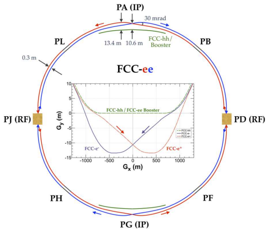
FCCee Physics



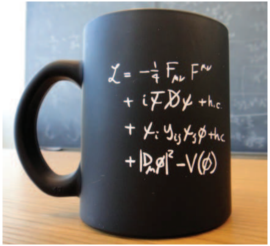
Antonio Pich

IFIC, Univ. Valencia – CSIC

FCC Open Day, IFIC, 16 April 2026

The SM in a Nutshell

$$SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$



Lagrangian

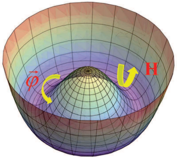
Gauge

Yukawas

EWSB

	Quarks		Leptons	
	$Q = \frac{2}{3}$	$Q = -\frac{1}{3}$	$Q = 0$	$Q = -1$
MATTER	0.002 Up	0.005 Down	< 0.000000001 Neutrino e (ν_e)	0.0005 Electron
	~ 1.3 Charm	~ 0.1 Strange	< 0.000000001 Neutrino μ (ν_μ)	0.1 Muon
	173 Top	~ 4.2 Beauty	< 0.000000001 Neutrino τ (ν_τ)	1.8 Tau
FORCES	0 Photon	0 Gluons	91, 80 Z^0 , $W^\pm$	125 Higgs

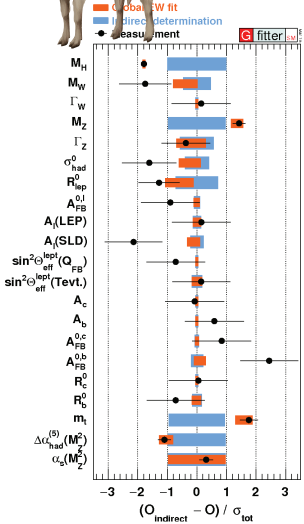
EWSB

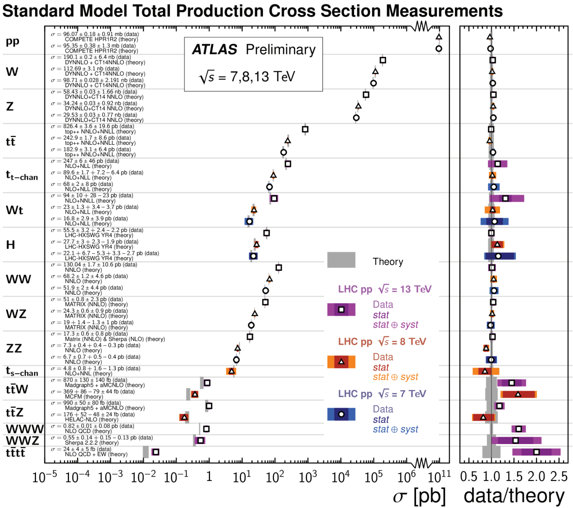


Everything looks SM-like at LHC

SM **G**reatest **O**f **A**ll **T**heories

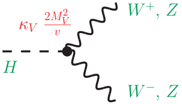
Daniel de Florian
EPS-HEP 2023

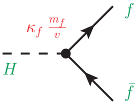


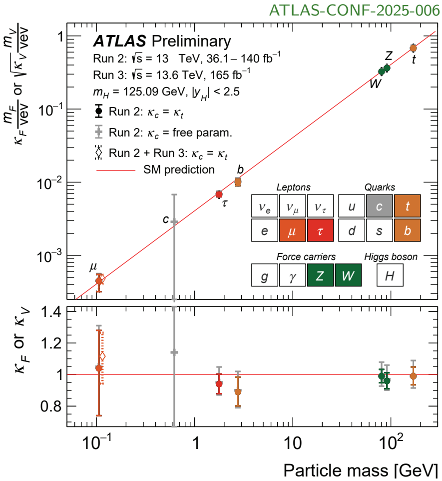


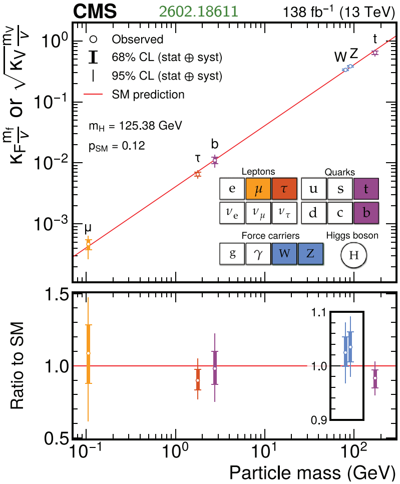
The Higgs particle

$$M_H = (125.20 \pm 0.11)\ \mathrm{GeV}$$









Flavour Puzzles

- **Dynamical origin of flavour**
- **Hierarchy of fermion masses**

  $m_{\nu_i} < 0.8$ eV, $\sqrt{\Delta m^2_{21}} \sim 0.009$ eV

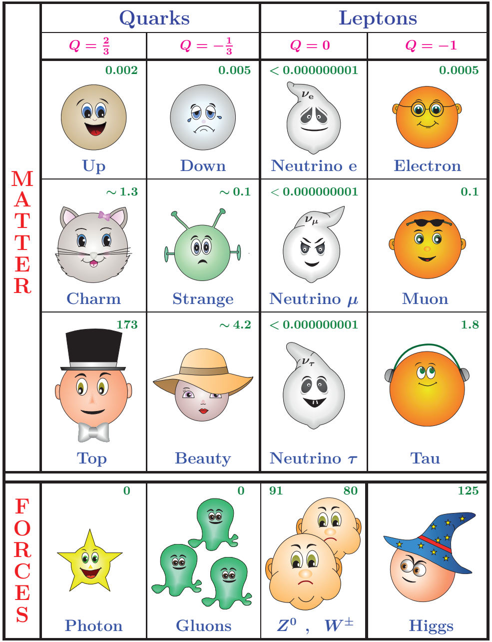
  $m_c \sim 1.3 \cdot 10^9$ eV, $m_t \sim 1.7 \cdot 10^{11}$ eV

- **Mixing structure**
- **CP violation**

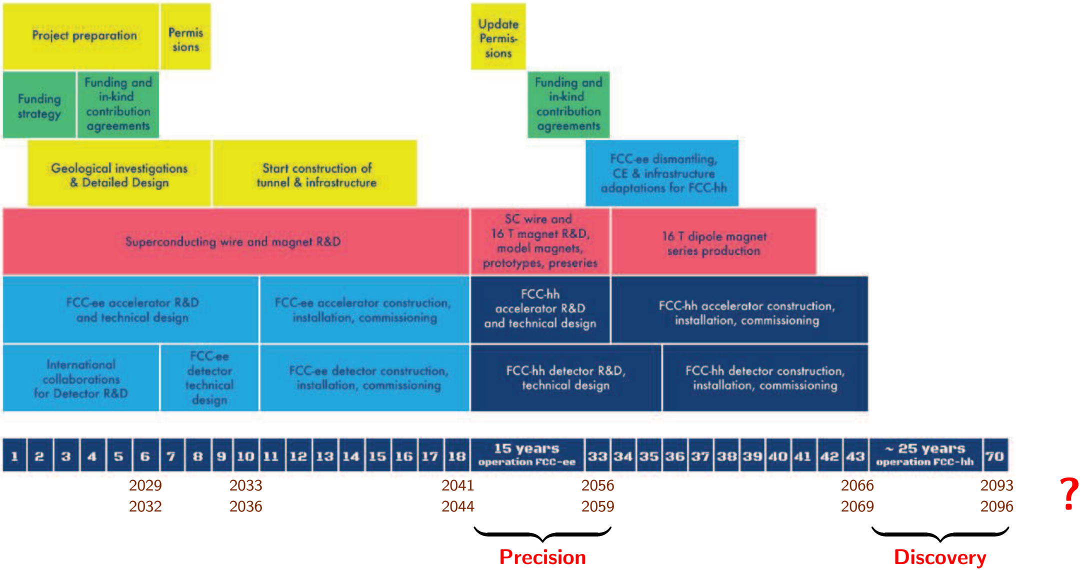
  Matter-antimatter asymmetry

- **Sterile ν_R ? ν mass scale?**
- **Dirac or Majorana ν ?**
- **B and L conservation**

  Accidental symmetries of the SM

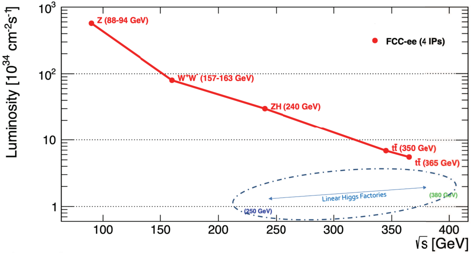


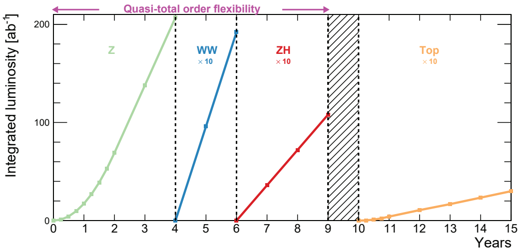
FCC - The integrated programme



FCCee Luminosity

FCC FSR, 2505.00272





Working point	Z pole	WW thresh.	ZH	$t\bar{t}$	
$\sqrt{s}$ (GeV)	88, 91, 94	157, 163	240	340–350	365
Lumi/IP (10^{34} cm^{-2}s^{-1})	140	20	7.5	1.8	1.4
Lumi/year (ab^{-1})	68	9.6	3.6	0.83	0.67
Run time (year)	4	2	3	1	4
Integrated lumi. (ab^{-1})	205	19.2	10.8	0.42	2.70
Number of events	6×10^{12} Z	2.4×10^{8} WW	2.2×10^{6} ZH + 65k WW → H	2×10^{6} $t\bar{t}$ + 370k ZH + 92k WW → H	

4 IPs

TeraZ: $2 \times 10^{11}\ \tau^+\tau^-$, $9 \times 10^{11}\ b\bar{b}$, $7 \times 10^{11}\ c\bar{c}$ in very clean conditions

Expected FCCee precision for selected observables

FCC FSR, 2505.00272

These challenging precisions require:

- **Tight control of systematic errors**
- **Appropriate theoretical developments**

  Higher orders (EW, QED, QCD)

  MC generators. . .

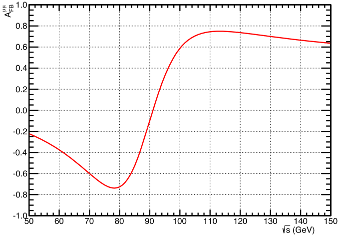
Observable	present value	±	uncertainty	FCC-ee Stat.	FCC-ee Syst.	Comment and leading uncertainty
m_Z (keV)	91 187 600	±	2000	**4**	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2 495 500	±	2300	**4**	12	From Z line shape scan Beam energy calibration
$\sin^2\theta_W^{\rm eff}$ $(\times 10^6)$	231,480	±	160	**1.2**	1.2	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{\rm QED}(m_Z^2)$ $(\times 10^3)$	128 952	±	14	**3.9** **0.8**	small tbc	From $A_{FB}^{\mu\mu}$ off peak From $A_{FB}^{\mu\mu}$ on peak QED&EW uncert. dominate
R_ℓ^Z $(\times 10^3)$	20 767	±	25	**0.05**	0.05	Ratio of hadrons to leptons Acceptance for leptons
$\alpha_S(m_Z^2)$ $(\times 10^4)$	1 196	±	30	**0.1**	1	Combined R_ℓ^Z, $\Gamma_{\rm tot}^Z$, $\sigma_{\rm had}^0$ fit
$\sigma_{\rm had}^0$ $(\times 10^3)$ (nb)	41 480.2	±	32.5	**0.03**	0.8	Peak hadronic cross section Luminosity measurement
$N_\nu (\times 10^3)$	2 996.3	±	7.4	**0.09**	0.12	Z peak cross sections Luminosity measurement
R_b $(\times 10^6)$	216 290	±	660	**0.25**	0.3	Ratio of $b\bar{b}$ to hadrons
$A_{FB}^{b,0}$ $(\times 10^4)$	992	±	16	**0.04**	0.04	b-quark asymmetry at Z pole From jet charge
$A_{FB}^{{\rm pol},\tau}$ $(\times 10^4)$	1 498	±	49	**0.07**	0.2	τ polarisation asymmetry τ decay physics
τ lifetime (fs)	290.3	±	0.5	**0.001**	0.005	ISR, τ mass
τ mass (MeV)	1 776.93	±	0.09	**0.002**	0.02	estimator bias, ISR, FSR
τ leptonic $(\mu\nu_\mu\nu_\tau)$ BR (%)	17.38	±	0.04	**0.00007**	0.003	PID, π^0 efficiency
m_W (MeV)	80 360.2	±	9.9	**0.18**	0.16	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2 085	±	42	**0.27**	0.2	From WW threshold scan Beam energy calibration
$\alpha_S(m_W^2)$ $(\times 10^4)$	1 010	±	270	**2**	2	Combined R_ℓ^W, $\Gamma_{\rm tot}^W$ fit
N_ν $(\times 10^3)$	2 920	±	50	**0.5**	small	Ratio of invis. to leptonic in radiative Z returns
$m_{\rm top}$ (MeV)	172 570	±	290	**4.2**	4.9	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\Gamma_{\rm top}$ (MeV)	1 420	±	190	**10**	6	From $t\bar{t}$ threshold scan QCD uncert. dominate
$\lambda_{\rm top}/\lambda_{\rm top}^{\rm SM}$	1.2	±	0.3	**0.015**	0.015	From $t\bar{t}$ threshold scan QCD uncert. dominate
ttZ couplings		±	30%	**0.5–1.5 %**	small	From $\sqrt{s} = 365$ GeV run

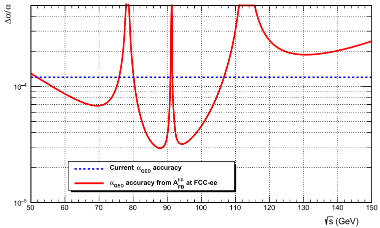
Determination of $\alpha(M_Z^2)$

Off peak

$$\mathcal{A}_{\rm FB}^{\mu\mu}(s) \approx \frac{3}{4}\,\mathcal{A}_e\mathcal{A}_\mu \left[1 + \frac{8\pi\sqrt{2}\,\alpha(s)}{M_Z^2\,G_F\,(1-4\sin^2\theta_W^{\rm eff})^2}\;\frac{s-M_Z^2}{2s}\right]$$

P. Janot, 1512.05544



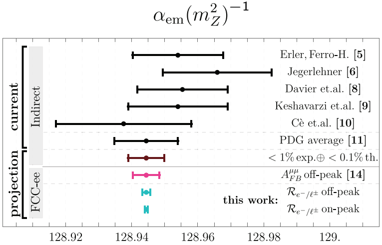


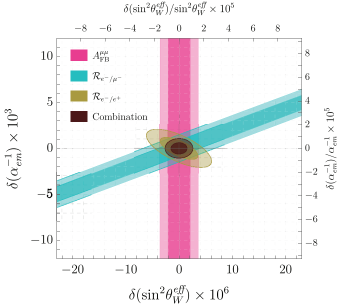
On peak

$\mathcal{R}_{e^-/\mu^-}(\theta)\,,\;\mathcal{R}_{e^-/e^+}(\theta)$

(s and t channels)

M. Riembau, 2501.05508

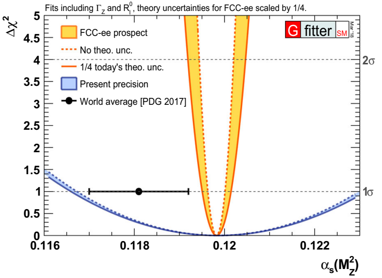




Determination of $\alpha_s(M_Z^2)$

$$\Gamma_Z\,,\;\sigma_0^{\rm had} = \frac{12\pi}{M_Z}\,\frac{\Gamma_e\Gamma_{\rm had}}{\Gamma_Z^2}\,,\;R_\ell^0 = \frac{\Gamma_{\rm had}}{\Gamma_\ell}$$

N^3LO



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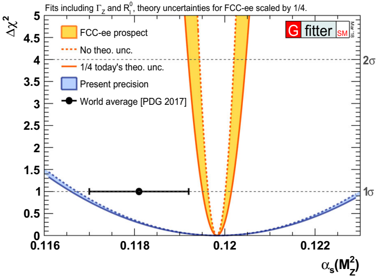
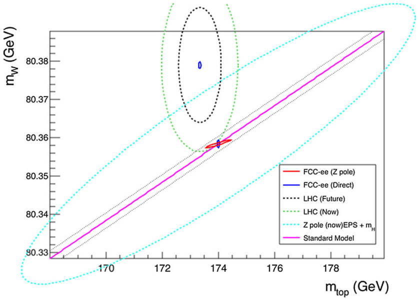




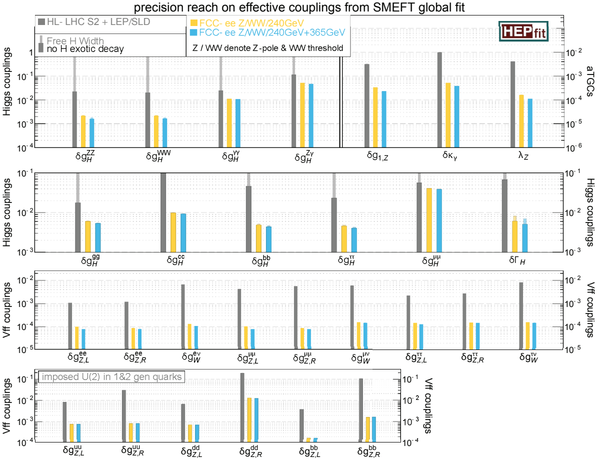
FCCee impact on EW fit

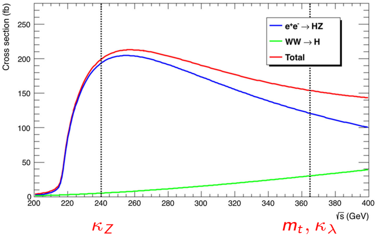
FCC CDR I, Eur. Phys. J. C 79 (2019) 6, 474

Expected FCC precision for Higgs Couplings

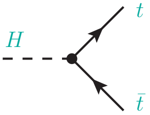
Coupling	HL-LHC	FCC-ee	FCC-ee + FCC-hh
κ_Z (%)	1.3*	0.10	0.10
κ_W (%)	1.5*	0.29	0.25
κ_b (%)	2.5*	0.38 / 0.49	0.33 / 0.45
κ_g (%)	2*	0.49 / 0.54	0.41 / 0.44
κ_τ (%)	1.6*	0.46	0.40
κ_c (%)	–	0.70 / 0.87	0.68 / 0.85
κ_γ (%)	1.6*	1.1	0.30
$\kappa_{Z\gamma}$ (%)	10*	4.3	0.67
κ_t (%)	3.2*	3.1	0.75
κ_μ (%)	4.4*	3.3	0.42
$\lvert\kappa_s\rvert$ (%)	–	${}^{+29}_{-67}$	${}^{+29}_{-67}$
Γ_H (%)	–	0.78	0.69
$\mathcal{B}_{inv}$ (<, 95% CL)	1.9×10^{-2} *	5×10^{-4}	2.3×10^{-4}
$\mathcal{B}_{unt}$ (<, 95% CL)	4×10^{-2} *	6.8×10^{-3}	6.7×10^{-3}

FCC FSR, 2505.00272





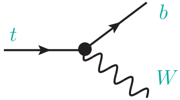
The Heaviest Mass Scale



$$y_t = \frac{\sqrt{2}}{v}\, m_t = 2^{3/4} G_F^{1/2} m_t \approx 1 \qquad (0.995)$$

The top quark:

- **Sensitive probe of Electroweak Symmetry Breaking**
- **Non-perturbative (strong) dynamics?**
- **Very different from other quarks:** $y_b = 0.025\,,\; y_c = 0.007\;\ldots$
- **Is it really a SM quark?**

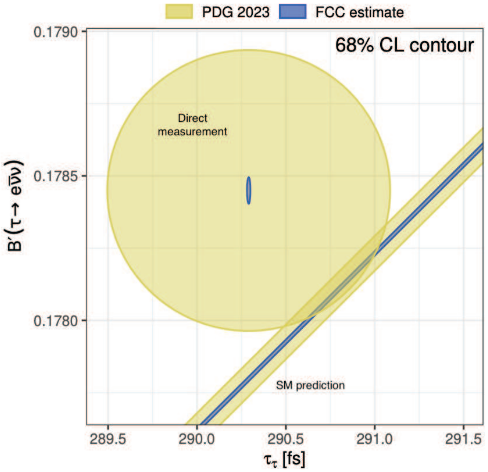


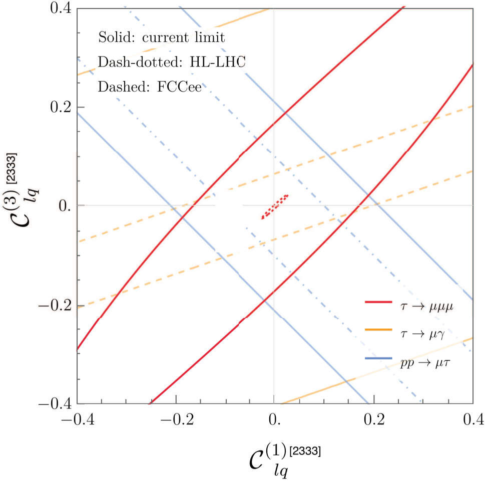
So far, we only know the decay $\mathbf{t \to W^+ b}$

$$|\mathbf{V_{tb}}| = \mathbf{1.010 \pm 0.027}$$

τ Physics @ FCCee

FCC FSR, 2505.00272

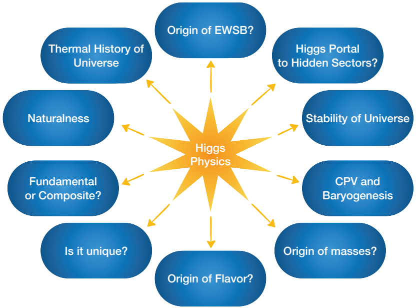




A New Force has been discovered

The Higgs field

- It is not a gauge interaction $(J = 0)$
- Related to many open questions
- We have just started to explore it



Higgs @ Snowmass 2021, 2209.07510

A thorough investigation of the Higgs force should be a priority goal of current and future HEP experiments