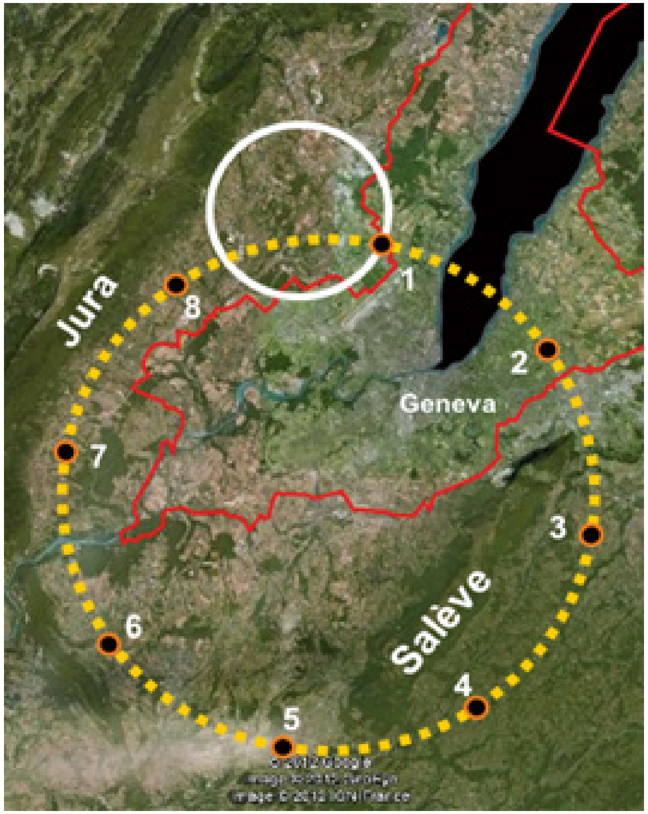
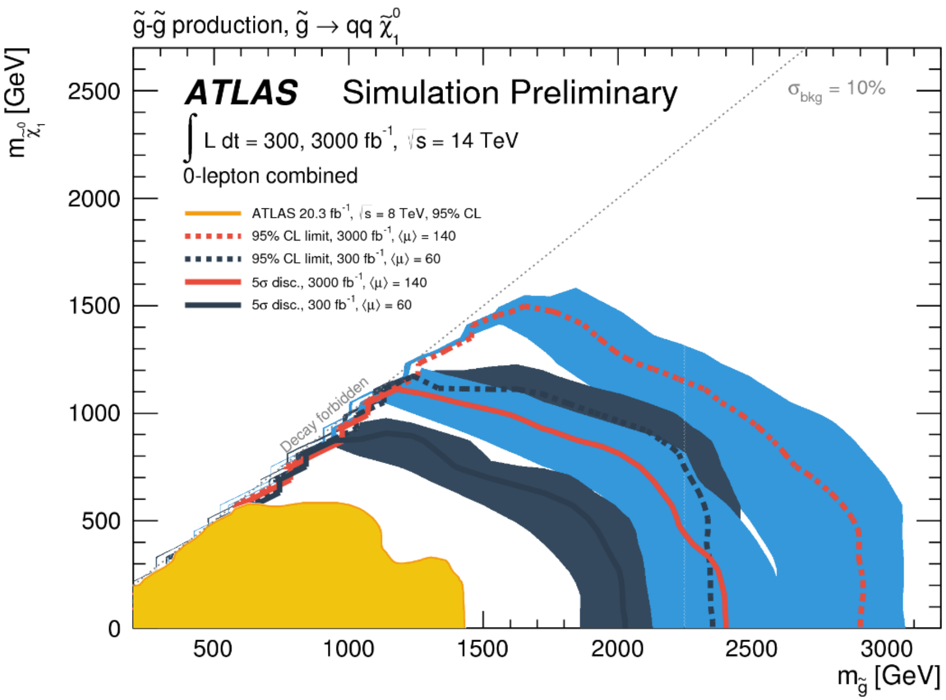
- Tests of physics motivation for higher energy colliders
  - LHC tunnel 33TeV
  - New tunnels 80TeV, 100TeV, 200TeV, …

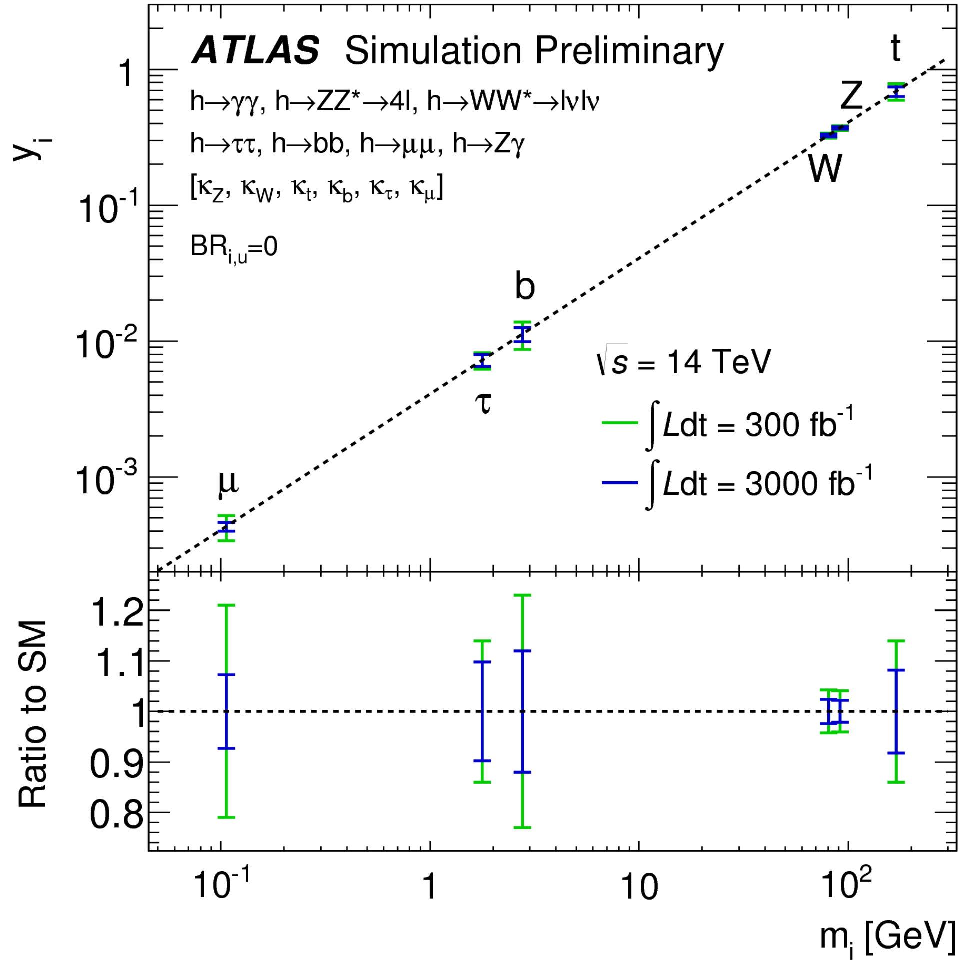


- My interest is "direct search of BSM".
  - SUSY
  - DM
  - Extra dimension
    (after SUSU-like events will be observed)

- "Delphes" description for FCC
  - https://indico.cern.ch/event/388119/contribution/2/material/slides/0.pdf
  - https://indico.cern.ch/event/388119/contribution/2/material/0/0.tcl

“Physics” reach with Hadron Colliders





H->μμ … ~1500fb-1 for observation

For LC (not for me…?)

Higgs BR

Tools

HDECAY and Prophecy4F

HDECAY … all relevant higher order QCD corrections to decays into quark pairs and into gluons. EW NLO corrections to H->$\gamma\gamma$ and gg are included.
Prophecy4F … WW/ZZ->4f. Complete NLO QCD and EW corrections and all interferences at LO and NLO.

125GeV SM Higgs (YR3)

	BR	Uncert[%]	Uncert[%]
H → bb	0.577000	3.21	-3.27
H → ττ	0.063200	5.71	-5.67
H → μμ	0.000219	6.01	-5.86
H → cc	0.029100	12.17	-12.21
H → ss	0.000246	4.88	-4.86
H → tt	0.000000	0	0
H → gg	0.085700	10.22	-9.98
H → γγ	0.002280	4.98	-4.89
H → Zγ	0.001540	9.01	-8.83
H → WW	0.215000	4.26	-4.2
H → ZZ	0.026400	4.28	-4.21
ΓH[GeV]	4.07E-03	3.97	-3.93

"Uncert." is defined as a linear sum of PUs and THUs.
PU = parametric uncertainty
THU = Theoretical uncertainty

$$\Delta^p_+ \mathrm{BR} = \max\{\mathrm{BR}(p+\Delta p), \mathrm{BR}(p), \mathrm{BR}(p-\Delta p)\} - \mathrm{BR}(p),$$
$$\Delta^p_- \mathrm{BR} = \mathrm{BR}(p) - \min\{\mathrm{BR}(p+\Delta p), \mathrm{BR}(p), \mathrm{BR}(p-\Delta p)\},$$

1) A list of PU = alphaS, bottom mass, charm mass, top mass
   Total PU is calculated from a quadrature sum of errors due to these 4 parameters.
2) A list of THU = missing higher order corrections
   Total THU is calculated from a linear sum.
3) BR Correlation -> Obtain from partial widths.
- PU … correlated
- THU … uncorrelated (except for 4fermion final states)

PU

Parameter	Central value	Uncertainty	$\overline{\text{MS}}$ masses $m_q(m_q)$
$\alpha_s(M_Z)$	0.119	±0.002	
m_c	1.42 GeV	±0.03 GeV	1.28 GeV
m_b	4.49 GeV	±0.06 GeV	4.16 GeV
m_t	172.5 GeV	±2.5 GeV	165.4 GeV

Charm, bottomはpole massを使っている.

THU

Table 2: Estimated theoretical uncertainties from missing higher orders.

Partial width	QCD	electroweak	total
$H \to b\bar{b}/c\bar{c}$	$\sim 0.1\%$	~ 1–2% for $M_H \lesssim 135$ GeV	$\sim 2\%$
$H \to \tau^+\tau^-/\mu^+\mu^-$		~ 1–2% for $M_H \lesssim 135$ GeV	$\sim 2\%$
$H \to t\bar{t}$	$\lesssim 5\%$	$\lesssim 2$–5% for $M_H < 500$ GeV	$\sim 5\%$
		$\sim 0.1(\frac{M_H}{1\ \text{TeV}})^4$ for $M_H > 500$ GeV	~ 5–10%
$H \to gg$	$\sim 3\%$	$\sim 1\%$	$\sim 3\%$
$H \to \gamma\gamma$	$< 1\%$	$< 1\%$	$\sim 1\%$
$H \to Z\gamma$	$< 1\%$	$\sim 5\%$	$\sim 5\%$
$H \to WW/ZZ \to 4f$	$< 0.5\%$	$\sim 0.5\%$ for $M_H < 500$ GeV	$\sim 0.5\%$
		$\sim 0.17(\frac{M_H}{1\ \text{TeV}})^4$ for $M_H > 500$ GeV	~ 0.5–15%

“Complete” higher order correctionはせいぜいNLO (NLOでもある近似を使っていることがある)

follows: For the decays $H \to b\bar{b}, c\bar{c}$, HDECAY includes the complete massless QCD corrections up to and including NNNNLO, with a corresponding scale dependence of about 0.1% [38–45]. The NLO electroweak corrections [46–49] are included in the approximation for small Higgs masses [50] which has an accuracy of about 1−2% for $M_H < 135$ GeV. The same applies to the electroweak corrections to

B. A. Kniehl, *Radiative corrections for H→f ¯ f (γ) in the Standard Model*, Nucl. Phys. **B376** (1992) 3–28.

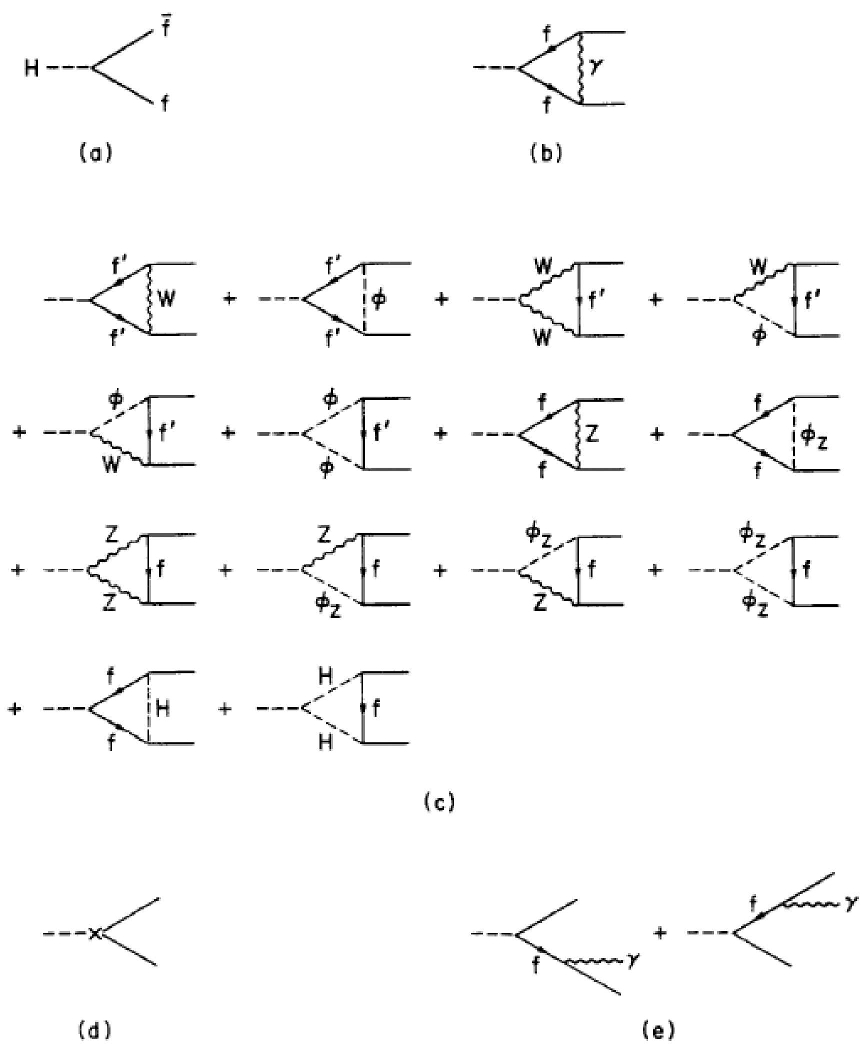
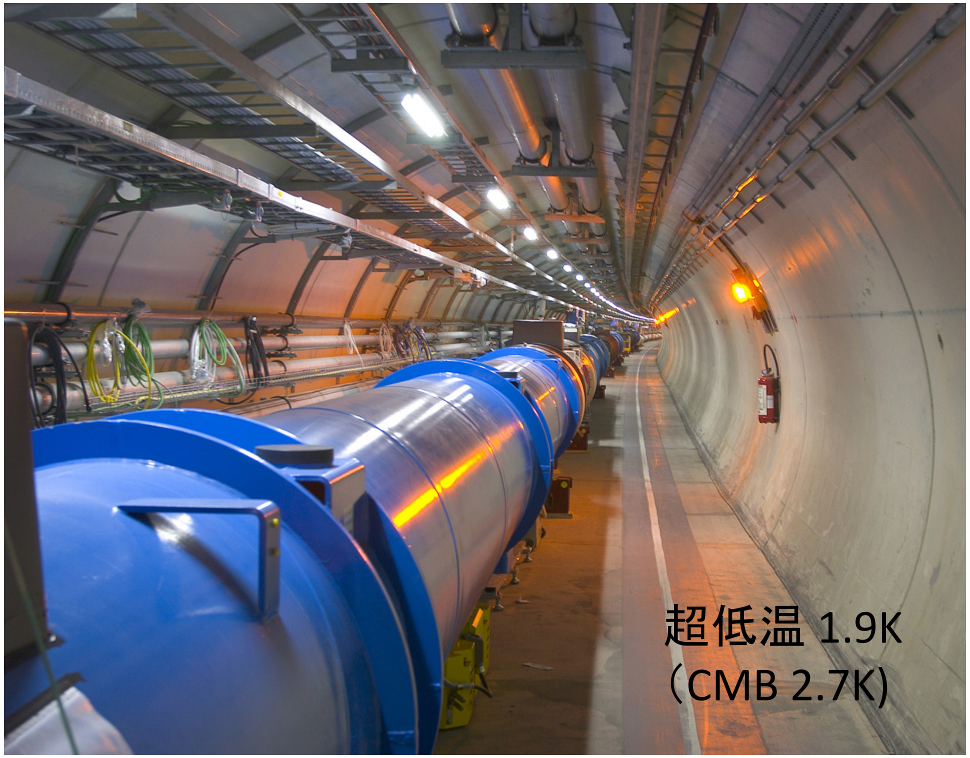


Fig. 1. Feynman diagrams pertinent to H → $f\bar{f}(\gamma)$ in the one-loop approximation: (a) Born graph, (b) virtual-photon exchange, (c) loops involving the W, Z, and Higgs bosons, (d) counterterm, and (e) photon bremsstrahlung. $\phi^{\pm}$ and ϕ_Z denote the Higgs–Kibble ghosts corresponding to the longitudinal degrees of freedom of the $W^{\pm}$ and Z-bosons.

Table 1: SM Higgs partial widths and their relative parametric (PU) and theoretical (THU) uncertainties for a selection of Higgs masses. For PU, all the single contributions are shown. For these four columns, the upper percentage value (with its sign) refers to the positive variation of the parameter, while the lower one refers to the negative variation of the parameter.

Channel	M_H [GeV]	Γ [MeV]	$\Delta\alpha_s$	Δm_b	Δm_c	Δm_t	THU
$H \to b\bar{b}$	122	2.30	−2.3% +2.3%	+3.2% −3.2%	+0.0% −0.0%	+0.0% −0.0%	+2.0% −2.0%
	126	2.36	−2.3% +2.3%	+3.3% −3.2%	+0.0% −0.0%	+0.0% −0.0%	+2.0% −2.0%
	130	2.42	−2.4% +2.3%	+3.2% −3.2%	+0.0% −0.0%	+0.0% −0.0%	+2.0% −2.0%
$H \to \tau^+\tau^-$	122	$2.51{\cdot}10^{-1}$	+0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.1%	+2.0% −2.0%
	126	$2.59{\cdot}10^{-1}$	+0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.1% −0.1%	+2.0% −2.0%
	130	$2.67{\cdot}10^{-1}$	+0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.1% −0.1%	+2.0% −2.0%
$H \to \mu^+\mu^-$	122	$8.71{\cdot}10^{-4}$	+0.0% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.1% −0.1%	+2.0% −2.0%
	126	$8.99{\cdot}10^{-4}$	+0.0% +0.0%	+0.0% −0.0%	−0.1% −0.0%	+0.0% −0.1%	+2.0% −2.0%
	130	$9.27{\cdot}10^{-4}$	+0.1% +0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.1% −0.0%	+2.0% −2.0%
$H \to c\bar{c}$	122	$1.16{\cdot}10^{-1}$	−7.1% +7.0%	−0.1% +0.1%	+6.2% −6.0%	+0.0% −0.1%	+2.0% −2.0%
	126	$1.19{\cdot}10^{-1}$	−7.1% +7.0%	−0.1% +0.1%	+6.2% −6.1%	+0.0% −0.1%	+2.0% −2.0%
	130	$1.22{\cdot}10^{-1}$	−7.1% +7.0%	−0.1% +0.1%	+6.3% −6.0%	+0.1% −0.1%	+2.0% −2.0%
$H \to gg$	122	$3.25{\cdot}10^{-1}$	+4.2% −4.1%	−0.1% +0.1%	+0.0% −0.0%	−0.2% +0.2%	+3.0% −3.0%
	126	$3.57{\cdot}10^{-1}$	+4.2% −4.1%	−0.1% +0.1%	+0.0% −0.0%	−0.2% +0.2%	+3.0% −3.0%
	130	$3.91{\cdot}10^{-1}$	+4.2% −4.1%	−0.1% +0.2%	+0.0% −0.0%	−0.2% +0.2%	+3.0% −3.0%
$H \to \gamma\gamma$	122	$8.37{\cdot}10^{-3}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+1.0% −1.0%
	126	$9.59{\cdot}10^{-3}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+1.0% −1.0%
	130	$1.10{\cdot}10^{-2}$	+0.1% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+1.0% −1.0%
$H \to Z\gamma$	122	$4.74{\cdot}10^{-3}$	+0.0% −0.1%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.1%	+5.0% −5.0%
	126	$6.84{\cdot}10^{-3}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.1%	+0.0% −0.1%	+5.0% −5.0%
	130	$9.55{\cdot}10^{-3}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+5.0% −5.0%
$H \to WW$	122	$6.25{\cdot}10^{-1}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%
	126	$9.73{\cdot}10^{-1}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%
	130	1.49	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%
$H \to ZZ$	122	$7.30{\cdot}10^{-2}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%
	126	$1.22{\cdot}10^{-1}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%
	130	$1.95{\cdot}10^{-1}$	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.0% −0.0%	+0.5% −0.5%

Superconducting magnet



超伝導線材 NbTi

-> 16T実現のための線材 Nb_3Sn
まだまだ技術的な問題が残っている.

	NbTi	Nb_3Sn
Transition temp	10K	18K
Critical field (Hc)@4.2K	~12T	~25T

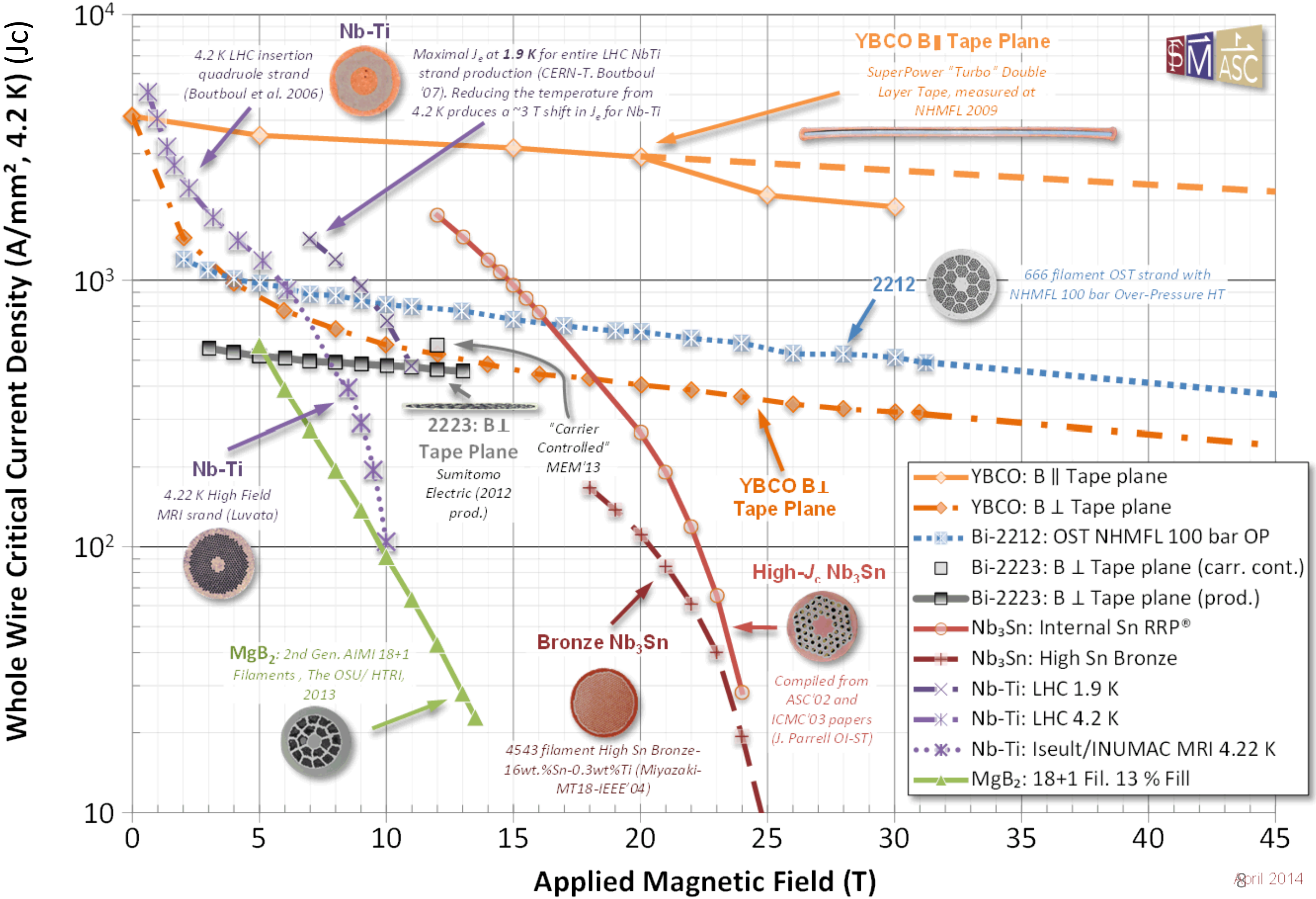
When a field, which is higher than Hc, is applied, superconductivity is destroyed.

8.3Tの強力な超伝導dipole magnet
この磁石の強さがLHCのエネルギーを決めている
(15m x 1232台 = 18.5km)

27kmという巨大なシステムで安定に超伝導状態でなければばならない.

In order to make a higher field, we need a higher current density.

http://fs.magnet.fsu.edu/~lee/plot/plot.htm



April 2014

CLIC

Compact Linear Collider : up to 3TeV

Higher energy than ILC -> Need higher RF cavity : 100MV/m

-> Use so-called "Drive Beams" for RF.

This is a next generation technology of the linear collider.

"CLIC technology"