# The FCC Option



# <u>Outline</u>

<u>F. Bedeschi, INFN</u> Roma3, January 29, 2020

Very brief motivations
FCCee
Machine and physics
FCChh
Machine and physics
Schedule and costs
Final comments



	ATLAS SUSY Searches* - 95% CL Lower Limits									<b>ATLAS</b> Preliminary $\sqrt{s} = 13$ TeV	
	Model	S	ignatur	e .	∫£ dt [fb⁻	'] Ma:	ss limit				Reference
s	$\tilde{q}\tilde{q}, \tilde{q} \rightarrow q \tilde{\chi}_1^0$	0 e, μ mono-jet	2-6 jets 1-3 jets	$E_T^{ m miss}$ $E_T^{ m miss}$	36.1 36.1	<ul> <li>\$\hfrac{q}{q}\$ [2x, 8x Degen.]</li> <li>\$\hfrac{q}{q}\$ [1x, 8x Degen.]</li> </ul>	0.43	0.9	1.55	m(ž <sup>0</sup> ₁)<100 GeV m(ž)-m(ž <sup>0</sup> ₁)=5 GeV	1712.02332 1711.03301
arche	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow q \bar{q} \tilde{\chi}_1^0$	0 <i>e</i> , <i>µ</i>	2-6 jets	$E_T^{\rm miss}$	36.1	Ř Ř		Forbidden	2.0 0.95-1.6	m(ℓ̃ 1)<200 GeV m(ℓ̃ 1)=900 GeV	1712.02332 1712.02332
'e Se	$\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$	3 е, µ ее, µµ	4 jets 2 jets	$E_T^{\rm miss}$	36.1 36.1	Ř Ř			1.85 1.2	m(𝔅˜₁)<800 GeV m(𝔅)-m(𝔅¯₁)=50 GeV	1706.03731 1805.11381
clusiv	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_1^0$	0 e,μ SS e,μ	7-11 jets 6 jets	$E_T^{miss}$	36.1 139	ğ ğ		1	1.8 15	m(𝔅̃)·<400 GeV m(𝔅̃)·m(𝔅̃))=200 GeV	1708.02794 ATLAS-CONF-2019-015
rl L	$\tilde{g}\tilde{g}, \tilde{g} \rightarrow t \tilde{t} \tilde{\chi}_1^0$	0-1 e,μ SS e,μ	3 b 6 jets	$E_T^{miss}$	79.8 139	i de la companya de l			1.25	2.25 m( $\tilde{t}_1^0$ )<200 GeV m( $\tilde{g}$ )-m( $\tilde{t}_1^0$ )=300 GeV	ATLAS-CONF-2018-041 ATLAS-CONF-2019-015
	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 {\rightarrow} b \tilde{\chi}_1^0 / b \tilde{\chi}_1^+$		Multiple Multiple Multiple		36.1 36.1 139	δ <sub>1</sub> Forbidden δ <sub>1</sub> δ <sub>1</sub>	Forbidden Forbidden	0.9 0.58-0.82 0.74	m(	$\begin{array}{c} m(\tilde{\chi}_{1}^{0}) {=} 300 \ \mathrm{GeV}, \ BR(b\tilde{\chi}_{1}^{0}) {=} 1\\ m(\tilde{\chi}_{1}^{0}) {=} 300 \ \mathrm{GeV}, \ BR(b\tilde{\chi}_{1}^{0}) {=} BR(\tilde{\chi}_{1}^{4}) {=} 0.5\\ \tilde{\chi}_{1}^{0}) {=} 200 \ \mathrm{GeV}, \ m(\tilde{\chi}_{1}^{4}) {=} 300 \ \mathrm{GeV}, \ BR(b\tilde{\chi}_{1}^{0}) {=} 1 \end{array}$	1708.09266, 1711.03301 1708.09266 ATLAS-CONF-2019-015
rks ion	$\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}^0_2 \rightarrow b h \tilde{\chi}^0_1$	0 e, μ	6 <i>b</i>	$E_T^{\rm miss}$	139	$ar{b}_1$ Forbidden $ar{b}_1$	0.23-0.48	C	23-1.35	$\Delta m(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 100 \text{ GeV}$ $\Delta m(\tilde{\chi}_{2}^{0}, \tilde{\chi}_{1}^{0}) = 130 \text{ GeV}, m(\tilde{\chi}_{1}^{0}) = 0 \text{ GeV}$	SUSY-2018-31 SUSY-2018-31
<sup>d</sup> gen. squa	$\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow Wb \tilde{\chi}_1^0 \text{ or } t \tilde{\chi}_1^0$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow Wb \tilde{\chi}_1^0$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{t}_1 b \nu, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{c}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$	0-2 e, μ 1 e, μ 1 τ + 1 e,μ, 0 e, μ	0-2 jets/1-2 3 jets/1 b 7 2 jets/1 b 2 c	$b \ E_T^{miss} \\ E_T^{miss} \\ E_T^{miss} \\ E_T^{miss} \\ E_T^{miss} $	36.1 139 36.1 36.1	<ul> <li> <i>i</i><sub>1</sub> <i>i</i><sub>1</sub> <i>i</i><sub>1</sub> <i>ē</i> </li> </ul>	0.44-0	1.0 .59 0.85	.16	m{{c}_1^p} = 1 GeV m{{t}_1^p} = 400 GeV m{{t}_1^p} = 800 GeV m{{t}_2^p} = 0 GeV	1506.08616, 1709.04183, 1711.11520 ATLAS-CONF-2019-017 1803.10178 1805.01649
σš	initial sector sector	0 e, µ	mono-jet	$E_T^{miss}$	36.1	$\tilde{t}_1$ $\tilde{t}_1$	0.46 0.43			$m(\tilde{r}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 50 \text{ GeV}$ $m(\tilde{r}_1, \tilde{c}) - m(\tilde{\chi}_1^0) = 5 \text{ GeV}$	1805.01649 1711.03301
	$\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + h$ $\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$	1-2 e, μ 3 e, μ	4 b 1 b	$E_T^{ m miss}$ $E_T^{ m miss}$	36.1 139	ĩ <sub>2</sub> ĩ <sub>2</sub>	Forbidden	0.32-0.88 0.86		$m(\tilde{\chi}_{1}^{0})=0 \text{ GeV}, m(\tilde{t}_{1})-m(\tilde{\chi}_{1}^{0})=180 \text{ GeV}$ $m(\tilde{\chi}_{1}^{0})=360 \text{ GeV}, m(\tilde{t}_{1})-m(\tilde{\chi}_{1}^{0})=40 \text{ GeV}$	1706.03986 ATLAS-CONF-2019-016
	$\hat{x}_1^{\pm} \hat{x}_2^0$ via WZ	2-3 e, μ ee, μμ	≥ 1	$E_T^{miss}$ $E_T^{miss}$	36.1 139	$ \frac{\tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0}}{\tilde{\chi}_{1}^{\pm}/\tilde{\chi}_{2}^{0}} = 0.205 $		0.6		$m(\tilde{k}_{1}^{0})=0$ $m(\tilde{k}_{1}^{*})-m(\tilde{k}_{1}^{0})=5 \text{ GeV}$	1403.5294, 1806.02293 ATLAS-CONF-2019-014
3	$\bar{\chi}_1^{\pm} \bar{\chi}_1^{\mp}$ via WW $\bar{\chi}_1^{\pm} \bar{\chi}_2^{0}$ via Wh	2 e,μ 0-1 e,μ	2 bi2 γ	$E_T^{miss}$ $E_T^{miss}$	139 139	$ \vec{X}_{1}^{\pm} $ $ \vec{X}_{1}^{\pm}/\vec{X}_{2}^{0} $ Forbidden	0.42	0.74		$m(\tilde{\chi}_{1}^{0})=0$ $m(\tilde{\chi}_{1}^{0})=70 \text{ GeV}$	ATLAS-CONF-2019-008 ATLAS-CONF-2019-019, ATLAS-CONF-2019-XYZ
EW	$\chi_1 \chi_1$ via $\ell_L / \nu$ $\tilde{\tau} \tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$	2 ε,μ 2 τ	0.1.1	$E_T$ $E_T^{miss}$	139	x1         τ          τ         τ         τ	0.12-0.39	1.0		$m(\ell, \nu)=0.5(m(\ell_1)+m(\ell_1))$ $m(\ell_1^0)=0$	ATLAS-CONF-2019-008 ATLAS-CONF-2019-018
	$\ell_{1,R}\ell_{1,R}, \ell \to \ell \chi_1^c$	2 e, μ 2 e, μ	$\ge 1$	$E_T^{\text{miss}}$ $E_T^{\text{miss}}$	139 139	<i>t</i> <i>t</i> 0.256		0.7		$m(\tilde{\ell}_{1}^{0})=0$ $m(\tilde{\ell})-m(\tilde{\chi}_{1}^{0})=10 \text{ GeV}$	ATLAS-CONF-2019-008 ATLAS-CONF-2019-014
	$HH, H \rightarrow hG/ZG$	0 e, μ 4 e, μ	$\geq 3 b$ 0 jets	$E_T^{miss}$ $E_T^{miss}$	36.1 36.1	й 0.13-0.23 й 0.3		0.29-0.88		$BR(\tilde{\chi}_1^0 \rightarrow h\tilde{G})=1$ $BR(\tilde{\chi}_1^0 \rightarrow Z\tilde{G})=1$	1806.04030 1804.03602
lived	$\text{Direct}\tilde{\chi}_1^{*}\!\tilde{\chi}_1^{-}\text{prod., long-lived}\tilde{\chi}_1^{*}$	Disapp. trk	1 jet	$E_T^{miss}$	36.1		0.46			Pure Wino Pure Higgsino	1712.02118 ATL-PHYS-PUB-2017-019
Long-	Stable ĝ R-hadron Metastable ĝ R-hadron, ĝ→qq∛1		Multiple Multiple		36.1 36.1	ğ ğ [τ(ğ) =10 ns, 0.2 ns]			2.0	5 2.4 m( $\tilde{x}_1^o$ )=100 GeV	1902.01636,1808.04095 1710.04901,1808.04095
N No	$ \begin{array}{l} LFV \ pp \rightarrow \tilde{\mathbf{y}}_{\tau} + X, \ \tilde{\mathbf{y}}_{\tau} \rightarrow e\mu/e\tau/\mu\tau \\ \tilde{\chi}_{1}^{\pm} \tilde{\chi}_{1}^{\mp} / \tilde{\chi}_{2}^{0} \rightarrow WW/Z\ell\ell\ell\ell\nu\nu \\ \tilde{g}\tilde{g}, \ \tilde{g} \rightarrow qq\tilde{\chi}_{1}^{0}, \ \tilde{\chi}_{1}^{0} \rightarrow qqq \end{array} $	еµ,ет,µт 4 е,µ 4	0 jets I-5 large- <i>R</i> je Multiple	$E_T^{miss}$ ets	3.2 36.1 36.1 36.1	$ \begin{array}{l} \widetilde{r}_{1} \\ \widetilde{X}_{1}^{b}/\widetilde{X}_{2}^{b} = [\lambda_{j,13} \neq 0, \lambda_{124} \neq 0] \\ \\ \widetilde{g} = [m(\widetilde{X}_{1}^{b}) - 200 \text{ GeV}, 1100 \text{ GeV}] \\ [\widetilde{X}_{112}^{c} - 2e-4, 2e-5] \end{array} $		0.82	1.9 1.33 1.3 1.9 i 2.0	$\begin{array}{c} \mathcal{X}_{311}'=0.11,\mathcal{A}_{132/133/233}=0.07\\ m(\tilde{x}_{1}^{0})=100~\text{GeV}\\ \text{Large}\mathcal{A}_{112}''\\ m(\tilde{x}_{1}^{0})=200~\text{GeV},\text{bino-like} \end{array}$	1607.08079 1804.03602 1804.03568 ATLAS-CONF-2018-003
æ	$\begin{array}{l} \tilde{t}\tilde{t},\tilde{t} \rightarrow \tilde{t}\tilde{\chi}_{1}^{0},\tilde{\chi}_{1}^{0} \rightarrow tbs\\ \tilde{t}_{1}\tilde{t}_{1},\tilde{t}_{1} \rightarrow bs\\ \tilde{t}_{1}\tilde{t}_{1},\tilde{t}_{1} \rightarrow q\ell \end{array}$	2 e,μ 1 μ	Multiple 2 jets + 2 b 2 b DV	6	36.1 36.7 36.1 136	$\begin{array}{l} g & [\lambda'_{333}=2e{\cdot}4, 1e{\cdot}2] \\ \hline \tilde{t}_1 & [qq, bs] \\ \hline \tilde{t}_1 & [1e{\cdot}10{<}\lambda'_{21k} {<}1e{\cdot}8, 3e{\cdot}10{<}\lambda'_{21k} \\ \end{array}$	0.55 0.42 ( <3e-9]	5 1.0 0.61 1.0	0.4-1.45 1.6	m( $k_1^0$ )=200 GeV, bino-like BR( $\bar{t}_1 \rightarrow be/b\mu$ )>20% BR( $\bar{t}_1 \rightarrow \mu$ )=100%, cos $\theta_i$ =1	ATLAS-CONF-2018-003 1710.07171 1710.05544 ATLAS-CONF-2019-006
Only	a selection of the available mas omena is shown. Many of the l	ss limits on limits are ba	new state ased on	s or	1	0-1			1	Mass scale [TeV]	

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#### ATLAS SUSY Searches\* - 95% CL Lower Limits

#### **Overview of CMS EXO results** July 2019 36 fb<sup>-1</sup> (13 TeV) Mode Signature (L dt [fb-1] Mass limit CMS SSM Z'(LL 1803.06292 (21) М, 4.5 $\tilde{q}\tilde{q}, \tilde{q} \rightarrow q\tilde{\chi}_1^0$ 0 e. u 2-6 jets 36. $E_T^{miss}$ $E_T^{miss}$ SSM Z'(qq) 806.00843 (2j) M2 1-3 jets 36.1 LFVZ', BR(eu) = 10% M-802.01122 (eu 44 0 e, µ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow q\bar{q}\tilde{\chi}_{1}^{0}$ 2-6 jets Emiss 36.1 803.11133 (# + E SSM W'(tv) M., SSM W(aā) M., 1806.00843 (2i) $\bar{g}\bar{g}, \bar{g} \rightarrow q\bar{q}(\ell\ell)\tilde{\chi}_1^0$ 3 e, µ 4 jets 36.1 55M W'(TV) 1807.11421 (T + E $E_T^{miss}$ Ma ee. µµ 2 jets 36.1 $LRSM W_{e}(IN_{e}), M_{H_{e}} = 0.5M_{H_{e}}$ 803 11116 (2/ + 2) 44 0 .... 7-11 jets $\tilde{g}\tilde{g}, \tilde{g} \rightarrow qqWZ\tilde{\chi}_{1}^{0}$ $E_T^{mi}$ 36.1 LRSM $W_{\pi}(\tau N_{\pi}), M_{N_{\pi}} = 0.5 M_{\text{vir}}$ Ma 1811.00806 (2T+2i 3.5 SS e.u 6 jets 139 Axigluon, Coloron, $cot\theta = 1$ 6.1 806.00843 (2j) 0-1 e, µ $\tilde{g}\tilde{g}, \tilde{g} \rightarrow t \tilde{\chi}_1^0$ 3 b Emis 79.8 SS e.u 6 jets 139 scalar LQ (pair prod.), coupling to $1^{st}$ gen. fermions, $\beta = 1$ 144 1811.01197 (2e+ 2i Me scalar LQ (pair prod.), coupling to $1^{st}$ gen, fermions, B = 0.51811.01197 (2e+ 2j; e + 2j + E<sub>T</sub><sup>minn</sup>) 1.27 Multiple Me $\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_1^0 / b \tilde{\chi}_1^0$ 36.1 scalar LQ (pair prod.), coupling to $2^{nd}$ gen. fermions, $\beta = 1$ 1808.05082 (2µ+2j) 153 Multiple 36.1 0.58-0.8 M. Multiple 139 scalar LQ (pair prod.), coupling to $2^{nd}$ gen. fermions, $\beta = 0.5$ 1808.05082 (2 u + 2i; u + 2i + Emiss) 1.29 м scalar LO (pair prod.), coupling to $3^{rd}$ gen, fermions, $\beta = 1$ $1811 00806 (2\tau + 2i)$ M. $\tilde{b}_1 \tilde{b}_1, \tilde{b}_1 \rightarrow b \tilde{\chi}_2^0 \rightarrow b h \tilde{\chi}_1^0$ 0 e. u 64 Emis 139 scalar LQ (single prod.), coup. to 3<sup>rd</sup> gen. ferm., $\beta = 1, \lambda = 1$ 0.23-0.48 м 1806.03472 (2T+b 0.74 $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow W b \tilde{\chi}_1^0 \text{ or } t \tilde{\chi}_1^0$ 0-2 e, µ 0-2 jets/1-2 b E<sub>T</sub>miss 36. excited light quark (gg), $\Lambda = m_{1}^{2}$ 1806.00843 (2) $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow Wb \tilde{\chi}_1^0$ 1 e.µ 3 jets/1 b Emis 139 0.44-0.59 excited light quark (qy), $f_5 = f = f' = 1$ . $\Lambda = m^2$ M 711.04652 (y + j 55 ET $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow \tilde{\tau}_1 hy, \tilde{\tau}_1 \rightarrow \tau \tilde{G}$ 1 T + 1 e.u.T 2 jets/1 b 36.1 excited b quark, $f_5 = f = f' = 1$ , $\Lambda = m_0^2$ 1711.04652 (v + i M. 0 e, µ $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow c \tilde{\chi}_1^0 / \tilde{c} \tilde{c}, \tilde{c} \rightarrow c \tilde{\chi}_1^0$ 20 Emis 36.1 0.8 excited electron, $f_5 = f = f' = 1, \Lambda = m_1^2$ 1811.03052 (**y** + 2e M excited muon, $f_5 = f = f' = 1$ , $\Lambda = m_{ij}^*$ 0 .... mono-iet Fmis 36.1 0.43 M. 1811.03052 (v + 21 1-2 e. µ $\tilde{t}_2\tilde{t}_2,\,\tilde{t}_2{\rightarrow}\tilde{t}_1+h$ 4h1-miss 36. 0.32-0 1803.08030 (2i) 12.8 guark compositeness ( $q\bar{q}$ ), $n_{\text{LURR}} = 1$ Λ., $\tilde{i}_2 \tilde{i}_2, \tilde{i}_2 \rightarrow \tilde{i}_1 + Z$ 3 e. µ Emis 139 1bForbidden 0. guark compositeness (11), nume = 1 1812 10443 (2/) Λ<sup>+</sup><sub>1.8</sub> $\hat{\chi}_1^{\dagger} \hat{\chi}_2^0$ via WZ 2-3 e. µ ET Emiss 36.1 0.6 guark compositeness ( $q\bar{q}$ ), $n_{\rm EURR} = -1$ AL.S 1803.08030 (2j) 17.5 ee, µµ $\geq 1$ 139 0.205 guark compositeness (11), $n_{\rm LUBB} = -1$ 1812.10443 (21) 31 Emiss $\tilde{X}_{1}^{\pm}\tilde{X}_{1}^{\mp}$ via WW 2 e. u 139 0.42 ADD (ii) HLZ, $n_{ED} = 3$ 1803.08030 (2j) $\tilde{\chi}_1^{\pm} \tilde{\chi}_2^0$ via Wh 0-1 e.u 2 b/2 y Emiss 139 $\tilde{\chi}_1^{\pm}/\tilde{\chi}_2^0$ 0.74 Forbidden ADD $(\gamma\gamma, ll)$ HLZ, $n_{ep} = 3$ 1812.10443 (2y, 20 9.1 $\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp}$ via $\tilde{\ell}_L / \tilde{\nu}$ 2 e, µ Emiss 139 M. ADD $G_{xx}$ emission, n = 2712.02345 (≥ 1j + E<sup>min</sup> 21 Emiss 139 TI TRI] 0.16-0.3 0.12-0.39 M $\tilde{\tau}\tilde{\tau}, \tilde{\tau} \rightarrow \tau \tilde{\chi}_1^0$ ADD QBH (jj), $n_{ED} = 6$ 803.08030 (2j) 0 jets $E_T^{miss}$ $E_T^{miss}$ Men 2 e. µ 139 $\tilde{l}_{1,R}\tilde{l}_{1,R}, \tilde{l} \rightarrow l\tilde{\chi}_{1}$ 0.7 ADD QBH ( $e\mu$ ), $n_{ED} = 6$ 2 e. µ 802.01122 (eµ $\geq 1$ 139 0 256 Mon RS $G_{\text{scc}}(q\bar{q}, qg), k/\overline{M}_{\text{Pl}} = 0.1$ M-1806.00843 (2i) 18 $\tilde{H}\tilde{H}, \tilde{H} \rightarrow h\tilde{G}/Z\tilde{G}$ 0 e. u >36 $E_T^{miss}$ $E_T^{miss}$ 36.1 36.1 0.13-0.23 0.29-0 $BSG_{m}(H) k/\overline{M}_{m} = 0.1$ 803.06292 (2/) 425 4 e, µ 0 iets Mc. RS $G_{\text{RC}}(\gamma\gamma)$ , $k/\overline{M}_{\text{Pl}} = 0.1$ 809.00327 (2v 4.1 M RS OBH (ij), n= 1 Direct $\tilde{\chi}_1^+ \tilde{\chi}_1^-$ prod., long-lived $\tilde{\chi}_1^+$ Disapp. trk 1 jet Emis 36.1 0.46 Mon 803 08030 (2i) 0.15 RS OBH (eu), n== 1 802.01122 (eu 36 805.06013 (≥ 7j(ℓ,γ) Stable # R-hadron Multiple non-rotating BH, Mp = 4 TeV, nep = 6 36.1 M ... Metastable $\tilde{g}$ R-hadron, $\tilde{g} \rightarrow qq \tilde{\xi}_1^0$ Multiple 36.1 split-UED, µ≥4 TeV 803.11133 (*l* + E<sub>T</sub><sup>mins</sup>) LEV $pp \rightarrow \tilde{y}_{*} + X, \tilde{y}_{*} \rightarrow euler/ut$ eu.et.ut 3.2 (axial-)vector mediator ( $\chi\chi$ ), $g_q = 0.25$ , $g_{DM} = 1$ , $m_\chi = 1$ GeV 1712.02345 ( > 1i + E" Mmer 18 0 jets $\tilde{\chi}_1^{\pm} \tilde{\chi}_1^{\mp} / \tilde{\chi}_2^0 \rightarrow WW/Z\ell\ell\ell\ell\nu\nu$ 4 e. µ $E_T^{miss}$ 36.1 (axial-)vector mediator ( $q\ddot{q}$ ), $g_q = 0.25$ , $g_{DM} = 1$ , $m_\chi = 1$ GeV 1806.00843 (2j) Mon $\tilde{g}\tilde{g}, \tilde{g} \rightarrow qq\tilde{\chi}_{1}^{0}, \tilde{\chi}_{1}^{0} \rightarrow qaq$ 4-5 large-R jets 36.1 scalar mediator (+ $t/t\bar{t}$ ), $g_q = 1$ , $g_{DM} = 1$ , $m_x = 1$ GeV Mened $1901.01553 (0, 1l + \ge 3j + E_T^{min}) = 0.29$ Multiple 36.1 pseudoscalar mediator (+t/tt), $q_n = 1$ , $q_{nut} = 1$ , $m_n = 1$ GeV M..... $1901.01553 (0, 1l + \ge 3j + E_T^{min}) = 0.3$ $\tilde{t}\tilde{t}, \tilde{t} \rightarrow t \tilde{\chi}_1^0, \tilde{\chi}_1^0 \rightarrow t bs$ Multiple 36.1 scalar mediator (fermion portal), $\lambda_{\nu} = 1, m_{\nu} = 1 \text{ GeV}$ M<sub>e</sub> 712.02345 (≥ 1j + E<sub>T</sub><sup>mins</sup>) 14 2 iets + 2 b 36.7 $\tilde{t}_1 \tilde{t}_1, \tilde{t}_1 \rightarrow bs$ 0.61 complex sc. med. (dark QCD), $m_{n_{DK}} = 5 \text{ GeV}$ , $c\tau_{x_{eK}} = 25 \text{ mm}$ 1810.10069 (4j) 1.54 Mr. $\tilde{t}_1\tilde{t}_1,\tilde{t}_1{\rightarrow}q\ell$ 20.1 2 b 36.1 1μ DV 136 Type III Seesaw, $B_e = B_\mu = B_\mu$ 0.84 1708.07962 ( > 34 Maran 806.00843 (**2**j) string resonance 7.7 10.0 01 10 $10^{-1}$ mass scale [TeV]

\*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on plified models, c.f. refs. for the accur

Selection of observed exclusion limits at 95% C.L. (theory uncertainties are not included)

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January 2019

Istituto Nazionale di Fisica Nucleare

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#### Higgs properties SM-like. After HL-LHC precision level of several % Granada 2019 $\sqrt{s}$ = 14 TeV, 3000 fb<sup>-1</sup> per experiment ATLAS and CMS Total Statistical **HL-LHC** Projection Experimental Uncertainty [%] Theory Tot Stat Exp Th Kγ 1.8 0.8 1.0 1.3 κ<sub>w</sub> 1.7 0.8 0.7 1.3 KZ 1.5 0.7 0.6 1.2 κ<sub>g</sub> 2.5 0.9 0.8 2.1 Kt 3.4 0.9 1.1 3.1 Kh 3.7 1.3 1.3 3.2 K<sub>T</sub> 1.9 0.9 0.8 1.5 κ<sub>u</sub> 4.3 3.8 1.0 1.7 $\kappa_{Z\gamma}$ 9.8 7.2 1.7 6.4 0.02 0.04 0.08 0 0.06 0.1 0.12 0.14 Expected uncertainty

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Higgs properties SM-like.

- After HL-LHC precision level of several %
- **>** Deviation from SM:  $\delta \sim v^2/M^2$  v = 246 GeV

M scale of new physics

 $\blacksquare M \sim 1 - 10 \text{ TeV} \quad \Rightarrow \delta \sim 6 - 0.06\%$ 



#### Higgs properties SM-like.

- After HL-LHC precision level of several %
- Deviation from SM:  $\delta \sim v^2/M^2$  v = 246 GeV
  - M scale of new physics
  - $\blacksquare M \sim 1 10 \text{ TeV} \quad \Rightarrow \delta \sim 6 0.06\%$

#### Need $< \sim \%$ sensitivity $\rightarrow$ beyond HL-LHC



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# Current physics landscape



- No (additional) signs of BSM physics.
  - After intensive searches at LHC
- Higgs properties SM-like.
  - At current precision level of several %
- ... but SM is an insufficient description

# Current physics landscape



- No (additional) signs of BSM physics.
  - After intensive searches at LHC
- Higgs properties SM-like.
  - At current precision level of several %
- ... but SM is an insufficient description
  - Prevalence of matter over anti-matter.
    - Not explained by current values of CKM elements
  - ▶ Neutrinos have masses not acquired in the SM.
  - Compelling evidence for the existence of dark matter in the Universe with no candidate particle(s) in the SM.
- What new machine in this scenario?

# Current directions



#### ICFA statement - Tokyo, March 2019:

"ICFA confirms the international consensus that the highest priority for the next global machine is a "Higgs Factory" capable of precision studies of the Higgs boson.

ICFA notes with satisfaction the great progress of the various options for Higgs factories proposed across the world. All options will be considered in the European Strategy for Particle Physics Update and by ICFA.

#### ICFA report – LP2019, Toronto, August 2019:

- Worldwide effort for e+e- Higgs Factory must not fail!
  - Linear or Circular
  - Asia or Europe (or elsewhere?)

#### Recent comments on ESPPU preparations (B. Vachon – LP2019)

- Emerging consensus for the importance of a "Higgs factory" to fully explore properties of the Higgs, EW sector, etc.
- Need to prepare a clear path towards highest energy.

Roma3, January 29, 2020



FCC integrated program can respond to these requests in an optimal way



FCC integrated program can respond to these requests in an optimal way

Comprehensive program to optimize physics opportunities





- Comprehensive program to optimize physics opportunities
  - Stage 1: FCC-ee (Z, W, H, tt)
    - Higgs factory, EW and top factory at highest luminosities.

# The FCC integrated program



Comprehensive program to optimize physics opportunities

Stage 1: FCC-ee (Z, W, H, tt)

Higgs factory, EW and top factory at highest luminosities.

Stage 2: FCC-hh (~100 TeV)

Natural continuation at energy frontier, with ion and eh options.

Complementary physics

Common civil engineering and technical infrastructures

Integrating an ambitious high-field magnet R&D program





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# The e+e- machine

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#### Double ring e+e- collider ~ 100 km

- RF power limited to 50 MW/beam
- ▶ 2 IP currently 4 IP possible







#### ofe Cenero Double ring e+e- collider ~ 100 km . LHC ► RF power limited to 50 MW/beam Jura ► 2 IP currently - 4 IP possible **Prealps** Booster ring for top up injection A (IP) Schematic of an 30 mrad 80 - 100 km FCC-hh long tunnel B 13.4 m 10.6 m Booster 0.3 m **Aravis** FCC-hh / Booster G<sub>y</sub> (m) J (RF) D (RF) Mandalaz Copyright CERN 2014 ---FCC-hh ---FCC-e-FCC-e+ FCO C-o -1000 -500 500 1000 G<sub>x</sub> (m) Η F G (IP)

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# FCCee parameters



parameter	Z	ww	H (ZH)	ttbar
beam energy [GeV]	45	80	120	182.5
beam current [mA]	1390	147	29	5.4
no. bunches/beam	16640	2000	393	48
bunch intensity [10 <sup>11</sup> ]	1.7	1.5	1.5	2.3
SR energy loss / turn [GeV]	0.036	0.34	1.72	9.21
total RF voltage [GV]	0.1	0.44	2.0	10.9
long. damping time [turns]	1281	235	70	20
horizontal beta* [m]	0.15	0.2	0.3	1
vertical beta* [mm]	0.8	1	1	1.6
horiz. geometric emittance [nm]	0.27	0.28	0.63	1.46
vert. geom. emittance [pm]	1.0	1.7	1.3	2.9
bunch length with SR / BS [mm]	3.5 / 12.1	3.0 / 6.0	3.3 / 5.3	2.0 / 2.5
luminosity per IP [10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup> ]	230	28	8.5	1.55
beam lifetime rad Bhabha / BS [min]	68 / >200	49 / >1000	38 / 18	40 / 18

- SR power 50 MW/beam
- Total site power <300 MW</p>

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## Luminosity comparisons



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♦ Higgs factory
>  $10^6 \text{ e+e-} \rightarrow \text{HZ}$ 





★ Higgs factory
> 10<sup>6</sup> e+e- → HZ
★ EW & Top factory
> 5x10<sup>12</sup> e+e- → Z
> 10<sup>8</sup> e+e- → W+W- ;
> 10<sup>6</sup> e+e- → tt





Higgs factory  $\rightarrow 10^6 \text{ e}+\text{e}- \rightarrow \text{HZ}$ **EW & Top factory** > 5x10<sup>12</sup> e+e- $\rightarrow$  Z  $\succ 10^8 \text{ e+e-} \rightarrow \text{W+W-};$  $> 10^6 \text{ e+e-} \rightarrow \text{tt}$ Flavor factory  $ightarrow 10^{12} \text{ e+e-} \rightarrow \overline{\text{bb, cc}}$  $> 10^{11} \text{ e}+\text{e}- \rightarrow \tau+\tau-$ 





Higgs factory  $\rightarrow 10^6 \text{ e} + \text{e} - \rightarrow \text{HZ}$ EW & Top factory > 5x10<sup>12</sup> e+e- $\rightarrow$  Z  $> 10^8 \text{ e}+\text{e}- \rightarrow \text{W}+\text{W}-$ ;  $> 10^6 \text{ e+e-} \rightarrow \text{tt}$ Flavor factory  $> 10^{12} \text{ e+e-} \rightarrow \text{bb, cc}$  $\succ$  10<sup>11</sup> e+e-  $\rightarrow \tau + \tau$ -

Potential discovery of NP

 $\triangleright$  ALPs, RH v's, ...

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# Higgs production



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#### Higgs production



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# Higgs total width



2000

120

130

140

Recoil mass (GeV)

150

100

90

110

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# Higgs total width



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# Higgs total width

Higgs recoil provides model independent measurement of coupling to Z

 $ightarrow \sigma(HZ) \propto g^2_{HZ}$ 



Critical:

Beam energy spread: SR+BS

Total width combining with decays in specific channels

$$\sigma(ee \to ZH) \cdot BR(H \to ZZ) \propto \frac{g_{HZ}^4}{\Gamma}$$



IDEA: Higgs recoil  $\Delta$  E/E = .136%



 $L = 5 ab^{-1}$ 

# Higgs coupling fits



Collider	HL-LHC	$ILC_{250}$	$\operatorname{CLIC}_{380}$	$CEPC_{240}$	FCC-ee <sub>240<math>\rightarrow</math>365</sub>
Lumi $(ab^{-1})$	3	2	1	5.6	5 + 0.2 + 1.5
Years		$11.5^{5}$	8	7	3+1+4
$g_{\rm HZZ}$ (%)	$1.5 \ / \ 3.6$	$0.29 \ / \ 0.47$	$0.44 \ / \ 0.66$	$0.18 \ / \ 0.52$	0.17 / 0.26
$g_{\rm HWW}$ (%)	1.7 / 3.2	$1.1 \ / \ 0.48$	$0.75 \ / \ 0.65$	$0.95 \ / \ 0.51$	0.41 / 0.27
$g_{\mathrm{Hbb}}$ (%)	$3.7 \ / \ 5.1$	$1.2 \ / \ 0.83$	$1.2 \ / \ 1.0$	$0.92 \ / \ 0.67$	0.64 / 0.56
$g_{ m Hcc}$ (%)	SM / SM	$2.0 \ / \ 1.8$	$4.1 \ / \ 4.0$	$2.0 \ / \ 1.9$	1.3 / 1.3
$g_{\mathrm{Hgg}}$ (%)	$2.5 \ / \ 2.2$	$1.4 \ / \ 1.1$	$1.5 \ / \ 1.3$	$1.1 \ / \ 0.79$	0.89 / 0.82
$g_{\mathrm{H} au au}$ (%)	$1.9 \ / \ 3.5$	$1.1 \ / \ 0.85$	$1.4 \ / \ 1.3$	1.0 / 0.70	0.66 / 0.57
$g_{\mathrm{H}\mu\mu}$ (%)	$4.3 \ / \ 5.5$	$4.2 \ / \ 4.1$	4.4 / 4.3	3.9 / 3.8	3.9 / 3.8
$g_{\mathrm{H}\gamma\gamma}$ (%)	$1.8 \ / \ 3.7$	$1.3 \ / \ 1.3$	$1.5 \ / \ 1.4$	$1.2 \ / \ 1.2$	1.2 / 1.2
$g_{\mathrm{HZ}\gamma}$ (%)	11. / 11.	11. / 10.	11. / 9.8	6.3 / 6.3	10. / 9.4
$g_{\rm Htt}$ (%)	$3.4 \ / \ 2.9$	2.7 / 2.6	2.7 / 2.7	2.6 / 2.6	2.6 / 2.6
$g_{\rm HHH}$ (%)	50. / 52.	28. / 49.	45. / 50.	17. / 49.	<b>19.</b> / <b>34.</b>
$\Gamma_{\rm H}$ (%)	SM	2.4	2.6	1.9	1.2
$BR_{inv}$ (%)	1.9	0.26	0.63	0.27	0.19
$BR_{EXO}$ (%)	SM(0.0)	1.8	2.7	1.1	1.0

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# Higgs coupling fits



#### Results limited only by statistics





# No direct production @ FCC-ee Sensitivity through loop effects







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![](_page_32_Picture_1.jpeg)

#### No direct production @ FCC-ee

![](_page_32_Figure_3.jpeg)

![](_page_33_Picture_1.jpeg)

#### No direct production @ FCC-ee

![](_page_33_Figure_3.jpeg)

## EWK

![](_page_34_Picture_1.jpeg)

# Outstanding program of precision EWK measurements > O(10-100) better than LEP precision

#### Substantially reduce parametric uncertainties in theory

Observable	Present value $\pm$ error	FCC-ee Stat.	FCC-ee Syst.	Comment and dominant exp. error	
m <sub>Z</sub> (keV)	$91,186,700 \pm 2200$	5	100	From Z line shape scan Beam energy calibration	1
$\Gamma_Z$ (keV)	$2,495,200 \pm 2300$	8	100	From Z line shape scan Beam energy calibration	
$R_{\ell}^{Z}$ (×10 <sup>3</sup> )	$20,767\pm25$	0.06	0.2-1.0	Ratio of hadrons to leptons acceptance for leptons	
$\alpha_{\rm s} \ ({\rm m_Z}) \ (\times 10^4)$	$1196 \pm 30$	0.1	0.4-1.6	From $R_{\ell}^{Z}$ above [43]	
R <sub>b</sub> (×10 <sup>6</sup> )	$216,\!290\pm 660$	0.3	< 60	Ratio of bb to hadrons stat. extrapol. from SLD [44]	
$\sigma_{\rm had}^0$ (×10 <sup>3</sup> ) (nb)	$41,541 \pm 37$	0.1	4	Peak hadronic cross-section luminosity measurement	7 pole
$N_{\nu}$ (×10 <sup>3</sup> )	$2991\pm7$	0.005	1	Z peak cross sections Luminosity measurement	
$\sin^2 \theta_W^{\text{eff}}$ (×10 <sup>6</sup> )	$231,480 \pm 160$	3	2-5	From $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration	
$1/\alpha_{QED} (m_Z) (\times 10^3)$	$128,952 \pm 14$	4	Small	From $A_{FB}^{\mu\mu}$ off peak [34]	
$A_{FB}^{b,0}$ (×10 <sup>4</sup> )	$992\pm16$	0.02	1-3	b-quark asymmetry at Z pole from jet charge	
$A_{FB}^{pol,\tau}$ (×10 <sup>4</sup> )	$1498\pm49$	0.15	< 2	$\tau$ Polarisation and charge asymmetry $\tau$ decay physics	
m <sub>W</sub> (MeV)	$80,350 \pm 15$	0.5	0.3	From WW threshold scan Beam energy calibration	
$\Gamma_W$ (MeV)	$2085 \pm 42$	1.2	0.3	From WW threshold scan Beam energy calibration	WW
$\alpha_{\rm s} \ ({\rm m_W}) \ (\times 10^4)$	$1170 \pm 420$	3	Small	From $R_{\ell}^{W}$ [45]	
$N_{\nu}$ (×10 <sup>3</sup> )	$2920\pm50$	0.8	Small	Ratio of invis. to leptonic in radiative Z returns	
mtop (MeV)	$172,740\pm500$	17	Small	From tt threshold scan QCD errors dominate	
$\Gamma_{top}$ (MeV)	$1410\pm190$	45	Small	From tt threshold scan QCD errors dominate	
$\lambda_{top}/\lambda_{top}^{SM}$	$1.2 \pm 0.3$	0.1	Small	From tt threshold scan QCD errors dominate	
ttZ couplings	$\pm 30\%$	0.5-1.5%	Small	From $E_{CM} = 365 \text{ GeV run}$	

#### **EWK** examples

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![](_page_35_Figure_1.jpeg)

#### ♦ W mass/width $\rightarrow$ 0.5/1.2 MeV resolution

 WW threshold scan/ direct measurements check and improve
 ★ Top quark mass/width → 17/45 MeV resolution
 > tt threshold scan – N<sup>3</sup>LO, ISR and FCCee luminosity spectrum F. Bedeschi, INFN-Pisa

![](_page_36_Picture_0.jpeg)

### EWK examples

![](_page_36_Figure_2.jpeg)

# S, T parameters (Peskin–Takeuchi)

#### Comparison of Higgs factories

![](_page_37_Figure_2.jpeg)

# NP sensitivity from EFT fits

# From exclusive fits Reach to several 10's TeV

![](_page_38_Figure_2.jpeg)

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# NP sensitivity from EFT fits

From exclusive fits
Reach to several 10's TeV

Theory uncertainties
Parametric~ exp. precision
Theory precision need
3 loop Z pole
2 loop WW

![](_page_39_Figure_3.jpeg)

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# Heavy flavors

![](_page_40_Picture_1.jpeg)

#### Large heavy flavor production at Z pole

Particle production $(10^9)$	$B^0$	$B^{-}$	$B_s^0$	$\Lambda_b$	$c\overline{c}$	$\tau^{-}\tau^{+}$
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-ee	400	400	100	100	800	220

Very clean, well separated, pairs

# Heavy flavors

![](_page_41_Picture_1.jpeg)

#### Large heavy flavor production at Z pole

Particle production $(10^9)$	$B^0$	$B^{-}$	$B_s^0$	$\Lambda_b$	$c\overline{c}$	$\tau^{-}\tau^{+}$
Belle II	27.5	27.5	n/a	n/a	65	45
FCC-ee	400	400	100	100	800	220

![](_page_41_Figure_4.jpeg)

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# Direct NP search example: HNL

◆ HNL mix with active neutrino's
> Fully reconstructable decay with W
> Small mixing → long lifetime

![](_page_42_Figure_2.jpeg)

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## Direct NP search example: HNL

![](_page_43_Figure_1.jpeg)

![](_page_43_Figure_2.jpeg)

![](_page_43_Figure_3.jpeg)

![](_page_43_Figure_4.jpeg)

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 $10 \text{ cm} < c\tau < 100 \text{ cm}$  $10^{12} \text{ Z}$ 

## Direct NP search example: HNL

![](_page_44_Figure_1.jpeg)

![](_page_44_Figure_2.jpeg)

![](_page_44_Figure_3.jpeg)

![](_page_44_Picture_4.jpeg)

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 $10 \text{ cm} < c\tau < 100 \text{ cm}$  $10^{12} \text{ Z}$ 

 $0.01 \text{ cm} < c\tau < 500 \text{ cm}$  $10^{13} \text{ Z}$ 

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![](_page_45_Picture_0.jpeg)

![](_page_45_Picture_1.jpeg)

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# The pp machine

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![](_page_45_Picture_4.jpeg)

# FCChh parameters

![](_page_46_Picture_1.jpeg)

parameter	FC	C-hh	HE-LHC	HL-LHC	LHC
collision energy cms [TeV]	1	100	27	14	14
dipole field [T]		16	16	8.33	8.33
circumference [km]	9	7.75	26.7	26.7	26.7
beam current [A]		0.5	1.27	1.1	0.58
bunch intensity [10 <sup>11</sup> ]	1 1		2.5	2.2	1.15
bunch spacing [ns]	25 25		25	25	25
synchr. rad. power / ring [kW]	2	400	101	7.3	3.6
SR power / length [W/m/ap.]	2	8.4	4.1	0.33	0.17
long. emit. damping time [h]	0	.54	1.8	12.9	12.9
beta* [m]	1.1	0.3	0.45	0.15 (min.)	0.55
normalized emittance [µm]	2.2		2.5	2.5	3.75
peak luminosity [10 <sup>34</sup> cm <sup>-2</sup> s <sup>-1</sup> ]	5 30		16	5 (lev.)	1
events/bunch crossing	170 1000		460	132	27
stored energy/beam [GJ]		8.4	1.4	0.7	0.36

#### Total site power <600 MW</p>

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# FCChh key facts

![](_page_47_Picture_1.jpeg)

![](_page_47_Figure_2.jpeg)

O(x10) E and L
100 TeV
20 ab<sup>-1</sup>/exp.
In 25 years
Key tech. issue:
High field magnets
20 T with HTS

#### LHC technology 8.3 T NbTi

![](_page_47_Picture_5.jpeg)

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![](_page_47_Picture_7.jpeg)

![](_page_47_Picture_8.jpeg)

![](_page_47_Picture_9.jpeg)

# FCChh magnets

![](_page_48_Picture_1.jpeg)

Magnet development: magnet models production

![](_page_48_Picture_3.jpeg)

FCC Status Michael Benedikt CERN, 13 January 2020

![](_page_48_Picture_5.jpeg)

![](_page_48_Picture_6.jpeg)

25 1

## FCChh magnets

![](_page_49_Picture_1.jpeg)

![](_page_49_Picture_2.jpeg)

#### US – MDP: 14 T magnet tested at FNAL

![](_page_49_Picture_4.jpeg)

![](_page_49_Figure_5.jpeg)

- 15 T dipole demonstrator
- Staged approach: In first step prestressed for 14 T
- Second test foreseen in fall 2019 with additional pre-stress for 15 T

![](_page_49_Picture_9.jpeg)

FCC Status Michael Benedikt CERN, 13 January 2020

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![](_page_50_Picture_0.jpeg)

#### **Exploration potential**

#### Search reach scaled from HL-LHC (2-3 TeV for SUSY)

![](_page_50_Figure_3.jpeg)

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![](_page_51_Picture_0.jpeg)

![](_page_51_Picture_1.jpeg)

#### Search reach scaled from HL-LHC (2-3 TeV for SUSY)

![](_page_51_Figure_3.jpeg)

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![](_page_52_Picture_0.jpeg)

#### **Exploration potential**

#### Search reach scaled from HL-LHC (2-3 TeV for SUSY)

![](_page_52_Figure_3.jpeg)

![](_page_53_Picture_0.jpeg)

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#### Exploration potential

#### Search reach scaled from HL-LHC (2-3 TeV for SUSY)

![](_page_53_Figure_3.jpeg)

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#### Dark matter

![](_page_54_Picture_1.jpeg)

#### Dark matter (simplified models)

# 100 TeV pp could cover all parameter space allowed by cosmological bounds M McCullough ECC week 2016

![](_page_54_Picture_4.jpeg)

![](_page_54_Figure_5.jpeg)

![](_page_54_Figure_6.jpeg)

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![](_page_55_Picture_0.jpeg)

#### FCC-ee + FCC-hh schedule

![](_page_55_Figure_2.jpeg)

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#### FCC costs

![](_page_56_Picture_1.jpeg)

Domain	Cost in MCHF	Share to Civil England an
Stage 1 - Civil Engineering	5,400	19%
Stage 1 - Technical Infrastructure	2,200	Stage 1 Technical Infrastructure Stage 2 FCC-hh Machine
Stage 1 - FCC-ee Machine and Injector Complex	<mark>4,000</mark>	8% and Injector complex 47%
Stage 2 - Civil Engineering complement	600	Stage 1 FCC-ee Machine and Injector Complex 14%
Stage 2 - Technical Infrastructure adaptation	2,800	
Stage 2 - FCC-hh Machine and Injector complex	13,600	Infrastructure adaptation 10%
TOTAL construction cost for integral FCC project	<mark>28,</mark> 600	Stage 2 Civil Engineering complement 2%

Total cost FCCee: 10,600 MCHF
 Addition for tt 1,100 MCHF
 Total additional cost for FCChh: 17,000 MCHF
 Stand alone ~25 BCHF

# ESG main scenarios

![](_page_57_Picture_1.jpeg)

#### 5 basic options for the future being explored by ESG

	2020-2040	2040-2060	2060-2080	
		1st gen technology	2nd gen technology	
CLIC-all	HL-LHC	CLIC380-1500	CLIC3000 / other tech	
CLIC-FCC	HL-LHC	CLIC380	FCC-h/e/A (Adv HF magnets) / other tech	
FCC-all	HL-LHC	FCC-ee (90-365)	FCC-h/e/A (Adv HF magnets) / other tech	
LE-to-HE-FCC-h/e/A	HL-LHC	LE-FCC-h/e/A (low-field magnets)	FCC-h/e/A (Adv HF magnets) / other tech	
LHeC-FCC-h/e/A	HL-LHC + LHeC	LHeC	FCC-h/e/A (Adv HF magnets) / other tech	

#### CERN funding:

First 3 scenarios: 10-13% CERN budget in 2025-2045

Civil engineering assumed outside of CERN budget

→ 4<sup>th</sup> scenario: ~20% CERN budget in 2025-2045

▶ 5<sup>th</sup> scenario is within the regular CERN budget

#### Last 2 scenarios assume that an e+e- collider is built outside of Europe

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# Schedule comparisons

![](_page_58_Figure_1.jpeg)

#### **U. Bassler**

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![](_page_59_Picture_1.jpeg)

Major physics potential at FCC-ee

- Study Higgs x10 better than HL-LHC
- EWPO x10-100 better than LEP
- ► HF studies complementary to LHC-b/Belle II

![](_page_60_Picture_1.jpeg)

Major physics potential at FCC-ee

- Study Higgs x10 better than HL-LHC
- EWPO x10-100 better than LEP
- ► HF studies complementary to LHC-b/Belle II

Matches right time scale immediately after HL-LHC

Gives time for high field magnet development

![](_page_61_Picture_1.jpeg)

Major physics potential at FCC-ee

- Study Higgs x10 better than HL-LHC
- EWPO x10-100 better than LEP
- ► HF studies complementary to LHC-b/Belle II
- Matches right time scale immediately after HL-LHC
  - Gives time for high field magnet development
- Major physics and exploration potential at FCC-hh
  - Shares tunnel and much of the FCCee infrastructure
  - ➢ HHH to 5% precision
  - Huge jump in direct discovery potential

![](_page_62_Picture_1.jpeg)

Major physics potential at FCC-ee

- Study Higgs x10 better than HL-LHC
- EWPO x10-100 better than LEP
- ➢ HF studies complementary to LHC-b/Belle II
- Matches right time scale immediately after HL-LHC
  - Gives time for high field magnet development
- Major physics and exploration potential at FCC-hh
  - Shares tunnel and much of the FCCee infrastructure
  - ► HHH to 5% precision
  - Huge jump in direct discovery potential

Great vision and plan for the next 70 years of HEP