Measurement definitions based on truth particles

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We have contacted representatives of experimental and theoretical "communities" for input to the session.

Many thanks to all contributions to the session (see indico agenda).

We have linked all contributions on the conference agenda

Aim is to introduce the problem, initiate a discussion at the start of the conference

We hope that during the conference you think and discuss
We have a summary discussion at the last day where your contribution can go in

Both sessions are in workshop style, so, please, interact.

Motivation

- Measurements at LHC become increasingly precise
- Fast progress on theory side in many areas:

  ME+PS merging, N(N)LO+PS matching, e.w. corrections etc.

  full description of final state instead of narrow width approximation

  e.g. pp -> l l l l vs pp-> Z Z
- Need accurate definitions of measurements to facilitate

  the comparison of data to theory predictions
- Suitable definition is based on the particle entering the detector
- Use of particle-based definition already standard methodology in HEP
- Standardized tools to compare data and predictions (Hztool, Rivet etc.)

Aim

- The following will not necessarily report on what is presently done, but aim to provide “baseline definitions” after discussion in the community as default starting point for refined definitions in dedicated measurements

- There will always be modifications for special analyses

- Proposals are based on informal discussions in and between the experiments (ATLAS and CMS). Work ongoing in the experiments.
  ALICE has contributed some informal answers where relevant
  (see contributions to this session)

Guiding Principles

- Define observable in theoretical safe and unambiguous way
- Measure observables correcting for detector effects minimizing the dependence on the MC model used
- Measure within detector acceptance (fiducial region) to avoid model dependent large extrapolations
- Define “truth” objects, e.g. stable particles entering the detector, as close as possible to physics objects reconstructed in the detector
- Stay practical: fiducial region only for main effects
- Use operational definitions based on “truth”-objects to define complex observables
- Provide separately corrections to “parton-level” or “total cross-sections” to ease theory comparisons and provide a benchmark for future corrections derivation

Overview of detailed discussion points

- Stable particle definition
- Charged lepton and photon association
- Jet building
- Jets with heavy flavour contents
- Missing transverse momentum
- Overlap jet/lepton treatment
- Complex topologies

Anything missing ?

Some thoughts on photons are included, but more work is needed.

Stable particles

- Particles in MC event record with status code 1 with live-time above a cut
- ATLAS and CMS use presently c tau=10mm
- ALICE: produced in collisions including products from strong and em decays excluding feedback from weak decays of strange particles
- Experiments use same definitions.

Cut might be reduced, with increasingly better detection abilities and presence of particle boosts

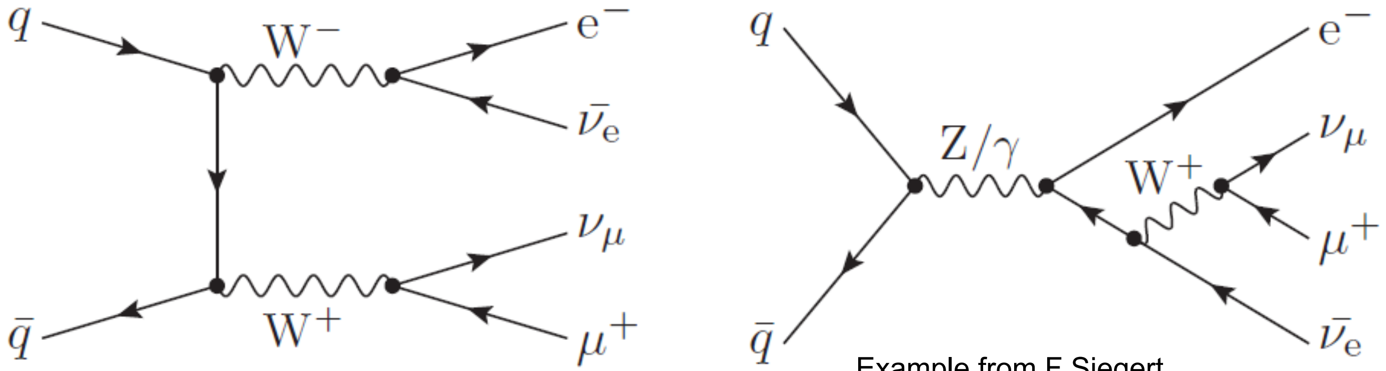
Prompt charged leptons

- Lepton with PDG-ID=11-16 not from hadron decays or quarks

  to select prompt lepton e.g. from W-decays
  - lepton origin check not always implemented in past analyses
  - is this general enough? Obvious exceptions like quarkonia, others?

  Avoid “lepton has W-boson mother” because of

  interferences or intermediate resonances
- Does the neutrino come from a W-boson ?



Example from F Siegert

Prompt charged leptons and photon association

- Photons: particle with PDG-ID=22 not from hadron decays (or tau-lepton ?)
- Need to specify treatment of radiated photons
- Three possibilities for photon treatment:

- **Bare:** leptons after QED radiation, take them as they are in the event record
- **Born:** leptons prior to QED FSR radiation
- **Dressed:** Operational definition:
  collect photons around charged leptons with cone (or jet algorithm ?)

Provide multiple results and/or corrections to move among them?

In principle, can calculate correction dressed->born a posteriori

Photon association to charged leptons

- **Bare:** leptons after QED radiation, take them as they are in the event record

  can not easily combine cross-section from electrons and muon

  highly model dependent (e.g. details on radiation cut-off etc.)
- **Born:** prior to QED FSR radiation

  e.g. compare with/without QED radiation or navigate in event record (needs expertise)

  Depends on details of implementation of QED radiation

  electron and muon cross-section can be combined and directly compared to fixed order theory
- **Dressed:** collect photons around charged leptons with cone (or jet algorithm ?)

  operational definition useable for any MC record (can be applied without expert knowledge)

  largely independent on QED model

  in practice only small differences between electron and muon cross sections

  needs further corrections for comparison to fixed order calculation

Dressed lepton as baseline ? Obviously some precise measurements, e.g. for inclusive Z production, are useful to be quoted on Born-level as well.

ALICE uses “bare muons” (measured with tracking and high density environment)

Tau-leptons

- Treatment of leptonic tau decays:

  electron/muon from tau-decays have different spectrum that prompt leptons

  Inclusion or subtraction in fiducial phase space definition?

  - at particle level mostly a matter of physical meaning/size of the contribution to be estimated
  - relevant for comparison with parton level calculation, where tau decays normally not included

- How to define hadronic tau-decays in model independent way ?

Isolation of prompt leptons and photons

Isolation with respect to hadrons:

- In lepton-IDs often a track- or cluster-based isolation requirement is applied to suppressed “fake lepton background”
- lepton-jet distance to avoid extrapolating where trigger is not measuring? Can be removed in unfolding, i.e. extrapolated ?

Isolation with respect to other leptons:

- Avoids overlaps that can not be reconstructed in detector
- Use dR cuts as on detector-level ?
- Extrapolate to full phase space ?

Photon isolation:

- often implemented as in experimental analysis
- theoretical issue to define “fragmentation” component (Frixione isolation)
- Photons from quark radiation ?

Jet building

- Jet algorithm analysis dependent, default choice: anti-k_t clustering algorithm
  - each experiment using its own size (ATLAS R=0.4, CMS R=0.5, now becoming R=0.4)
  - also analysis dependent,e.g. boosted regime

- Possible algorithm to collect particles as inputs to jet algorithm:

1. collect all stable particles
2. identify leptons not from hadron decay and remove them from list of stable particles
3. dress charged leptons with photons not from hadron decays (remove these photons)
4. cluster remaining particles to jets

In some analyses, jets use only charged particles.

Open questions in jet building

- Neutrinos and muon from hadron decays are included in jets

  However, in jet calibration neutrinos and muons are excluded to avoid tails

  Introduces model dependence -> Can be extrapolated ?

  otherwise overall event reconstruction becomes complicated

  (done by ATLAS and ALICE)
- Neutrinos from bottom/charm hadron decays to be included?
  - exclusion closer to experimental definition
- Treatment of isolated photons not associated to lepton (analysis dependent)
- Treatment of jets that contain only photons or leptons constituents
- Some experiments use jet area based event-by-event pile-up subtraction on detector-level. This might subtract particles from underlying event (UE) and add them back in unfolding.

- Use this method on particle-level as well ?
- Subtract UE contribution gets special treatment in pile-up subtraction

Jets lepton overlap removal

- On detector-level jets and leptons need to be separated
- For leptons not contained in jet constituents impose dR cut ?
  dR cut value close to R used in jet algorithm ?
- Value used in experimental analysis should be used
- Veto jets or events ?
- Can be extrapolated ?

Jets with heavy flavour content

- A heavy-flavour (HF) hadron that contains a b or c quark
  - use primary hadrons (directly after hadronisation)

    or weakly-decaying hadrons (HF-flavour is lost)
  - exclude quarkonia, like ccbar or bbar ?

- Jets that contain a HF-hadron with pt>5 GeV

  to mimic experimental HF-tagging algorithms
- Use ghost-association to define which HF-hadron is contained

  (cluster undecayed HF-hadron modified to negligible momentum

  contain means have a HF-hadron as jet constituent

- Treatment of close-by HF-hadrons (flavour k_t algorithm ?)

Missing transverse momentum

- Aims to identify the vector sum of invisible particles from the hard scattering

- Use vector-sum of all neutrinos not from hadron decays

Complex topologies

Examples are multi-boson topologies

e.g. pp -> ZZ or pp -> W Z

Problem to assign leptons to “mother bosons”

Definition of Higgs production modes, e.g. VBF

Use operational definitions

Top-quark from operational definition (Pseudo-top)

- non-resonant contributions pp->tt vs pp-> Wb Wb
- several top quarks can be found in the MC records

  no unique definition across MC generator

→ Use operational definition based on stable particles

- Simple prescription for l+jet events: see arXiv:1502.05923
  - Select prompt dressed lepton and form transverse momentum from neutrinos
  - Cluster jets from stable particles excluding prompt and charged dressed leptons
  - Identify jets with b-content and select the two high pt HF-jets
  - The remaining two highest pt jets are assigned to form the hadronic W-boson
  - The b-jet closed to the lepton is assigned to form the leptonic top-quark decay
  - The hadronic top quark is defined from the hadronic W-boson and the remaining b-jets
  - The leptonic W-boson is assigned from the remaining lepton and the missing transverse energy using the W-mass to constrain the neutrino pz-momentum (two solutions from kinematics)

- Similar prescription in boost regime based on large-R jets (see ATLAS-CONF-2014-057)

Possible studies for Heavy Ion collisions

- Large energy fluctuations from peripheral nucleon-nucleon collisions (UE) requires:
  - jet-by-jet correction of the energy scale
  - unfolding
  - fake-jet rejections (e.g. min pt cut on leading particle

Introduces possible model dependence

- Particle correlations
  - Purist view: only correlation functions can be measured
  - Pragmatic view: decompose in background, jet-like correlation and particle flow

- Event characterisation: centrality, event plans etc. based on particles

  might provide additional tool for direct comparison of results

Common definition of ultra-peripheral collisions

Some references

- TopLHC-WG: https://twiki.cern.ch/twiki/bin/view/LHCPhysics/ParticleLevelTopDefinitions
- A. Buckley et al., arXiv:1003.0694
- C. Buttar et al., arXiv:0803.0678