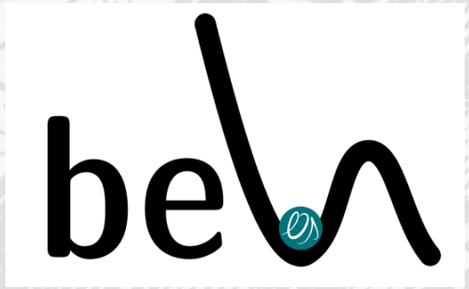


Top physics at LHC:

Run 2 → Run 3

Kirill Skovpen (UGent)

EOS be.h

Equinox meeting

2021/09/09

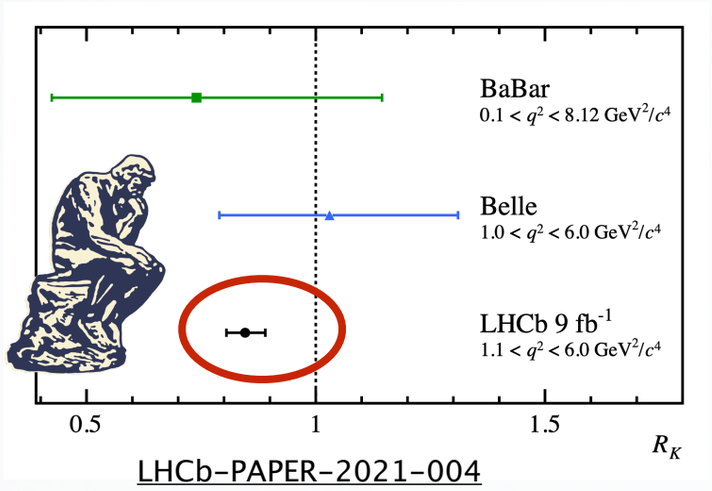

BSM
SM
LHC
Run 3

WANTED: BSM

So far, no strong evidence of new resonance production at the LHC

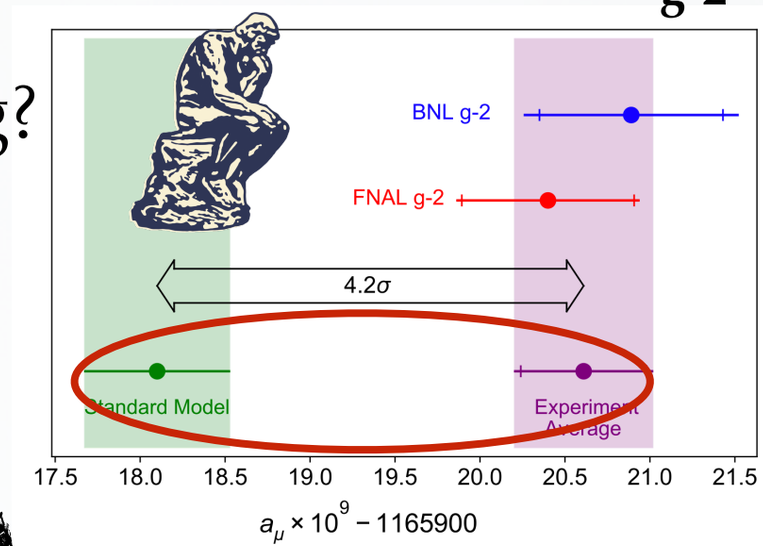
Where is the new physics hiding?

Lepton universality



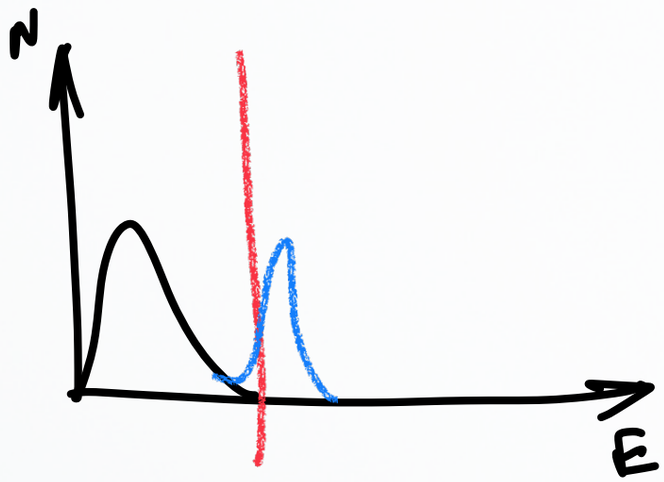
LHCb-PAPER-2021-004

g-2

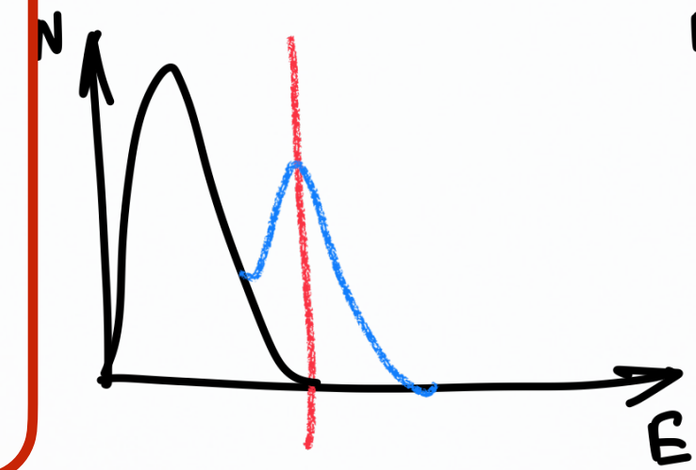


PRL 126 (2021) 141801

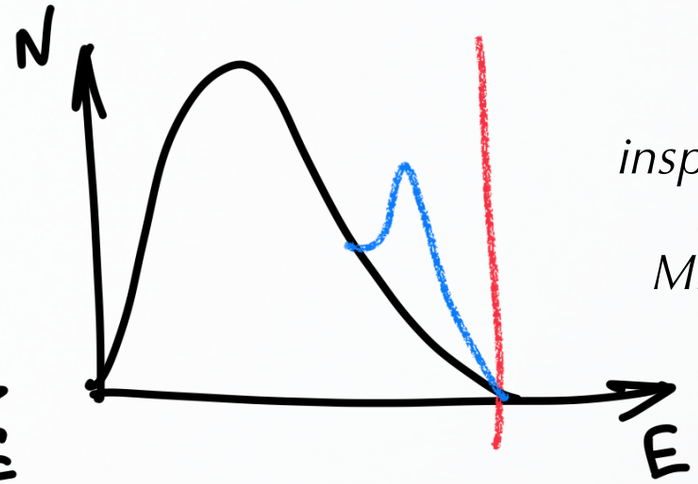
« Just around the corner »
LHC Run 3



« A few blocks away »
HL-LHC

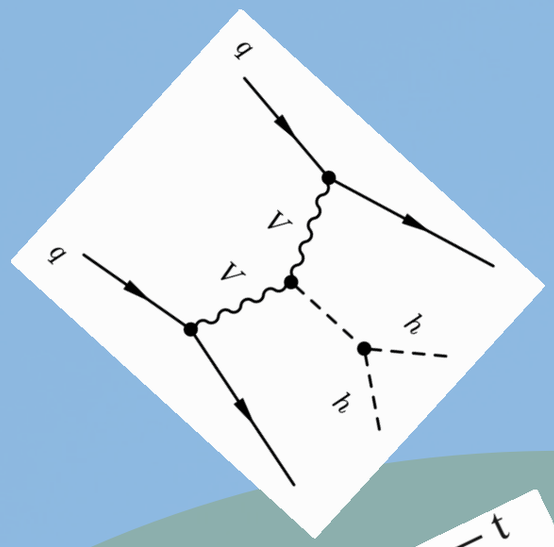


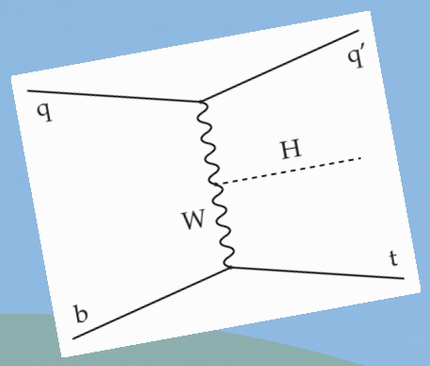
« Miles away »
FCC and other
future colliders

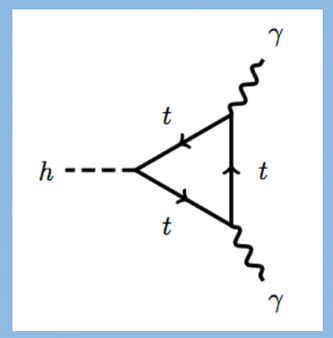


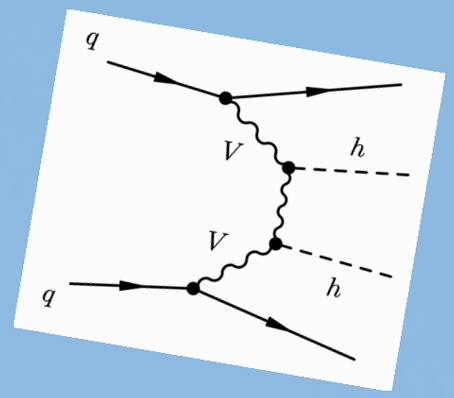
inspired by Ken Mimasu

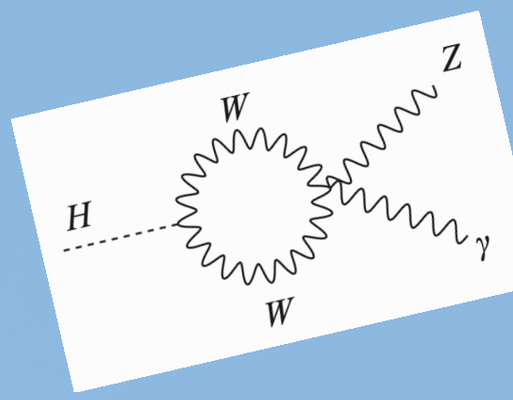
Higgs

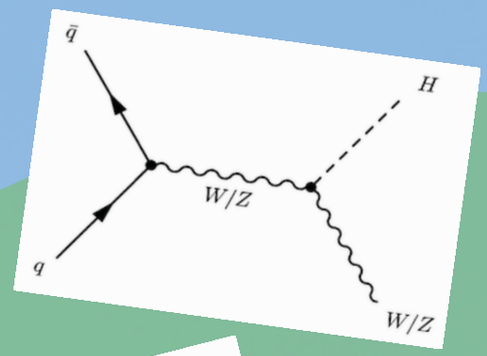

q
V
V
q
h
h

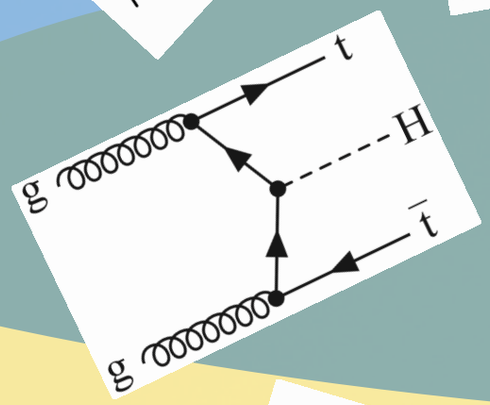

q
q′
H
W
t
b

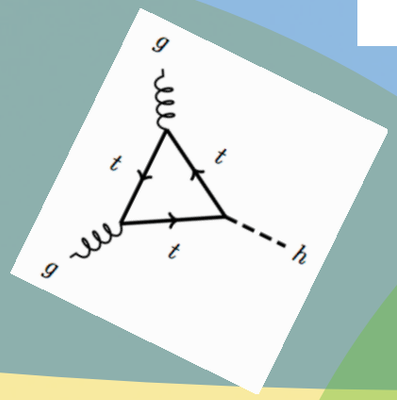

γ
t
h
t
t
γ


q
V
h
V
q
h


Z
W
H
γ
W


q̄
H
W/Z
q
W/Z


t
H
g
t̄
g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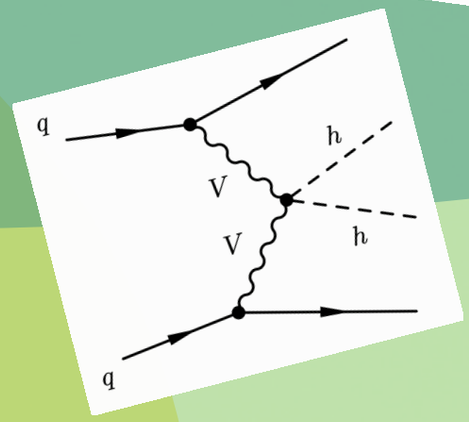
q
h
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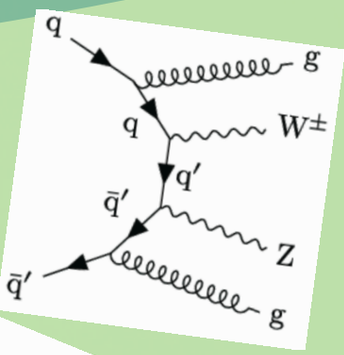
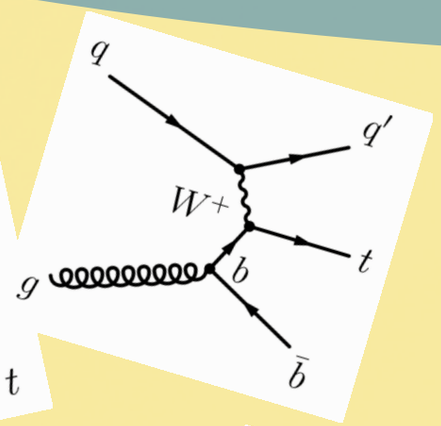
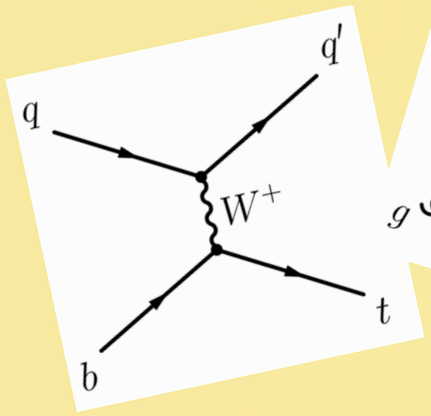

q
g
W±
q
q′
q̄′
Z
q̄′
g


q
q′
W+
t
g
b
b̄


q
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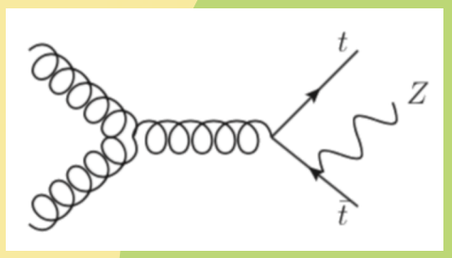
t
Z
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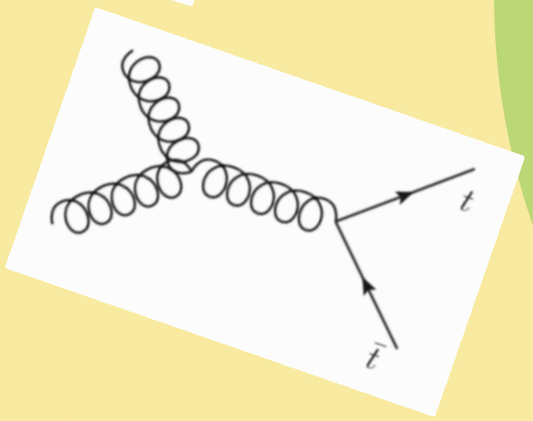
t
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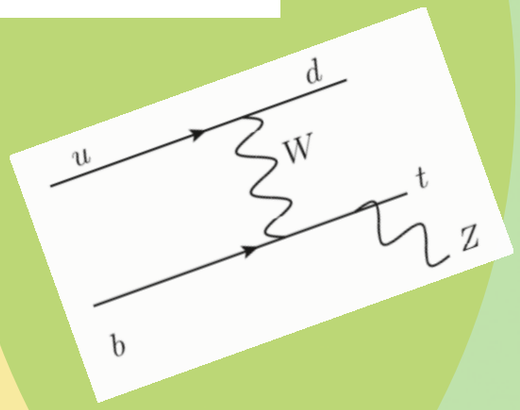
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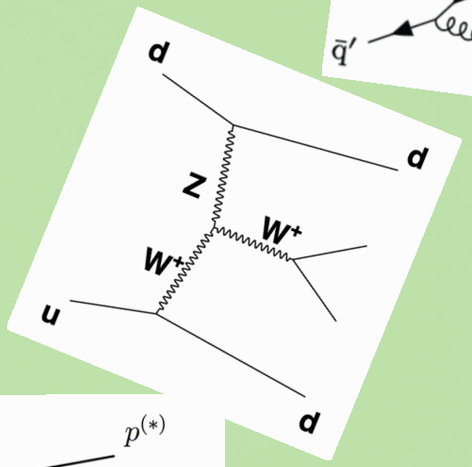
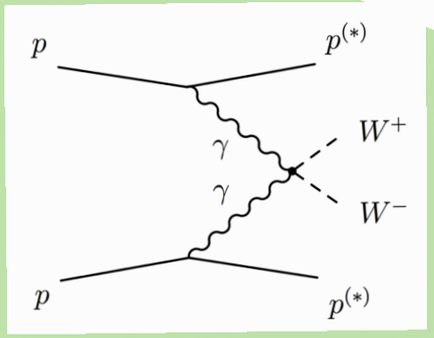
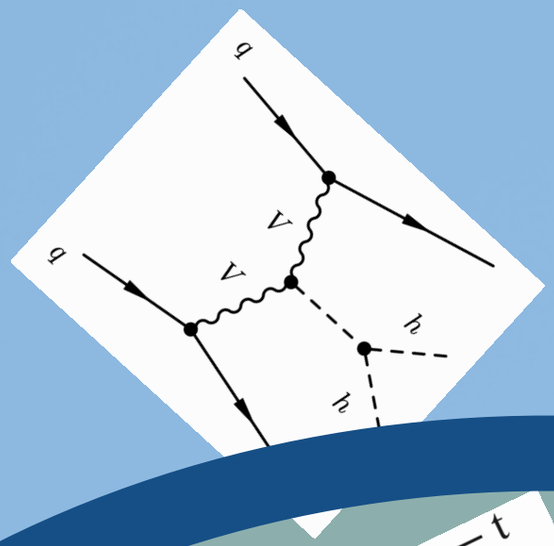

d
d
Z
W+
W+
u
d

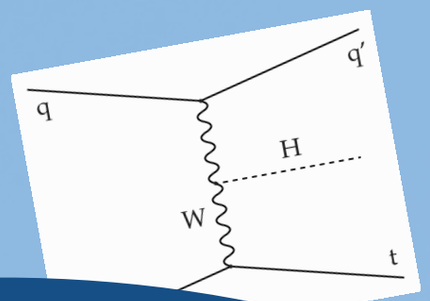

p
p(*)
γ
W+
γ
W−
p
p(*)

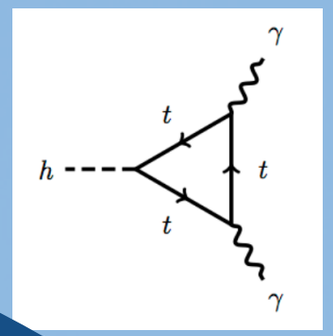
Top

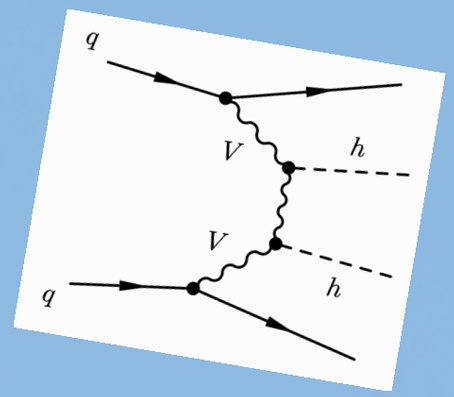
EW

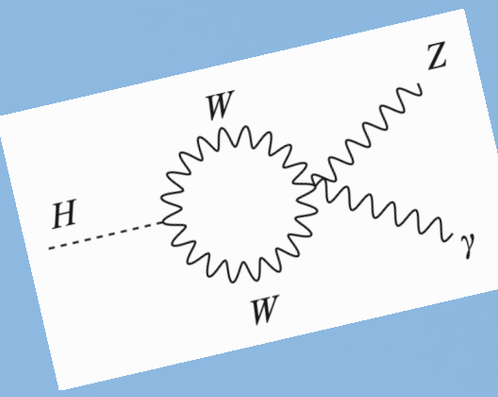
Higgs

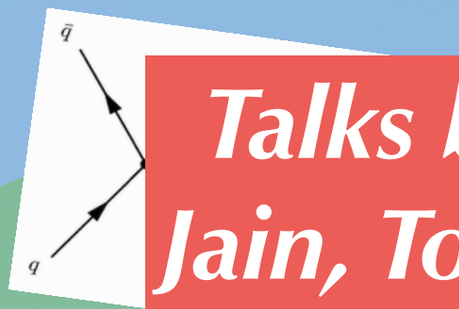


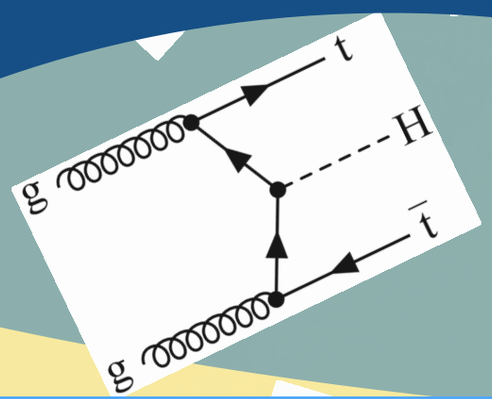


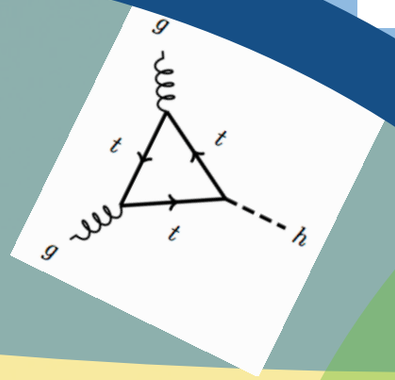


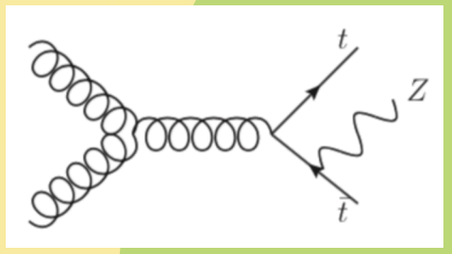


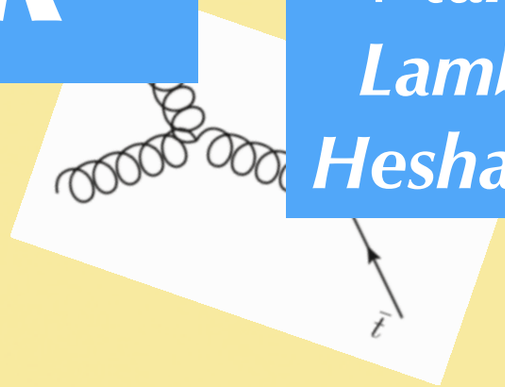


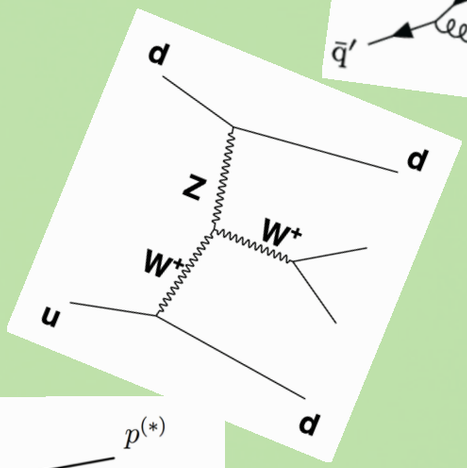


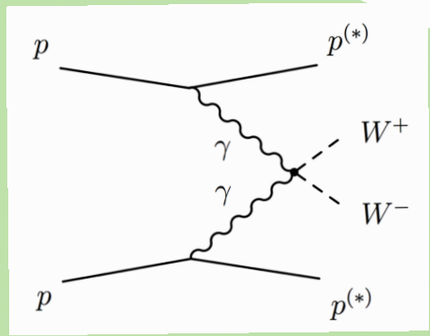












This talk

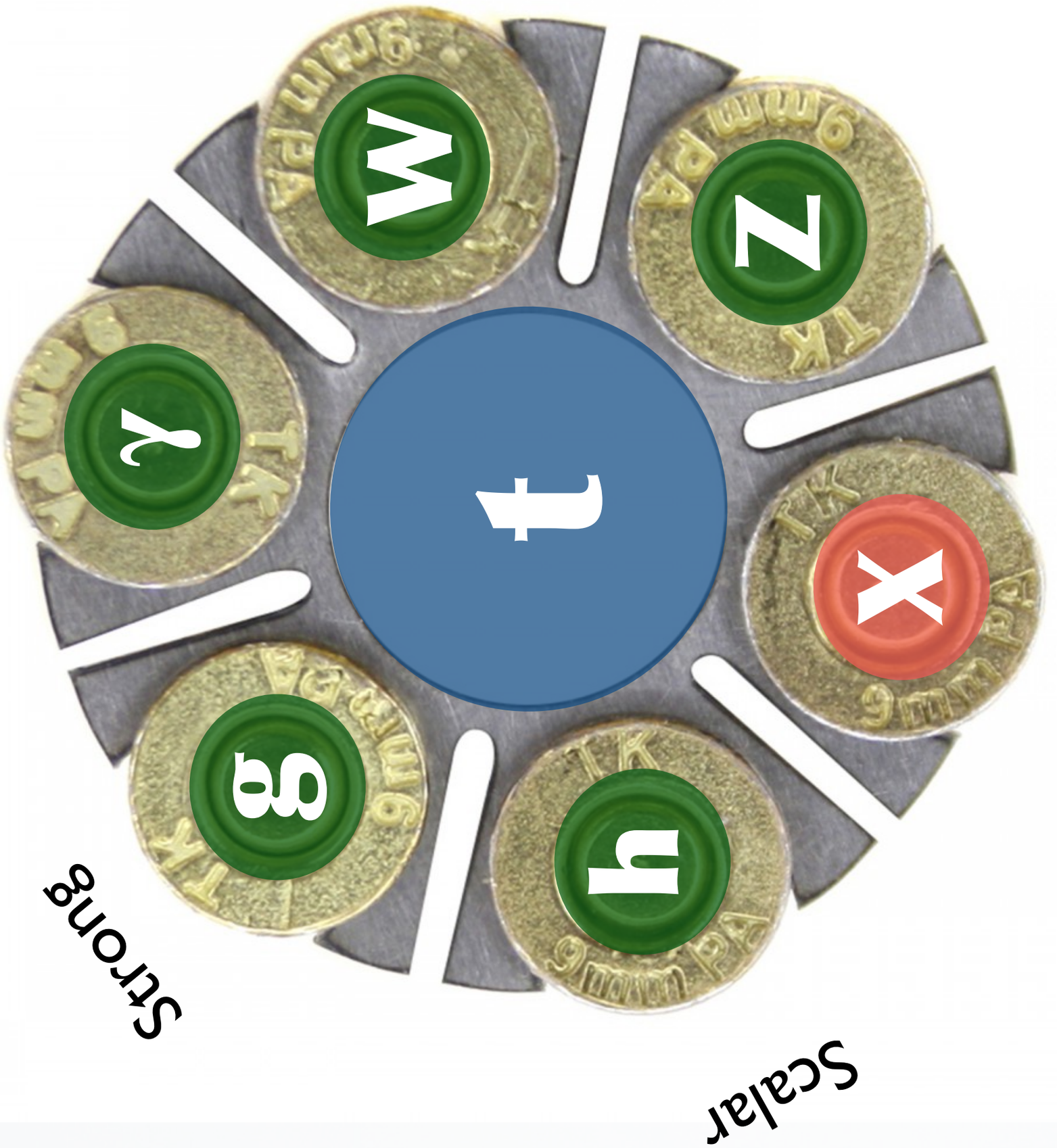
+ talks by Luka Lambrecht and Hesham El Faham

Talks by Sadhya Jain, Tomas Kello, Santiago Paredes, Bugra Bilin, Amandeep Kalsi

Top

EW

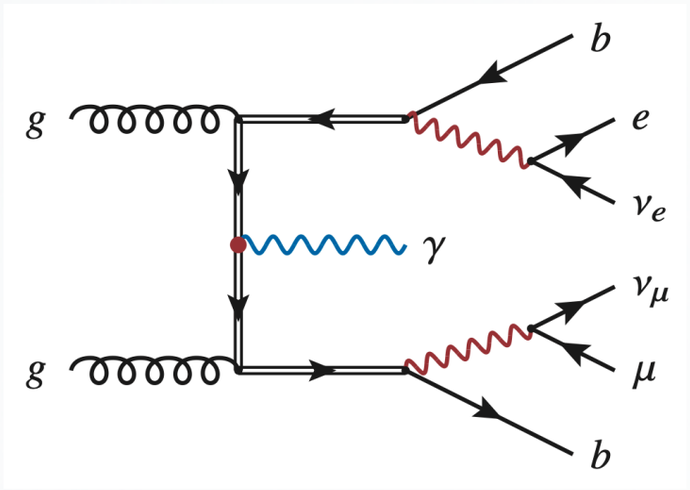
Electroweak

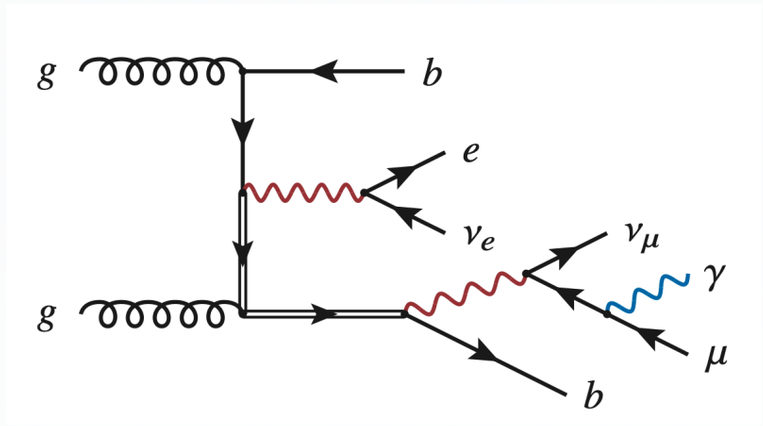


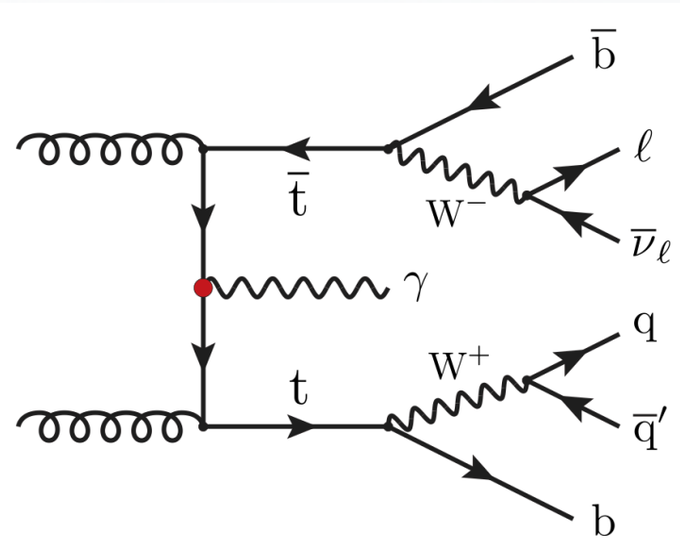
EW

Run 2

ttγ

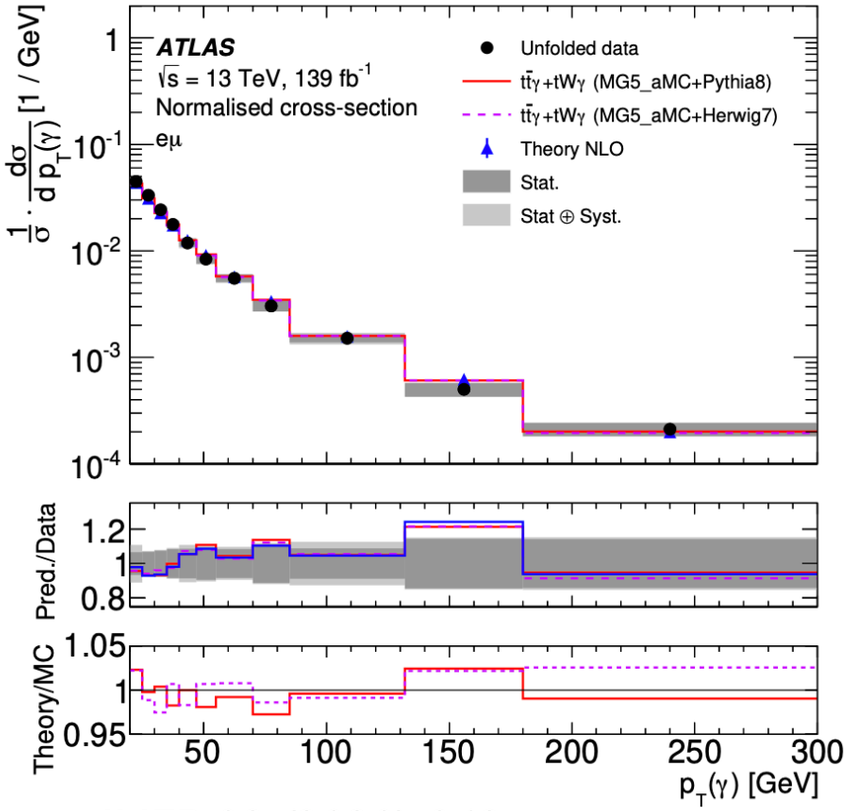




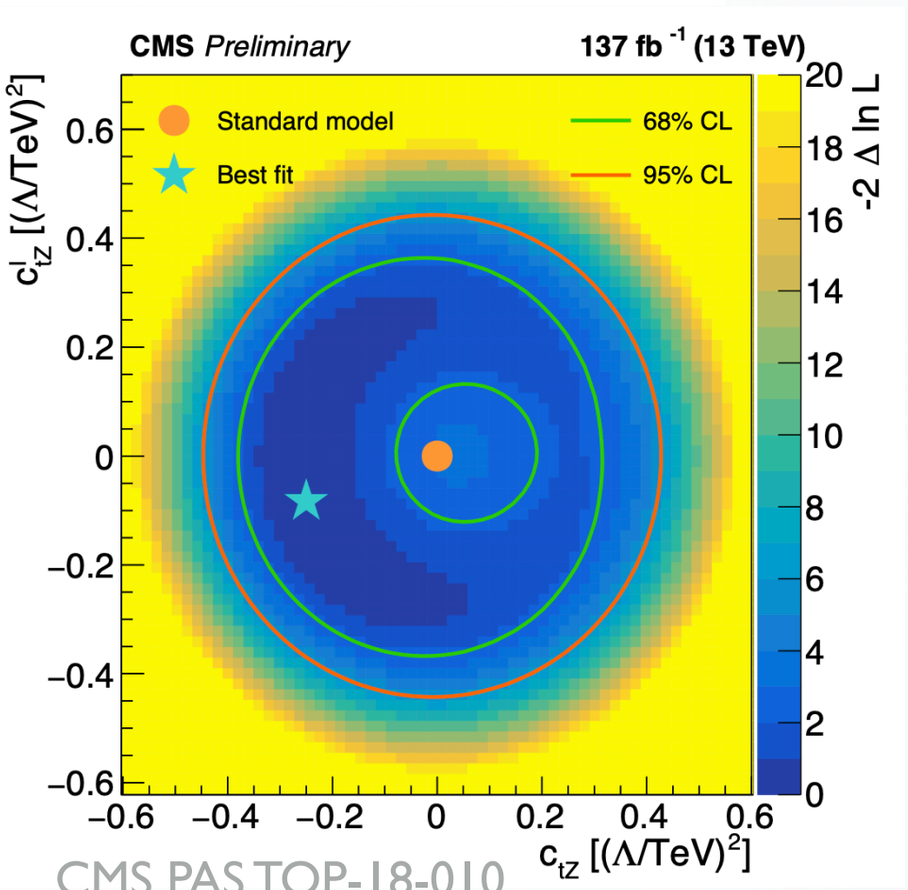


$$C_{tA} \equiv c_w C_{tB} + s_w C_{tW} = \frac{1}{s_w}\left(C_{tW} - c_w C_{tZ}\right)$$

- Sensitive to **top quark electric charge**
- Excellent probe of new physics effects using **photon p_T** spectrum
- **Charge asymmetry** already at LO



JHEP 09 (2020) 049



CMS PAS TOP-18-010

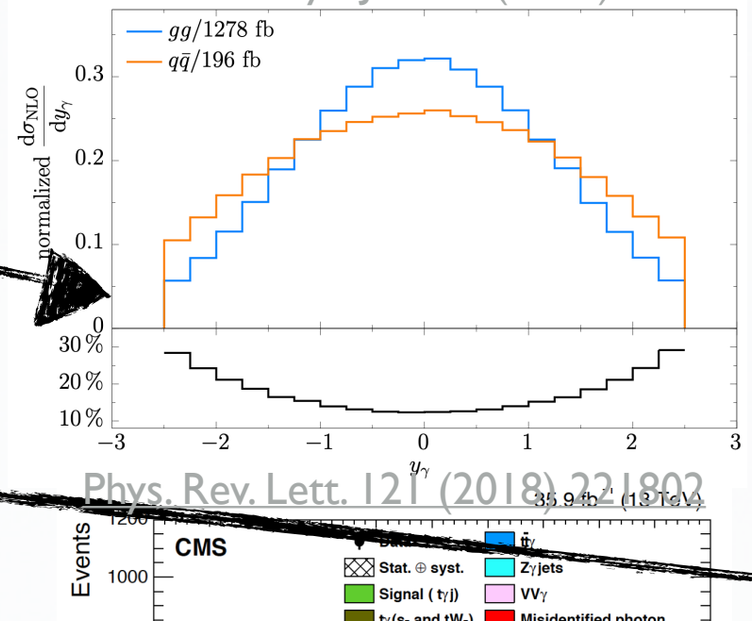
EW

Run 3

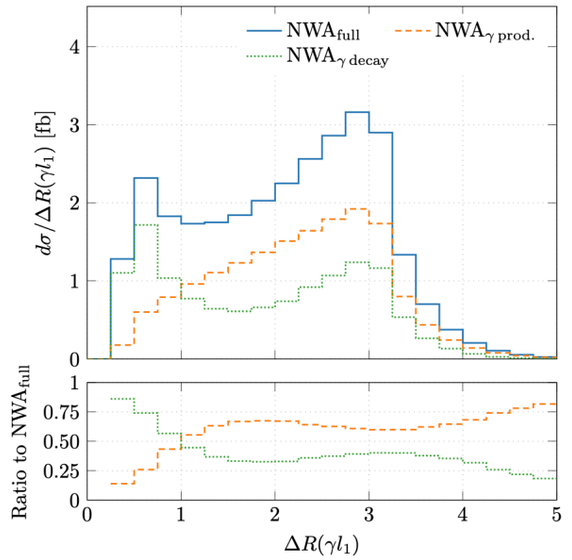
t(t)γ

- Measure **charge asymmetry** in the **ttγ process**
- **Observe** the **tWγ process**
- **Observe** the **ttγγ process**
- Evidence for the **tγ process** at CMS - **observation** possible already in Run 2!
- **Reconstruct** top quark **kinematic variables including photon radiation** - the method is available!
- **Probe** triple/quadric **EFT** gauge couplings
- Use NLO signal simulation

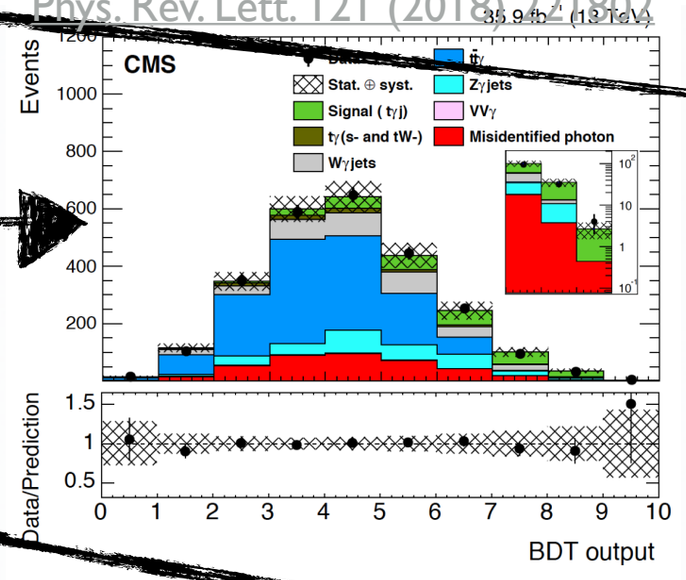
Eur. Phys. J. C 79 (2019) 189



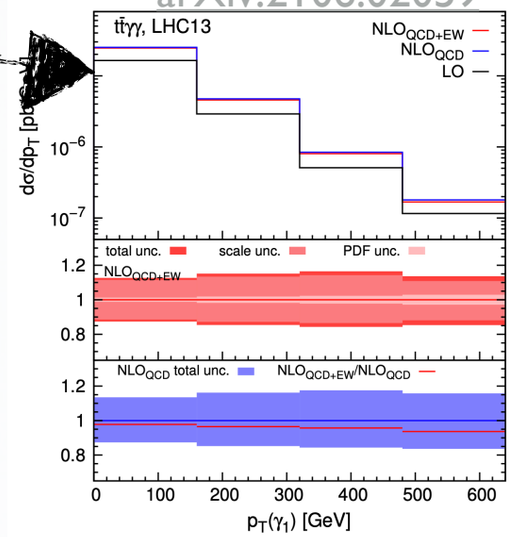
JHEP 03 (2020) 154



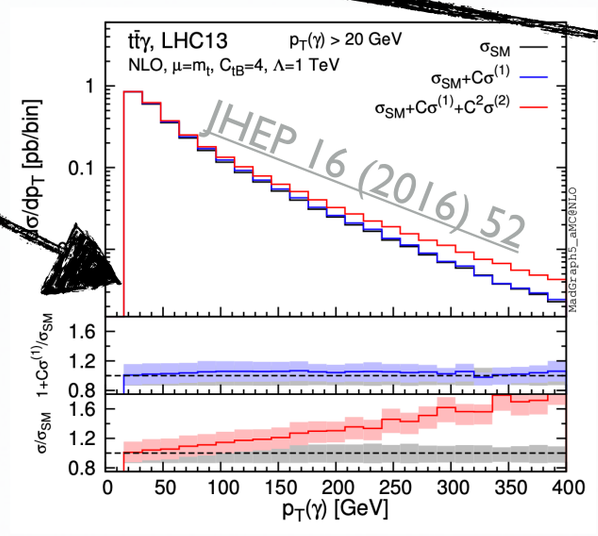
Phys. Rev. Lett. 121 (2018) 221802



arXiv:2106.02059



JHEP 16 (2016) 52



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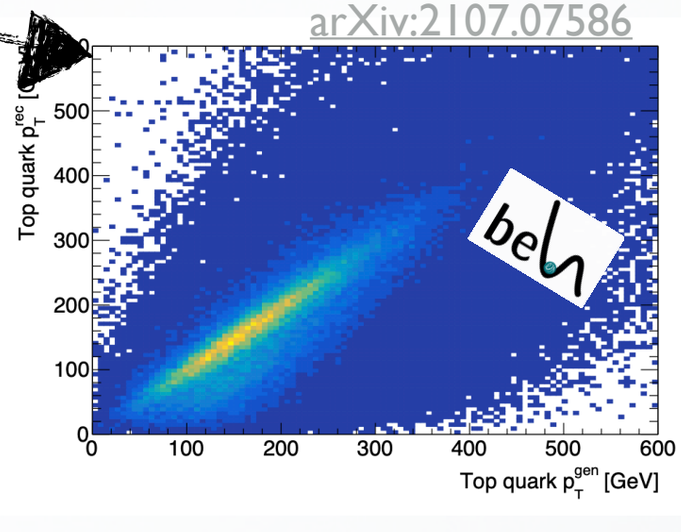
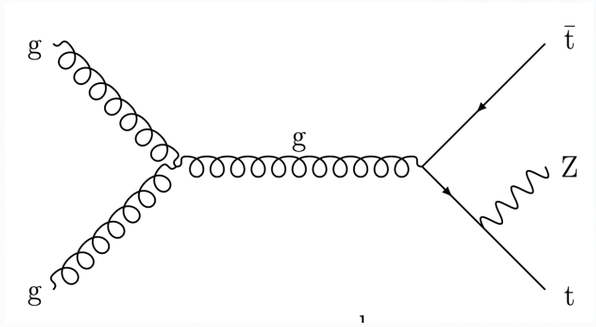
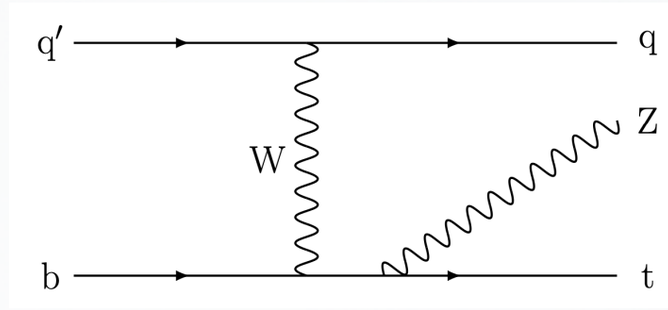


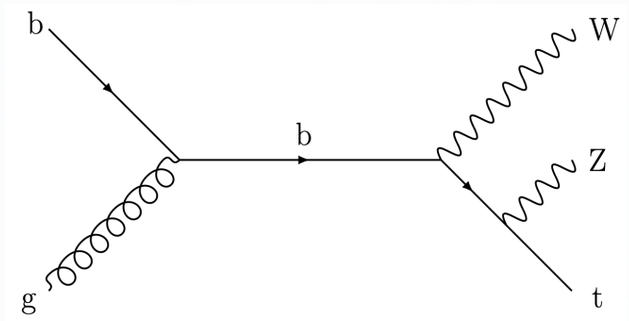
EW

Run 2 ttZ, tZq, tWZ

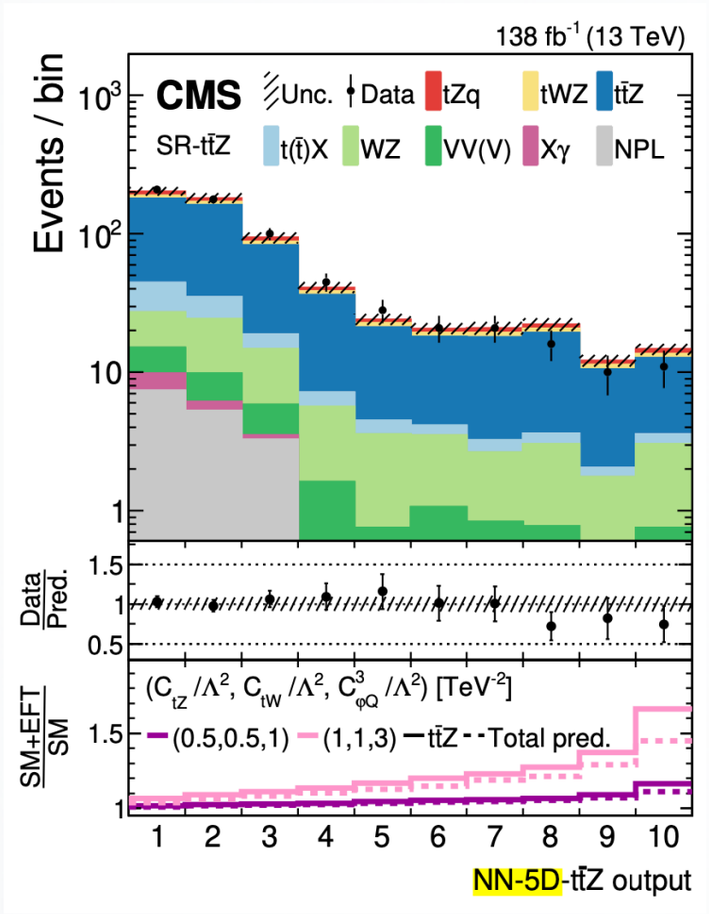
- Probe **EW couplings** of the top quark
- Sensitive to multiple **EFT** operators
- **Simultaneous** study of several top-Z processes
- Likelihood-free inference NNs to **discriminate between EFT and SM**
- Includes **5D** EFT fits





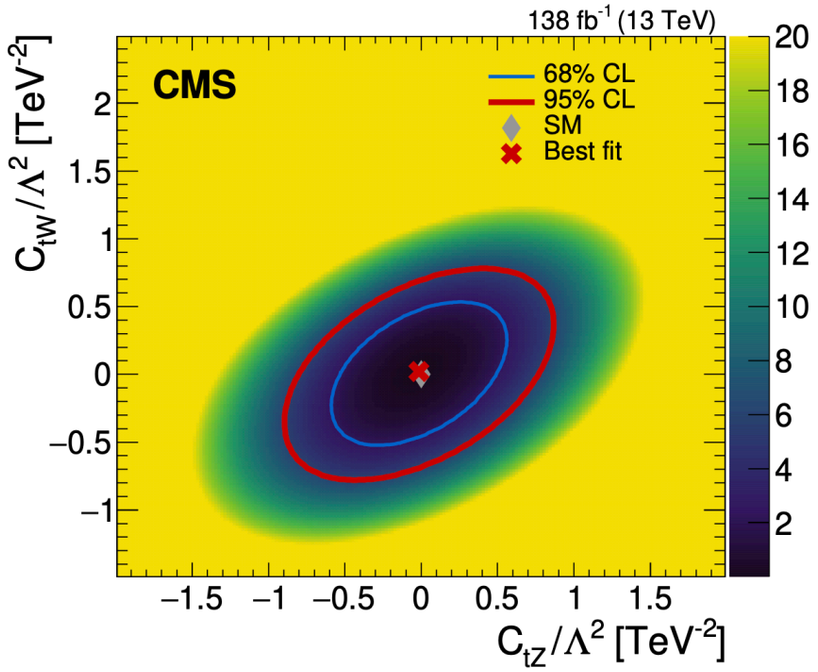


More on tWZ in Hesham El Faham's talk



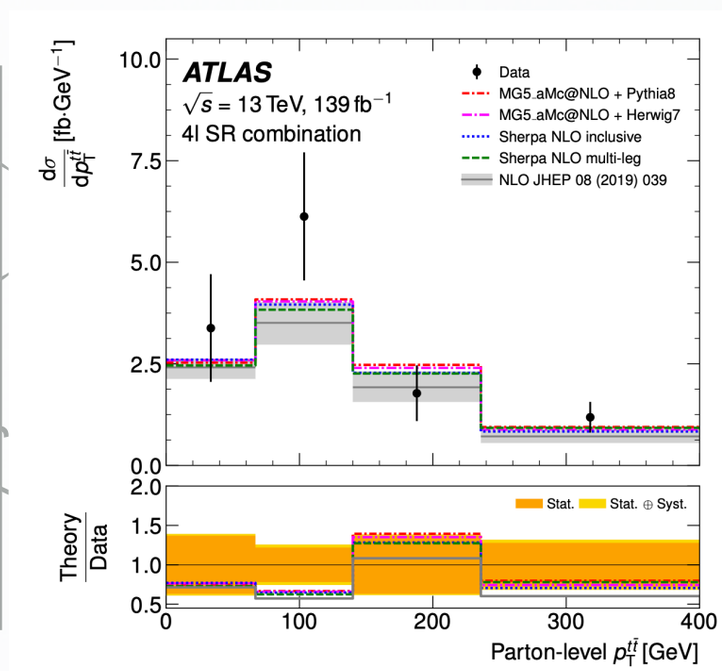
arXiv:2107.13896

Phys. Rev. D 98 (2018) 052004



$$\sigma(pp \to t\bar{t}Z) = 0.99 \pm 0.05\,(\text{stat.}) \pm 0.08\,(\text{syst.})\ \text{pb}.$$

Eur. Phys. J. C 81 (2021) 737



EW

Run 2

tZq

Luka Lambrecht, Didar Dobur

- **Most precise measurement** of the **inclusive** and **differential** cross sections
- Measurement of top/antitop **cross section ratio** and **spin asymmetry**

CMS PAS TOP-20-010

≈12%!

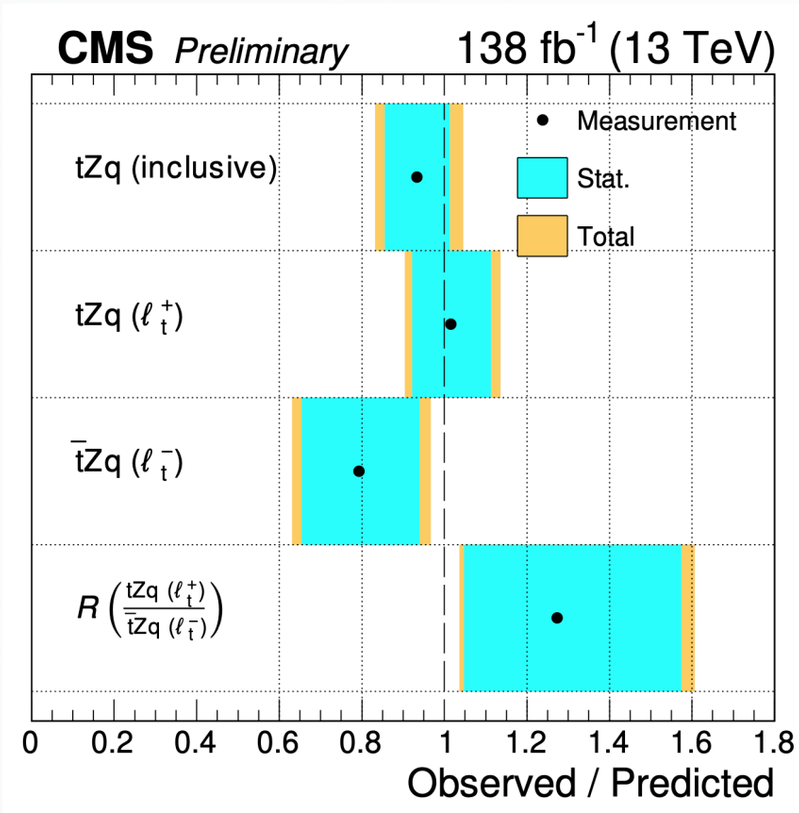
$$\sigma_{tZq} = 87.9\ ^{+7.5}_{-7.3}\ (stat)\ ^{+7.3}_{-6.0}\ (syst)\ fb\ .$$

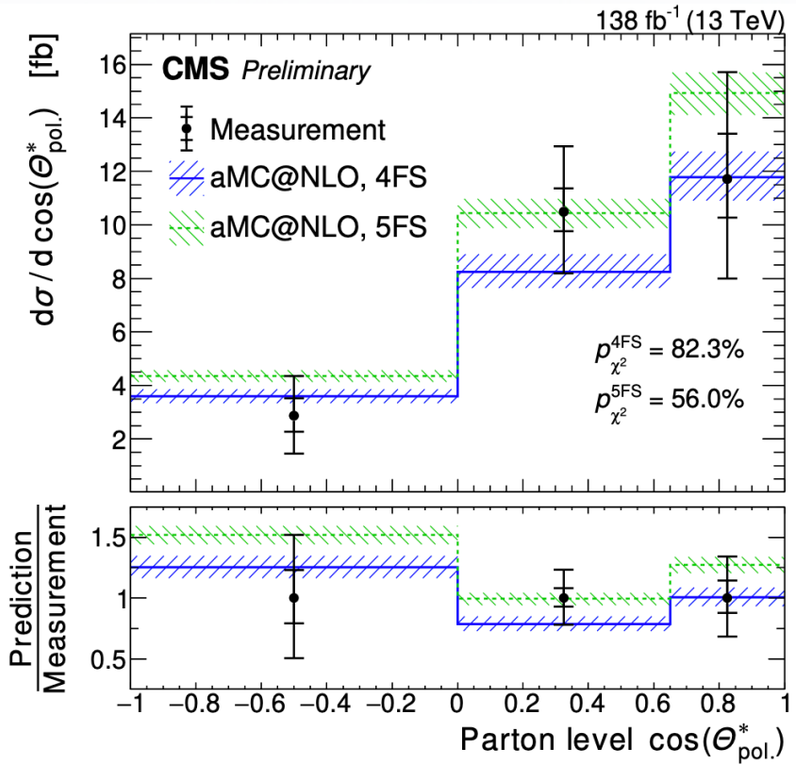
$$\sigma_{tZq(\ell_t^+)} = 62.2\ ^{+5.9}_{-5.7}\ (stat)\ ^{+4.4}_{-3.7}\ (syst)\ fb\ ,$$

$$\sigma_{\bar{t}Zq(\ell_t^-)} = 26.1\ ^{+4.8}_{-4.6}\ (stat)\ ^{+3.0}_{-2.8}\ (syst)\ fb\ ,$$

$$R = 2.37\ ^{+0.56}_{-0.42}\ (stat)\ ^{+0.27}_{-0.13}\ (syst)\ .$$

See Luka Lambrecht's talk





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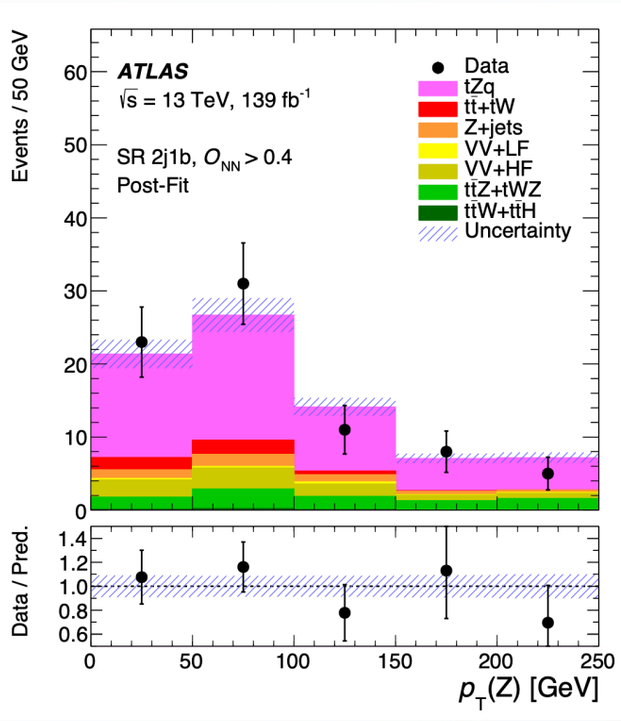
$97 \pm 13\ (stat.) \pm 7\ (syst.)\ fb$

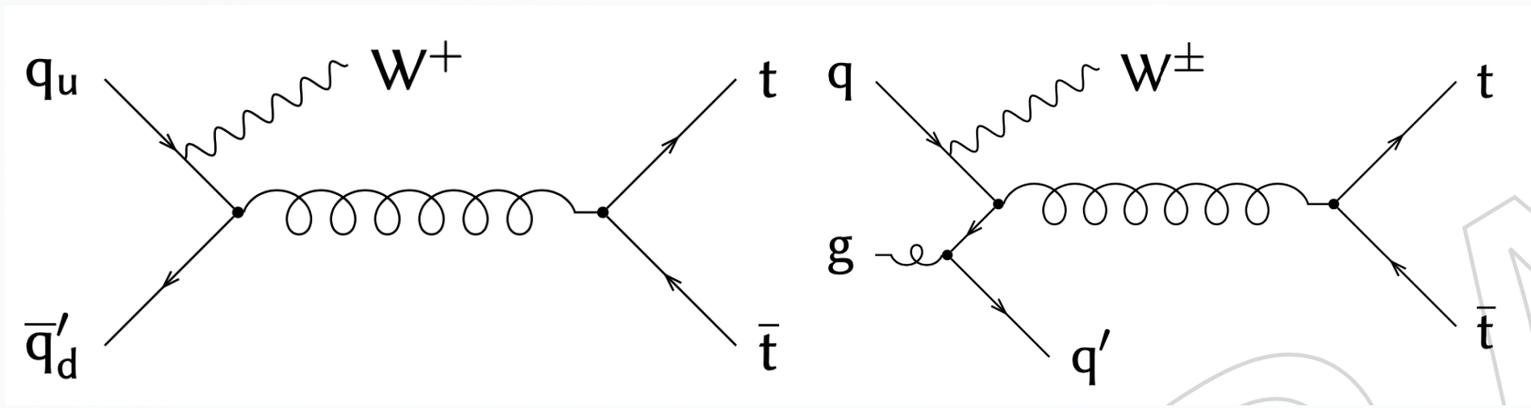
≈14%

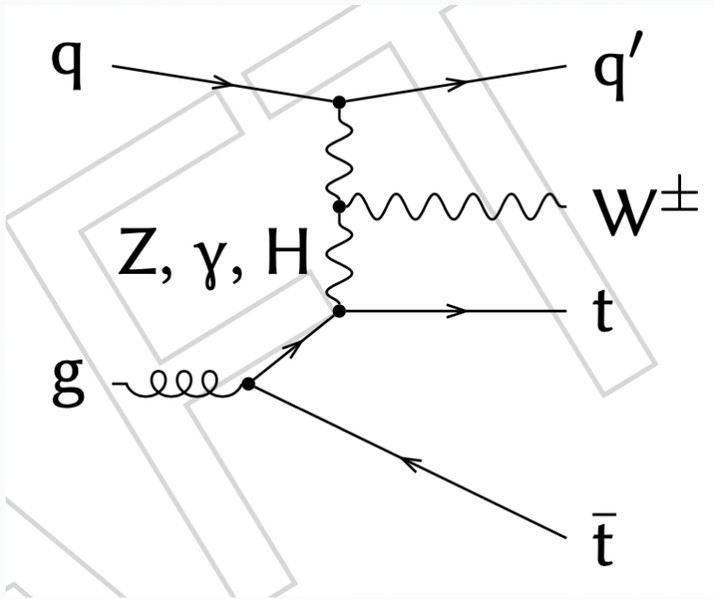


EW

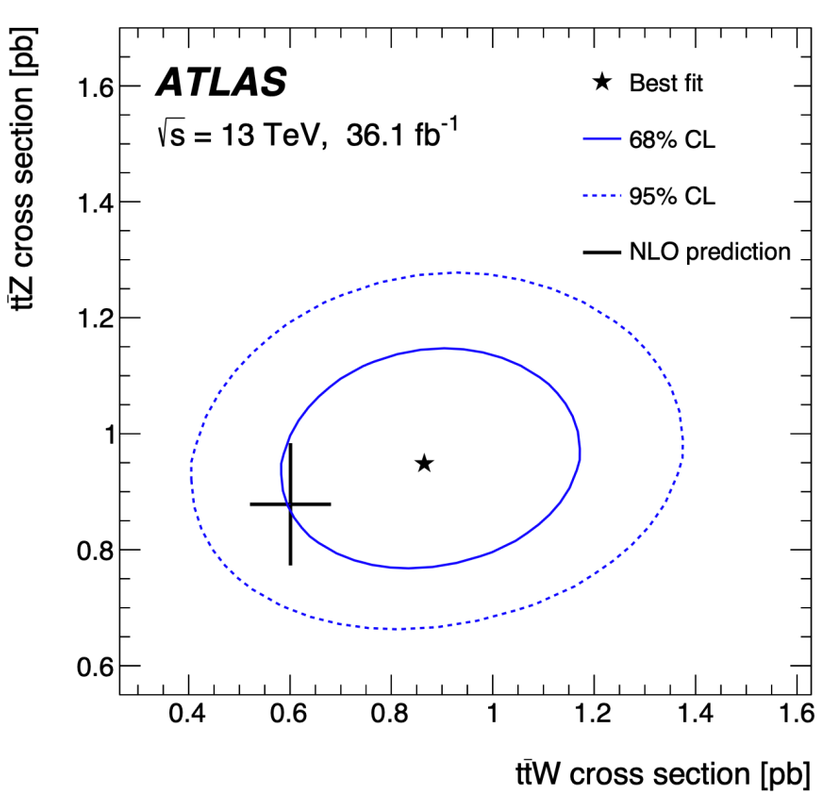
Run 2

ttW





- Distinctive feature: W bosons are not radiated from top quarks
- Predominantly produced in **qqbar** and **gq-induced** processes
- Sizeable **charge asymmetry** at LO
- Significant **NLO EW** contributions in production cross section



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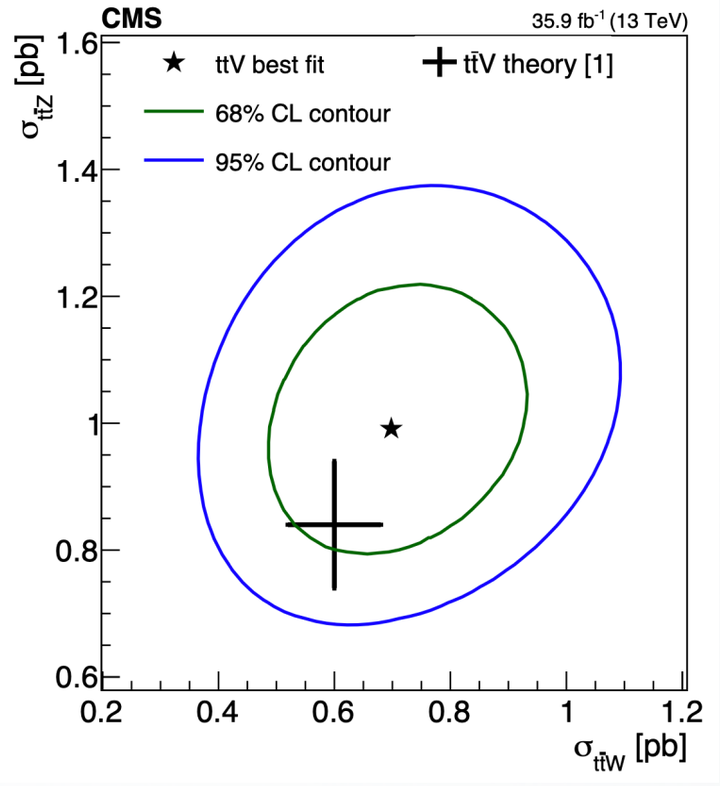

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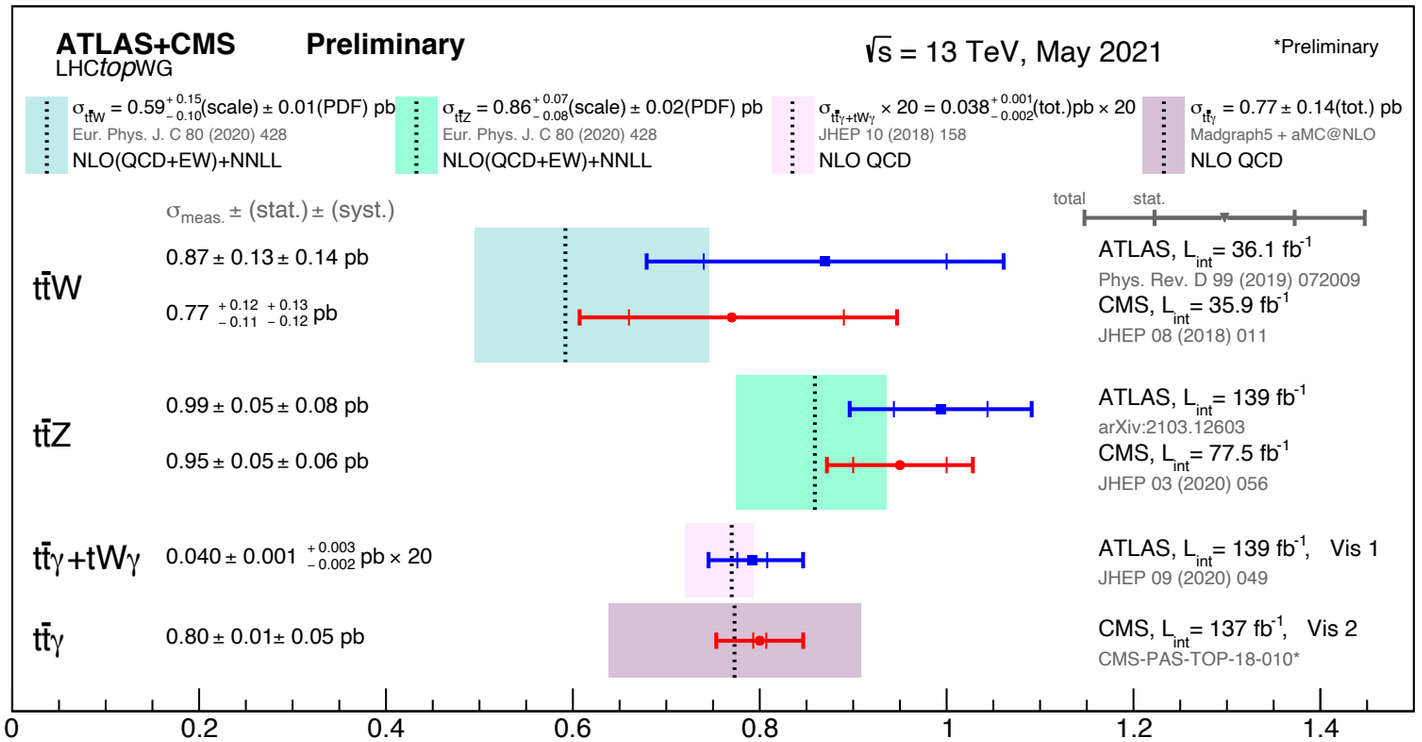
EW

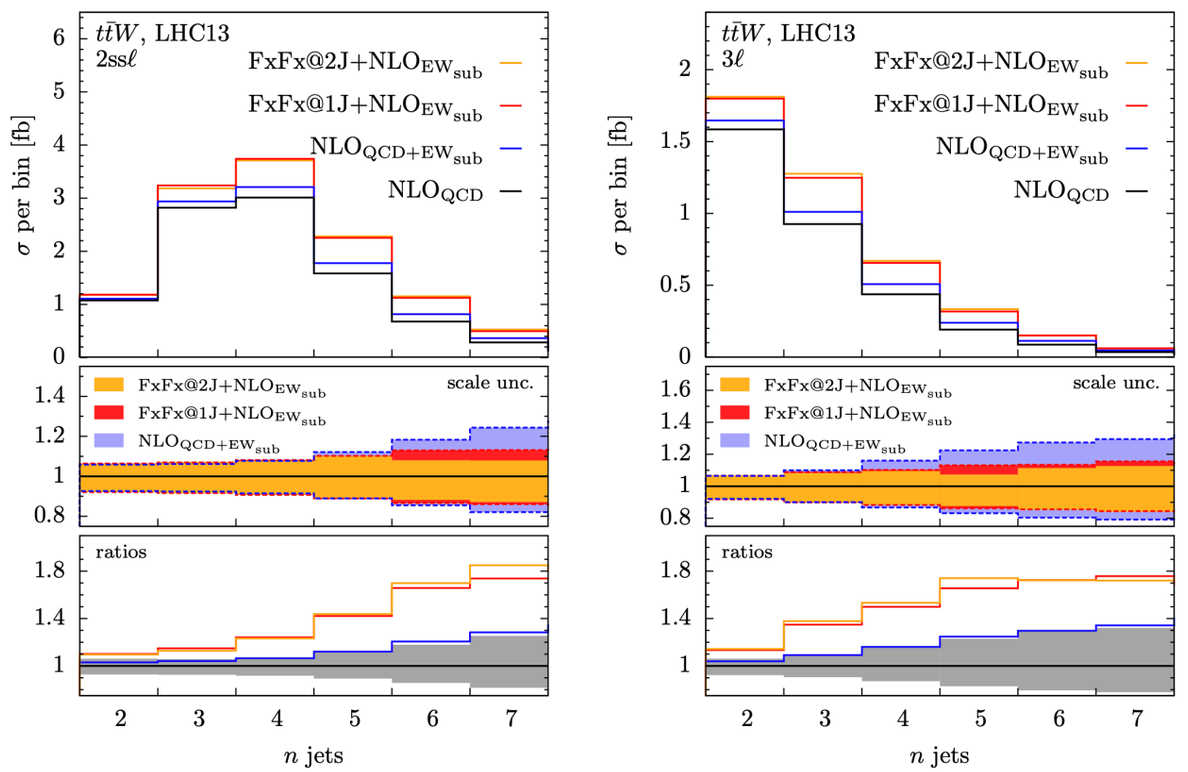
Run 3

t(t)Z/W

- **t(t)Z**:
  - **improve** tZq cross section precision by adding more data
  - **tackle systematic uncertainties** in ttZ measurement
  - search for **rare tWZ production**
- **ttW**:
  - measure **differential** cross sections
  - use **updated** theoretical predictions (improved FxFx merging + NLO EW)
  - perform an **EFT** analysis
- **Combined EFT interpretation** of all **t(t)V** processes



arXiv:2108.07826



Strong

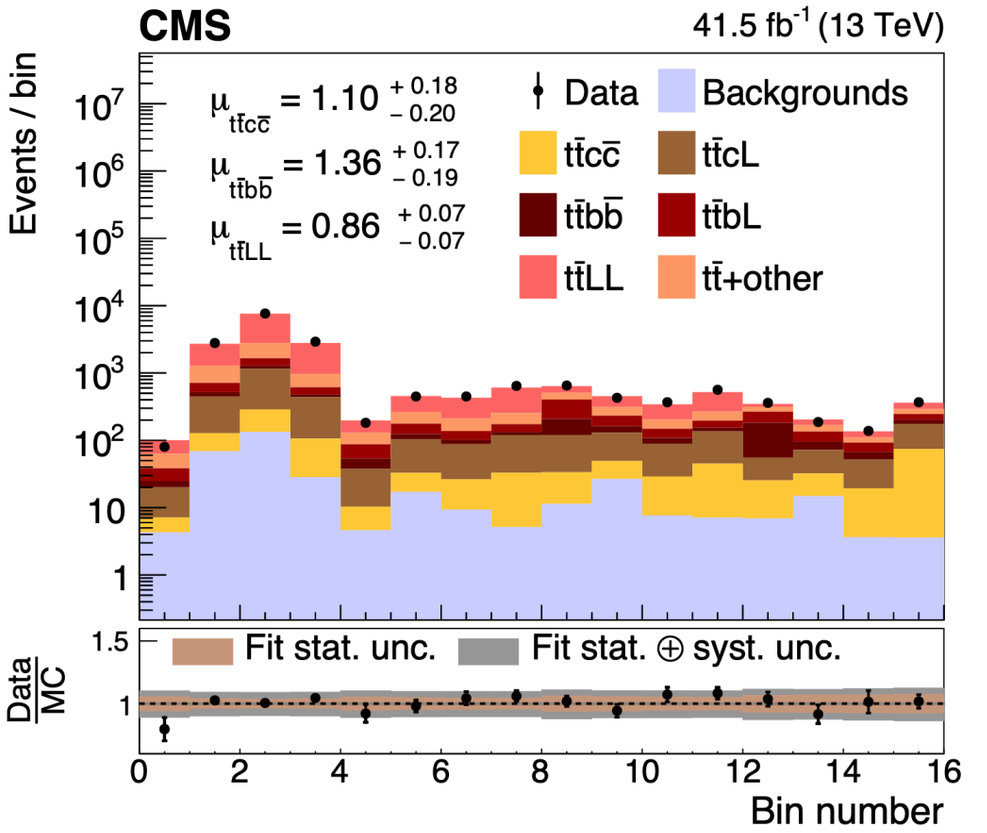
Run 2

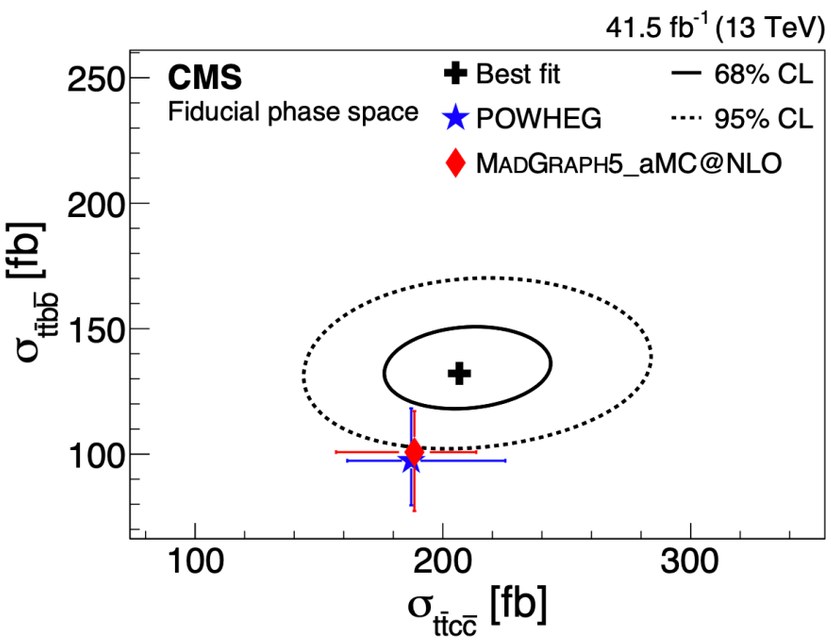
tt+cc

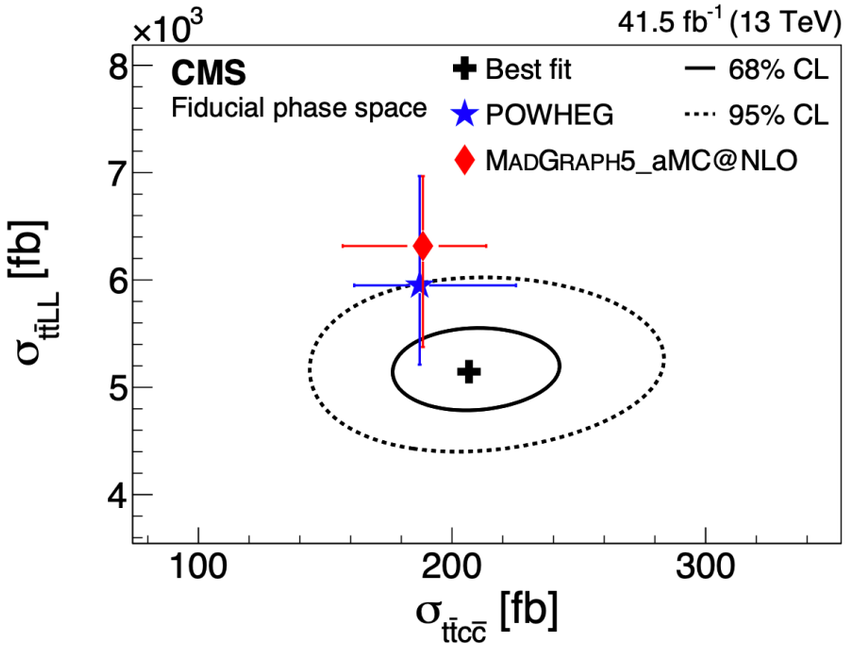
Seth Moortgat,
Jorgen D'Hondt

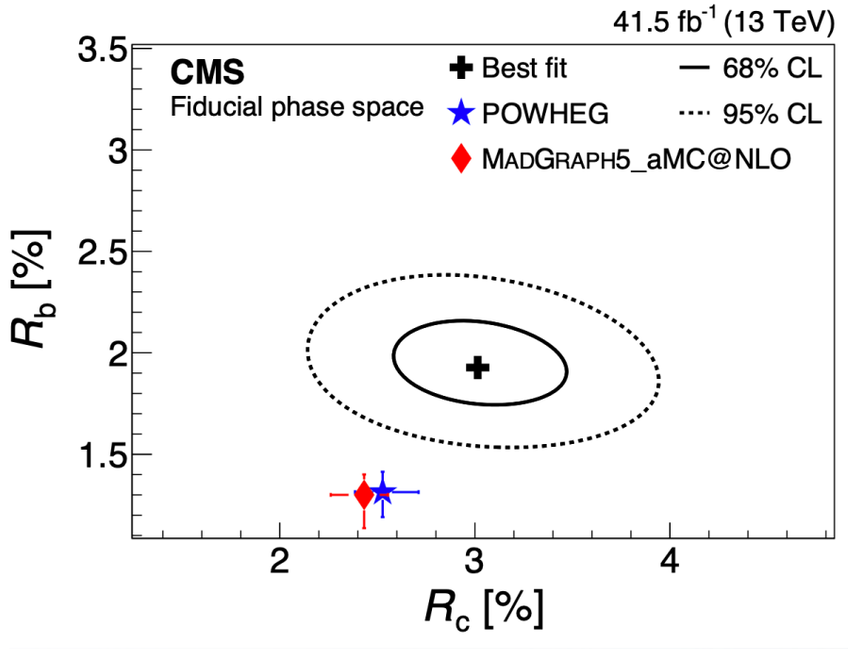
Phys. Lett. B. 820 (2021) 136565

- **First measurement** of the tt+cc cross section!
- **Simultaneous** extraction of tt+bb, tt+cc and tt+LF cross sections
- Improve tt+cc extraction with **dedicated c-jet tagging methods** and its **in-situ calibration**
- **Next**:
  - full Run 2 analysis
  - include EFT interpretation
  - compare to (if any) improved theoretical predictions



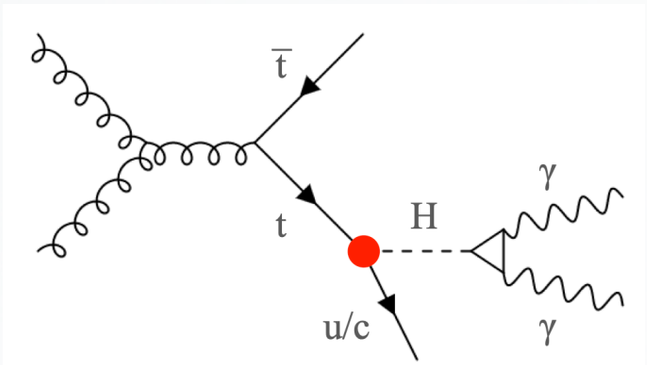


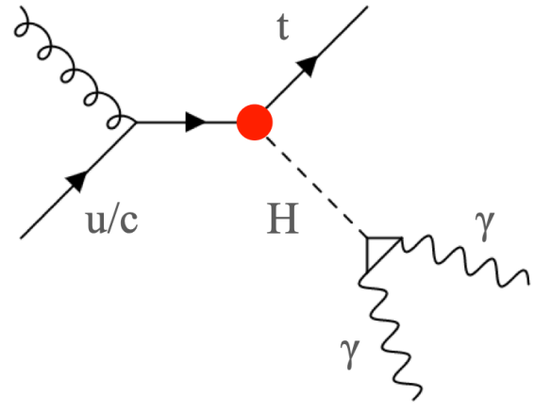


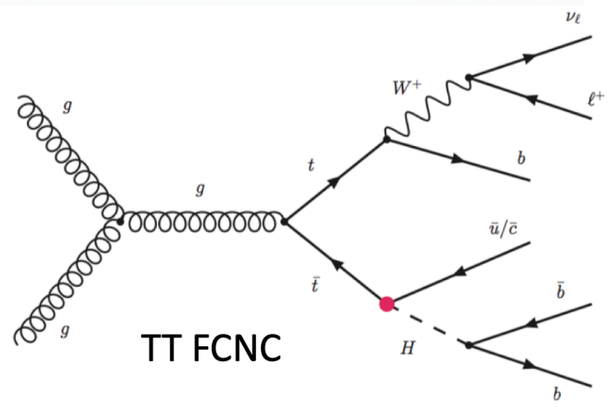


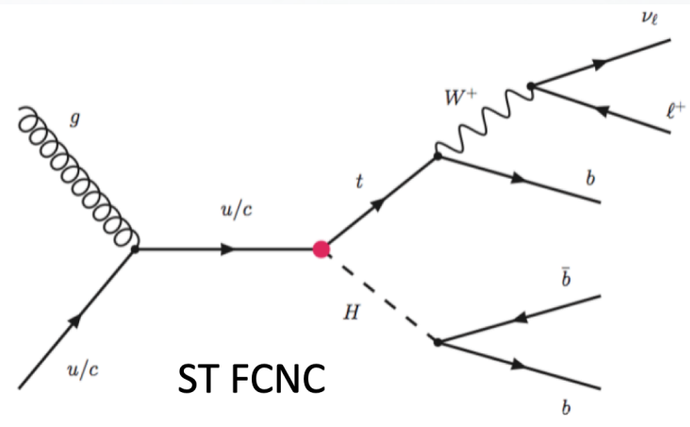
Scalar X

Run 2 Top-Higgs FCNC





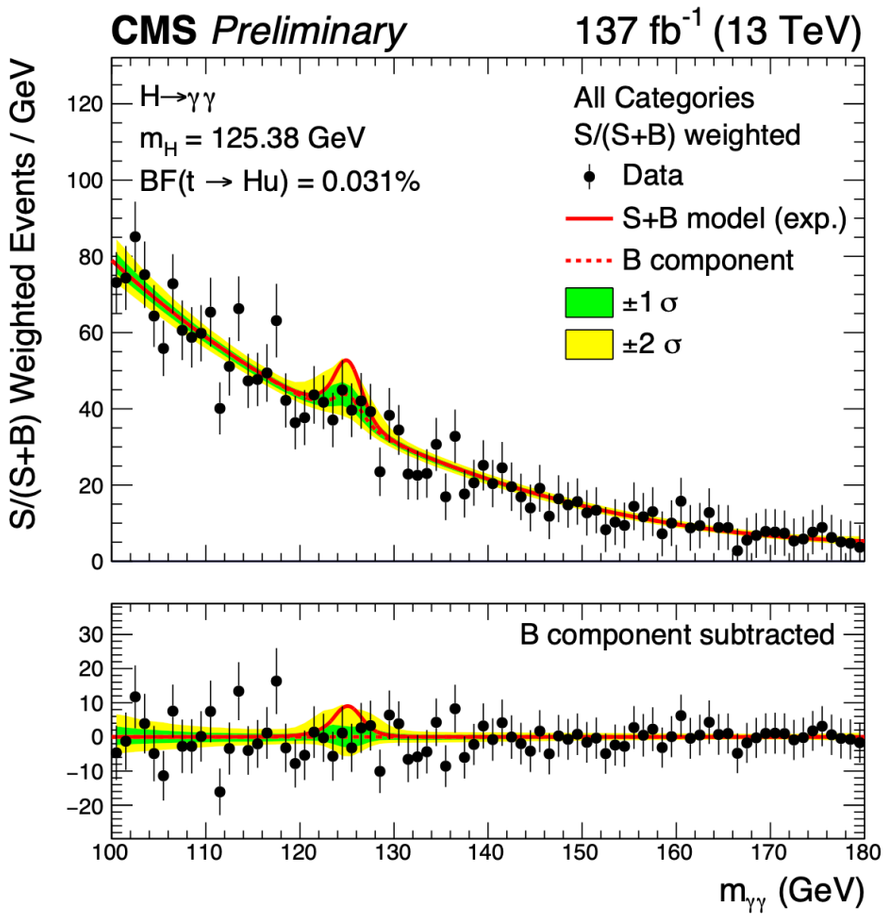


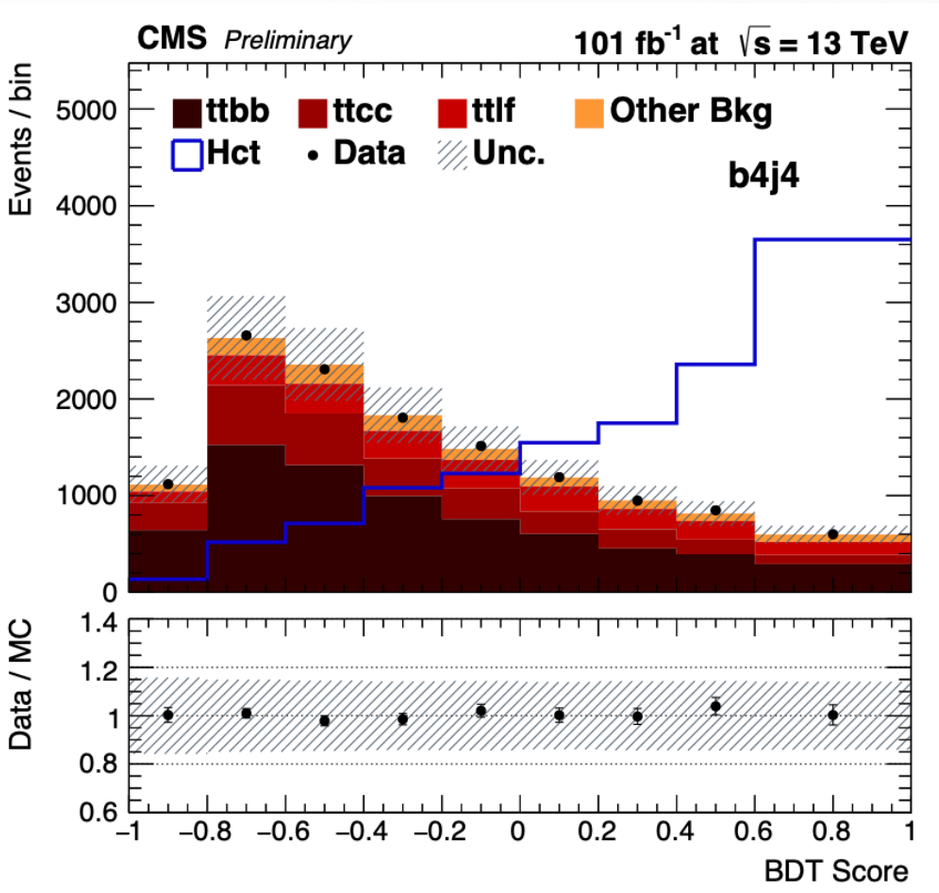


CMS PAS TOP-20-007

CMS PAS TOP-19-002

- **Best limits** on the top-Higgs FCNC couplings
- Study of **H→γγ** and **H→bb** channels
- Towards the **combination** of all channels
- **EFT@NLO** analysis is foreseen in Run 3

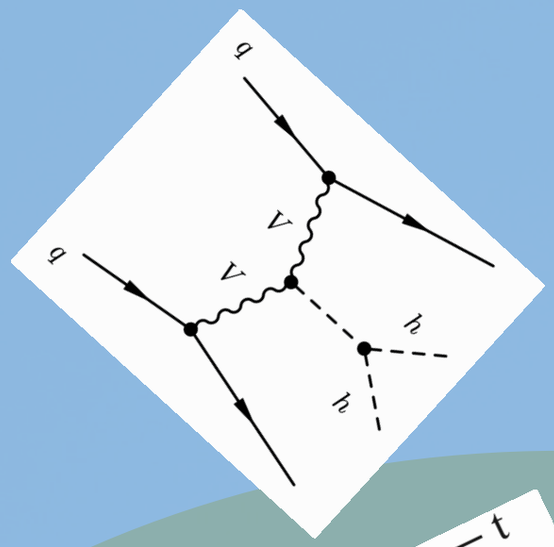


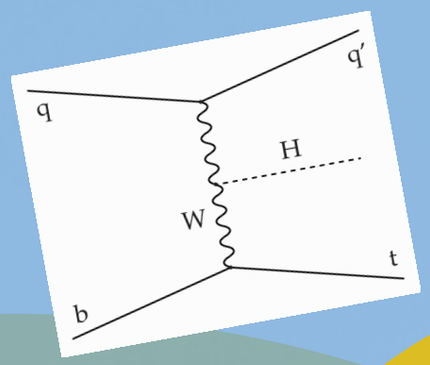


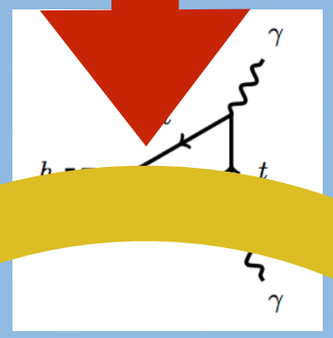
B(t→Hu) < 1.9 x10-4 @95% CL
B(t→Hc) < 7.3 x10-4 @95% CL

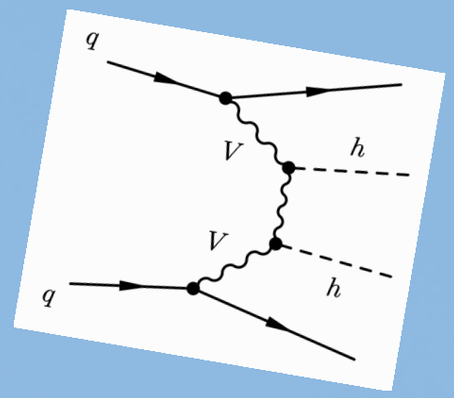
B(t→Hu) < 7.9 x10-4 @95% CL
B(t→Hc) < 9.4 x10-4 @95% CL

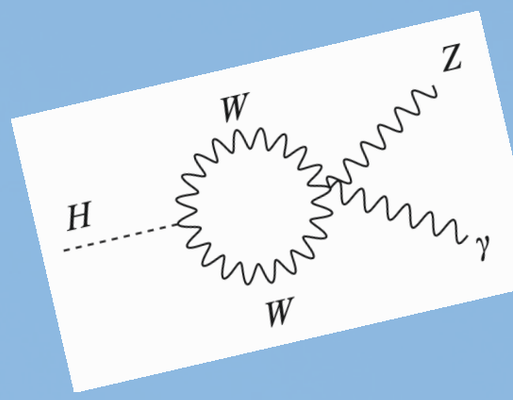
Higgs

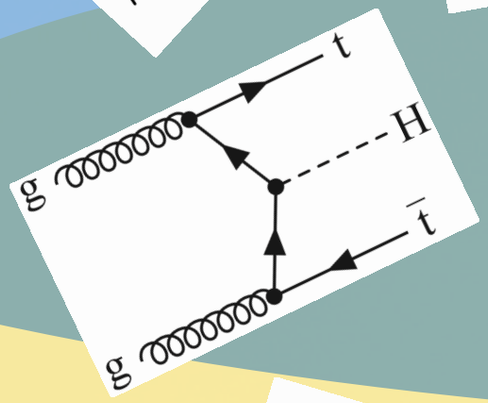


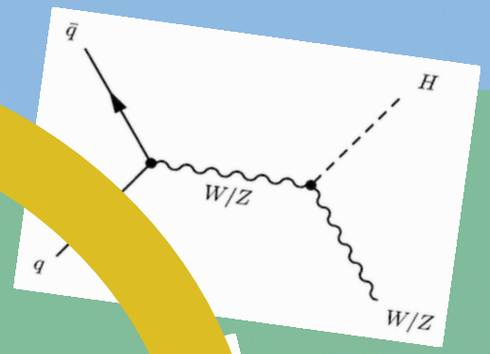




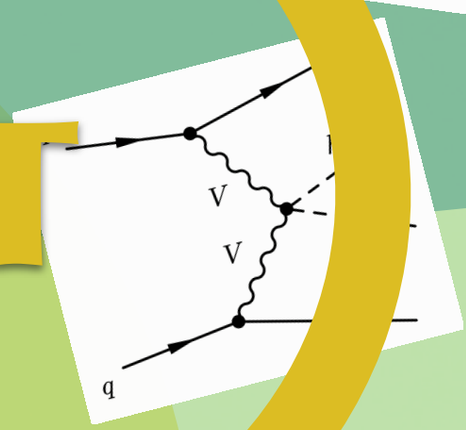


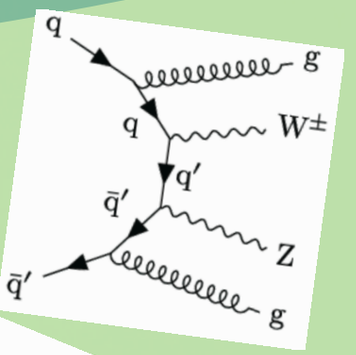


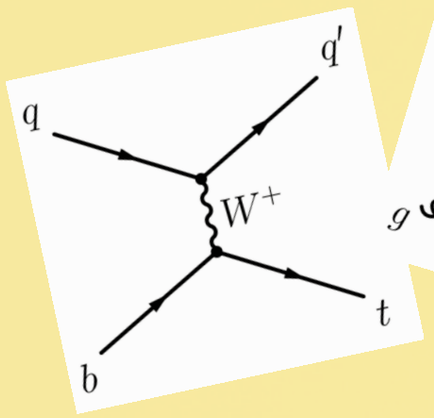


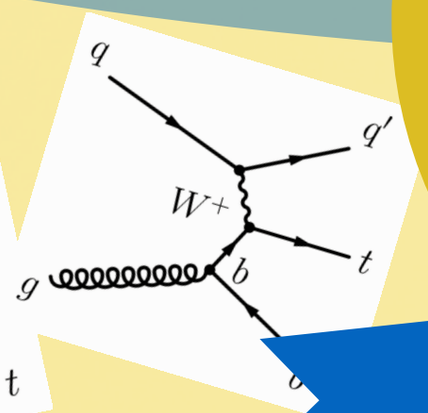


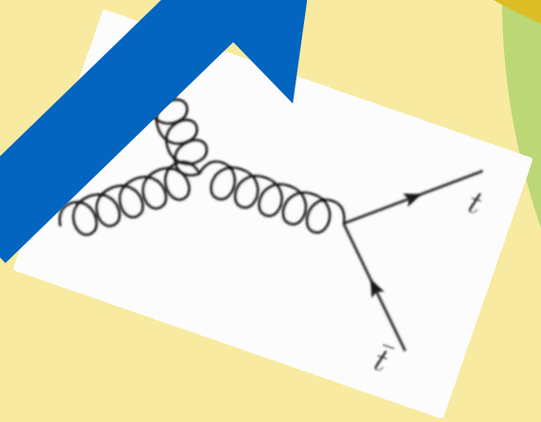
EFT

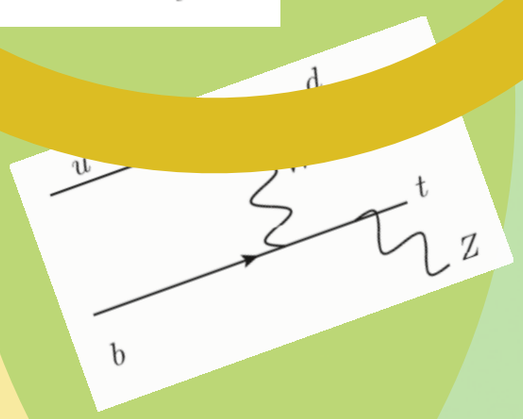


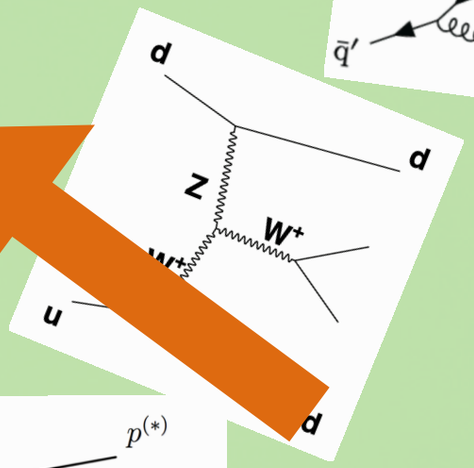


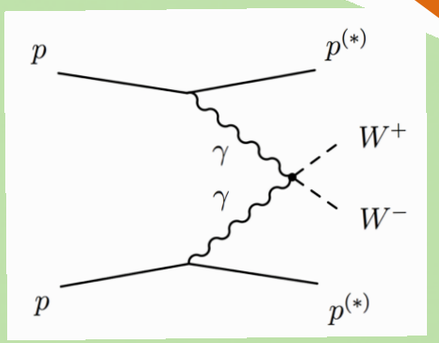












Top

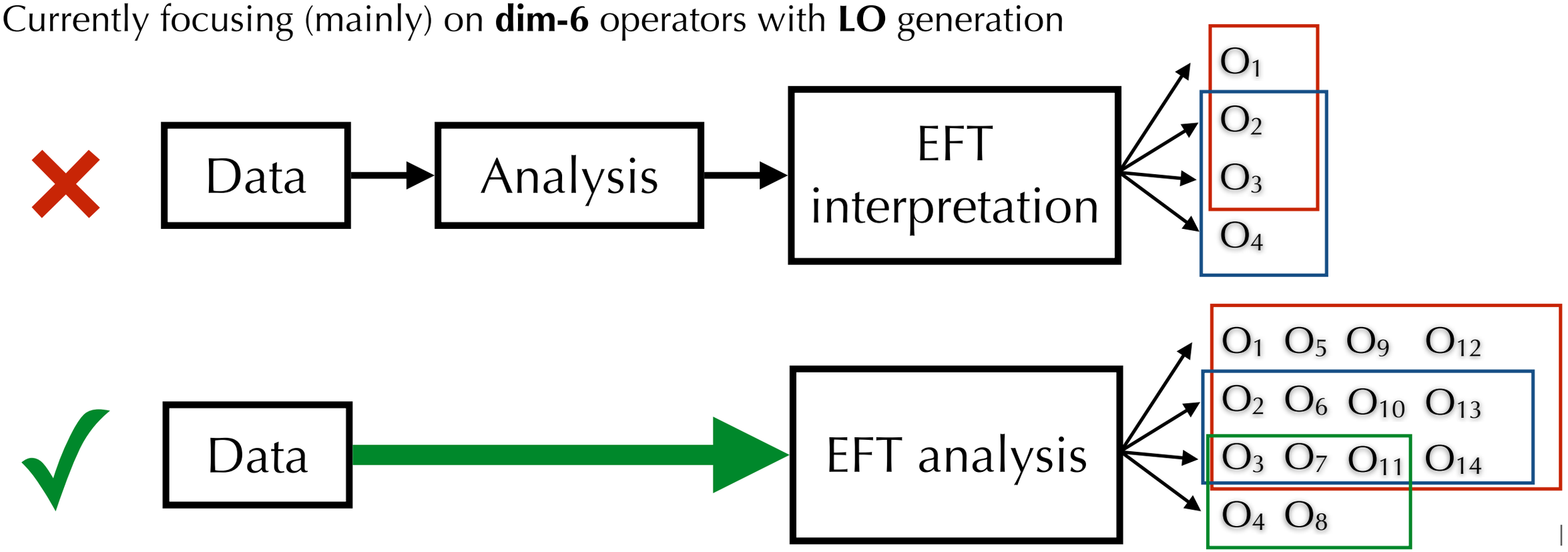
EW

EFT ⇄ LHC data

- An application of EFT to LHC data provides the most general approach (at the moment) for **interpreting** and **preserving** the LHC results
- **Direct access to experimental data** → the best EFT sensitivity can be reached with a fully optimized experimental **EFT analysis**
- Availability of the necessary **event generation tools** is crucial for establishing an EFT analysis

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \frac{C_i}{\Lambda^2} O_i^{(6)}$$

- **Higher precision** in EFT predictions → more precise extraction of BSM contributions
- A full detector event simulation, multidimensional fits to data - **significant computing resources** are required!
- Currently focusing (mainly) on **dim-6** operators with **LO** generation



Approaching global fits

- First **successful** experimental attempt to approach **global EFT fits** in the **top** sector
- Comprehensive study of the associated top quark (and ttbar) production in **multilepton** final states
- Sensitivity optimized based on the event yield predicted in various event categories at **detector level**
- Full control over **systematic correlations** within an experimental study

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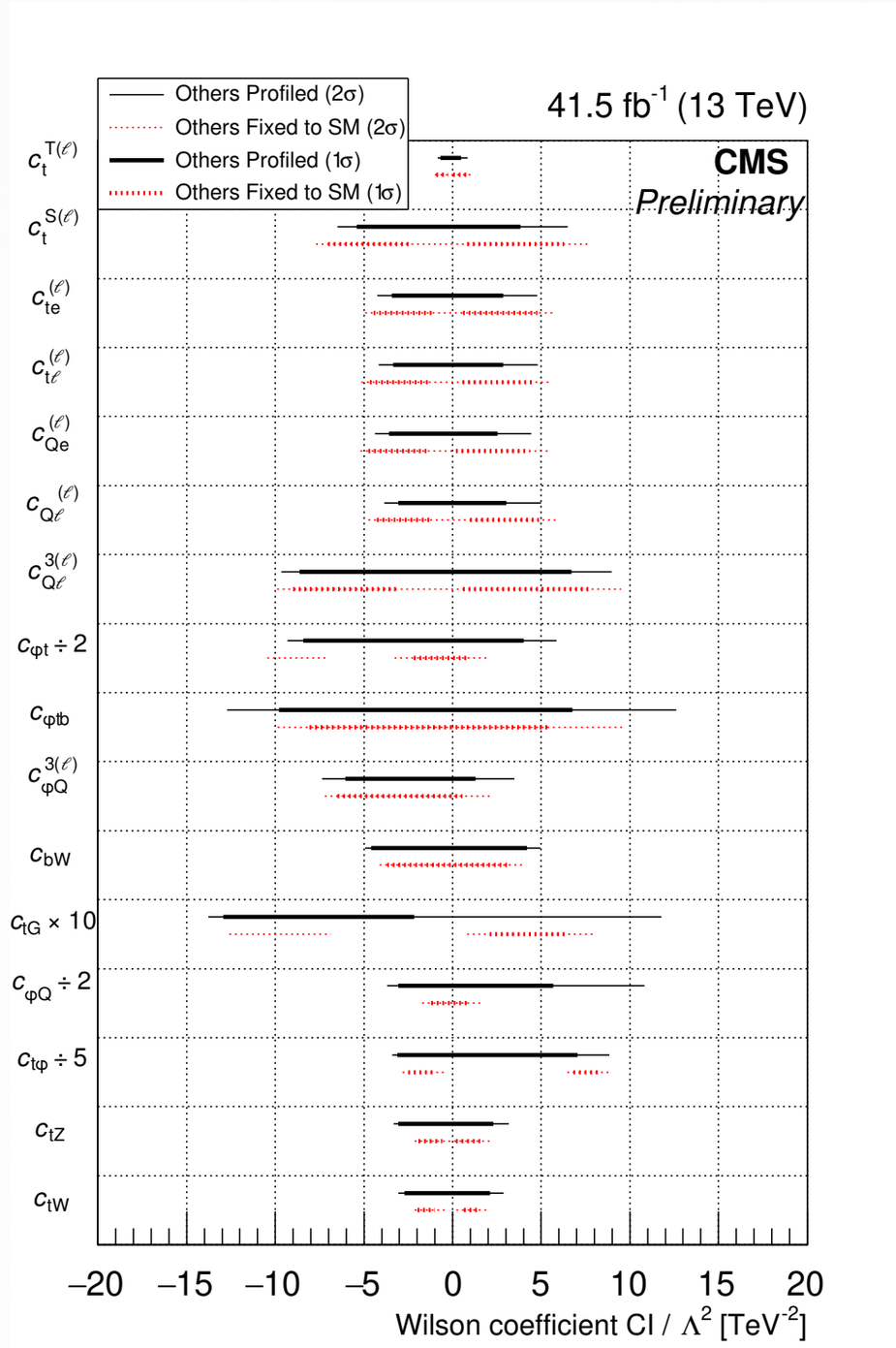

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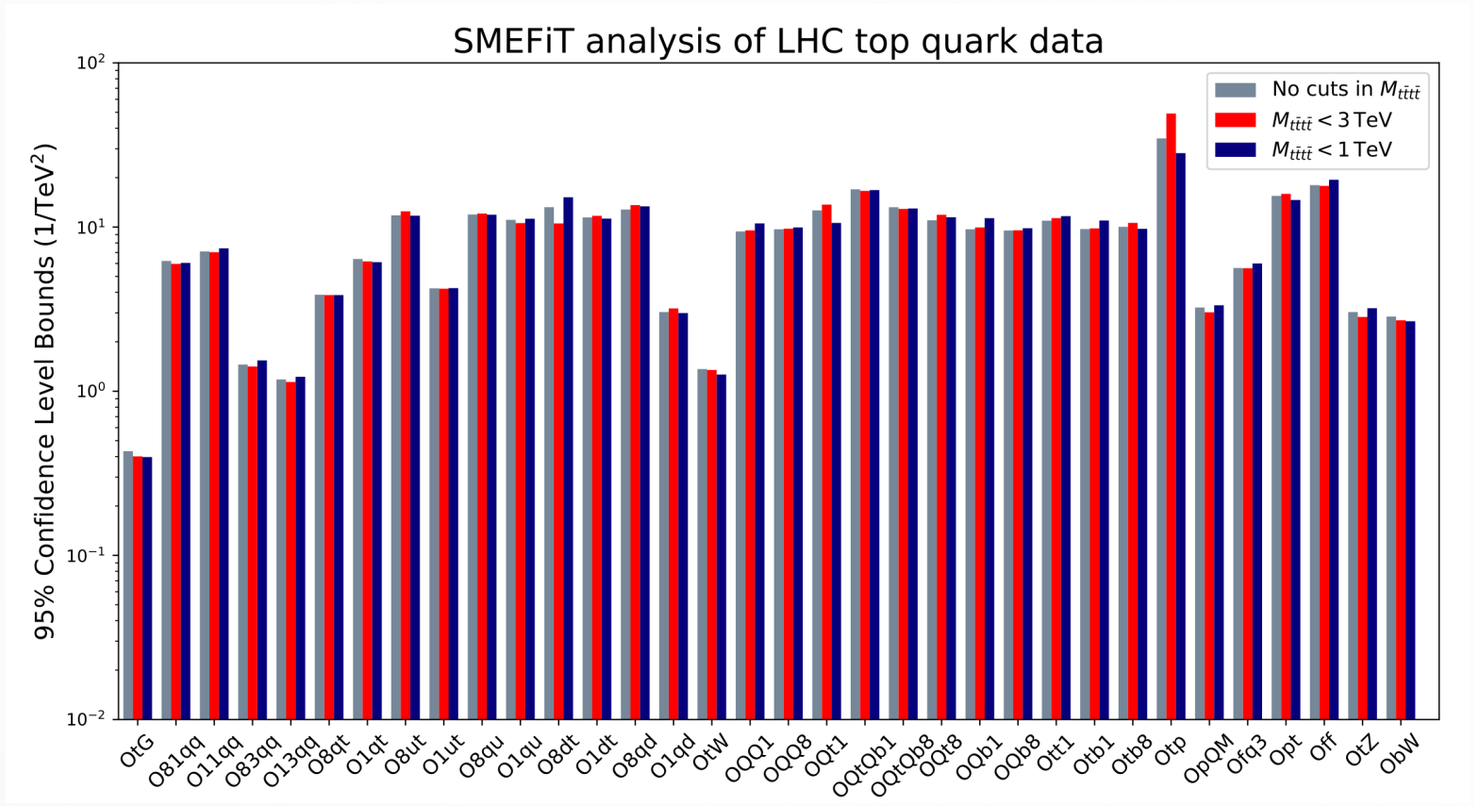
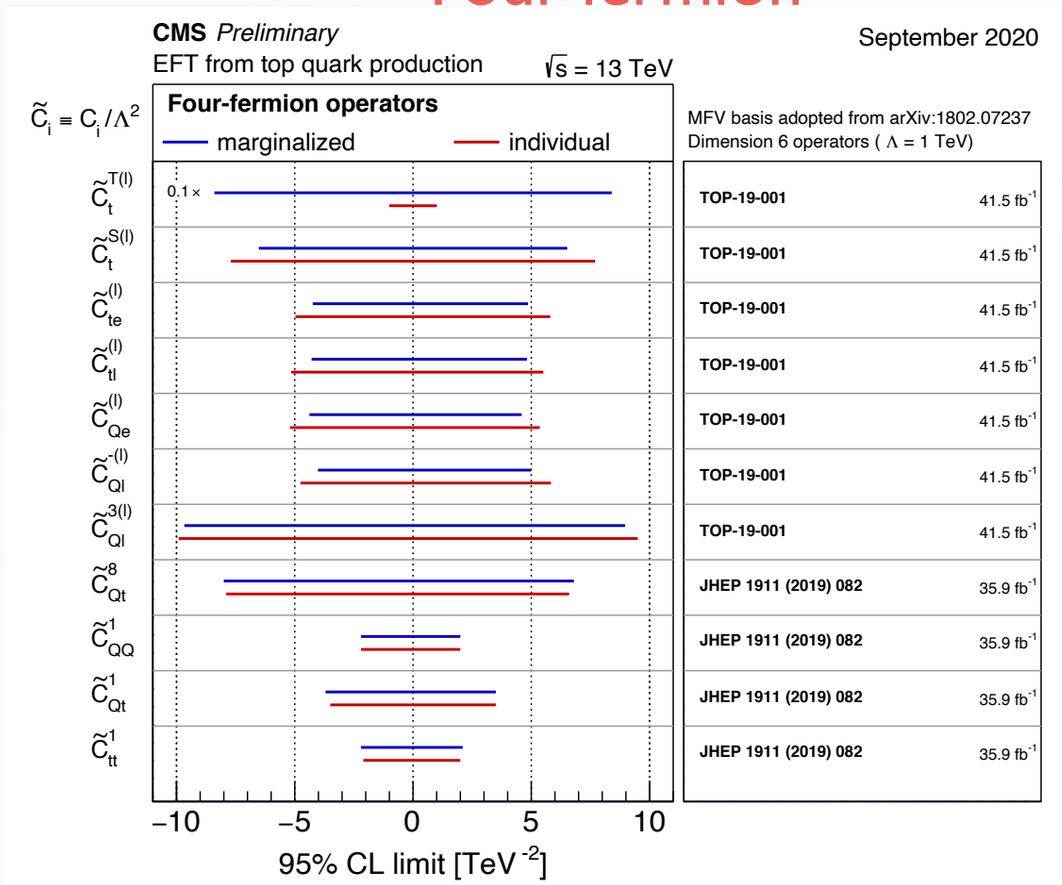


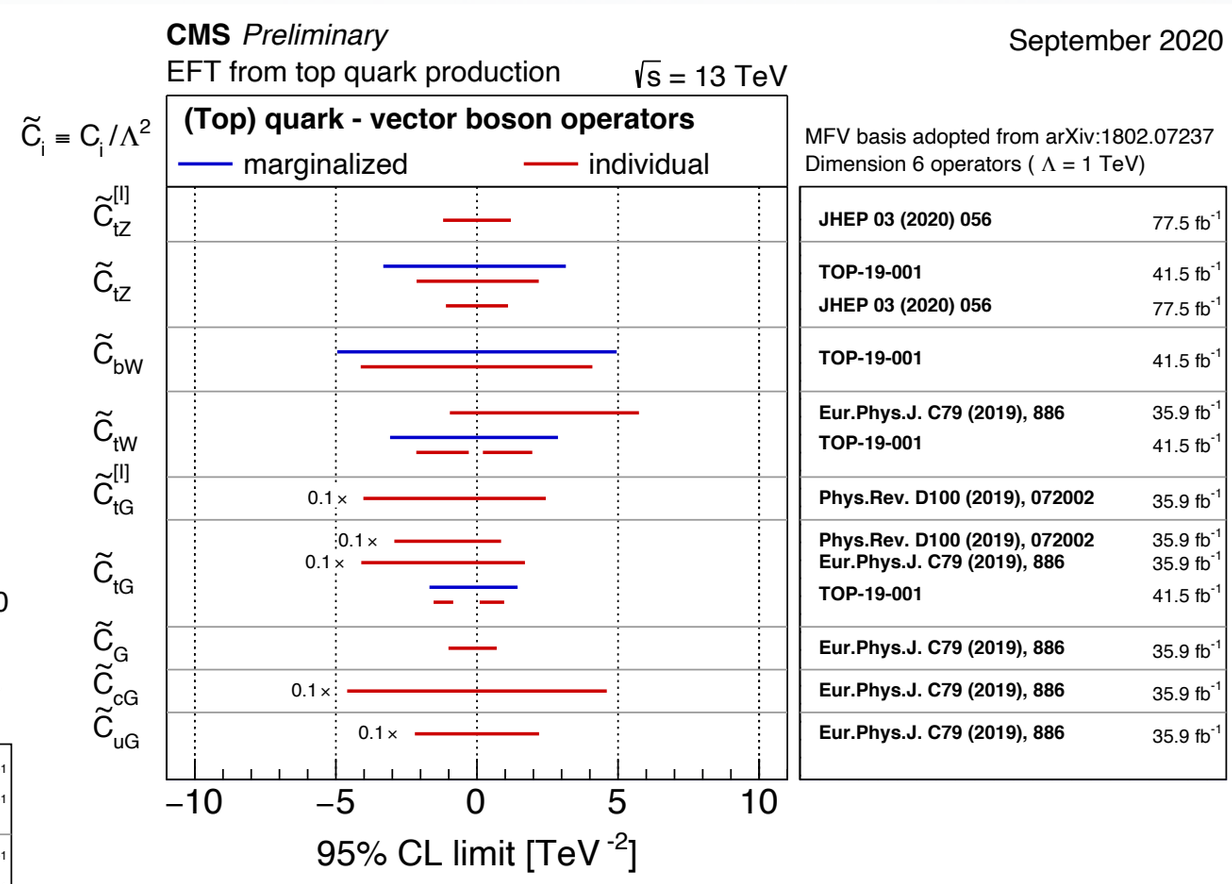
Top EFT results

Four-fermion

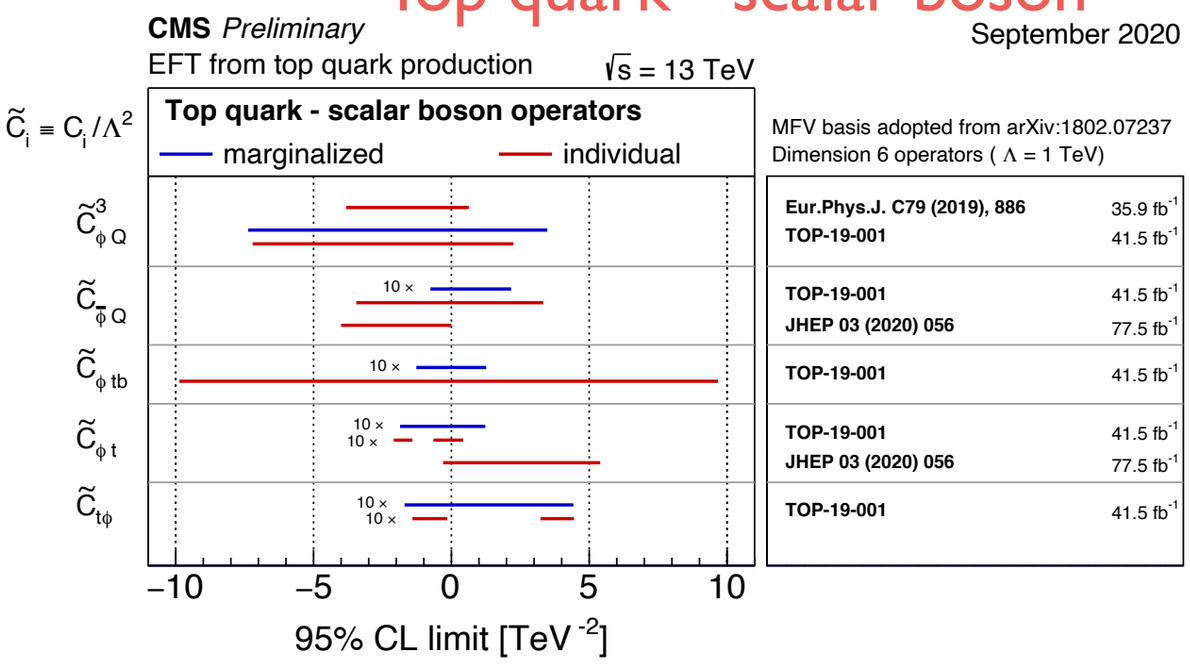


PhysicsResultsTOPSummaryFigures

(Top) quark - vector boson



Top quark - scalar boson



EFT x ML

Seth Moortgat,
Jorgen D'Hondt,
Alberto Mariotti,
Ken Mimasu

- Approach **multidimensional** EFT analysis with **machine learning** for better sensitivity
- **Multi-classification** applied to WCs
- **Parametrized networks** to capture WC kinematic dependences and correlations
- Computing resources **intensive**!

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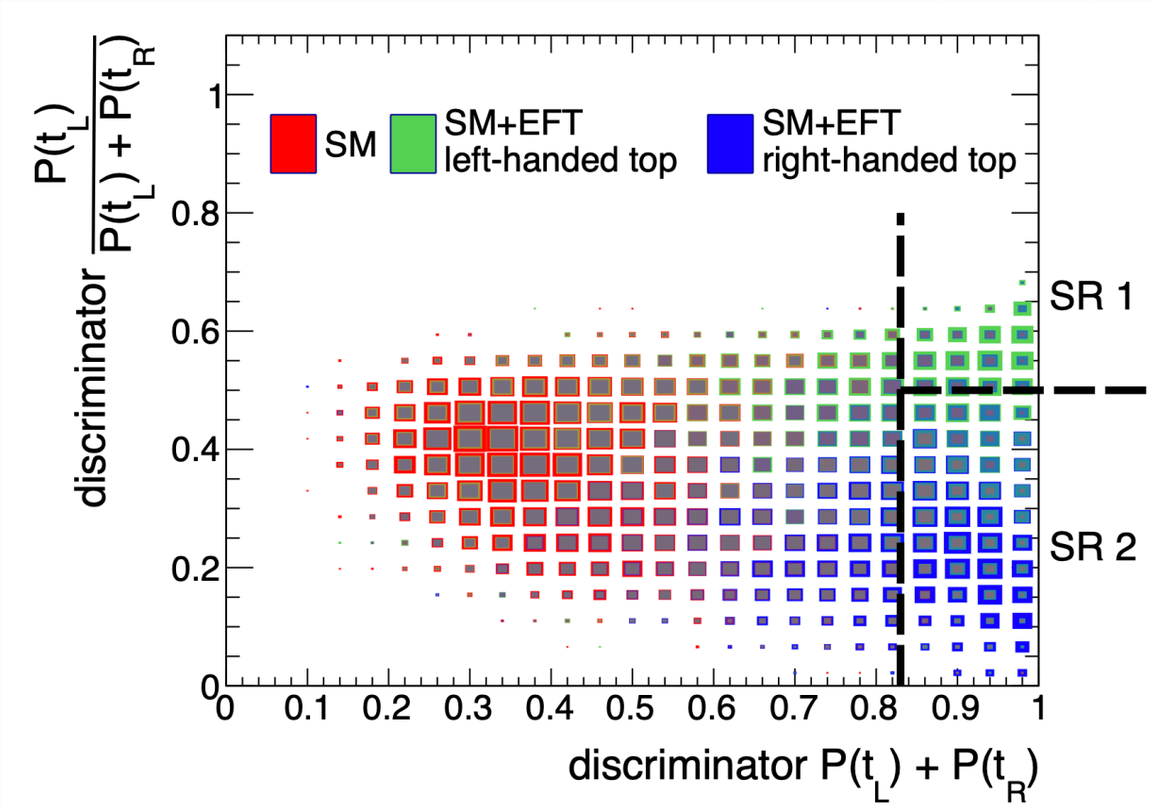

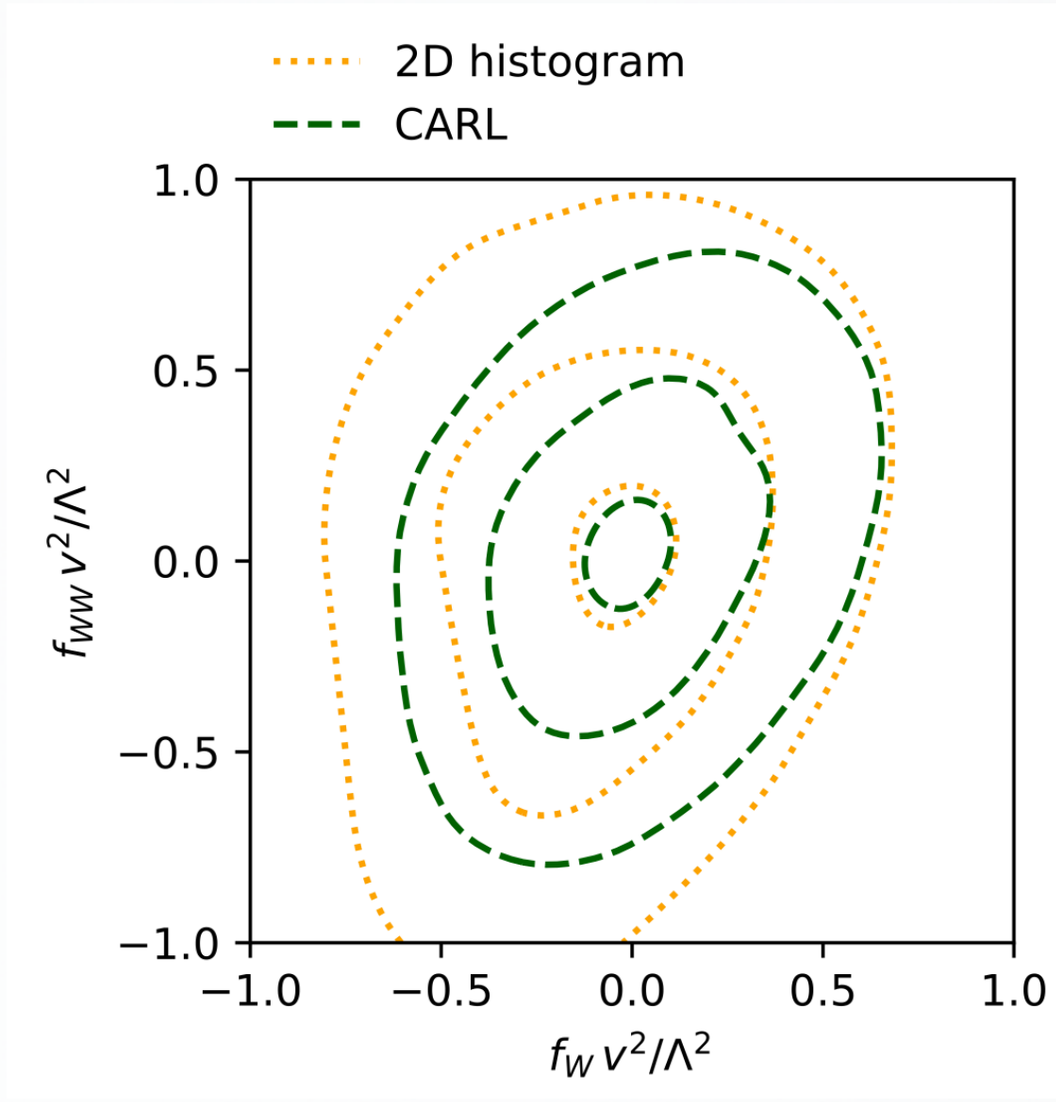

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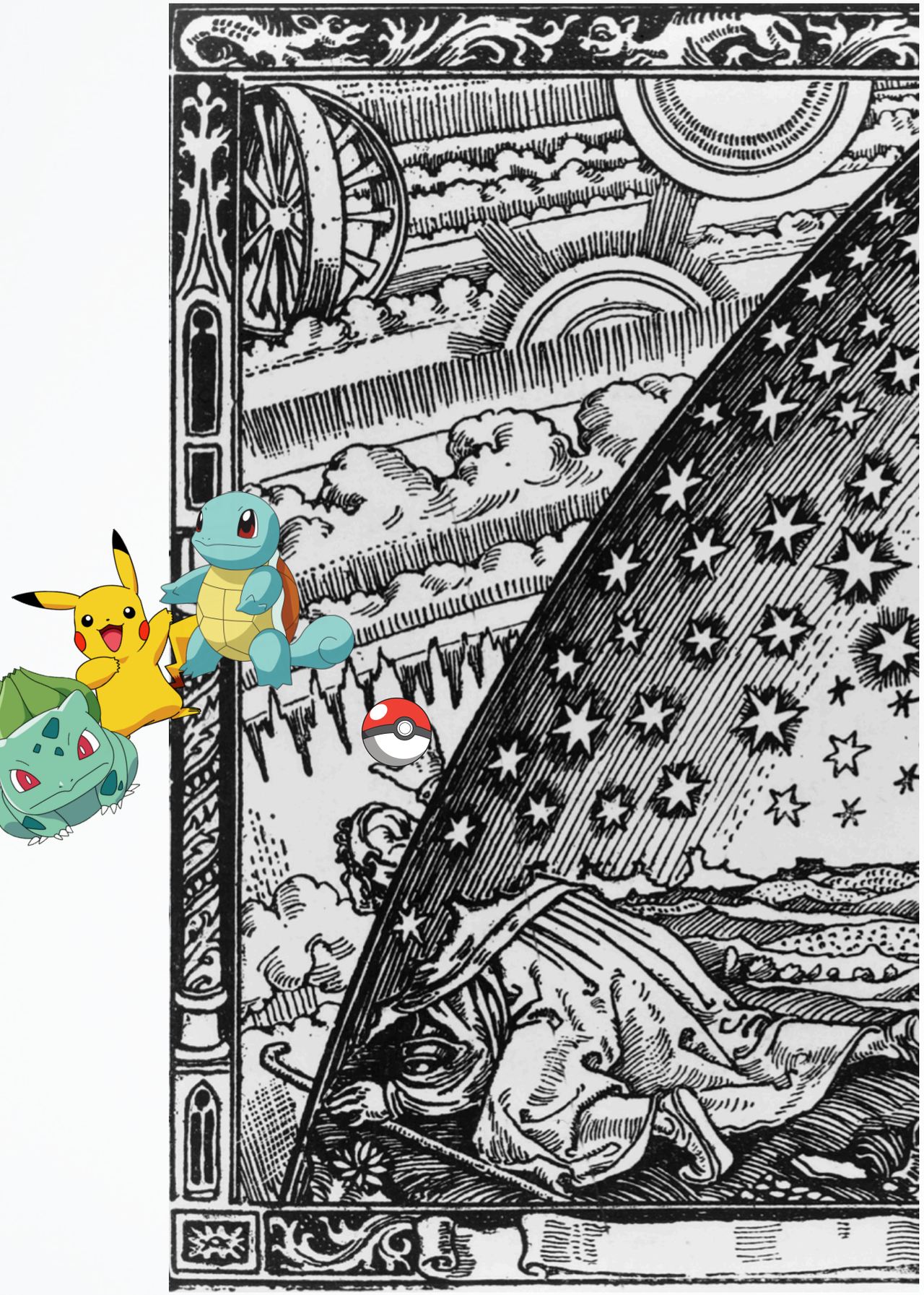

- **A large number of exciting studies** of top quark processes from **Run 2**
- Even **more results** are coming in the following weeks

- We are about to take off for the **Run 3** adventure!
- **First things first**: detector **commissioning** and **data taking**
- Towards the global full detector-level analysis of **top EFT** processes