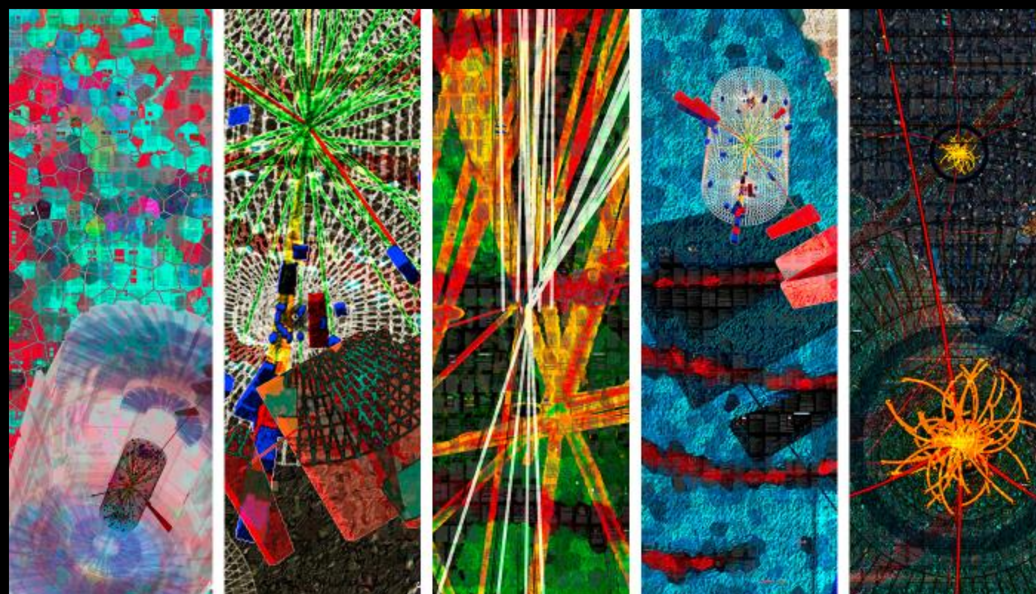
Highlights from New Physics Group Report



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Markus Luty (UC Davis)

Yuri Gershtein (Rutgers)

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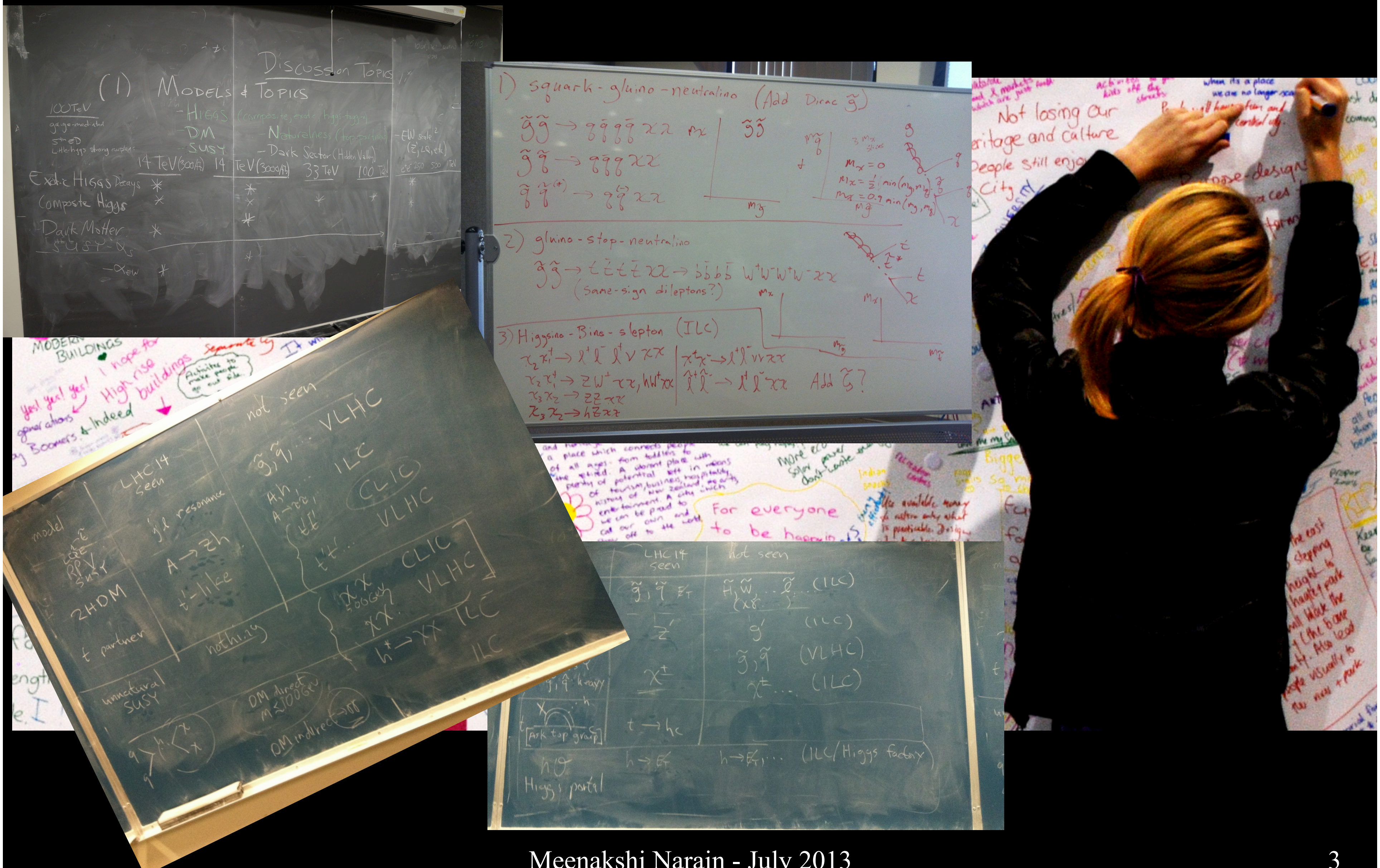
Daniel Whiteson (UC Irvine)

Report and whitepapers

- Link to NP report (working version)
- http://www.snowmass2013.org/tiki-download_file.php?fileId=271

- Links to whitepapers (abstracts, drafts, etc..)
- http://www.snowmass2013.org/tiki-index.php?page=BSM+Whitepapers

developing the stories..... the future...



“The Stories”

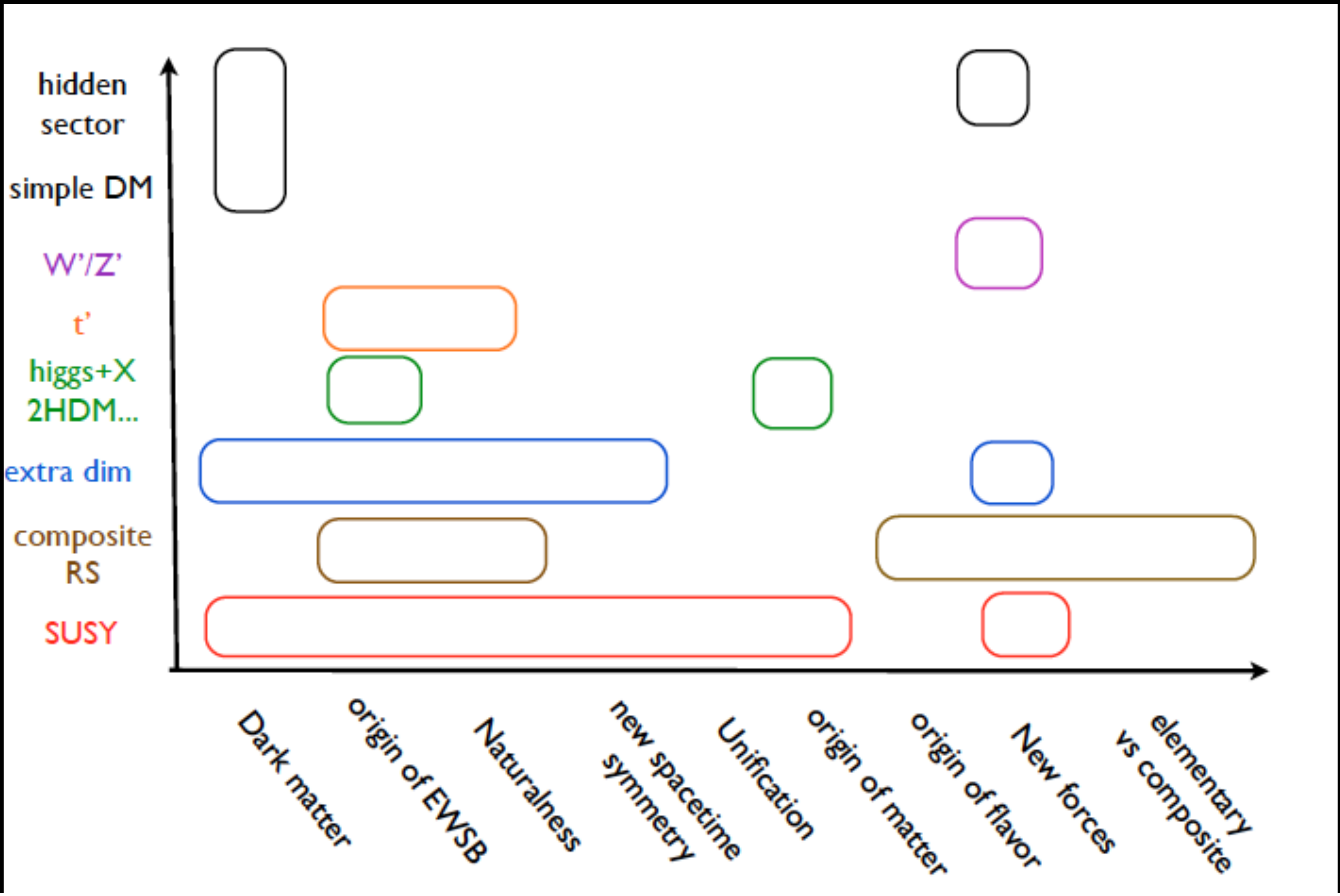
- Many indications that there is new physics to be discovered in searches at the energy frontier and discussed in the many white papers

- In the report, we illustrate possible scenarios and develop a comprehensive picture which motivates various facilities
  - The `discovery stories' rely heavily on the white papers

- To highlight the impact of such a discovery and the possibilities for further study, we consider
  - in each case a particular model where a discovery can be made at LHC Run 2 (14 TeV with a luminosity of 300/fb).
  - In each case, such a discovery suggests one or more natural candidate models that can be studied in more detail at future experimental facilities.

The Stories

- Cover Big Questions and ideas:



The Stories:

If you see __________ at LHC14,
what can you learn at potential future facilities?

1. Simple SUSY
2. SUSY with a light stop
3. Excess of leptons+missing ET events
4. R-Parity violating SUSY
5. “Only” the Standard Model
6. Dark Matter
7. Heavy Resonances Z’
8. Multiple Higgs Bosons (with Higgs WG)
9. Heavy quarks (with Top WG)
10. Quark or lepton compositeness

The Stories:

If you see _________ at LHC14,
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1. Simple SUSY
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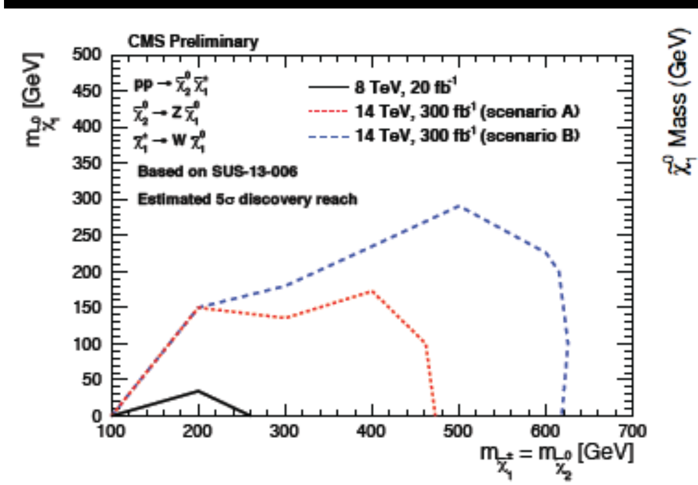
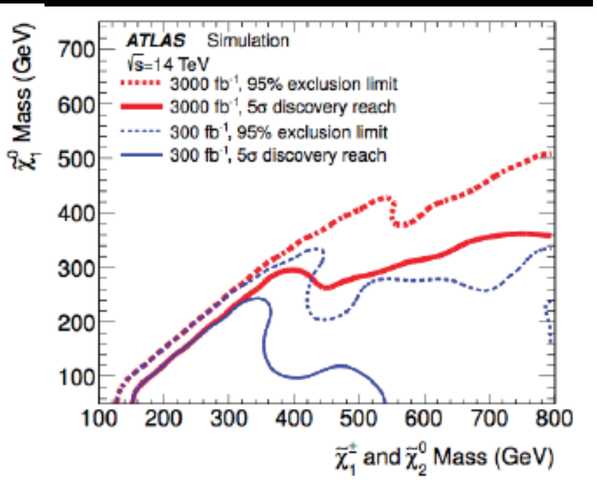
Conclusions:

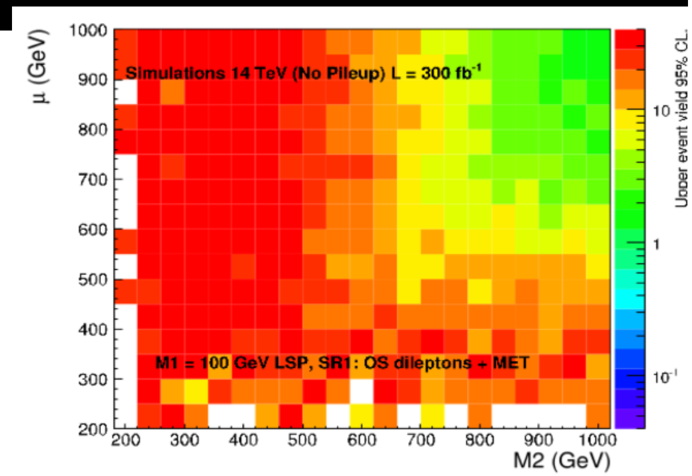
- Searches and possible discovery at the LHC Run2
- After Discovery:
  - Model independent determination require high statistics (HL-LHC).
  - Lepton colliders important for further exploration e.g. measurement of properties
  - understanding the full spectrum needs higher energies (VLHC)

1+3. Simple SUSY

- In most SUSY models, the colored superpartners (gluino and squarks) are significantly heavier than the lightest supersymmetric particle (LSP)
  - LSP which is stable and appears in the detector as missing energy.
- Simplified analyses based on missing energy signatures show that LHC run 2 will extend the reach in searches for superpartners
  - chargino $\chi\pm$ reach: ~500-600 GeV, neutralino χ^0: ~650 GeV.
- Electro-weakino search w/ several analysis to probe higgs in the final state: Possibility to “rule out naturalness” with μ ~700 GeV ONLY using 300 fb^{-1}
- Probes SUSY weak-sector in the most general way



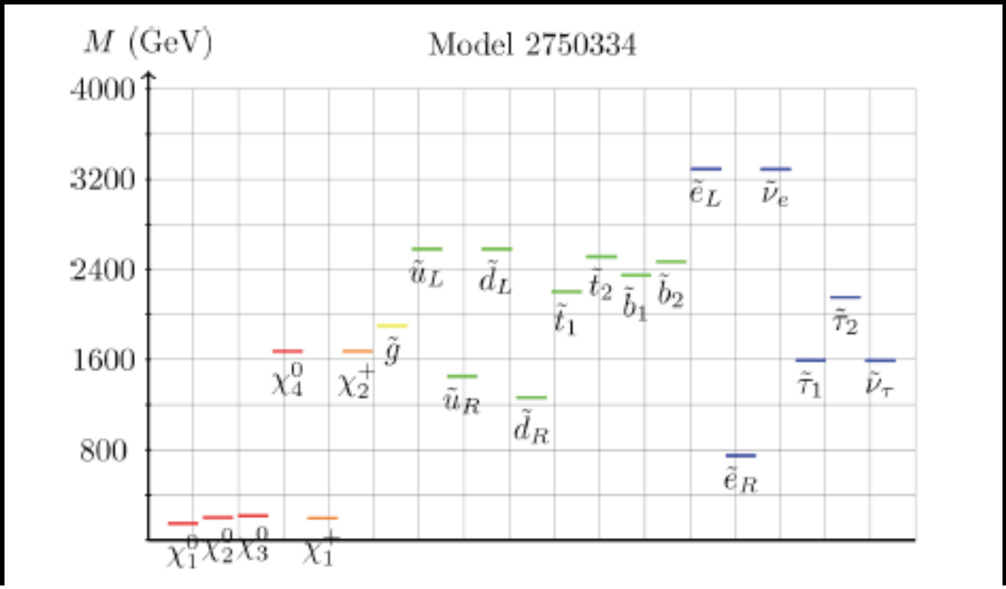




S. Padhi, T. Han, S. Su, J. List
M. Berggren, T. Tanabe

1+3. Simple SUSY

- Potential discovery Scenario
- illustrated by model 2750334 of the `pMSSM'
  - light neutralinos and charginos clustered around 200 GeV, the lightest neutralino is a mixture of bino and Higgsino and a viable dark matter candidate. Mass of lightest squark ~1.3 TeV
- e.g. LHC14 run1 discovers new physics in the jets plus MET channel with high significance and no other signal of new physics is observed.
- SUSY as the leading interpretation of the signal explored further:
  - mass diff between the colored particle and the stable neutral particle (MT2?).
  - Difficult to get more information about the spectrum.
  - Rate difficult to interpret due to an unknown number of similar states, & multiple decays.



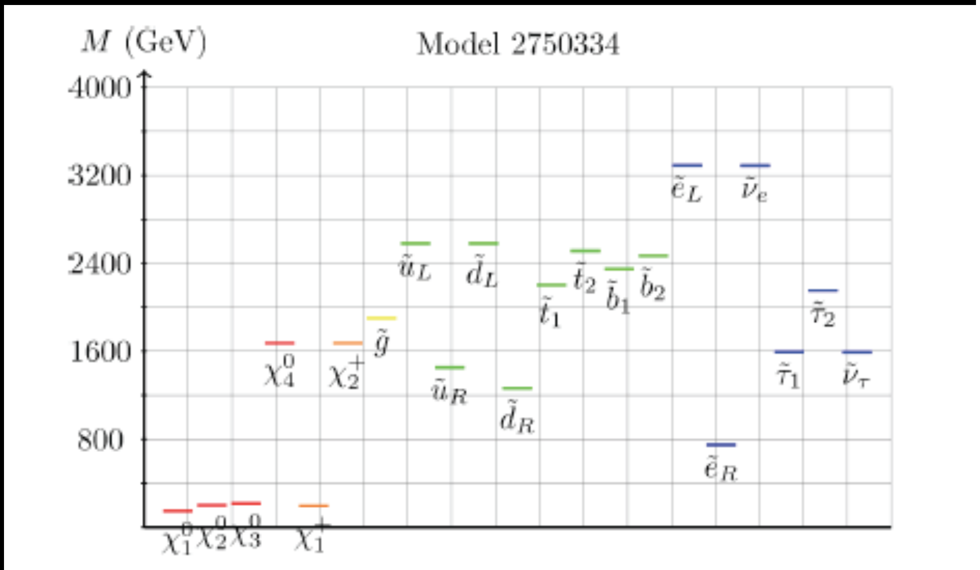
M. Cahill-Rowley, J. Hewett,
A. Ismail, and T. Rizzo (SLAC)

1+3. Simple SUSY

- Other possibilities:
  - universal extra dimensions model have extra-dimensional excitations for all SM particles that give rise to similar signals.
- A lepton collider (500 GeV) would measure the masses and spins of the gauginos, as well as the branching fractions in their transitions.
- If sleptons are not found at the 500 GeV ILC, it would suggest that the sleptons are not important for the thermal relic density of the LSP.
  - SUSY is established and the sleptons are the last major missing piece of the puzzle.

An ILC upgrade, or CLIC or
a muon collider would be strongly
motivated to search for these.

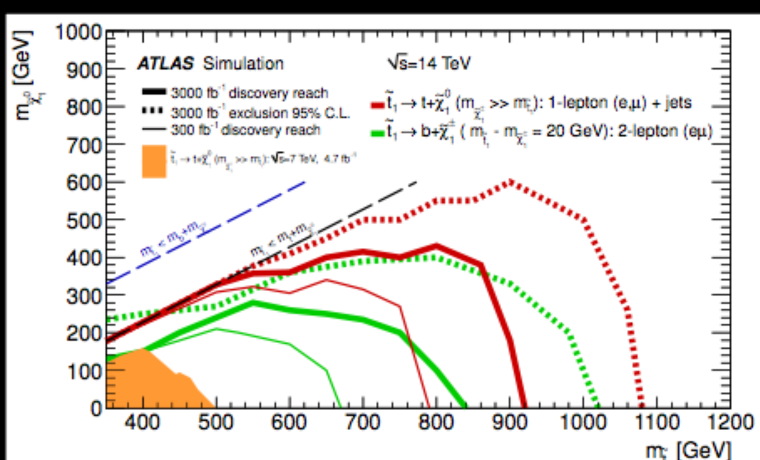
To observe higher mass colored
super partners: need LHC33 or VLHC

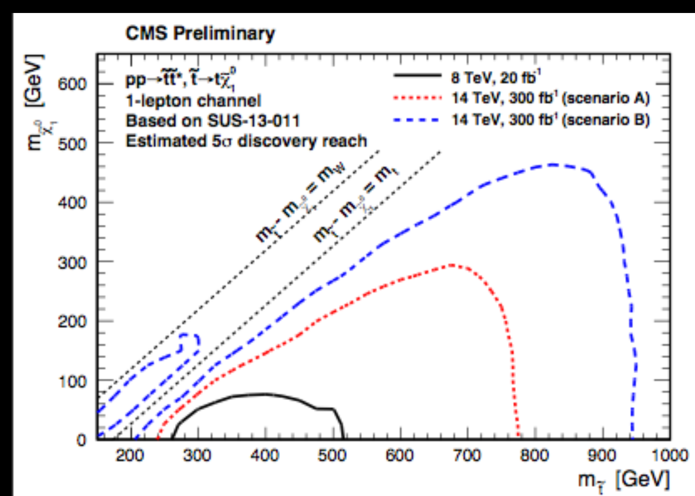


2. SUSY: Light stop

- Light stop: crucial piece in testing naturalness.
- Example: 800 GeV Stop.
  - LHC Run 2: 40 signal evt, 3.1 σ
  - At least 5 σ at HL-LHC
  - Reach scales up at higher energy pp colliders.

- Will be a spectacular success for SUSY, naturalness.
- Many more to explore, more superpartners to discover.
- MET, discovery of dark matter at the same time!

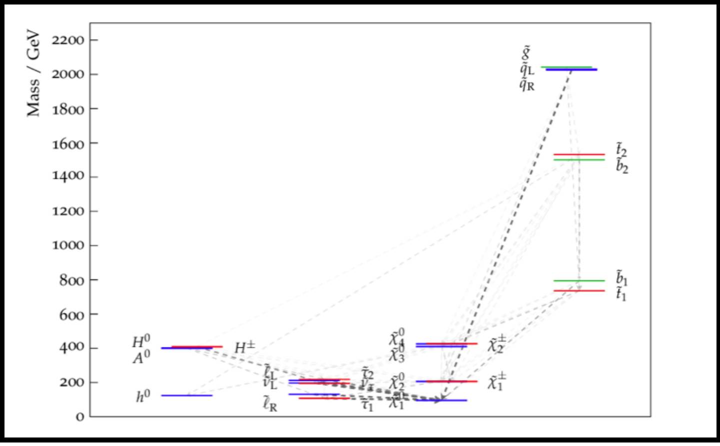


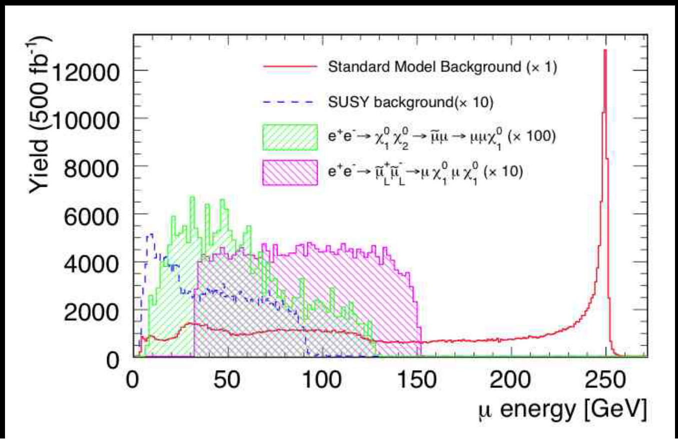


ATLAS, CMS whitepaper

2. SUSY: Light stop

- After Discovery: understanding the light stop
- Want to measure its mass, spin, mixing angles
  - Initial estimate from production rate with model assumptions.
  - Model independent determination require high statistics (HL-LHC).
- stop-Higgs coupling: The couple that ensures naturalness. Need VLHC.
- The rest of (natural) spectrum: light electroweak-inos , sleptons.
- Example: explored in the joint ILC-LHC study of the stau co-annihilation model.
  - neutralino in the model accounts for the observed amount of the Dark Matter in the Universe. The top squark in this model has multiple decay channels
  - HL-LHC has a chance to see soft leptons from the gaugino transitions in the cascades.
  - At 500 GeV ILC sleptons & lighter gauginos are accessible, and their mass and quantum numbers will be measured. Measuring tau polarization can get higgsino fraction of the lightest neutralino.





M. Berggren , A. Cakir ,
D. Kr¨ucker , J. List ,
A. Lobanov ,
B. I.-A. Melzer-Pellmann

4. RPV SUSY

Naturalness suggests light superpartners to be produced at the TeV scale

- natural values m(stop) and m(gluino) are ruled out by LHC run1

If R-parity is not conserved, then

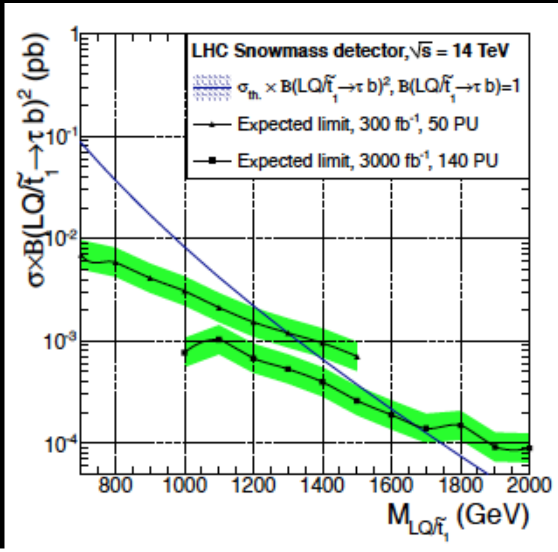
  - missing energy is no longer a generic signature of SUSY at colliders.
  - Dark matter would be explained by a particle other than the LSP.

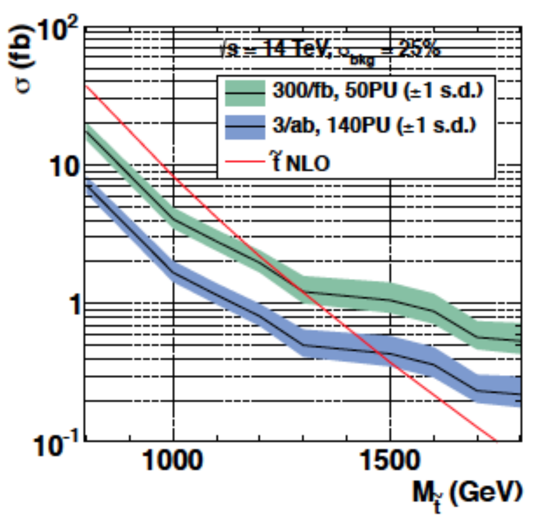
Case 1: stop as a 3rd generation lepton quark stop$\rightarrow\tau$+b

- LHC run2 reach: 3 sigma for stop masses up to 1.3 TeV.

Case 2: stop $\rightarrow$top+χ_0 & $\chi_0\rightarrow$jjj

- LHC run2 reach: 3 sigma for stop masses around 0.9 TeV.





Daniel Duggan, Jared Evans, James Hirschauer, Ketino Kaadze, Amit Lath, David Kolchmeyer, and Matthew Walker.

4. RPV SUSY

After Discovery:

- HL-LHC can increase the significance ~5 sigma and help disentangle plausible other interpretations
- e.g. for Case1,
  - double higgs decay hh$\rightarrow\tau\tau$bb. spin-1 third generation LQ etc.
- HL-LHC needed to probe SUSY interpretation in other ways (study associate channels)
  - looks for sbottoms, electroweakinos (lighter than stop), gluino pair production…

- Lepton colliders:
  - able to probe the electroweakino sector essentially without loopholes for and neutralino masses up to half the center of mass energy.
  - In this scenario, the 500 GeV ILC will probe a significant region of the parameter space
- Higher energy lepton colliders such as 1 TeV ILC, CLIC, or muon colliders will further extend the reach.
- Remaining colored superpartners can be explored only at LHC33 or a VLHC.

Stories:

If you see _________ at LHC14,
what can you learn at potential future facilities?

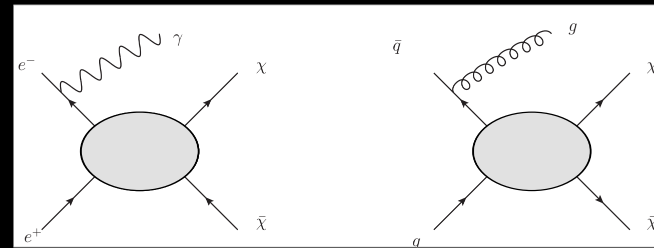
6. Dark Matter
7. Heavy Resonances Z’
8. Multiple Higgs Bosons (with Higgs WG)
9. Heavy quarks (with Top WG)
10. Quark or lepton compositeness

Conclusions:

- Searches and discovery at the LHC Run2 or HL-LHC or higher energy colliders
- After Discovery:
  - Property determination require high statistics
  - Lepton colliders are complementary to the LHC and necessary to resolve/understand different couplings and other properties

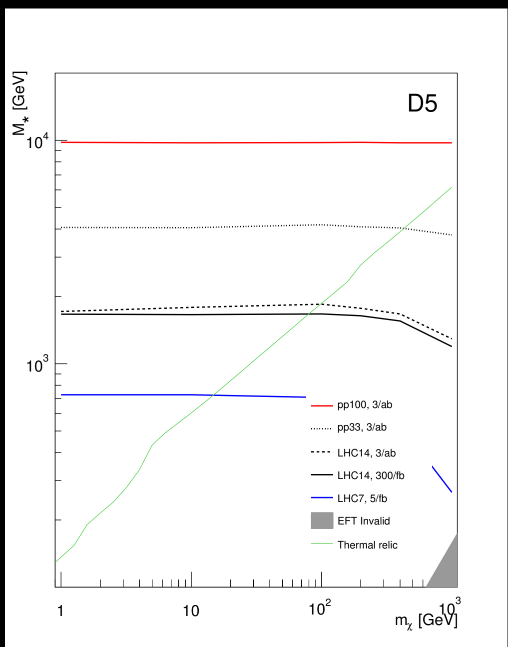
6. Dark Matter (WIMPs)

- Connection to Cosmic and Intensity Frontiers
- signature: jet+MET, photon+MET

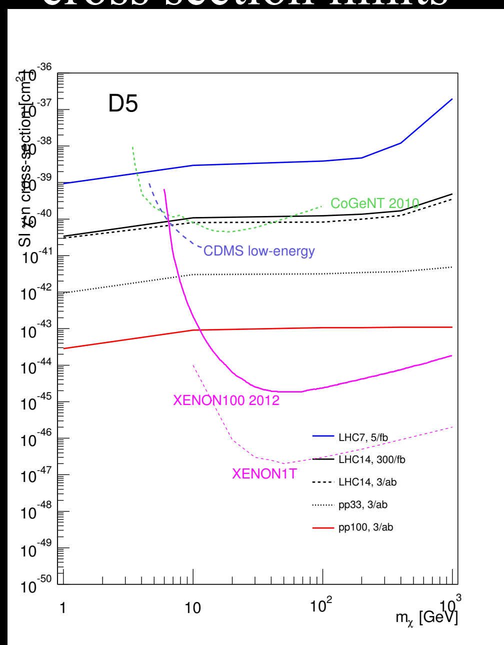


- Results for Effective Field Theories:
  - useful when facility does not have the necessary center-of-mass energy to produce on-shell mediators.

mass scale of the unknown interaction M_*

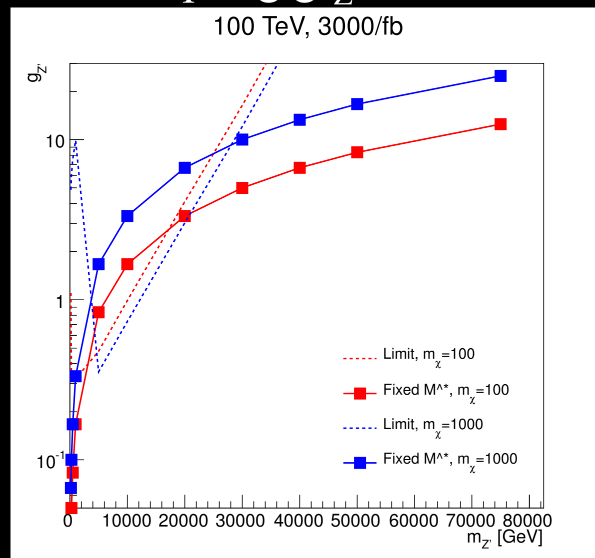


WIMP-nucleon cross section limits



Results for on-shell mediators: Z'

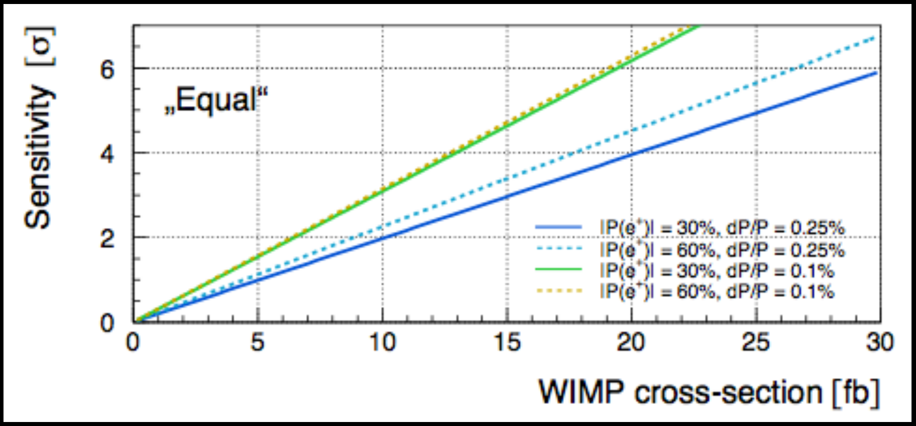
expected limits on coupling g'_Z

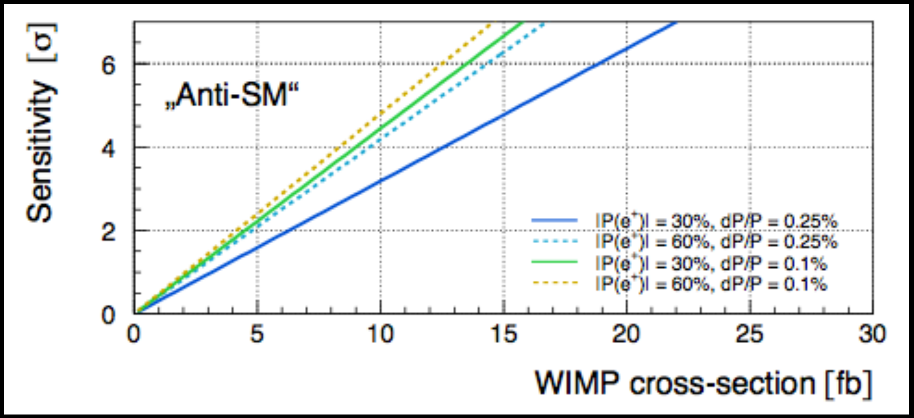


N. Zhou, D. Berge, T. Tait, L.-T. Wang, and D. Whiteson

6. WIMPs

- Lepton colliders:
  signatures: photon+missing energy
  advantages:
  - polarization of the initial state may be controlled
    - distinguish between the WIMP signal and the backgrounds, which may have distinct polarization-dependent couplings.
  - sensitivity to WIMP mass through its effect on the observed photon total energy
- Coupling Scenarios considered for the studies:
  - equal: couplings are independent of the helicity of the initial state,
  - helicity: couplings conserve helicity and parity, and
  - anti-SM: WIMPs couple only to right-handed electrons (left-handed positrons)
    - highest power to disentangle the SM backgrounds from WIMP production



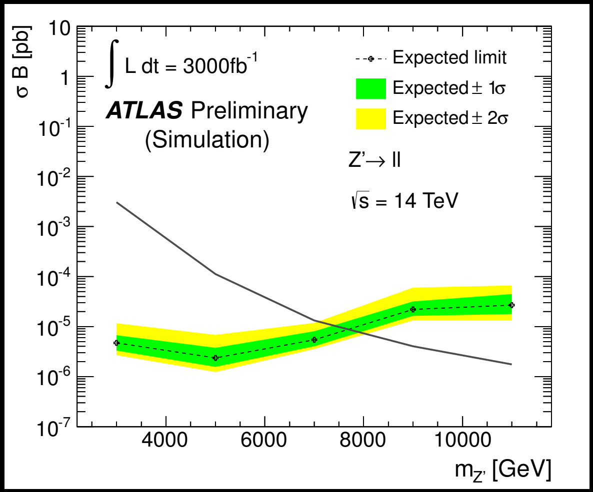


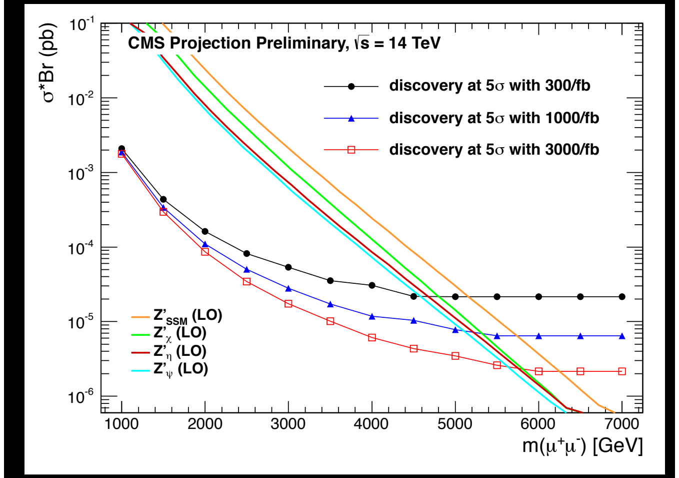
C. Bartels, M. Berggren, and J. List. arXiv:1206.6639 , 2012.

7. Heavy resonances (Z')

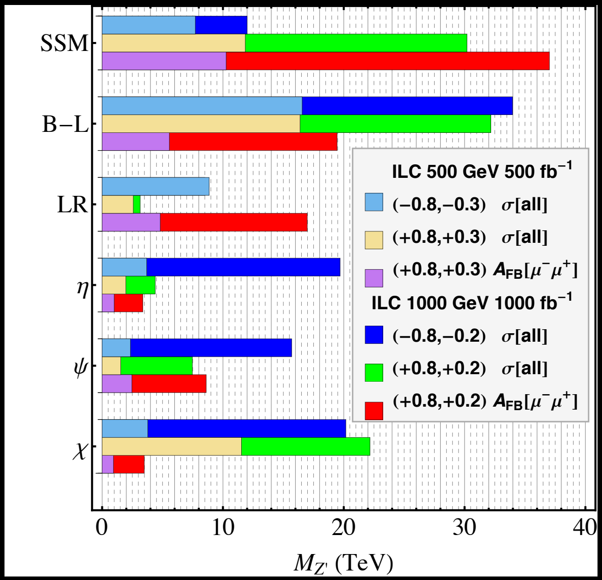
- Typical example of new force beyond the Standard Model.
- Common in many fundamental theories: string compactification, extra-dimension, GUTs…
- Hadron Colliders X → ll, jj, ttbar
  - LHC Run 2: ~5 TeV
- lepton colliders: X→di-muons

LHC Run 2 Sensitivity





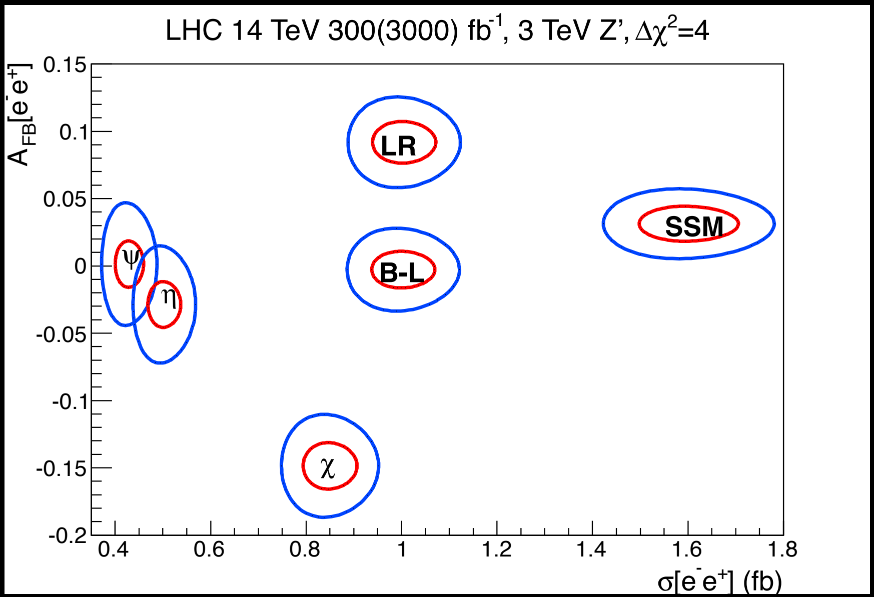
Lepton Colliders



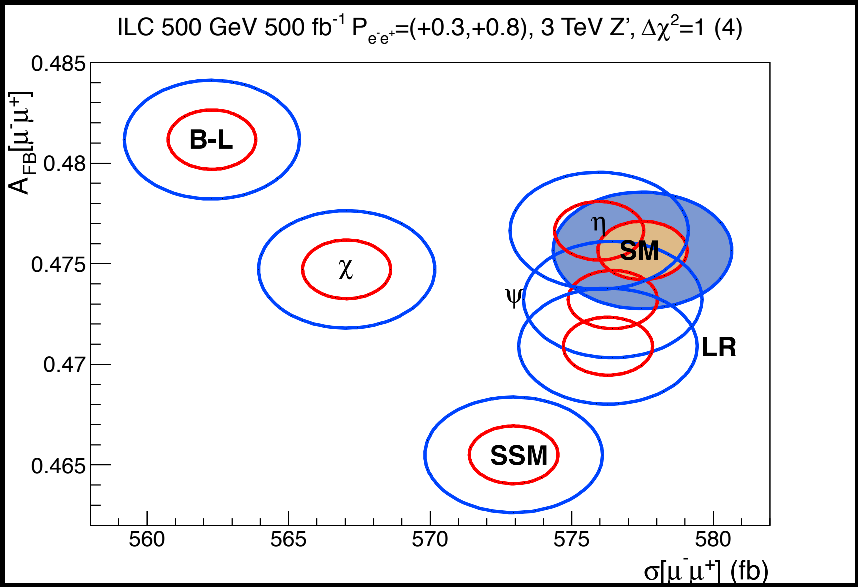
7. Heavy resonances

- After the discovery (e.g. Z'@3TeV)
- LHC and ILC can give complementary information.
  - combining the measurements can be very valuable in distinguishing different models.
- Discovery of **Z'** leads to many new implications which can lead to further searches at colliders.

LHC Run 2



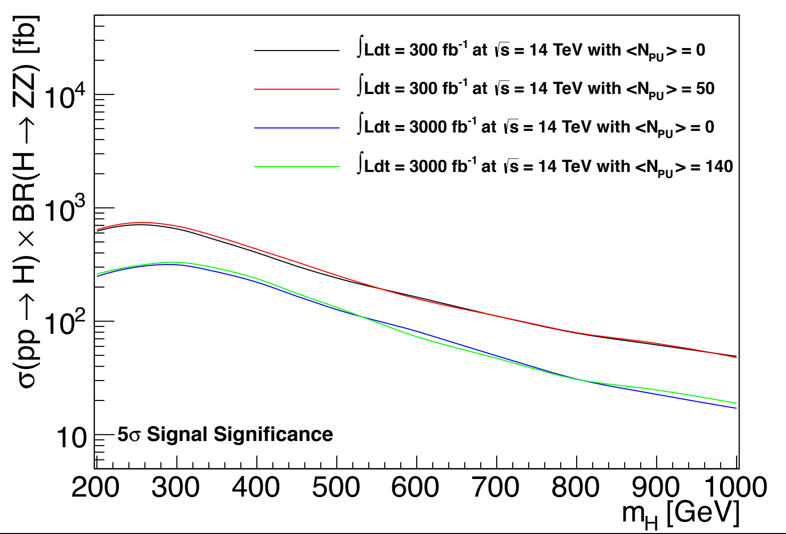
Lepton Colliders

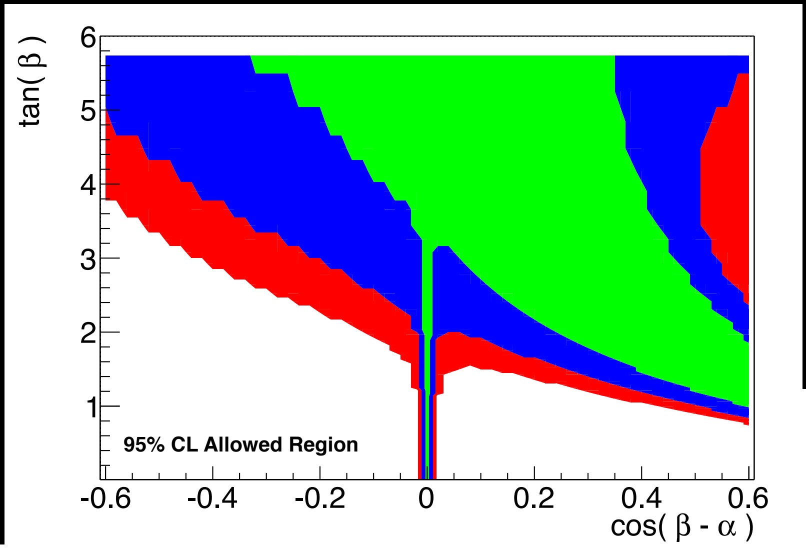


8. Multiple Higgs Bosons

- A strongly motivated scenario! Naturalness often implies extended Higgs sector.
- Two Higgs doublet models provide an effective description for many such EWSB extensions
- Two Higgs Doublet models are a complicated model-space
  – 3 important parameters: α, β, g_{Hhh} (Choose MSSM-like g_{Hhh} to simplify)
  – Cross section and branching ratios still complicated functions of α, β

- heavy neutral $H \to ZZ \to 4l$
- sensitivity for LHC14 and HL-LHC



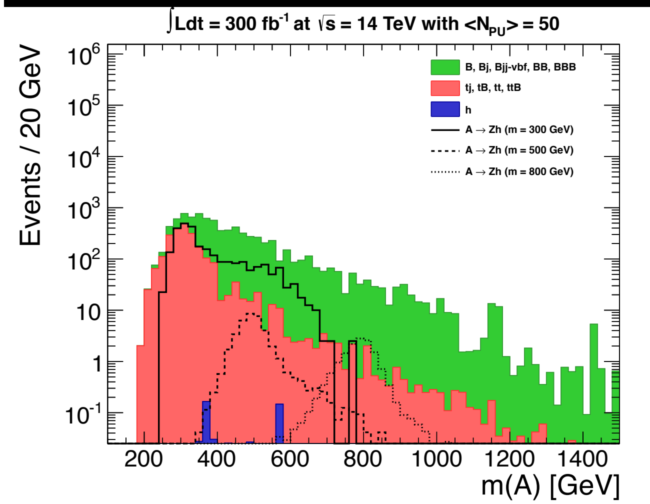


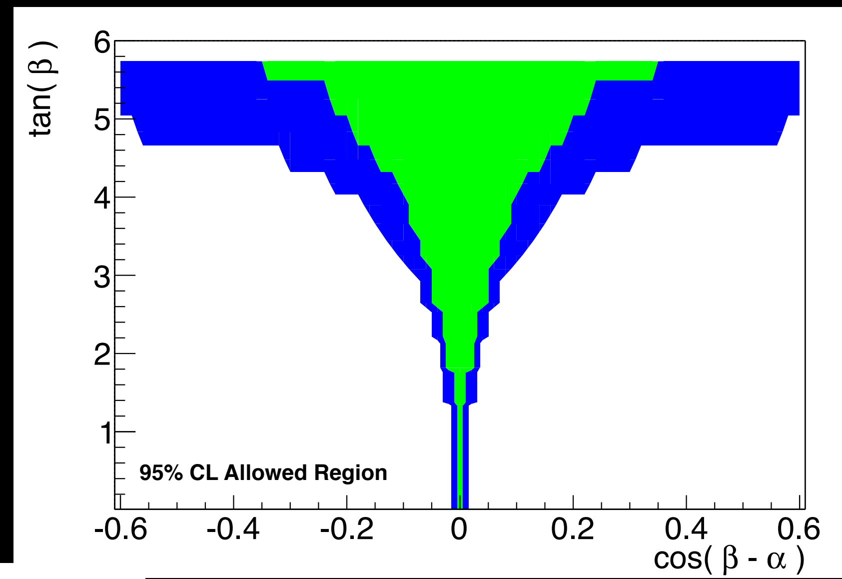
Blue: 300/fb w/ 50 PU
green 3000/fb w/ 140 PU
red: existing limit.

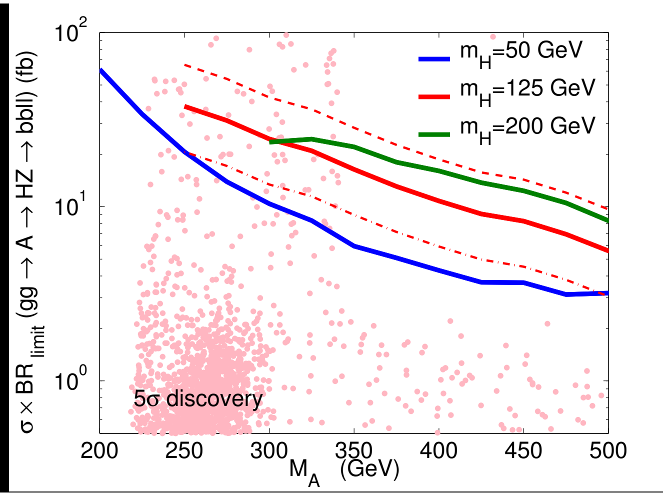
Eric Brownson, N. Craig, U. Heintz, M. Narain, and John Stupak III

8. Multiple Higgs Bosons

- 2HDM results: A $\rightarrow$ZH $\rightarrow$llbb/$\tau\tau$
- LHC14 reach







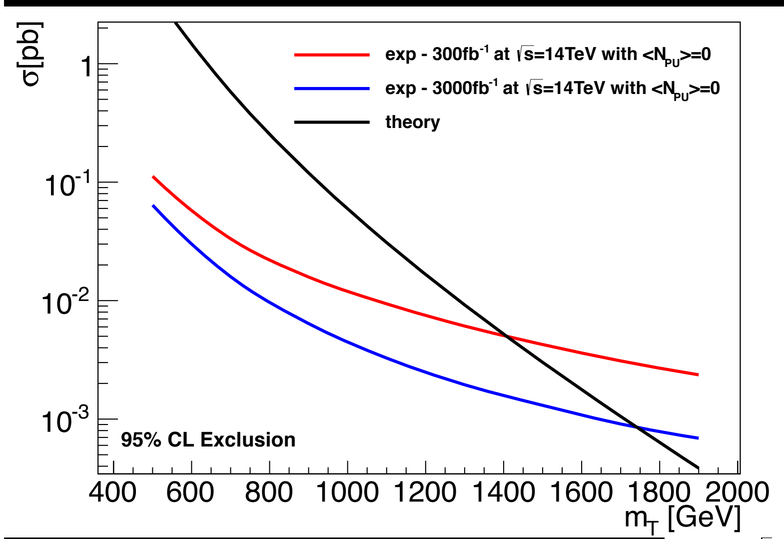
Blue: 300/fb w/ 50 PU
green 3000/fb w/ 140 PU

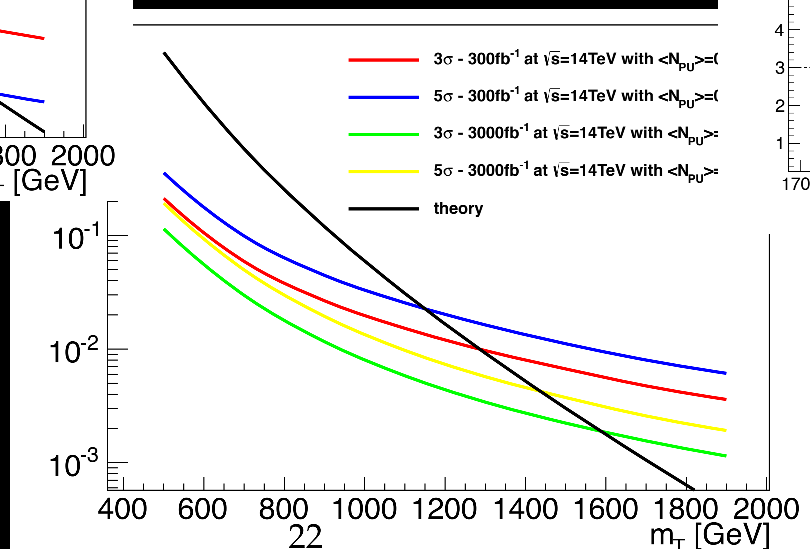
Eric Brownson, N. Craig, U. Heintz, M. Narain, and John Stupak III

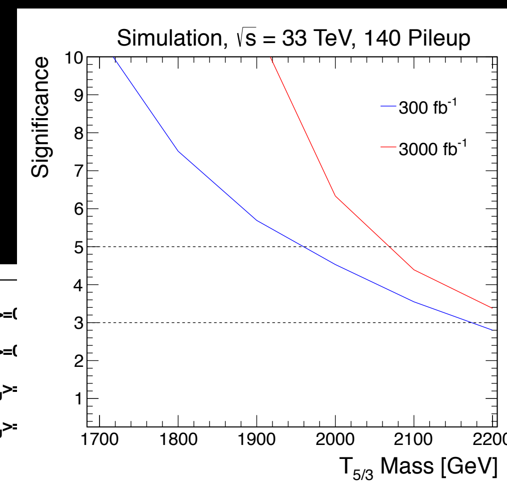
Baradhwaj Coleppa, Felix Kling, Shufang Su

9. Heavy Quarks

- vector like quark searches charge 2/3, 5/3
  - T→Wb, tH, tZ; B→bZ, bH, tW
- Sensitivity for heavy top partners:
  - LHC14: ~1.5TeV, LHC33: ~ 2-2.5 TeV





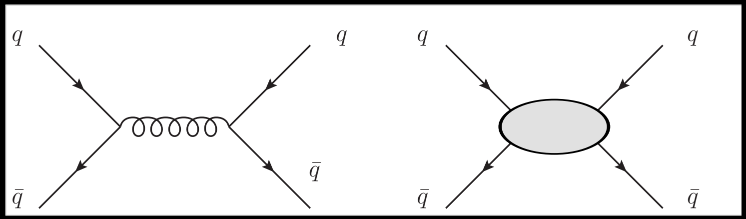


A. Avetisyan, T. Bose

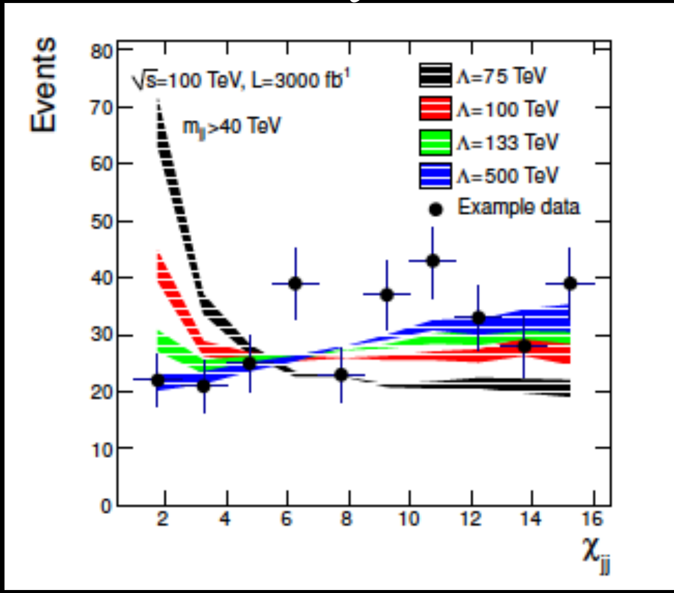
Saptaparna Bhattacharya, Jimin George,
Ulrich Heintz, Ashish Kumar,
Meenakshi Narain, and John Stupak III

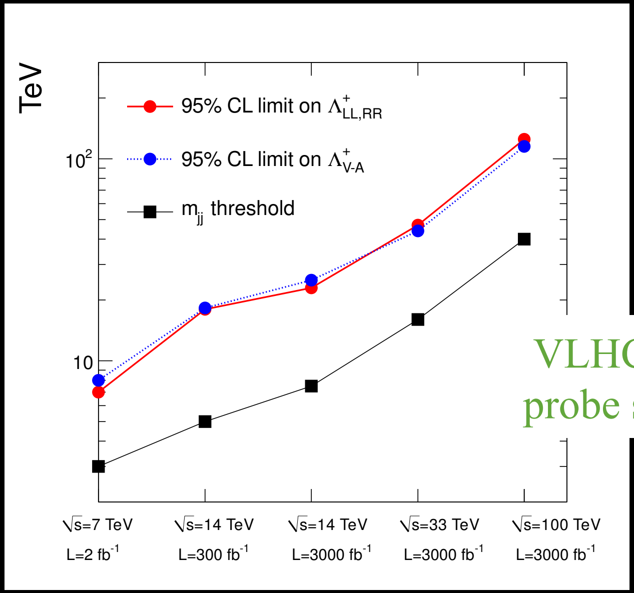
10. Compositeness

- sensitivity to new interactions between quarks at a large characteristic energy scale Λ .
- probe quarks via dijets signature, and leptons via dilepton signature
  - Evidence for contact interactions appear as an enhancement of dijet production with large dijet invariant mas and angle relative to the beam axis



sensitivity to the contact interaction scale Λ





VLHC@100 TeV
probe scales above 125 TeV

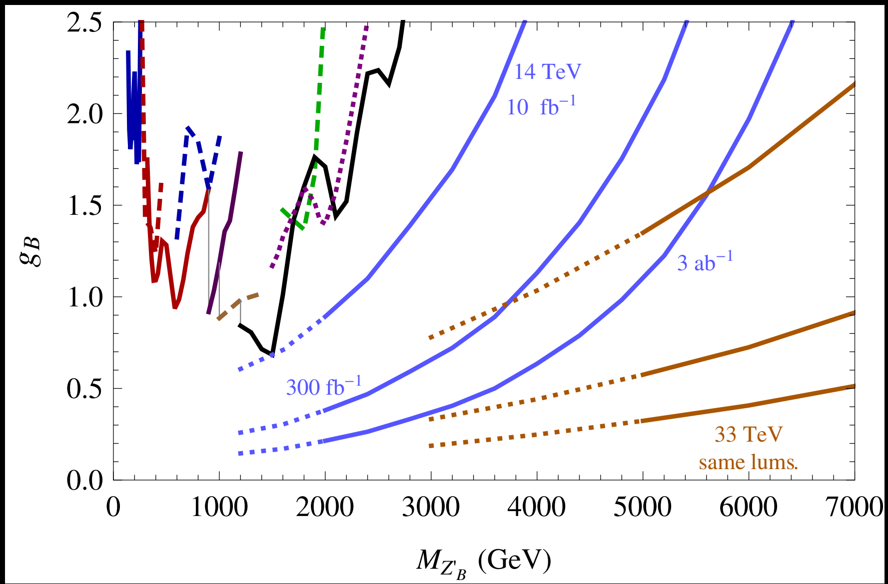
S Upadhyay, N. Varelas, F. Yu, and D. Whiteson.

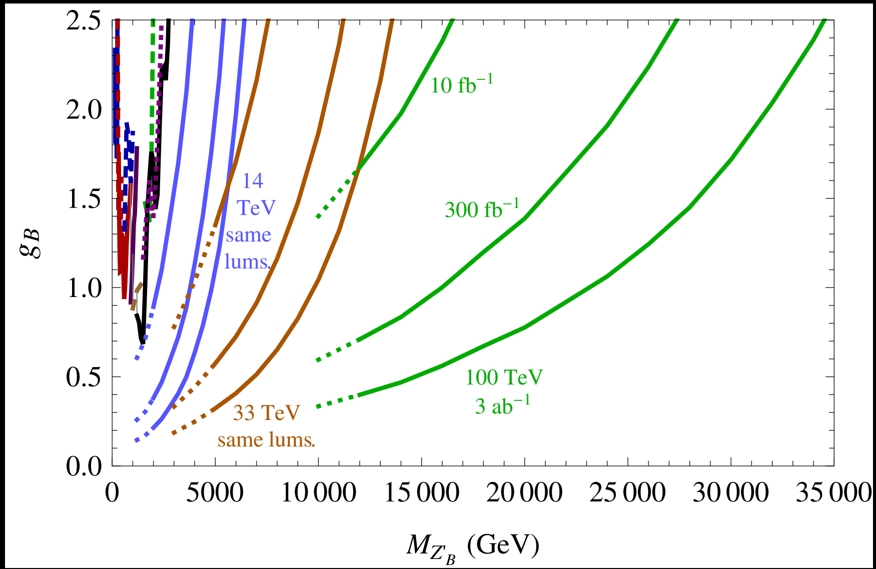
10. Compositeness

- If a deviation from QCD production is seen at the LHC14 then a facility with higher energy will be needed to directly produce the new heavy particle that mediates the interaction of the quark constituents.

- Z' mediator would appear as a dijet resonance
- e.g., an exclusion of $\Lambda > 18$ TeV would correspond to excluding a Z' with mass 1200 GeV, g_Z'=0.12.

$$\frac{g_{Z'}^2}{36 M_{Z'}^2} = \frac{2\pi}{\Lambda^2}.$$





Our Plan for this week

- Collect input on the NP report
  - identify missing pieces, if any, of the stories; include the feedback and input from community and finalize the report

- Wednesday July 31st, 8:30-10:00am
  - Discussion: overlap session with CF, IF
- Friday Aug 2nd, 8:30-noon:
  - Discussion of the report
- Saturday Aug 3rd, 8:30-10:00am
  - Discussion: public response to input on NP report

We would like to encourage you to read the report and come prepared with comments and questions.

Backup

5. “only” the Standard Model

- Many unresolved questions, many reasons to go forward.
- Higgs boson. We need to measure all its properties precisely.
- Naturalness. Fundamental concept underlying our understanding of quantum field theory. Test it as much as we can.
  - LHC Run 2: O(0.01), 100 TeV VLHC O(0.0001).
- Dark Matter.

$$m_{\mathrm{WIMP}} \leq 2\ \mathrm{TeV}\left(\frac{g_{\mathrm{eff}}^2}{0.3}\right)$$

  - Need Higher energy to explore fully the WIMP scenario.
- Little Hierarchy
  - Precision measurements, flavor, seems to indicate NP is heavier, perhaps $\gtrsim$ 10 TeV.

5. “only” the Standard Model

- Fully explore several exciting new physics scenarios.
- Supersymmetry.
  - New spacetime symmetry. Unification....
- Composite Higgs models.
  - Natural extension. Compositeness works (e.g. QCD).
- It is plausible that we are still very close to discovery.
- HL-LHC and ILC essential to cover all possible parameter space
- VLHC extend the reach.