Physics at CLIC and other future colliders

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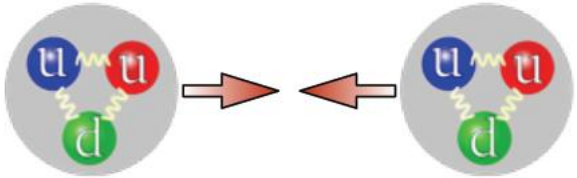
Reminder: presently and recently

- LHC (7-13 TeV):
  discovery of the Higgs boson
- Tevatron (2 TeV):
  discovery of the Top quark
- LEP (88-209 GeV):
  hyper-precise electroweak measurements
- B-factories (10 GeV):
  hyper-precise flavour physics

Choice of collider type



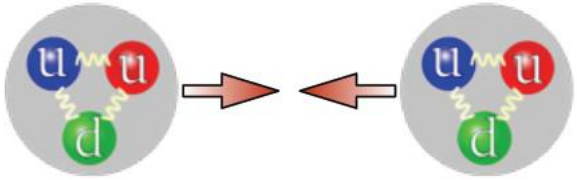
- e^+e^- collisions
- Point-like particles
- Total annihilation: initial state known
- Decent background
- Limited in energy, but – precision!

- pp(bar) collisions
- Composite particles
- Random energy of the hard interaction
- High background
- Highest energy frontier – discovery!

Choice of e^+e^- collider scheme

- e^+e^- circular colliders are limited in energy by the synchrotron radiation due to the beam curvature
- Either you build a tunnel of enormous size…
- Or you build a linear collider with enormous acceleration gradient
- Linear collider: advantage in energy
- Circular collider: re-use for a next pp-collider

Future collider candidates



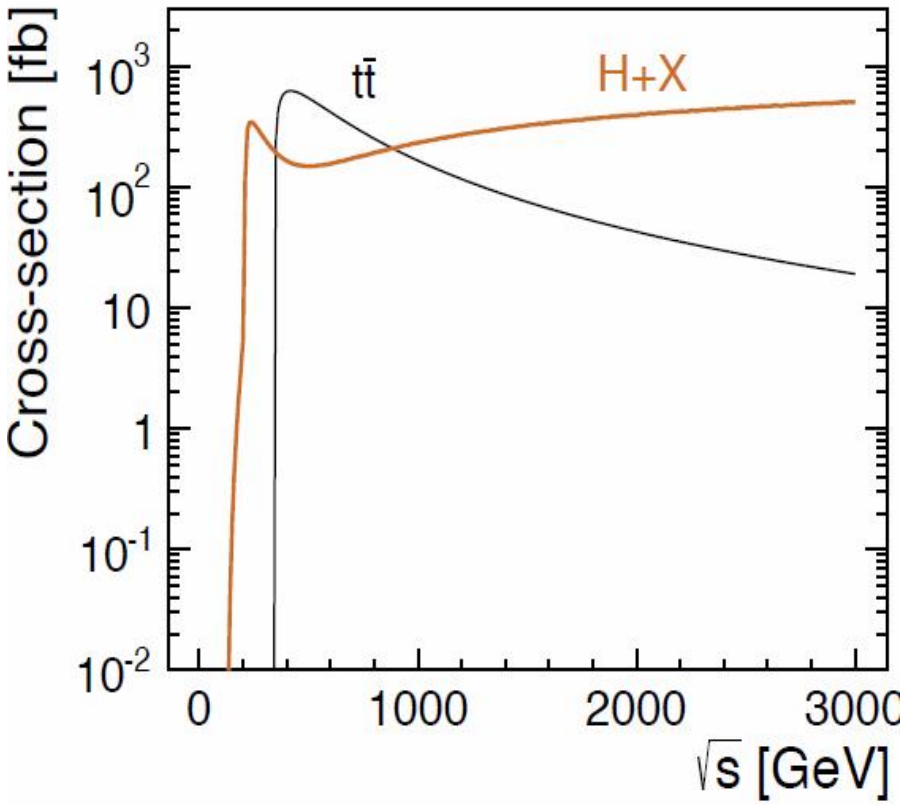
- CEPC: 70 km, 250 GeV, Higgs physics
- FCC: 100 km, 350 GeV, Higgs + Top
- ILC: 30 km, 500-1000 GeV, Higgs, Top, discoveries
- CLIC: 50 km, 3000 GeV, Higgs, Top, discoveries

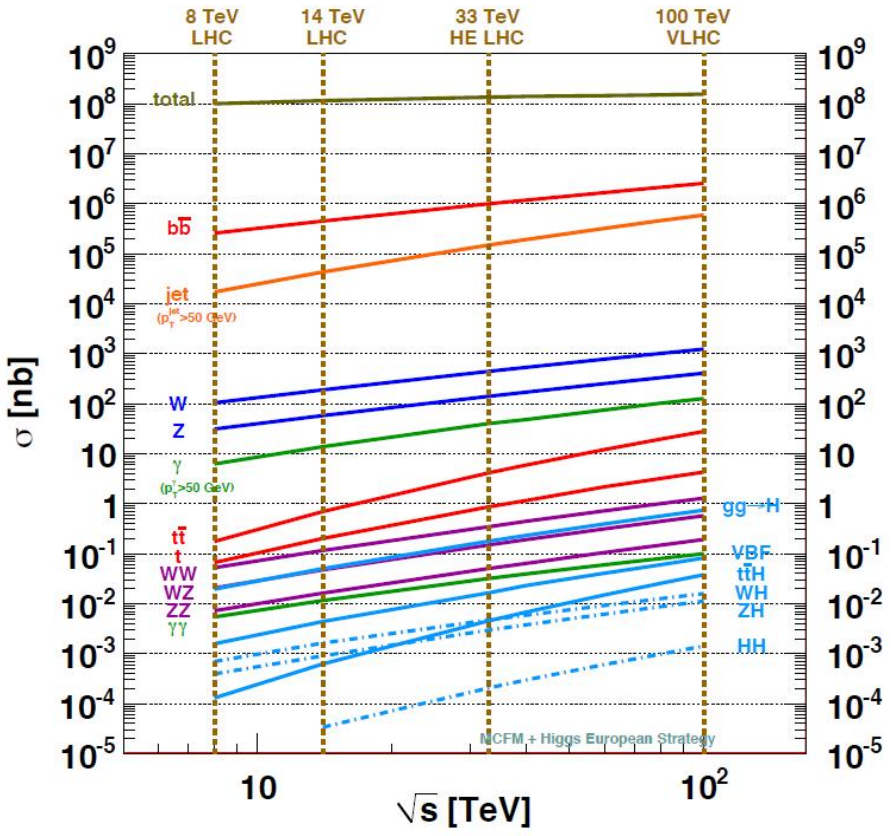
- HL LHC: 14 TeV, 3 ab^{-1}
- HE-LHC: 33 TeV, 2 ab^{-1}
- CEPC: 70 TeV, 10 ab^{-1}
- FCC: 100 TeV, 5 ab^{-1}

Physics at the high-energy frontier

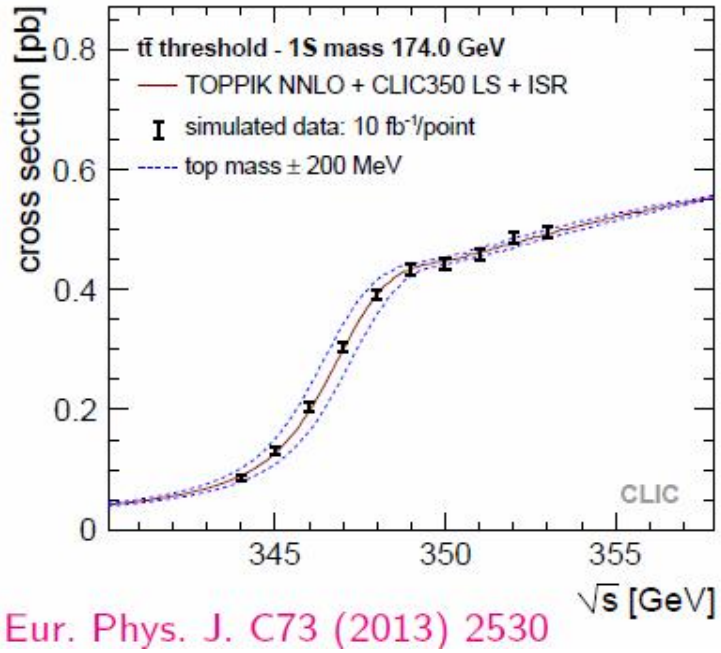
- Top quark physics
- Higgs boson physics
- Searches for the new physics
  - Supersymmetry
  - New gauge bosons
  - Extended Higgs sector
  - WIMP, Dark matter
  - Many others

“Old physics” at ee and pp colliders





Top physics: e^+e^- threshold scan



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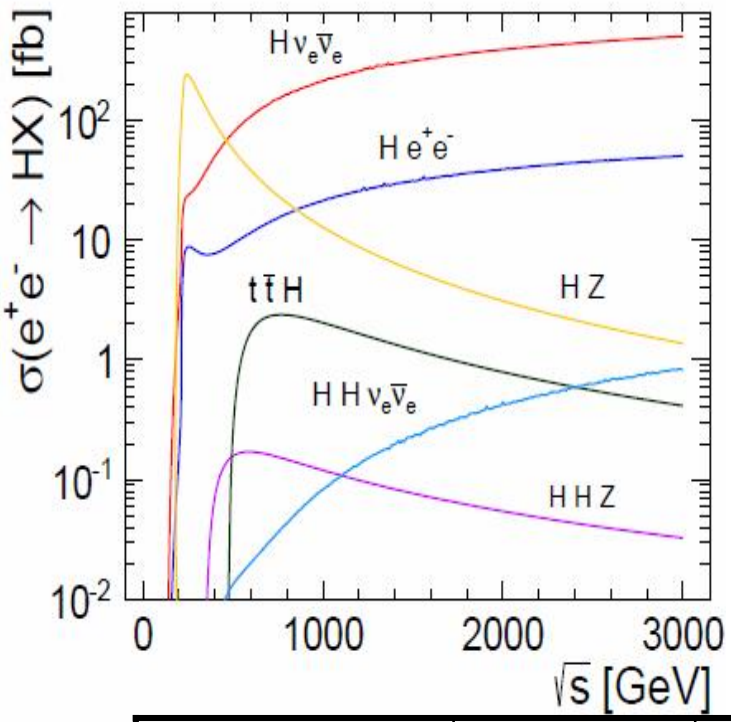
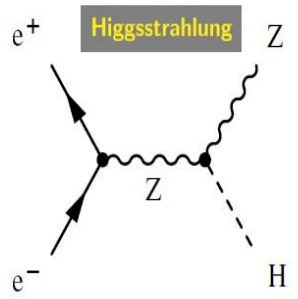
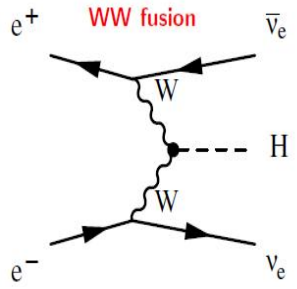
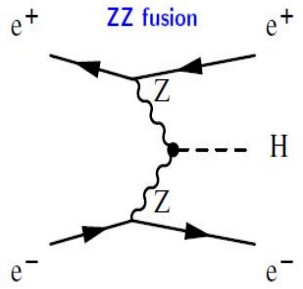
- Collision energy scans the threshold near E=350 ГэВ
- Sufficient to take 10 points with 10 fb^{-1} each
- Statistical precision $\Delta m_t = \pm 33$MeV (CLIC)
- Systematics dominated by beam energy determination
- Current world average: $\Delta m_t = \pm 760$MeV

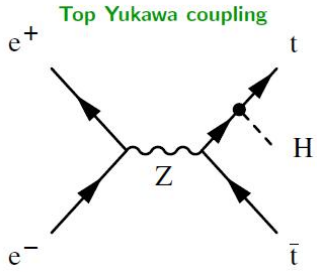
Higgs production at CLIC

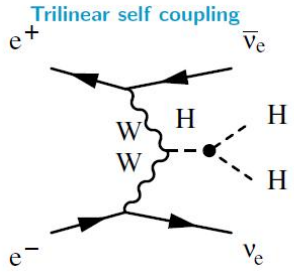


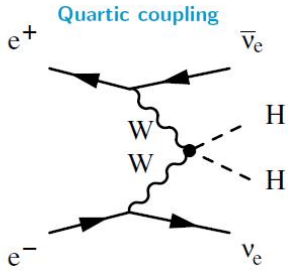






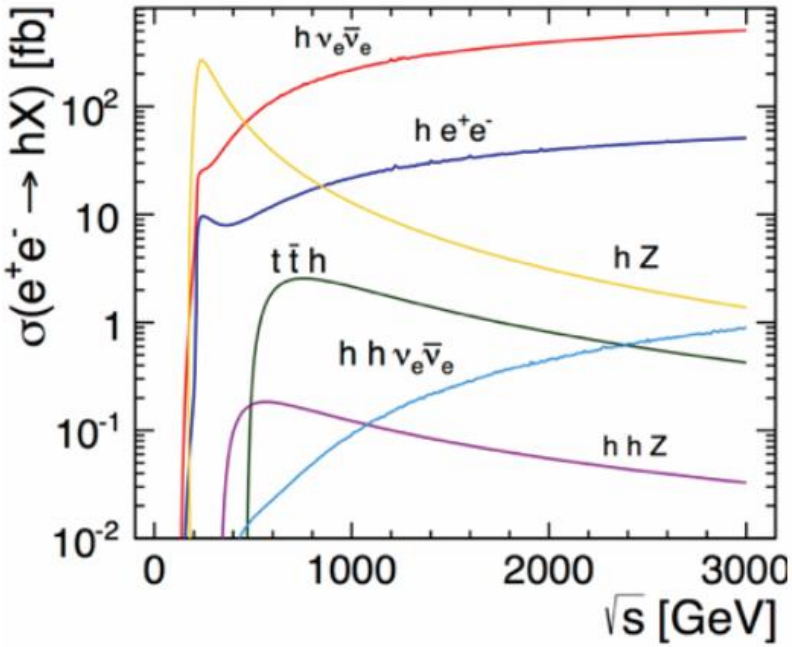


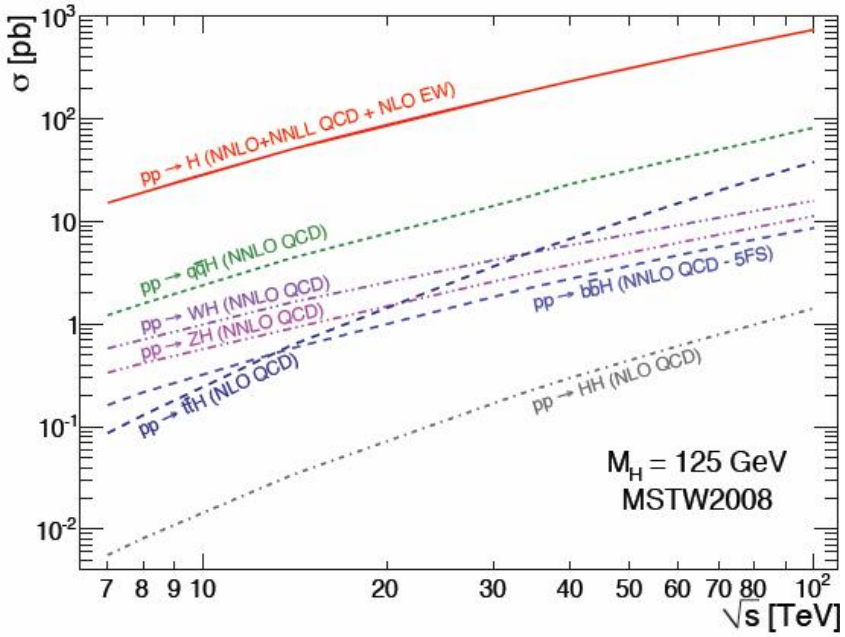




	ZH	Hνν	Hee	ttH	HHνν
350 GeV (500 fb^{-1})	68K	17K	3700	-	-
3 TeV (2000 fb^{-1})	11K	830K	84K	1400	1200

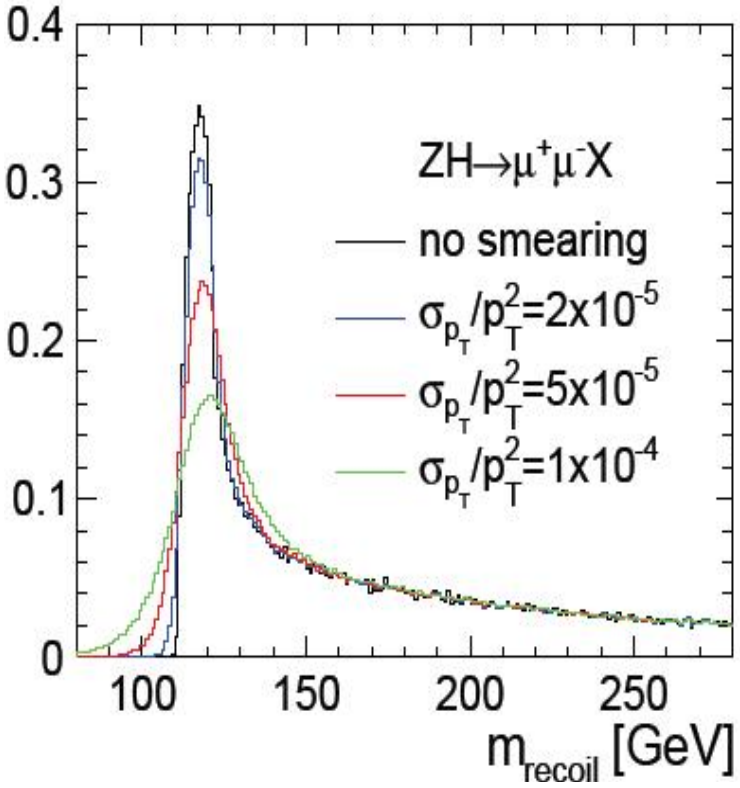
Higgs production in ee and pp





Production at e^+e^- is 3 orders of magnitude lower
But: consider efficiency and precision!

“Golden channel” for precision Higgs physics



- $e^+e^- \to HZ$, $Z \to \mu\mu$, $H \to$ anything
- Higgs ***predicted*** as a recoiling M=125 GeV
- We know that a Higgs was produced for sure, 4-momentum known
- Can directly measure any decay channel – even invisible (!!!)

Higgs measurements: ee vs pp

- The dominant Higgs decay $H \rightarrow bb$ (58%) still undiscovered at LHC
- The best seen at LHC is $H \rightarrow \gamma\gamma$ (0.2%)
- ee collider allows the measurements of all channels – huge advantage over pp
- Relative precision at CLIC:
  1% ($H \rightarrow bb$), 3% ($H \rightarrow gg$), 4% ($H \rightarrow cc$)

Importance of precision branchings

Expected maximal deviations

With assumptions from before:

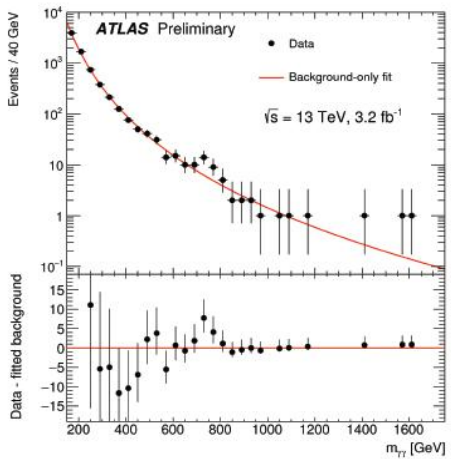
	$\lvert\Delta hVV\rvert$	$\lvert\Delta h\bar{t}t\rvert$	$\lvert\Delta h\bar{b}b\rvert$	$\lvert\Delta hhh\rvert$
Mixed-in Singlet	6%	6%	6%	18%
Composite Higgs	8%	tens of %	tens of %	tens of %
MSSM	$< 1\%$	3%	10%, 100%	2%, 15%

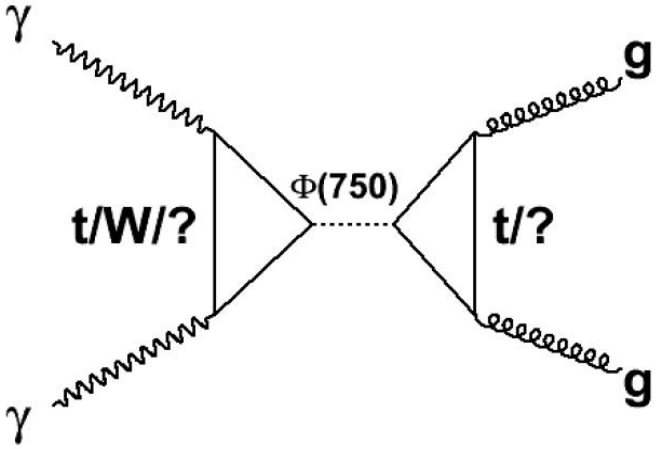
$\tan\beta > 20$ no superpartners

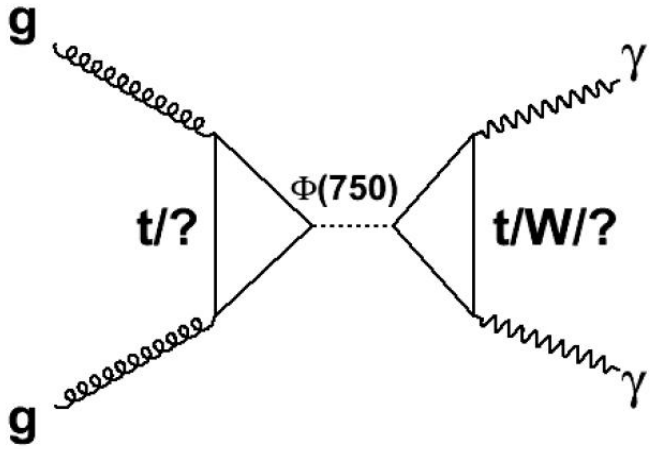
all other cases

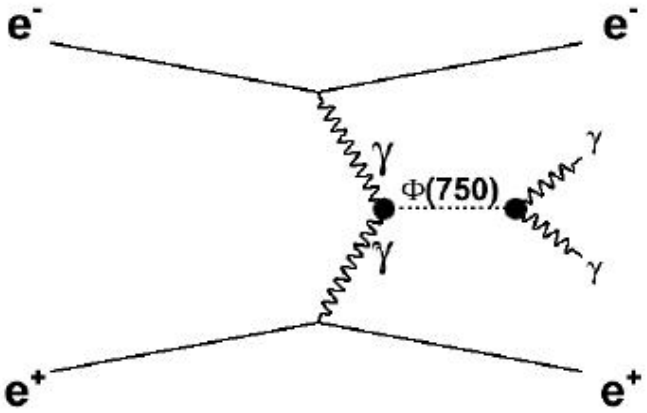
BSM physics

Difoton resonance @750 GeV

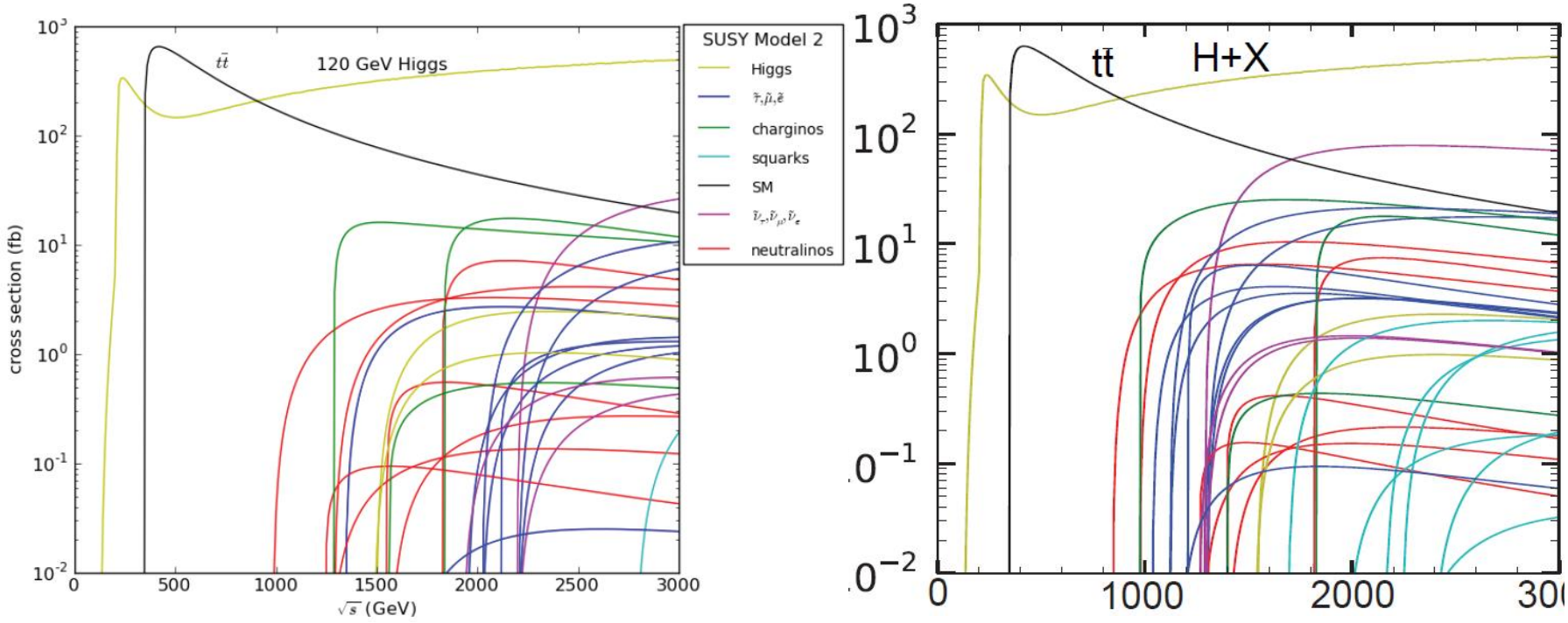




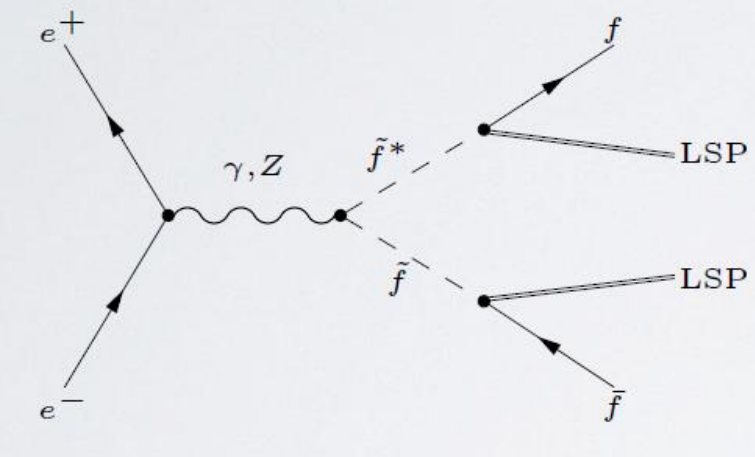


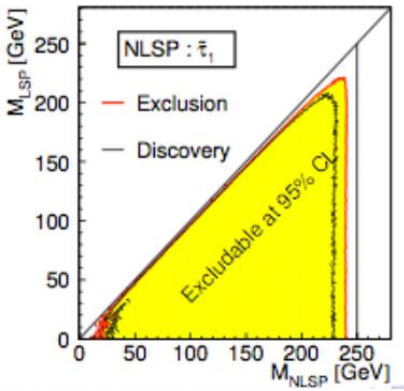


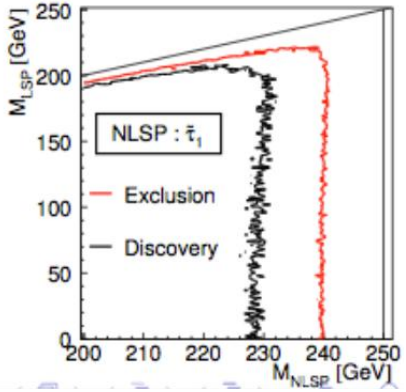
Supersymmetry



LSP/NLSP at ee collider: "nearly model-independent search"

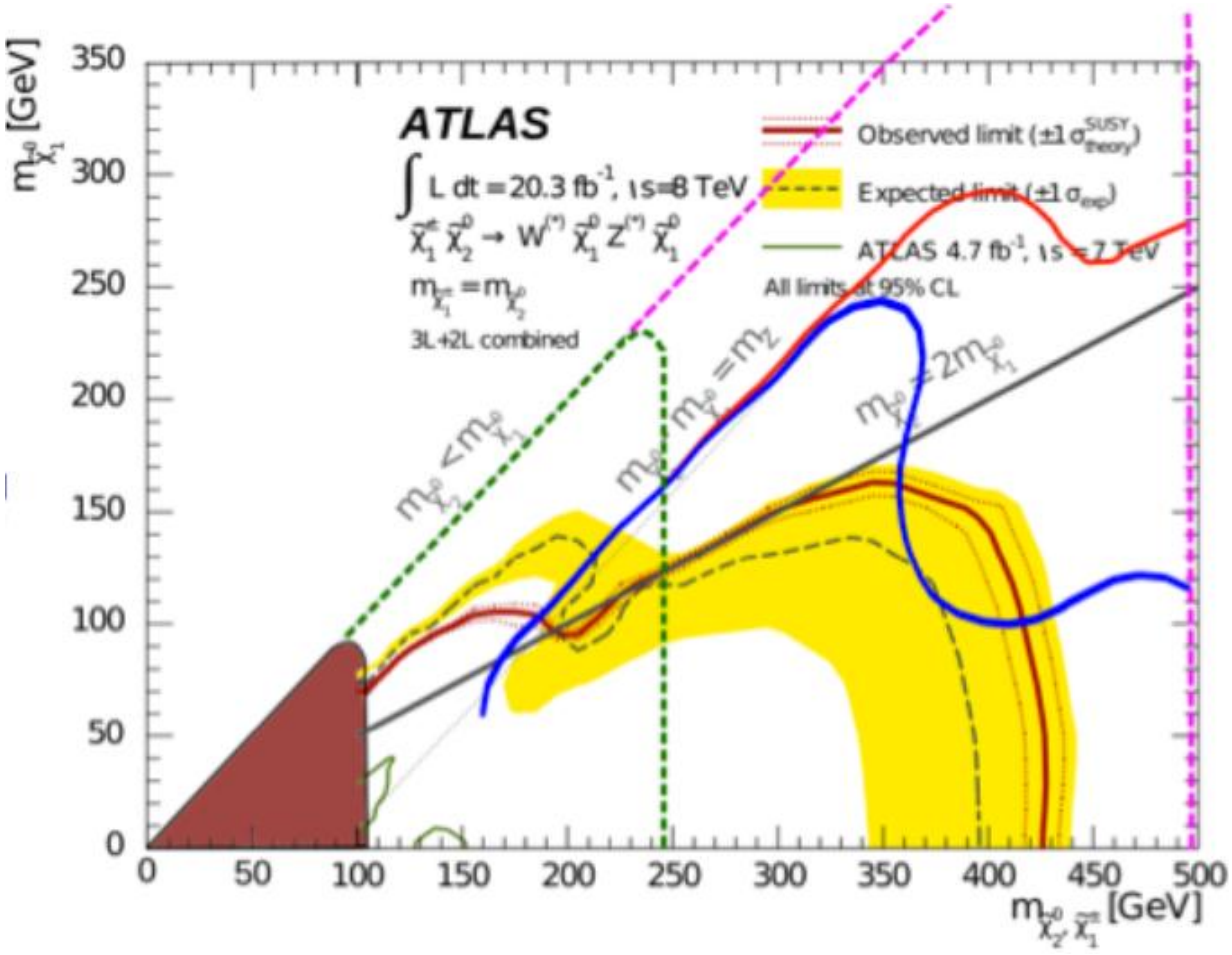




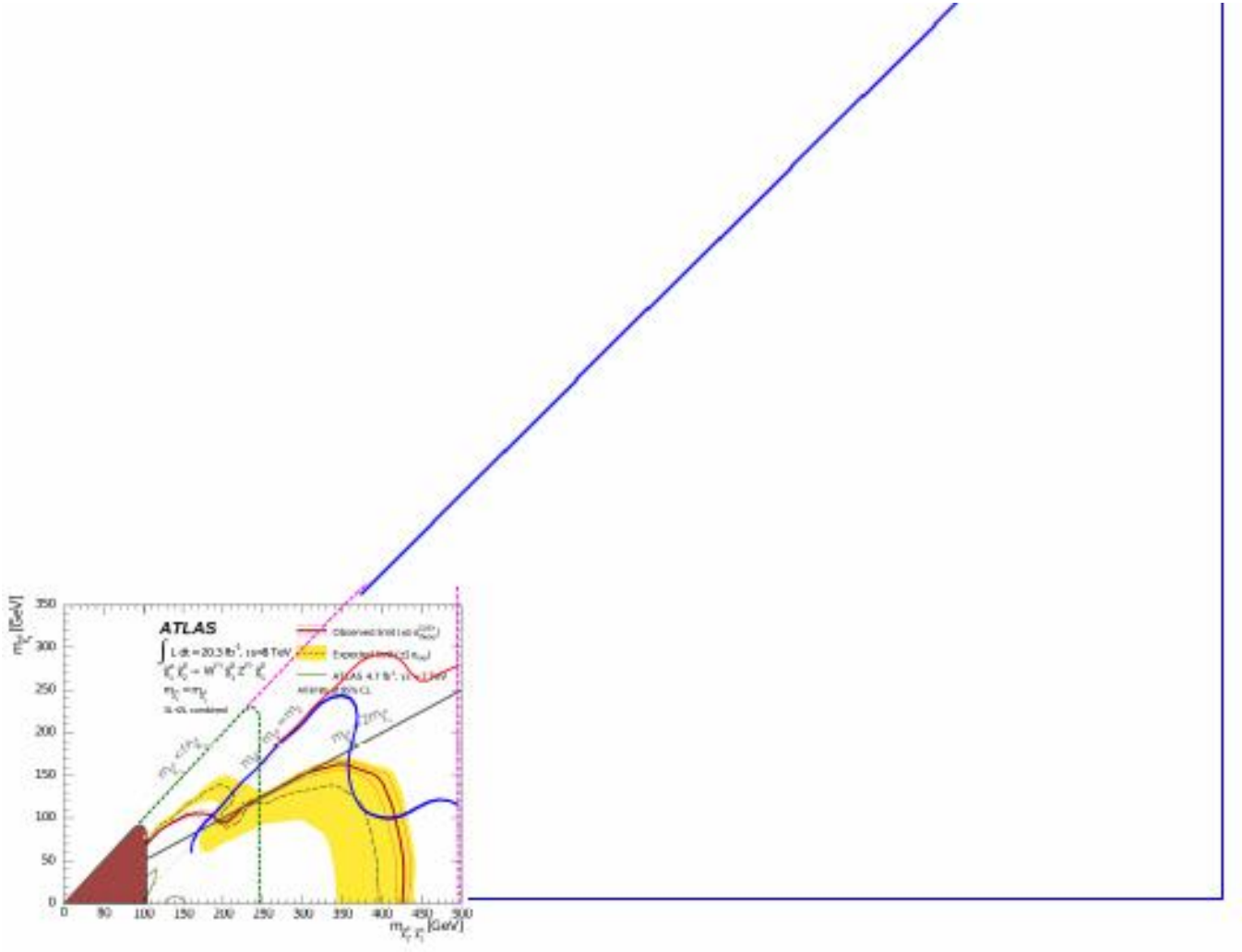


- Only postulated is the existence of an EW interaction of LSP/NLSP with Z/γ
- Look for ee→ ff with missing mass and energy
- Discovery limits are nearly at the kinematical boundary

LSP/NLSP: ILC vs LHC

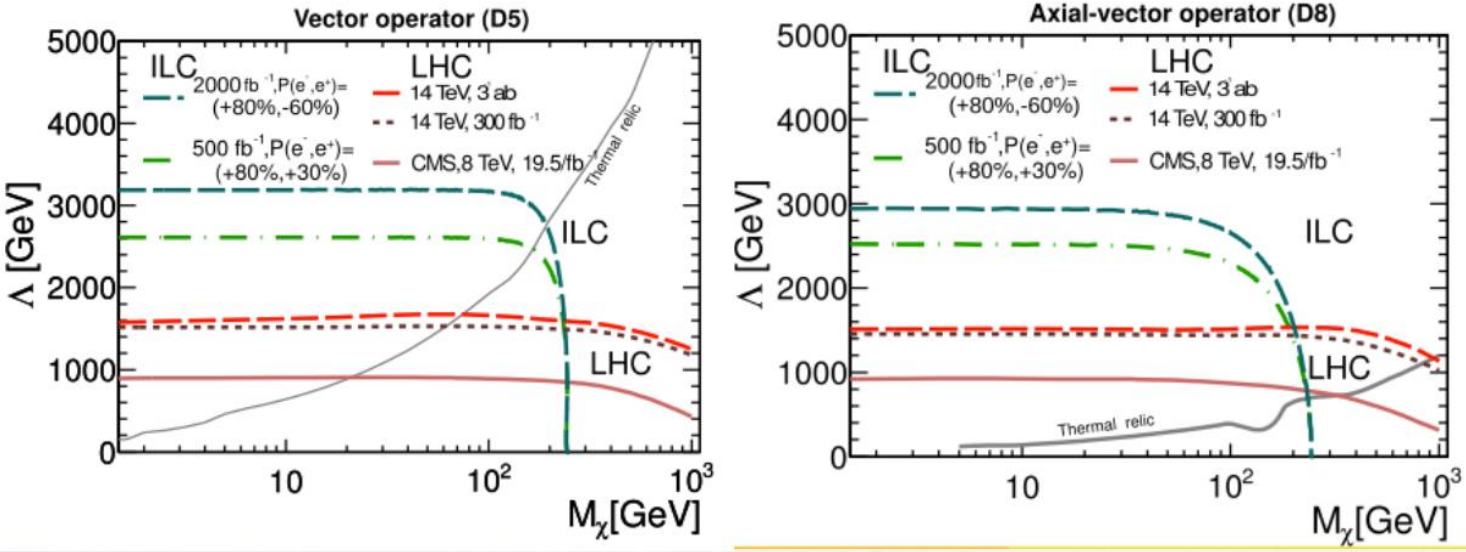


LSP/NLSP: CLIC vs LHC



Search for WIMP/Dark matter

- Look for 1-gamma events ee→γXX (X invisible)
- Similar to measurement of number of ν generations
- In terms of cross-section, ee few times better than LHC
- In terms of mass, ee sensitivity up to the kinematic limit



Summary

- There are many future collider projects on the market, both ee and pp
- ee collider make emphasis on precision measurements, pp are more discovery-oriented
- Thank to its 3 TeV energy, CLIC project combines both precision and discovery potential