Event Generators and Theory Formulae for FCC-ee

Present status

1. I have requested from the FCC-ee working groups a slide or two on their present use and future needs for event generators

2. it is evident that we are not quite ready to answer this question
   -- the detailed work is only starting

Theory ← → Experiment

1. we generally assume that the experiment will be able to extract PSEUDO-OBSERVABLES

-- Z cross-sections, angular distributions,→ partial widths and asymmetries

-- W cross-sections and ratio of branching ratios → partial widths

-- Higgs cross-sections with and without Z tag → partial& total widths and branching ratios

-- top pair production → parametric extraction of top mass, width, vertex corrections (α_{QCD}, λ_{Htt}, etc.)

-- tau branching ratios → weak couplings, α_{QCD}

-- ee → H (s-channel Higgs production) is also a tricky process

→ **This requires event generators which have a good description of the basics**

-- (multiple) initial state radiation, final state radiation, interference etc…

-- exists for ee->ff (nγ)

2. and then theory/pheno will then proceed to link the pseudo-observables to more fundamental theory parameters (e.g. mixing with RH neutrinos, EFTs, etc)

-- note however that for such detailed fits, the experimenters have a better grasp of the statistical form of experimental systematic effects and their treatment and will become involved at some point.

Theory ← → Experiment

3. the other important aspect of detailed event generators is to allow a direct test of the theoretical prediction of observable 'real' radiative effects

-- precision/sensitivity in the relationship between pseudo-observables and cross-sections etc…

-- multiphotons, interference effects etc…

-- higher order lepton pair production,

-- gluon splitting in heavy quarks and effect on R_b, R_c etc….

and understand in advance how well we could in principle perform these tests.

4. it is in any case essential to have generators for all occurring final state topologies

-- reweighting for matrix elements etc… is also possible.

Feedback from the working groups

EW group

Heavy Flavour group

Higgs group

More feedback will be collected from the top, QCD, BSM groups etc… this is thus only a very limited sample

EW WG (Z, W)

Tenchini, Azzurri, Piccinini

- Bhabha scattering at small angle, fully exclusive on electron and photons
  - target precision: 0.01% B. Ward
  - luminosity working examples: BHLUMI, BABAYAGA
- $e^+e^- \to \gamma\gamma$ as cross check for luminosity C.M. Carloni Calame
- $e^+e^- \to f\bar{f}$ at large angle
  - required: NNLO electroweak with resummed QED
  - examples at LEP: TOPAZO, ZFITTER, KORALZ → KKMC
- $e^+e^- \to 4$ fermions
  - complete tree-level matrix elements real rad. corr. to Bhabha and $e^+e^- \to f\bar{f}$
  - examples: automated tools available, e.g. MadGraph, Whizard, ...
- $e^+e^- \to 4$ fermions for WW (and $We\nu_e$, ZZ, Ze^+e^-, ...)
  - NLO matrix elements ⊕ higher order rad. corr.
    - $2 \to 4$ NLO is available today in automatic tools

    C. Schwinn on issues about higher orders
  - examples: RACOONWW, YFSWW3 J. Reuters, M. Skrzypek
- universal "afterburners" for photon showers (PHOTOS)
- τ decays and polarization TAUOLA Z. Was
- Parton Shower MC: diff. shower models to match precision

Heavy Flavours, (b)

Stéphane Monteil

Sequence for simulating *b*-hadron decays events - Example

- **Generate:** $e^+e^- \to Z \to b\bar{b}$
- **Fragmentation and hadronisation** of the *b* quarks.
- **Filter B^0** particles.
- **Force the B^0 decay:** $B^0 \to K^{0*}\tau^+\tau^-$
- **Force** the tau lepton decay in **three prongs**:
  $\tau^+ \to a_1^+ \bar{\nu}_\tau \qquad a_1^+ \to \pi^+\pi^-\pi^+$

Pythia

EvtGen

EvtGen: it is the most comprehensive generator of *b*-hadron decays. At use in *B* factories and LHCb experiments. Models for angular distributions. Covers as well tau lepton decays. This must be the generator to use.

https://evtgen.hepforge.org/

Markus Klute

Monte Carlo for FCC-ee Higgs

In general, MC tools are available for FCC-ee Higgs program

- PYTHIA, Whizard, and Madgraph used for studies
- Similar to LHC workflows
- Tools support tree, ISR, NLO QCD, NLO EW (partially), loop induced processes, simulation of beam spectra

Conclusions

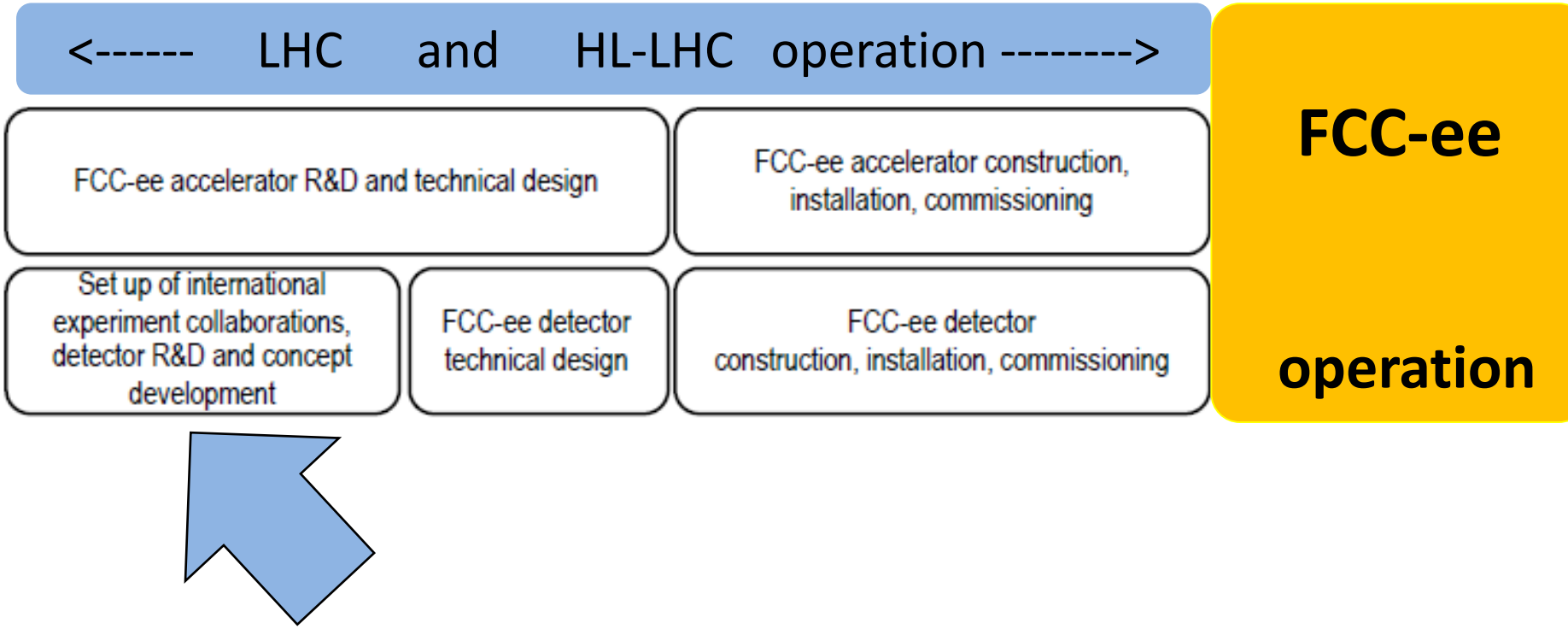
1. The event generators and cross-section formulae are one of the most natural places for the Experiment-theory interface

2. We have a legacy of event generators from LEP and some improvements

3. The FCC-ee experiment – theory connected work is only beginning
   e.g. α_{QED} and σ_E , ΔE determination with $A_{FB}^{\mu\mu}(s)$

4. Moving soon to higher gear for the conceptual design of detectors!

ESPP 2020



Start exploring this step this week