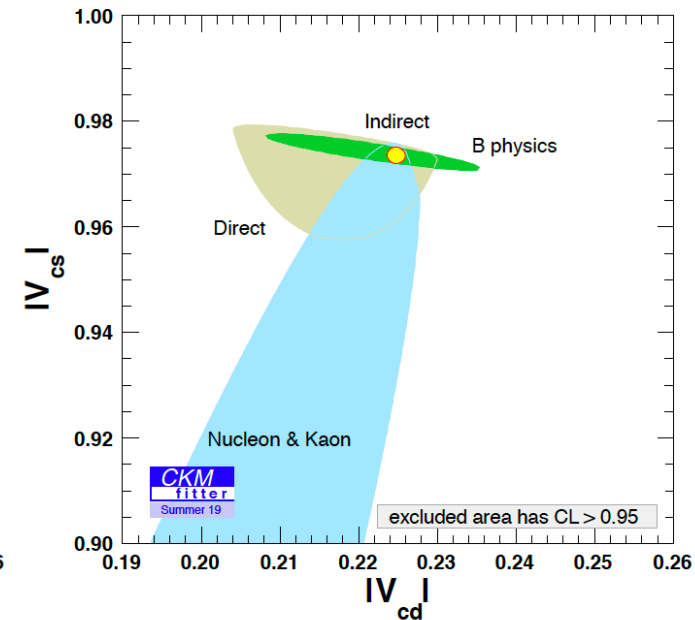
Indirect : B physics and Nucleon & Kaon measurements



Direct : neutrino scat.
and $W^+ \rightarrow c\bar{s}$ decay

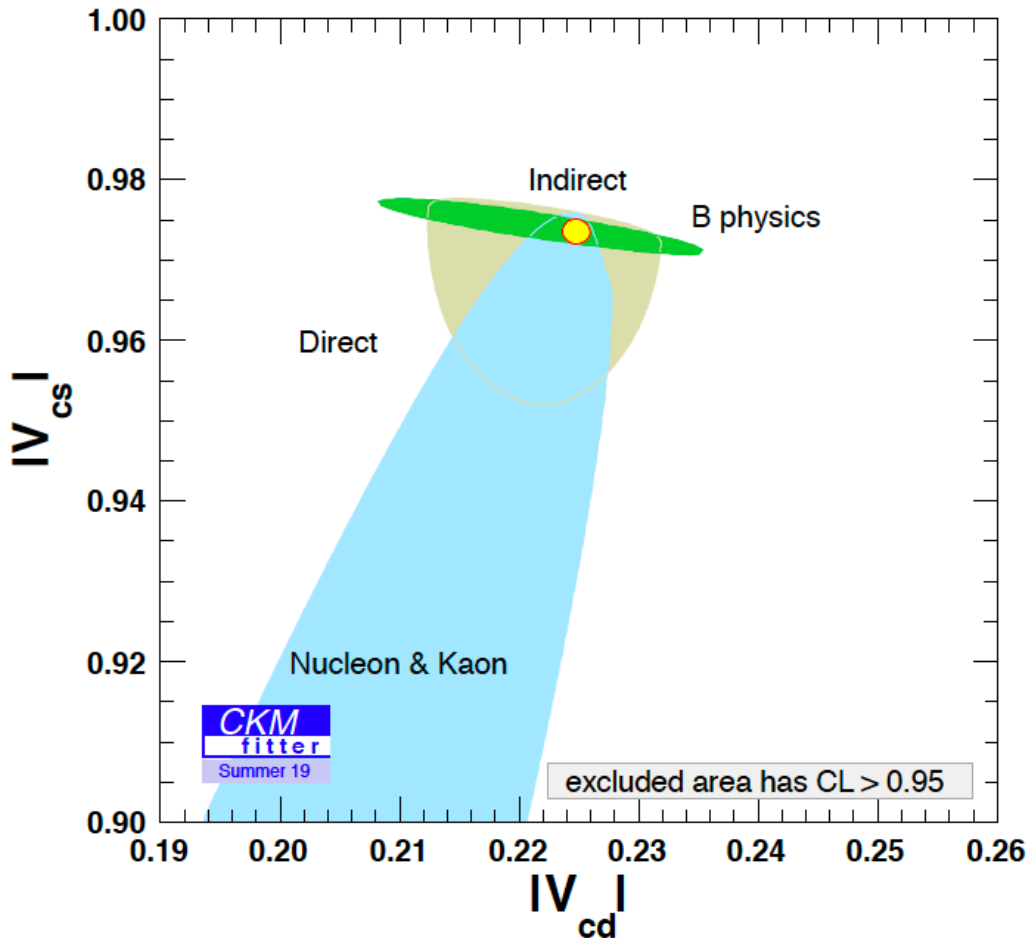


Direct : charm
semileptonic decay
with lattice.



Direct : charm
leptonic decay with
lattice.

Indirect and all direct combined



This time, compatibility between indirect and direct determinations turned out to be fine, but contour shrinking by the compilation of measurements has seen to be impressive.

In the case indirect determination is precisely done by unitarity, compilation of the direct measurements and comparison can be the way to notice an anomaly!

Final remarks

- It is uneasy to predict where the NP appears.
- We should exploit unitarity (possible symmetry as well).
- Two teams for global fit exist in our community
 - CKMfitter and UTfit, scientific merit in our research community.
- The compatible apex of unitarity triangle found.
 - Except for a few tensions between B physics measurements, i.e. semileptonic decay incl. and excl., $\phi_3 = \gamma$ dep. on B mesons.
- Comparison between indirect determination (by the fit) and compilation of direct measurements is shown to be an effective way to hunt an anomaly, keeping these attempts would be large benefit in our community.
- $\Delta F=2$ NP search discussed in the paper <https://arxiv.org/pdf/2006.04824.pdf>