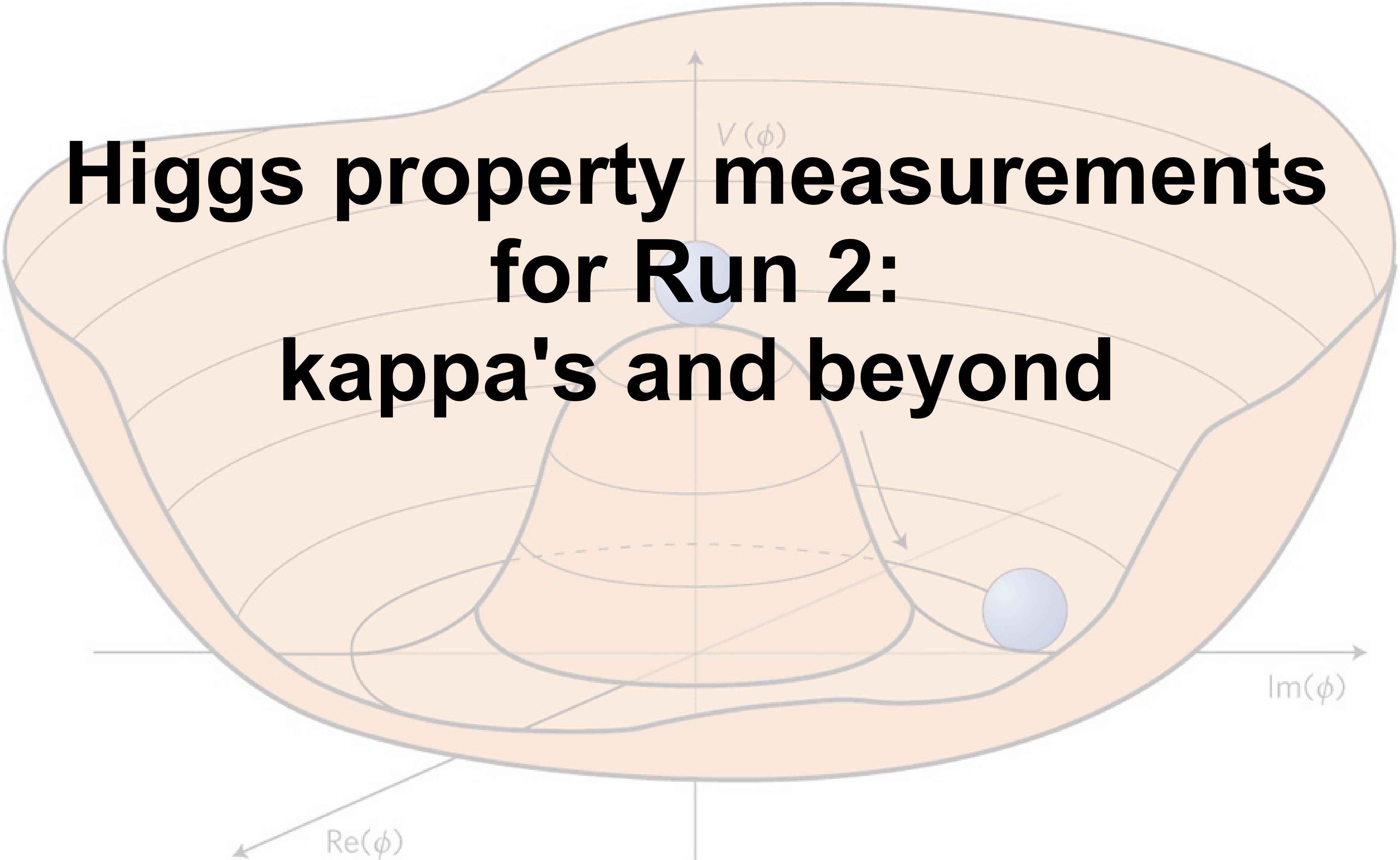
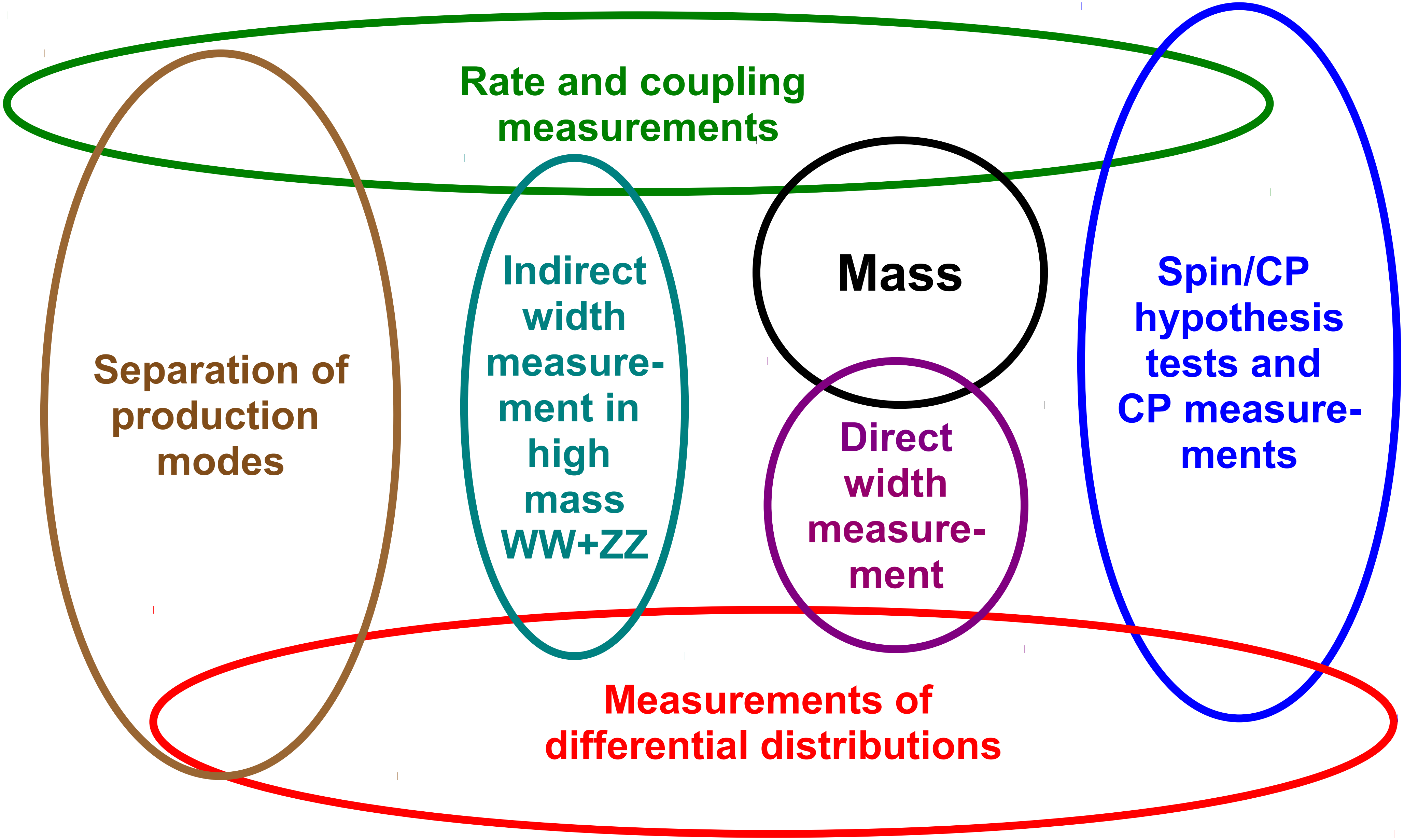
Higgs property measurements for Run 2: kappa's and beyond



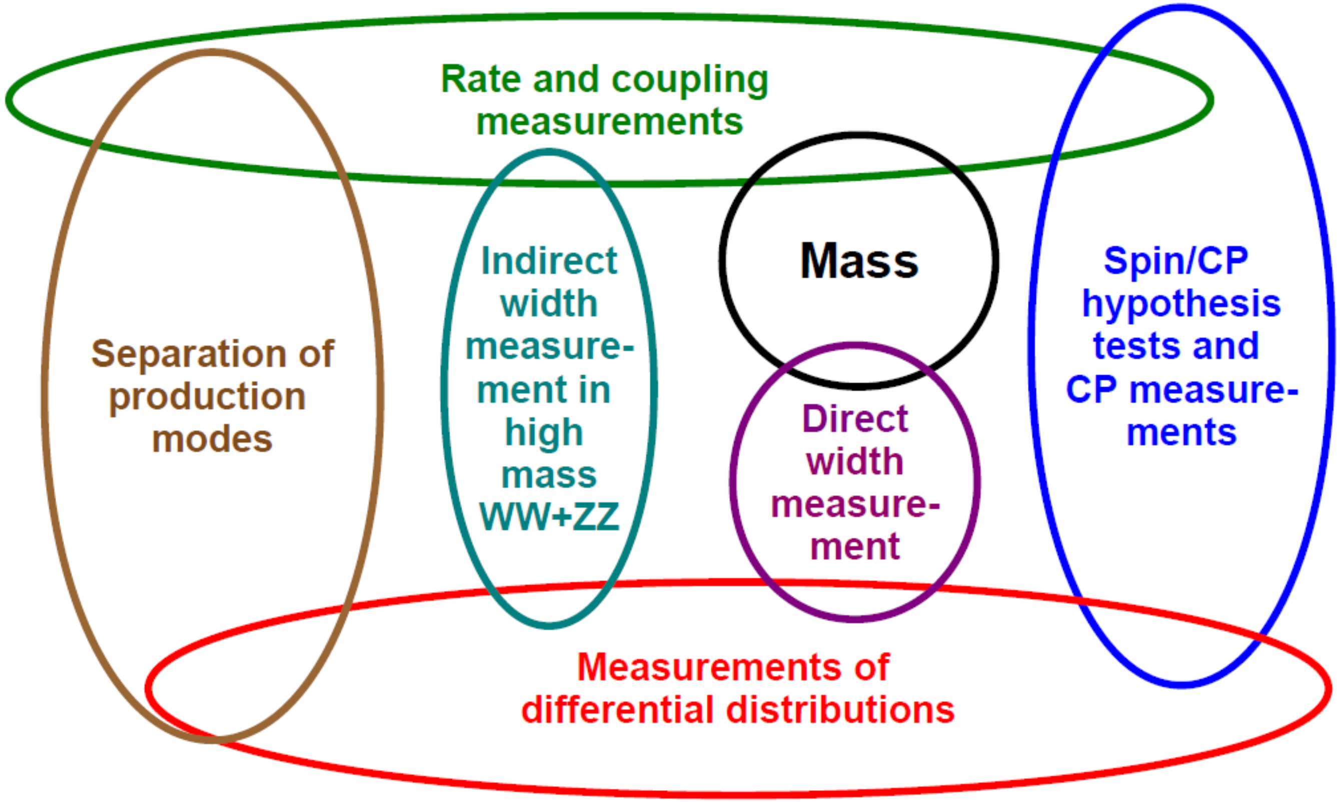
Michael Duehrssen

LHC Higgs XS WG workshop, 12th June 2014

Higgs measurements from the experimental point of view

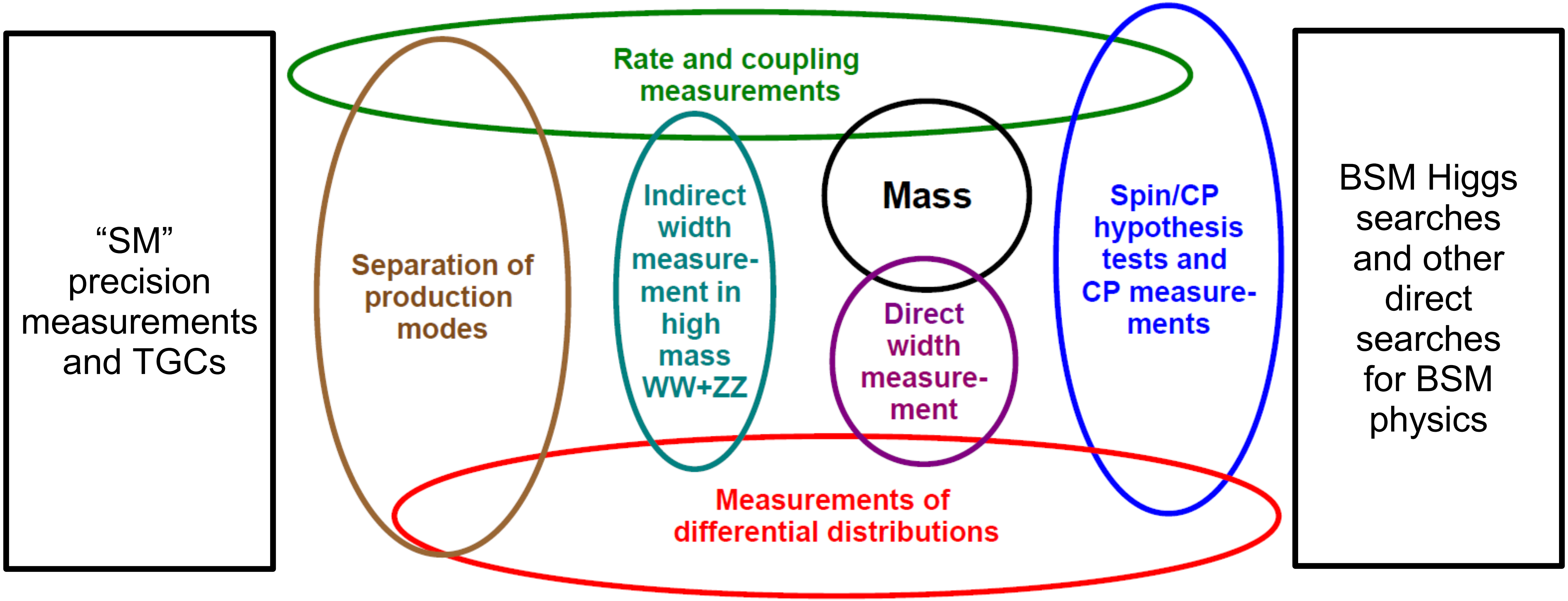


Higgs measurements from the experimental point of view



- All these measurements tell us something about the observed Higgs (but also need some assumptions)
- Many measurements use the same data
  → this makes it difficult to extract the big picture

Higgs measurements from the experimental point of view



- All these measurements tell us something about the observed Higgs
- Many measurements use the same data
  → this makes it difficult to extract the big picture
- The same applies to beyond Higgs searches/measurements

Focus of the light mass sub-group so far

Rate and coupling measurements

Spin/CP hypothesis tests and CP measure-ments

… and the big picture: EFT

(Also other topics were discussed, but by far not as extensive as couplings, Spin/CP and EFT)

Focus of the light mass sub-group so far

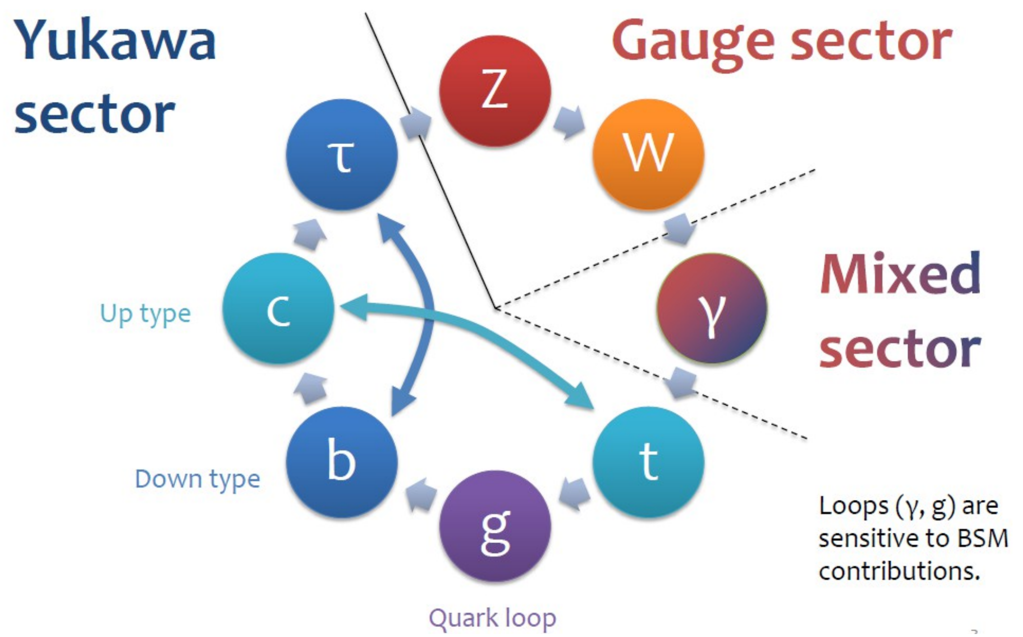
- Define a common framework between the theory community and ATLAS+CMS on how to do Higgs coupling fits in Run 1.
  - Includes proposals for benchmark parameterizations for coupling measurements

- Discussion of Higgs Spin and CP hypothesis tests and CP measurements
  - Proposed benchmark parametrizations
  - Anomalous couplings vs. EFT discussion

- Start of the work for an EFT approach to Higgs (coupling) measurements in Run 2
  - EFT approach goes beyond the Higgs sector: Allows a consistent treatment of a wide range of measurements!
  - Can go beyond leading order and include EWK corrections
  - Naturally includes CP odd operators
  - But: several basis choices possible (all equivalent)

Couplings: κ-framework

- **Define a framework in which to look for deviations from the SM in the Higgs coupling sector. Focus only on one Higgs!**
- **Make sure that the theory community understands exactly which definitions are used and how to interpret the results**
- **Experimental precisions on observed rates are at best O(20%) in Run 1. Try to keep it simple:**
  - Introduce one scale factor κ per SM particle with observable "Higgs coupling" at the LHC: κ_W, κ_Z, κ_t, κ_b, κ_τ, κ_μ, κ_γ, κ_g, κ_H



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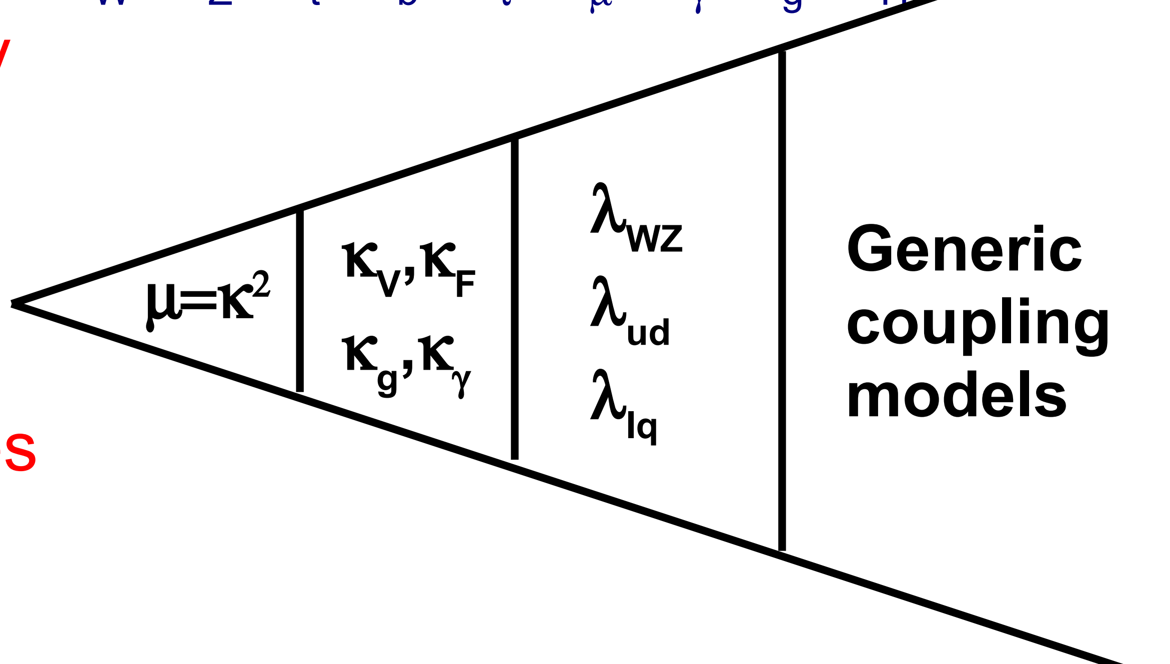
  - Very "experimental" friendly definition:
    - SM Higgs analysis can be used out-of-the-box after some κ-dependent rescaling of expected rates
    - Natural evolution from simple to complicated fits



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  - Use best available SM calculation for cross-section and BR → we want to look for deviations from the SM!
  - Example:

$$(\sigma \cdot \mathrm{BR})(\mathrm{gg} \to \mathrm{H} \to \gamma\gamma) = \sigma_{\mathrm{SM}}(\mathrm{gg} \to \mathrm{H}) \cdot \mathrm{BR}_{\mathrm{SM}}(\mathrm{H} \to \gamma\gamma) \cdot \frac{\kappa_g^2 \cdot \kappa_\gamma^2}{\kappa_H^2}$$

Include all higher order QCD and EW corrections! These corrections are also scaled with κ !

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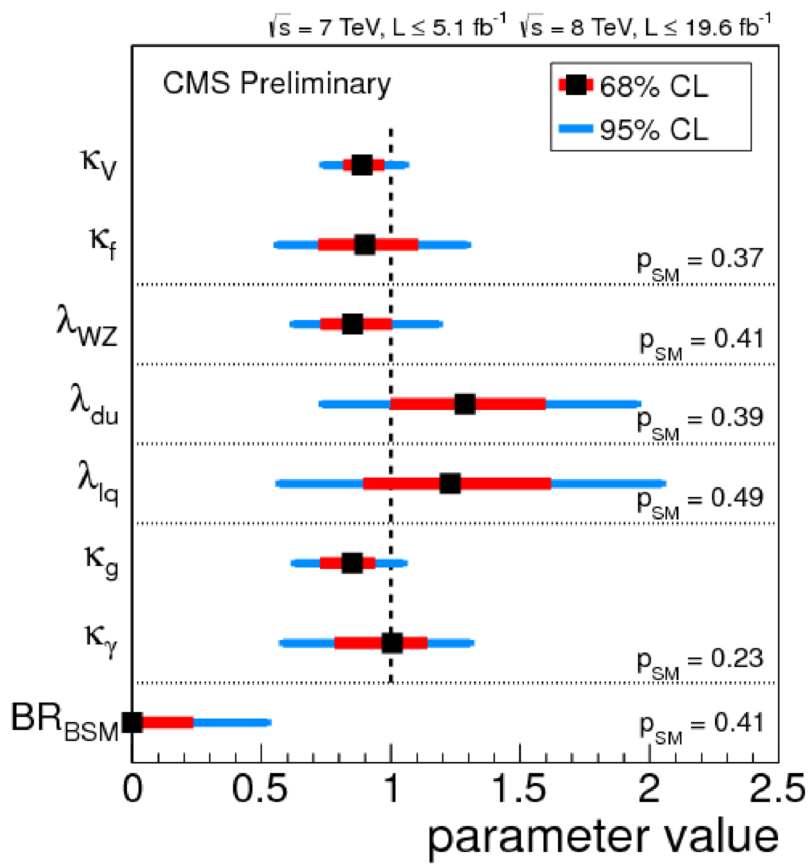
  - Needs assumptions:
    - Only one low mass state (m_H~125 GeV): no other "signals"
    - Zero/narrow width approximation
    - Only modification of scalar coupling strength: no change to production and decay kinematics of Higgs processes
- **All simplifications/assumptions should be valid as long as all results agree with the SM expectations**

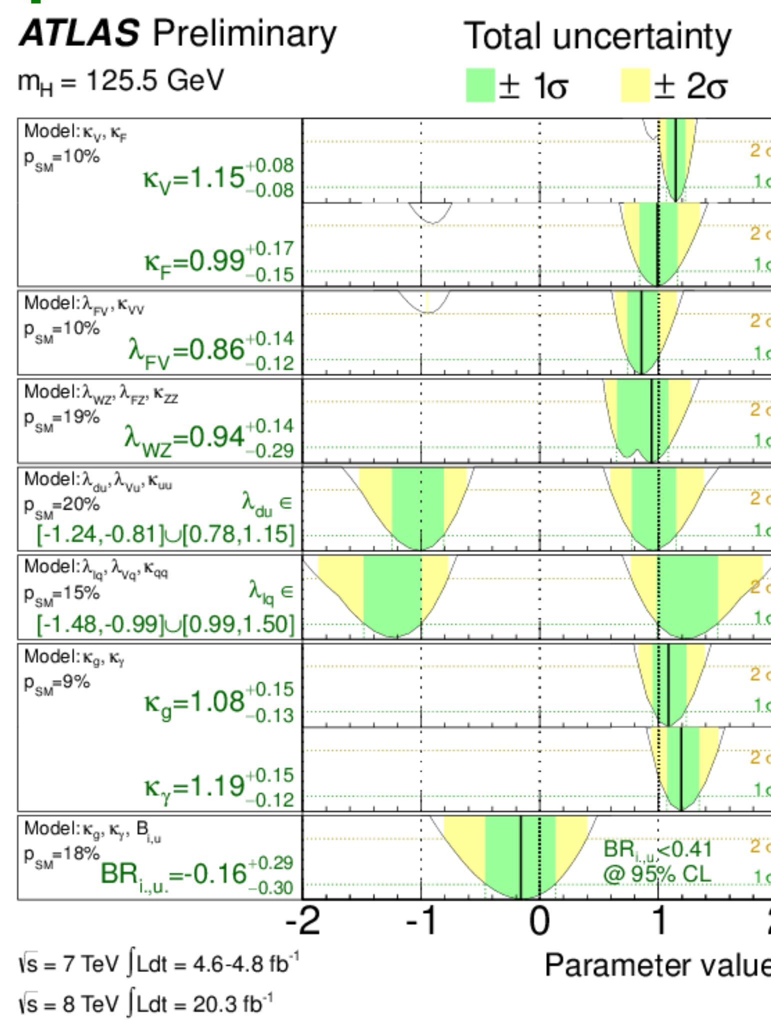
  → the κ-framework does not give a true measurement!

κ-framework: known limitations

- **NLO corrections are not treated properly. The known SM EWK corrections are just scaled with κ**
  - **EWK corrections are expected at the ~10% level**
    → uncritical as long as experimental precision is >>10%
    → but we are getting close...

- **Best cases 15-20% uncertainty on κ^2 with Run 1**





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- **And expected to get to <10% with Run 2 and beyond**

S-LHC projections		$\kappa_g \kappa_Z / \kappa_H$	κ_W / κ_Z	κ_γ / κ_Z	κ_g / κ_Z	κ_b / κ_Z	κ_τ / κ_Z	κ_μ / κ_Z	$\kappa_{Z\gamma} \kappa_Z$	κ_t / κ_g
$300 fb^{-1}$	ATLAS	[3,6]	[4,5]	[5,11]	[11,12]	N/a	[11,13]	[20,22]	[78,78]	[17,18]
	CMS	[4,6]	[4,7]	[5,8]	[6,9]	[8,11]	[6,9]	[22,23]	[40,42]	[13,14]
$3000 fb^{-1}$	ATLAS	[2,5]	[2,3]	[2,7]	[5,6]	N/a	[7,10]	[6,9]	[29,30]	[6,7]
	CMS	[2,5]	[2,3]	[2,5]	[3,5]	[3,5]	[2,4]	[7,8]	[12,12]	[6,8]

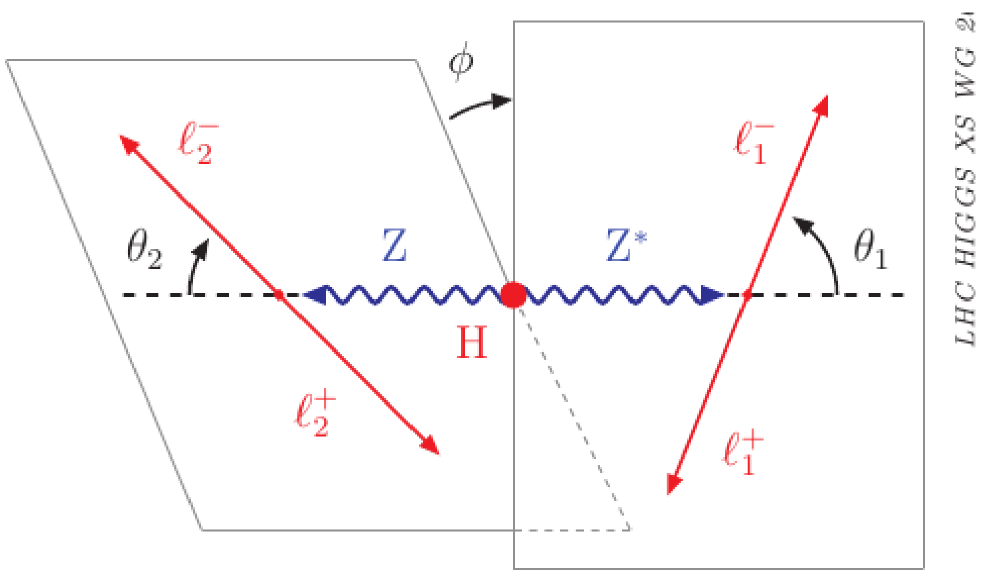
κ-framework: known limitations

- NLO corrections are not treated properly. The known SM EWK corrections are just scaled with κ

- Changes to the W- and Z-couplings would likely also cause changes to event kinematics
  - Visible in H→WW and H→ZZ decays
  - Visible in VBF and VH production

  → κ-framework is good for inclusive quantities

  → but a coupling strength is not sufficient for distributions



κ-framework: known limitations

- **NLO corrections are not treated properly. The known SM EWK corrections are just scaled with κ**
- **Changes to the W- and Z-couplings would likely also cause changes to event kinematics**
- **If several couplings contribute to a Higgs process, some kinematic dependence is expected. Examples:**
  - **gg→H production:**
    - **At low p_T the b-t-interference contributes with ~ -7%**
    - **At high p_T ~100% t-loop in the SM. But would expect largest influence from heavy BSM particles here**
  - **tH production:**
    - **size of t-, W- and interference terms depends on event selection**

Spin/CP

- So far the angular correlations in $H \rightarrow ZZ$, $H \rightarrow WW$ and $H \rightarrow \gamma\gamma$ are used to test alternative Spin/CP hypothesis

- Benchmarks/examples for

scenario	X production	$X \rightarrow VV$ decay	comments
0^+_m	$gg \rightarrow X$	$g_1^{(0)} \neq 0$ in Eq. (200)	SM Higgs boson scalar
0^+_h	$gg \rightarrow X$	$g_2^{(0)} \neq 0$ in Eq. (200)	scalar with higher-dim. operators
0^-	$gg \rightarrow X$	$g_4^{(0)} \neq 0$ in Eq. (200)	pseudo-scalar
1^+	$\overline{q}q \rightarrow X$	$g_2^{(1)} \neq 0$ in Eq. (202)	exotic pseudo-vector
1^-	$\overline{q}q \rightarrow X$	$g_1^{(1)} \neq 0$ in Eq. (202)	exotic vector
2^+_m	$g_1^{(2)} \neq 0$ in Eq. (203)	$g_1^{(2)} = g_5^{(2)} \neq 0$ in Eq. (203)	graviton-like tensor with min. couplings
2^+_h	$g_4^{(2)} \neq 0$ in Eq. (203)	$g_4^{(2)} \neq 0$ in Eq. (203)	tensor with higher-dimension operators
2^-_h	$g_8^{(2)} \neq 0$ in Eq. (203)	$g_8^{(2)} \neq 0$ in Eq. (203)	"pseudo-tensor"

documented in YR3 but mixings possible.
For Spin 0, CP measurements are a natural continuation of the 0^+ and 0^- hypothesis tests

- Can be viewed in the amplitude (JHU) or EFT picture (MG5)

Spin/CP

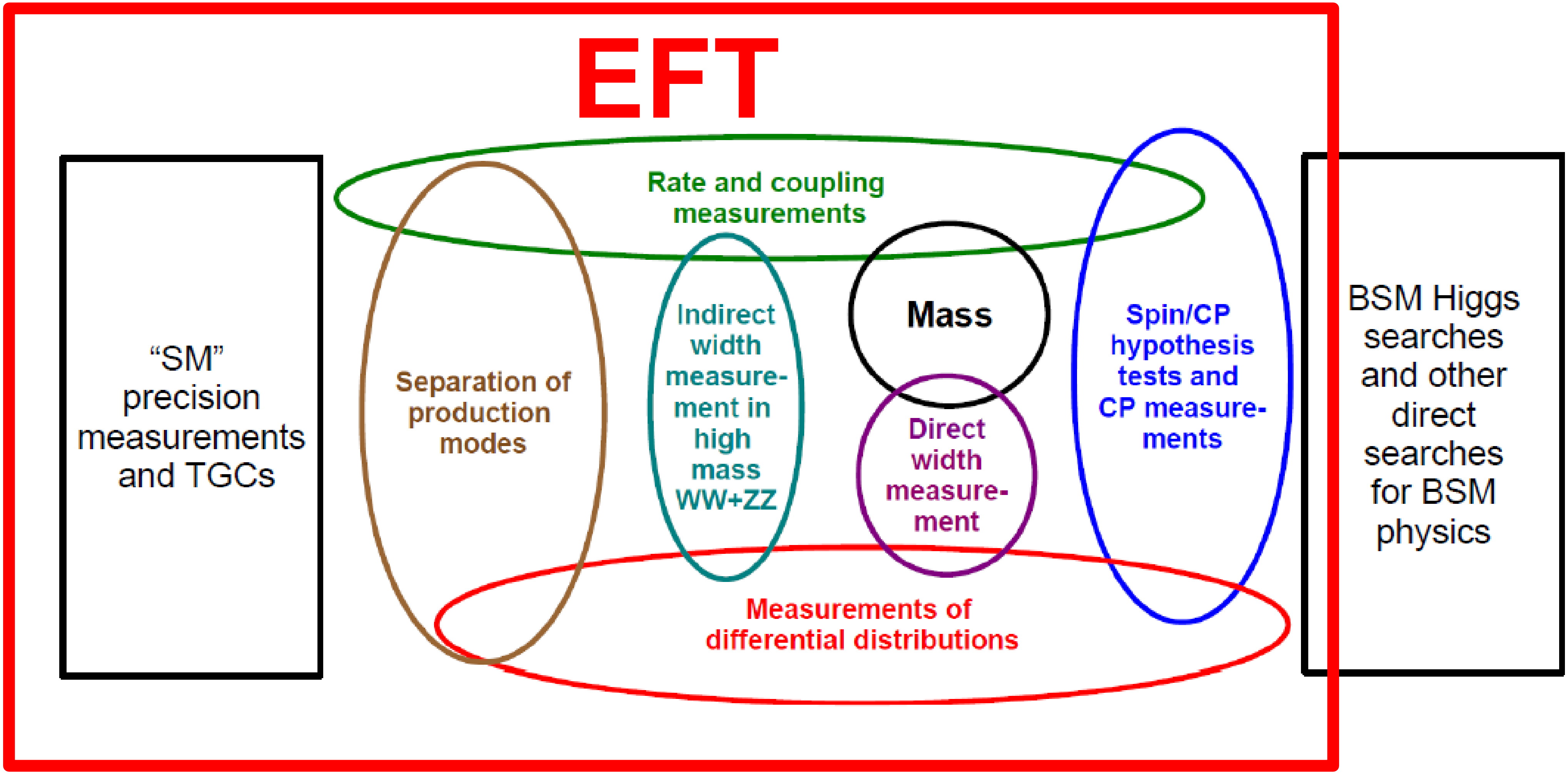
- So far the angular correlations in $H \rightarrow ZZ$, $H \rightarrow WW$ and $H \rightarrow \gamma\gamma$ are used to test alternative Spin/CP hypothesis

- The measurements do NOT use the observed rates, just decay correlations!
  - Results in some inconsistencies, e.g. tested Spin 2 models predict rates which are incompatible with the observation

- Ongoing discussion for Spin 2 models:
  - Additional (more consistent?) benchmarks
  - General measurements of helicity amplitudes

- For Spin 0 measurements:
  - Goal is to merge with the coupling measurements using a consistent EFT approach with CP odd operators
  - $H \rightarrow \tau\tau$ will be crucial, as it allows to probe CP in fermion couplings

EFT (Higgs) measurements



- **Effective Lagrangian approach, obtained from integrating out heavy particles. Assumption: new physics appears at scale $\Lambda >> m_H \sim 125$ GeV**

EFT (Higgs) measurements

- Systematic approach: expansion in inverse powers of Λ:

$$\Delta\mathcal{L} = \sum_i \frac{a_i}{\Lambda^2}\mathcal{O}_i^{d=6} + \sum_j \frac{a_j}{\Lambda^4}\mathcal{O}_j^{d=8} + \ldots$$

- Minimal complete basis of dimension-6 operators has 59 independent operators (for one fermion family)
  - Allows to include (and calculate) higher order corrections
  - Allows consistent treatment of all measurements
    - SM precision observables
    - Higgs rate measurements
    - Higgs differential distributions and angular correlations (the coupling tensor structure is naturally included)
    - Anomalous non-Higgs coupling measurements
  - Systematic and coherent approach to organize the expansion in ratio of the momentum over the new physics scale Λ

- Basis choice is not unique → need "rotation" functions

EFT challenges

- **What about light BSM particles ?**
  Complementary approach between
  - **EFT measurements and**
  - **analysis in specific BSM benchmark models (e.g. MSSM) with light degrees of freedom**

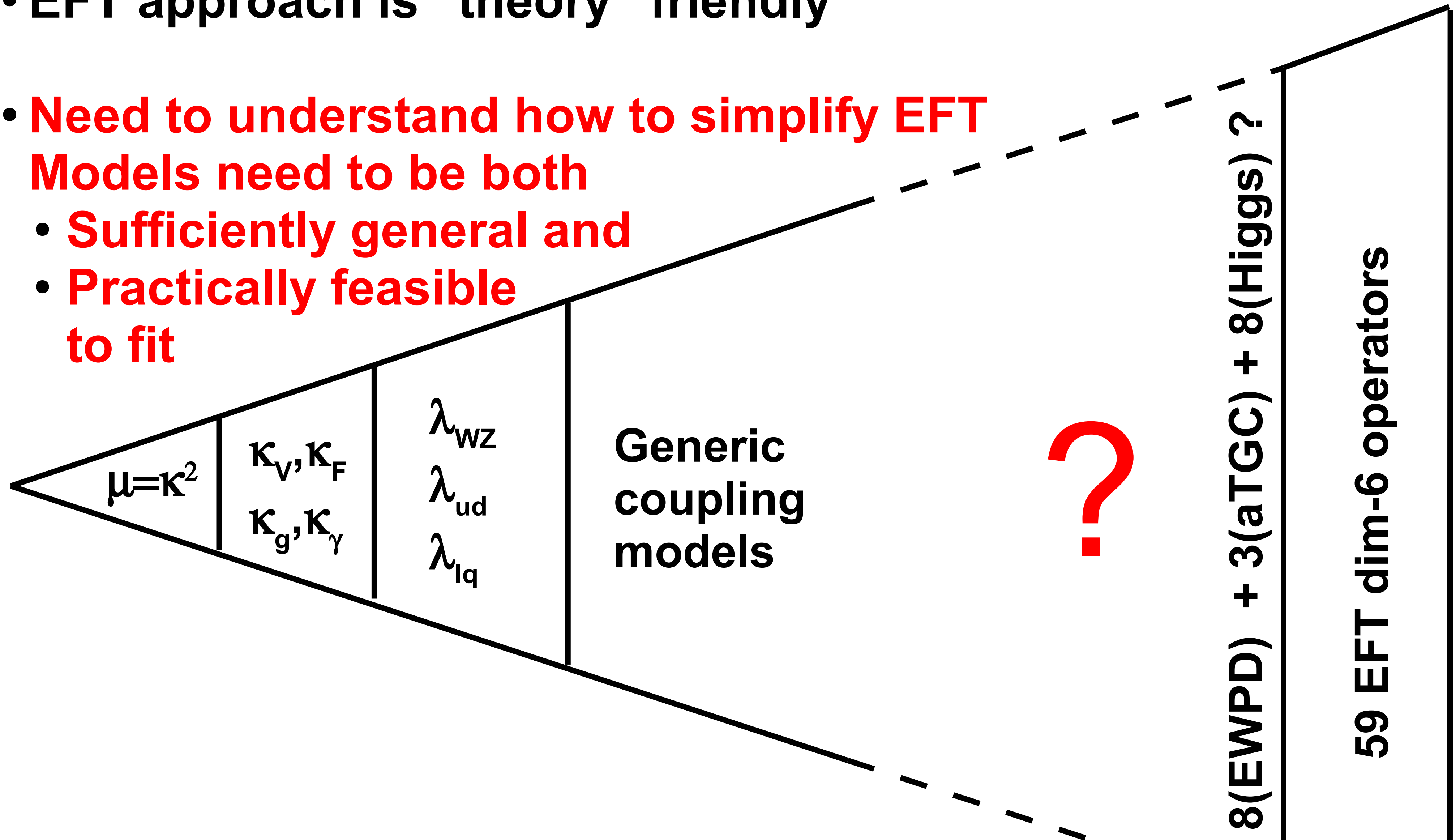
EFT challenges

- **What about light BSM particles ?**

- **EFT approach is "theory" friendly**
  - **Everything emerges from one Lagrangian**
  - **Experimental analysis will have to grow in order to take the full variability of the EFT approach into account:**
    - **simultaneous rate and differential measurements in several observables**
    - **A simple κ-like scaling of the SM analysis is not possible, as signal (and background) acceptances can change with modified kinematic distributions**

EFT challenges

- **What about light BSM particles ?**
- **EFT approach is “theory” friendly**
- **Need to understand how to simplify EFT Models need to be both**
  - **Sufficiently general and**
  - **Practically feasible to fit**



EFT challenges

- What about light BSM particles ?

- EFT approach is “theory” friendly

- Need to understand how to simplify EFT

- Full EFT aware theory tool chain will be needed
  - MC generators for signal AND background
    (e.g. MG5_aMC@NLO)
  - (N)NLO calculations for signal and background
    (e.g. HAWK, HIGLU)
  - BRs
    (e.g. eHDECAY)
  - “Rotations” between different EFT basis choices
  - Predictions should recover the best known SM predictions (including all higher order QCD and EWK corrections) in the SM limit

Summary

- κ-framework did good job for Run 1 for the searches for deviations in Higgs couplings
  - do we want to (can we?) do something similar for differential distributions?
- Spin/CP benchmarks allowed to characterize the observed particle to be very likely Spin 0
- For Run 2, the EFT approach offers the possibility of
  - Precision BSM measurements
  - Consistent treatment of observables, also outside the Higgs sector, within one BSM theory framework
  - Especially combination with electroweak precision data and aTGC measurements
    → need coherent approach with LHC EW WG
  - And don't forget: theory systematics are crucial!

Summary

Many thanks to the theory conveners and theory colleagues of the LM group! Their inputs made the ATLAS+CMS Higgs property measurements possible!