



# 2015 expectations

1





# 2015 expectations and reality

2

[ Courtesy of Mauro Donegà ]





# MIDDLE WAY



KAPPAS  
FIDUCIAL CROSS-SECTIONS

EFFECTIVE FIELD THEORY  
WILSON COEFFICIENTS

Higgs Days at Santander 2015  
Theory meets Experiment  
14.-18. September

André David (CERN)



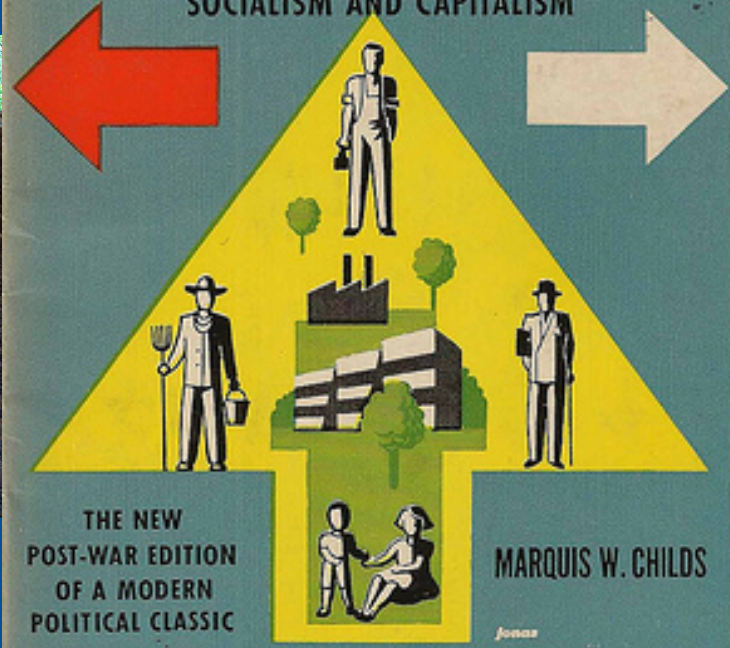
P24



35c

# SWEDEN THE MIDDLE WAY

THE STORY OF A CONSTRUCTIVE COMPROMISE BETWEEN  
SOCIALISM AND CAPITALISM



THE NEW  
POST-WAR EDITION  
OF A MODERN  
POLITICAL CLASSIC

MARQUIS W. CHILDS

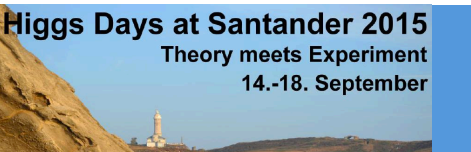
PELICAN BOOKS



KAPPAS  
FIDUCIAL CROSS-SECTIONS



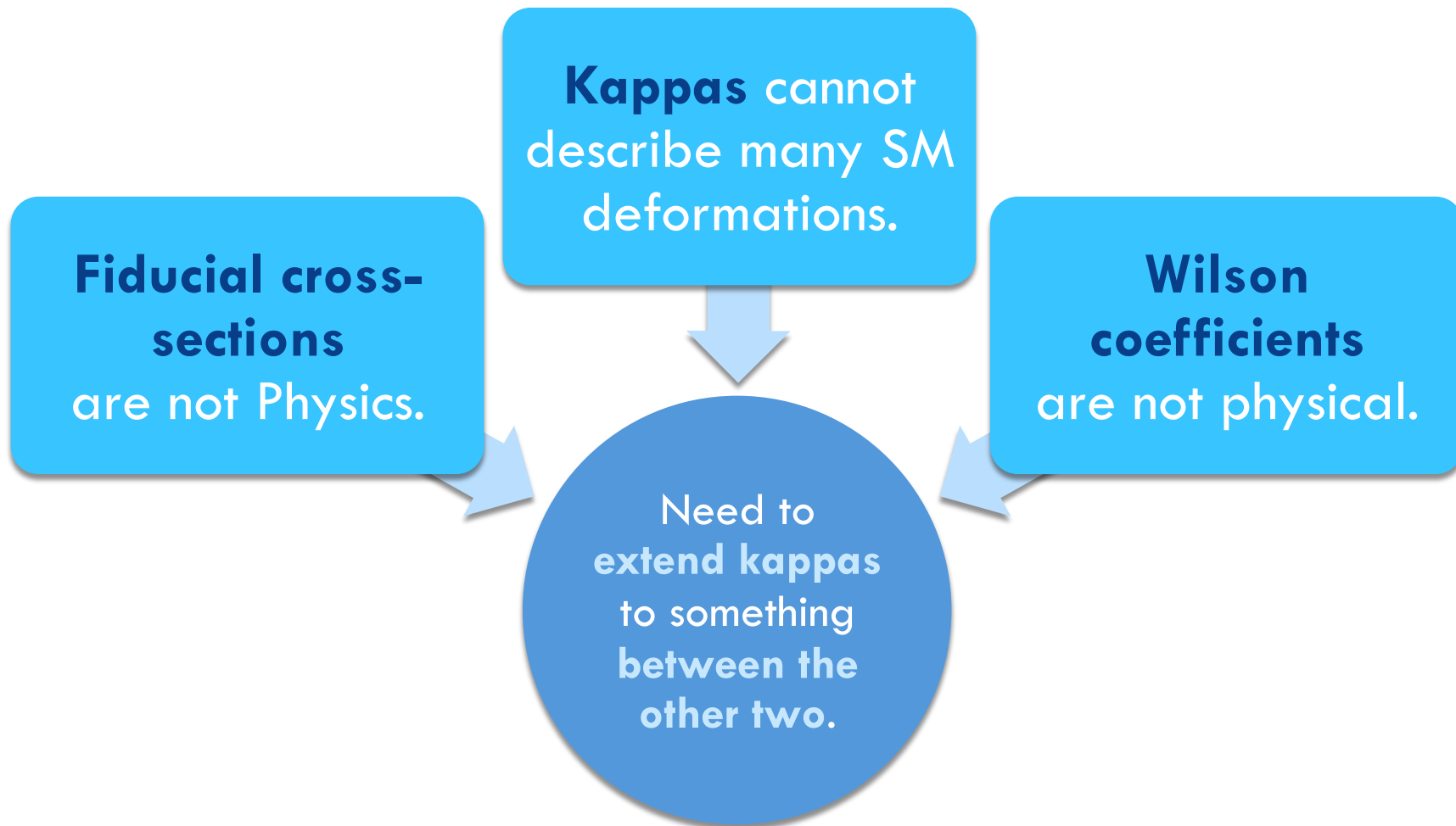
EFFECTIVE FIELD THEORY  
WILSON COEFFICIENTS



André David (CERN)



# 4-box summary





# As seen on (Spanish) TV



# The Next Standard Model



$$\begin{aligned} & -\frac{1}{2}\partial_\nu g_\mu^\alpha \partial_\nu g_\mu^\alpha - g_s f^{abc} \partial_\mu g_\nu^a g_\mu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^a g_\nu^b g_\mu^c g_\nu^d g_\mu^e + \frac{1}{2}ig_s^2 (\bar{q}_i^c \gamma^\mu q_j^c) g_\mu^a + \bar{C}^a \partial^2 C^a + g_s f^{abc} \partial_\mu C^a G^b G^c - \\ & \partial_\mu W_\nu^+ \partial_\nu W_\mu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{20v} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\mu A_\nu \partial_\nu A_\mu - \frac{1}{2}\partial_\mu H \partial_\nu H - \frac{1}{2}m_h^2 H^2 - \partial_\mu \phi^+ \partial_\nu \phi^- - \\ & M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\mu \phi^0 \partial_\nu \phi^0 - \frac{1}{2v} M \phi^0 \phi^0 - \partial_\mu [ \frac{2M^2}{v^2} + \frac{2M}{v} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-) ] + \frac{2M^4}{v^2} \alpha_h - ig_{sw} [ \partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\ & W_\mu^- W_\nu^+) - Z_\mu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) ] - ig_{sw} [ \partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\mu^- W_\nu^+) - \\ & A_\mu (W_\nu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\nu W_\mu^+) + A_\mu (W_\mu^+ \partial_\nu W_\nu^- - W_\mu^- \partial_\nu W_\nu^+) ] - \frac{1}{2}g^2 W_\mu^+ W_\mu^- W_\nu^+ W_\nu^- + \frac{1}{2}g^2 W_\mu^- W_\mu^+ W_\nu^- W_\nu^+ + \\ & g^2 c_w^2 (Z_\mu^0 W_\nu^+ Z_\nu^0 W_\mu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 s_w^2 (A_\mu W_\nu^+ A_\nu W_\mu^- - A_\mu A_\nu W_\nu^+ W_\mu^-) + g^2 s_w c_w [ A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\ & W_\mu^- W_\nu^+) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^- ] - g\alpha [ H^3 + H \phi^0 \phi^0 + 2H \phi^+ \phi^- ] - \frac{1}{2}g^2 \alpha_h [ H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + \\ & 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2 ] - gM W_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{v} Z_\mu^0 Z_\nu^0 H - \frac{1}{2}ig [ W_\mu^+ (\phi^0 \partial_\nu \phi^- - \phi^- \partial_\nu \phi^0) - W_\mu^- (\phi^0 \partial_\nu \phi^+ - \phi^+ \partial_\nu \phi^0) ] + \\ & \frac{1}{2}g [ W_\mu^+ (H \partial_\nu \phi^- - \phi^- \partial_\nu H) - W_\mu^- (H \partial_\nu \phi^+ - \phi^+ \partial_\nu H) ] + \frac{1}{2}ig \frac{1}{v} [ Z_\mu^0 (H \partial_\nu \phi^0 - \phi^0 \partial_\nu H) - ig \frac{2c_w}{s_w} M Z_\mu^0 (W_\mu^+ \phi^- - \\ & W_\mu^- \phi^+) + ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2s_w} Z_\mu^0 (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) ] + ig s_w A_\mu (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) - \\ & \frac{1}{4}g^2 W_\mu^+ W_\mu^- [ H^2 + (\phi^0)^2 + 2\phi^+ \phi^- ] - \frac{1}{4}g^2 \frac{1}{c_w} Z_\mu^0 Z_\nu^0 [ H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^- ] - \frac{1}{2}g^2 \frac{s_w}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- - \\ & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- - W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- - W_\mu^- \phi^+) - \\ & g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\nu \phi^+ \phi^- - g^4 s_w^2 A_\mu A_\nu \phi^+ \phi^- - e^\lambda (\gamma \partial + m_\lambda^2) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^2) u_j^\lambda - \bar{d}_j^\lambda (\gamma \partial + m_d^2) d_j^\lambda + \\ & ig_{sw} A_\mu [ -(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda) ] + \frac{ig}{4c_w} Z_\mu^0 [ (\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{1}{3}s_w^2 - \\ & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{2}{3}s_w^2 - \gamma^5) d_j^\lambda) ] + \frac{ig}{2\sqrt{2}} W_\mu^+ [ (\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda e} d_j^\lambda) ] + \frac{ig}{2\sqrt{2}} W_\mu^- [ (\bar{e}^\lambda \gamma^\mu (1 + \\ & \gamma^5) \nu^\lambda) + (\bar{d}_j^\lambda C_{\lambda e} \gamma^\mu (1 + \gamma^5) u_j^\lambda) ] + \frac{ig}{2\sqrt{2}} \frac{m_\lambda}{M} [ -\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda) ] - \frac{g}{2} \frac{m_\lambda^2}{M} [ H (\bar{e}^\lambda e^\lambda) + \\ & i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda) ] + \frac{ig}{2M\sqrt{2}} \phi^+ [ -m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e} (1 - \gamma^5) d_j^\lambda) + m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e} (1 + \gamma^5) u_j^\lambda) ] + \frac{ig}{2M\sqrt{2}} \phi^- [ m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e} (1 + \gamma^5) u_j^\lambda) - \\ & m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e} (1 - \gamma^5) d_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) ] + \bar{X} + (\partial^2 - \\ & M^2) X^+ + \bar{X} - (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + ig_{sw} W_\mu^+ (\partial_\mu \bar{X}^0 X^- - \partial_\mu \bar{X}^+ X^0) + ig_{sw} W_\mu^+ (\partial_\mu \bar{X}^- X^0 - \\ & \partial_\mu \bar{X}^+ Y) + ig_{sw} W_\mu^- (\partial_\mu \bar{X}^- X^0 - \partial_\mu \bar{X}^0 X^+) + ig_{sw} W_\mu^- (\partial_\mu \bar{X}^- Y - \partial_\mu \bar{X}^+ X^+) + ig_{sw} Z_\mu^0 (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) + \\ & ig_{sw} A_\mu (\partial_\mu \bar{X}^+ X^+ - \partial_\mu \bar{X}^- X^-) - \frac{1}{2}gM [ \bar{X}^+ X^+ H + \bar{X}^- X^- H + \frac{1}{c_w} \bar{X}^0 X^0 H ] + \frac{1-2c_w^2}{2c_w} igM [ \bar{X}^+ X^0 \phi^+ - \\ & \bar{X}^- X^0 \phi^- ] + \frac{1}{2c_w} igM [ \bar{X}^0 X^+ \phi^+ - \bar{X}^0 X^+ \phi^- ] + igM s_w [ \bar{X}^0 X^+ \phi^+ - \bar{X}^0 X^+ \phi^- ] + \frac{1}{2}igM [ \bar{X}^+ X^+ \phi^0 - \bar{X}^- X^- \phi^0 ] \end{aligned}$$

# The Next Standard Model



$$\begin{aligned} & -\frac{1}{2}\partial_\nu g_\mu^\alpha \partial_\nu g_\mu^\alpha - g_s f^{abc} \partial_\nu g_\mu^a g_\nu^b g_\nu^c - \frac{1}{4}g_s^2 f^{abc} f^{ade} g_\mu^b g_\nu^c g_\nu^d g_\nu^e + \frac{1}{2}ig_s^2 (\bar{l}_i^\alpha \gamma^\mu q_i^\beta) g_\mu^\alpha + \bar{C}^a \partial^2 G^a + g_s f^{abc} \partial_\nu G^a G^b g_\nu^c - \\ & \partial_\nu W_\mu^+ \partial_\nu W_\mu^- - M^2 W_\mu^+ W_\mu^- - \frac{1}{2}\partial_\nu Z_\mu^0 \partial_\nu Z_\mu^0 - \frac{1}{20\epsilon} M^2 Z_\mu^0 Z_\mu^0 - \frac{1}{2}\partial_\nu A_\mu \partial_\nu A_\nu - \frac{1}{2}\partial_\nu H \partial_\nu H - \frac{1}{2}m_h^2 H^2 - \partial_\nu \phi^+ \partial_\nu \phi^- - \\ & M^2 \phi^+ \phi^- - \frac{1}{2}\partial_\nu \phi^0 \partial_\nu \phi^0 - \frac{1}{2\epsilon} M \phi^0 \phi^0 - \partial_\nu [\frac{2M^2}{g^2} + \frac{2M}{g} H + \frac{1}{2}(H^2 + \phi^0 \phi^0 + 2\phi^+ \phi^-)] + \frac{2M^4}{g^2} \alpha_h - ig_{sw} [\partial_\nu Z_\mu^0 (W_\mu^+ W_\nu^- - \\ & W_\mu^- W_\nu^+) - Z_\mu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + Z_\mu^0 (W_\mu^+ \partial_\nu W_\mu^- - W_\nu^- \partial_\mu W_\mu^+) - ig_{sw} [\partial_\nu A_\mu (W_\mu^+ W_\nu^- - W_\mu^- W_\nu^+) - \\ & A_\mu (W_\mu^+ \partial_\nu W_\mu^- - W_\mu^- \partial_\nu W_\mu^+) + A_\mu (W_\nu^+ \partial_\mu W_\mu^- - W_\nu^- \partial_\mu W_\mu^+) - \frac{1}{2}g^2 W_\mu^+ W_\nu^- W_\nu^+ W_\mu^- + \frac{1}{2}g^2 W_\mu^- W_\nu^+ W_\nu^- W_\mu^+ - \\ & g^2 c_w^2 (Z_\mu^0 W_\nu^+ Z_\nu^0 W_\mu^- - Z_\mu^0 Z_\nu^0 W_\mu^+ W_\nu^-) + g^2 s_w^2 (A_\mu W_\nu^+ A_\nu W_\mu^- - A_\mu A_\nu W_\nu^+ W_\mu^-) + g^2 s_w c_w [A_\mu Z_\nu^0 (W_\mu^+ W_\nu^- - \\ & W_\nu^+ W_\mu^-) - 2A_\mu Z_\mu^0 W_\nu^+ W_\nu^-] - g\alpha [H^3 + H \phi^0 \phi^0 + 2H \phi^+ \phi^-] - \frac{1}{2}g^2 \alpha_h [H^4 + (\phi^0)^4 + 4(\phi^+ \phi^-)^2 + 4(\phi^0)^2 \phi^+ \phi^- + \\ & 4H^2 \phi^+ \phi^- + 2(\phi^0)^2 H^2] - g M W_\mu^+ W_\mu^- H - \frac{1}{2}g \frac{M}{c_w} Z_\mu^0 Z_\mu^0 H - \frac{1}{2}ig [W_\mu^+ (\phi^0 \partial_\nu \phi^- - \phi^- \partial_\nu \phi^0) - W_\mu^- (\phi^0 \partial_\nu \phi^+ - \phi^+ \partial_\nu \phi^0)] + \\ & \frac{1}{2}g [W_\mu^+ (H \partial_\nu \phi^- - \phi^- \partial_\nu H) - W_\mu^- (H \partial_\nu \phi^+ - \phi^+ \partial_\nu H)] + \frac{1}{2}g \frac{1}{c_w} [Z_\mu^0 (H \partial_\nu \phi^0 - \phi^0 \partial_\nu H) - ig \frac{2s_w}{c_w} M Z_\mu^0 (W_\mu^+ \phi^- - \\ & W_\mu^- \phi^+) + ig s_w M A_\mu (W_\mu^+ \phi^- - W_\mu^- \phi^+) - ig \frac{1-2c_w^2}{2c_w} Z_\mu^0 (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) + ig s_w A_\mu (\phi^+ \partial_\nu \phi^- - \phi^- \partial_\nu \phi^+) - \\ & \frac{1}{4}g^2 W_\mu^+ W_\mu^- [H^2 + (\phi^0)^2 + 2\phi^+ \phi^-] - \frac{1}{4}g^2 \frac{1}{c_w} Z_\mu^0 Z_\mu^0 [H^2 + (\phi^0)^2 + 2(2s_w^2 - 1)^2 \phi^+ \phi^-] - \frac{1}{2}g^2 \frac{s_w}{c_w} Z_\mu^0 \phi^0 (W_\mu^+ \phi^- + \\ & W_\mu^- \phi^+) - \frac{1}{2}ig^2 \frac{s_w^2}{c_w} Z_\mu^0 H (W_\mu^+ \phi^- + W_\mu^- \phi^+) + \frac{1}{2}g^2 s_w A_\mu \phi^0 (W_\mu^+ \phi^- + W_\mu^- \phi^+) + \frac{1}{2}ig^2 s_w A_\mu H (W_\mu^+ \phi^- + W_\mu^- \phi^+) - \\ & g^2 \frac{s_w}{c_w} (2c_w^2 - 1) Z_\mu^0 A_\mu \phi^+ \phi^- - g^4 s_w^2 A_\mu A_\mu \phi^+ \phi^- - e^\lambda (\gamma \partial + m_e^\lambda) e^\lambda - \bar{\nu}^\lambda \gamma \partial \nu^\lambda - \bar{u}_j^\lambda (\gamma \partial + m_u^\lambda) u_j^\lambda - \bar{d}_j^\lambda (\gamma \partial + m_d^\lambda) d_j^\lambda + \\ & ig s_w A_\mu [-(\bar{e}^\lambda \gamma^\mu e^\lambda) + \frac{2}{3}(\bar{u}_j^\lambda \gamma^\mu u_j^\lambda) - \frac{1}{3}(\bar{d}_j^\lambda \gamma^\mu d_j^\lambda)] + \frac{ig}{4c_w} Z_\mu^0 [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) \nu^\lambda) + (\bar{e}^\lambda \gamma^\mu (4s_w^2 - 1 - \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (\frac{1}{3}s_w^2 - \\ & 1 - \gamma^5) u_j^\lambda) + (\bar{d}_j^\lambda \gamma^\mu (1 - \frac{2}{3}s_w^2 - \gamma^5) d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^+ [(\bar{\nu}^\lambda \gamma^\mu (1 + \gamma^5) e^\lambda) + (\bar{u}_j^\lambda \gamma^\mu (1 + \gamma^5) C_{\lambda e} d_j^\lambda)] + \frac{ig}{2\sqrt{2}} W_\mu^- [(\bar{e}^\lambda \gamma^\mu (1 + \\ & \gamma^5) \nu^\lambda) + (\bar{d}_j^\lambda C_{\lambda e} \gamma^\mu (1 + \gamma^5) u_j^\lambda)] + \frac{ig}{2\sqrt{2}} \frac{m_\lambda}{M} [-\phi^+ (\bar{\nu}^\lambda (1 - \gamma^5) e^\lambda) + \phi^- (\bar{e}^\lambda (1 + \gamma^5) \nu^\lambda)] - \frac{g}{2} \frac{m_\lambda^2}{M} [H (\bar{e}^\lambda e^\lambda) + \\ & i\phi^0 (\bar{e}^\lambda \gamma^5 e^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^+ [-m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e} (1 - \gamma^5) d_j^\lambda) + m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e} (1 + \gamma^5) u_j^\lambda)] + \frac{ig}{2M\sqrt{2}} \phi^- [m_\lambda^2 (\bar{d}_j^\lambda C_{\lambda e} (1 + \gamma^5) u_j^\lambda) - \\ & m_\lambda^2 (\bar{u}_j^\lambda C_{\lambda e} (1 - \gamma^5) d_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{u}_j^\lambda u_j^\lambda) - \frac{g}{2} \frac{m_\lambda^2}{M} H (\bar{d}_j^\lambda d_j^\lambda) + \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{u}_j^\lambda \gamma^5 u_j^\lambda) - \frac{ig}{2} \frac{m_\lambda^2}{M} \phi^0 (\bar{d}_j^\lambda \gamma^5 d_j^\lambda) + \bar{X} + (\partial^2 - \\ & M^2) X^+ + \bar{X} - (\partial^2 - M^2) X^- + \bar{X}^0 (\partial^2 - \frac{M^2}{c_w^2}) X^0 + \bar{Y} \partial^2 Y + ig_{sw} W_\mu^+ (\partial_\mu \bar{X}^0 X^- - 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Something else





# As seen on (Spanish) TV

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## ENTREGAS

### 1ª ENTREGA LA MATERIA OSCURA



### 2ª ENTREGA LOS AGUJEROS NEGROS



### 3ª ENTREGA EL BOSÓN DE HIGGS





# Supplementing the Standard Theory

10

## Concrete BSM

- SUSY: MSSM, NMSSM, etc.
- Possibly:
  - ▣ Light new physics.
  - ▣ Other states.
  - ▣ Non-decoupled.
- Specific benchmarks.
  - ▣ LHC HXSWG WG3.

## EFT expansion

- Add higher-dimensional operators.
- Assumes:
  - ▣ Heavy new physics.
  - ▣ Indirect effects, loops.
  - ▣ Decoupled.
- Generic interpretation.
  - ▣ LHC HXSWG WG2.



# Supplementing the Standard Theory

11

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# Supplementing the Standard Theory

12

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# Not all EFT are born the same

13

[ <http://cern.ch/go/L98Q> ]

## Top-down EFT

- Full theory known:
  - ▣ Matching conditions bridge EFT and full theory.

## Bottom-up EFT

- Full theory **unknown**:
  - ▣ Add operators as theory can calculate and data can discern.

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# EFT vs. Effective Lagrangians

16

arXiv.org > hep-ex > arXiv:1508.02507

High Energy Physics - Experiment

Constraints on non-Standard Model Higgs boson interactions in an **effective field theory** using differential cross sections measured in the  $H \rightarrow \gamma\gamma$  decay channel at  $\sqrt{s} = 8$  TeV with the ATLAS detector

ATLAS Collaboration

(Submitted on 11 Aug 2015)

- Let's look at the relevant references:
  - [3] Sec. 10.4 is titled "**Effective Lagrangians** for Higgs interactions".
  - [4] titled "**Effective lagrangian** analysis [...]".
  - [5] abstract "dimension-six operators in the **effective Lagrangian**".
  - [6] abstract "An **effective [...] Lagrangian** approach".
  - [7] an actual **EFT** basis that is not used in the preprint.
  - [8] titled "**Effective Lagrangian** for a light Higgs-like scalar".
  - [10] is titled "Phenomenology of the Higgs **Effective Lagrangian** via FeynRules".
  - [11] mentions in the abstract "parametrizing BSM effects with **dimension-six operators**".
  - [12] is the only one to mention "**effective field theory**" (in the abstract, not the title).
- Ref. [10] **neglects operators** by using "a set of [...] operators assumed to encompass all possible effects of new physics on the Higgs sector".
  - **Whether this assumption is a good one depends on the goal: see, e.g., 1508.05060.**



# A taxonomy of dim-6 SMEFT operators

| Class                                | $N_{\text{op}}$ | $CP$ -even   |    |      | $CP$ -odd   |    |      |
|--------------------------------------|-----------------|--|----|------|---|----|------|
|                                      |                 | $n_g$  | 1  | 3    | $n_g$   | 1  | 3    |
| 1 : $X^3$                            | 4               | 2  | 2  | 2    | 2   | 2  | 2    |
| 2 : $H^6$                            | 1               | 1  | 1  | 1    | 0   | 0  | 0    |
| 3 : $H^4 D^2$                        | 2               | 2  | 2  | 2    | 0   | 0  | 0    |
| 4 : $X^2 H^2$                        | 8               | 4  | 4  | 4    | 4   | 4  | 4    |
| 5 : $\psi^2 H^3 + \text{h.c.}$       | 3               | $3n_g^2$   | 3  | 27   | $3n_g^2$  | 3  | 27   |
| 6 : $\psi^2 XH + \text{h.c.}$        | 8               | $8n_g^2$   | 8  | 72   | $8n_g^2$  | 8  | 72   |
| 7 : $\psi^2 H^2 D$                   | 8               | $\frac{1}{2}n_g(9n_g + 7)$                               | 8  | 51   | $\frac{1}{2}n_g(9n_g - 7)$                              | 1  | 30   |
| 8 : $(\overline{LL})(\overline{LL})$ | 5               | $\frac{1}{4}n_g^2(7n_g^2 + 13)$                          | 5  | 171  | $\frac{7}{4}n_g^2(n_g - 1)(n_g + 1)$                    | 0  | 126  |
| 8 : $(\overline{RR})(\overline{RR})$ | 7               | $\frac{1}{8}n_g(21n_g^3 + 2n_g^2 + 31n_g + 2)$           | 7  | 255  | $\frac{1}{8}n_g(21n_g + 2)(n_g - 1)(n_g + 1)$           | 0  | 195  |
| 8 : $(\overline{LL})(\overline{RR})$ | 8               | $4n_g^2(n_g^2 + 1)$                                      | 8  | 360  | $4n_g^2(n_g - 1)(n_g + 1)$                              | 0  | 288  |
| 8 : $(\overline{LR})(\overline{RL})$ | 1               | $n_g^4$  | 1  | 81   | $n_g^4$   | 1  | 81   |
| 8 : $(\overline{LR})(\overline{LR})$ | 4               | $4n_g^4$   | 4  | 324  | $4n_g^4$  | 4  | 324  |
| 8 : All                              | 25              | $\frac{1}{8}n_g(107n_g^3 + 2n_g^2 + 89n_g + 2)$          | 25 | 1191 | $\frac{1}{8}n_g(107n_g^3 + 2n_g^2 - 67n_g - 2)$         | 5  | 1014 |
| Total                                | 59              | $\frac{1}{8}(107n_g^4 + 2n_g^3 + 213n_g^2 + 30n_g + 72)$ | 53 | 1350 | $\frac{1}{8}(107n_g^4 + 2n_g^3 + 57n_g^2 - 30n_g + 48)$ | 23 | 1149 |

**Table 2.** Number of  $CP$ -even and  $CP$ -odd coefficients in  $\mathcal{L}^{(6)}$  for  $n_g$  flavors. The total number of coefficients is  $(107n_g^4 + 2n_g^3 + 135n_g^2 + 60)/4$ , which is 76 for  $n_g = 1$  and 2499 for  $n_g = 3$ .



# EFT questions

- From 2499 dim-6 operators to  $\sim 60$  operators.
  - **Symmetries** guide the culling:
    - Flavour,  $\sim$ custodial, CP.
    - Each assumption needs **testing** measurements/observables.
  
- But to go down from  $\sim 60$ :
  - Guidance from **experimental sensitivity**.
  - Use **complementary information**:
    - LEP, Tevatron, etc experimental constraints.
    - $\alpha$ TGC/ $\alpha$ QGC, top quark, EDM searches, etc.

# EFT questions

- From 2499 dim-6 operators to  $\sim 60$  operators.

- **Symmetries** guide the culling:

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**colliders** (ee, eh),

- But to go down from  $\sim 60$ :

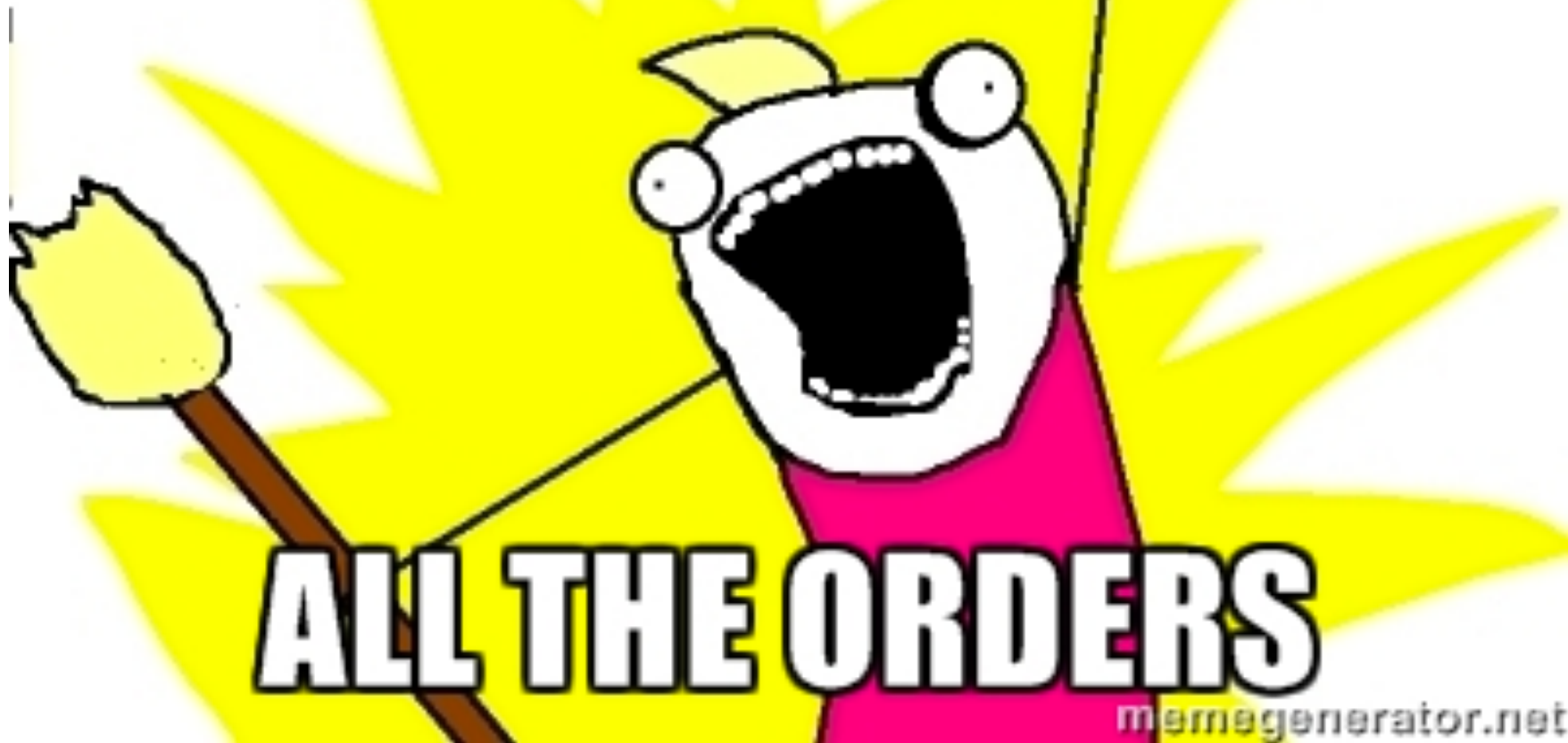
- **sectors** (multi-bosons, top),

- Use **complementary information**:

**and searches** (LFV, EDM)...

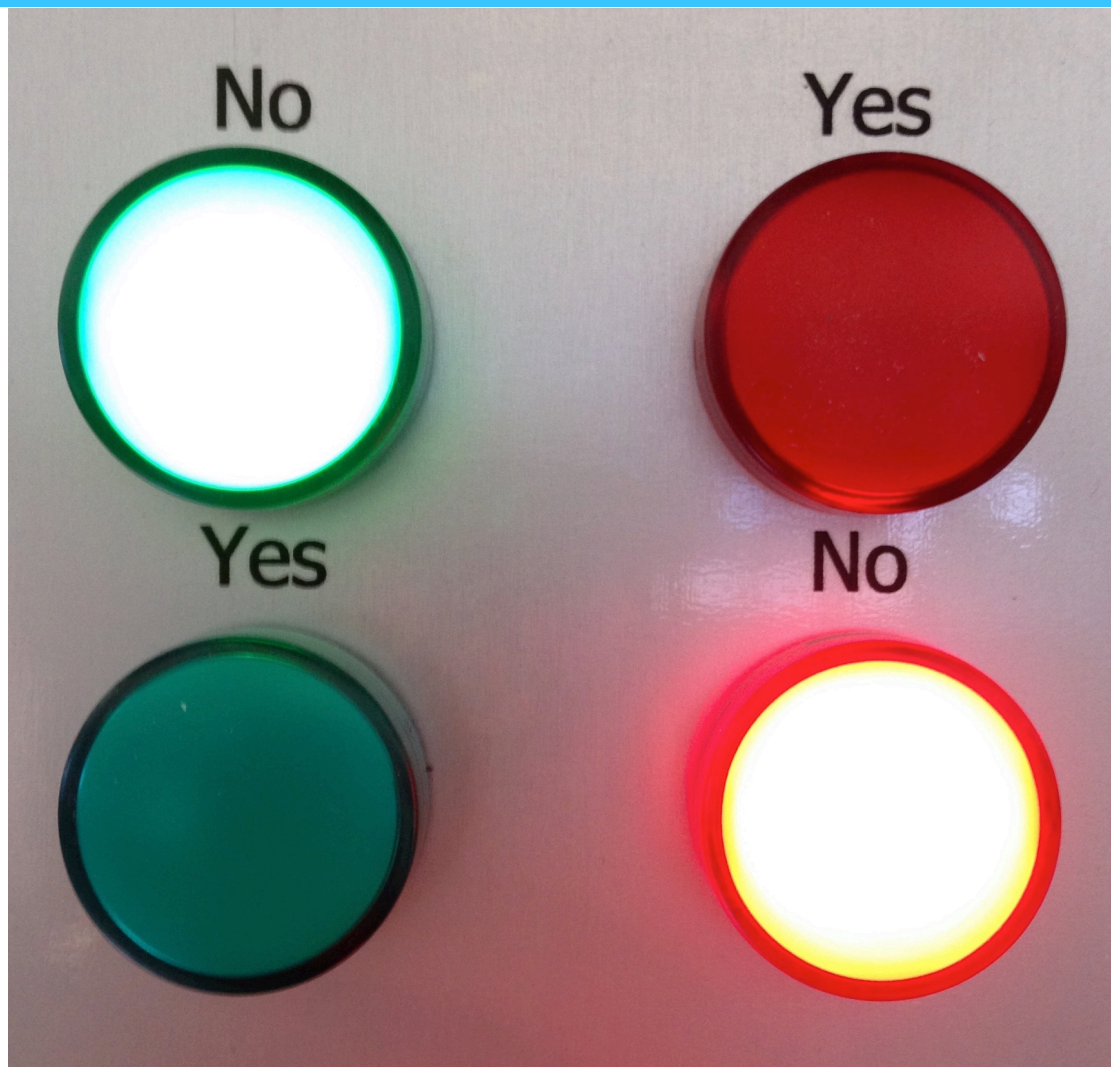
- LEP, neutrino, experimental constraints.
- aTGC/aQGC, top quark, EDM searches, etc.

**CALCULATE**



memegenerator.net

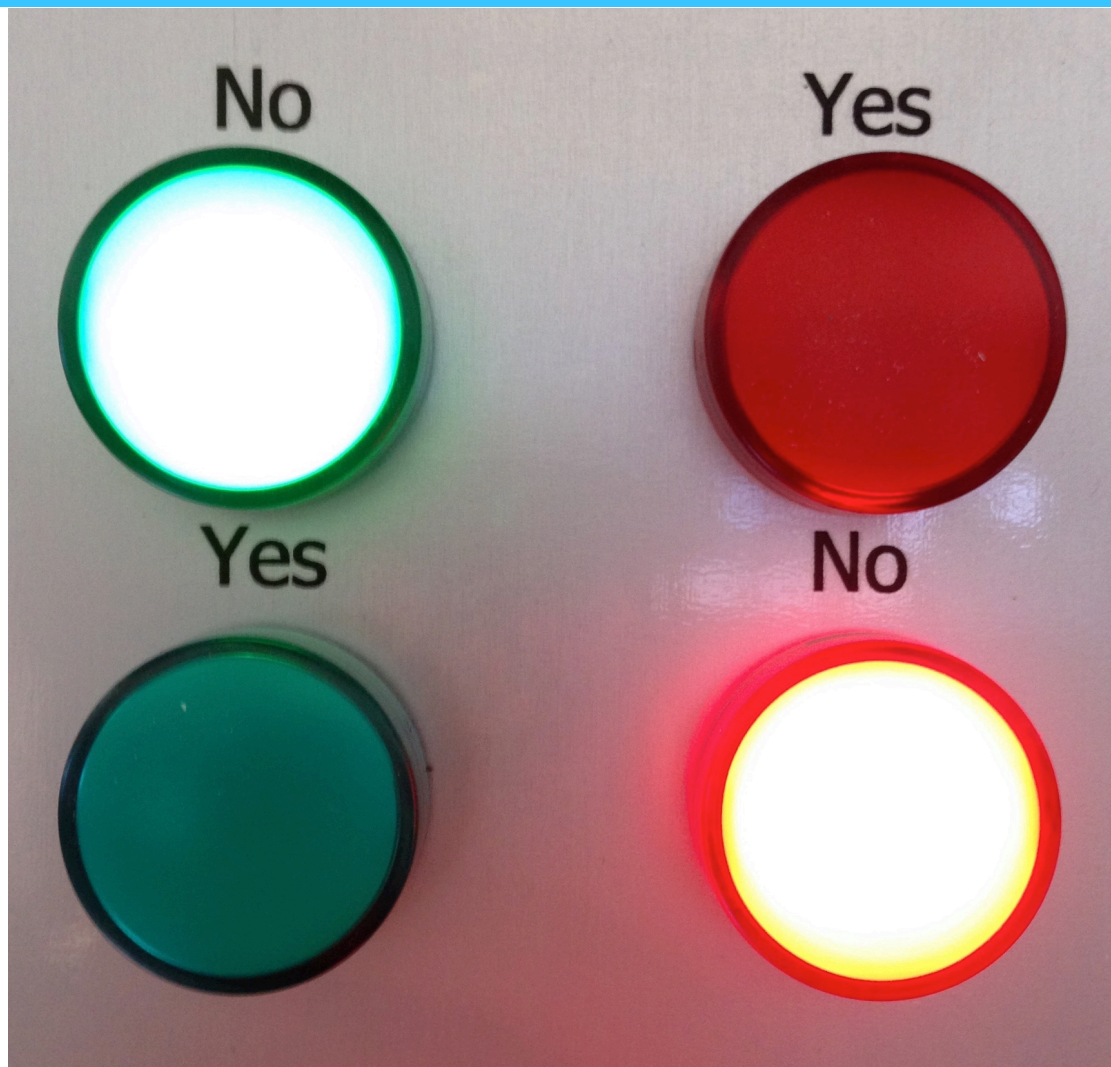
# Summary: Effective Lagrangians



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Can't we just fit  
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Are we ready to  
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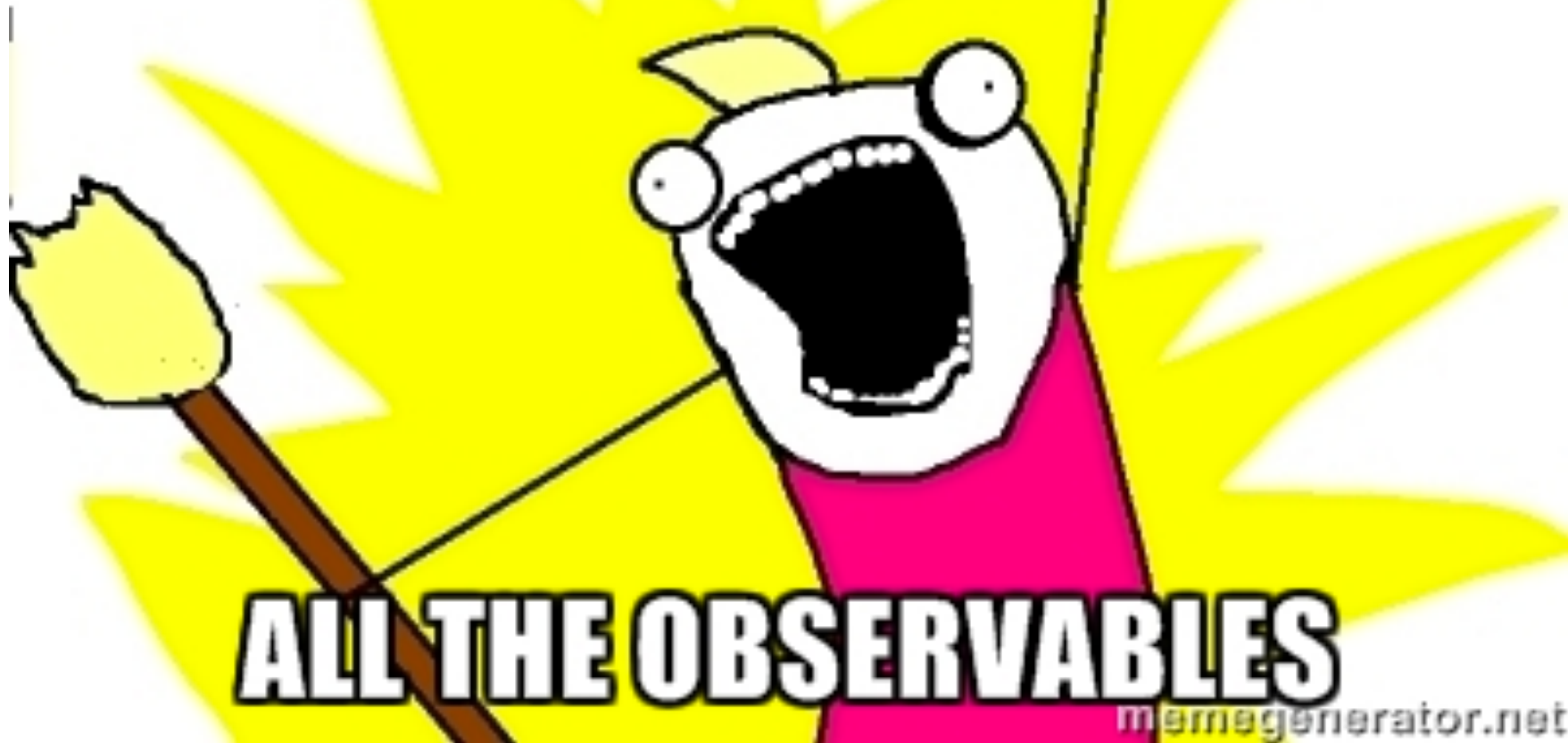
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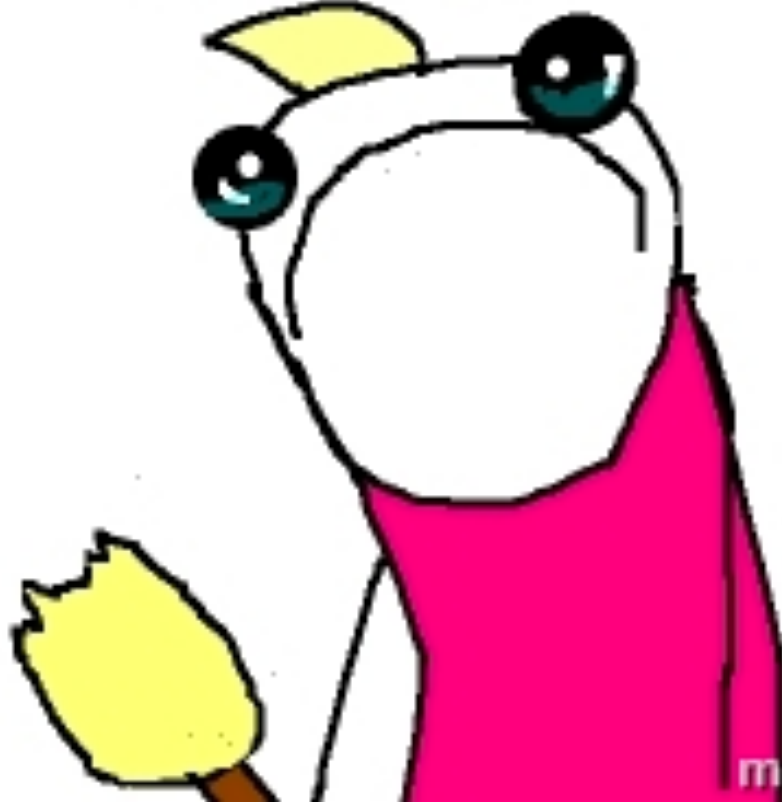
# MEASURE





EVERY SINGLE

ONE?



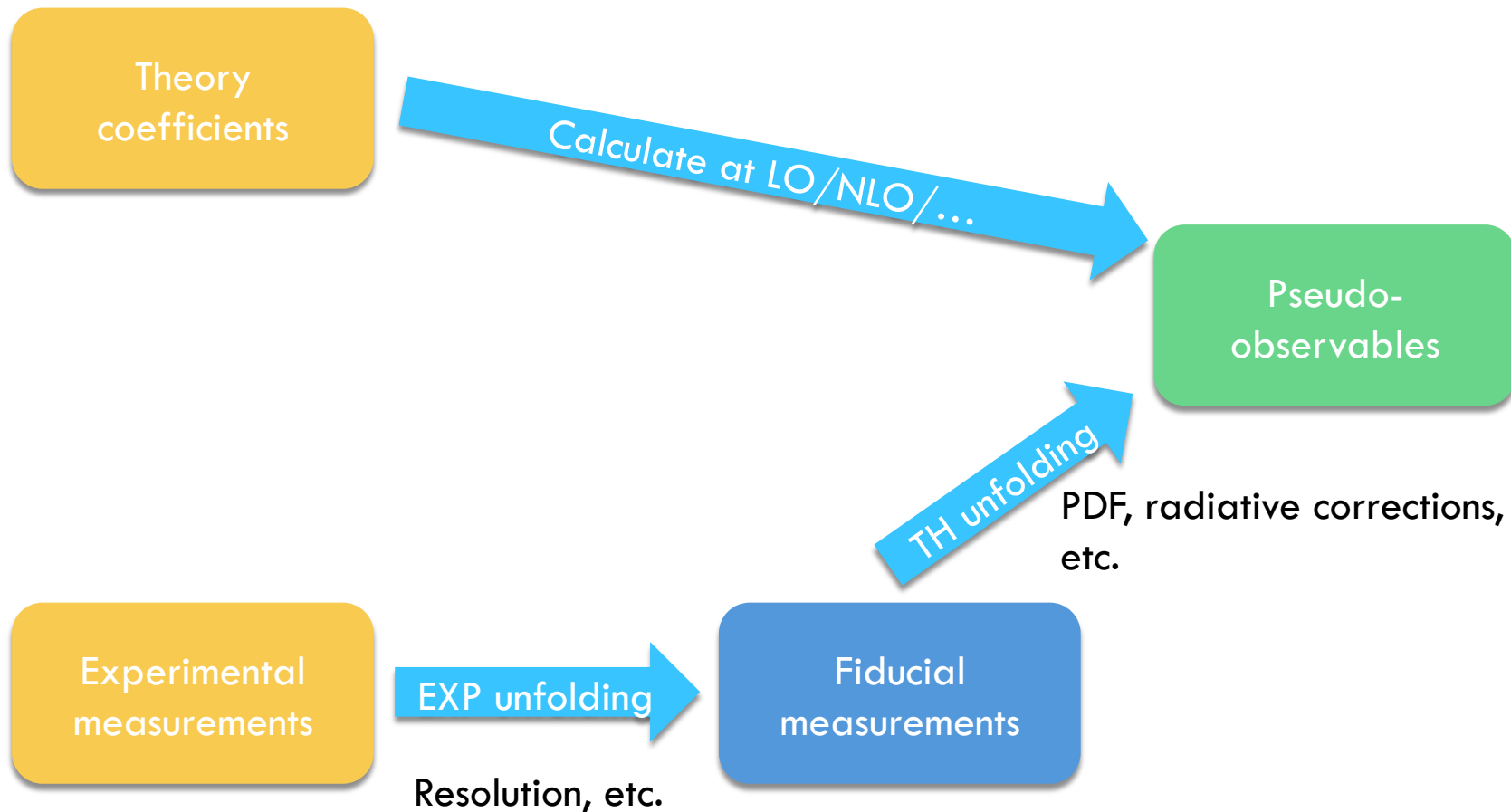
memegenerator.net



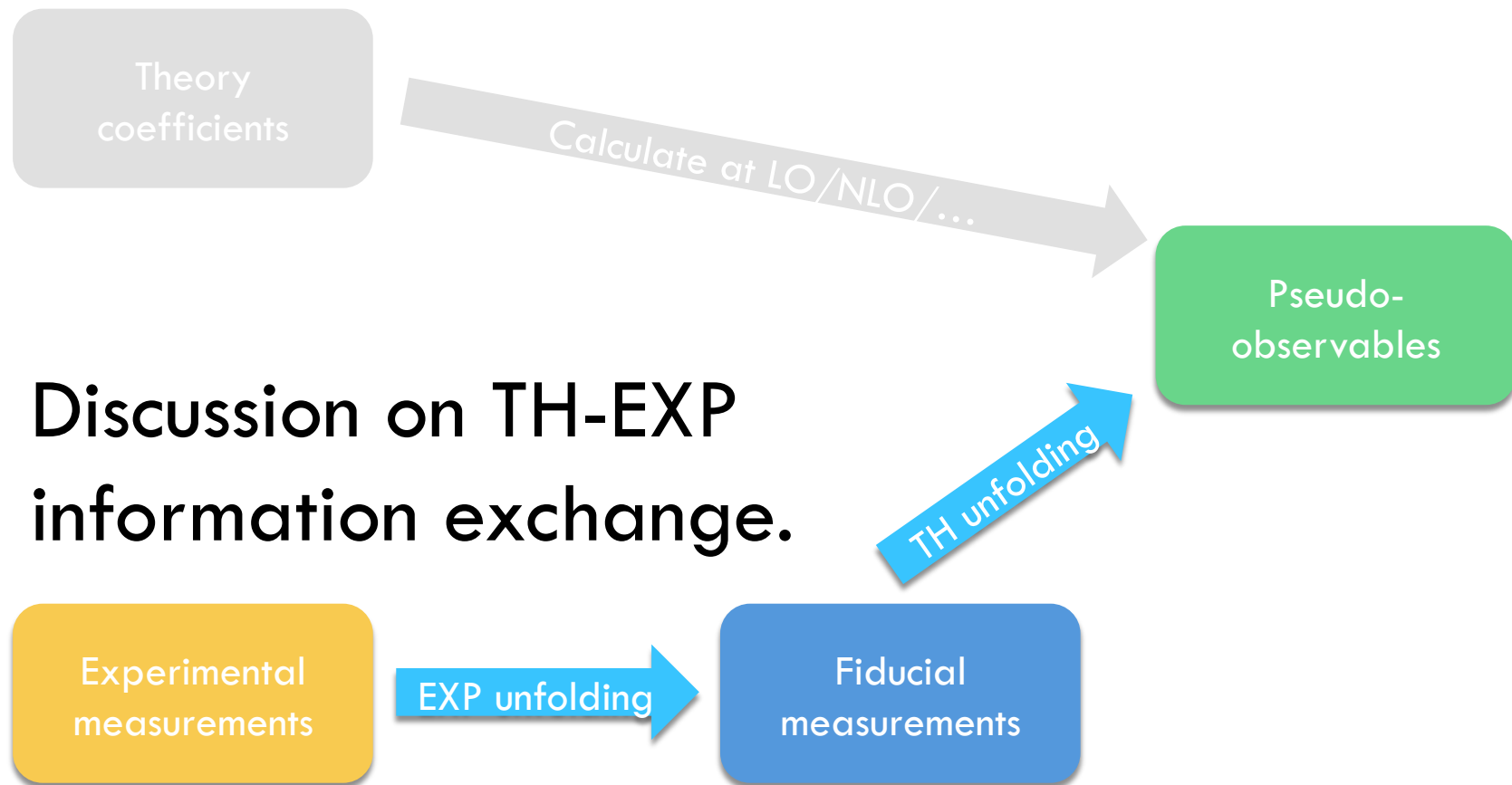
# The need for the middle way

- **EFT** is all-encompassing, calculable, and evolving.
  - ▣ **But** too costly to redo all analyses if/when higher order calculations become available.
- **Fiducial cross-section** could be produced differentially for many quantities.
  - ▣ **But** no physical interpretation of every single bin by itself.
- **The middle way: pseudo-observables (PO).**
  - ▣ LEP-inspired scheme where theory and experiment intersect at clearly-defined points.

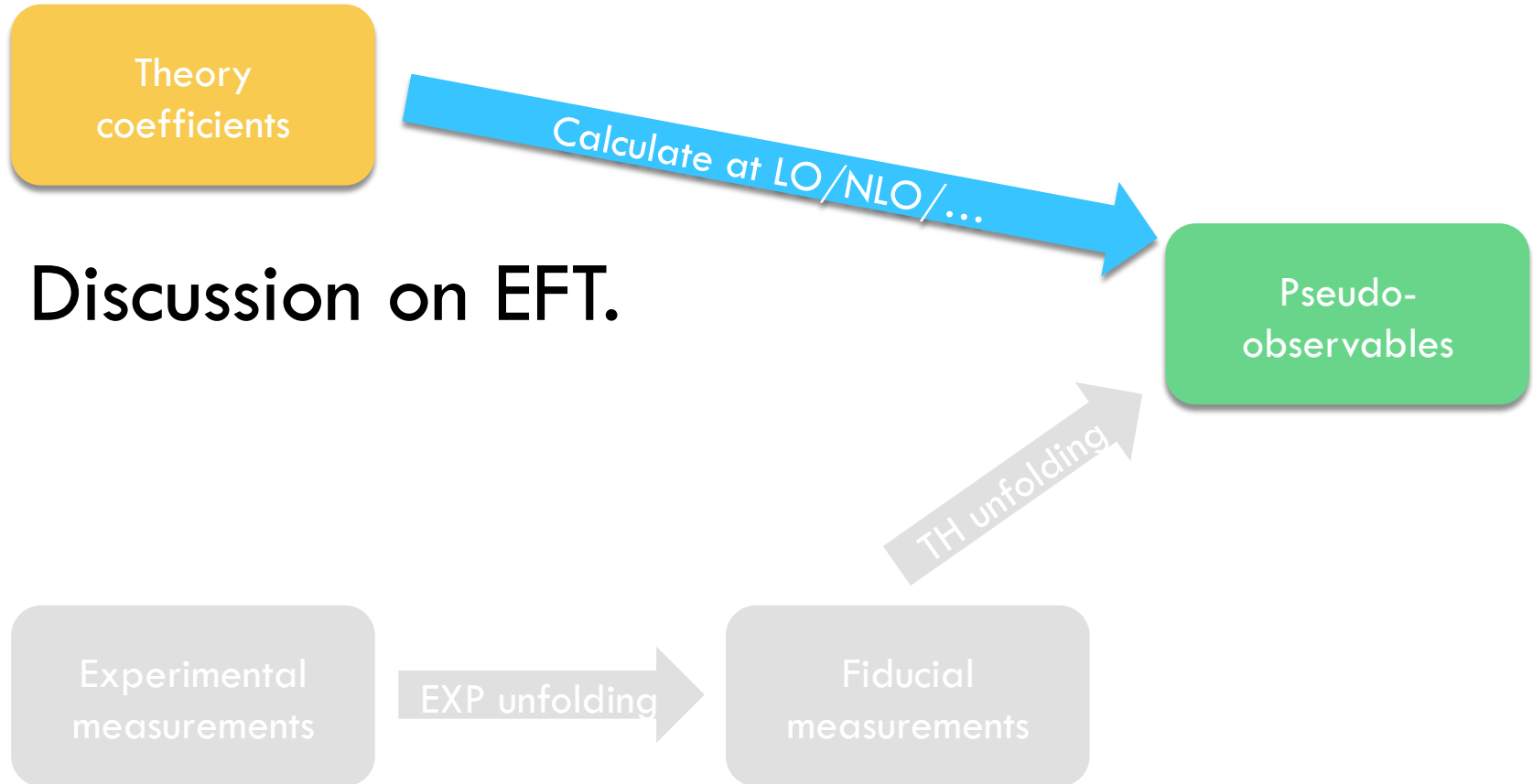
# With some LEP inspiration



# With some LEP inspiration

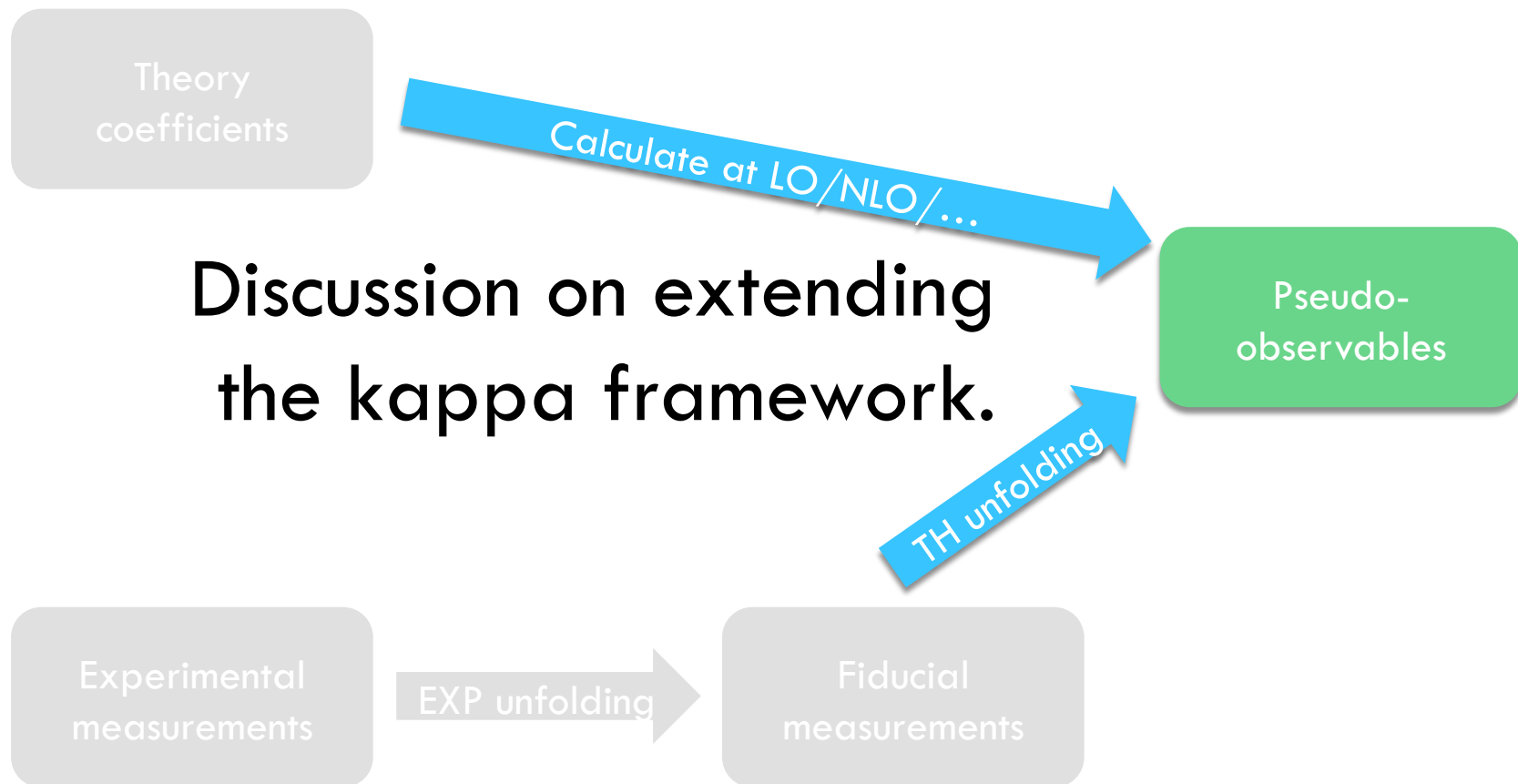


# With some LEP inspiration





# With some LEP inspiration





# From kappas that fit little stuff...



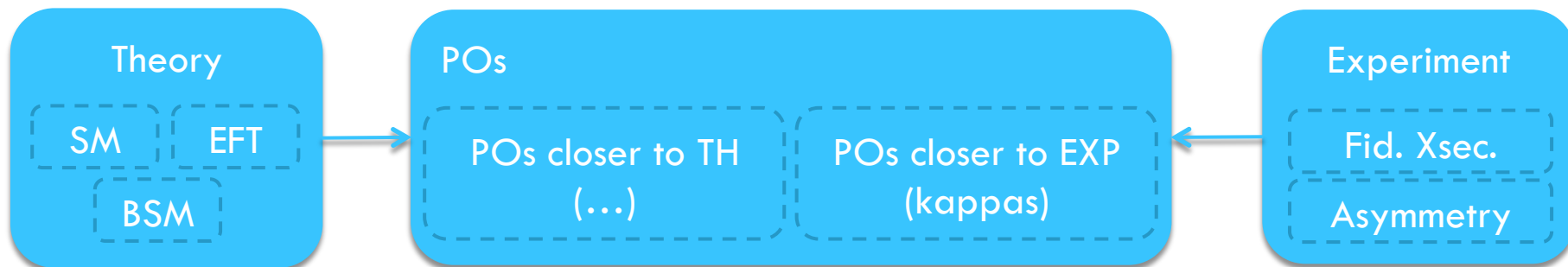
# ...to kappas that fit more stuff.





# Kappas might have been our first POs

- Kappas **must be extended** to:
  - ▣ Differential quantities.
  - ▣ Remove some assumptions.
  - ▣ Cover smooth deviations from the SM.
  
- With better/more POs, kappas may remain as part of the PO framework:



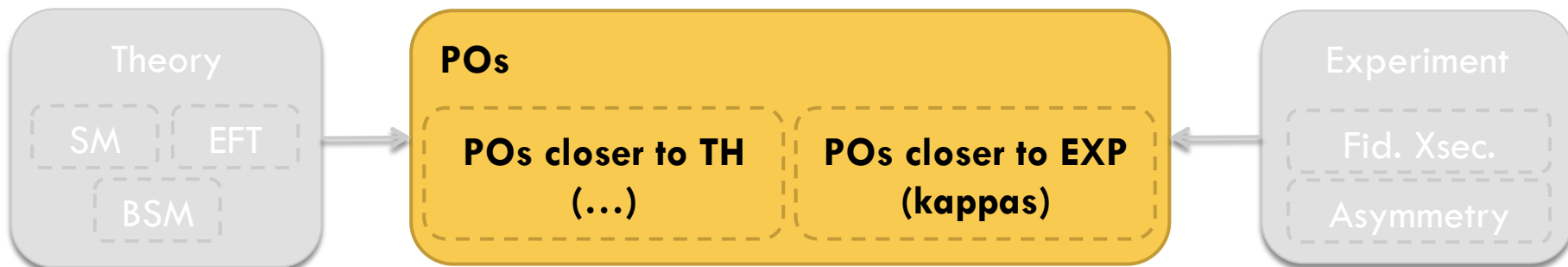
# Inspiration for building PO

- If we assume that:

$$\text{Next SM} \sim |\text{dim-4} + \text{dim-6} + \text{dim-8} + \dots|^2$$

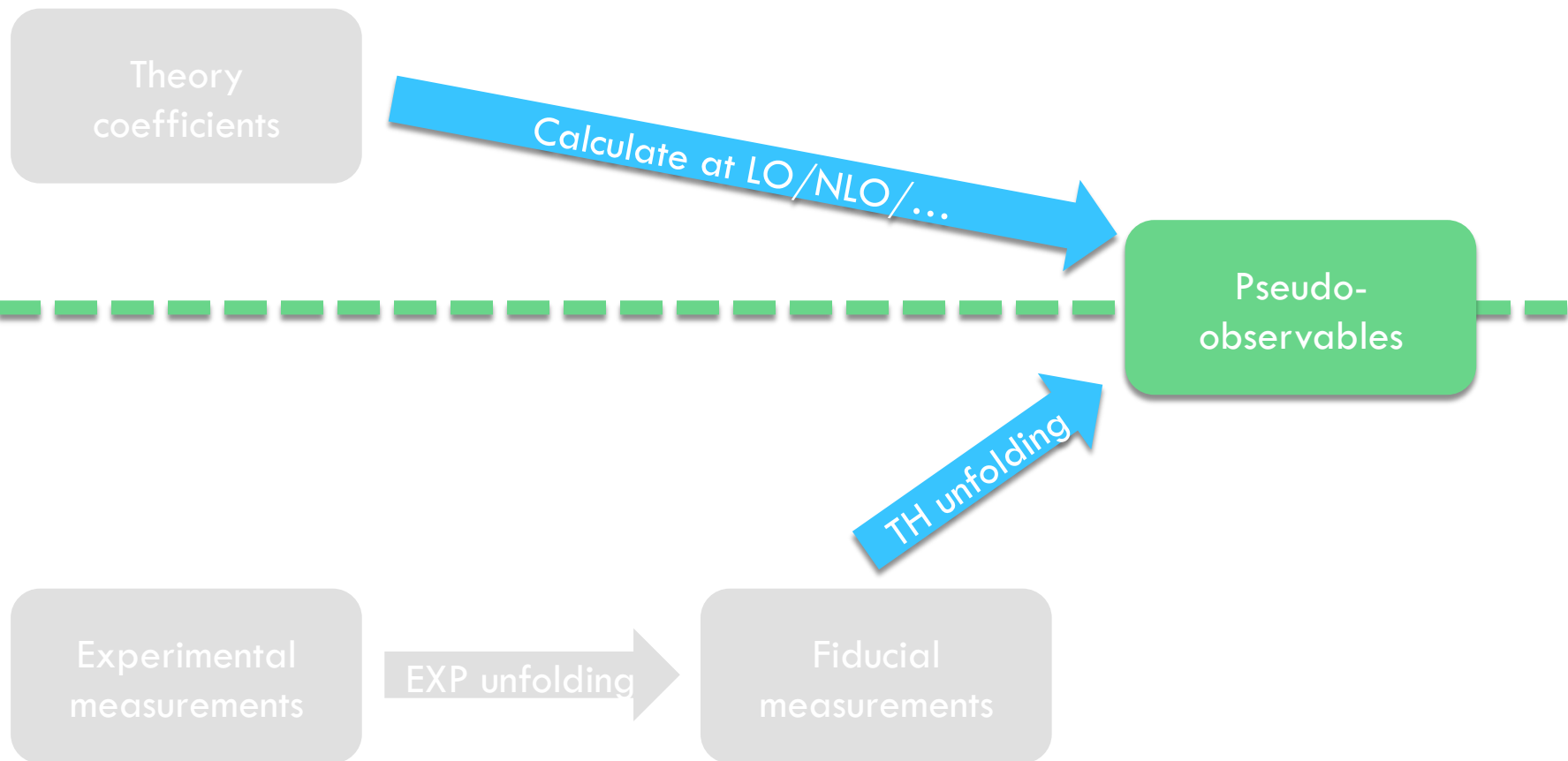
- Then POs can be motivated to parametrize:

$$\delta(\text{PO}_i) \sim (\text{Data} - \text{d4}^2) = \text{d4} \times \text{d6} + \text{d6}^2 + \text{d4} \times \text{d8} + \dots$$





# The middle way in action



# The middle way in action

Theorists refine calculations and interpret against PO.

Theory coefficients

Calculate at LO/NLO/...

Pseudo-observables

Experimental measurements

EXP unfolding

Fiducial measurements

TH unfolding

# The middle way in action

Theory coefficients

Calculate at LO/NLO/...

Pseudo-observables

If SM predictions improve, experiments may redo PO.

TH unfolding

Experimental measurements

EXP unfolding

Fiducial measurements



# Summary: PO

- Proposition 1:
  - ▣ **EXP** can (sort of) fit parameters of models to data.
  - ▣ **TH** can fit parameters of models to (sort of) data.
- Proposition 2:
  - ▣ **EXP** do not want (to produce)  $10^3 \times 10^3$  covariances.
  - ▣ **TH** do not want (to digest)  $10^3 \times 10^3$  covariances.
- Synthesis:

**We have to get (our act) together and define PO.**



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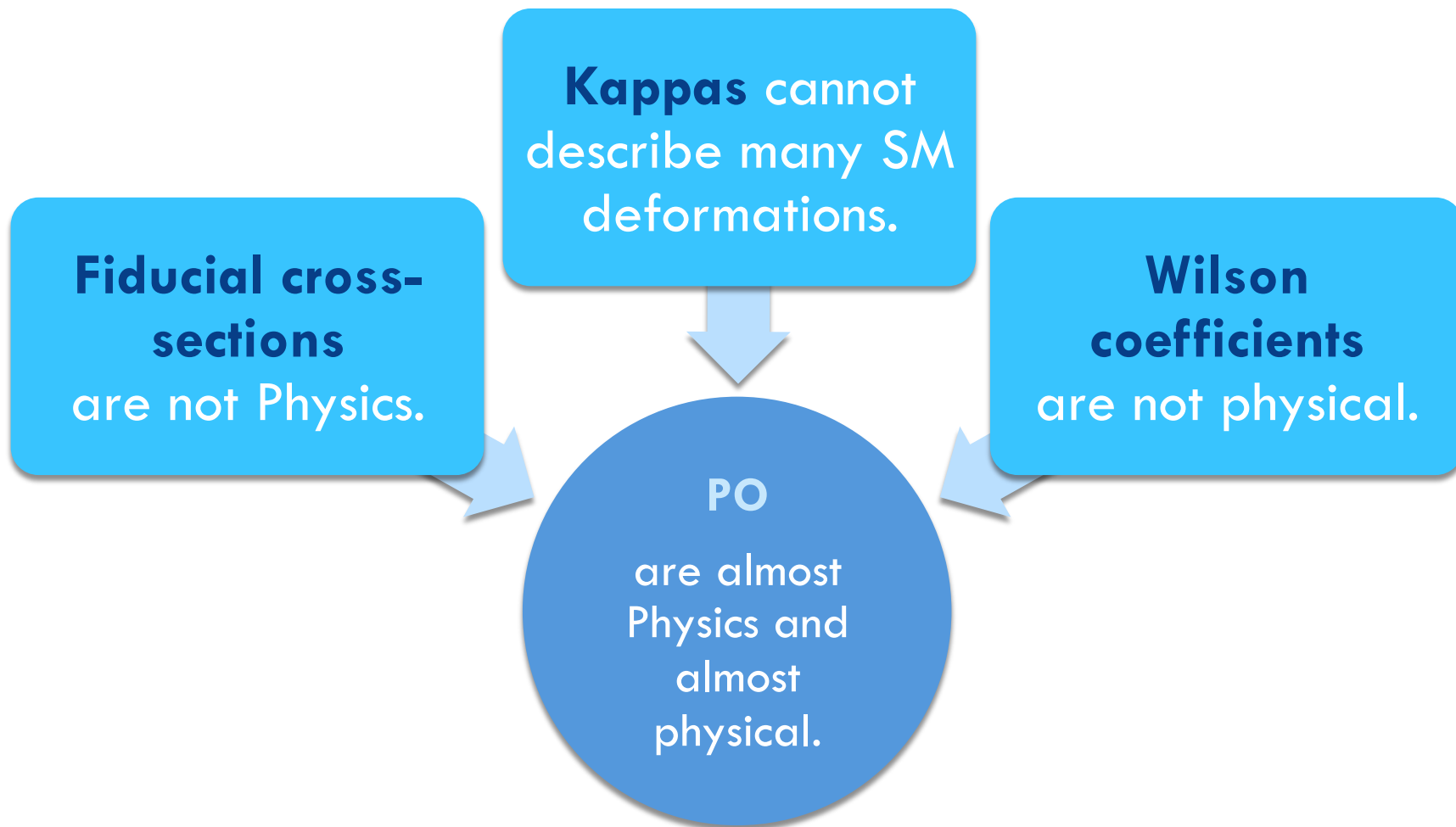
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**We have to get (our act) together and define PO.**





# 4-box summary





# Coming up

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PO

are almost Physics and almost physical.

**Decay:** smooth deformations from power expansion.  
(Gino)

**Production:** template cross sections. (Michael)

**Have an idea?**  
lhc-higgs-properties-convener@cern.ch



# Conclusions

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- What is EFT and what is an Effective Lagrangian:
  - ▣ **“One operator at a time”** phenomenology useful to explore the operator phase-space.
  - ▣ **Global approach** mandatory when interpreting data.
  
- What to do with data:
  - ▣ **Data results** should be comprehensively reported.
  - ▣ **Pseudo-observables**: calculable, measurable, compressing redundant information.

# As seen on (Spanish) TV

## VENTAJAS DE SER SUSCRIPTOR

### 1 Importantes descuentos



1<sup>er</sup> envío

**Libro 1 por solo 3,95€**



2<sup>o</sup> envío: **2X1**

**Libro 2 GRATIS**  
**Libro 3 por solo 8,95€**



3<sup>er</sup> envío: **2X1**

**Libro 4 GRATIS**  
**Libro 5 por solo 8,95 €**



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**1€ de descuento por Libro**