Some thoughts on Future EW Measurements at the LHC

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- introduction
- a detour: photons
- vector boson scattering
- the interface to QCD
- quantum mechanics
- outlook

instead of an introduction

("sort of summary")

disclaimer

- apologies first:
  - couldn't follow most of the meeting, speed-read the slides
  - please, don't be offended when I missed things or misrepresent them
- clear danger for me to carry coal to Newcastle
- therefore: just some thoughts on possible **additions** to extremely well-thought out programme
- and sorry: no plots or new insights, mostly questions ...

current trajectory

- testing deeper and deeper tails, severe tests of SM dynamics
- well-established standard candles (DY, VBS, di-bosons, dots) and methods (higher orders, EFTs, dots)
- increasing blurring of lines between EW, QCD, top, & Higgs: inter-dependence on fundamental inputs, methods, backgrounds, ...
- race for "ultimate" theoretical precision:
  - fixed-orders: NNLO, QCD$\otimes$EW will become standard across board
  - matched/merged with parton showers: beyond NLL accuracy
    need to improve EW radiation (QED)?
  - suspicion: future dominance of non-perturbative uncertainties
    $\Longrightarrow$ how prepared are we?

useful additions?

- in the following I will try to
  - add some personal thoughts
  - make some unconventional suggestions for additional studies

    (many of which may not work out or be useless)
  - blur the lines between EW, top, Higgs, QCD a bit further

Detour

(some thoughts on photons)

the role of photons

- interesting final state, couple to everything electrically charged
  - no discussion concerning issues with isolation etc.

    (you know this better, anyway)
  - how do multi-photon cross sections scale with N_γ?
    steps on a ladder or Poissonian?
- important initial state
  - part of the parton content of the proton ($\longrightarrow$ PDFs)
  - but: also coherently emitted by protons/ions

    (large-Z enhancement of Weizsaecker–Williams photons)

    $\Longrightarrow$LHC is a photon collider
  - different signatures for PDF and WW photons

VBS

(prime laboratory for coupling structure analyses)

forgotten (?) channels

- goal: constrain **all** VVV couplings
  $WW\gamma$, WWZ and dim-6 deviations:
  - VBS production of the neutrals
  - VBS production of single-W: use WW photons vs. PDF photons?

    (i.e. use a large rapidity gap in one forward direction/forward proton)

  triple-neutral coupling: higher-dim (≥ 8) in EFTs, but:
  part of old-fashioned anomalous gauge coupling framework
  - single-Z production with WW photons?
- goal: constrain **all** $VVVV$ couplings:
  - VBS production of VV pairs
  - again: use WW photons vs. PDF photons?

    (i.e. use a large rapidity gaps in both directions)

$\gamma\gamma$ collisions

- clean signature with WW photons:
  system produced centrally, rapidity gaps/forward protons
- $\gamma\gamma$ scattering:
  - sensitive to charged particles in loop
  - unforeseen resonant structures (axions?)
  - axions/dark photons/etc. in final state

(signal: single $\gamma + \not{E}_T$)

  - how about γZ final states?

same-sign W's

- "wonderful" final state, probes lots of gauge structures
- curious: $qq' \to \tilde{q}\tilde{q}' W^{\pm} W^{\pm}$ is finite for all quark $p_{\perp}$
  $\Longrightarrow$ no need per se to look for jets in forward direction
  - this is not true for backgrounds such as WZ, $W \pm W^{\mp}$, ...
  - can this be used? (maybe in ratio w.r.t. leading jet $p_{\perp}$ ...)
- also: great for measurements of double-parton scattering:
  - supremely clean: $\sigma_{DPS} \approx \sigma\mathrm{direct}$
  - use this more differentially?

QCD interface

(EW final states for QCD studies)

heavy quarks

- use of $V + Q$ final states for measurements of PDFs:
  - $W + c \longrightarrow f_s$, $Z + c, b \longrightarrow f_{c,b}$
- have to understand heavy-quark production:
  - $g \to Q\bar{Q}$ a persistent problem in parton showers
  - can we measure ratio of $g \to b\bar{b}/g \to c\bar{c}$?

(maybe in $Z + Q\bar{Q}$, $W + Q\bar{Q}$?)

- relevant for boosted H, HH, ...

"dirty" QCD

- interesting issue with underlying event models:
  hard to accommodate MPIs in both QCD and DY production
  maybe worth a second look?
- the "ridge" in high-multi events:
  strong azimuthal correlation in "towards" side
  can we use $V + QCD$ with V the towards side?
  what is the flavour of the ridge?

spins?

(some basic quantum mechanics)

entanglement and information

- spins of produced systems can be correlated: recent little wave of papers on entangled systems, especially in $t\bar{t}$ production
- this program can be extended to VV production:
  - measure spin-correlations of ZZ pairs
  - "old" QM (interference) effect: radiation zeroes, which are being "destroyed" by real radiation
  - are LO spin-correlations destroyed by real/virtual EW corrections?

(I genuinely have no idea, in how far chiral nature does that)

a stupid idea

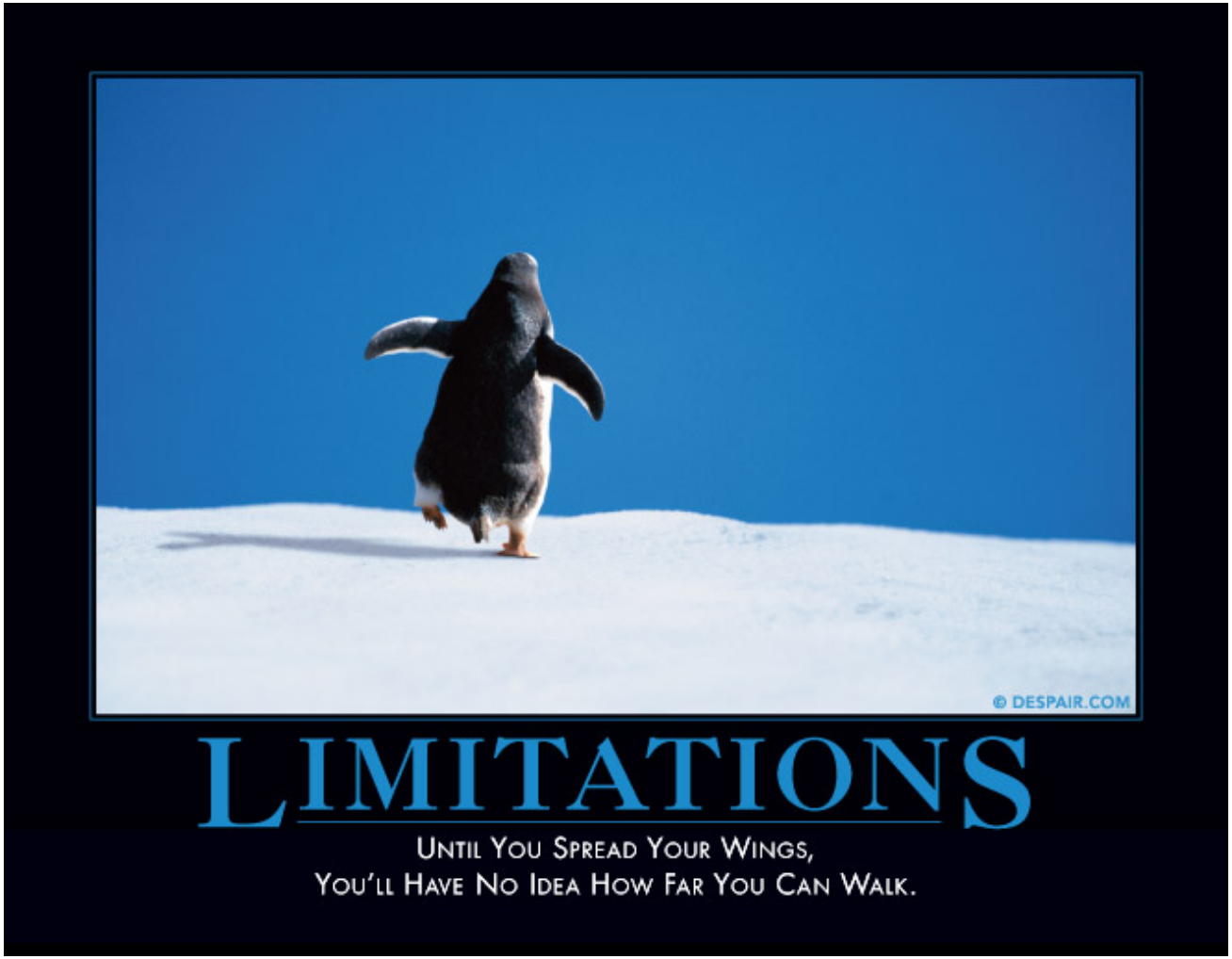
- observations:
  - 10% of all b quarks become Λ_b
  - Λ_b "inherit" spin of quark
  - in high-energy limit chirality $\longleftrightarrow$ helicity $\longleftrightarrow$ spin:

can we measure b chirality in Λ_b decays?

- I think this is an experimental question ...
- can we use this for further spin correlation studies?

outlook

(what the future holds for us)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