

Physics, Experiments, Detectors (PED) Overview: Physics

May 30th 2022

FCC Week

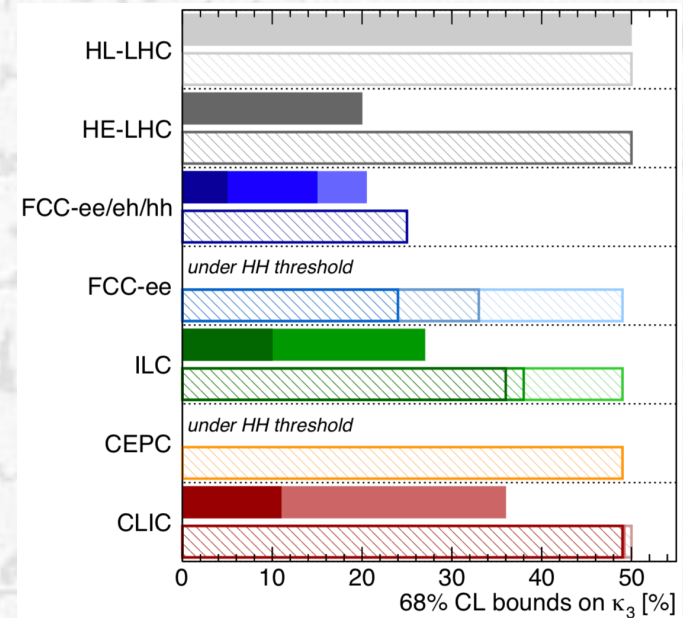
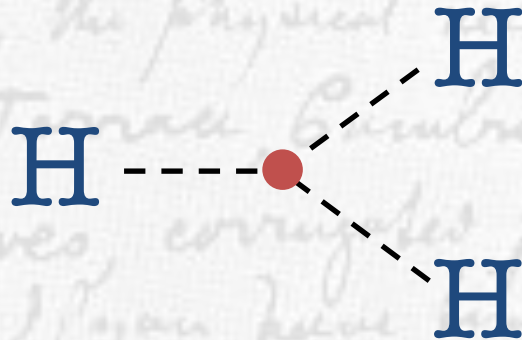
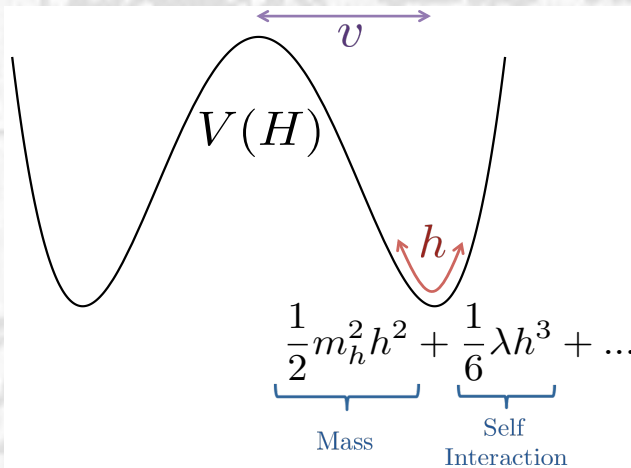
Matthew McCullough

(On behalf of colleagues Patrizia Azzi, Emmanuel Perez,
Frank Simon)



The FCC Physics Landscape

The physics landscape of FCC is vast. Personal highlights include:



True exploration of the Higgs self-coupling, one of the most profoundly important parameters in nature...

The FCC Physics Landscape

... and a quantum leap in our understanding of electroweak physics due to the Tera-Z programme!

Observable	Present value	\pm error	FCC-ee (statistical)	FCC-ee (systematic)
m_Z (keV/c ²)	91 186 700	\pm 2200	5	100
Γ_Z (keV)	2 495 200	\pm 2300	8	100
R_ℓ^Z ($\times 10^3$)	20 767	\pm 25	0.06	1
$\alpha_s(m_Z)$ ($\times 10^4$)	1196	\pm 30	0.1	1.6
R_b ($\times 10^6$)	216 290	\pm 660	0.3	<60
σ_{had}^0 ($\times 10^3$) (nb)	41 541	\pm 37	0.1	4
N_ν ($\times 10^3$)	2991	\pm 7	0.005	1
$\sin^2\theta_W^{\text{eff}}$ ($\times 10^6$)	231 480	\pm 160	3	2–5
$1/\alpha_{\text{QED}}(m_Z)$ ($\times 10^3$)	128 952	\pm 14	4	Small
$A_{\text{FB}}^{b,0}$ ($\times 10^4$)	992	\pm 16	0.02	<1
$A_{\text{FB}}^{\text{pol},\tau}$ ($\times 10^4$)	1498	\pm 49	0.15	<2
m_W (keV/c ²)	803 500	\pm 15 000	600	300

The FCC Physics Landscape

However, we are only at the beginning of the journey...

CHAPTER I

THE PHYSICS CASE

Physics with a Multi-TeV Hadron Collider

C.H. Llewellyn Smith

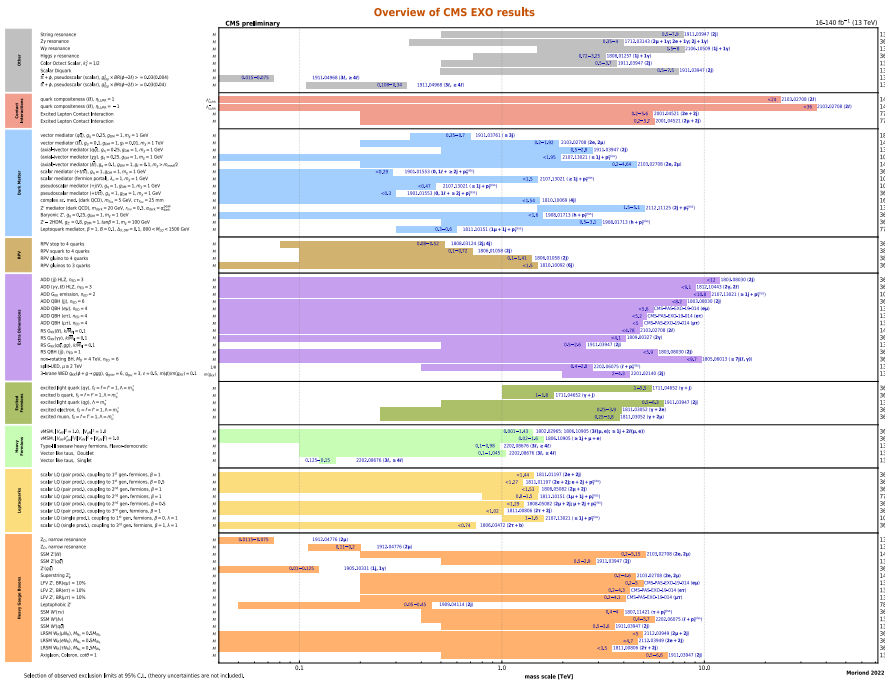
11. SUMMARY AND CONCLUSIONS

A theoretical consensus is emerging that new phenomena will be discovered at or below 1 TeV. There is no consensus about the nature of these phenomena but it is interesting that many of the ideas which have been suggested can be tested in experiments at an LHC. Although many, if not all, of these ideas will doubtless have been discarded, disproved or established by the time an LHC is built, this demonstrates the potential virtues of such a machine.

Consider the LHC Physics programme in 1984...

The FCC Physics Landscapes

However, we are only at the beginning of the journey...



ATLAS SUSY Searches* - 95% CL Lower Limits

Status: SUSY 2013

ATLAS Preliminary
 $\int \mathcal{L} dt = (4.6 - 22.9) \text{ fb}^{-1}$ $\sqrt{s} = 7, 8 \text{ TeV}$

Model	$\epsilon, \mu, \tau, \gamma$	Jets	E_{T}^{miss}	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Mass limit	Reference	
Inclusive Searches	MSUGRA-CMSSM	0, 2-6 jets	Yes	20.3	1.7 TeV	m(\tilde{g})=m(\tilde{u})	
	MSUGRA-CMSSM	1 μ , 3-6 jets	Yes	20.3	1.2 TeV	any m(\tilde{g})	
	MSUGRA-CMSSM	0, 7-10 jets	Yes	20.3	1.1 TeV	any m(\tilde{g})	
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}$	0, 2-6 jets	Yes	20.3	740 GeV	m(\tilde{t})=0 GeV	
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}$	0, 2-6 jets	Yes	20.3	1.3 TeV	m(\tilde{t})=0 GeV	
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}, \tilde{g} \rightarrow q\bar{q}W^{\pm}$	1 μ , 3-6 jets	Yes	20.3	1.18 TeV	m(\tilde{t})=200 GeV, m(\tilde{b})=0.5m(\tilde{t})=m(\tilde{g})	
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}, \tilde{g} \rightarrow q\bar{q}W^{\pm}$	2 μ , 0-3 jets	Yes	20.3	1.12 TeV	m(\tilde{t})=0 GeV	
	GMSB (f NLSB)	2 μ , 2-4 jets	Yes	4.7	1.24 TeV	tan β =15	
	GGM (bino NLSB)	2 γ	Yes	20.7	1.4 TeV	tan β =18	
	GGM (wino NLSB)	1 e, μ, γ	Yes	4.8	619 GeV	m(\tilde{t})=50 GeV	
	GGM (Higgsino-bino NLSB)	2 e, μ , 1 τ	Yes	4.8	600 GeV	m(\tilde{t})=50 GeV	
	GGM (Higgsino NLSB)	2 e, μ , 1 τ	Yes	4.8	800 GeV	m(\tilde{t})=200 GeV	
	Gravitino LSP	0 mono-jet	Yes	10.5	649 GeV	m(\tilde{t})>10 ⁻⁴ eV	
1/2 gen. squarks	$\tilde{g} \rightarrow b\bar{b}$	0, 3 b	Yes	20.1	1.2 TeV	m(\tilde{t})=500 GeV	
	$\tilde{g} \rightarrow t\bar{t}$	0, 7-10 jets	Yes	20.3	1.1 TeV	m(\tilde{t})=300 GeV	
	$\tilde{g} \rightarrow t\bar{t}$	0-1 e, μ , 3 b	Yes	20.1	1.34 TeV	m(\tilde{t})=400 GeV	
	$\tilde{g} \rightarrow b\bar{t}$	0-1 e, μ , 3 b	Yes	20.1	1.2 TeV	m(\tilde{t})=300 GeV	
3rd gen. squarks	$\tilde{t}_1, \tilde{t}_2 \rightarrow b\bar{b}$	2 μ (SS)	0-2 b	Yes	20.1	m(\tilde{t})=90 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow b\bar{t}$	2 μ (SS)	0-2 b	Yes	20.7	m(\tilde{t})=m(\tilde{b})	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	2 μ , 0-2 jets	Yes	4.7	110-187 GeV	m(\tilde{t})=45 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	2 μ , 0-2 jets	Yes	20.3	130-220 GeV	m(\tilde{t})=m(\tilde{b}), m(W)=50 GeV, m(\tilde{t}), m(\tilde{b})>0	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	2 μ , 2 jets	Yes	20.1	225-325 GeV	m(\tilde{t})=m(\tilde{b}), m(W)=50 GeV, m(\tilde{t})=m(\tilde{b})	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	1 μ , 1 b	Yes	20.7	200-810 GeV	m(\tilde{t})=0 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	0, 2 b	Yes	20.1	320-560 GeV	m(\tilde{t})=200 GeV, m(\tilde{t})=m(\tilde{b})=50 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	1 μ , 1 b	Yes	20.7	90-200 GeV	m(\tilde{t})=0 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	0 mono-jet(+tag)	Yes	20.3	500 GeV	m(\tilde{t})=m(\tilde{b})=85 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	2 e, μ , 1 τ	Yes	20.7	271-520 GeV	m(\tilde{t})=150 GeV	
	$\tilde{t}_1, \tilde{t}_2 \rightarrow \text{light}$	3 e, μ , 1 τ	Yes	20.7	271-520 GeV	m(\tilde{t})=m(\tilde{b})=180 GeV	
EW direct	$\tilde{W}_1 \rightarrow WZ$	2 μ , 0	Yes	20.3	85-315 GeV	m(\tilde{W}_1)=0 GeV	
	$\tilde{W}_1 \rightarrow WZ$	2 μ , 0	Yes	20.3	125-450 GeV	m(\tilde{W}_1)=0 GeV, m(\tilde{Z})=0.5m(\tilde{W}_1), m(\tilde{W}_1)>0	
	$\tilde{W}_1 \rightarrow WZ$	2 τ	Yes	20.7	100-330 GeV	m(\tilde{W}_1)=0 GeV, m(\tilde{Z})=0.5m(\tilde{W}_1), m(\tilde{W}_1)>0	
	$\tilde{W}_1 \rightarrow WZ$	3 e, μ , 0	Yes	20.7	600 GeV	m(\tilde{W}_1)=m(\tilde{Z}), m(\tilde{W}_1)=0.5m(\tilde{W}_1)=m(\tilde{Z})	
	$\tilde{W}_1 \rightarrow WZ$	3 e, μ , 0	Yes	20.7	315 GeV	m(\tilde{W}_1)=m(\tilde{Z}), m(\tilde{W}_1)=0, sleptons decoupled	
	$\tilde{W}_1 \rightarrow WZ$	1 μ , 2 b	Yes	20.3	203 GeV	m(\tilde{W}_1)=m(\tilde{Z}), m(\tilde{W}_1)=0, sleptons decoupled	
Long-lived particles	Direct $\tilde{L}_i \rightarrow e, \mu, \tau$ prod., long-lived \tilde{L}_i	Disapp. bk	1 jet	Yes	20.3	m(\tilde{L}_i)=m(\tilde{L}_i)=160 MeV, $\tau(\tilde{L}_i)$ =0-2 ns	
	Stable, stopped \tilde{g} -R-hadron	0, 1-5 jets	Yes	22.9	632 GeV	m(\tilde{g})=100 GeV, $10 \mu\text{s} < \tau(\tilde{g}) < 1000$ s	
	GMSB, stable $\tilde{L}_i \rightarrow \tilde{L}_i + e, \mu, \tau$	1 μ , 2 μ	Yes	15.9	875 GeV	10-tan β =50	
	GMSB, $\tilde{L}_i \rightarrow e, \mu, \tau$, long-lived \tilde{L}_i	2 γ	Yes	4.7	230 GeV	0.4 < $\tau(\tilde{L}_i)$ < 0.5 ns	
	$\tilde{g}, \tilde{g} \rightarrow q\bar{q}$ (RPV)	1 μ , split. vtx.	-	20.3	1.0 TeV	1.5 < $\tau < 156$ mm, BR($\mu \rightarrow e \gamma$)=1, m(\tilde{t})=188 GeV	
RPV	LFV $\mu\mu \rightarrow \nu_i + X, \nu_j \rightarrow e + \mu$	2 e, μ	-	4.6	1.81 TeV	$\kappa_{12} = 0.10, \kappa_{23} = 0.05$	
	LFV $\mu\mu \rightarrow \nu_i + X, \nu_j \rightarrow e + \mu$	1 e, μ, τ	-	4.8	1.1 TeV	$\kappa_{12} = 0.10, \kappa_{23} = 0.05$	
	Bilinear RPV GMSB	1 e, μ	7 jets	Yes	4.7	m(\tilde{g})=m(\tilde{u}), $\kappa_{12} = 1$ mm	
	$\tilde{L}_i \tilde{L}_j \rightarrow W^{\pm} \tilde{L}_k \rightarrow \nu_i \nu_j + e, \mu, \tau$	4 e, μ	Yes	20.7	760 GeV	m(\tilde{L}_i)=300 GeV, $\kappa_{12} = 0$	
	$\tilde{L}_i \tilde{L}_j \rightarrow W^{\pm} \tilde{L}_k \rightarrow \nu_i \nu_j + e, \mu, \tau$	3 e, μ, τ	Yes	20.3	300 GeV	m(\tilde{L}_i)=80 GeV, $\kappa_{12} = 0$	
	$\tilde{g} \rightarrow \tilde{t}, \tilde{t} \rightarrow b\bar{b}$	0, 6-7 jets	Yes	20.3	916 GeV	BR($\tilde{t} \rightarrow bW$)=BR($\tilde{t} \rightarrow qW$)	
	$\tilde{g} \rightarrow \tilde{t}, \tilde{t} \rightarrow b\bar{b}$	2 e, μ (SS)	0-3 b	Yes	20.7	880 GeV	
Other	Scalar gluon pair, gluon $\rightarrow \tilde{g}$	0 jets	4.6		100-287 GeV	incl. limit from 1110.2693	
	Scalar gluon pair, gluon $\rightarrow \tilde{g}$	2 μ (SS)	4.3		293 GeV		
	WMP interaction (D5, Dirac χ)	0 mono-jet	Yes	10.5	704 GeV	m(\tilde{g})=80 GeV, limit of 687 GeV for \tilde{b}	

*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 σ theoretical signal cross section uncertainty.

Consider the LHC Physics programme in 1984, versus now...

Some questions...

Have we discovered everything FCC can discover?

Can we do better than preliminary performance estimates?

What is required to realise systematic < statistics?

What are detector/technological performance requirements?

Are we presenting FCC capabilities optimally?

PED Physics Organisation

Coordination split into two branches of the same tree, with overlapping goals:

Physics Performance

P. Azzi & E. Perez

- Optimising case studies
- Specifying detector requirements
- Developing analysis and software tools
- ...

Physics Programme

M. M. & F. Simon

- Developing discovery stories
- Roadmapping precision calculations
- Developing generators
- ...

Further broken down into topics.

PED Physics Organisation

Coordination split into two branches of the same tree, with overlapping goals:

Physics Performance

Synergy with many ECFA activities
(e.g. ECFA WG1 and WG2 monthly seminars, etc)

- Optimising
- Specifying detector requirements
- Developing analysis and software tools
- ...

Physics Programme

M. M. & F. Simon

- precision experiments
- Developing generators
- ...

Further broken down into topics.

Precision Electroweak

Conveners

Performance

C. Paus, G. Wilson

Programme

A. Freitas

Selected Goals

Developing roadmap for higher-order and generators

Understanding the control of systematic uncertainties to unprecedented level

Activities

Kickoff meeting in May 18

Precision calculations for future e+e- colliders: targets and tools (FC Unit Workshop June 7-17)

Higgs

Conveners

Performance

M. Selvaggi, J.
Eysermans

Programme

C. Grojean, G. Durieux, J.
de Blas

Selected Goals

Establishing precision (e.g. $h \rightarrow ss$, hZ at stat precision)

Connecting coupling reach with microscopic landscape

Activities

Meetings March 28 (flavour), May 23

Synergy with ECFA Higgs Factory activities

(e.g. ECFA Higgs & top Factory workshop October.)

Flavour

Conveners

Performance

S. Monteil, A. Lusiani

Programme

G. Isidori, J. Kamenik

Selected Goals

Develop scope of flavour at FCC

Establishing experimental sensitivity

Activities

Kickoff programme meeting April 12

Mini-Workshop foreseen for Sept

Performance meeting March 28

QCD

Conveners

Performance

D. d'Enterria

Programme

P. Monni

Selected Goals

Roadmapping precision and observables

Understanding role of α_s uncertainties

Activities

Precision calculations for future e+e- colliders:
targets and tools (FC Unit Workshop June 7-17)

Beyond the Standard Model

Conveners

Performance

R. Gonzalez-Suarez, G.
Polesello

Programme

S. Heinemeyer, T. You

Selected Goals

Develop “Exploring Origins” physics of FCC
Investigating detector coverage of exotica

Activities

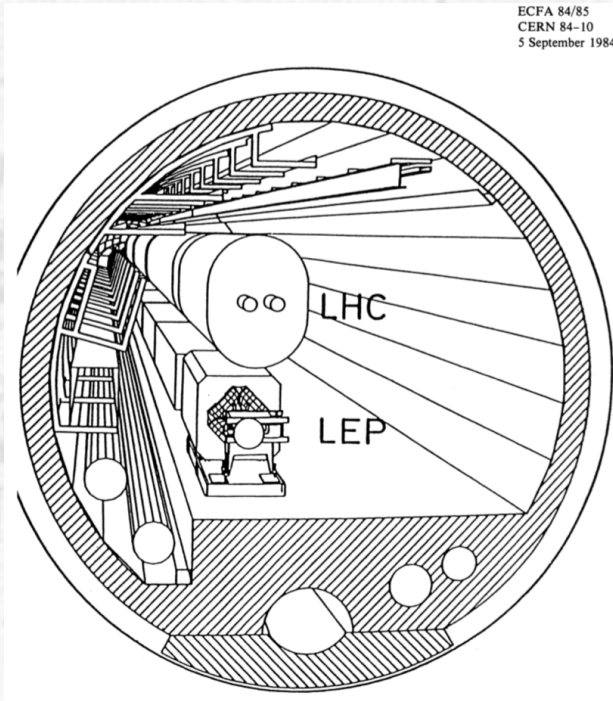
Kickoff meeting in May 10

Mini-Workshop foreseen for Sept

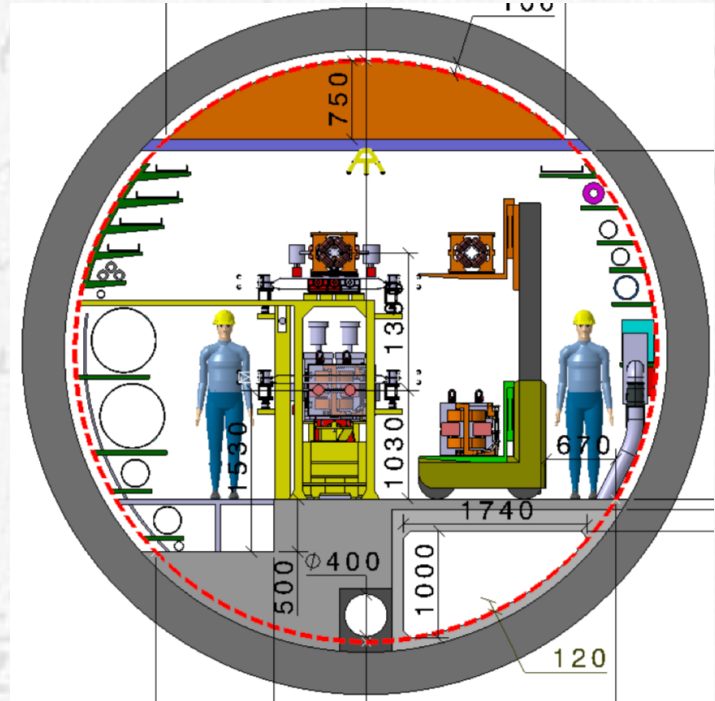
Summary

We know, from experience, the physics scope of a combined ee+hh facility is vast, requiring thousands of scientists to explore.

From



to



Physics PED is laying the foundation stones.

Join us!

<https://fcc-ped.web.cern.ch>

Thanks to everyone in PED
physics!