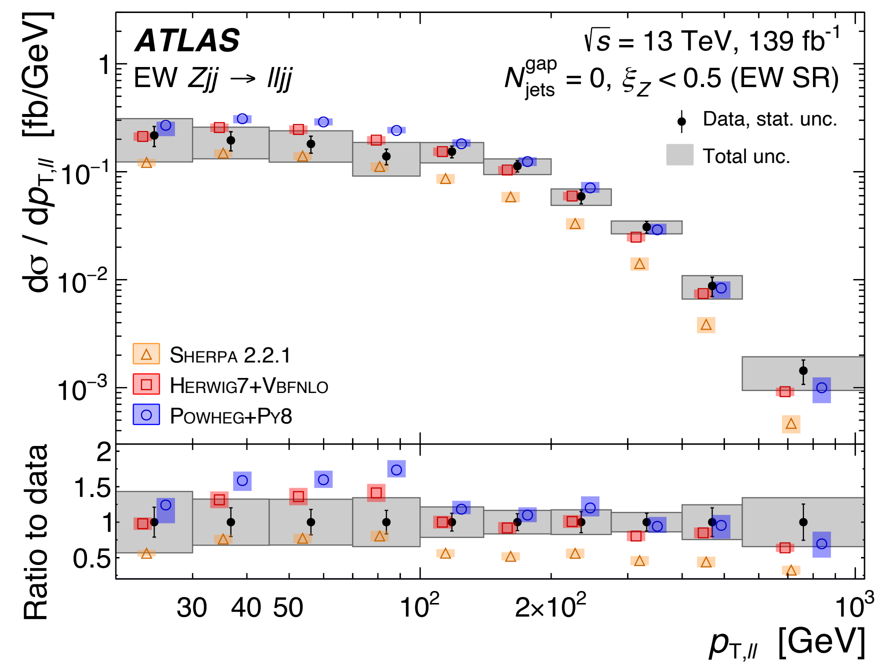
Summary of theoretical and experimental questions in Area 3: Experimental measurements and observables

Andrei Gritsan & Eleni Vryonidou
on behalf of the LHC EFT WG conveners

11 January 2021
Topical Meeting of the LHC EFT Working Group

EFT analysis:

- identify EFT operator(s) of interest, e.g. $C^{\varphi WB}$
- identify sensitive channel(s), e.g. VBS $qq \rightarrow \ldots \rightarrow jj4f$
- identify sensitive observable(s), e.g. m_{jj}
- identify the path to experimental measurement



  — (fiducial) inclusive (process) cross section

  — (fiducial) differential (process) cross section 1D

  — multiple (correlated) differential 1D

  — differential 2D, 3D or >3D

  — binned sub-process cross sections (STXS - unique to Higgs so far)

  — dedicated cross sections per operator (e.g. spin density, polarization, etc)

  — dedicated operator constraints

  (each path has its own pros and cons)

- (global) fit using experimental measurements: next meeting, but relevant for today

  — make sure measurements can be used in the global fit

On the following slides we are trying to extract key ideas expressed by the speakers for discussion

Inclusive, fiducial, and differential measurements in application to EFT

- long history of unfolded measurements
  - — used for comparing fixed-order calculations, MC tuning, etc…
  - — application to EFT is a bonus, but can it be used for EFT out of the box?
- “unfolded measurements are biased towards the SM by construction…”
  - — unfolding, phase-space corrections, background assumes SM
  - — is it typically a small effect in unfolding for most BSM ?
  - — can systematics / bias be determined in the unfolding framework by experiments?
- how significant are background effects on EFT?
  - — target high S/B
  - — how to deal with sizable background which could be affected by EFT?
- including many observables
  - — can we go beyond 2D differential measurements? (currently rare)
  - — multiple 1D differential with correlations (e.g. in top) — how to treat? (see backup)
  - — how to retain full information in a given channel?

“sort-of” differential measurements: STXS

- arise from the unique challenge in Higgs physics: multiple productions and decays

  — does it make sense to apply to Top and EW?

- some questions are similar:

  — detector effect modeling assumes SM
  can systematics / bias be determined in the STXS framework by experiments?

  — number of observables is limited by defined bins,
  is it easy to expand in stages?

  — how to treat background which could be affected by EFT?

- considerations, however, are very different

— likelihood-based fits: somewhere in between differential and dedicated measurements
(combines their pros and cons)

Dedicated EFT measurements

pros: use full detector information (folded), can be most optimal and correct

optimal: employ multivariate techniques (e.g. Matrix Element, Machine Learning)

correct: model detector effects / correlations for EFT operators (not only SM)

cons: limited to pre-defined list of operators, no alternative reinterpretation

computationally and human demanding

questions: do cons outweigh the pros?

questions: what information required to include in global fits?

(1) report intermediate results as measurements:

report cross sections per operator: further interpretation required

report operators: take care to carry flat directions in reporting

(2) proceed to “global fit” in direct combination by experiments

Matrix element inspired approach for EFT measurements

Idea that full kinematics is accessible

natural to extract Quantum Mechanical interference (relevant for EFT)

(1) creating the likelihood directly (still need acceptance, transfer functions, etc…)

(2) creating the "optimal observables" for EFT (e.g. $\mathscr{D}_{\rm int}$)

— guide machine learning to do the same (full input, ME-based MC samples)

compare: Matrix Elements, Machine Learning, STXS

successful application where one can identify clearly:

list of targeted operators

(full) reconstruction of the final state

questions: those from "dedicated measurements"

Machine learning–based inference

Idea that EFT inference should be based on a likelihood combination
for data in the folded space (as opposed to unfolded)

clean conceptually, powerful, and robust statistically approach

compare: MELA, Matrix Element Method, and Optimal Observables

(all approaches approximate the likelihood in some way)

Machine learning allows: detector response, neutrinos, jet radiation, particle ID,
flavor tagging, etc.

We should always be aiming for the most sensitive measurements…

questions: those from "dedicated measurements"

Fitting EFT in Top Physics

Crucial to combine different production channels and differential information
Examples of how to use different observables to bound top operators and to break degeneracies:

- 15 operators enter top pair production: to fully constrain them the total rate, ttbar mass/pT distribution, rapidity/asymmetry, and top polarization observables are the minimum. Spin correlation observables help the chromo-dipole, and sensitive to CPV.
- pT and rapidity distributions in t-channel single top seem sufficient to constrain the relevant operators. The full angular distribution in top decay can be used to extract CPV parameters, but its constraining power on the CP conserving ones needs further investigation.
- W helicity provides the best limit on OtW, but 4-fermion operators may enter as well without producing a W-boson. A formalism beyond helicity fraction is needed to make use of this information.

Fitting EFT in Top Physics

Crucial to combine different production channels and differential information

Examples of how to use different production channels to bound top operators and to break degeneracies:

- Adding ttZ/ttW on top of ttbar, and the combination of Tevatron + LHC 7/8/13 both help to disentangle incoming quark flavors (u/d).
- ttH, ttZ and ttphoton can benefit from cross section ratios.
- The E^2/Lambda^2 behaviour as naively expected in EFT is activated only in the channels that involve a multipoint dim-6 vertex (apart from 4-fermion operators). They are typically rare processes, but are 1) much more sensitive to EFT operators in high mass range and 2) mostly limited by statistics. Single top + Z/H are the most known examples, but more need to be studied.
- Top operators are also constrained by Higgs measurements through loop effects. However, care should be taken when combining both, as this typically also interferes with precision EW measurements.

Fitting EFT in Higgs and EW Physics

- 20 operators in Higgs, diboson and electroweak physics, 34 including top for global CP-even fit at linear level. Map including quadratic dependencies? Many more measurements and operators relevant at quadratic level.

- To what extent should experiments do combinations of SM EFT fits? Is the ultimate goal an official LHC global combination of all data for ATLAS+CMS?

- How should experiments take into account non-LHC constraints, e.g. EWPO, if at all?

- Best way to report measurements for input into global fits? Share predictions?

- SMEFT effects in backgrounds? e.g. top or four-fermion operators.

Next steps:

We would like to start putting in writing
the main ideas discussed in this meeting
(to be included in the WG writeup)

— connecting EFT operators to exp. observables

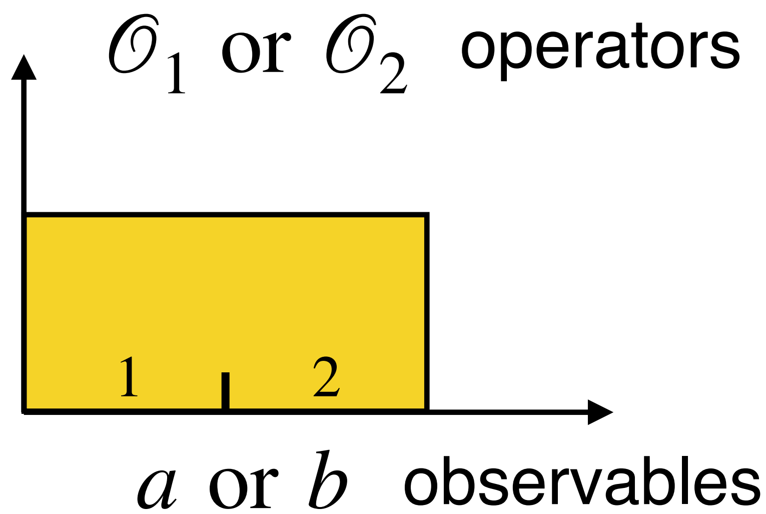
— performing experimental measurements

start with the survey, pros & cons …

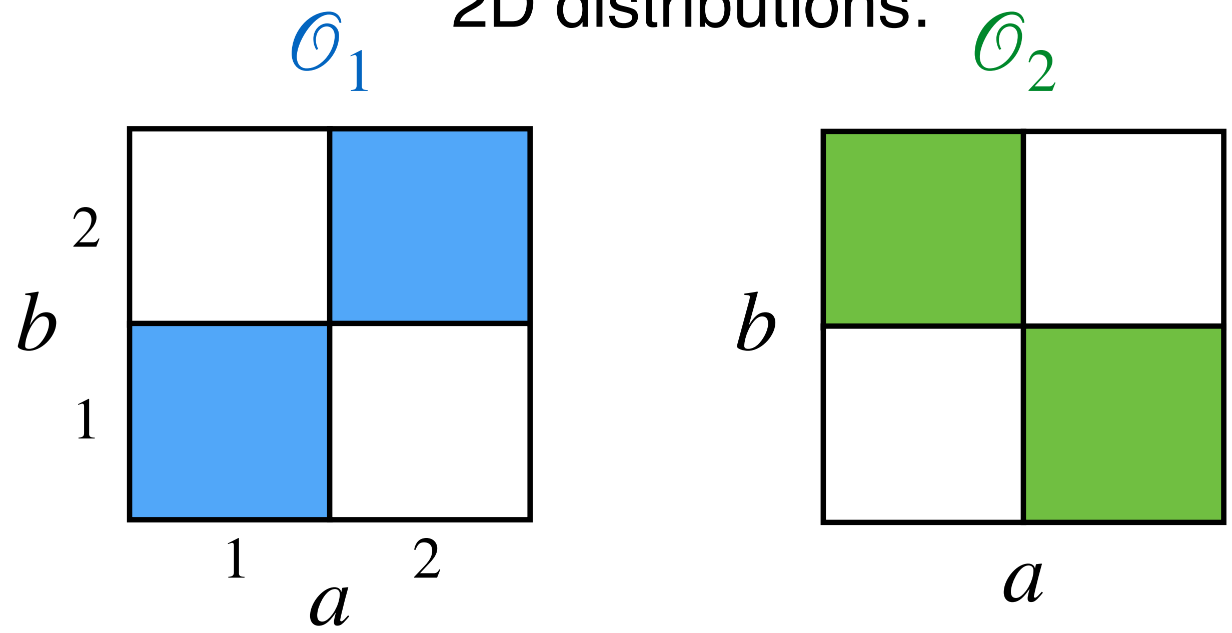
BACKUP

Discussion of multiple (correlated) differential 1D: Toy model:

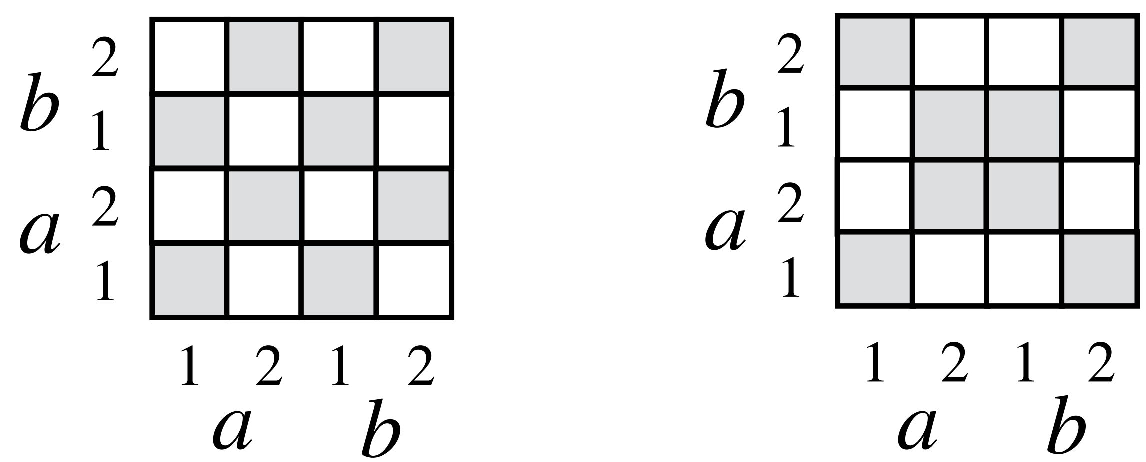
1D distributions = flat



2D distributions:



Correlation:



This measurement is about correlations, which is already in the 2D distribution without any Gaussian assumptions

$$\Big[4\,|A_{00}|^2\,\sin^2\theta_1\sin^2\theta_2$$
$$+\,|A_{++}|^2\left(1+2A_{f_1}\cos\theta_1+\cos^2\theta_1\right)\left(1+2A_{f_2}\cos\theta_2+\cos^2\theta_2\right)$$
$$+\,|A_{--}|^2\left(1-2A_{f_1}\cos\theta_1+\cos^2\theta_1\right)\left(1-2A_{f_2}\cos\theta_2+\cos^2\theta_2\right)$$
$$+\,4|A_{00}||A_{++}|(A_{f_1}+\cos\theta_1)\sin\theta_1(A_{f_2}+\cos\theta_2)\sin\theta_2\cos(\Phi+\phi_{++})$$
$$+\,4|A_{00}||A_{--}|(A_{f_1}-\cos\theta_1)\sin\theta_1(A_{f_2}-\cos\theta_2)\sin\theta_2\cos(\Phi-\phi_{--})$$
$$+\,2|A_{++}||A_{--}|\sin^2\theta_1\sin^2\theta_2\cos(2\Phi-\phi_{--}+\phi_{++})\Big]$$

← 3D example in $H \rightarrow 4\ell$

~ disappear in 1D and 2D