BSM Theory in Broadbrush

Mihoko Nojiri
KEK & IPMU

Photo from http://www.torange.biz

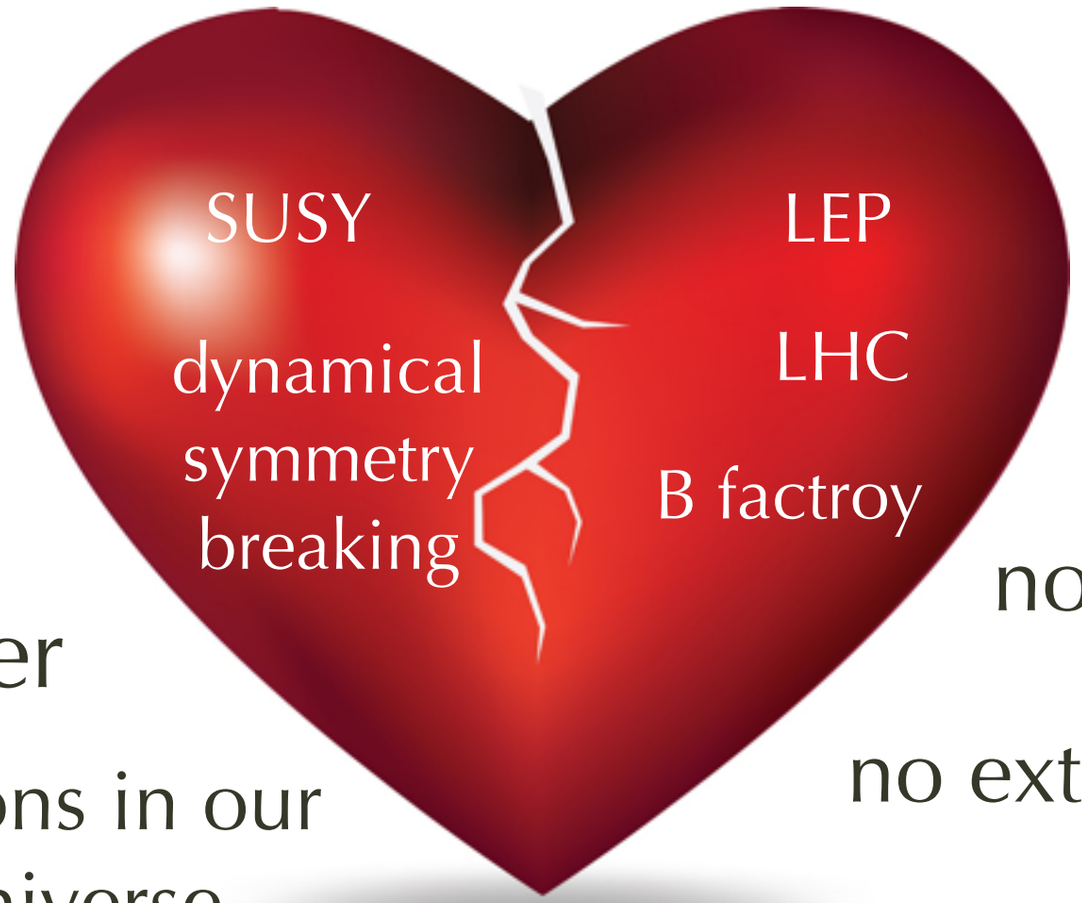
BSM is the target

existing Mystery

Matter content
and gauge
interaction

higgs boson
is light
dark matter

baryons in our
Universe



Constraints

no large EW
correction

no extra FCNC

no proton decay

no extra CP violation

Contents

- Higgs and SUSY search; What is **Natural SUSY**?
- **"Composite way"** ; Composite Higgs, top partner
- **"QCD wins"**; Why LHC was successful
- **Model independent Model**; "Simplified" & "effective"
- **Leptons and Photons in future**

Classic Solution:Supersymmetry

- symmetry to exchange boson and fermion.
  - new particle predictions sfermions(0), gaugino(1/2), higgsinos(1/2)

Higgs vs SUSY

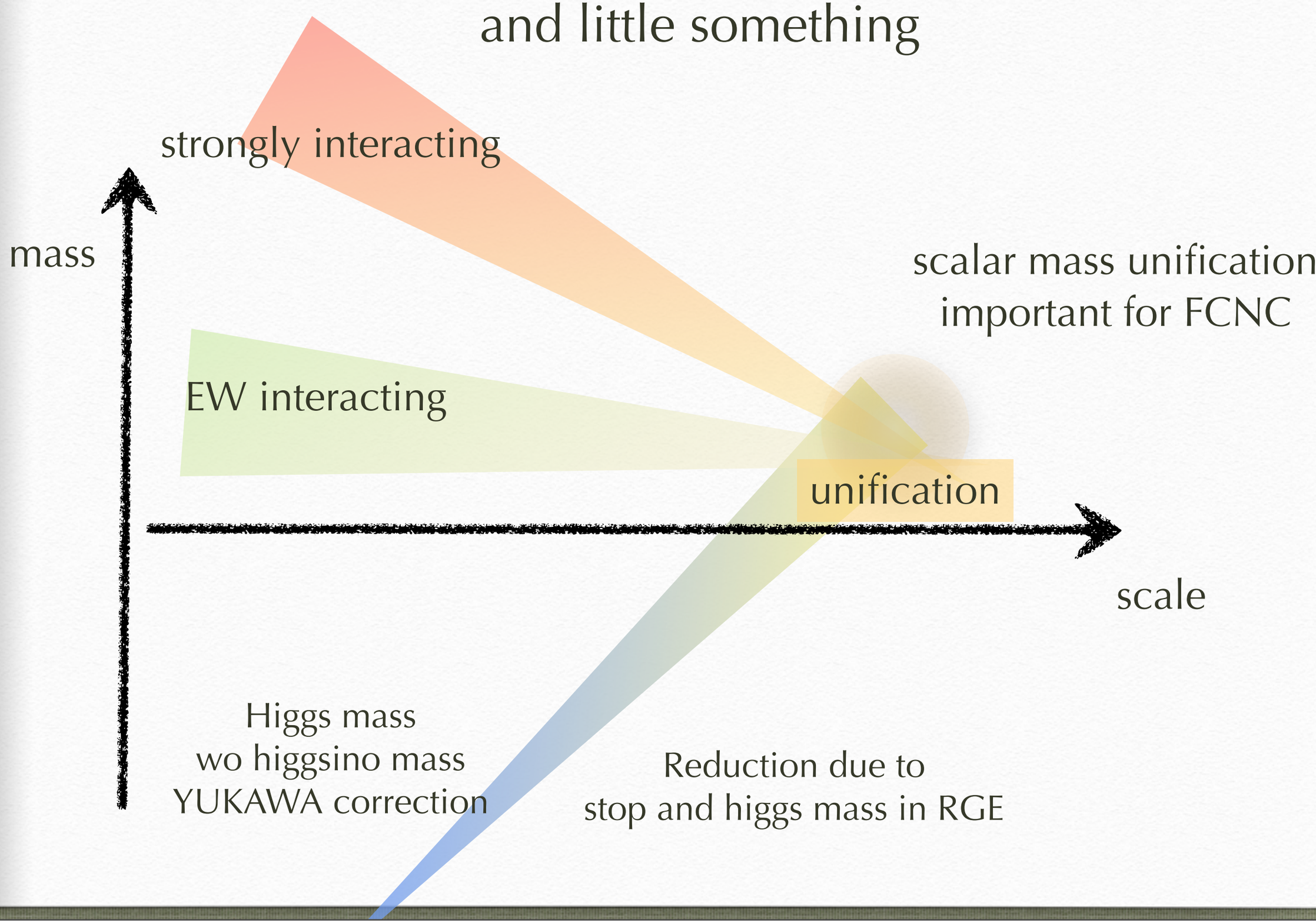
- No new dimensionless coupling and no quadratic divergence
- Higgs 4 point coupling ～gauge coupling. (no negative 4 point coupling)+ radiative correction b

Answering big question

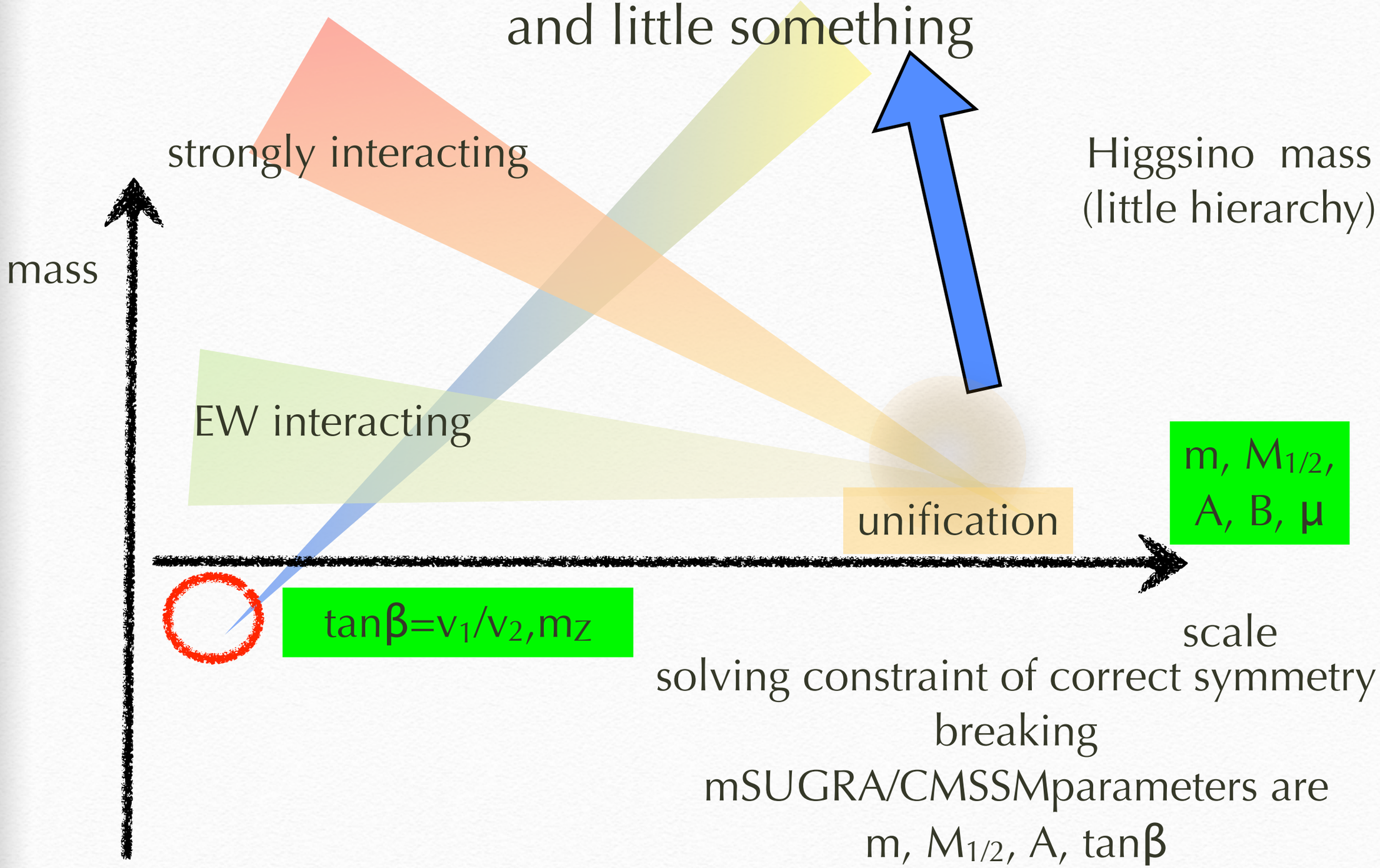
- gauge coupling unification
- R parity in MSSM . New stable particle→ DM candidate.

but flavor and CP problem -> SUSY breaking models

gauge coupling/soft parameter unification
mass spectrum (mSUGRA/CMSSM)
and little something



gauge coupling/soft parameter unification
mass spectrum (mSUGRA/CMSSM)
and little something



solving constraint of correct symmetry breaking

mSUGRA/CMSSMparameters are

m, $M_{1/2}$, A, tanβ

What is natural,anyway?

$$\frac{m_Z^2}{2} = \frac{m_{H_d}^2 + \Sigma_d^d - (m_{H_u}^2 + \Sigma_u^u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

only wave function renormalization
relatively stable prediction

$$\left| \frac{a_i}{M_Z^2} \frac{\partial M_Z^2(a_i; y_t)}{\partial a_i} \right| < \Delta$$

fine tuning is the **response of Z mass** to the **fundamental parameters "a"**

Now what is the "a" ? This idea has been **criticized since it was proposed** in '88

GUT scale based (Barbieri et al ->)

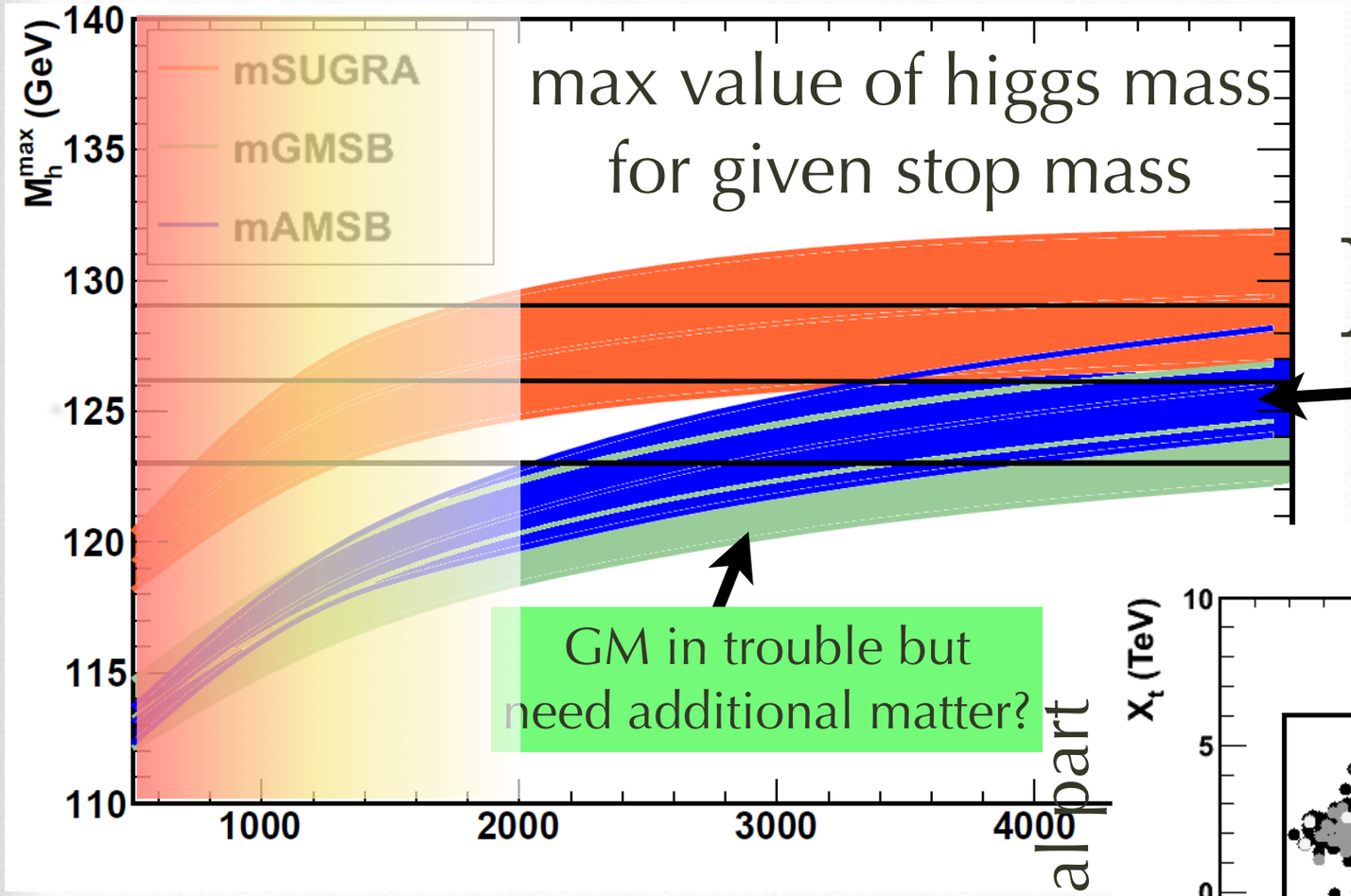
use GUT scale parameters: m, $M_{1/2}$, Δ is order of 1000
The level of tuning also changes #parameters at GUT scale

Weak scale based (Baer et al)

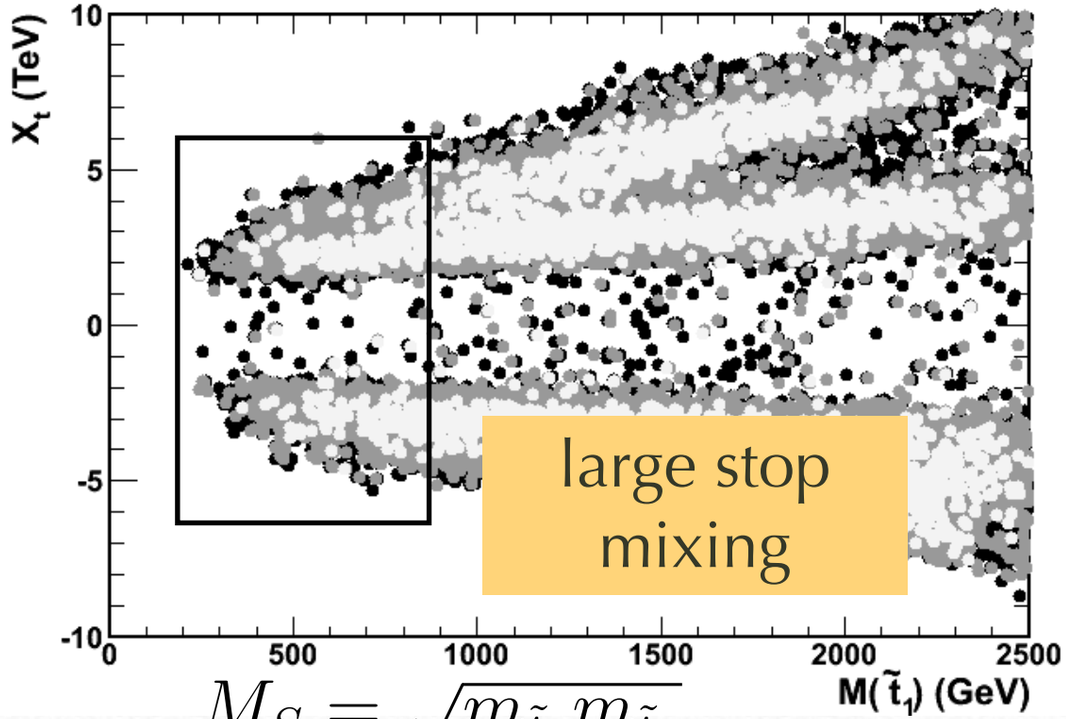
use parameter at weak scale: typically 1/10 less fine tuned compared with GUT based analysis

.... Why should we mind?

Higgs mass vs SUSY



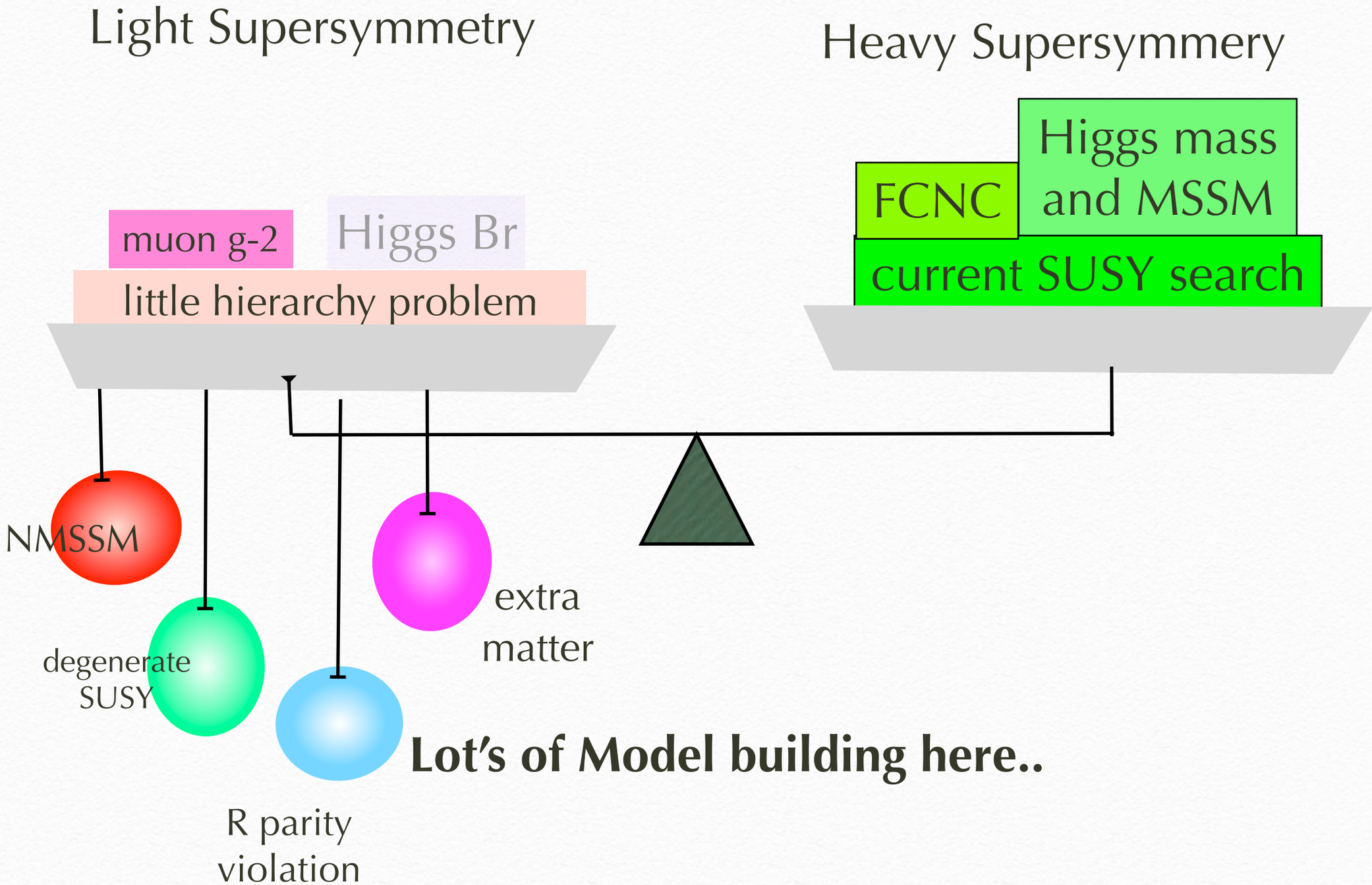
off diagonal part



$$M_S = \sqrt{m_{\tilde{t}_1} m_{\tilde{t}_2}}$$

Theorists are considering
high scale /non-minimal
SUSY more seriously

Mind of SUSY theorists



SUSY spectrum on market

MSUGRA classic

heavy scalar AM

light higgsino or stop for naturalness

degenerate

sq/gl

stop2

stop1

gluino

Small cross section top background

KKLT

very hard to access →ILC?

stop2

stop1

higgsino

gaugino

wino LSP

higgsino

Composite ways

- Technicolor model... Scale up of chiral symmetry breaking in QCD. Higgs as pion （bound state of some strong interaction)　conflicts with EW precision data

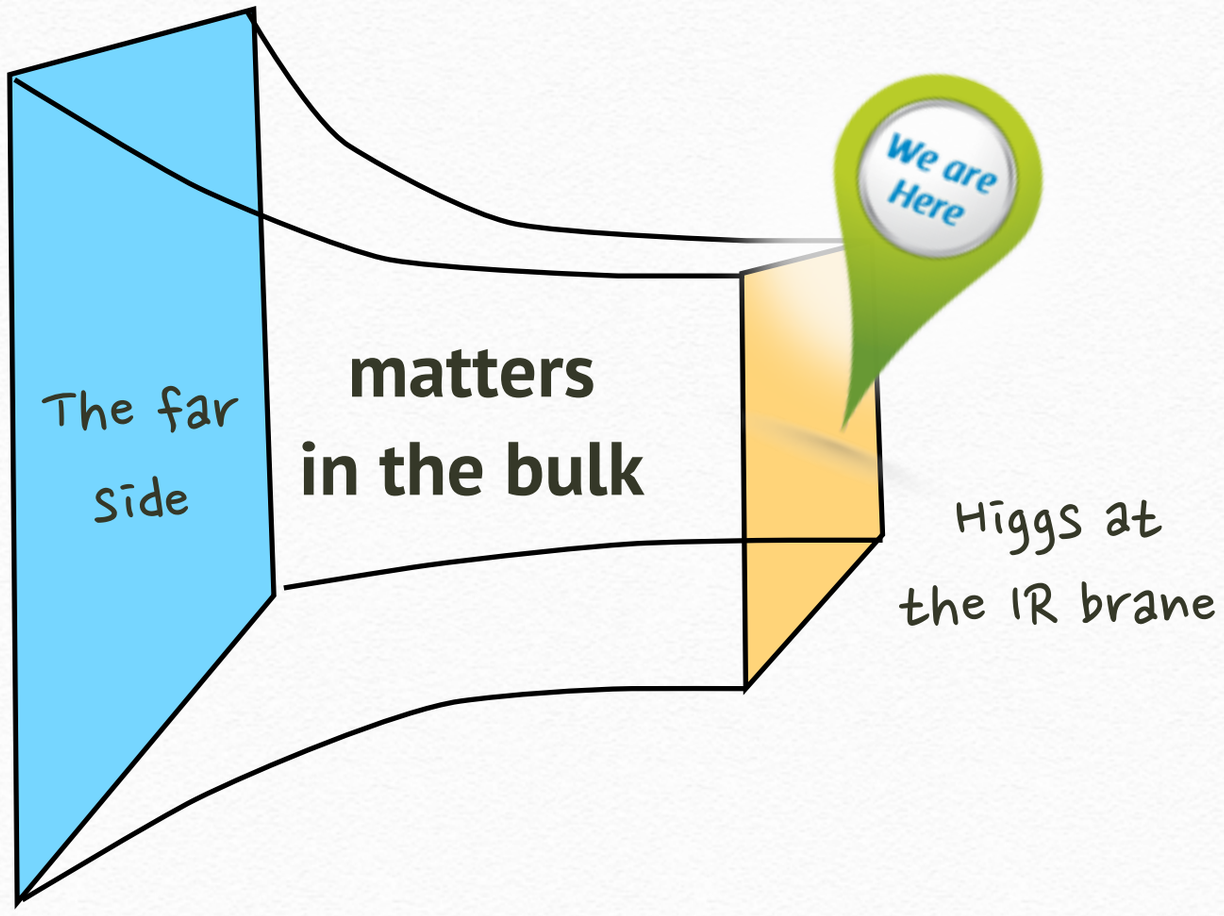
- The Little Higgs model→Composite Higgs model

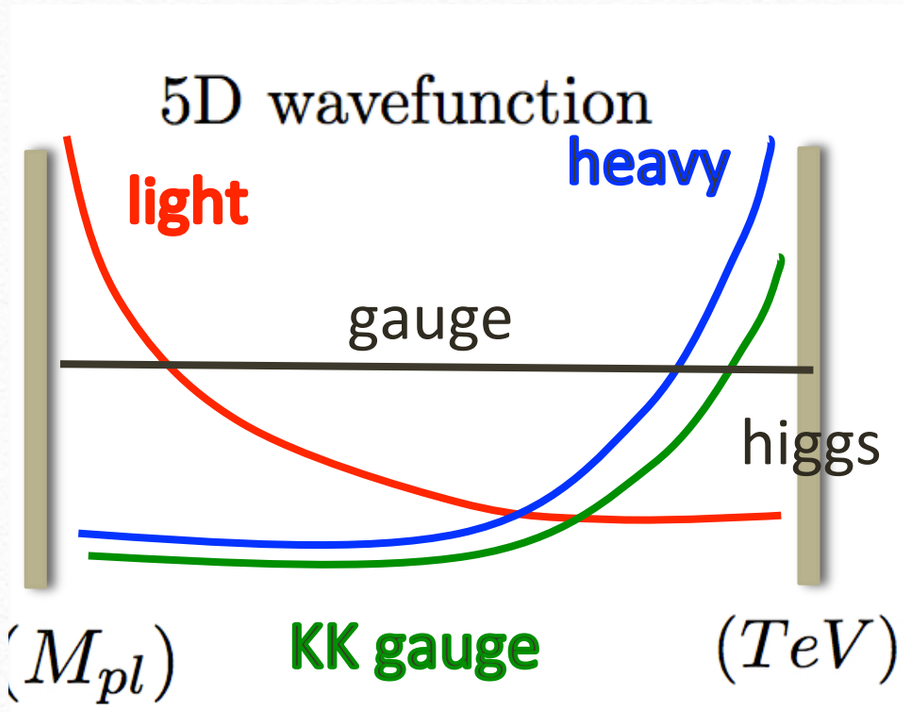
- Higgs as the pNGB of some global symmetry breaking. Typically SO(5)/SO(4), either elementary or composite

- The theory still needs **“top partners”**, because top must be in a representation of the global symmetry

- UV completion ⇄ RS model　　Holography

- Randall Sundrum model ⇄ Composit Higgs model





In Holography(ADS/CFT) expectation/imagination

IR brane: breaking of Conformal invariance

anomalous dimension to generate Yukawa coupling

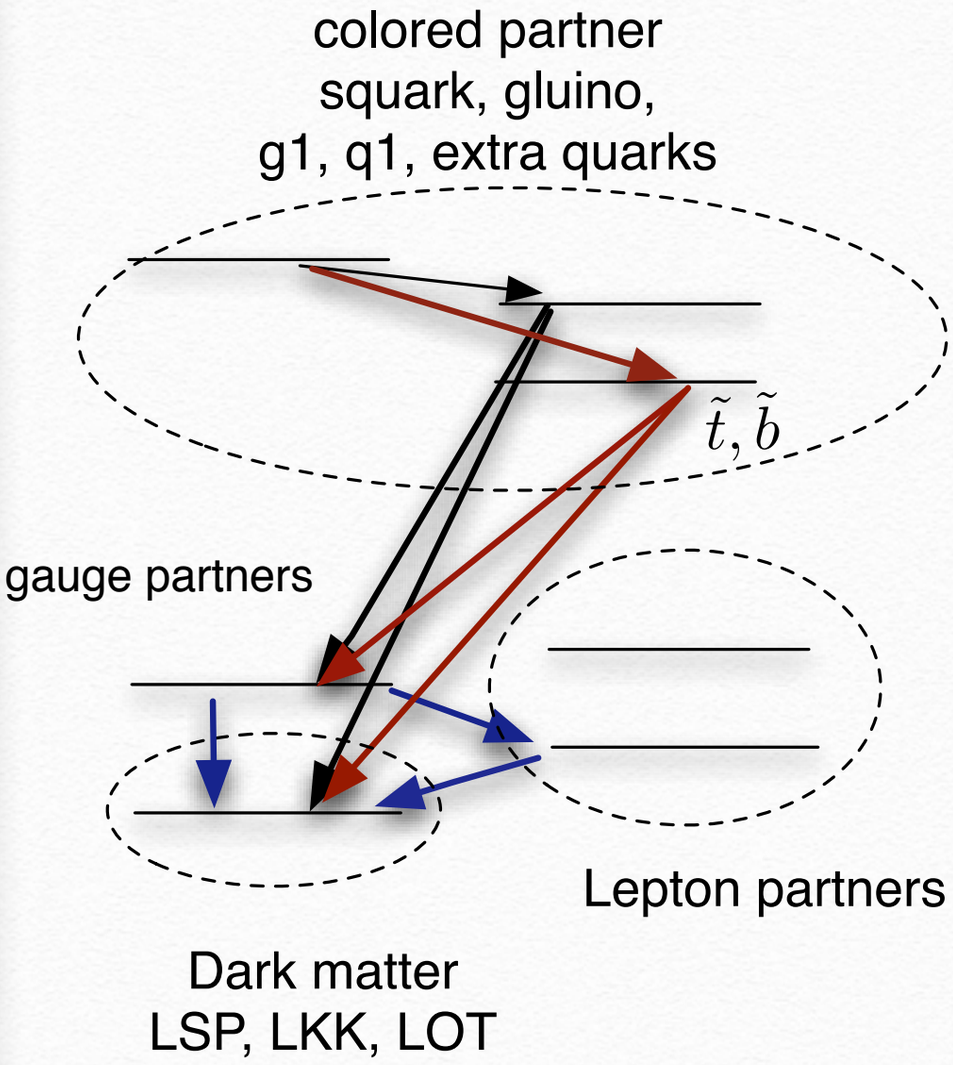
Physics

- Top partners from $SU(2)_L$x $SU(2)_R$ symmetry
  - T_L T_R mixed with t_L t_R in standard model sector then decay into bW, tZ, tH.

    Agashe, Contino Pomarol
    - q(Q=5/3), q(2/3), q(-1/3)
- RS model --gluon KK (production: coupling to the 1st generation quark, dominantly decays into ttbar)
- Radiative correction to Higgs decay
- Being now constrained by LHC

Collider searches "QCD wins"

dark matter and collider signature



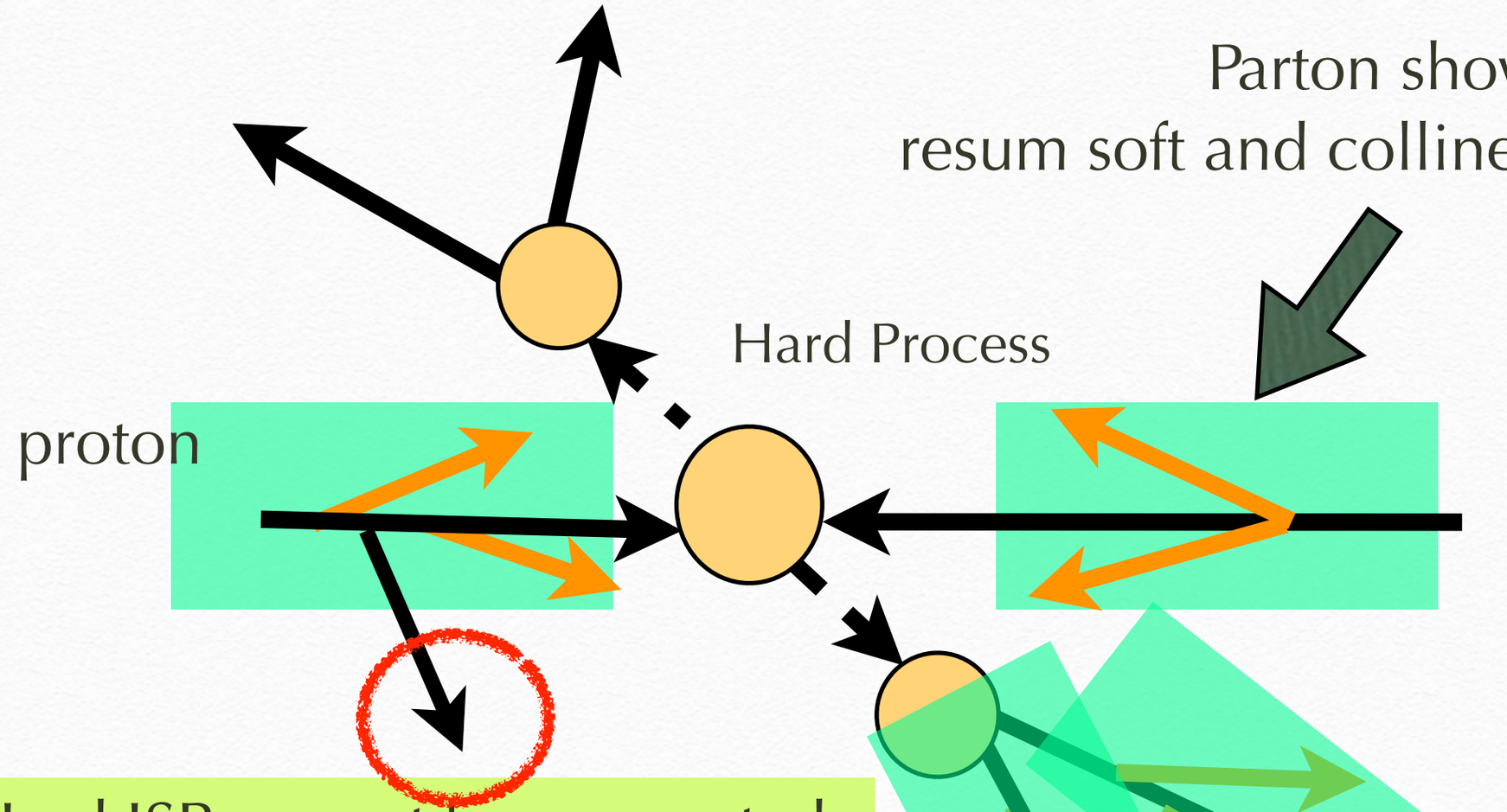
- **"SUSY signature"**
  - "Models with new colored particles decaying into a stable neutral particle--LSP"
- Some of "New physics" are migrated into SUSY category.
- Signal:
  High P_T jets hiph P_T leptons and E_{Tmiss}

assume mass difference is large

if there are R parity violation, we have additional jets and leptons instead of E_{Tmiss}

Production of W, Z, and top with additional jets would be significant background

background estimation powered by “Matching”

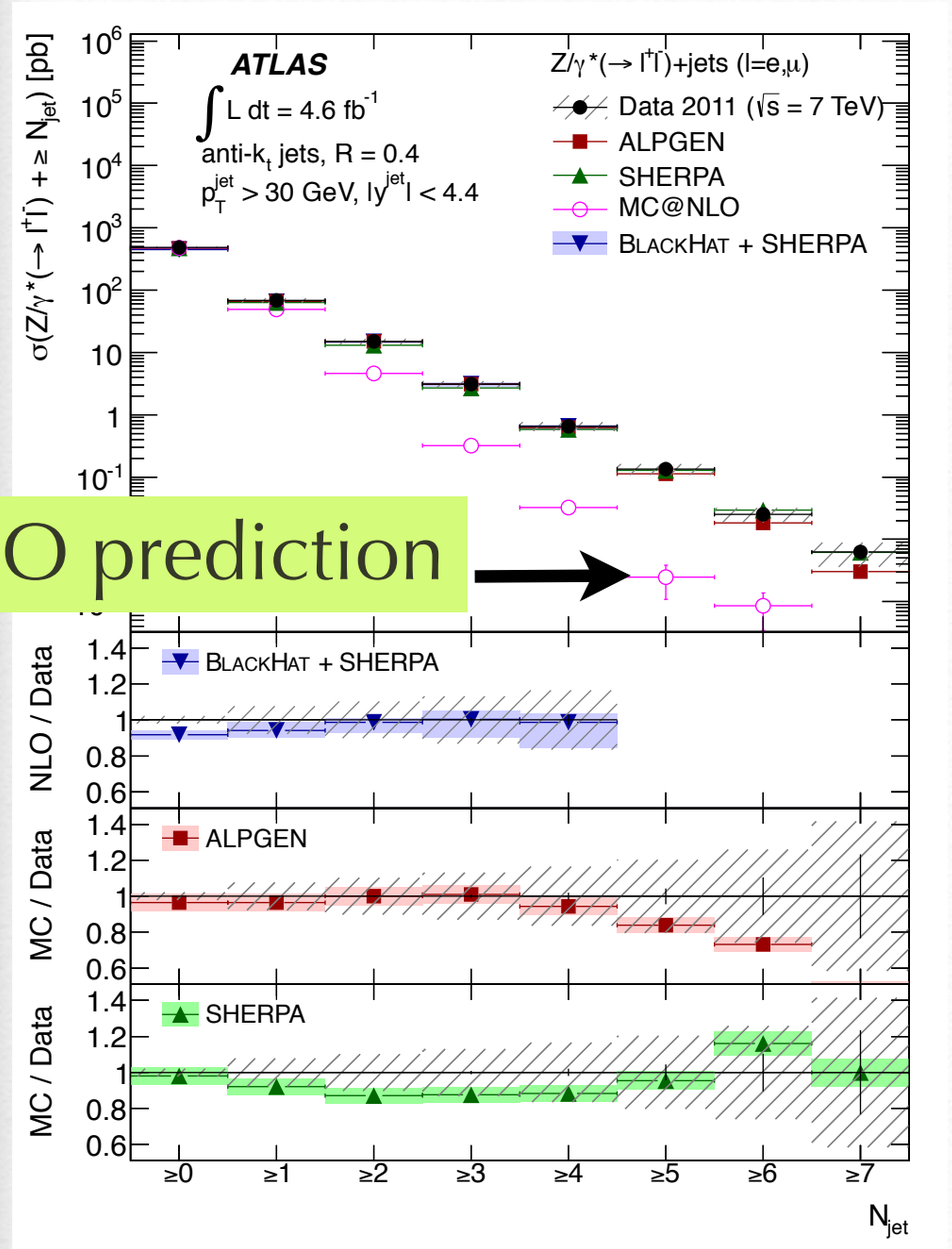


Hard ISR cannot be accounted
by PS approximation
but “overlap” near boundary
“Matching” remove the overlap

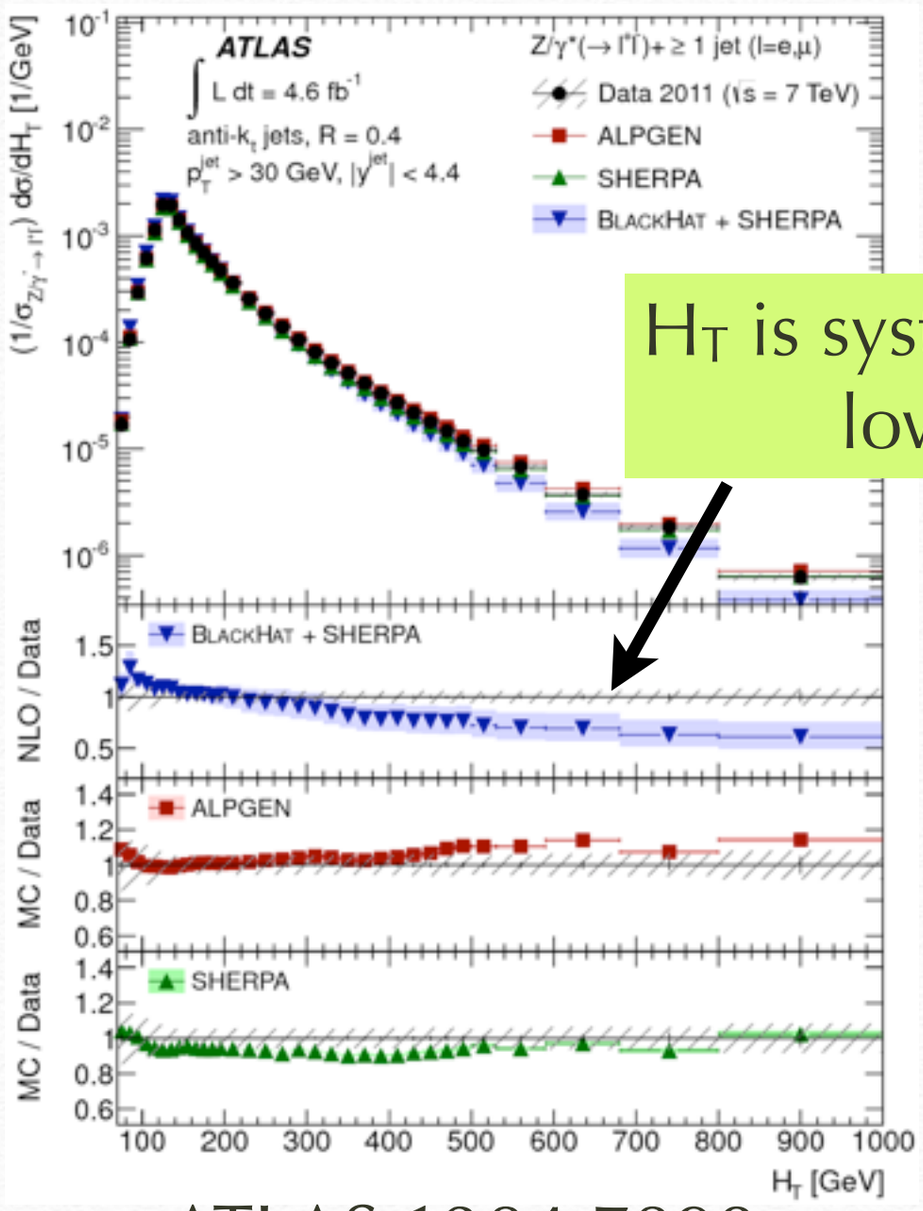
MLM
CKKW 2001

The inclusion of additional emission to the SM process is important when we rely on the cut on P_{T3}, P_{T4} and inclusive quantity like H_T, Meff...

reproducing multijet distribution



NLO prediction



HT is systematically low yet

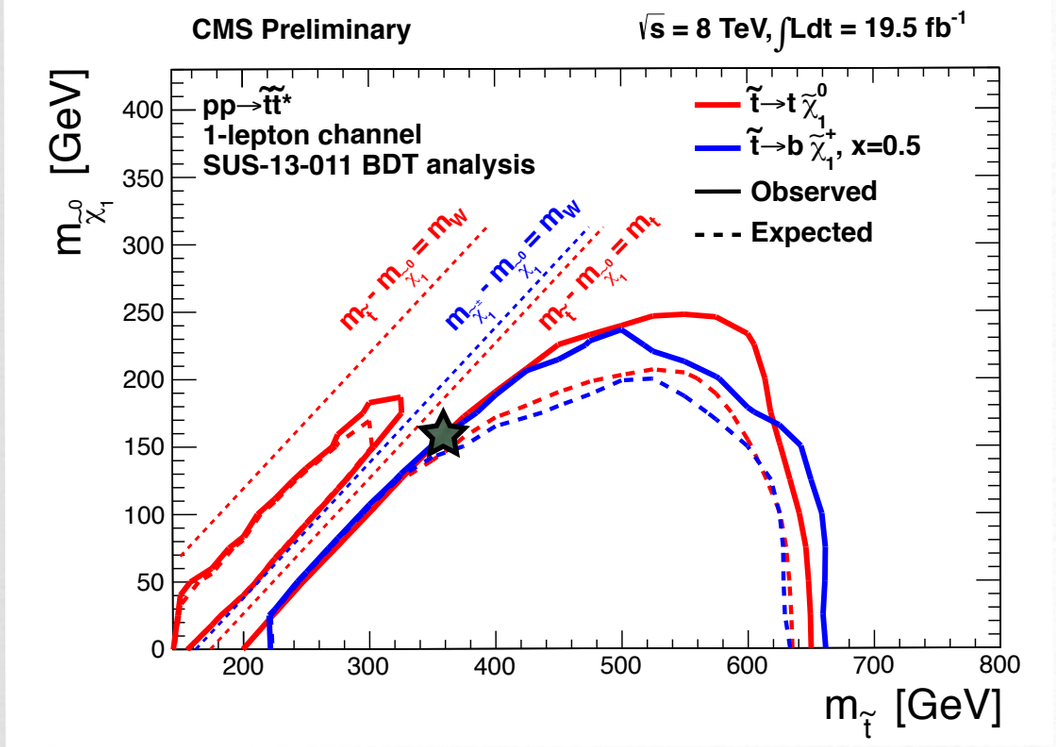
NLO

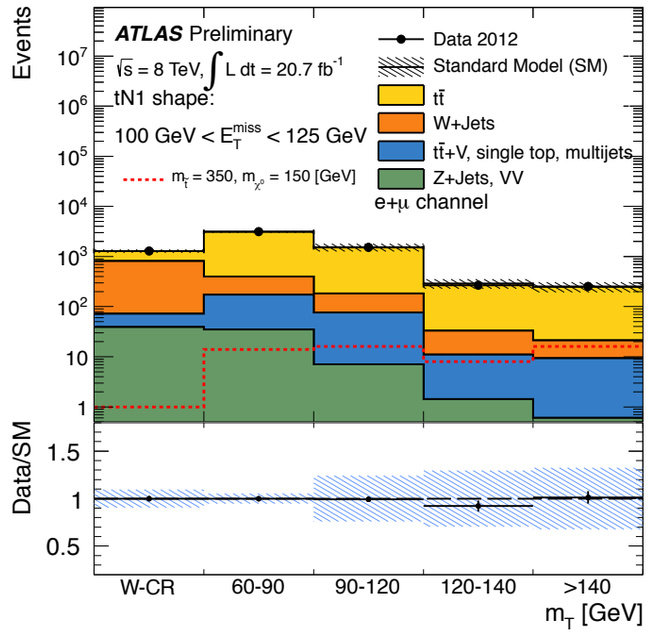
Tree

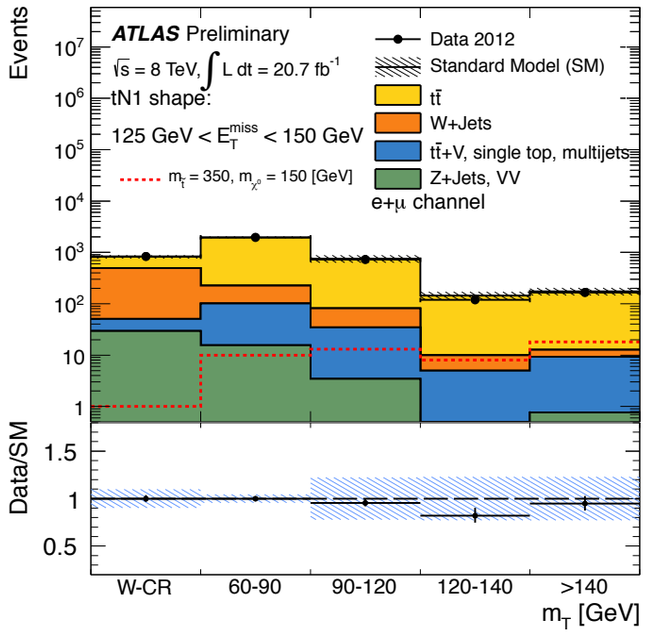
Tree

ATLAS 1304.7098

good background prediction
= exclusion up to kinematical limit

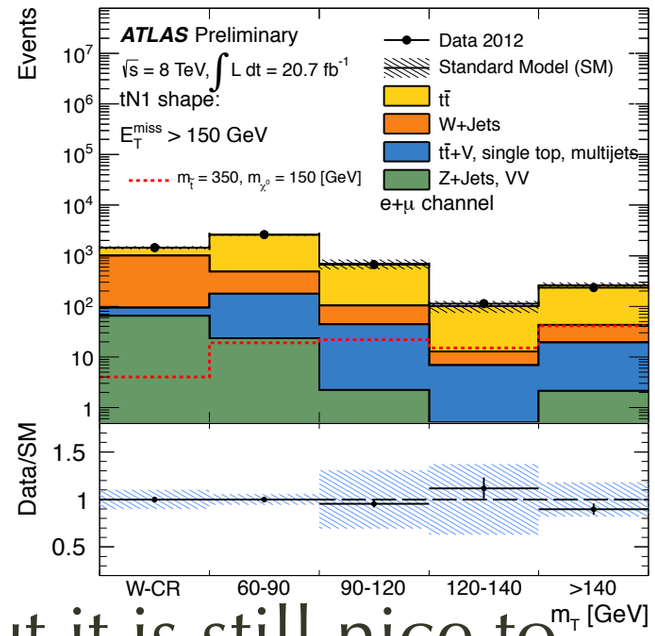






exclude up to the region
where mstop~mLSP+mt +30GeV

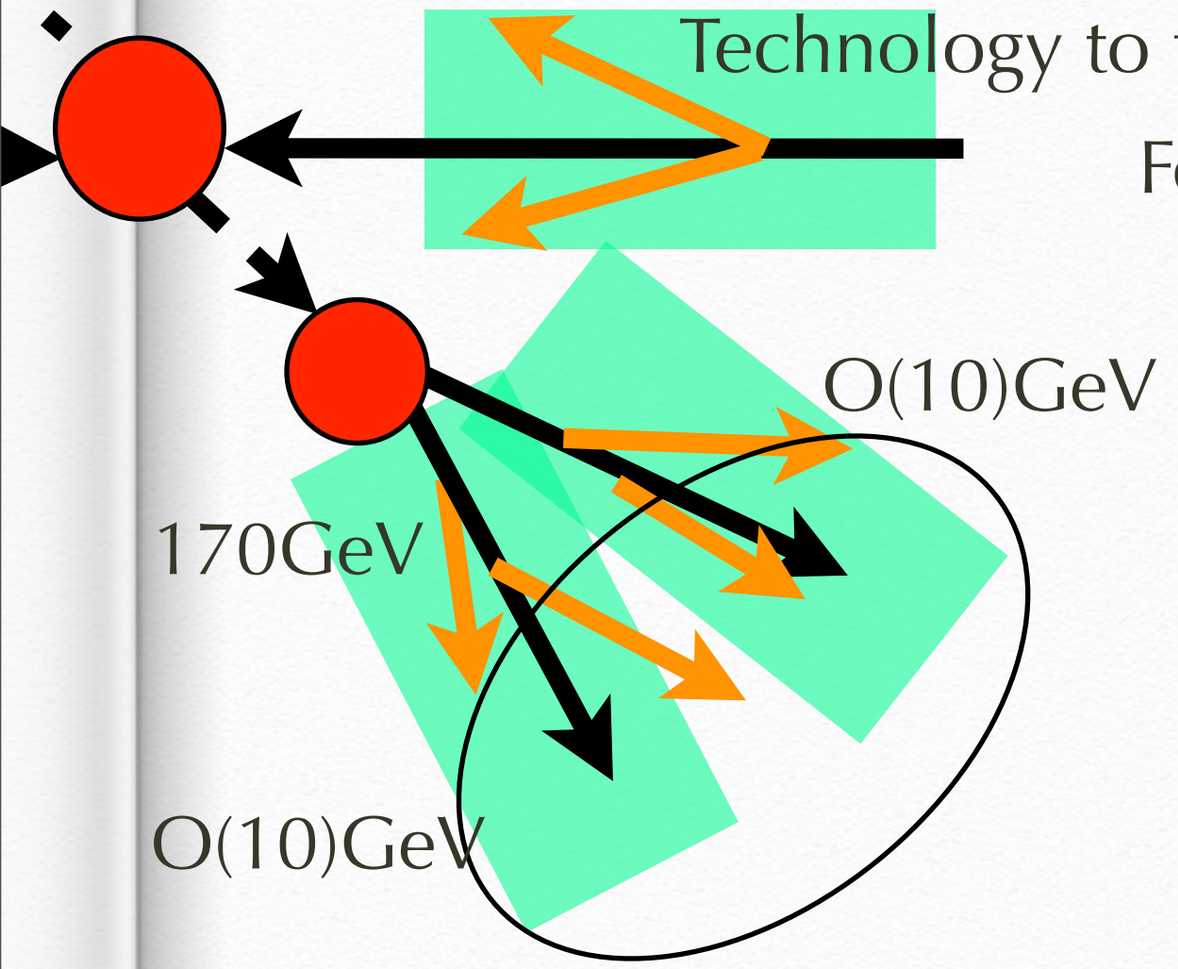
stop 350GeV and LSP 150GeV
There are no region with
S/N>0.1 in this plot!



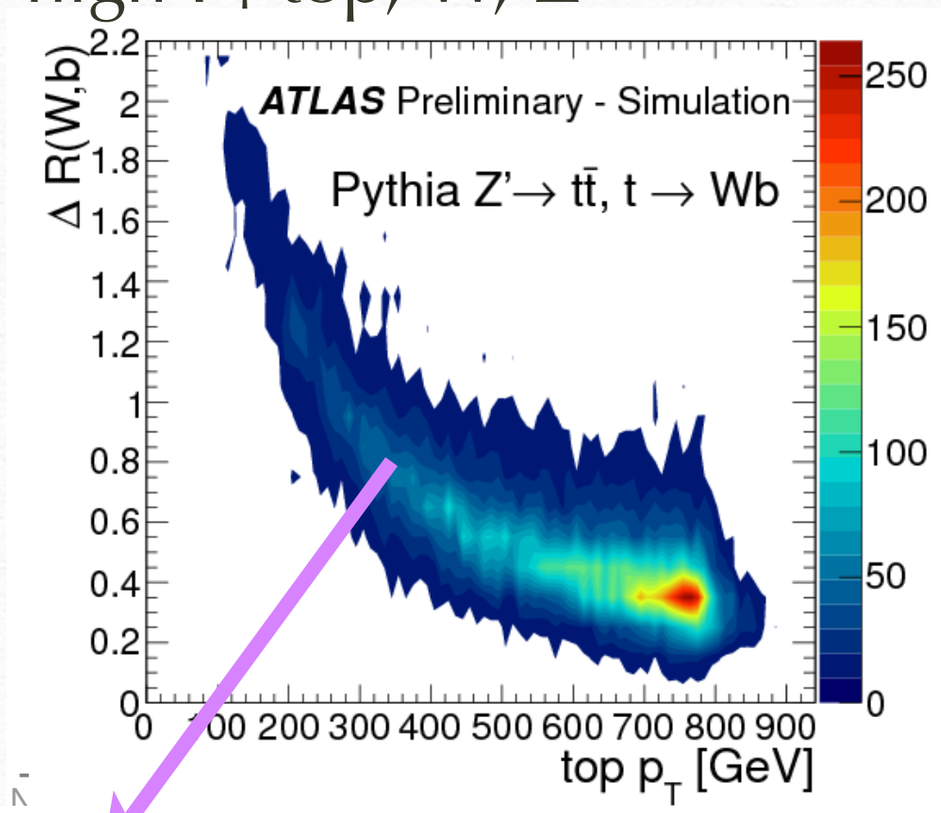
I am not sure if I take this as face value but it is still nice to have such efforts from experimental side

Jet substructure

Technology to find boosted heavy object in a jet

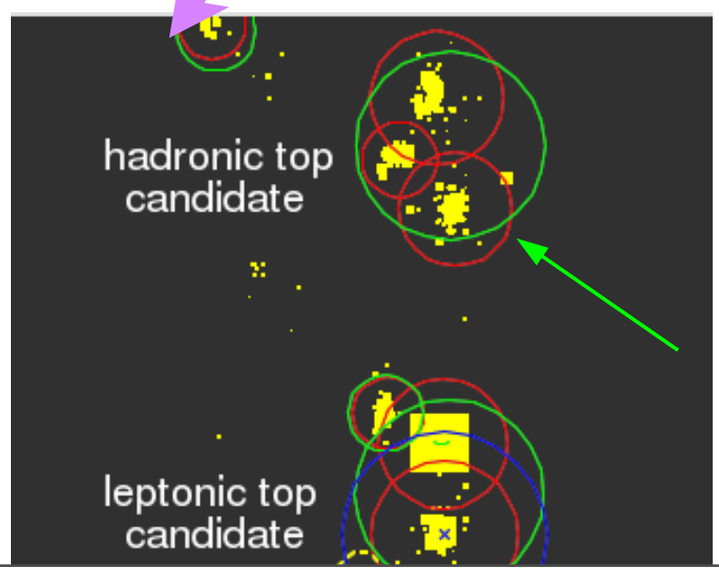


For heavier particle search we expect high P_T top, W, Z

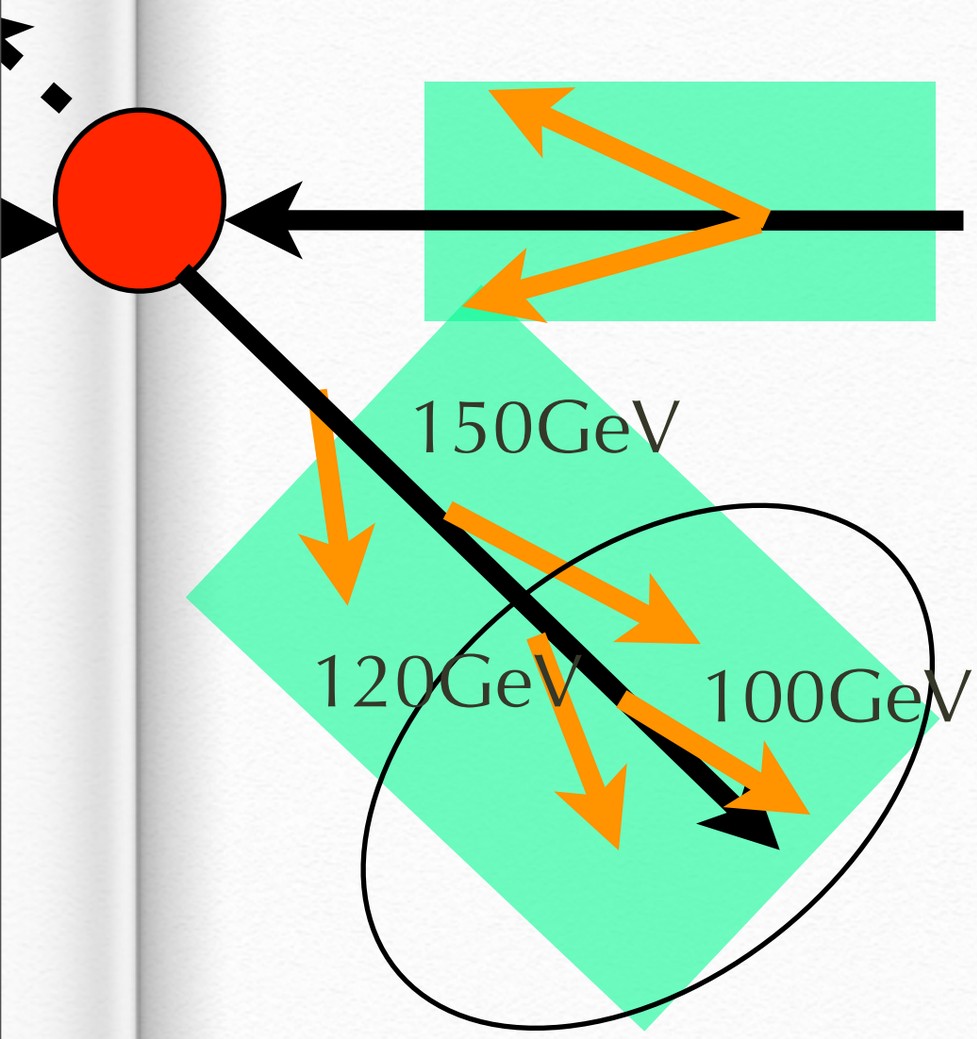


The boosted t, W, Z maybe identified as a single jet but there are structures inside

=mass drop



R = 1.0
m_j = 197 GeV
E_T = 356 GeV

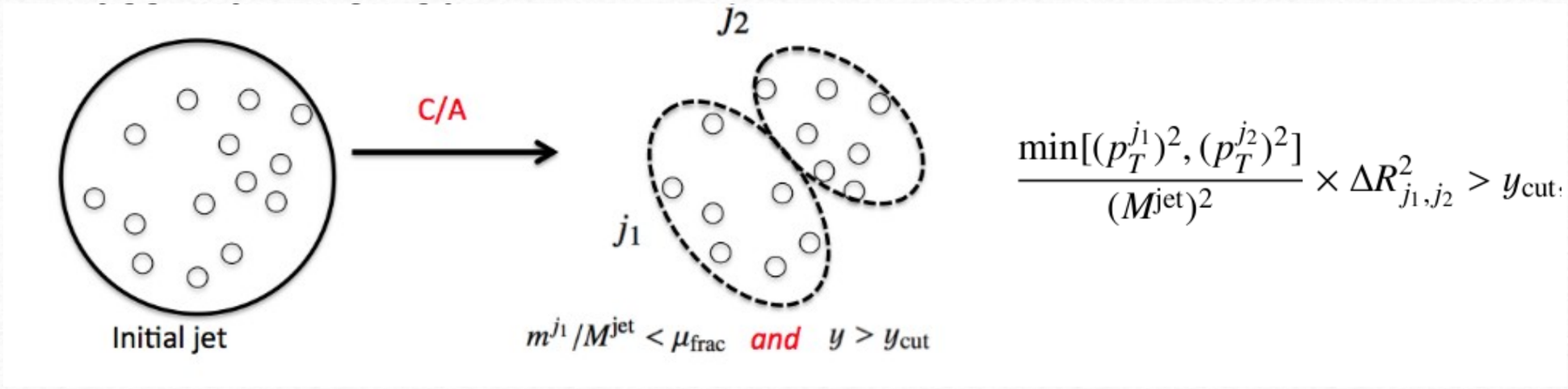


Jet substructure reduce QCD background

single parton would not create sub-substructure

→Mass Drop(identify hard object)

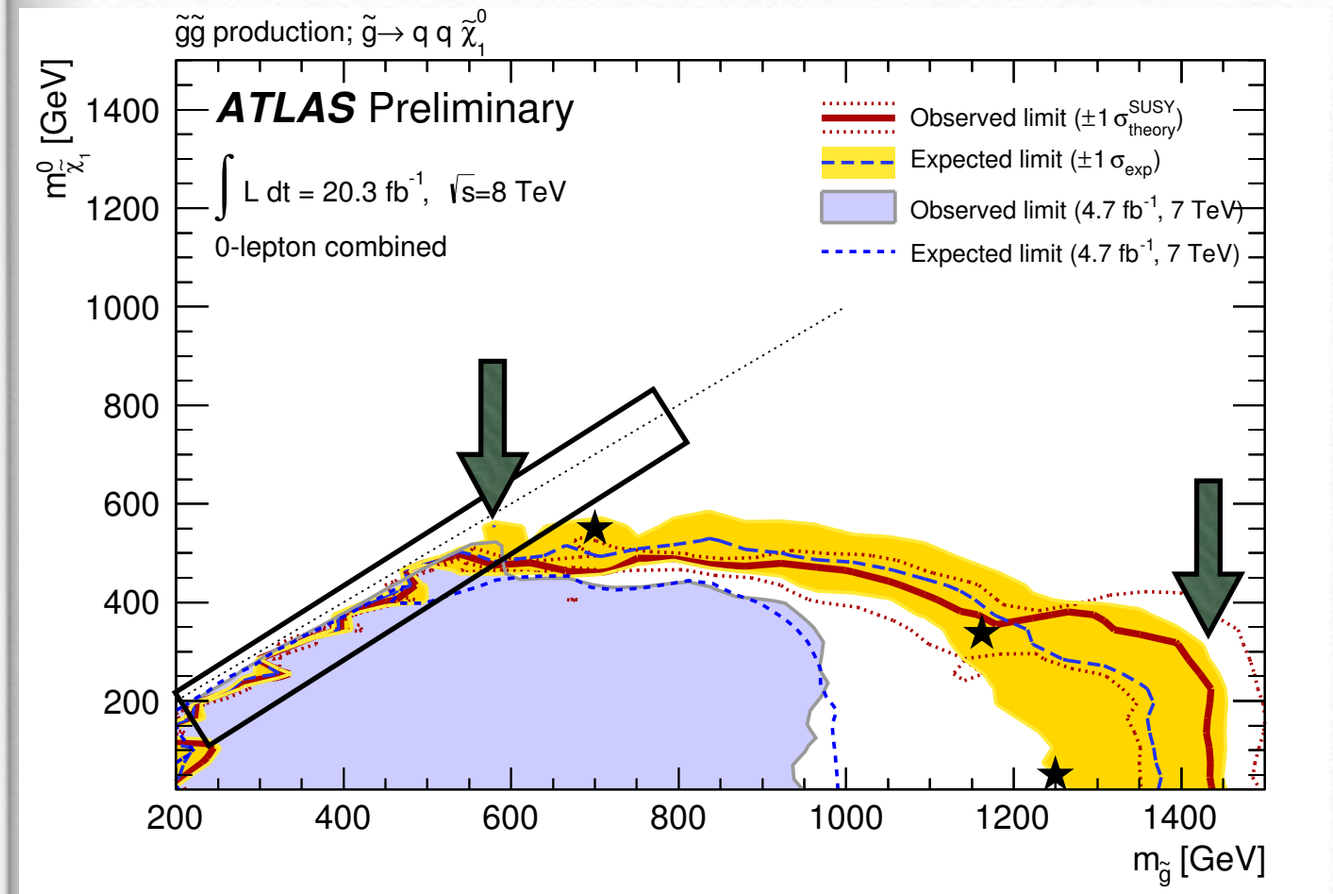
→Trimming(ignore soft activities)



Degenerate SUSY in Simplified model

- **Simplified model: Specify mass and decay pattern instead using full model prediction**
  - Production cross section →mostly QCD
  - Pick up representative decay patterns and mass difference
- Important especially when theorists (roughly) interpret LHC result to their own context.

How light the SUSY particle could be



gluino decay into 2j + LSP

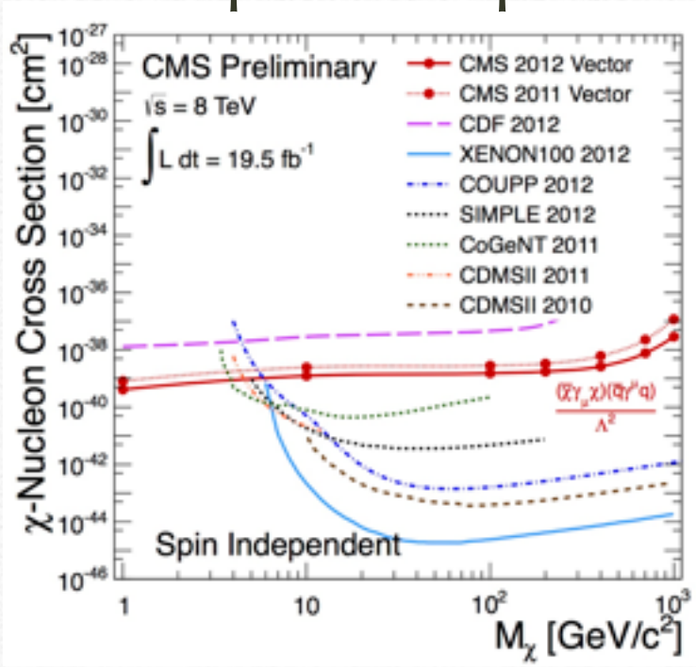
search in the degenerate region
by using ISR
pp→ gluino gluino + jets using
PS-Matrix element matching

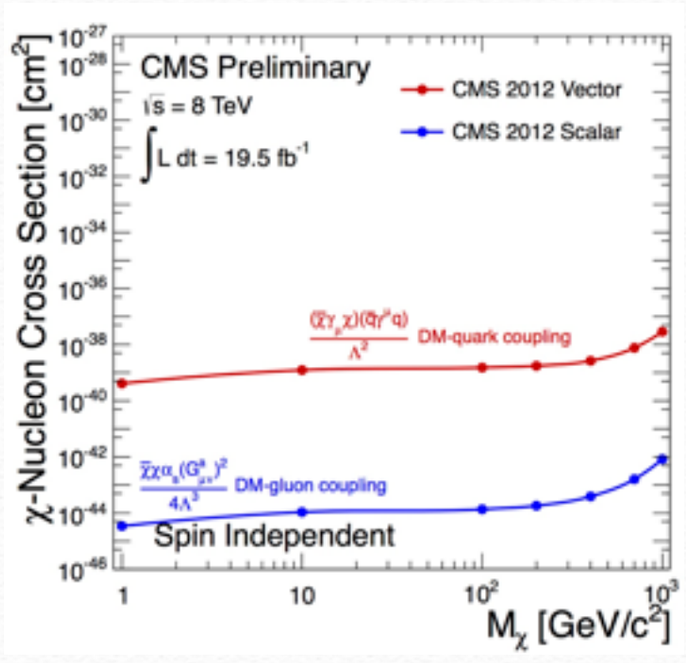
Effective dark matter interactions

- For the dark matter, we may also consider a model independent approach--namely, the coupling between dark matter and matter is expressed by effective coupling
  χΓχ qΓq

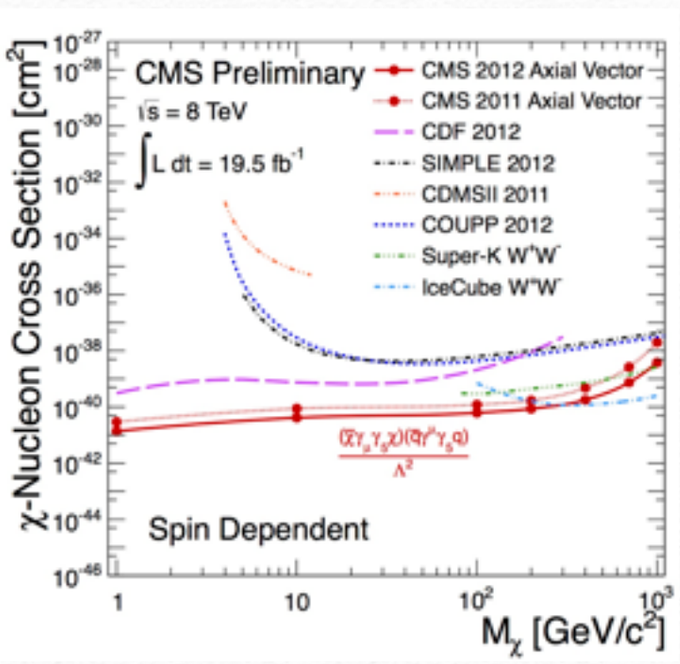
- Especially for spin dependent interaction LHC give very strong limit, especially for light DM($m_\chi < 10$GeV)

spin independent interactions



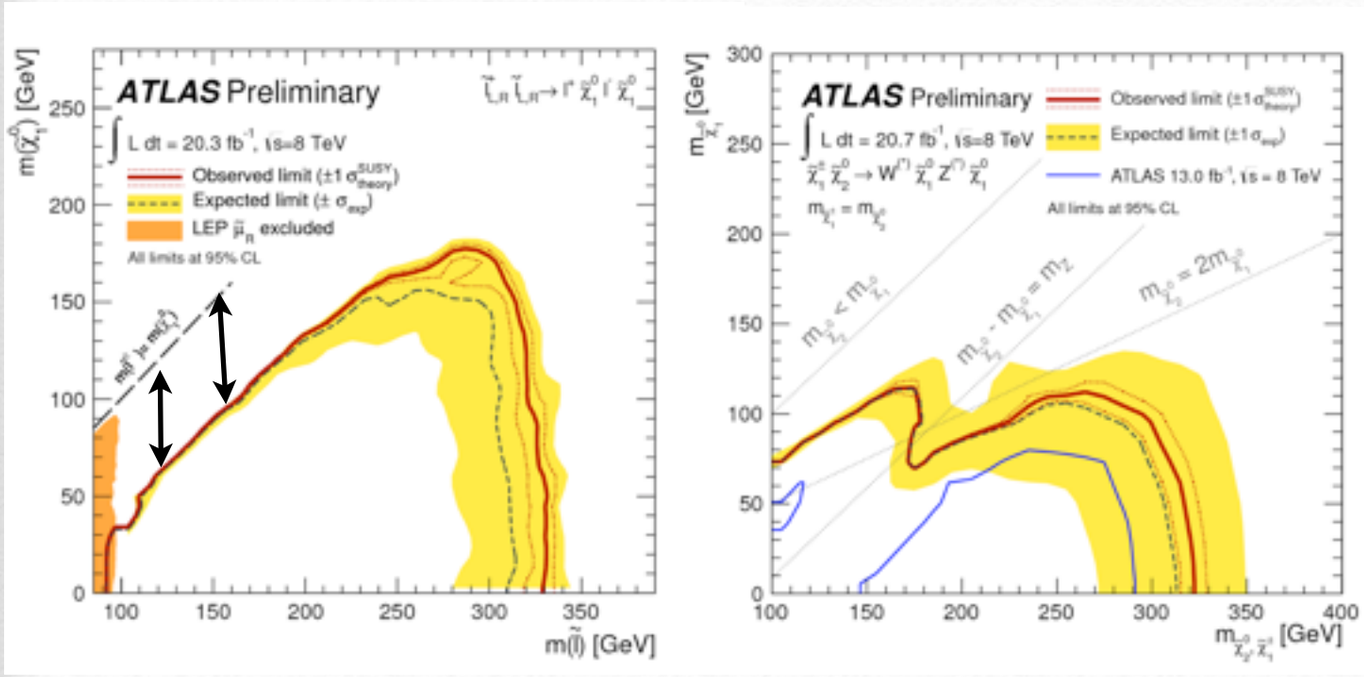


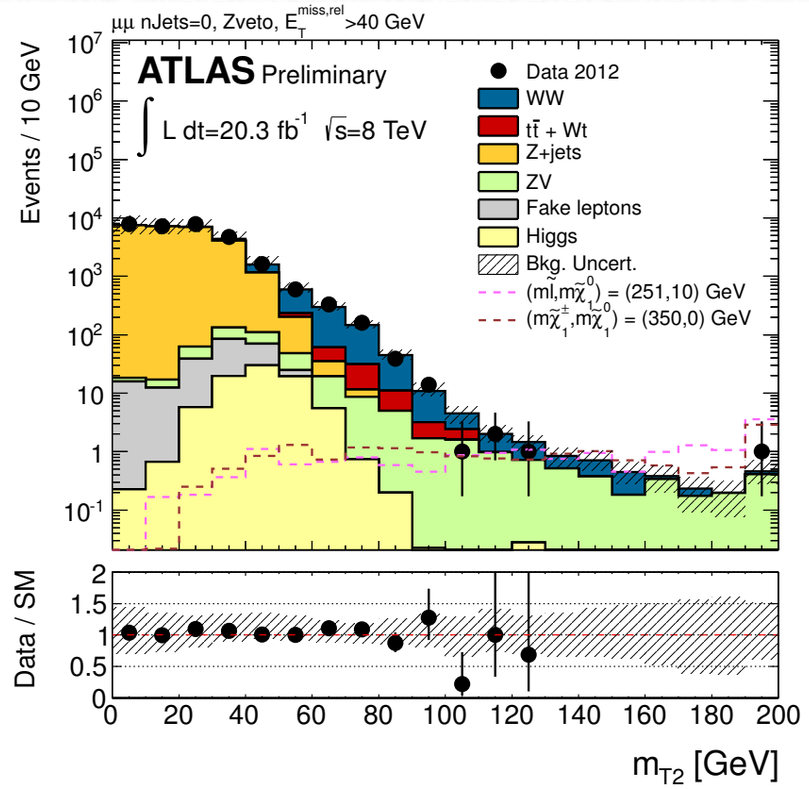
spin dependent



Leptons and photons in Future

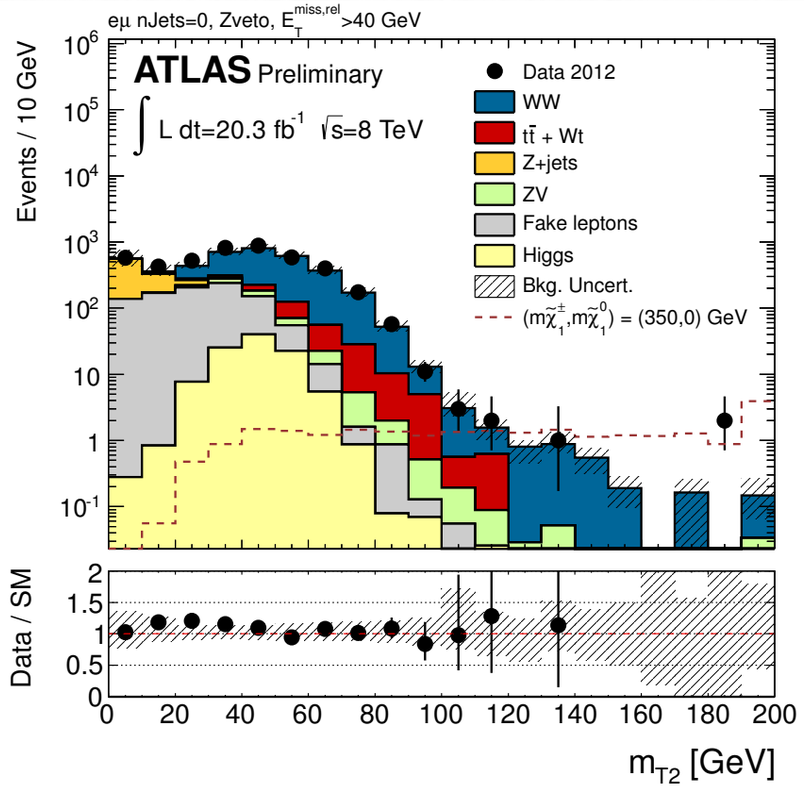
EW SUSY and dark matter





Reach up to 350 GeV!

(f)



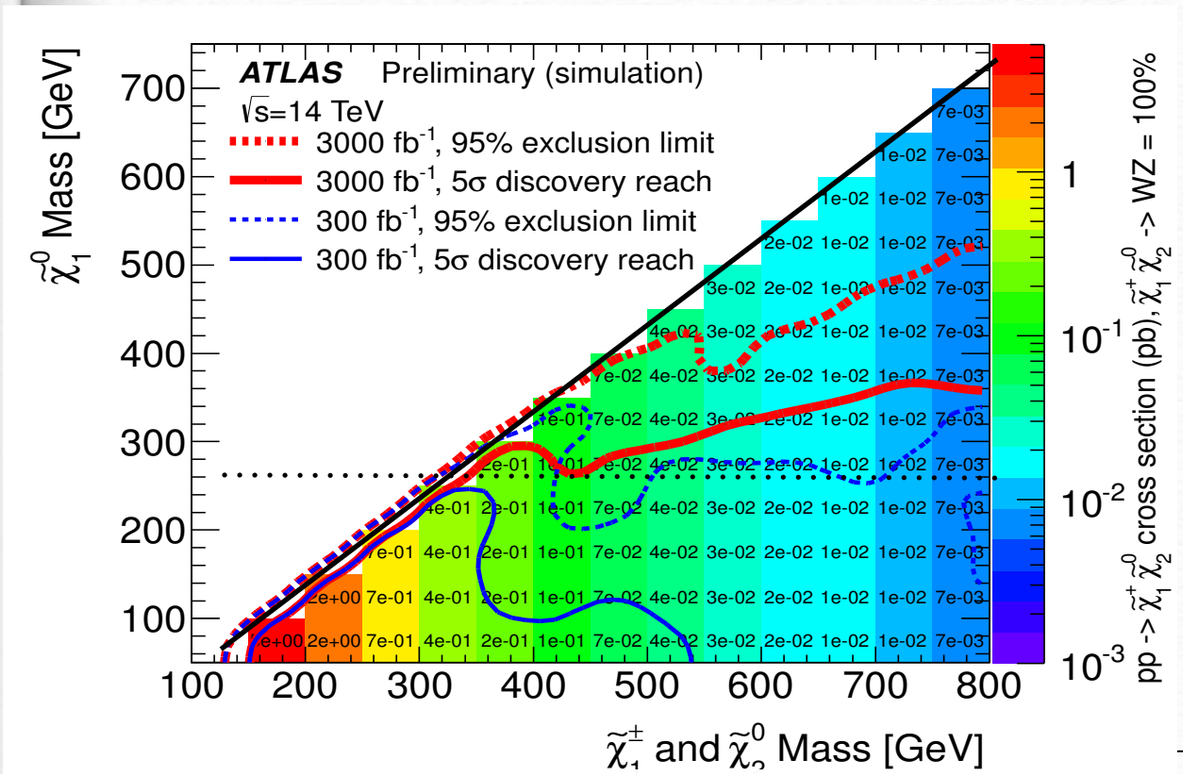
Note however

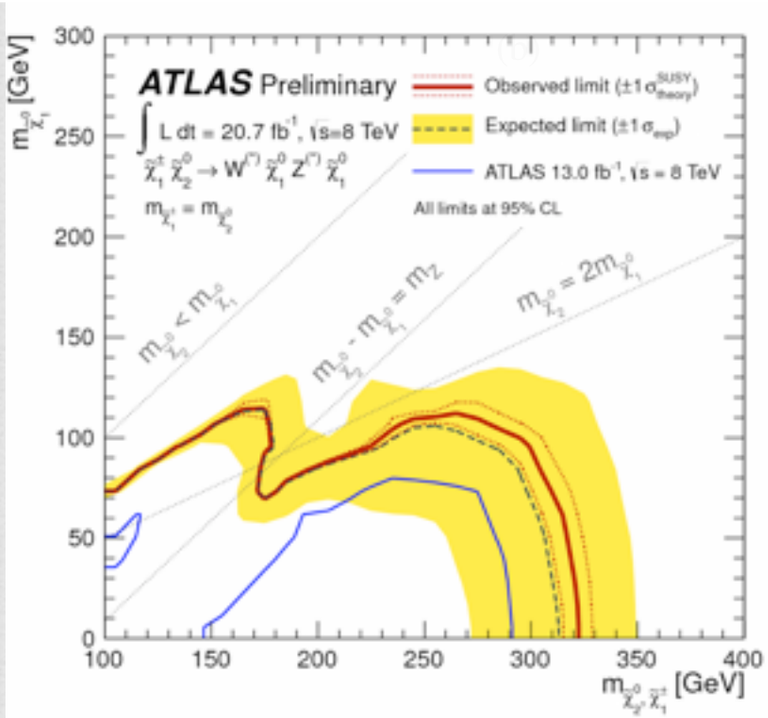
Mass difference 50 GeV required due to the overlap with W and Z's

LHC seems not to sensitive about tau channel

(ILC is more sensitive to those.)

EW SUSY at HL-LHC





current limit

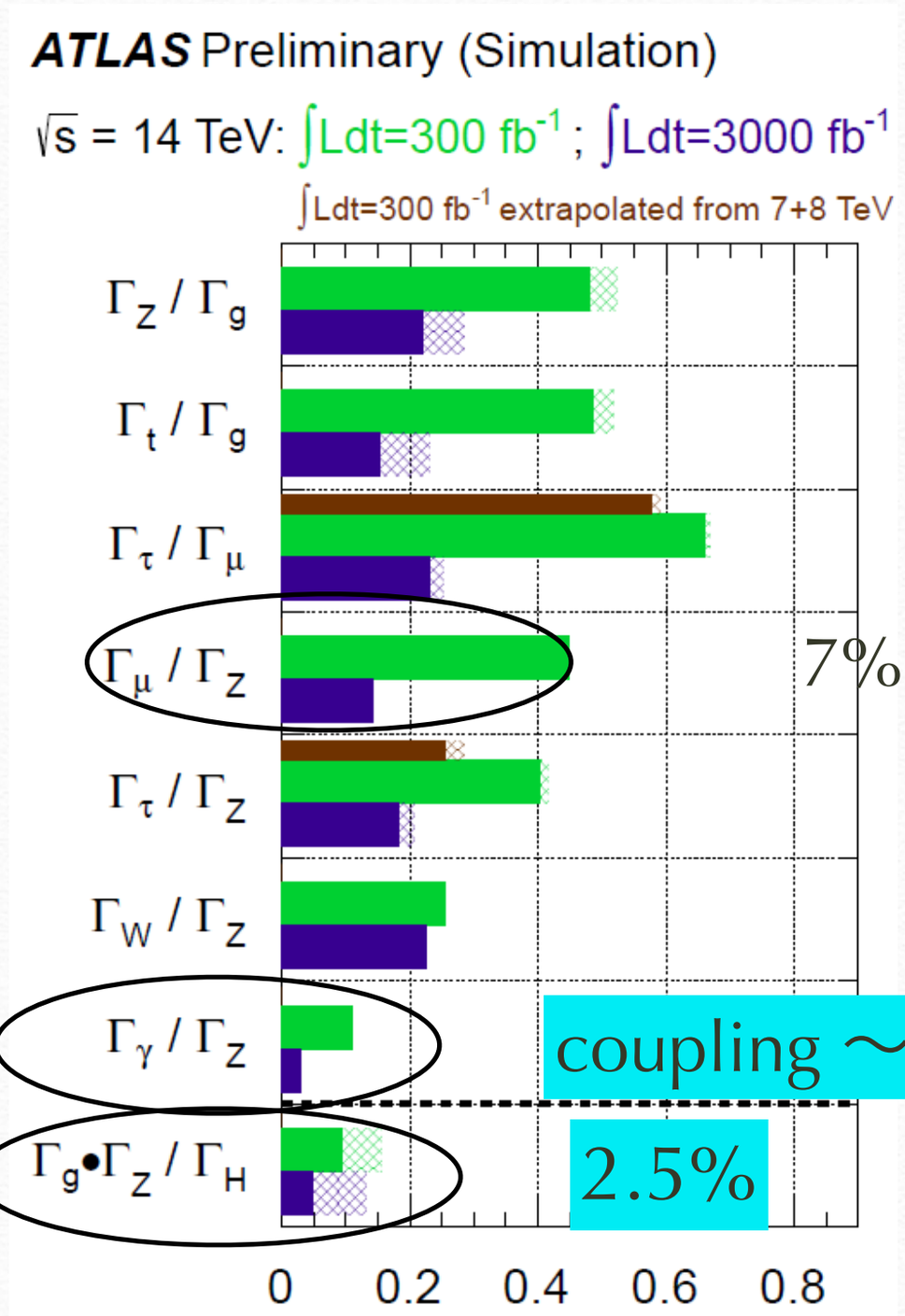
extension at HL-LHC (up to 3000fb^{-1}) because lepton trigger rate will be kept

LHC will be sensitive to Lepton channel !

Object(s)	Trigger	Estimated Rate no L1Track	Estimated Rate with L1Track
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz*
μ	MU20	$>$ 40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	$<$ 1 kHz
$\gamma\gamma$	2EM10	as above	$\sim$5 kHz*
$e\mu$	EM10_MU6	30 kHz	$<$ 1 kHz
$\mu\mu$	2MU10	4 kHz	$<$ 1 kHz
$\tau\tau$	2TAU15I	40 kHz	2 kHz
Other	JET + MET	$\sim$ 100 kHz	$\sim$ 100 kHz
Total		$\sim$ 500 kHz	$\sim$ 200 kHz

Table 2.3: The expected Level-1 trigger rates at 7×10^{34} cm^{-2} s^{-1} for the baseline sel

HL-LHC and Higgs Boson



Γγ/Γz ~2% error from HL-LHC phase2

⊕

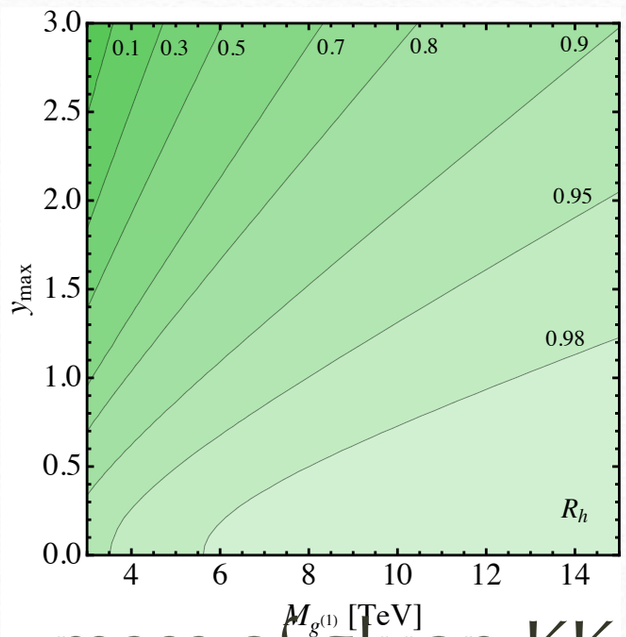
ILC error of H width
0.44% at 500GeV,

⇓

O(1%) Br for γγ, and gg, loop physics

correction to gg→ h production
Carena et al JHEP 1208(2012)156

Yukawa of KK



H->γγ is more sensitive mass of gluon KK

conclusion

- Existing BSM starts being constrained. Extended models are not so simple-- if they are correct answer, why?

- The success of LHC is based on QCD/MC technology

- after 13TeV run, there will be HL-LHC run. Low threshold allows us to study EW sector of new physics strongly.

- ILC, if can be build will allow us to study it further.