BSM after LHC Run 1

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discussion session

"Physics at LHC and beyond"
Rencontres du Vietnam 2014

BSM is broad.

* BSM to explain the weak scale:

   SUSY, Large or Warped or Universal Extra Dim, Dynamical EWSB, …

* DM at Collider, Sky and Precision Detector:

   DM at Collider, Axions, Other Exotic DM, …

* Others:

   Heavy (t, Z, W, ..) partners, Vector-like quarks, Leptoquarks,

   Shaposhinikinos, ….

* Flavor

* Higgs

* Neutrinos

* EDMs, …

* Multiverse(?), …

To begin with, we may consider SUSY first.

SUSY signatures at LHC:

multijets (possibly with leptons or photons) + MET, displaced vertices,
long-lived (disappearing) particle tracks, large multiplicities, ….

Details of signatures depend on

    * What is the LSP?

       Bino-like
       Higgsino/Wino-like
       Singlino-like
       Extremely-weakly-interacting LSP (gravitino, axino,..)

    * $m\_colored / m\_EW \sim \alpha\_c / \alpha\_EW$

   More compressed or split?

    * $m\_scalar / M\_gaugino$

        Comparable or split?

    * RPC or RPV?, …

Theorist can construct a reasonably nice (even based on string theory)
model yielding
  * any form of LSP mentioned before,

  * a variety of different patterns of
          m_squarks/m_sleptons, M3 : M2 : M1,
  * wide range of m_scalar / m_gaugino,
 and involving extra singlets and/or extra U(1)s

(should avoid flavor/CP problem, moduli/gravitino problem, mu problem)
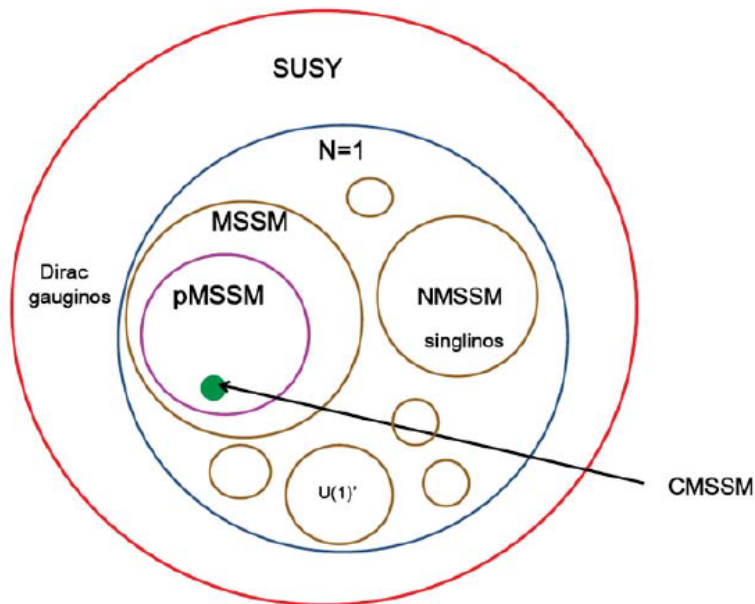
Theory space is big!

Gravity mediation,   (mini)split SUSY,

Gauge mediation,   Spread SUSY,

Anomaly mediation,   Compressed SUSY,

Mirage mediation,   Stealth SUSY,

Gaugino medition,   Supersoft SUSY,

….   ….

T. Rizzo '12

However there is always a free parameter, the overall (or lightest) SUSY scale which may be constrained by

* Naturalness of the weak scale:
     Quadratic dependence on the higgsino mass (tree),
        the scalar top & EWKino masses (1-loop),
        the gluino mass (2 loop)
     ➔ Near the weak scale, but becomes less convincing

* m_h = 125 GeV:
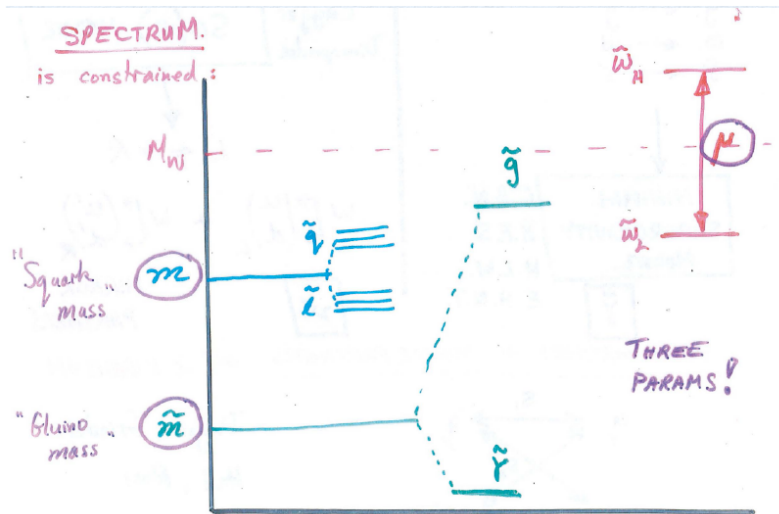   Logarithmic dependence on the scalar top masses

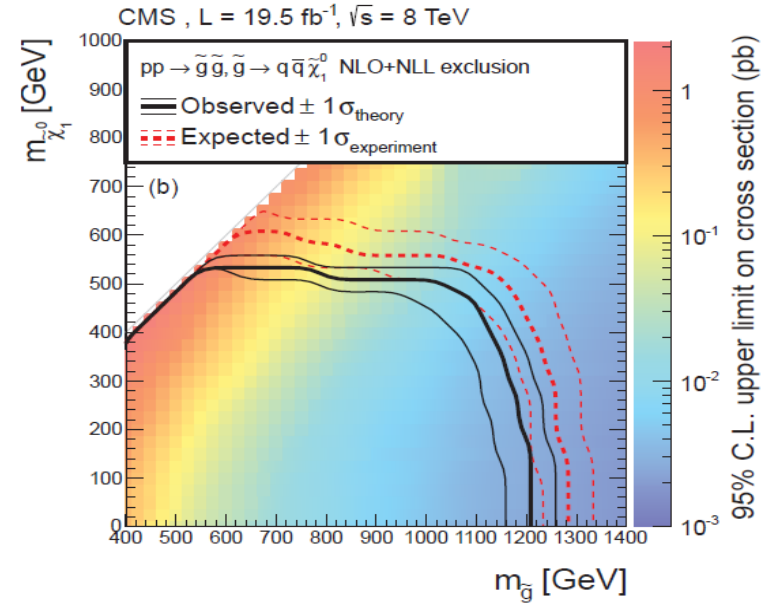   ➔ TeV – 10^6 TeV

* Gauge coupling unification:

     Logarithmic dependence on the higgsino mass
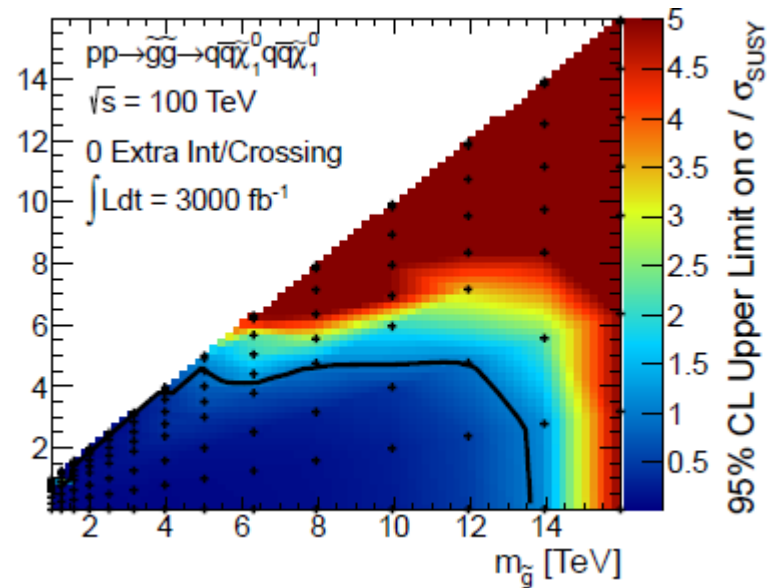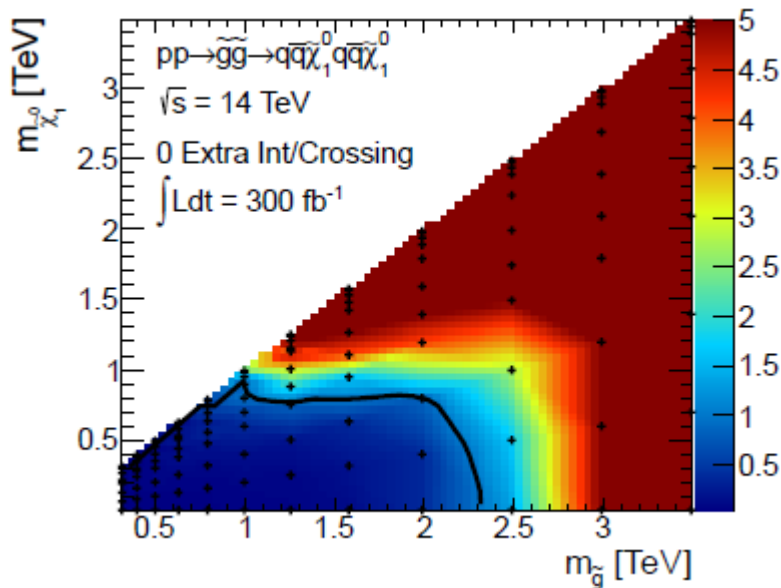   ➔ TeV – 10^3 TeV

Past (L. Hall '84)

Present (LHC Run1)

Future (LHC Run2)   T. Cohen et al '13   (100 TeV)

Strategies for SUSY search at RUN2:
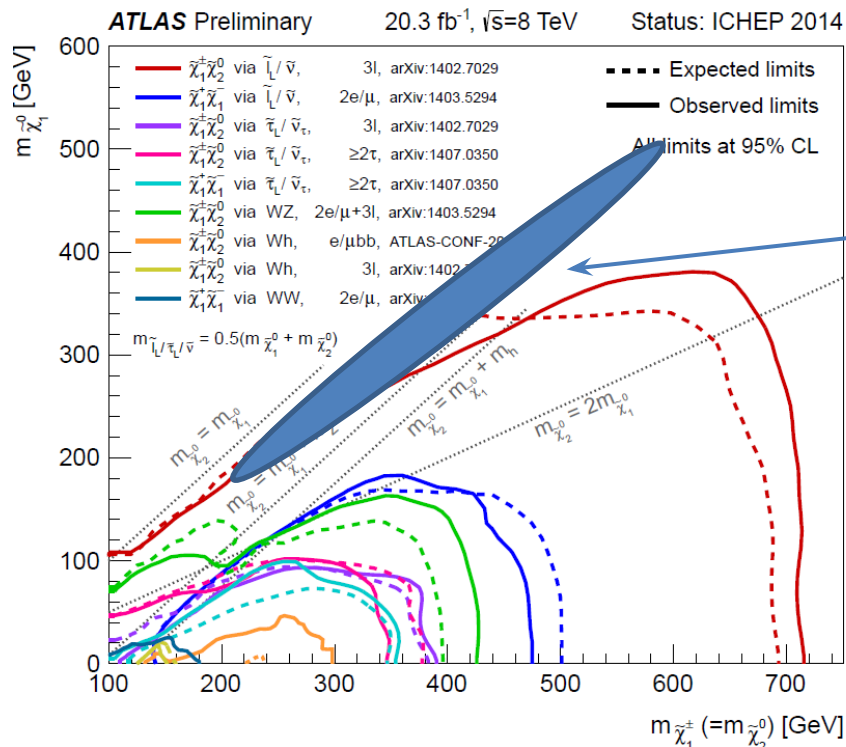
* We can go to higher energy and higher luminosities at RUN2.

* We should leave no stone unturned.

- We may have more room to improve the EWK SUSY sector.

  * Any idea to maximize the efficiency for EWK SUSY search at RUN2?

Degenerate NLSP chagino & LSP neutralino

- Wino-like LSP (AMSB): $M3 \approx 9 M2$
- Higgsino-like LSP (Naturalness)

ATLAS Preliminary   20.3 fb^{-1}, $\sqrt{s}$=8 TeV   Status: ICHEP 2014

$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via $\tilde{l}/\tilde{\nu}$,	3l,	arXiv:1402.7029
$\tilde{\chi}_1^+\tilde{\chi}_1^-$ via $\tilde{l}/\tilde{\nu}$,	2e/μ,	arXiv:1403.5294
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via $\tilde{\tau}_L/\tilde{\nu}_\tau$,	3l,	arXiv:1402.7029
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via $\tilde{\tau}_L/\tilde{\nu}_\tau$,	$\geq 2\tau$,	arXiv:1407.0350
$\tilde{\chi}_1^+\tilde{\chi}_1^-$ via $\tilde{\tau}_L/\tilde{\nu}_\tau$,	$\geq 2\tau$,	arXiv:1407.0350
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via WZ,	2e/μ+3l,	arXiv:1403.5294
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh,	e/μbb,	ATLAS-CONF-2
$\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ via Wh,	3l,	arXiv:1402
$\tilde{\chi}_1^+\tilde{\chi}_1^-$ via WW,	2e/μ,	arXiv:

Expected limits
Observed limits
All limits at 95% CL

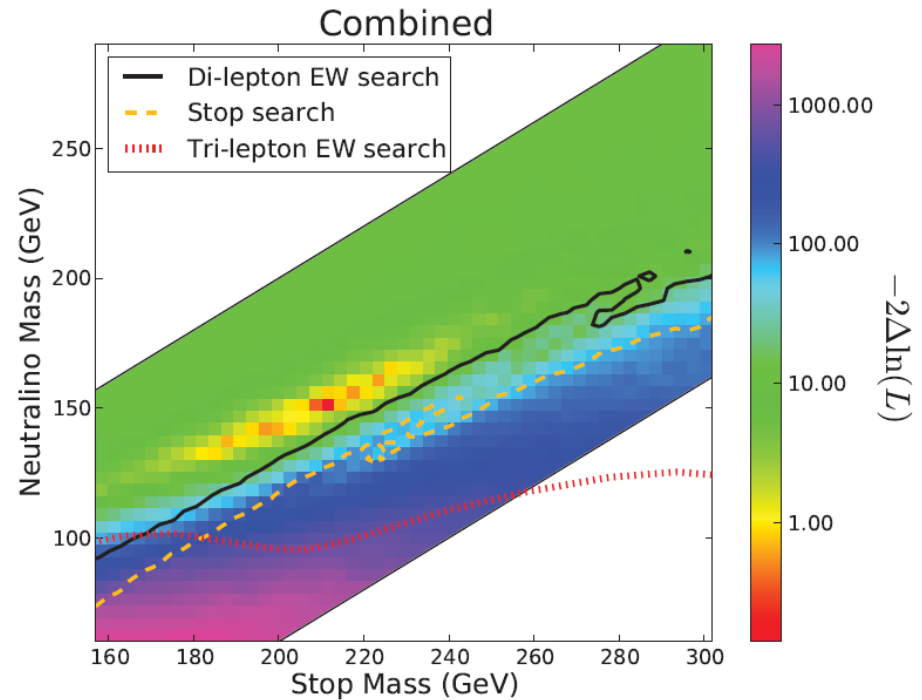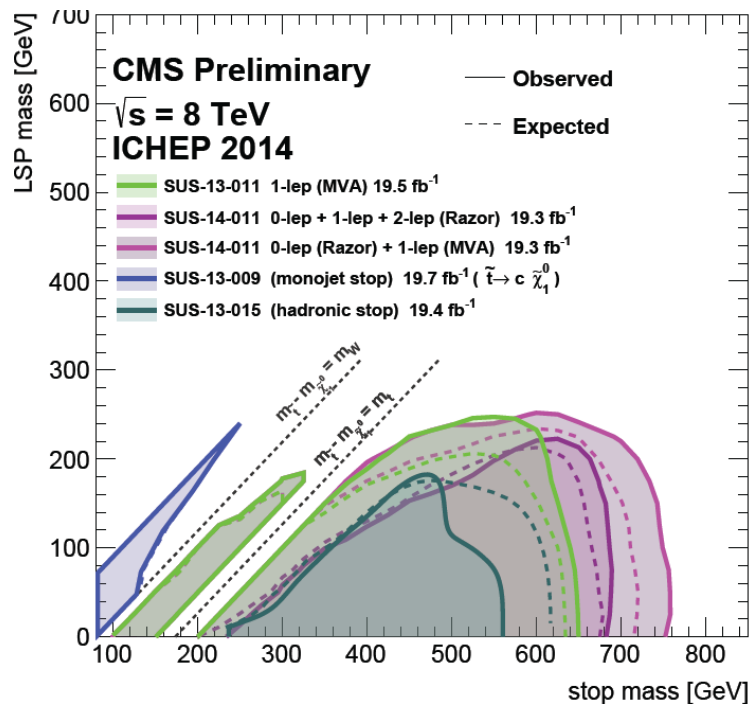* What is the strategy to probe this theoretically well-motivated diagonal region?

mono-jet, Z, gamma + MET?

(ILC may have a good sensitivity.)

M. Nojiri's talk

* Light Stop at diagonal region for WW excess?

J.S. Kim et al, 1406.0852

m_stop = 220 GeV

m_chargino = 160 GeV
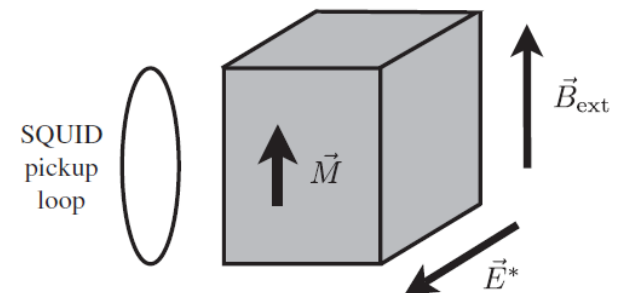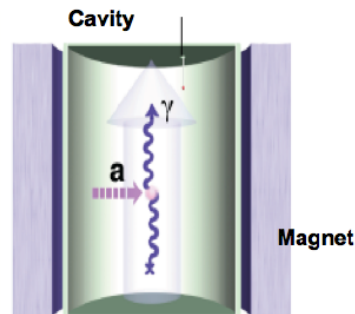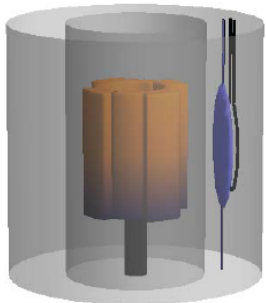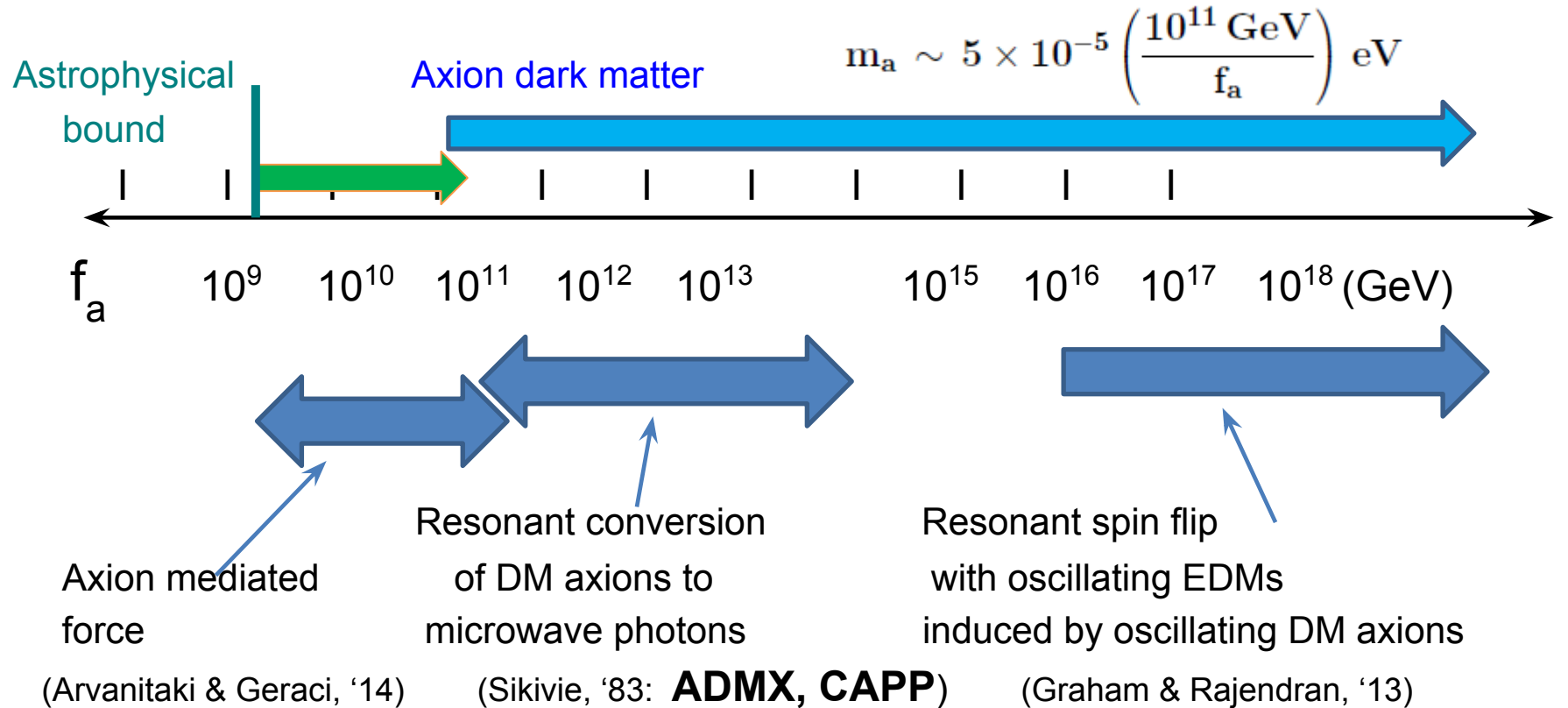
m_neutralino = 150 GeV

Is there any idea to confirm or exclude this possibility?

* Any collider signature specific to Singlet or U(1) extended MSSM?

BSM physics at precision frontier may be able to probe high scales far above TeV, e.g. axions:

Astrophysical bound

Axion dark matter

$$m_a \sim 5 \times 10^{-5} \left(\frac{10^{11}\,\text{GeV}}{f_a} \right) \text{eV}$$

f_a 10^9 10^{10} 10^{11} 10^{12} 10^{13} 10^{15} 10^{16} 10^{17} 10^{18} (GeV)

Axion mediated force

(Arvanitaki & Geraci, '14)

Resonant conversion of DM axions to microwave photons

(Sikivie, '83: **ADMX, CAPP**)

Resonant spin flip with oscillating EDMs induced by oscillating DM axions

(Graham & Rajendran, '13)

Discussion

discussion topics (SUSY/BSM)

Need to give up naturalness/cMSSM and look for other SUSY/BSM?

Beyond the cMSSM --- pros and cons of approaches
- MSSM interpretations at GPD to include indirect constraints of flavour experiments (see talk Shindou)?
    - specific (realistic) models not already excluded by flavour physics?
- effective field theories & simplified models: pros & cons for LHC Run 2?
- importance of RPV models
- Compressed spectra vs more analysts detailed SM measurements?
- More exotic SUSY scenarios → some already covered by 'exotica' searches?

discussion topics: experimental issues

Reliance on models

- Low mass 'gaps' in limits → driven by theory understanding of ISR → strategy to improve
- Triggers ---> as already mentioned by J. Virdee earlier this conference: How do we make sure not to miss any signature and not write it to tape?
-

general question 'if there is bsm in the sub-20 GeV photon+W+c-jet signature (or any other non-standard channel) would we see it', etc etc)

- How will pileup, and pileup removal, affect searches for non-traditional signatures, boosted objects or non-isolated signatures, particularly on trigger level ?(talks: Rosten, Majumder,Cochran)

LHC Run 2 readiness

Any additional models do we need for LHC Run 2 ?

- Does it matter?

   making sure no stone is left unturned - are all important signatures being analysed (or even worse: triggered on)?

- all bases covered? Theory perspective welcome here

Are we ready for a quick discovery?

- identify challenging areas/subjects

Outlook future colliders?

Usefulness BSM/SUSY studies for long-term future collider feasibility studies?

- depends on the BSM model?
- EWK susy vs squark/gluino lsp?
- SUSY-factory (talk Gouskos)

Ideas for strategy for some scenarios:

- New physics!!
- No significant new physics in LHC2
- Hint of something QCD-mediated (high mass bump) but not significant enough?
- Hint of something EWK-SUSY-like?
- Excesses in SM distributions? non-consistent SM scalar BRs, flavour physics, top precision measurements?
- Anything else?

author: Shindou

In the MSSM

Mahmoudi, arXiv:1205.3099
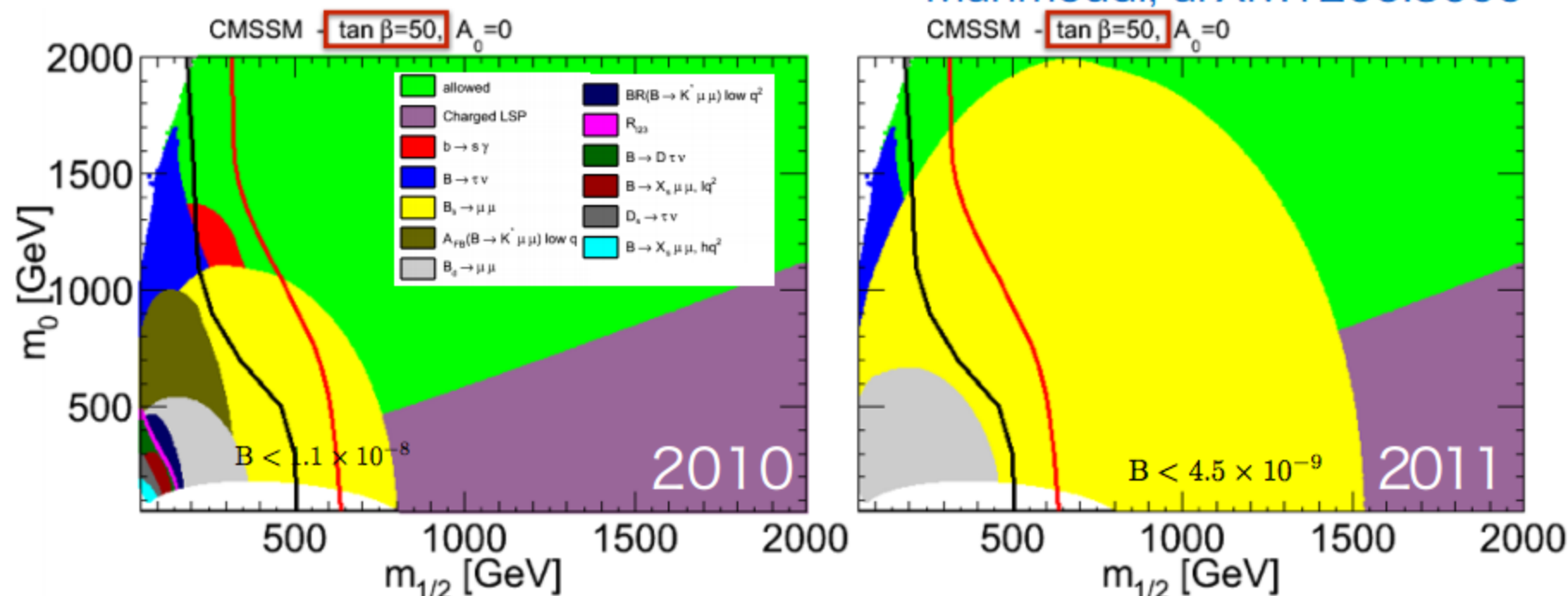
Wide region for large $\tan\beta$ is excluded

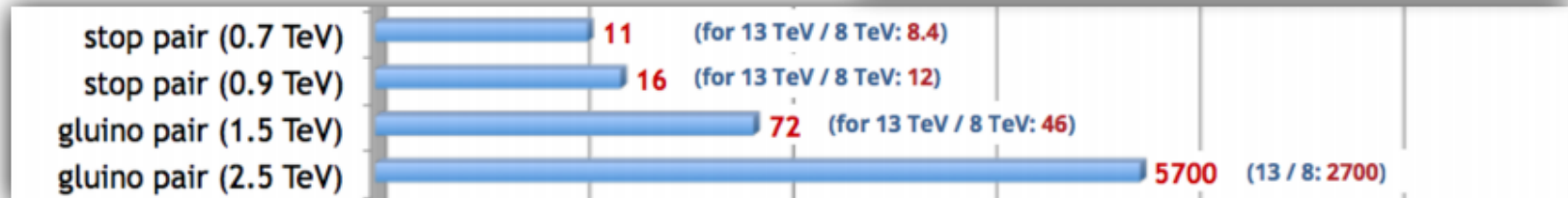When a NP model is considered,

Contribution to $B_s \rightarrow \mu\mu$ should be seriously tested

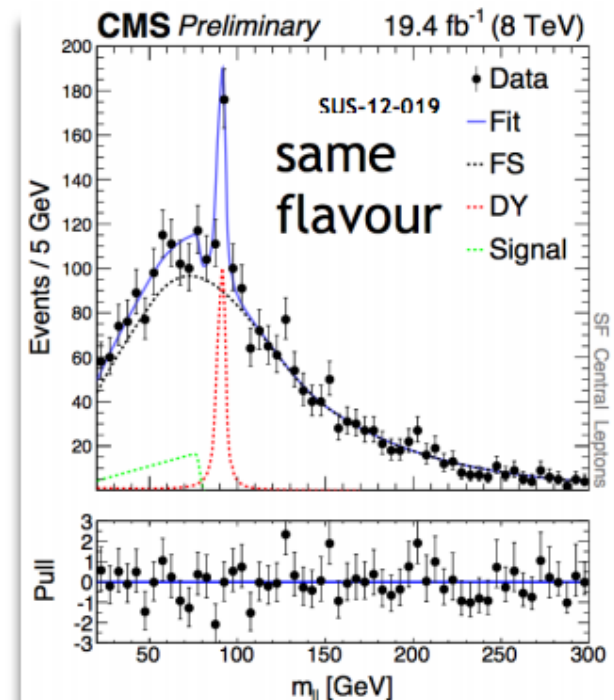in addition to contribution to the $b \rightarrow s\gamma$

Looking Ahead

- **Explore the new energy scale as the LHC turns on in Spring 2015, SUSY may indeed be just around the corner!**

Cross section ratios: 14 (13) TeV / 8 TeV

stop pair (0.7 TeV)	11	(for 13 TeV / 8 TeV: 8.4)
stop pair (0.9 TeV)	16	(for 13 TeV / 8 TeV: 12)
gluino pair (1.5 TeV)	72	(for 13 TeV / 8 TeV: 46)
gluino pair (2.5 TeV)	5700	(13 / 8: 2700)

- **Relax the pre-LHC expectations, i.e. naturalness and parsimony, and strengthen the program looking for**

  - **very compressed SUSY**

  - **RPV**

  - **Long Lived**

  - **non Minimal SUSY**

  - **… exploit further kinematic variables**

CMS *Preliminary*   19.4 fb^{-1} (8 TeV)

SUS-12-019

same flavour

- Data
- Fit
- FS
- DY
- Signal

Events / 5 GeV

Pull

m_{ll} [GeV]

SF Central Leptons

Search for Stop

- **Key to naturalness but challenging!**

  - cross section is suppressed, 10pb to 1fb from 200 to 900 GeV stops

  - sensitivity highly dependent on the decay mode, the mass hierarchy of "sparticles" participating (and to some extent on the stop "handiness")

$$\Delta m = m(\tilde{t}_1) - m(\tilde{\chi}_1^0)$$

$m(\tilde{\chi}_1^0)$ [GeV]

$m(\tilde{t}_1) < m(\tilde{\chi}_1^0)$

$\tilde{t}_1 \to c\tilde{\chi}_1^0$

$\tilde{t}_1 \to bf f'\tilde{\chi}_1^0$

$\tilde{t}_1 \to bW\tilde{\chi}_1^0$

$\tilde{t}_1 \to t\tilde{\chi}_1^0$

$\Delta m > m(W) + m(b)$

$\Delta m > m(t)$

100

0

0   m(W)+m(b) 100   m(t) 200   300 $m(\tilde{t}_1)$ [GeV]