Physics Performance effort & the case studies

4th FCC Physics Workshop - 10/11/2010

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Where we stand

- Published several physics studies in the CDRs and arXiv to show the potential for physics of the FCC-ee program and motivate its importance for the future of HEP
  - the clean environement for physics at an e+e- collider allows predictions to be made from extrapolations from previous data, simplified analysis, full and fast simulation.
  - However, the next step will be to prepare for a « Physics, Experiment and Detector » (PED) CDR in a 4-5 years time that will include several detector concepts designed to be able to achieve physics results
- To make this a reality we need:
  - to choose the most significant benchmark measurements
  - to extract the detector requirements
  - to develop the software tools for the simulation of this detector concepts and the event reconstruction
  - to design detectors exploring all the most innovative ideas
- Physics Performance Coordination (PPC) is the forum where all these aspects come together, to coordinate and facilitate the progress of the various studies through sharing of information and common tools

defining the « case studies »

- the physics landscape of the FCC-ee program extends in all possible directions:
  - the difference in the physics focus at the different √s
  - the difference in the event kinematic of running from 90GeV (and possibly below) up to 365GeV
  - the challenge of being able to achieve superbe precision on SM processes but also perform unique direct searches for new physics
- The list of interesting processes and measurement is extensive, and it has not been fully explored yet, even in terms of sensitivity.
- From this richness, we need to extract concrete benchmark measurements, the « case studies » that will be used to extract requirements on what is missing to achieve our ambitious goals: detector requirements, reconstruction tools, calibration techniques.

what is a « case study »?

- A « case study » is not really just a physics analysis, it is more the « reverse engineering » of a physics analysis
  - usually we have the input and we find the output (measurement) in a case study it is the opposite: we have a target for the output and we need to find the input.
- The baseline is physics measurement goal. It could be either the observation of a process or the accuracy of the measurement itself. For instance:
  - systematic uncertanties commensurate to the tiny statistical ones
  - maximize potential for discovery of FIP in the decays of Z or H
  - even just estimate new statistical limits
- Many ingredients contribute. The work to do is disentagle the various contributions and figure out how to push the maximum performance in all directions:
  - need to improve on baseline detectors to perform as needed
  - need to develop a detector simulation that allows this performance to be merged in the full analysis
  - need to develop reconstruction algorithms that fully exploit the detector information
  - need to develop calibration strategies and analysis techniques to shrink the uncertainties as needed

current list of case studies

- Started collecting idea a proposal in the past months:
  - Draft List of Case Studies
  - taking advantage also of the Snowmass process to extend the message LOIs by FCC-ee are collected at https://indico.cern.ch/event/951830/
- These lists are the result of a first pass and they are far from being complete.
- The « case studies » will grow from the input from the Physics Groups to the PPC and the ideas from colleagues like you.
  - **Important note:** extending and deepening the physics studies will bring in new ideas and measurements that have not been considered before in the CDR.
  - They demand maybe « sensitivity studies » to evaluate the potential of the FCC-ee.
    - The tools needed to realize them, however, are the same that are developed and discussed in the PPC group.
    - A constructive collaboration between all involved in physics studies will provide a faster turnaround for the developments needed and results

« case studies » in Higgs physics

Measurement	Phys. Goal	Need to	Constraining
Higgs boson coupling to c quark *see talk #120 L. Gouskos*	Ideal case: $\sigma ZH \times$ BR($H \to c\bar{c}$) precision better than 1%	improve efficiency and purity of charm tagging	interaction region and vtx detector design new tagging algorithms
ZH production cross section	0.1-0.2% precision	extend to hadronic Z decays	hadronic mass and hadronic recoil-mass resolution
Higgs Boson mass via recoil with leptonic Z	5MeV ultimate	- $\sqrt{s}$ with precision of O(1MeV) - calibration strategies	lepton and jet angular resolution & acceptance. Reduction of systematics ele energy and muon mom. resolution
Higgs boson mass in hadronic final states		- extend to Z hadronic - calibration strategies	b-tagging eff and purity, jet angular resolution, jet reco, kin fits

« case studies » in Higgs physics (2)

Measurement	Goal	Need to	Constraining
total Higgs width (part 1)	Higgs width from H->ZZ* multilepton or H->WW*	increase efficiency, reduce the background	jet clustering and kinematic fits and jet angolar resolution vs jet energy resolution
Total Higgs width (part 2)	using WW fusion process with H->bb	separation of signal and bkg	visible and missing mass resolution. profit of $\sqrt{s}$=365 kinematic before going to $\sqrt{240}$
HZgamma coupling	better than HL-LHC	measure of ZH->ZZγ, H->γγ and ee->Hγ	photon identification, photon energy/angular resolutions, in p
ee->H production in s-channel at Higgs pole (talk #82 D. D'Enterria)	assess the ultimate reach on the H->ee coupling	resonant production & monochromatization ee->H	- machine challenges - ML tools needed to beat the huge background

« case studies » at the Z peak

Measurement	Goal	Need to	Constraining
Measurement of $R_\ell = \frac{\sigma(Z \to hadrons)}{\sigma(Z \to leptons)}$	key quantity. Statistical precision of O(3x10^{-6})	-reduce limiting systematics known from LEP - adding interaction region details	- lepton acceptance but also hadronic
Z total width	4keV statistical precision at Tera-Z	-reduce limiting systematic known from LEP: ptp error on the 3 resonance scan points. Use dimuon events -interaction region design	- muon momentum, angular resolution and scale stability -reoptimization of scan strategy
Z peak cros ssection	precision of O(10^{-6})	-reduce limiting sstematic from lumi	- measure luminosity with photons and separate from bkg at large angles
$Z \to \nu_e$ *see talk #116 R. Aleksan*	improve measurement maybe to ~1.4%	separate interference effects	- precise measurement of photon pt - EM energy scale

« case studies » for EWK

Measurement	Goal	Need to	Constraining
Z pole EWK observables with heavy-quark	O(10^{-6}) precision on Z decays to h.f. ewk properties	reduce systematics to match with statistics unc.	- detector design in general - vertexing/tracking - b/c-tagging algorithms
W mass	~500keV maybe less (measure at threshold and above)	- beam energy calibration at 300keV - competitive measurement of final state reco	- event reconstruction - lepton mom scale & resolution - kinematical fitting

- The Z & W studies here might seem similar to a repeat of the LEP program, but this is a wrong assumption!
- The Tera-Z luminosity brings the overall approach to measurements at a totally different scale. The statistical precision achievable and the large statistics of events allows to shrink and control the systematics to the desired level.
- It's a completely new paradigm!

« case studies » for flavor physics

Measurement	Goal	Need to	Constraining
	CKM angle gamma	$B_s \to D_s^{\pm} K^{\pm}$	PID and K/pi separation
CP violation in HF (see talk on Flavor #117 S.Mor	Modes with π^0 in the final state	$B^0 \to \pi^+ \pi^- \pi^0 \pi^0$	Ecal with excellent energy resolution also at low energies
	CP violation in the B(Bs) meson mixing	charge particle detection asymmetry limiting systematic	overall detector design and reconstruction methods
	FCNC modes	$B^0 \to K^{*0} \tau^+ \tau^-$ $B_c^+ \to \tau^- \nu_\tau$	precise vertex detection for partial-reconstruction cases

- Initial list in term of « case studies ». More coming.
- Ongoing studies already for exclusive decays, *see talk #122 D. Hill*
- Obvious need of a high performance of the vertexing for all the time-dependent measurement as well

« case studies » for tau physics

Measurement	Goal	Need to	Constraining
Tau properties (@Tera-Z) *see talk#124 J. Hansen*	- tau lepton lifetime - tau lepton mass - leptonic branching ration - tau flavor violating decays	matching detetor systematics with the statistics available	- vtx radial alignement - tracker mom scale - lepton eff and ID - lepton momentum resolution
Tau polarization	highest precision as ingredient for Atau, Ae and sin2θW	- use leptonic decays, but extend to hadronic decays - limit systematics from cross-channel	- photon and pi0 reconstruction - K/pi separation

- Tau physics is an extremely rich playground for very stringent contraint on detector performances and in particular PID and photon/π0 separation
- Not quoted here, tau reconstruction and ID with new ML techniques for additional improvements *(see talk#121 S. Giagu)*

« case studies » in top physics

Measurement	**Goal**	**Need to**	**Constraining**
Measurement of top properties at threshold *see talk #123 J. Andrea*	high precision measurement of mass, widtg, Yt and EWK couplings	- reduce beam energy uncertainty at threshold - tt kin reconstruction - differential distribution	- b-tagging - jet algorithms - kin fitting
FCNC in the top sector	improve sensitivity wrt HL-LHC	- combine different √s - improve efficiency/reduce bkg	- kin fitting - c-tagging - photon reco

- In the case of top physics these studies do not seem to be the « critical » drivers for some quantities (compared to other examples)
- However, the approach of doing the exercise also in the rich final state of top production and differen √s might highlight new and specific needs along the way.

« case studies » for new physics search

Measurement	Goal	Need to	Constraining
Long lived particle search (or other FIP)	extend sensitivity as much as possible	- improve efficiencies for observation of unusual final states	- vertexing/tracking - photon reco to low energies - maybe timing/PID
New Scalars in Higgs decay	extend sensitivity to invisible decays or exotic signatures using recoil method	- reduce leading background from 2/4 fermion processes	- lepton momentum res - energy resolution

- The BSM searches are the most natural place to start from exploring the sensitivity of new models for direct observation of FIP and from there define new detector requirements.
- It's a new and exciting possibility offered by the FCC-ee *talk #118 R. Gonzalez Suarez*
- Let's not forget, there is a large amount of BSM interpretation to be extracted from the precision measuremens described before as well.

physics performance coordination organization

- Several « case studies » have already been picked up and the work in progress will be presented during the Friday morning session.
- The work outlined here has to start now but we are aware that the overall input of detector description and software simulation and tools needs to be developed at the same time as the studies.
- It is important to begin exploiting the tools available:
  - the Delphes Fast Simulation, in particular with the information about the track covariance matrix, can already help out make progress on several aspects, (such as develop new b-tagging algorithms) that can be ported to FullSim
  - the edm4hep data model will soon be a reference to develop reconstruction code in a coherent manner for different detector simulation inside the FCCSW framework
    - *For more details see FCC Software talk #112*

the path ahead

- **« case studies » have generated a very nice momentum and we are happy to receive expression of interest from new colleagues every day.**
  - Physics Group will continue to participate with PPC in the gathering of the case studies
- This is a very good strategy if:
  - your group is interested in a specific detector technology and your student can have a physics study connected to it
  - you have/are a student that wants to explore some future physics studies while working at an LHC experiment
  - you are interested in taking the challenge of pushing the limits of detector and analysis performance, trying new technologies & new algorithms
  - you just have a new idea!
- Follow reports of the ongoing work in PPC during:
  - **Session Experiment&Detector Wednsday at 11:00**
  - **Session Experiment & Detector Friday at 11:00**