宇宙の進化と素粒子模型

平成２５年度宇宙線研究所共同利用研究成果発表会

宇宙線研究所理論グループ　伊部昌宏

東大宇宙線研 ：川崎、伊部、金田、他

名古屋大：久野　　　京都大学：瀬波

金沢大：青木　　　東北大：高橋史宜

KEK：郡　　　東工大：山口、斎川

神奈川大：粕谷　　　佐賀大：高橋智

（合計２３名）

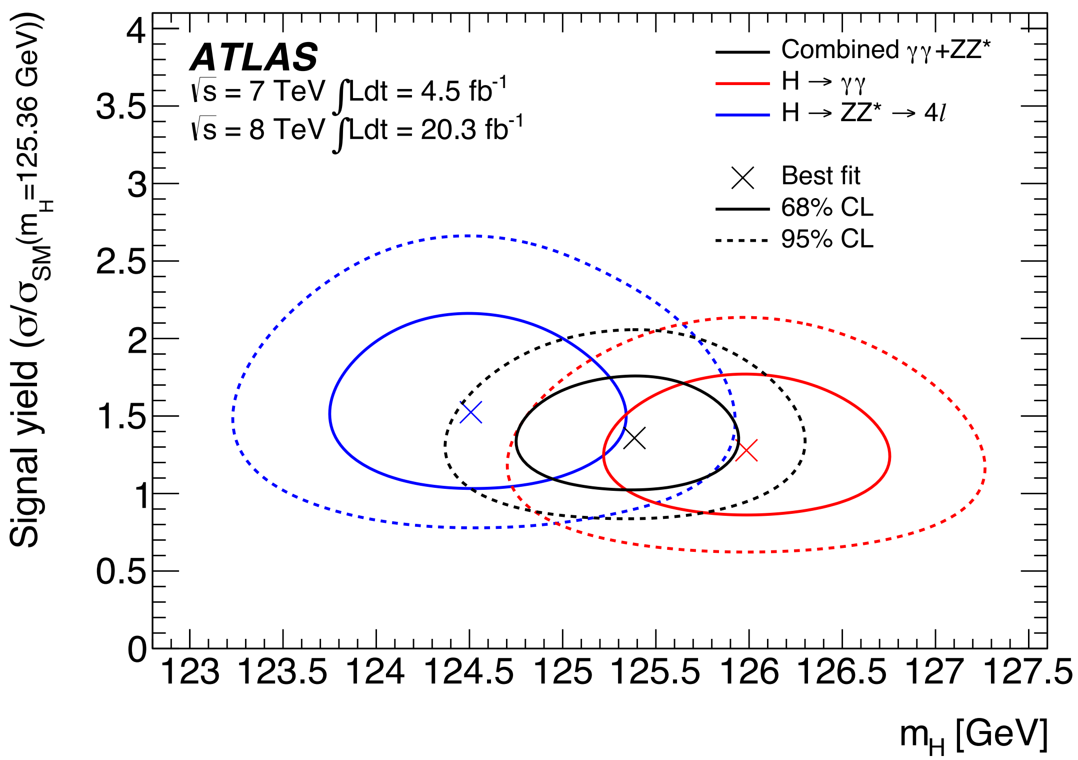
国内旅費：10万円

Coupling Unification and Dark Matter in a small extension of the Standard Model

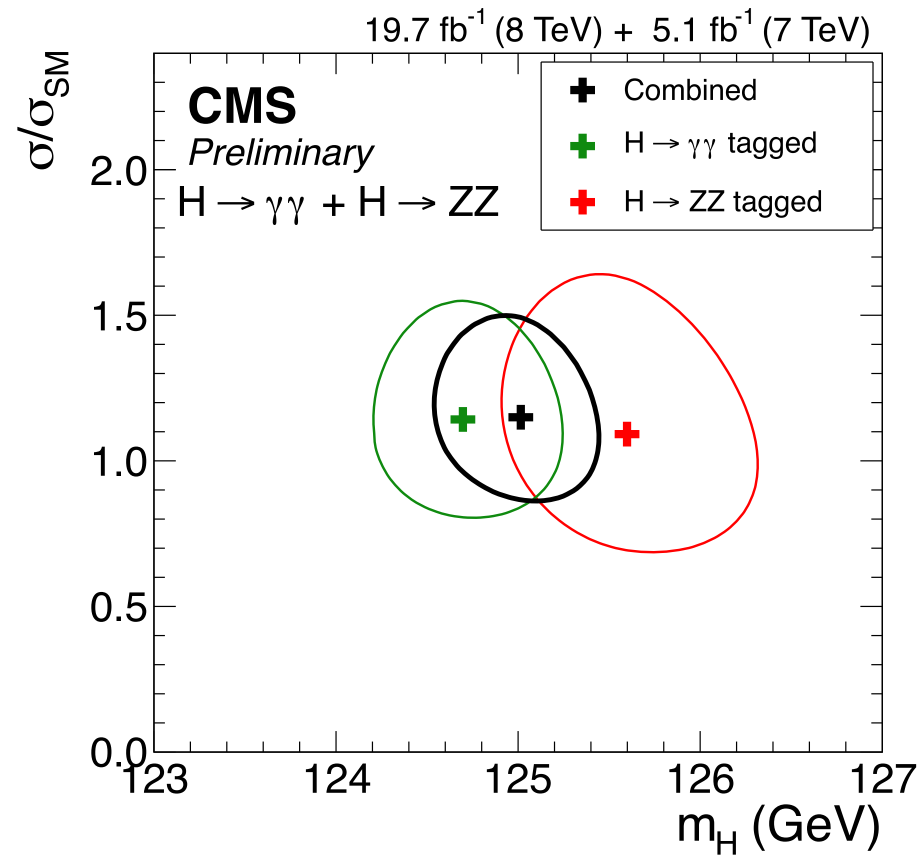
SM is being completed

The mass of the Higgs is around ***125GeV*** !

[ATLAS:1406.3827]



[CMS:HIG-14-009]



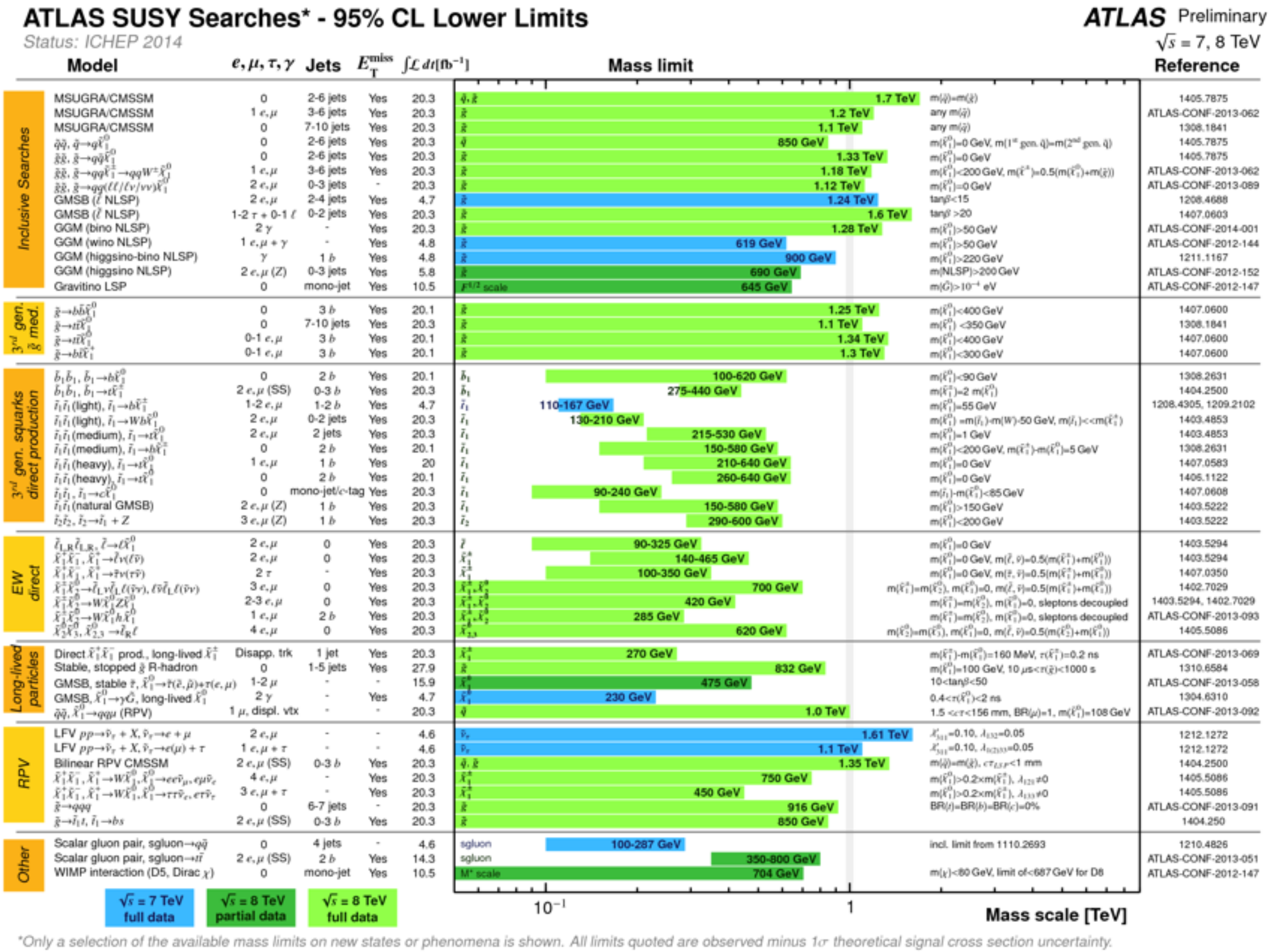
Both the ATLAS and the CMS discovered a new boson with mass around 125-126 GeV compatible with the SM Higgs boson!

[ATLAS:Phys.Lett.B716(2012)1, CMS:Phys.Lett.B716(2012)30]

The SM has been completed !

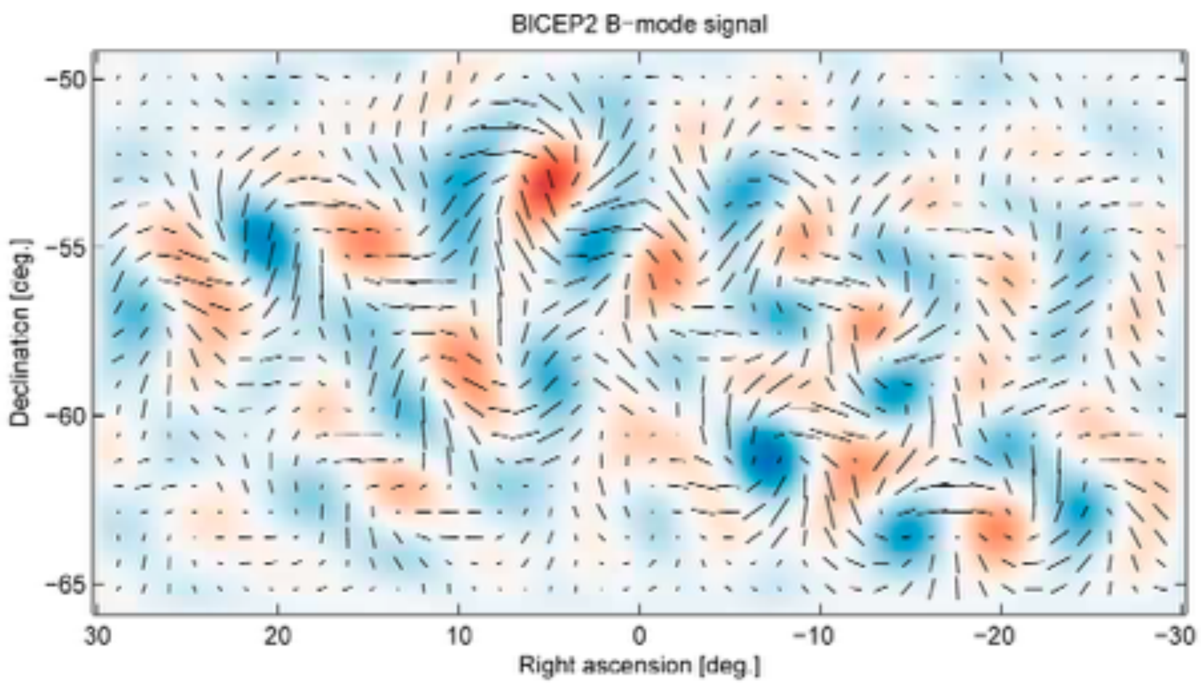
How about New Physics @ Collider Experiments?

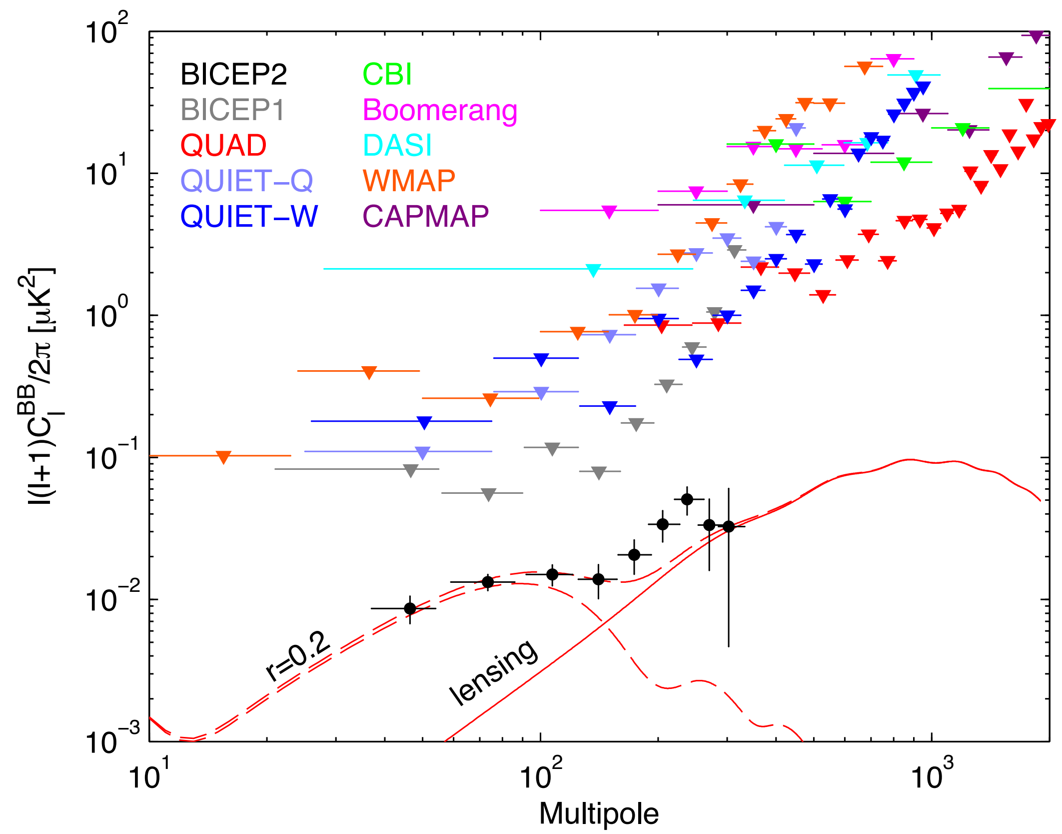
No signals so far … (ex. Supersymmetry)



Other Indications ?

CMB B-mode detection by the BICEP2 → ***r ~ 0.2*** ?





If this is correct, it indicates the energy scale during inflation !

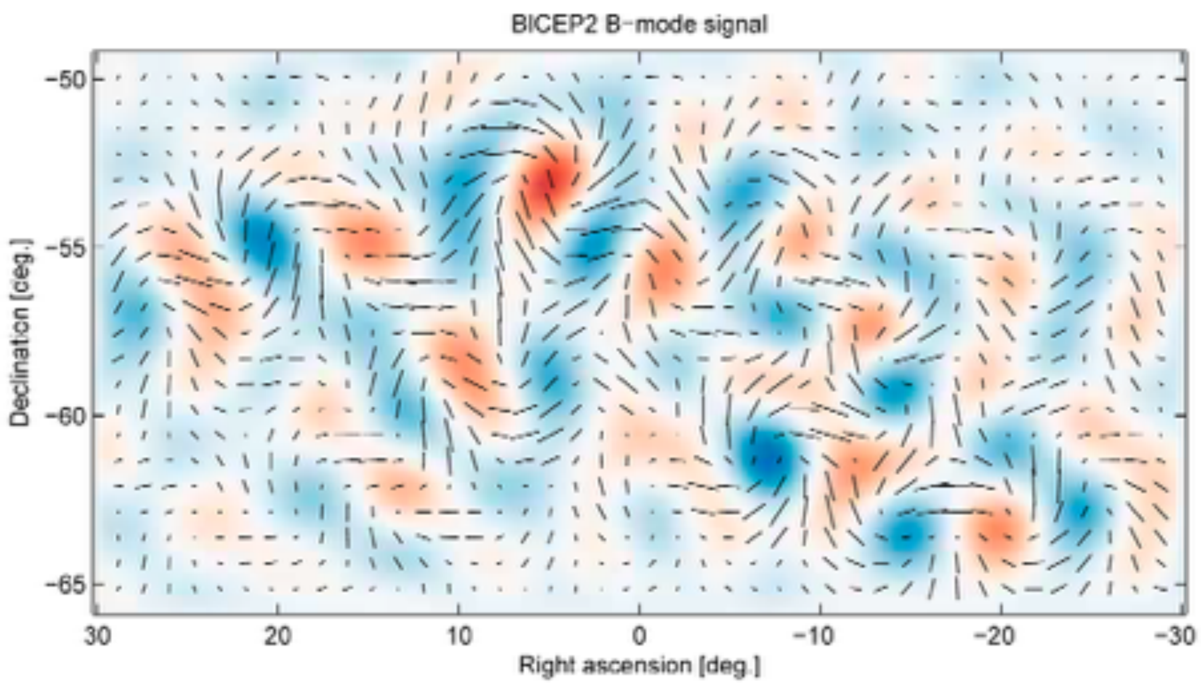
$$V \sim (2 \times 10^{16}\ \mathrm{GeV})^4 (0.2/r)$$

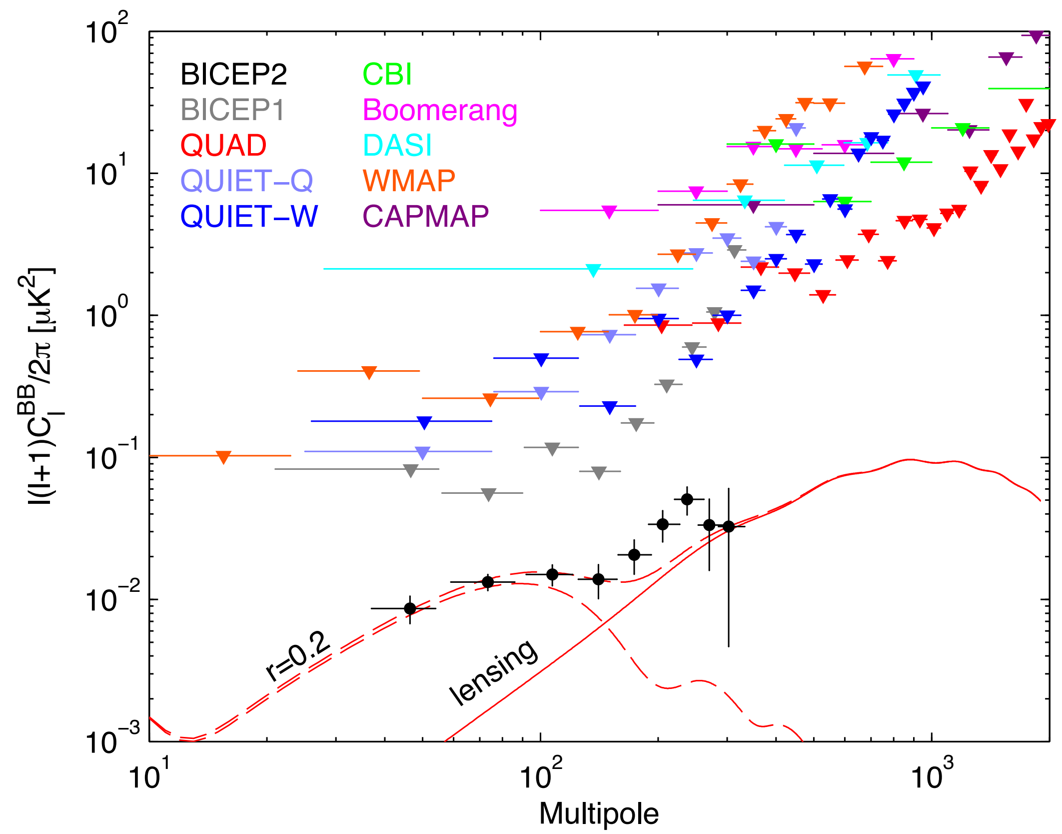
This result also suggests a very special type of inflation

Chaotic Inflation !

Other Indications ?

CMB B-mode detection by the BICEP2 → ***r ~ 0.2*** ?

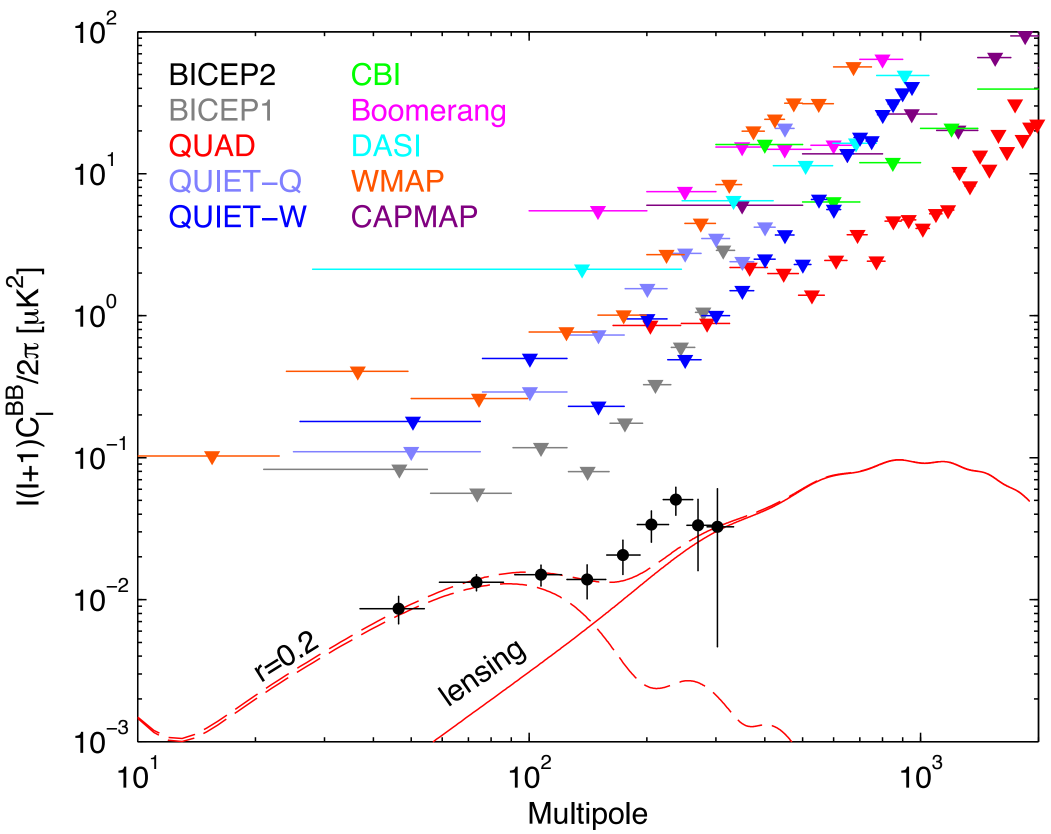


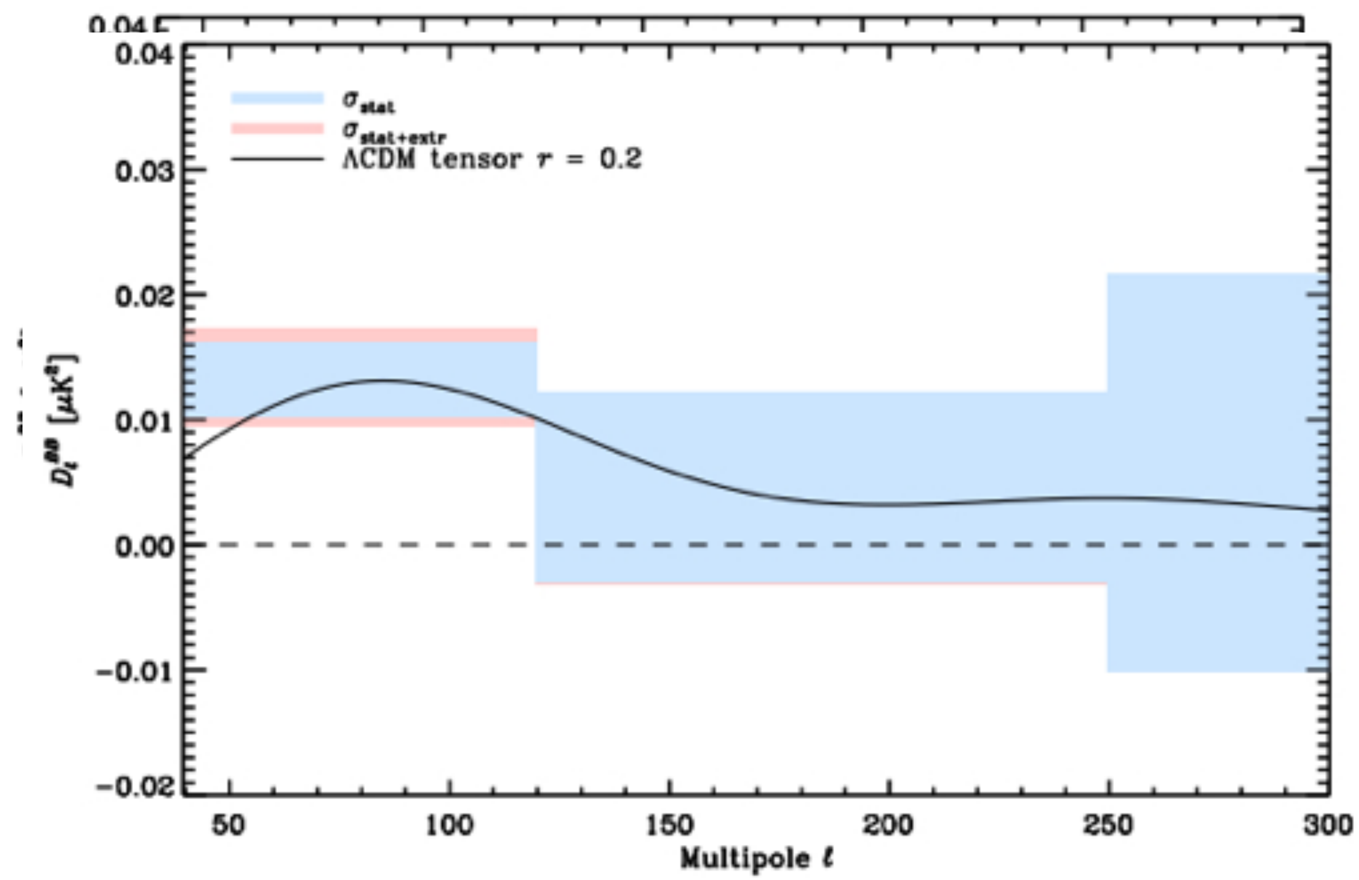


We were inspired a lot and our group produced more than 30 papers in 10 months !

Other Indications ?

CMB B-mode detection by the BICEP2 → ***r ~ 0.2*** ?





Planck experiments showed that the foreground contribution seems larger than expected…

→ ***We need to wait for the results of the joint analysis…***

Guiding Principles for Beyond the Standard Model ?

Ground Unification

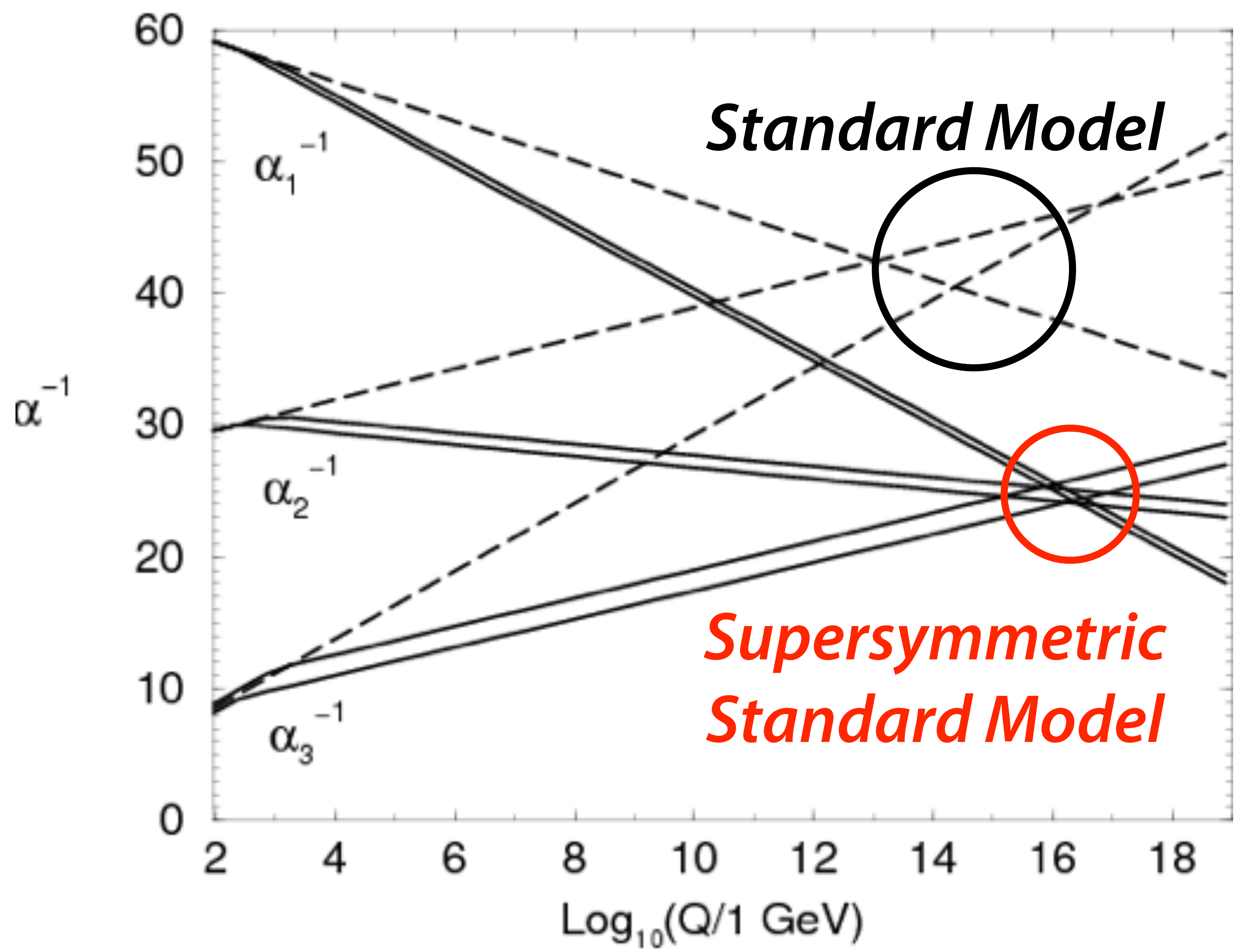
- ✓ ***Standard Model = Unified theory of electromagnetic and weak interaction.***
- ✓ ***Three gauge coupling constants unify at high energy rather well.***

Dark Matter

- ✓ ***Rotational curve of the galaxies***
- ✓ ***Gravitational Lensing***
- ✓ ***CMB, Large Scale Structure***

Guiding Principles for Beyond the Standard Model ?

Very Good Example = Supersymmetry



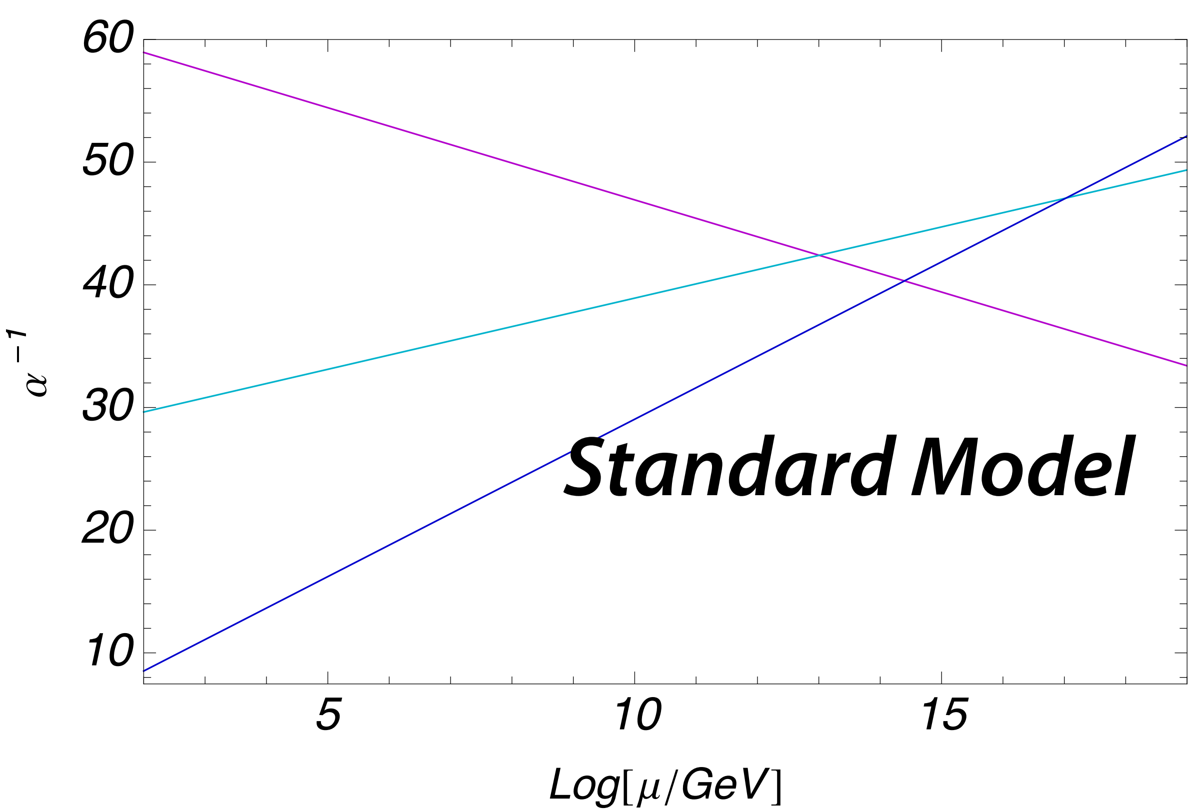
Better Unification & LSP dark matter

Guiding Principles for Beyond the Standard Model ?

However, to achieve unification and dark matter, we do not need a gorgeous symmetry

For unification (with long enough proton lifetime) :

- ✔ ***We need colored and SU(2) charged matter to bend the running of coupling.***



The running of α_1^{-1} only bends downwards

Long lifetime of proton requires to bend both SU(2) and SU(3) running.

Guiding Principles for Beyond the Standard Model ?

However, to achieve unification and dark matter, we do not need a gorgeous symmetry

For unification (with long enough proton lifetime) :

- ✓ ***We need colored and SU(2) charged matter to bend the running of coupling.***

For dark matter

- ✓ ***We need a stable neutral particle .***

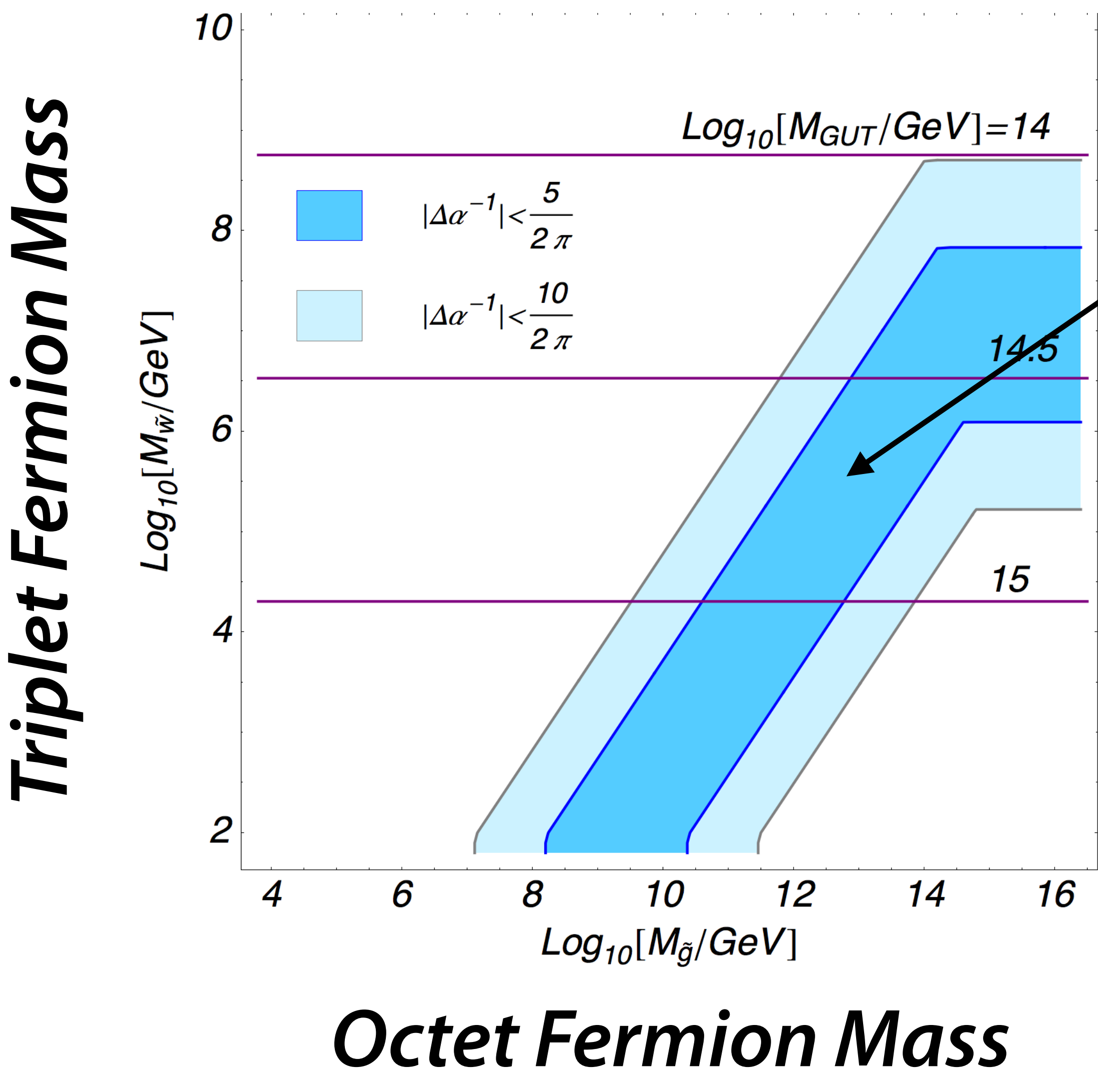
What is the minimal choice ?

Majora adjoint fermions !

[SU(2) triplet (e.g. Z, W-boson) , SU(3) octet (e.g. gluon)]

Majorana Fermion Extension

We can predict mass ranges from better unification !



- ***In this range, the couplings unify as good as in the MSSM!***

  Triplet : 10^2 - 10^4 GeV

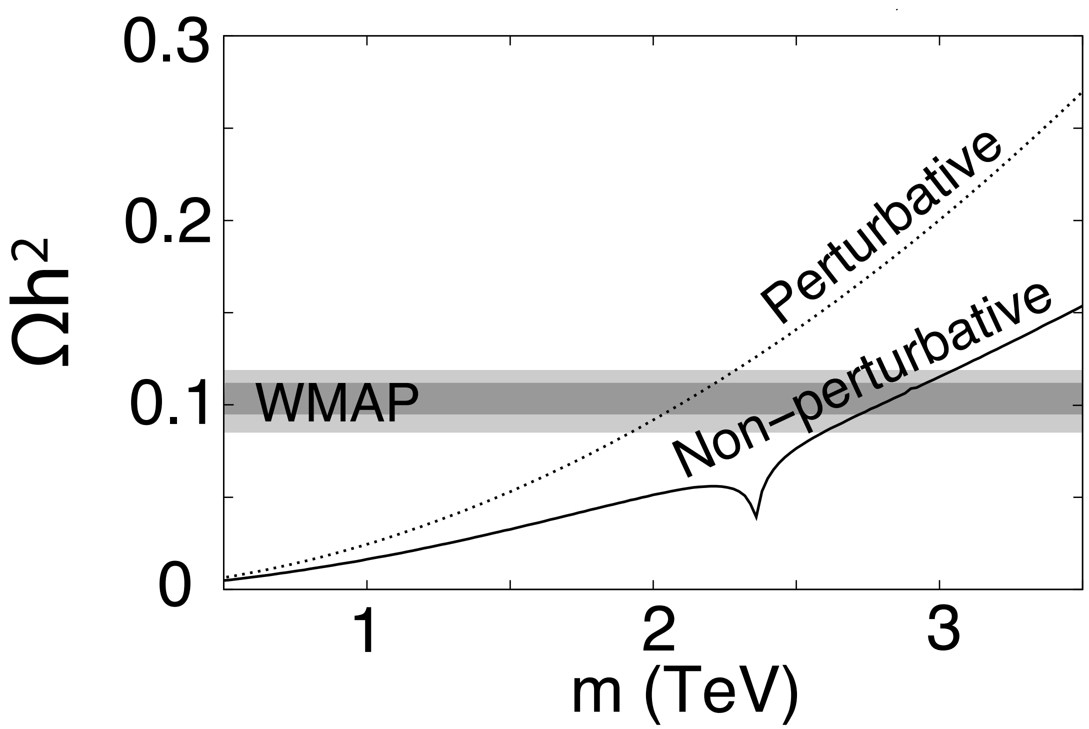
  Octet : $10^{7\text{-}8}$ x Triplet Mass

- ***The model predicts a rather low GUT scale !***

Majorana Fermion Extension

Triplet Mass : 10^2 - 10^4 GeV !

Thermal Wino Dark Matter



['07 Hisano, Matsumoto, Nagai, Saito, Senarmi]

✔ ***Triplet Fermion includes Neutral Component***

→ Good Dark Matter Candidate !

If it is produced thermally

→ Triplet Mass = 3TeV !

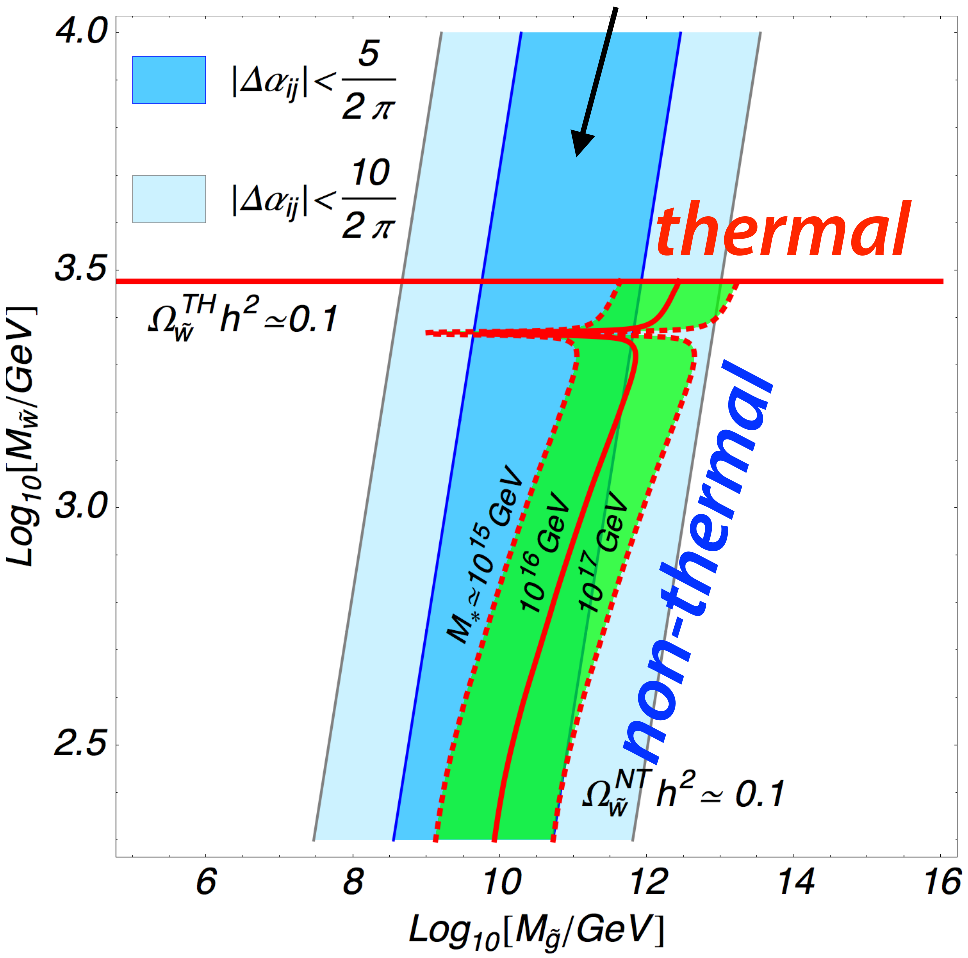
Can the lighter triplet be a good DM candidate ?

Majorana Fermion Extension

The triplet Dark Matter can be provided by the decay of the Octet Fermion !

Late time decay of Octet → Triplet + a quark pair !

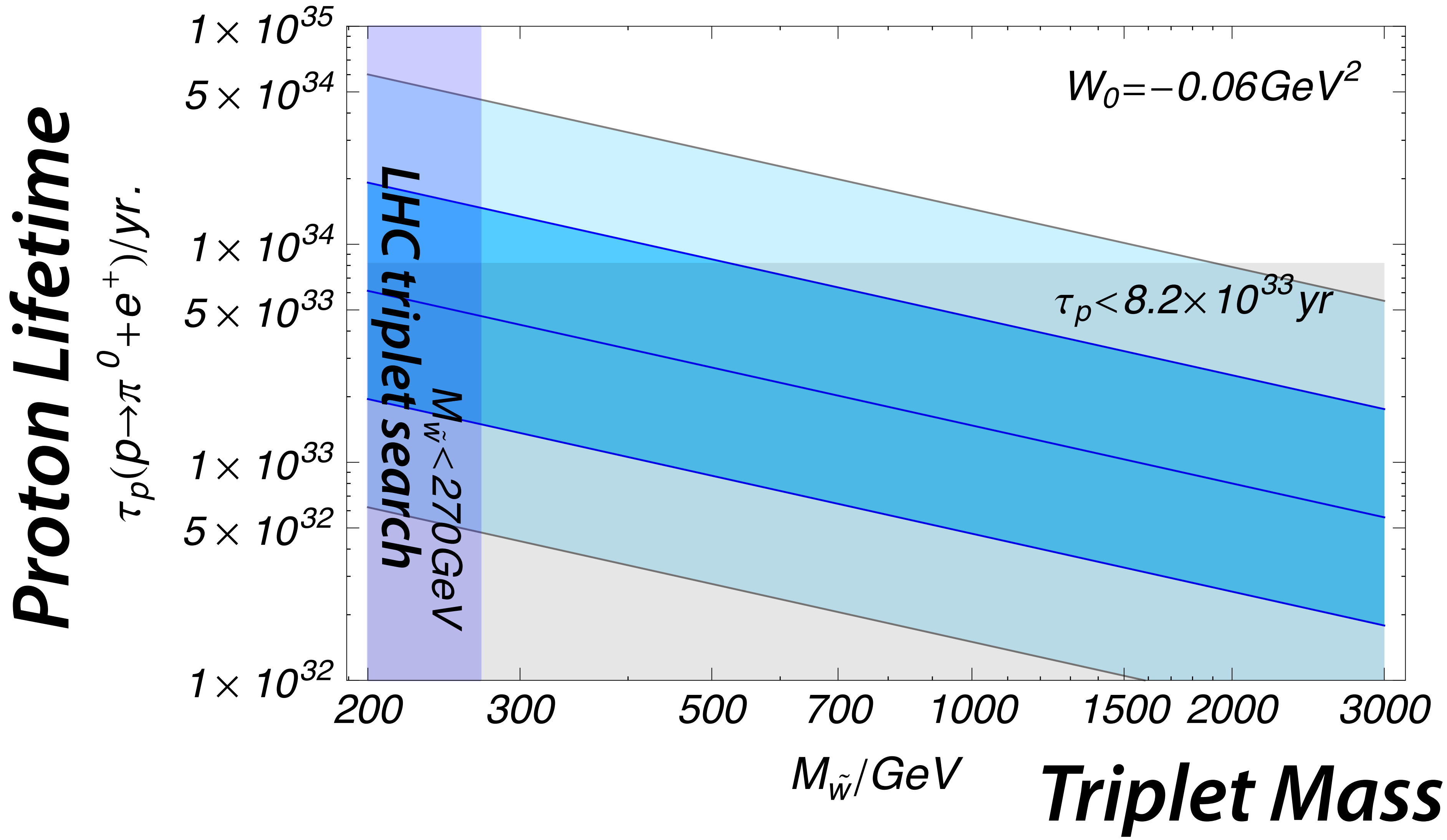
Good Unification



The non-thermal triplet abundance is independent of the octet fermion abundance.

Majorana Fermion Extension

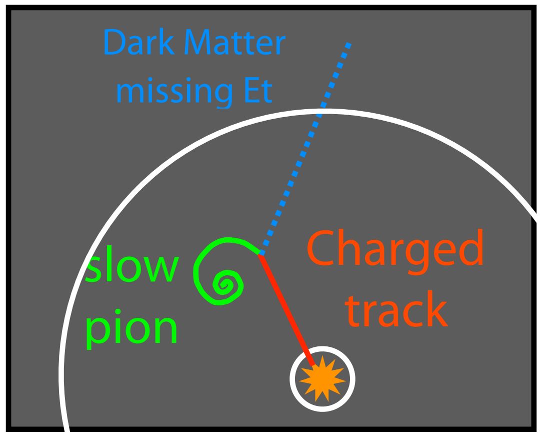
Prediction on the Proton Decay



Most Parameter space has been excluded by the SK !

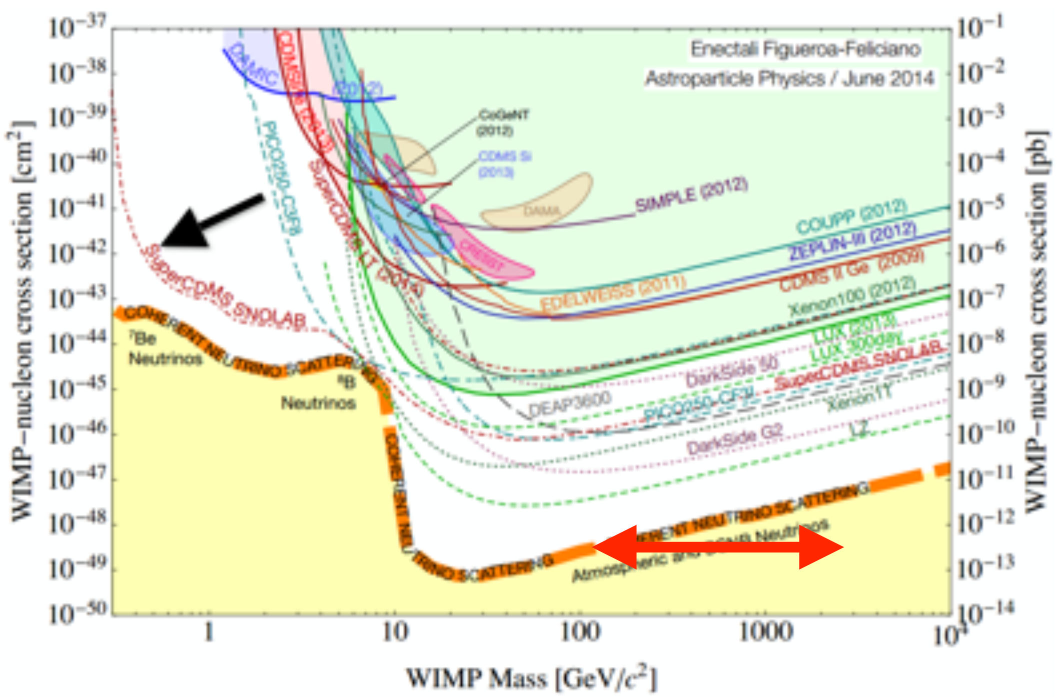
With the HK, this model can be fully tested !

Majorana Fermion Extension



LHC triplet search : lower limit 270GeV

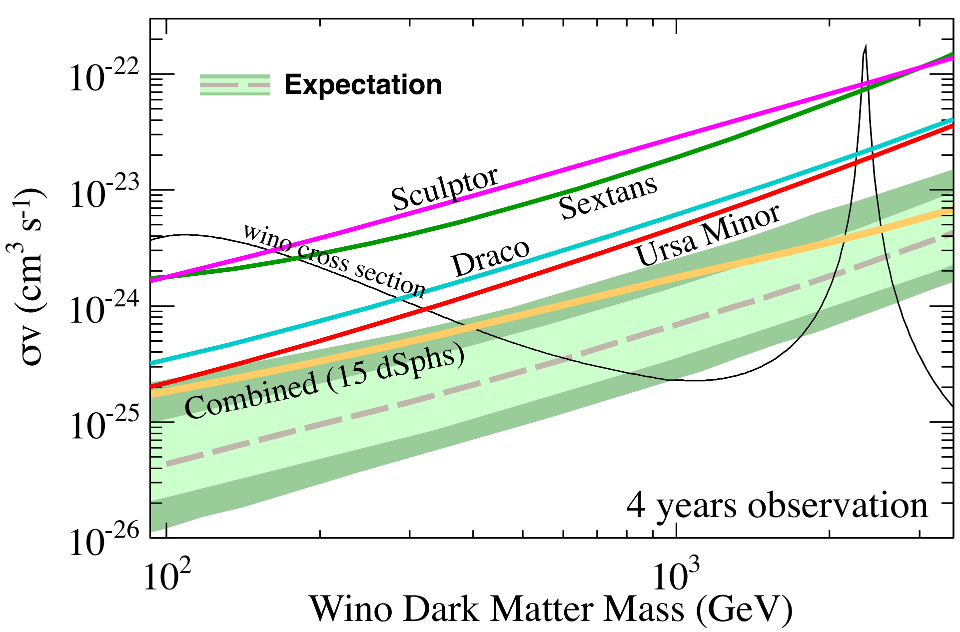
Future LHC could reach to 500GeV



Direct Detection :

$\sigma \sim 10^{-47} cm^2$

challenging but not impossible!



Gamma Ray search (from dSps)

Lower limit 400 GeV

Most promising in foreseeable future!

Summary

After the success of the Standard Model (i.e. the unified theory of the electromagnetic and weak interaction), it is worthy to reappraise the long-standing idea, the Grand Unification.

In particular, it is one of the good strategy to start from the minimal possibilities.

The Majorana extension is one of the minimal possibilities.

Can be tested via the proton decay, the LHC search, the Dark Matter direct and indirect searches !