"Implications of LHC results for TeV-scale physics"
CLIC

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What is CLIC?

One answer: e^+e^- at 3 TeV with several ab^{-1} ("Full CLIC")

Another answer: An e+e- linear collider program that is to have multiple energy and luminosity stages from a few hundred GeV to 3 TeV ("Staged CLIC").

3 simple statements of LHC results

#1: Strongly coupled states have increased direct bounds that are greater than 1 TeV.

#2: No anomalies to speak of at the LHC.

#3: No sign of Higgs boson, although range of mass ruled out.

3 simple implications for future e+e-

#1: Light new physics states available to a low-energy e+e- machine or stage can be judged “less likely” than before, although e+e- mostly about EW states and LHC7 mostly about strongly coupled states.

#2: The existence of a Higgs boson is neither more nor less likely than before.

#3: A light Higgs boson (115-140 GeV) can be judged “more likely” than before.

Implications for CLIC

Argument for "Full CLIC": Let's blow the lid off energy, and reach much further into the EW frontier for a new discovery.

Argument for "Staged CLIC": The Higgs is probably light, let's plan to squeeze it for all its worth at low-energy machine, then ramp up the energy over time.

Staged CLIC best of both worlds?

Staged CLIC sounds like obvious path, since it appears to include "Full CLIC". But … it's value added over other paths not certain upon some reflection:

- LHC will measure Higgs mass very well. How much better to we really need the mass?

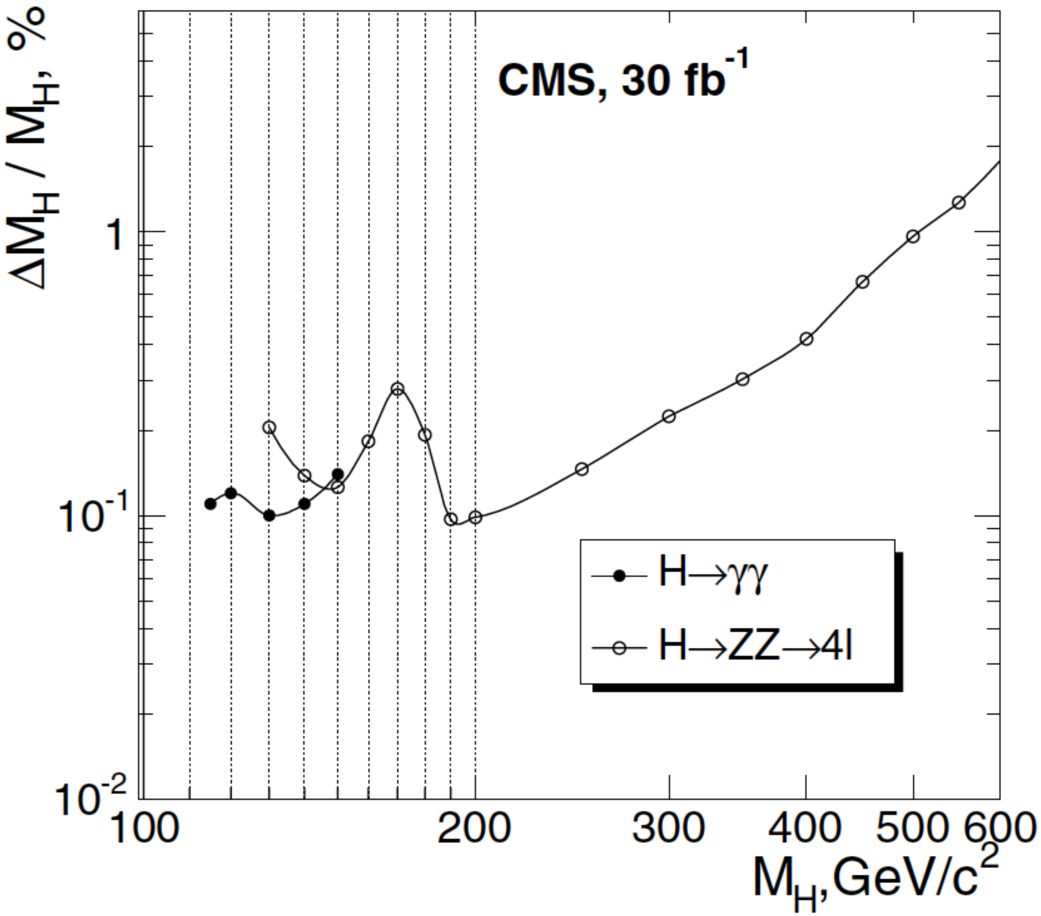
- How well can the LHC measure the couplings in the end, and will e+e- higgs study yield significant value added? How do we decide what level of measurement is added value? (Gupta, Rzehak, JW)

- How long do we have to be a low-energy studying something we know exists before going to the energy frontier? Several inverse ab^{-1}? Is this many years? Does it matter how long?

- Could high-energy machine do Higgs physics just as well in the end? Can we gain with increased cross-section of $h\nu\nu$ at 3 TeV?

- New physics could be easier to reveal in increments. Staging above Higgs study energies could be scientifically beneficial as wells as technologically easier?

Higgs Mass



CMS TDR, vol.II 2007

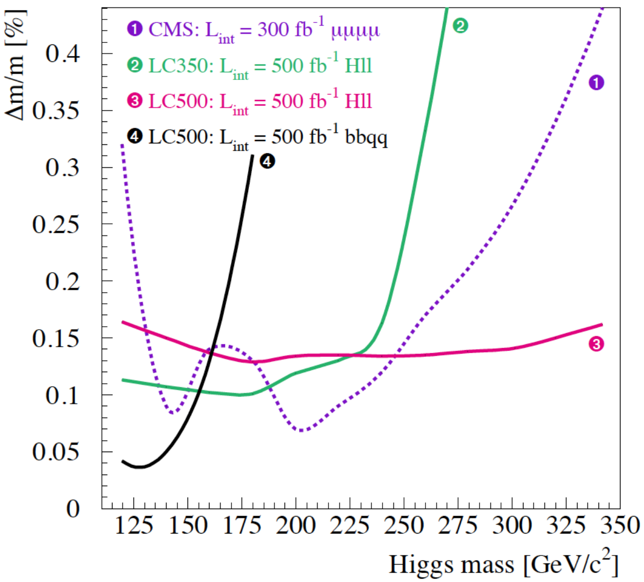


Figure 3: Relative error on the measurement of the SM Higgs mass versus mass for the LHC (CMS simulation) and an LC.

Drollinger, Sopczak, '01

Why do we need it better than the LHC?

Higgs Couplings

Rauch, '11

Is low E CLIC stage worth it? Probably yes.

But, sigma*BR(h->bb) measurement at 3 TeV is 0.22% for 120 GeV Higgs. And, triple Higgs may be easier at 3 TeV. Studies ongoing.

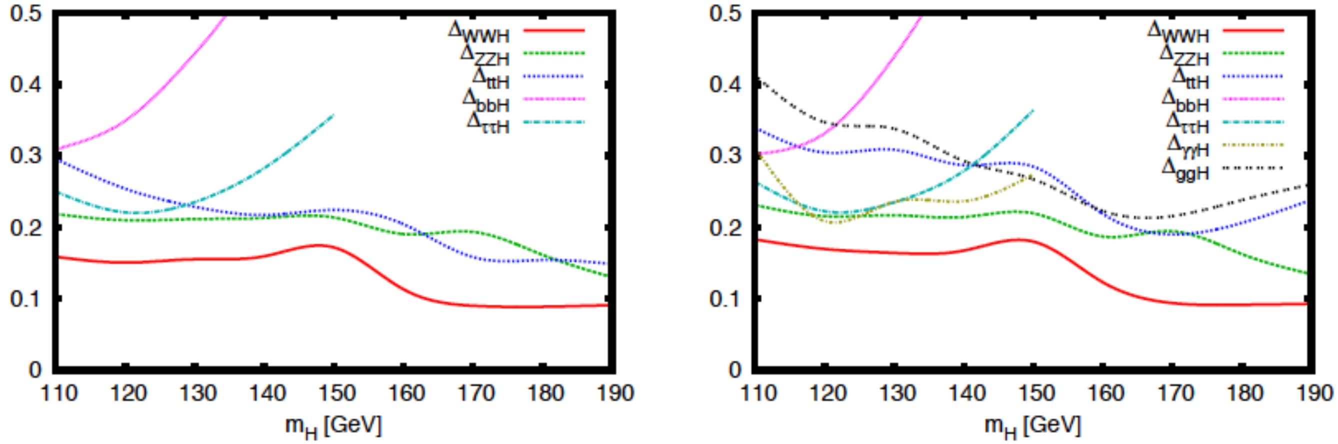
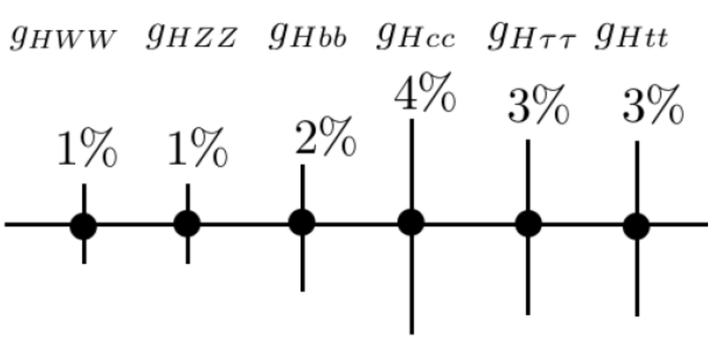


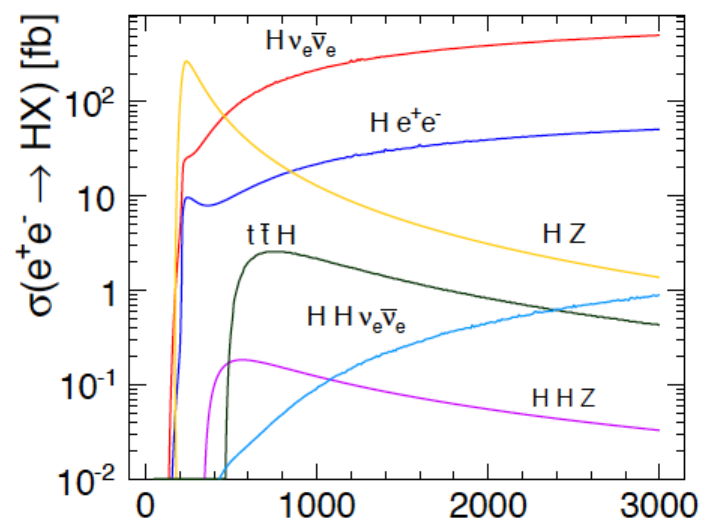
Figure 1: Error on the Higgs-boson couplings as a function of the Higgs mass without (*left*) and including (*right*) additional dimension-five operators for the 14 TeV LHC with 30 fb^{-1} and SM couplings.

$m_H = 120$ GeV

500 GeV 500 fb^{-1}

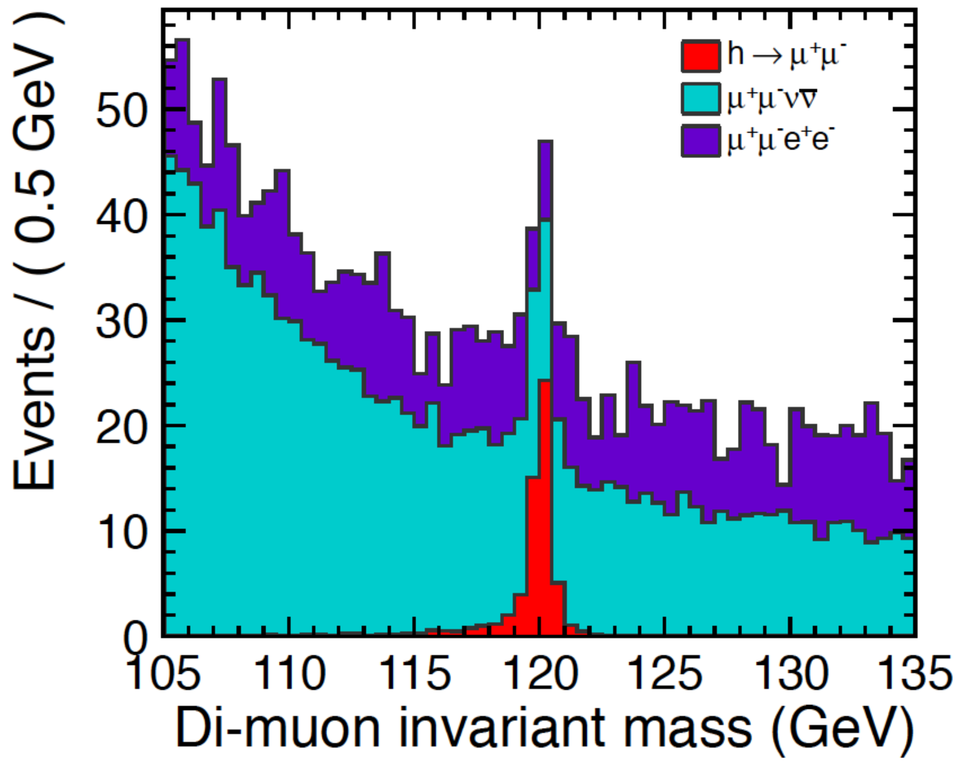


CLIC CDR, extrapolating TESLA TDR numbers



CLIC CDR

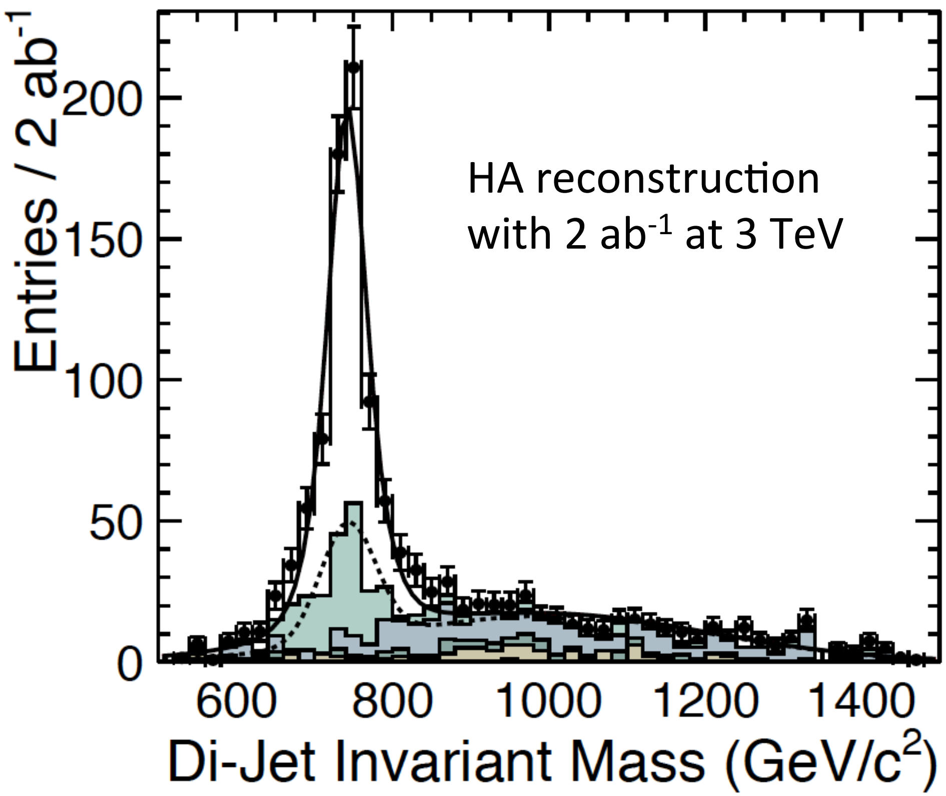
“Full CLIC” Example: Higgs decay to muons

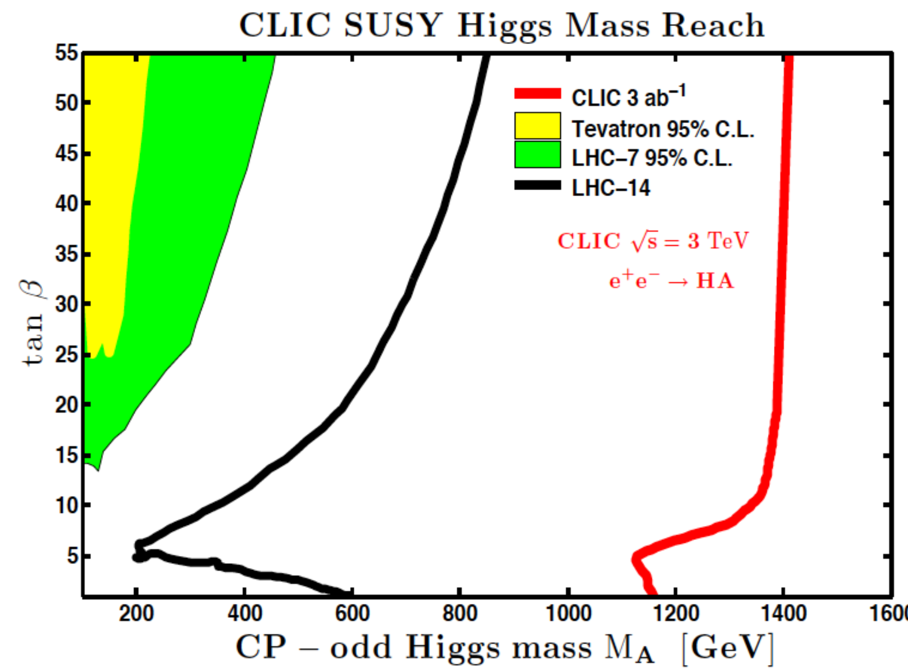


CLIC CDR, 2011

For 3 TeV CLIC with 2 ab^{-1}, the σ.BR of higgs to $\mu+\mu-$ is better than 20%.

Heavy Higgs at "Full CLIC"

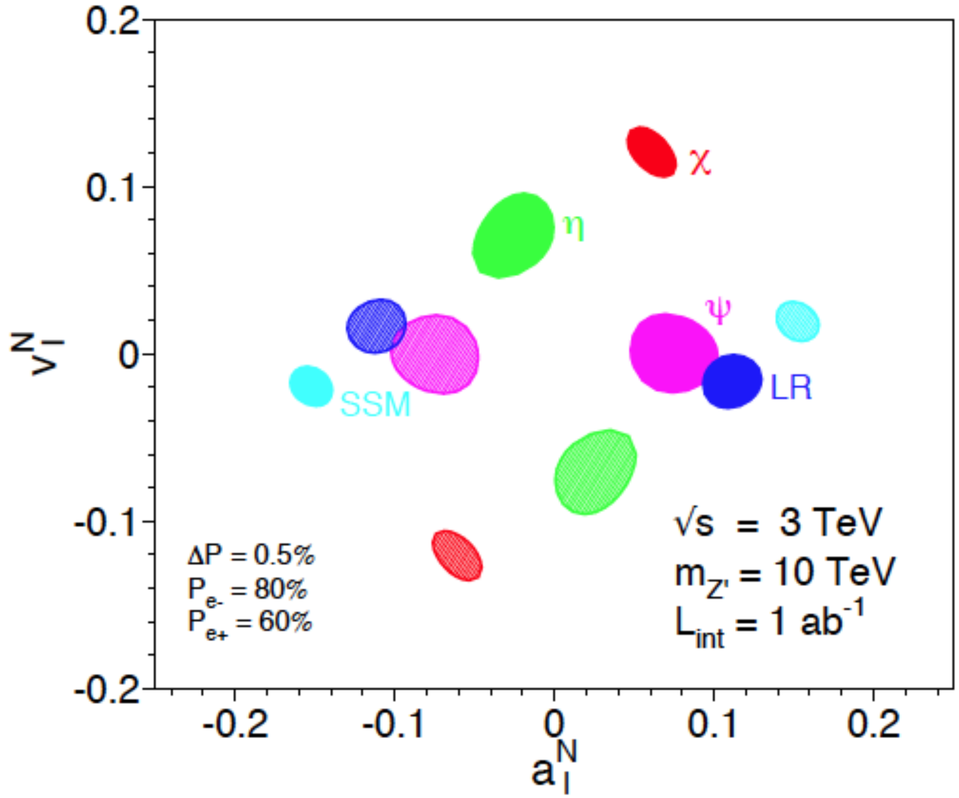




CLIC CDR, 2011

Z' searches at LHC and CLIC

LHC's search of Z's covers small part of parameter space accessible to CLIC.



14 TeV LHC with 100 fb^{-1} does not even see evidence for this boson much less measure its couplings.

CLIC CDR

SUSY above LHC 7 expected sensitivity

Model input parameters:

$$M_1,\ M_2,\ M_3 = 840,\ 600,\ 450\ \mathrm{GeV}$$

$$A_0 = -800\ \mathrm{GeV}$$

$$\tan\beta = 20, \qquad \mu = +902\ \mathrm{GeV}, \qquad m_{A^0,\mathrm{pole}} = 765\ \mathrm{GeV},$$

$$m_{\tilde{Q}_{1,2}} = m_{\tilde{u}_{1,2}} = m_{\tilde{d}_{1,2}} = 2000\ \mathrm{GeV},$$

$$m_{\tilde{Q}_3} = m_{\tilde{u}_3} = m_{\tilde{d}_3} = 900\ \mathrm{GeV},$$

$$m_{\tilde{L}_{1,2,3}} = m_{\tilde{e}_{1,2,3}} = 500\ \mathrm{GeV}.$$

The model is defined by its SLHA file, produced by SoftSUSY 3.2.0 from these inputs.

Physical masses in GeV

Neutralinos $(\tilde{N}_{1,2,3,4})$:	357, 487, 904, 911
Charginos $(\tilde{C}_{1,2})$:	487, 911
Sleptons $(\tilde{e}_R, \tilde{e}_L, \tilde{\nu}_e)$:	559, 650, 644
$(\tilde{\tau}_1, \tilde{\tau}_2, \tilde{\nu}_\tau)$:	517, 642, 630
Squarks $(\tilde{t}_1, \tilde{t}_2, \tilde{b}_1, \tilde{b}_2)$:	844, 1120, 1078, 1191
$(\tilde{d}_R, \tilde{u}_R, \tilde{d}_L, \tilde{u}_L)$:	2167, 2181, 2197, 2196
Higgs bosons $(h^0, A^0, H^0, H^\pm)$:	117.8, 765, 765, 769

Significant Observables

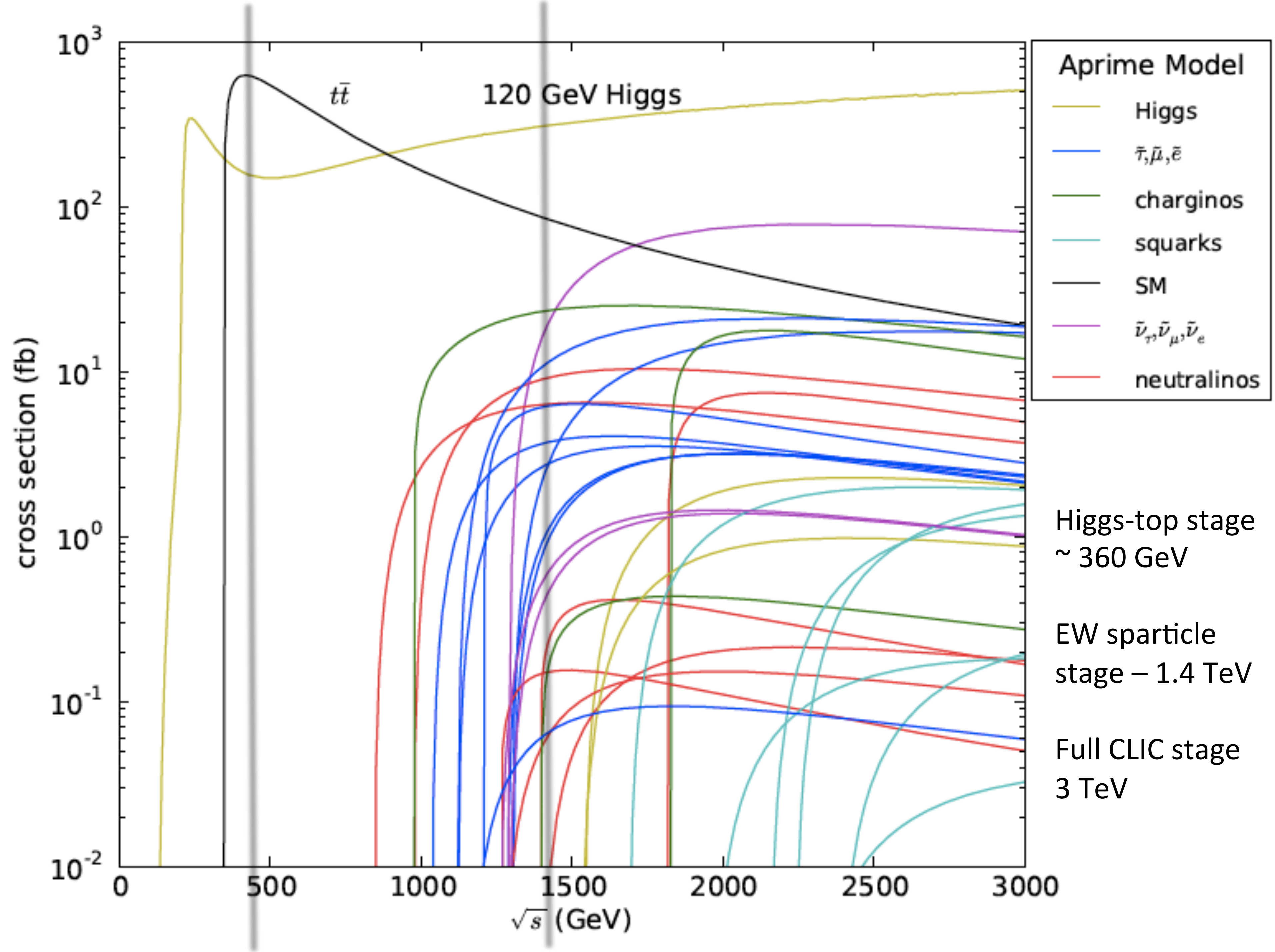
$$\Omega_{\rm DM} h^2 = 0.110$$

$$\sigma_{\rm SI}(\text{nucleon}, \tilde{N}_1) = 7.4 \times 10^{-10}\,\text{pb}$$

$$\Delta(g-2)_\mu = 6.35 \times 10^{-10}$$

$$\text{BR}(B_s \to \mu^+\mu^-) = 4.0 \times 10^{-9}$$

$$\text{BR}(b \to s\gamma) = 3.26 \times 10^{-4}$$



Aprime Model
Higgs
$\tilde{\tau},\tilde{\mu},\tilde{e}$
charginos
squarks
SM
$\tilde{\nu}_\tau,\tilde{\nu}_\mu,\tilde{\nu}_e$
neutralinos
$t\bar{t}$
120 GeV Higgs
cross section (fb)
$\sqrt{s}$ (GeV)
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0
500
1000
1500
2000
2500
3000
Higgs-top stage
~ 360 GeV
EW sparticle
stage – 1.4 TeV
Full CLIC stage
3 TeV

Conclusions

Positive discoveries at LHC are critical to how we pursue e+e- collider options.

In the very near future we will have difficult questions to address:

- Do we want to pursue just a Higgs and top factory now?
- Do we want to wait for ability to expand significantly in center of mass energy?
- Will the e+e- technologies advocated be ready for the timeline we will envision?
- When/where does HL-LHC, HE-LHC, eLHC and muon collider options fit into the planning path?

CLIC/ILC are excellent future collider options for many possible future LHC results that are still allowed by current results.