

Summary of LHC EFT Working Group activities

Ken Mimasu, on behalf of the LHCEFTWG conveners
King's College London

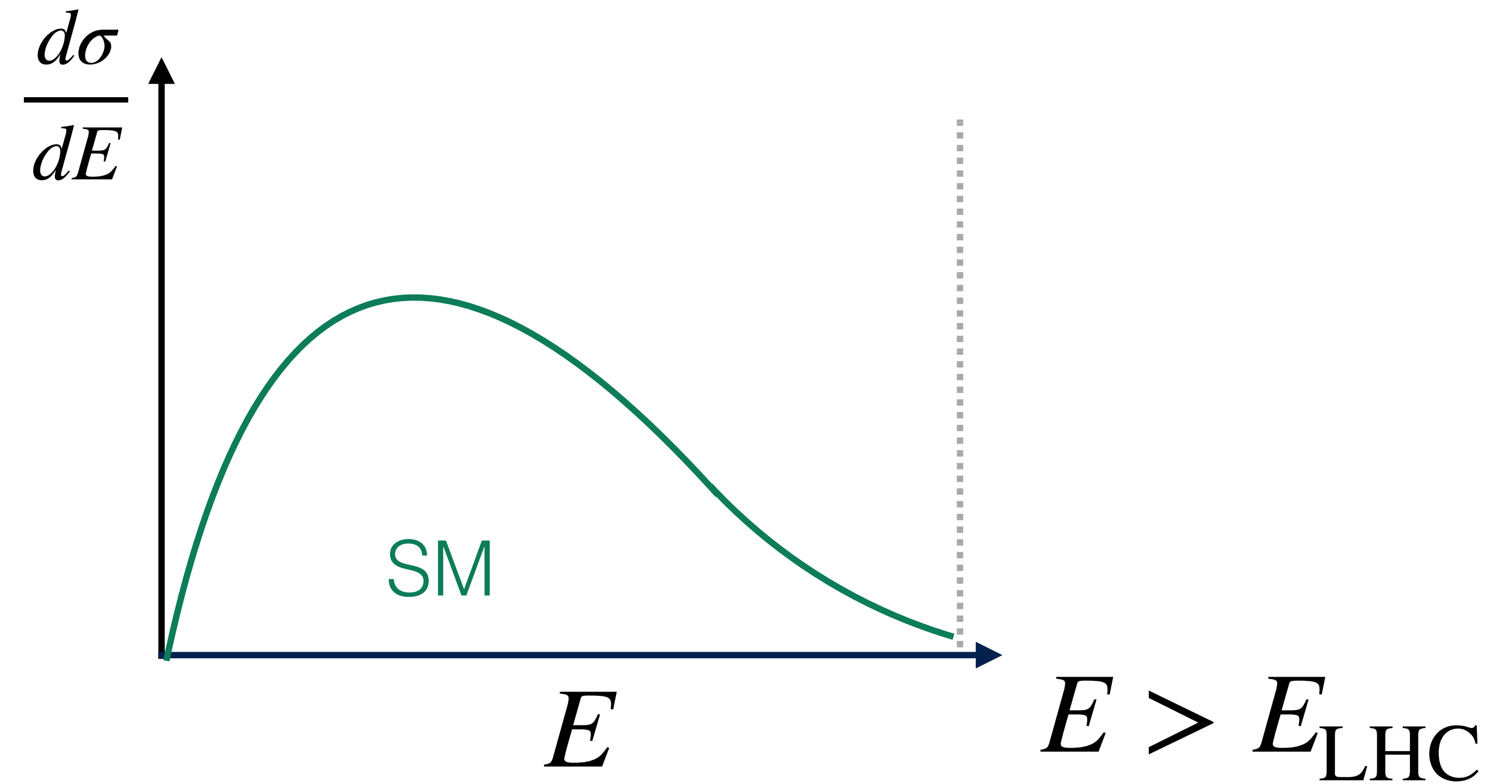
(Re)interpretation of the LHC results for new physics

31st August 2023

Special thanks to Ilaria Brivio & Nicholas Wardle for their (un)knowing input!

Energy & precision

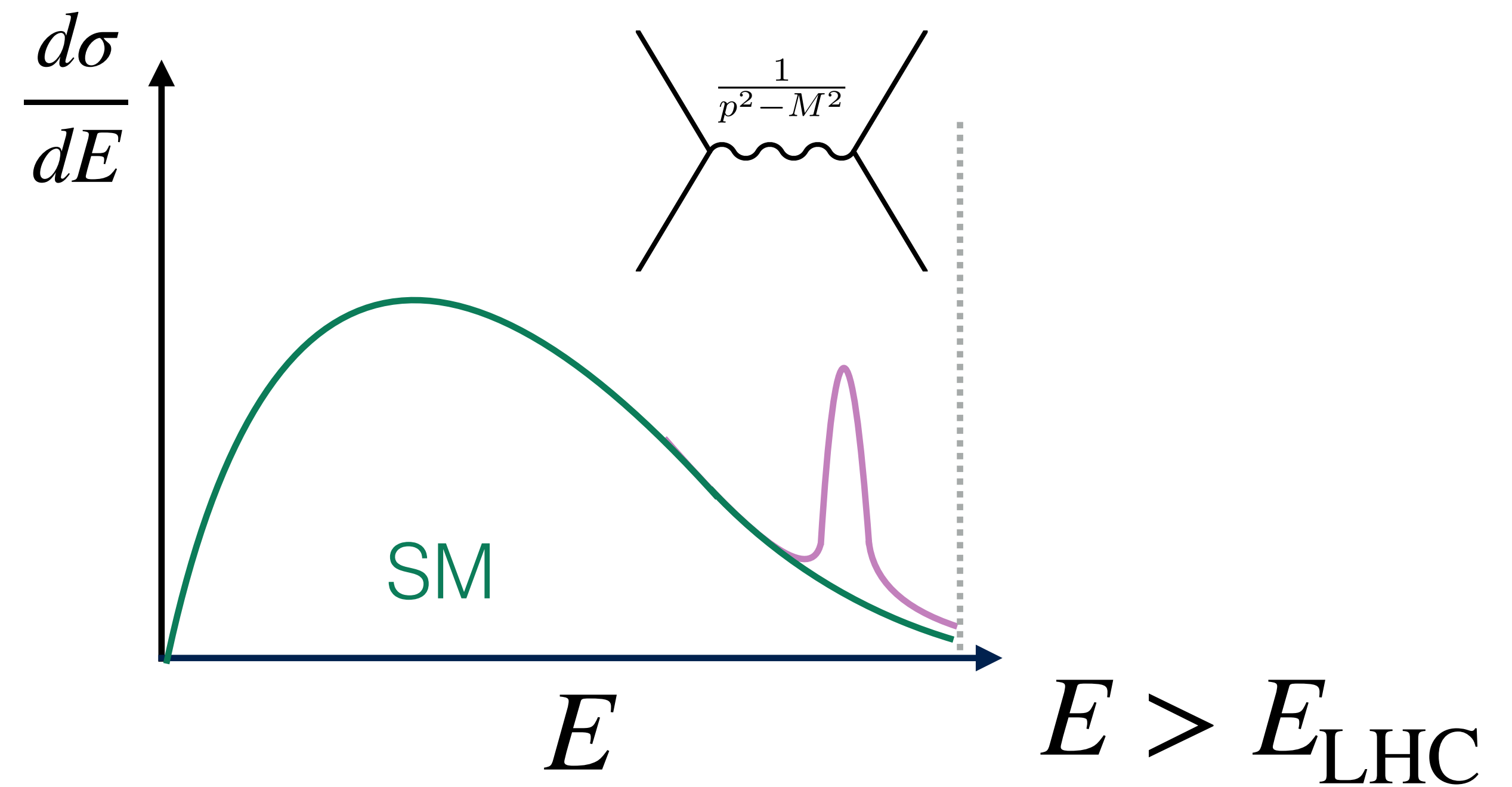
Paradigm shift at the energy frontier for BSM searches



Energy & precision

Paradigm shift at the energy frontier for BSM searches

Direct (bumps)



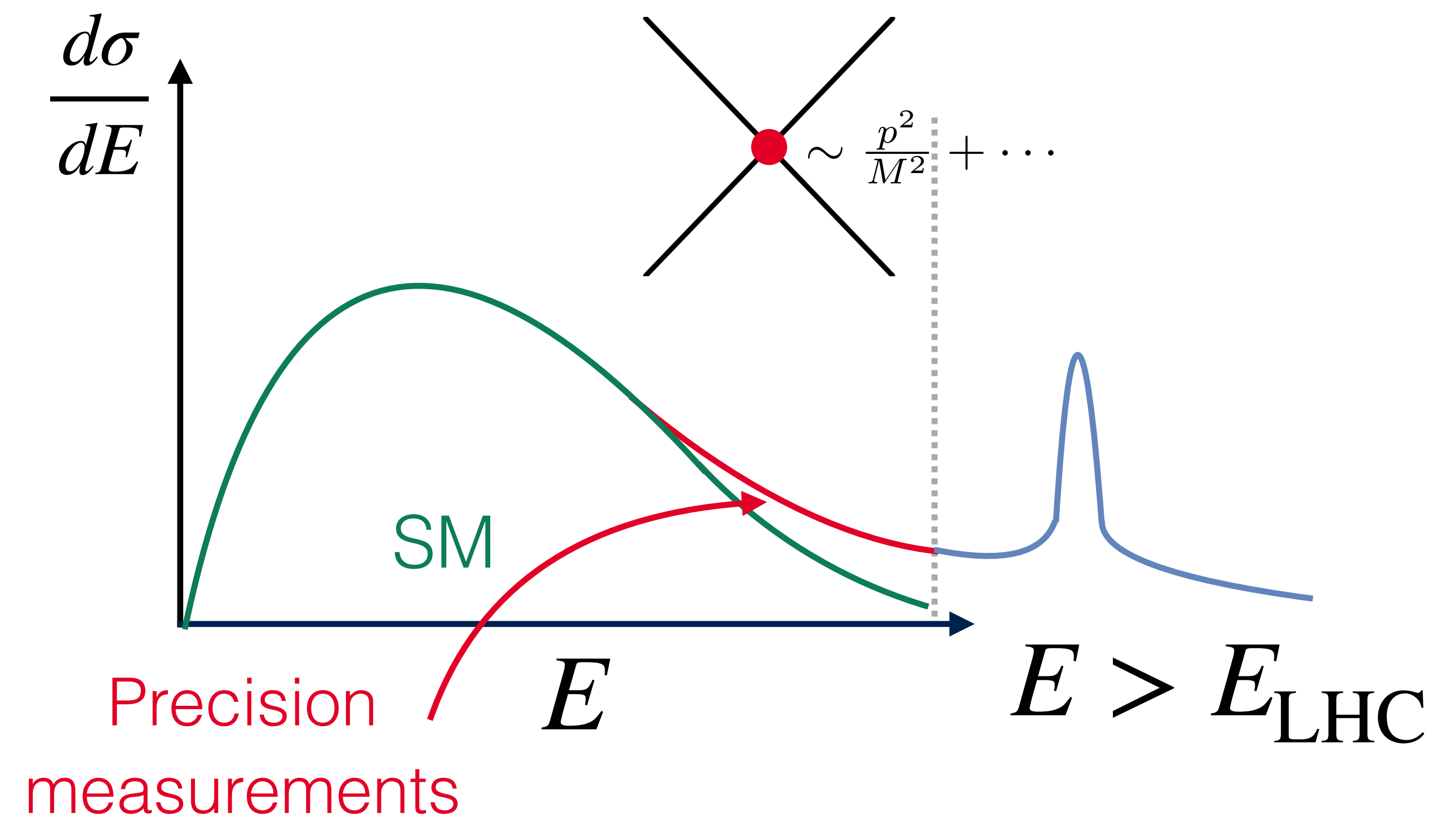
Energy & precision

Paradigm shift at the energy frontier for BSM searches

Direct (bumps)

Indirect (tails)

⇒ New physics is heavy



Energy & precision

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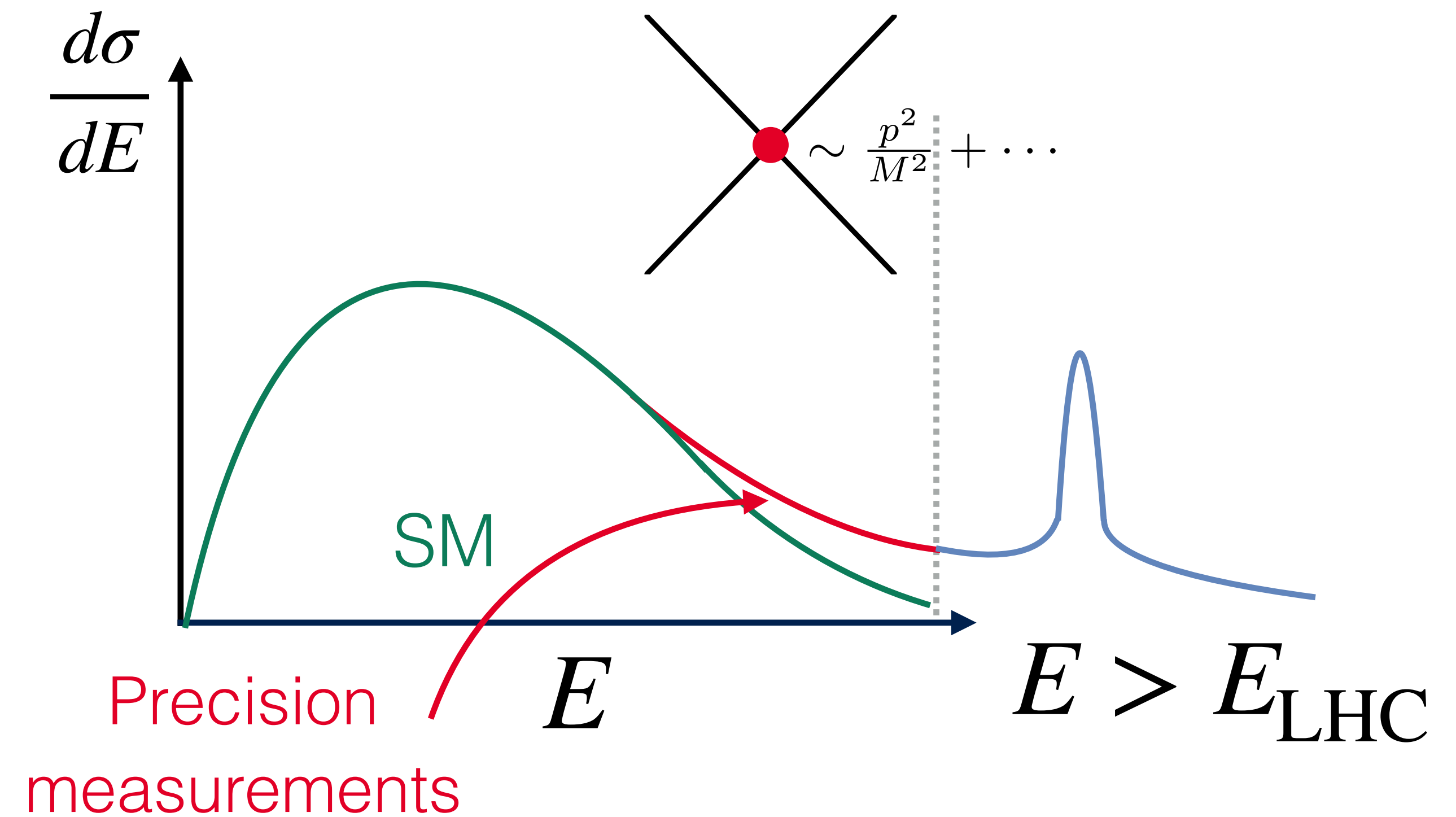
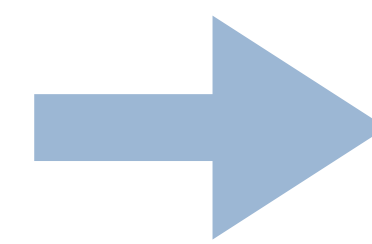
Indirect (tails)

⇒ New physics is heavy

Heavy new physics

Precision measurements

High energy



Effective Field Theory (EFT)

Energy & precision

Paradigm shift at the energy frontier for BSM searches

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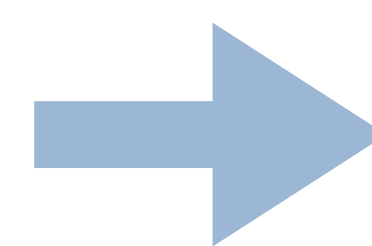
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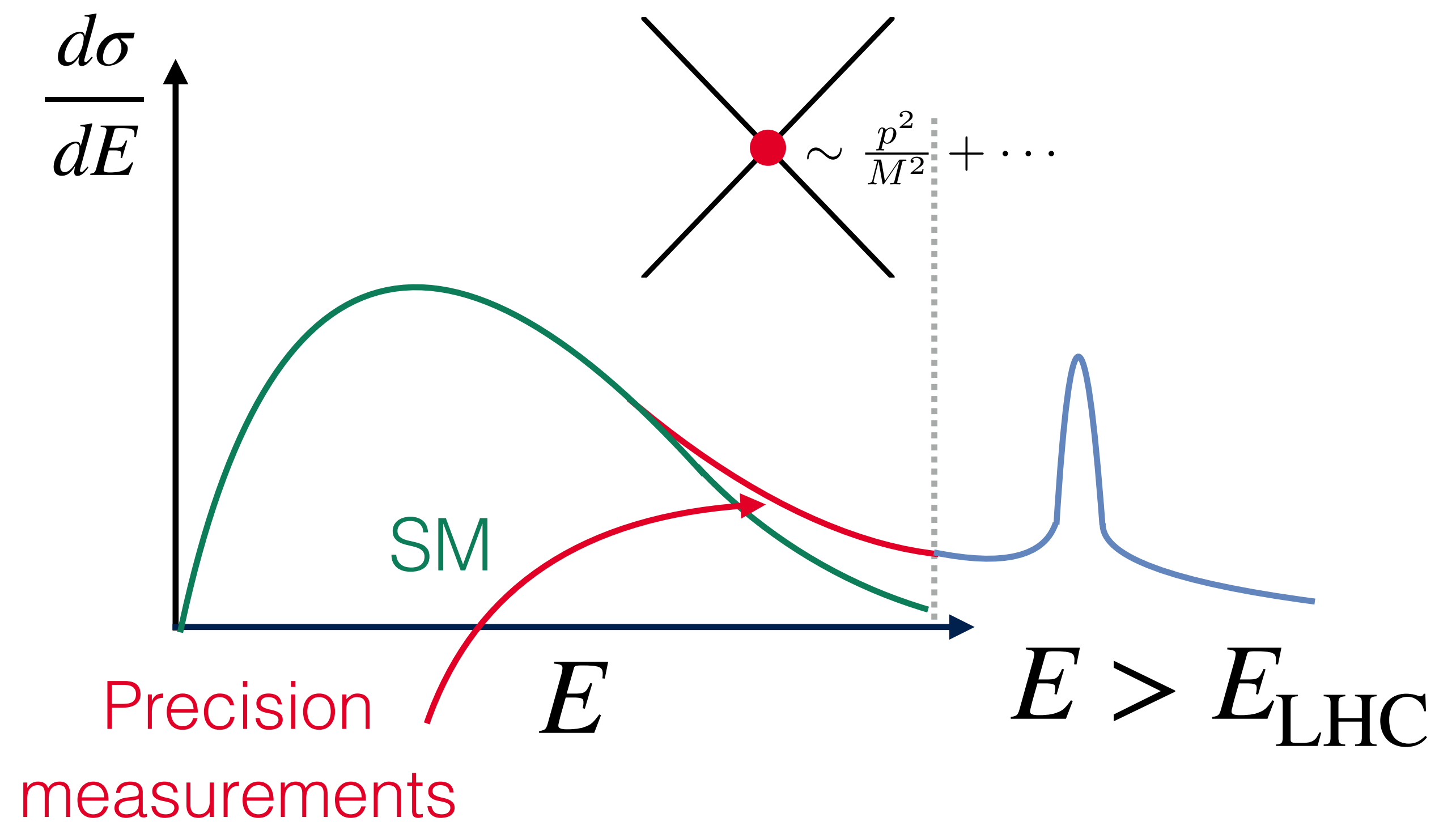
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Effective Field Theory (EFT)



$$\mathcal{A}_{\text{BSM}}^n(E, M) \sim E^{4-n} \left(a_0 + a_1 \frac{E}{M} + a_2 \frac{E^2}{M^2} + \dots \right), \quad E \ll M$$

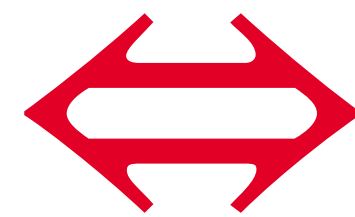
SMEFT: SM v2.0

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_{i,D} \frac{c_i^{(D)} \mathcal{O}_i^{(D)}}{\Lambda^{D-4}}$$

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BSM particle masses M

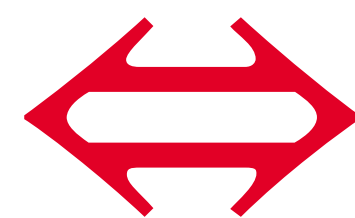


Generic new physics scale Λ

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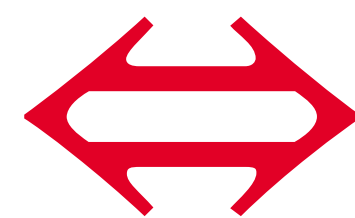
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Taylor expansion of \mathcal{A}_{BSM}



Tower of operators $\mathcal{O}_i^{(D)}$

$\mathcal{O}_i^{(D)} \supset$

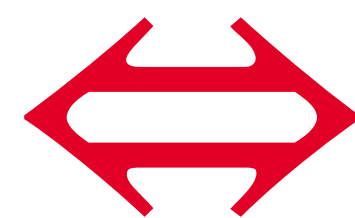


Low energy (SM) fields & symmetries

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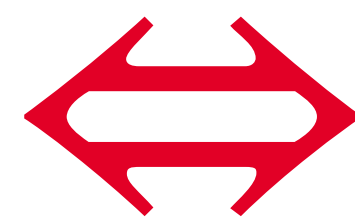
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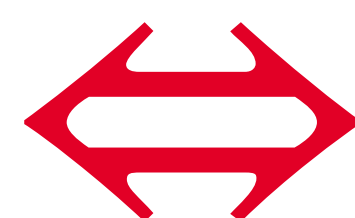
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Low energy (SM) fields & symmetries

Model parameters $\{g_{\text{BSM}}^i, M_k\}$



Wilson coefficients $\frac{c_j^{(D)}}{\Lambda^{D-4}} (g_{\text{BSM}}^i, M_k)$

measure g_i : new physics model parameters

“Matching”

measure c_i : coupling strengths of new BSM interactions

SMEFT

Model independent

- Few underlying assumptions

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*Heavy new physics: $\Lambda > E_{\text{exp}}$
SM field content & symmetries*

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Systematically improvable

- Double expansion $\frac{E}{\Lambda}$ & $\{g_S, g_W, g'\}$ *higher dimensions* *quantum corrections*

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- Model independence: **we don't know** what operators new physics will generate
- *Patterns & correlations* among *observables & operators* are key

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- Ultimate goal: **complete SMEFT likelihood** confronted with HEP dataset

LEP data, **Higgs**, *multiboson*, *top*, **flavor physics**, ...

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$\mathcal{L}(c_i) \Rightarrow$ **indirectly constrain many UV models**

SMEFT interpretation

$$\Delta o_n = o_n^{\text{EXP}} - o_n^{\text{SM}} = \sum_i a_{n,i}^{(6)}(\mu) \frac{c_{n,i}^{(6)}(\mu)}{\Lambda^2} + \mathcal{O}\left(\frac{1}{\Lambda^3}\right)$$

SMEFT interpretation

Maximising sensitivity means improving...

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As many observables
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Identify patterns &
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Exploit energy-growth

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Experiment:

Best measurements & understanding of uncertainties and correlations

Theory:

Best available SM predictions for observables

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Interpretation

Accurate knowledge of the size & correlations among a_i

Determining c_i requires most precise available SMEFT predictions

Collider probes of SMEFT

Dedicated searches

- SRs optimised to discriminate between SM and SMEFT

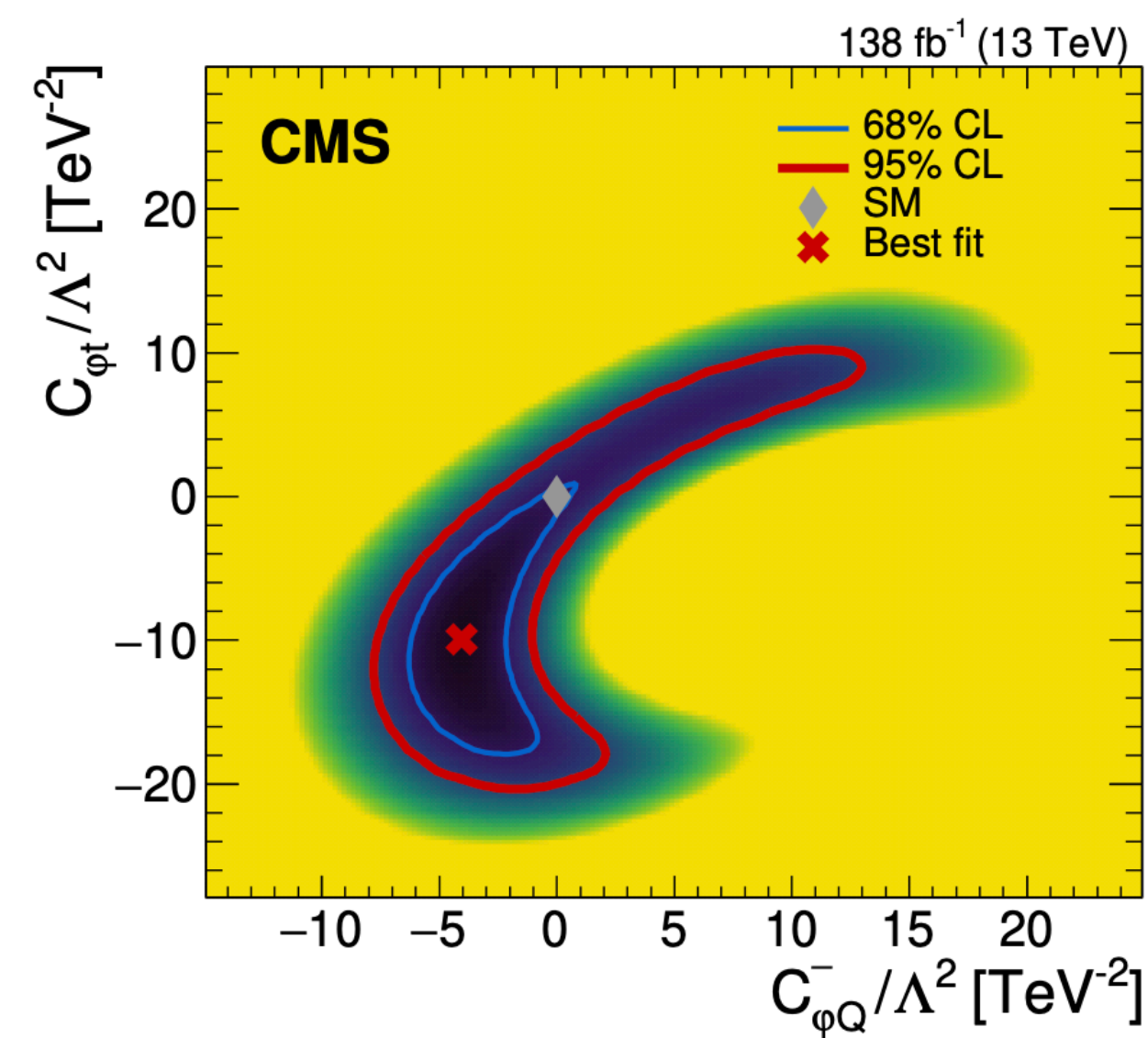
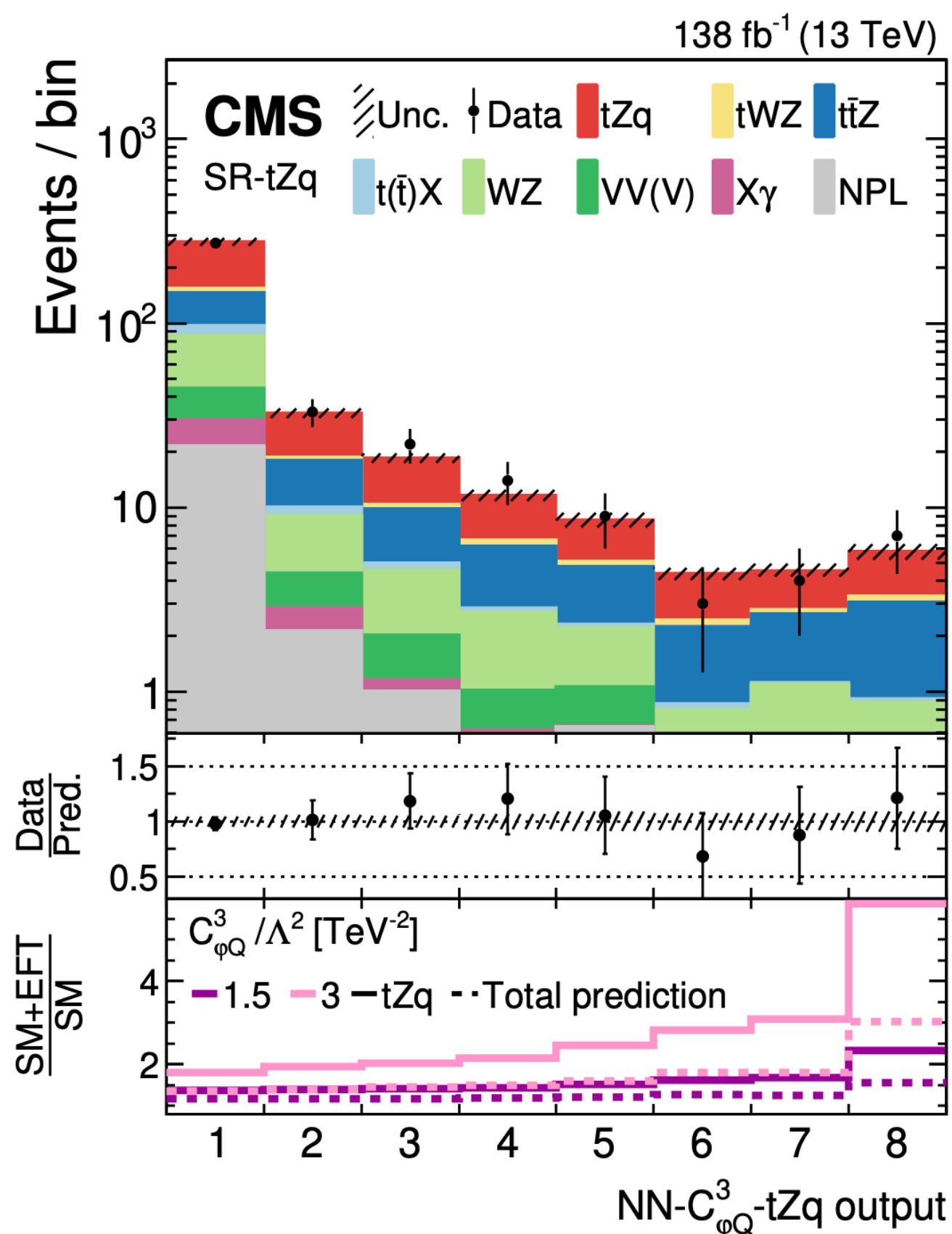
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[CMS; JHEP 12 (2021) 083]

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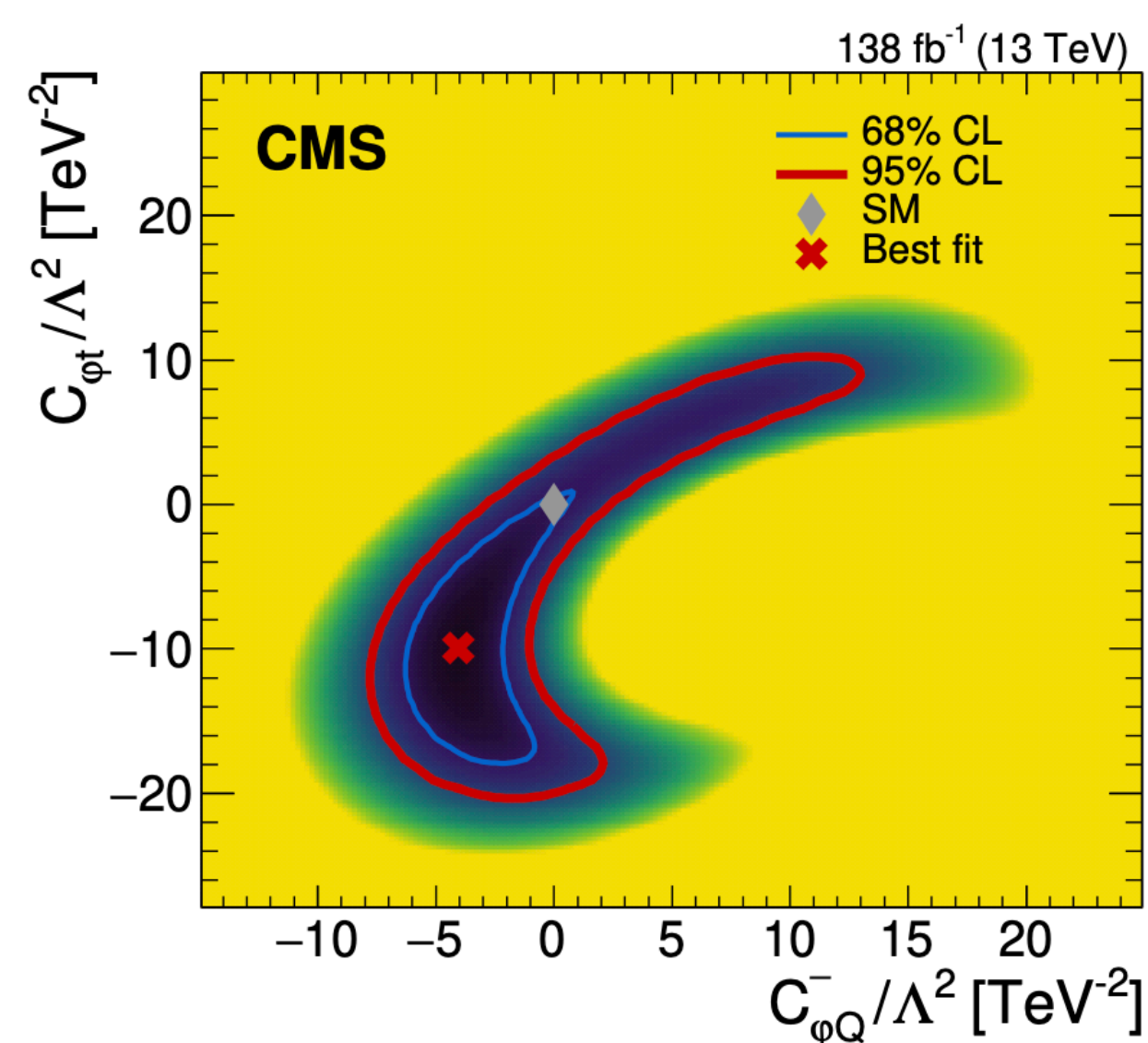
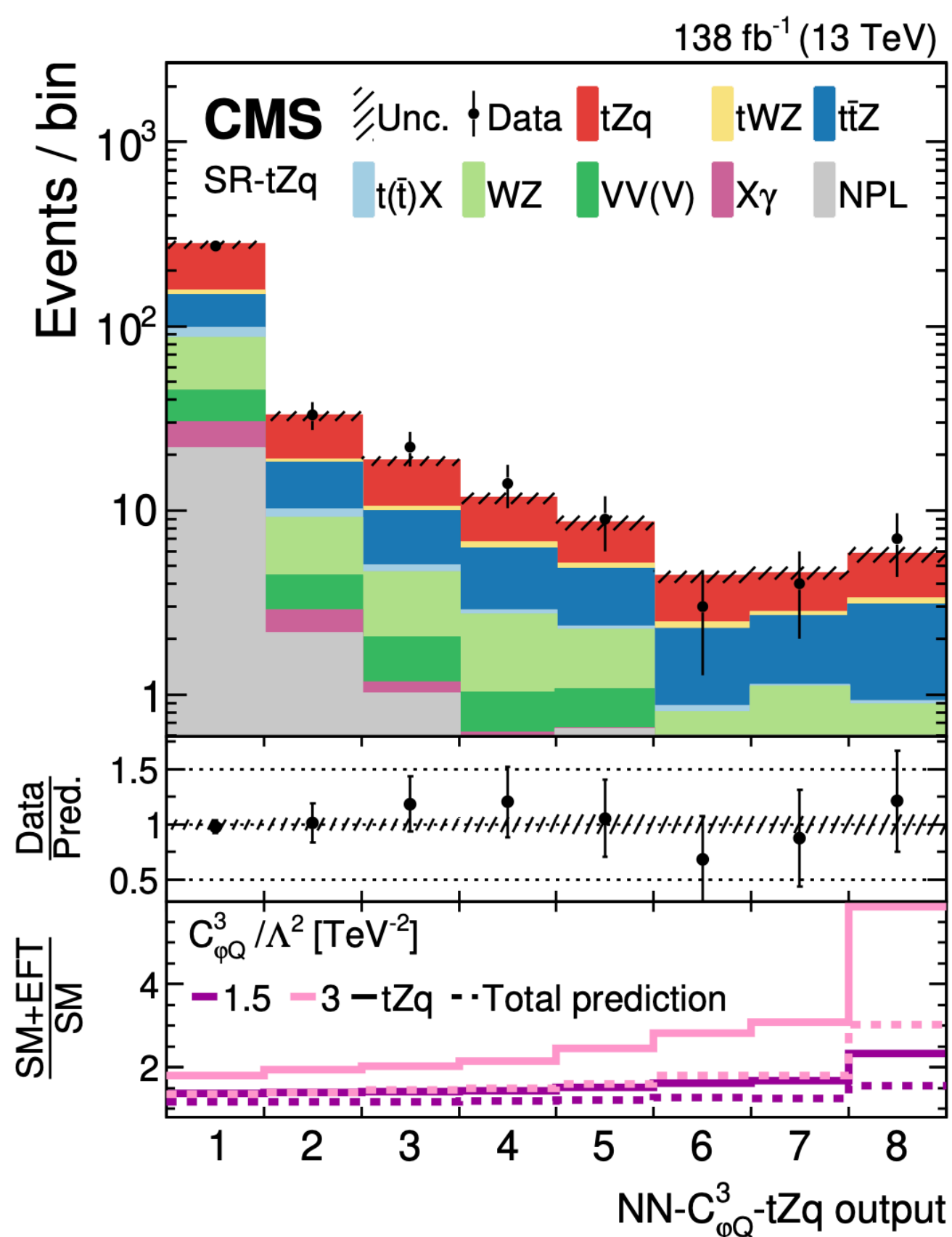
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(Re)interpretation

- Re-use existing measurements
- Differential cross sections, signal strengths, asymmetries, ...
- Combine into global analysis



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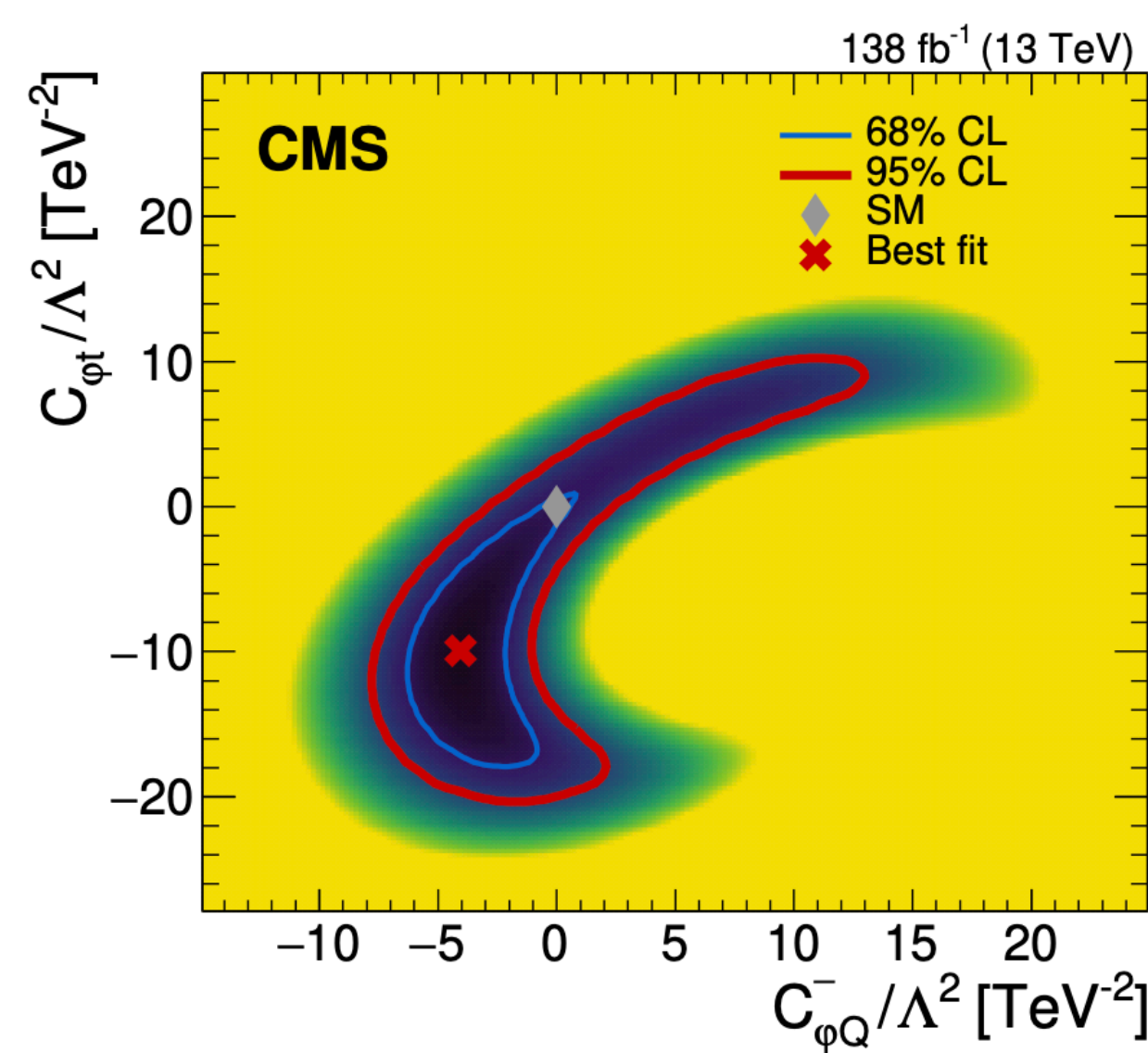
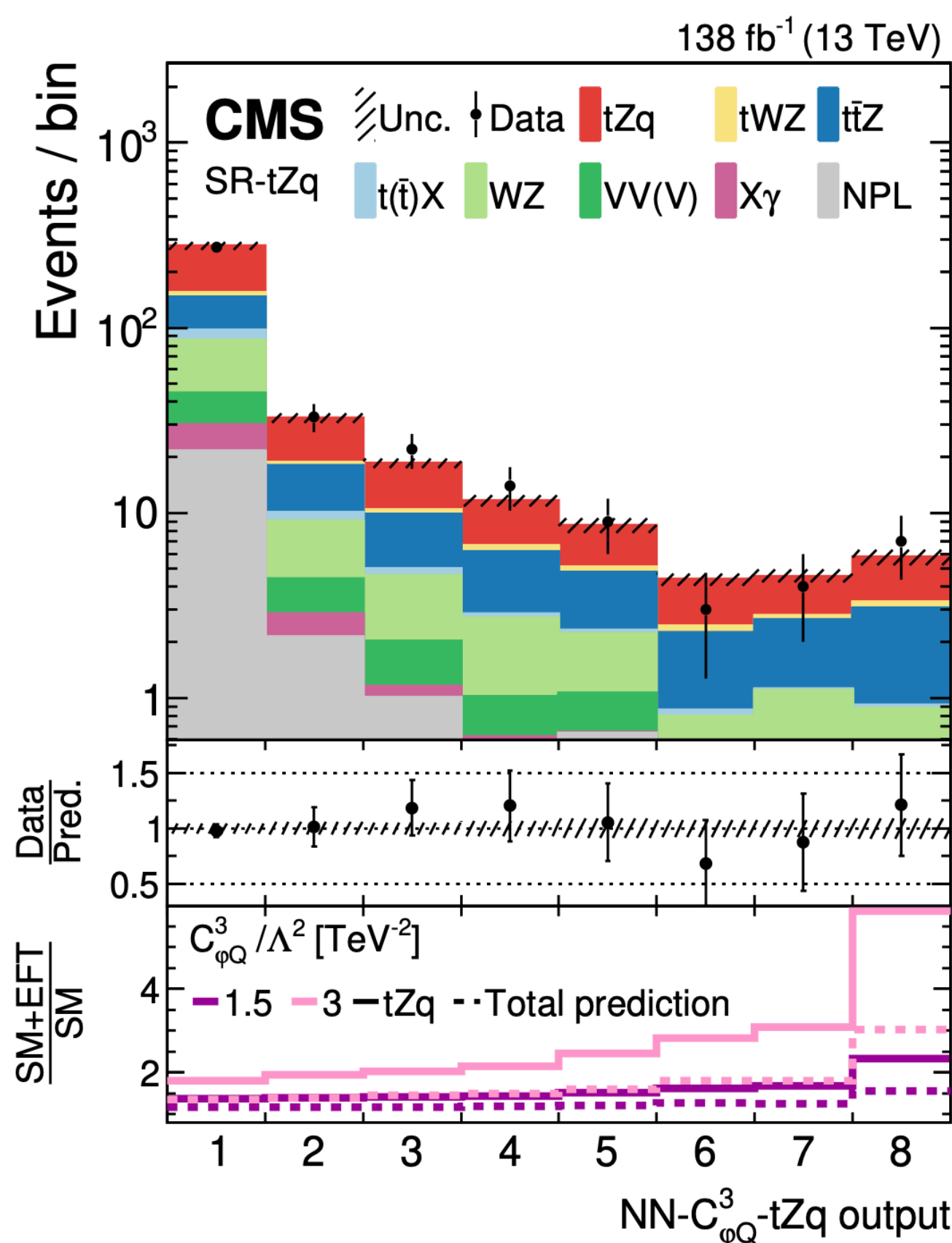
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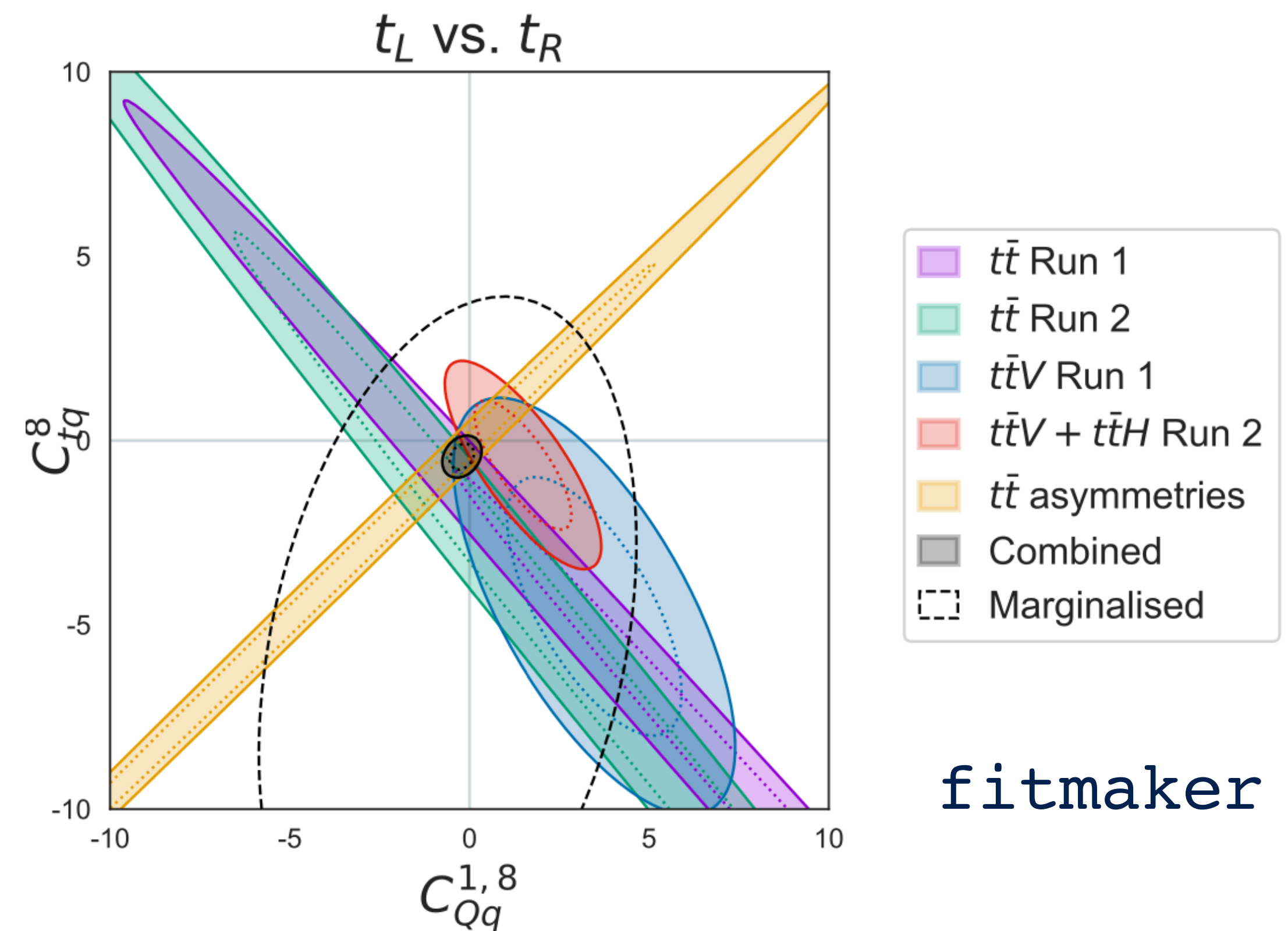
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[CMS; JHEP 12 (2021) 083]



[Ellis, Madigan, KM, Sanz & You; JHEP 04 (2021) 279]

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Pros & Cons

- ✓ 'Optimal' \Rightarrow best sensitivity
- ✗ Restricted to specific SMEFT effects considered
- ✗ Not easy to reinterpret

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Pros & Cons

- ✓ 'Optimal' \Rightarrow best sensitivity
- ✗ Restricted to specific SMEFT effects considered
- ✗ Not easy to reinterpret
- ✓ 'Easy' to interpret \Rightarrow repeat for new parameter sets, better theoretical predictions ...
- ✓ More global \Rightarrow applicable to a wider range of UV completions
- ✗ Not optimal

The LHC EFT WG: 2020-

Webpage: lpsc.web.cern.ch/lhc-eft-wg

TWiki: twiki.cern.ch/twiki/bin/view/LHCPhysics/LHCEFT

Meetings: indico.cern.ch/category/12671/ Contact: lhc-eftwg-admin@cern.ch

Sign up: simba3.web.cern.ch/simba3/SelfSubscription.aspx?groupName=lhc-eftwg

Mandate

The LHC effective field theory working group (LHC EFT WG) gathers members of the LHC experiments and the theory community to provide a framework for the interpretation of LHC data in the context of effective field theories (EFTs)...

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Conveners

ATLAS

Sarah Heim (Higgs)
Jacob Kempster (Top)
Sandra Kortner
Kristin Lohwasser (EW)

CMS

Nadjieh Jafari
Matteo Presilla (EW)
Robert Schöfbeck (Top)
Nicholas Wardle (Higgs)

LHCb

Greg Cisarek
Christoph -
Langenbruch

Theory

Shankha Banerjee (EW)
Anke Biekötter (Higgs)
Ilaria Brivio
Gauthier Durieux
Admir Greljo
Ken Mimasu (Top)

Contacts with the RIF

Informal meeting between WG conveners & Sabine in Feb.

- Many LHC EFT interpretations cannot always be directly reused
- Encourage reusability of experimental SMEFT results
- EFT fitting groups can benefit from the expertise & experience of RIF
- Synergies & possible joint activities between EFTWG & RIF

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Why we are here today!

- EFT day @ RIF is a first 'joint meeting' between EFTWG & RIF
- If it is well received, we can continue the exchange
- RIF contacts: Nicholas Wardle and Ken Mimasu

WG structure

[Googledoc](#) summarising targets & activities of each area

Area 1: EFT formalism

- Ilaria Brivio, Gauthier Durieux, Matteo Presilla

Area 2: Predictions and tools

- Ilaria Brivio, Sarah Heim, Robert Schöfbeck, Ken Mimasu

Area 3: Experimental measurements and observables

- Shankha Banerjee, Anke Biekötter, Nadjieh Jafari, Jacob Kempster, Kristin Lohwasser

Area 4: Fits and related systematics

- Anke Biekötter, Jacob Kempster, Kristin Lohwasser, Ken Mimasu, Nicholas Wardle

Area 5: Benchmark scenarios from UV models

- Shankha Banerjee, Admir Greljo, Sandra Kortner

Area 6: Interplay with (heavy) flavour

- Greg Cisarek, Gauthier Durieux, Admir Greljo, Christoph Langenbruch

Area 1: formalism

[TWiki](#)

Aim: Establish key parameters of the formalism

- Operator basis, perturbation orders, symmetry assumptions (flavor, CP,...)
- How to combine operators of different dimension
- EFT validity, other theoretical constraints
- Practical considerations relating to experimental analyses

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2 WG notes released

- ‘Electroweak input parameters’ [[CERN-LHCEFTWG-2021-001](#)]
- ‘Truncation, validity & uncertainties’ [[CERN-LHCEFTWG-2021-002](#)]
- ‘Benchmarks for flavour assumptions’ in progress with areas 3 & 6

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Recent meeting on positivity constraints ([link](#))

- What are they and how can we use them alongside exp. results

Area 2: predictions & tools

TWiki

Aim: how to simulate EFT and generate events

- Guidance/recommendations on use and limitations of MC models
- Higher order/loop calculations
- Benchmarking & validation of techniques for generation predictions (reweighting, morphing, ...)
- Identify theory systematics
- Publication of predictions, shared event samples,...

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Ongoing activities, notes in preparation

- *'EFT predictions'* benchmarking exercise
- *'Publishing SMEFT parametrisations for HEP measurements'*

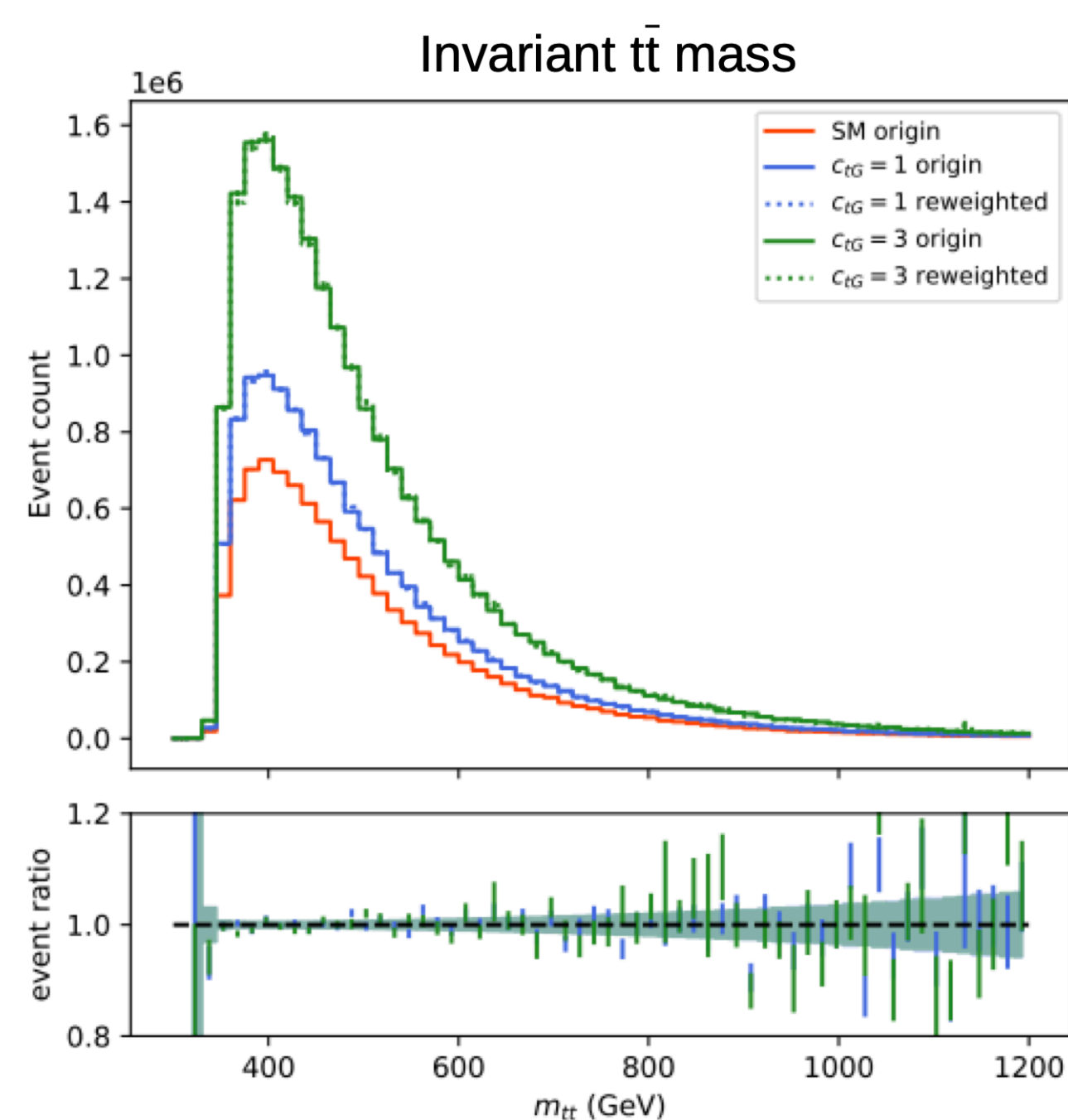
Area 2 activities

EFT predictions ([googledoc](#))

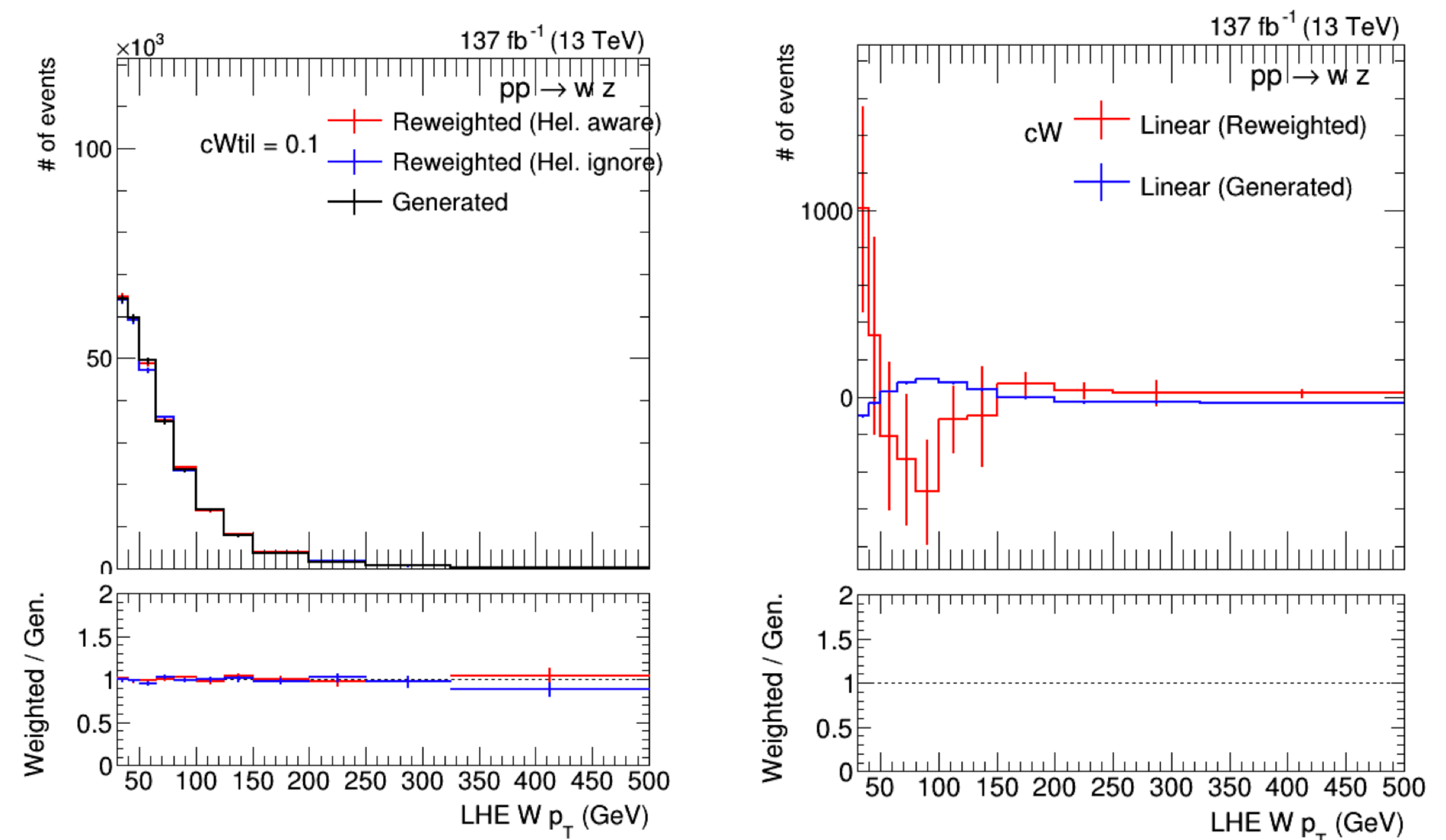
Contacts: R. Schöfbeck, M. Presilla, C. Knight

- Establish best practises using benchmarks for simulated EFT predictions
- 3 meetings: [6th April \(kick-off\)](#), [24th May](#), [28th June](#)
- Next meeting: [21st September](#)
- Validation/closure tests on reweighting and sample-based (morphing) techniques
- Ongoing studies on VH, tt, ttZ, multi-boson

A. Grohsjean & L. Jeppe



S. Chatterjee



Area 2 activities

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Publishing SMEFT parametrisation: collab w/ LHCHWG2

- Validate complex calculations & avoid duplication of efforts
- Use case: Higgs STXS - a 'standardised' set of observables
- ATLAS & CMS colleagues who worked on generating STXS parametrisation + developers of `SMEFTsim` & `SMEFTatNLO`
- Common data format for SMEFT parametrisation of HEP measurements
- Public codebase for generating the numbers using [*EFT2Obs*](#)
- Extendable to any observable

Contact: K. Mimasu

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ex: `H_gluglu.json`

```
{
  "metadata": {
    "coefficients": [ "chgtl", "chg" ],
    "observable_shape": "(1,)",
    "observable_names": [ "gluglu" ],
    "flavor_scheme": "topU3l",
    "inputs": {
      "Lambda": 1000,
      "MW": 91.1876,
      "GF": 1.16638e-05,
      ...
    }
  }
}
```

```
"data": {
  "central": {
    "a_chgtl": [ -5.1261021119540705e-06 ],
    "a_chg": [ 39.34896452737338 ],
    "b_chgtl_chgtl": [ 387.08519581710067 ],
    "b_chgtl_chg": [ 5.1261021119540705e-06 ],
    "b_chg_chg": [ 387.08519581710067 ]
  },
  "u_MC": {
    "a_chgtl": [ 0.0 ],
    "a_chg": [ 0.0036136598569541825 ],
    "b_chgtl_chgtl": [ 0.0 ],
    "b_chgtl_chg": [ 0.0 ],
    "b_chg_chg": [ 0.0 ]
  }
}
```

Area 3: measurements

[TWiki](#)

Aim: study experimental approaches for EFT inference

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- Differential vs. dedicated
- Identification of optimal observables/ML based
- Quantify detector/acceptance effects & impact of EFT in backgrounds
- Optimise presentation of experimental results

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[\[CERN-LHCEFTWG-2022-001\]](#)

Recent note: *‘Experimental measurements & observables’*

- Summary of relations between operators & measurements used in global SMEFT analyses
- Contributions from various fitting groups

$$I_{ij}(\mathbf{c}) = -\mathbb{E} \left[\frac{\partial^2 \ln f(\boldsymbol{\sigma}_{\text{exp}}|\mathbf{c})}{\partial c_i \partial c_j} \right]$$

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$$I_{ij}(\mathbf{c}) = -\mathbb{E} \left[\frac{\partial^2 \ln f(\boldsymbol{\sigma}_{\text{exp}}|\mathbf{c})}{\partial c_i \partial c_j} \right]$$

Planned activity: ML in EFT analyses

- How to construct them & how to reinterpret existing analyses

Area 4: fits

TWiki

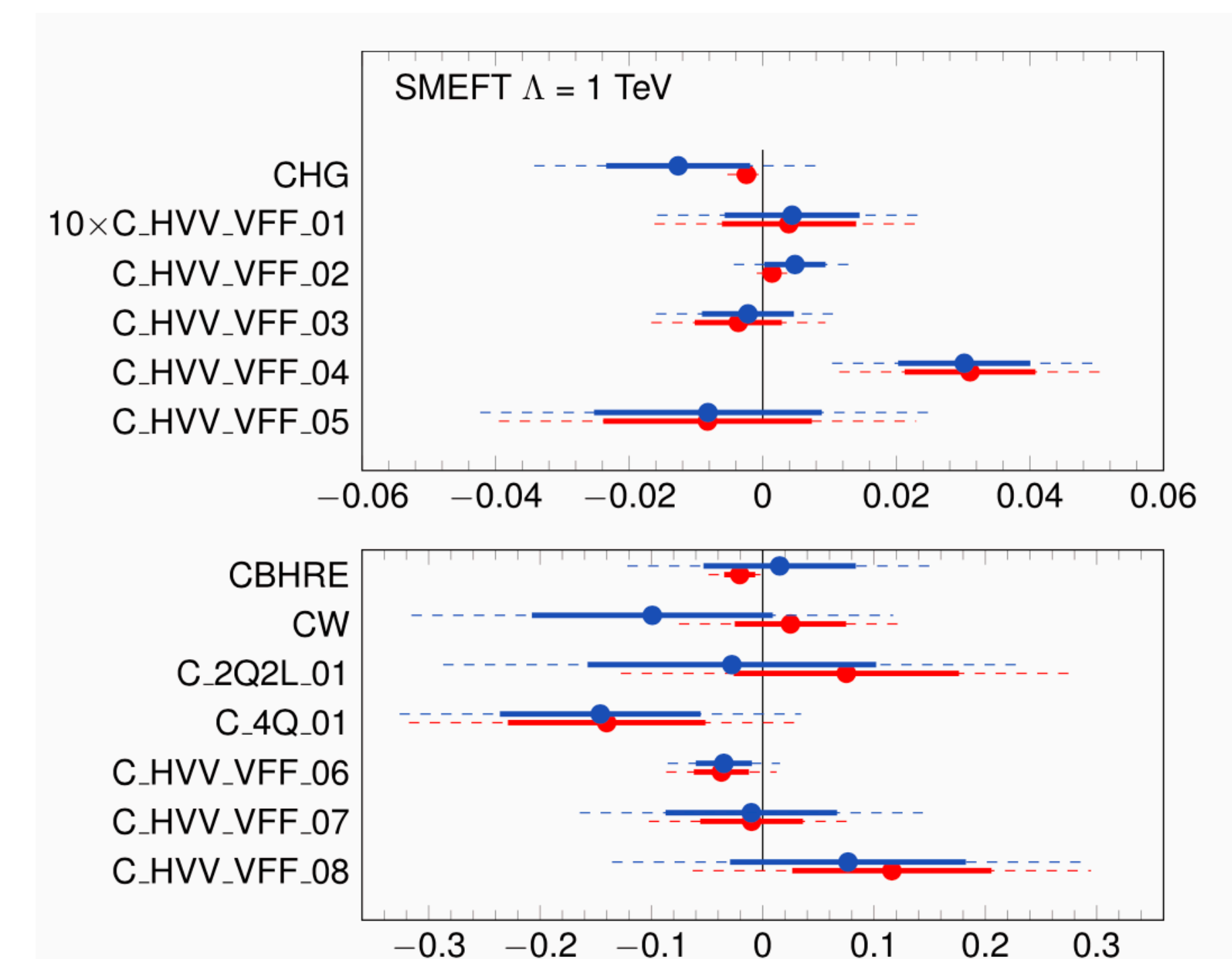
Aim: discuss issues that concern global fits

- Combining ATLAS, CMS, LHCb data
- Benchmarks for theory fits
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Ongoing: CMS+ATLAS fitting exercise

- ‘Playground’ SMEFT fit combining Top/Higgs/EW data from both experiments
- Harmonise workspaces/conventions
- Iron out differences & identify potential pitfalls
- Using public data, public combination code [ATLAS/CMS](#) repos

Area 5: UV benchmarks [TWiki](#)

Aim: study matching to specific models *see next talk by Shankha!*

- Identify BSM-driven subsets of operators
- Well-motivated benchmarks/patterns that come from classes of UV completions
- Benchmarks beyond SMEFT e.g. nonlinear EW symmetry breaking → HEFT
- Compare EFT constraints to direct searches

Area 5: UV benchmarks [TWiki](#)

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[\[CERN-LHCEFTWG-2022-002\]](#)

Note: *'Precision matching of microscopic physics to SMEFT'*

- Review of existing tools for 1-loop matching to SMEFT
- Supplementary codes for basis conversion & RG running

[ModelMatch](#): Github repo to archive matching results

Area 6: flavour

[TWiki](#)

Aim: study interplay between high energy and flavour physics

- Most SMEFT operators are flavourful!
- How to input LHCb, other flavour data into global fits
- How does LHCb handle SMEFT analyses?
- Connecting SMEFT to the weak (low energy) EFT

1 \Rightarrow 3 generations
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[TWiki](#)

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Recent meeting: Heavy flavour aspects in EFT fits

<https://indico.cern.ch/event/1274528/>

Possible future activities

some topics brought up at past meetings:

- ▶ Studies for $H + HH$ combinations (\rightarrow Higgs WG)
- ▶ **Validation** procedure for NLO event generators
- ▶ Database of **conversions** between tools and notations
- ▶ Preparation of **shared samples** for some measurements
- ▶ Adding **EFT weights to HEPdata** for reco-level observables
- ▶ Start a **full-likelihood combination** in parallel to fitting exercise
- ▶ Database of **1-loop matching** results for UV benchmark models
- ▶ Matching of **MSSM** in decoupling limit
- ▶ ...

new suggestions are always welcome!

participation to the activities is open to anyone!

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[I. Brivio, HEFT 2023]

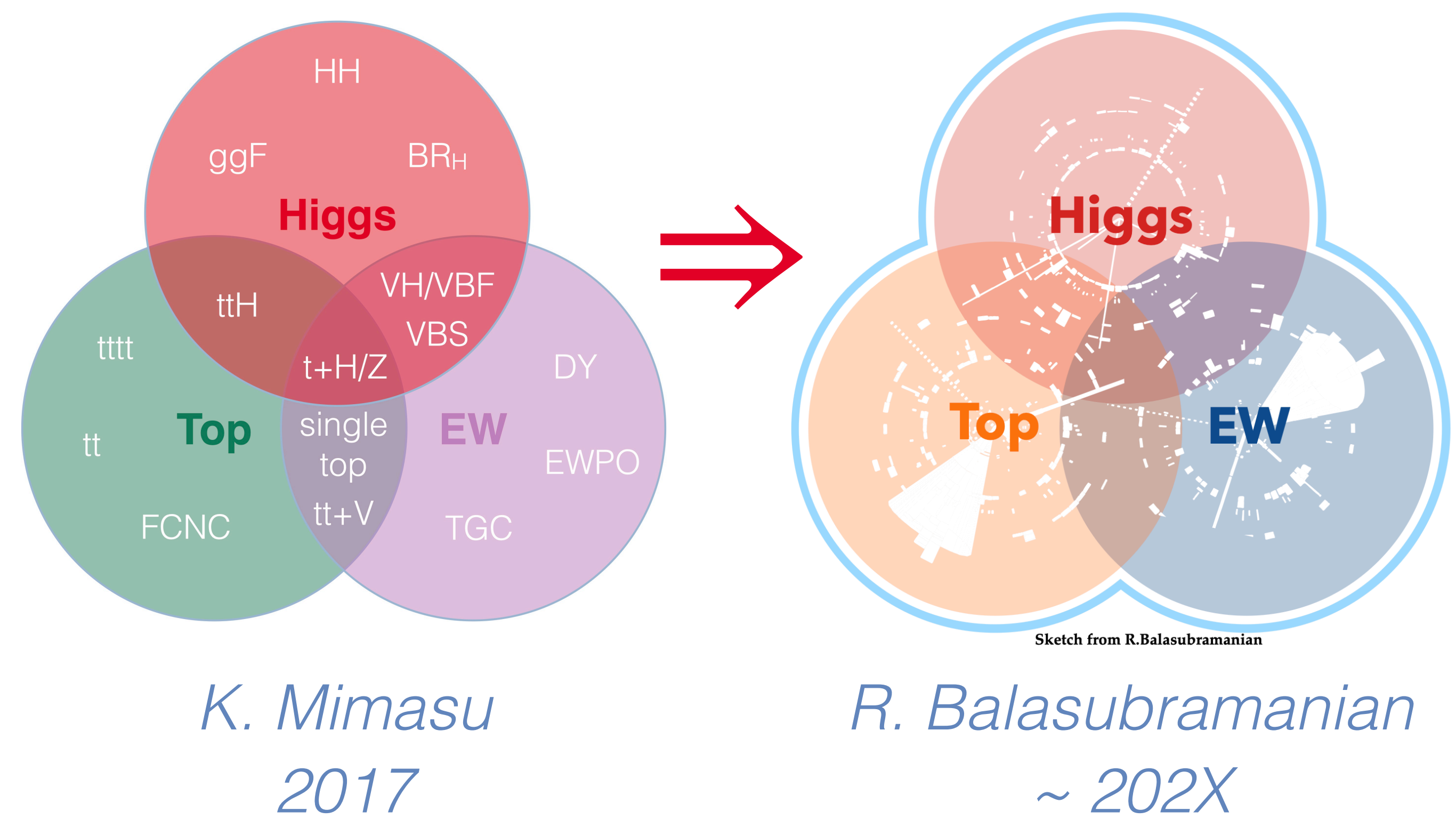
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Conclusions

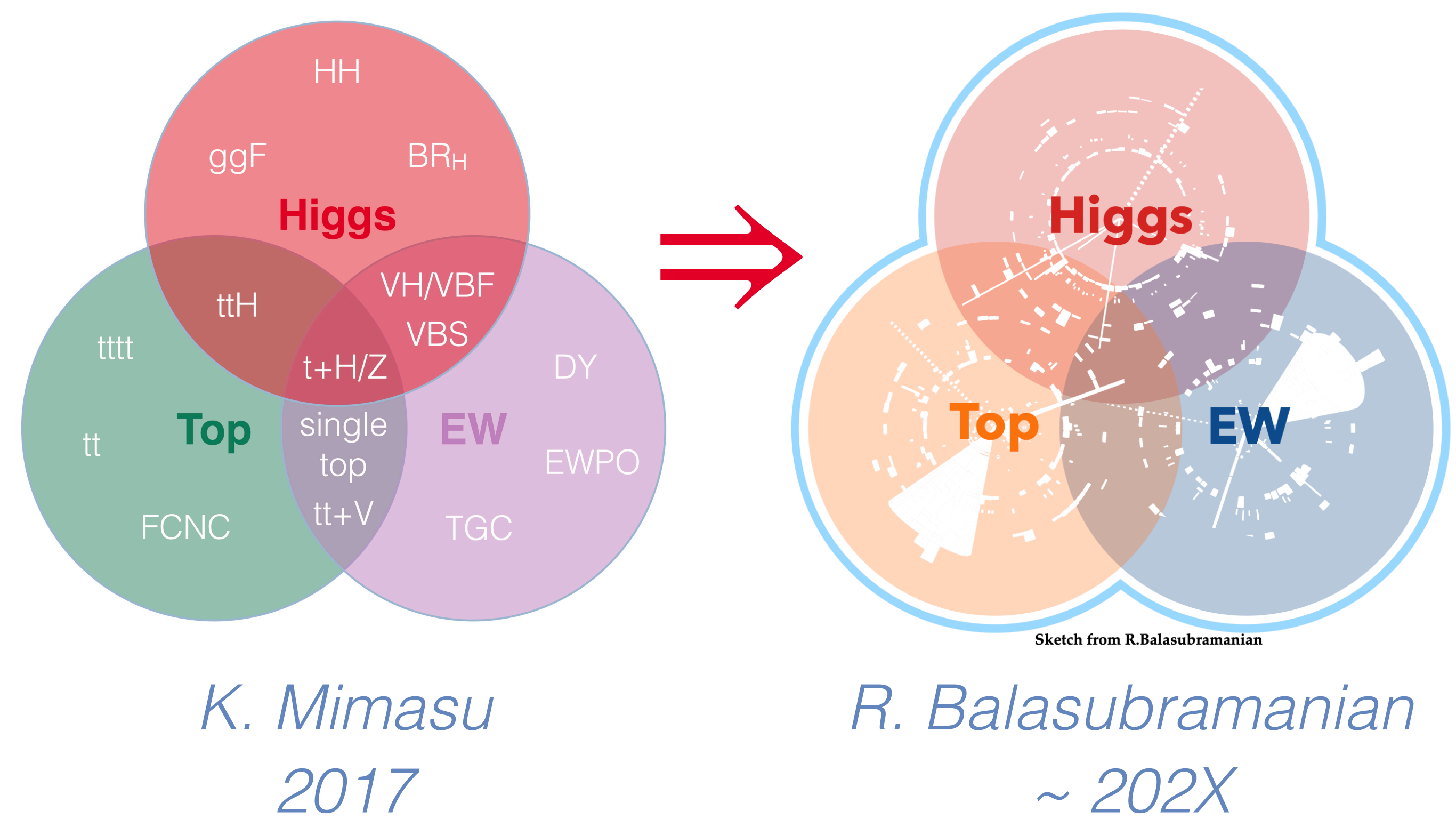
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Conclusions

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- Precision calculations have an impact: NLO/loops
- Sophisticated statistical inference - beyond Gaussians etc.
- Treatment of theory uncertainties
- Optimising experimental data presentation for SMEFT interpretations
- Shared theory predictions/MC samples
- Your ideas...



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The start of a beautiful friendship?

Hope for ongoing exchange & collaboration with the RIF

