SEARCH FOR A HEAVY CHARGED HIGGS BOSON

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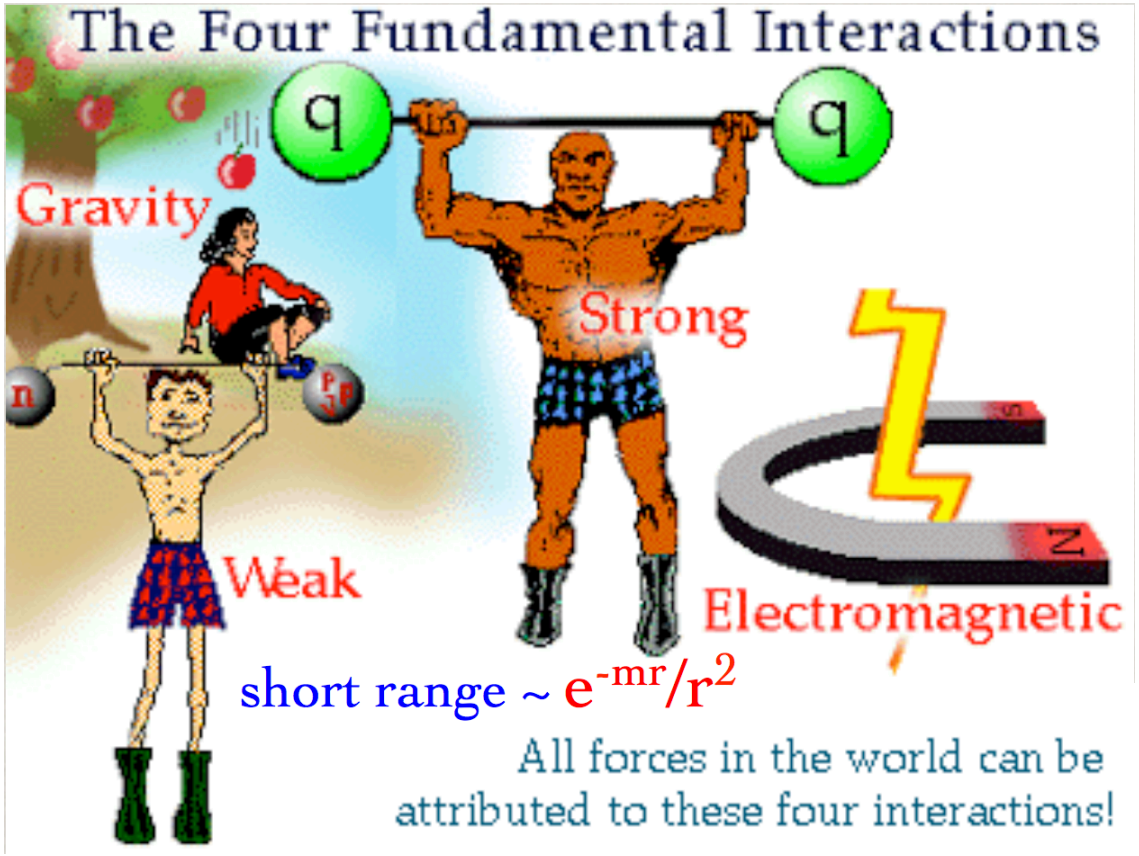
OUTLINE

- Introduction
  - Standard Model
  - Charged Higgs
  - LHC & ATLAS
- Analysis
  - Analysis introduction
  - Analysis strategy
  - Reconstruction BDT
  - Results
- Summary

STANDARD MODEL



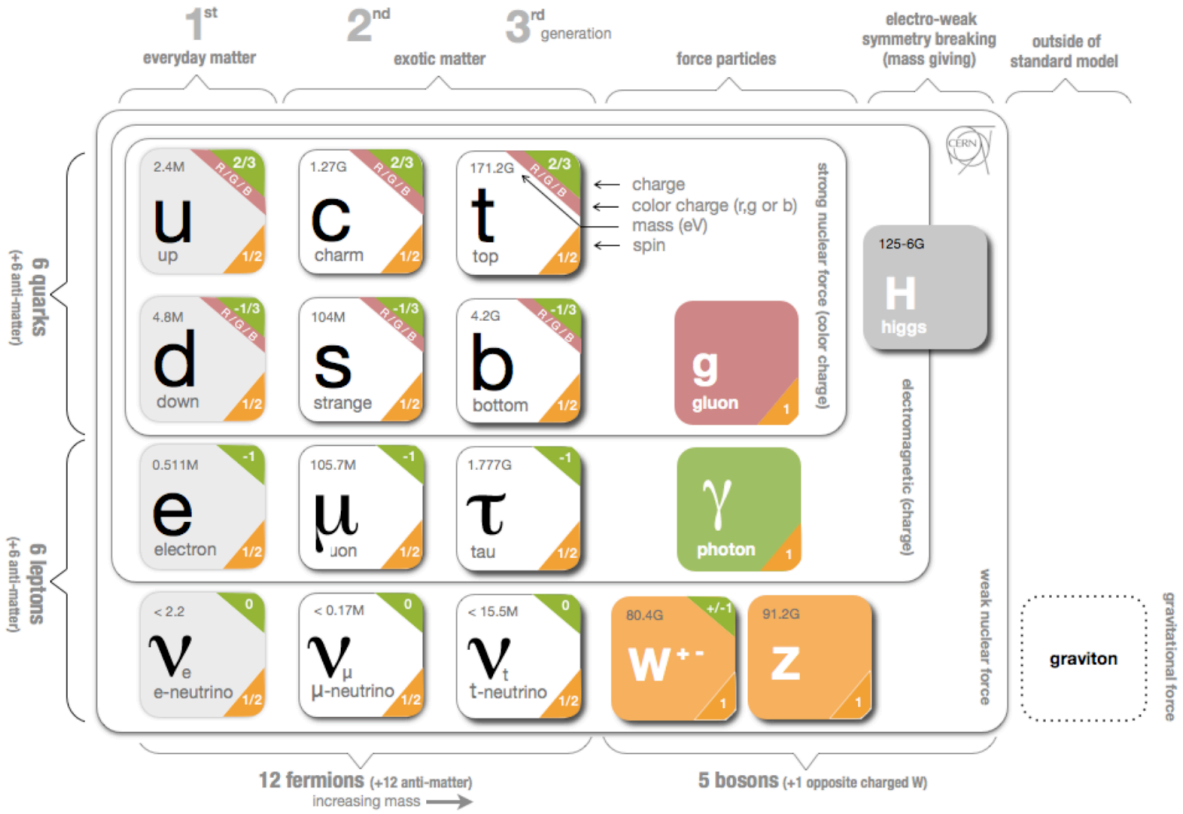
- A way of understanding the fundamental nature
- The 4 fundamental interactions:
  - Electromagnetic
  - Weak
  - Strong
  - Gravity
- So far it's the most successful theory we have
  - High precision
  - Predictive
  - ~ 19 Nobel prizes

$$\underbrace{SU(3)_{\text{Color}}}_{\text{QCD}} \quad \underbrace{\otimes SU(2)_{\text{Left}} \otimes U(1)_{\text{Hyper charge}}}_{\text{WEAK} \oplus \text{QED}}$$

(Strong Interaction)

Unification of Weak and Electromagnetic

STANDARD MODEL



All particles predicted have been discovered

Particles are split into 2 categories by spin:

- Fermion : Half integer spin
- Boson : Integer spin

Fermion :

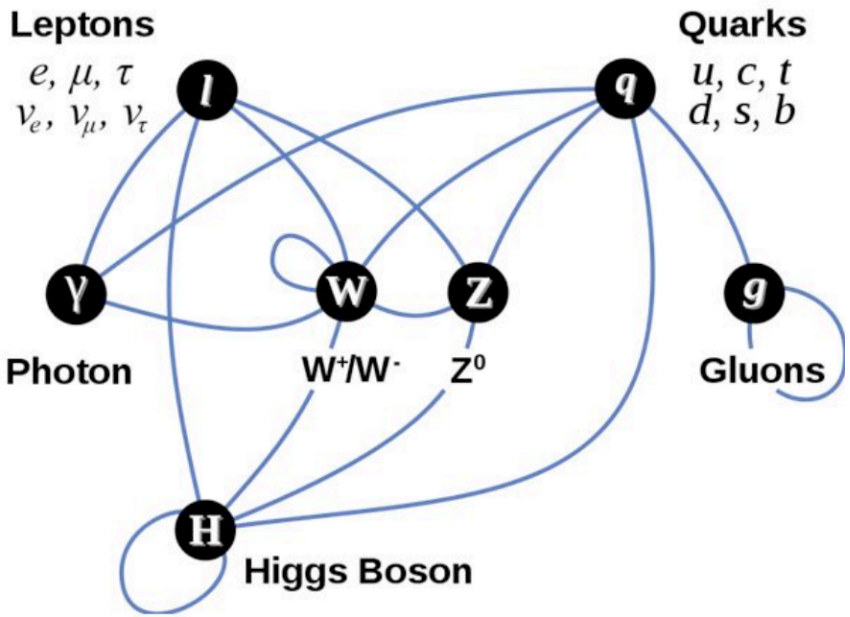
- Lepton:
  - Charged (electrons, muons, taus)
  - Neutrinos
- Quark:
  - up, charm, top
  - down, strange, bottom

Boson:

- Photon : Electromagnetic
- W+/W-/Z : Weak
- Gluon : Strong
- Higgs

} Intermediate

STANDARD MODEL



Tree level interactions between SM particles:

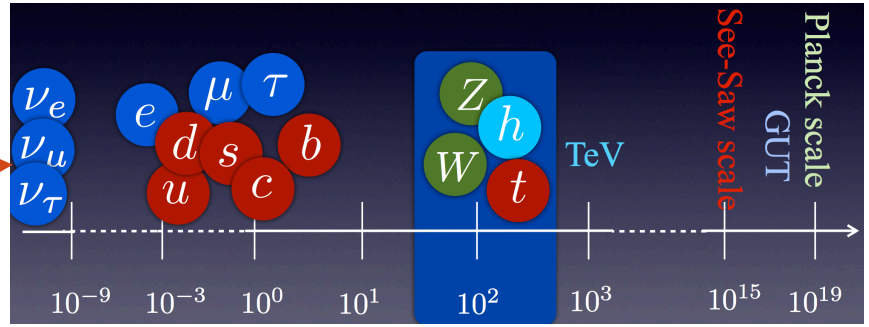
- Leptons don't undergo strong interaction
- Quarks undergo all interactions
- All charged particles interact with photon
- Higgs boson interact with all massive particles

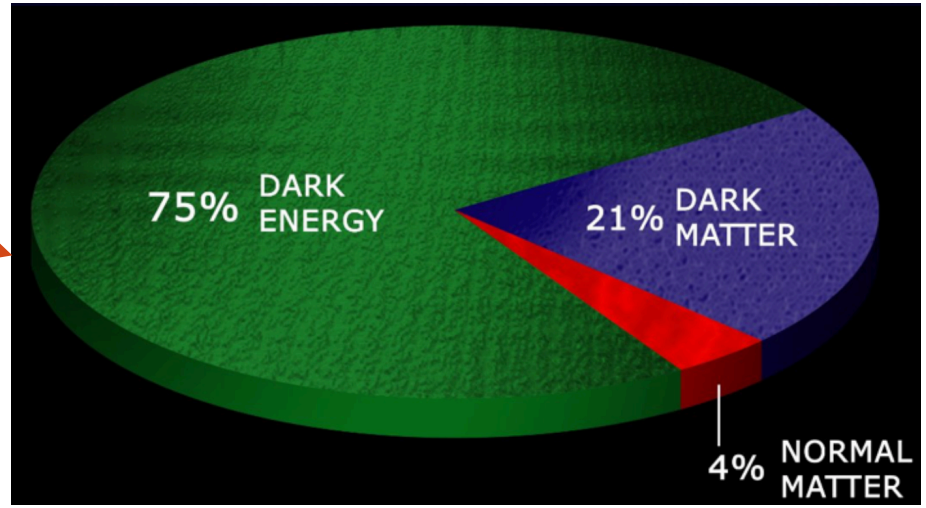
A bit more (basic decays):

- W+(-) -> l+(-)v
- W -> qq'
- Z -> l+l-
- Z -> qq
- …

WHY NEW PHYSICS?

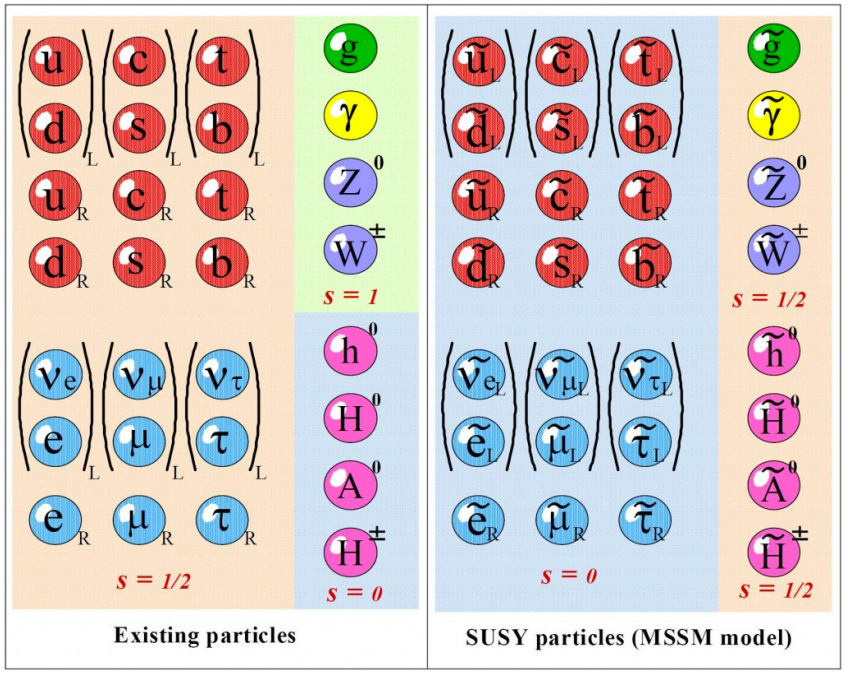
- Standard Model is not a theory of everything
- Open questions
  - hierarchy problem
  - Neutrino mass
  - Dark matter
  - …
- Some popular new theories:
  - Supersymmetry (SUSY) ?
  - extra dimensions ?
  - …
  - String theory ???





CHARGED HIGGS BOSON

- Charged Higgs bosons appear in most of the theories where the Higgs sector is extended
- Several non-minimal Higgs scenarios:
  - Higgs-Triplet-Model
  - Two-Higgs-Doublet-Model (2HDM)
  - Little Higgs model
- SUSY is one of the most famous theory
- minimal Supersymmetry Standard Model theory (MSSM) is an example of 2HDM.
- A direct search for new physics.

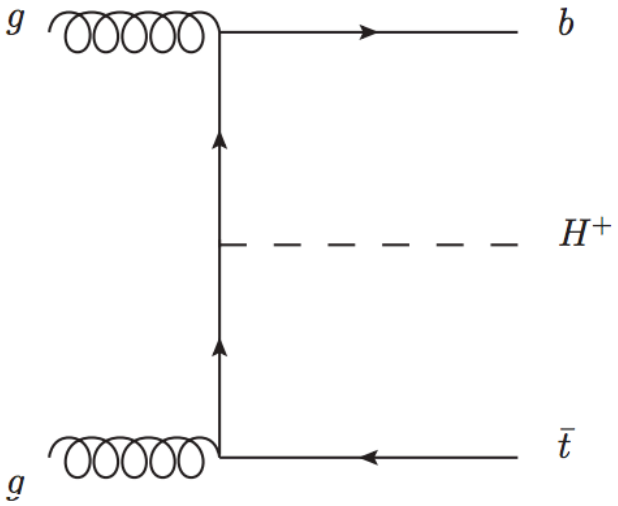


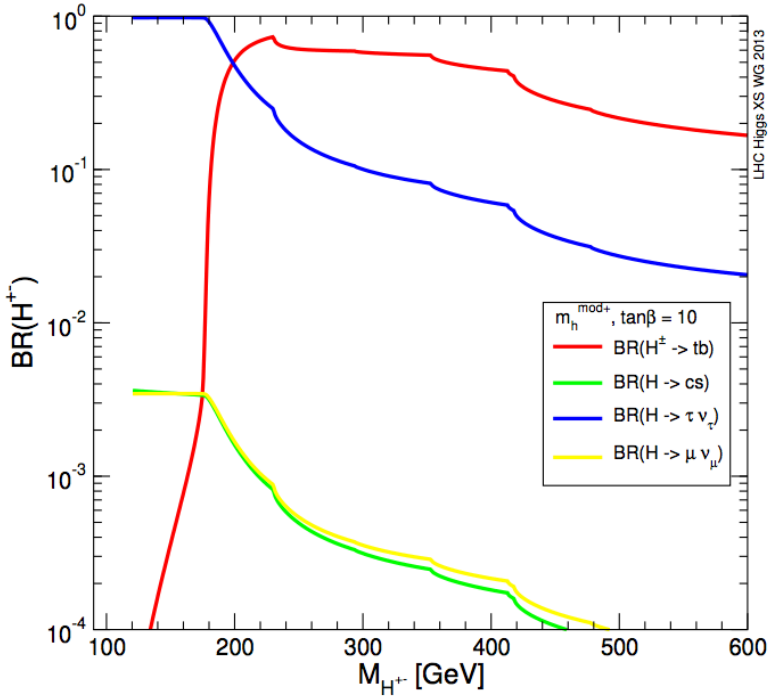
CHARGED HIGGS BOSON

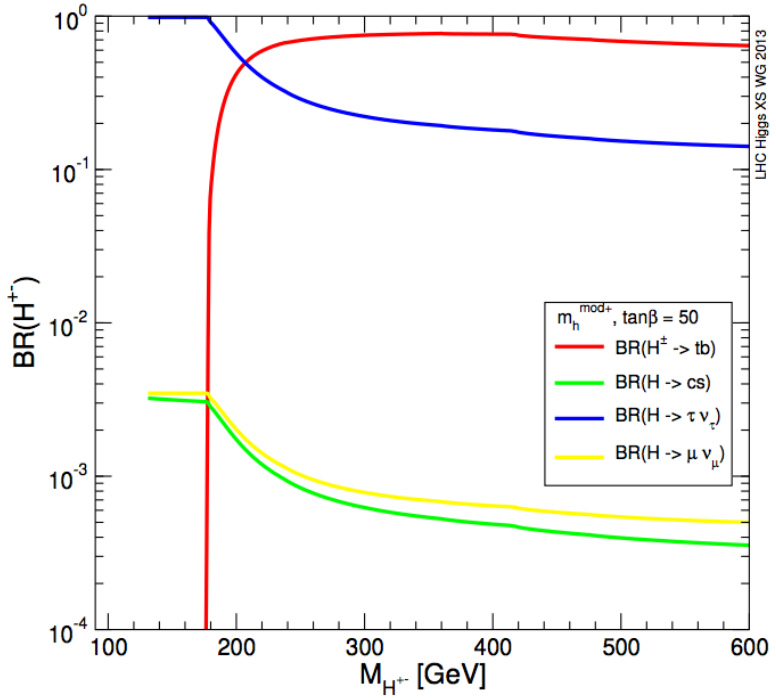
- From now on, we'll focus on 2HDM.
- 2HDM usually features 5 Higgs bosons:
  - h, H: neutral CP-even bosons
  - A: neutral CP-odd boson
  - H±: charged bosons -> later we will only talk about H+, H- is just charge conjugate
    - Spin 0
    - Charge ±1
    - CP-even
- Basically the property of charged Higgs can be described by:
  - Mass
  - tan β: the ratio of the vacuum expectation values of the two Higgs doublets

CHARGED HIGGS BOSON

- For a heavy charged Higgs boson(mass > m(Top)), main production mode is associated with a top quark.
- Decay mode is determined by tanβ and mass

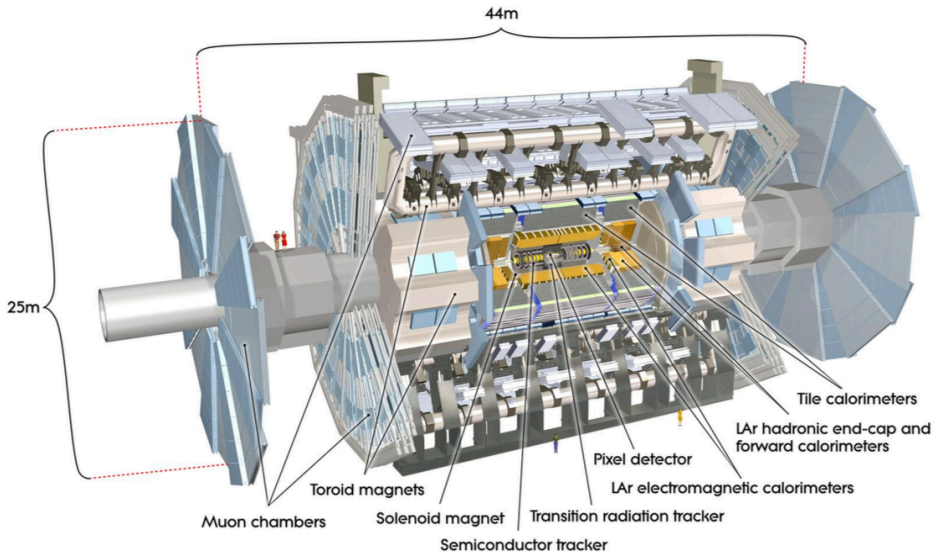


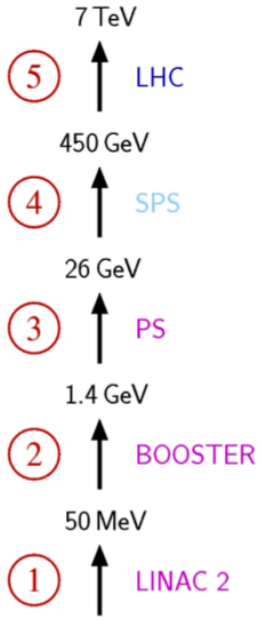


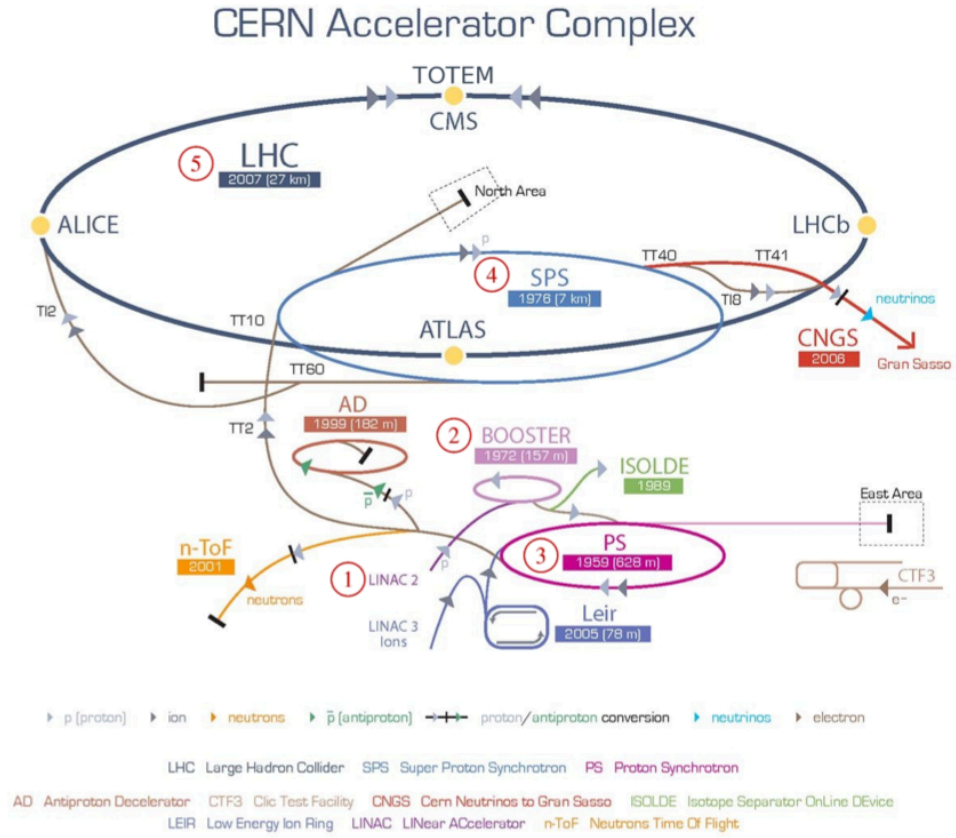


LARGE HADRON COLLIDER & ATLAS

- Located at CERN (Geneva)
- Perimeter ~ 27 km
- 4 detectors
- Centre-of-mass energy : 7/8 TeV -> 13 TeV

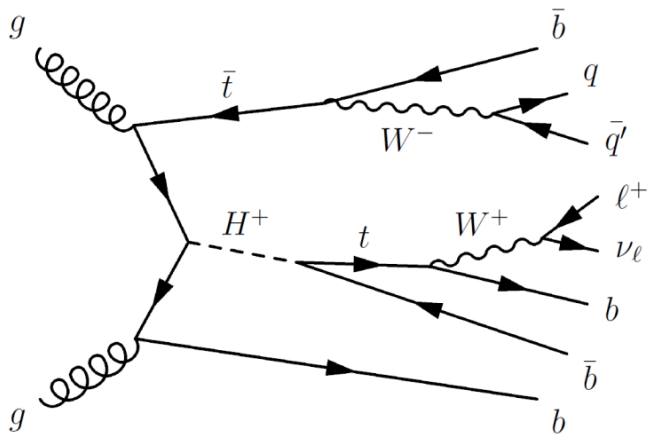




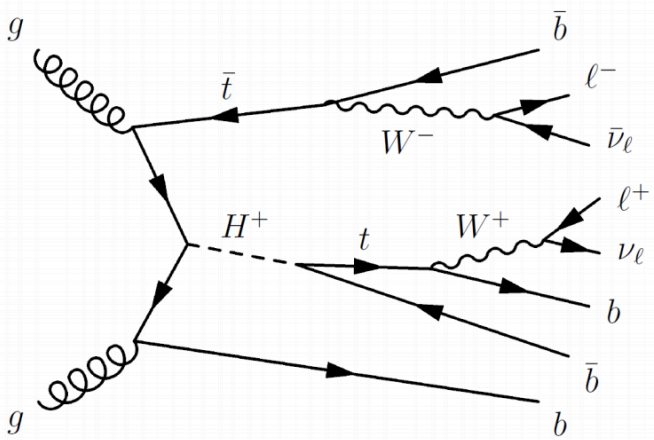


ANALYSIS INTRODUCTION

- Signal : H+, mass range from 200 GeV to 2000 GeV, 18 mass points
- $gg \rightarrow \bar{t}bH^+ \rightarrow \bar{t}bt\bar{b} \rightarrow 4b + W^+W^-$
- According to the decay mode of W boson, there are different final states:
  - ~~All hadron~~ (Due to detector resolution, etc)
  - single lepton
  - di-lepton



Single lepton



Dilepton

ANALYSIS STRATEGY

- Split events into different categories (Control Region/Signal Region)by jet and b-tagged jet multiplicities.
  - Single lepton:

	2 b-tags	3 b-tags	$\geq$ 4 b-tags
5 jets	CR	SR	SR
$\geq$6 jets	CR	SR	SR

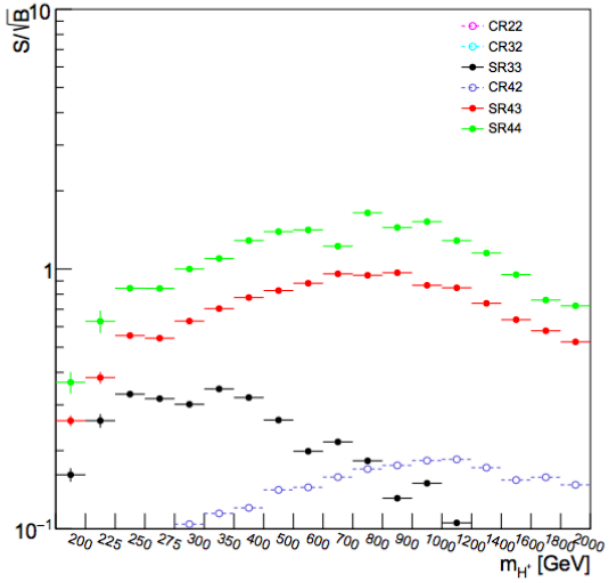
  - Dilepton:

	2 b-tags	3 b-tags	$\geq$ 4 b-tags
3 jets	CR	CR/SR	
$\geq$4 jets	CR	SR	SR

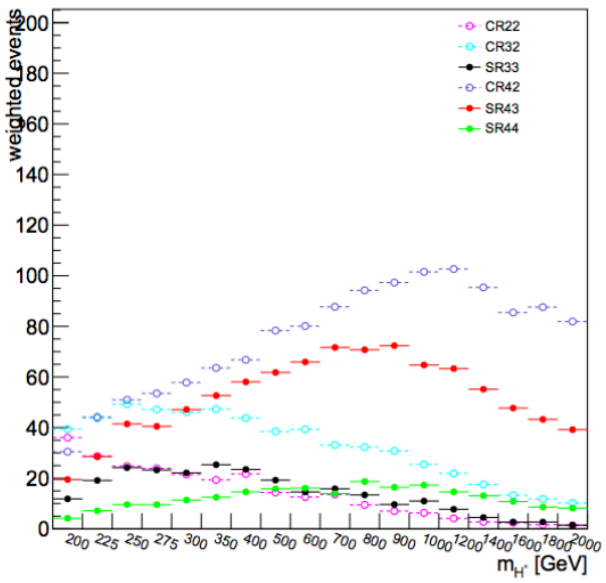
  - Either SR or CR is based on signal purity.

SIGNIFICANCE STUDY

- Significance : $S/\sqrt{B}$, S and B are the signal and background yields, respectively.
- Higher significance --> higher confidence to observe a true signal



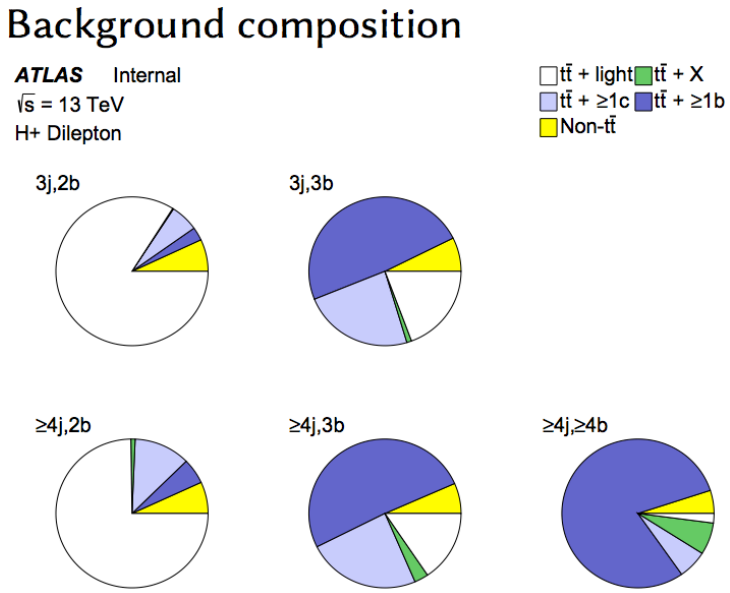
(a) $S/\sqrt{B}$ for various SR and CR, and H^+ masses.



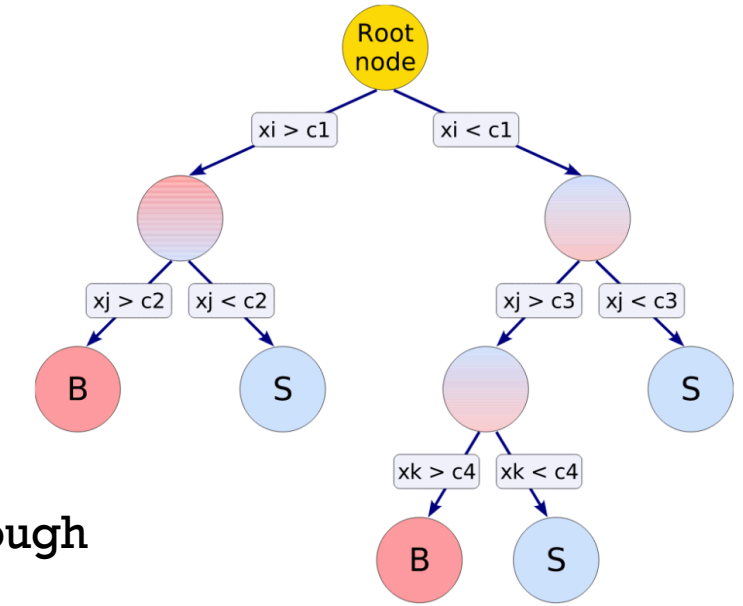
(b) Signal yield for various SR and CR, and H^+ masses.

BACKGROUND MODELLING

- Background : all SM processes that mimic the signal signature
- To search for new physics, it's essential to have a good understanding about known processes.
- Backgrounds for H+:
  - ttbar : pair production of top quarks
    - Irreducible bkg. : tt + bb (has the exactly same final state, $4b + W^+W^-$)
    - It's hard to have a good theoretical estimate of ttbb
    - Controlled by floating the normalization factor
  - tt + V/H : ttbar associated with vector boson (W/Z) or Higgs boson.
  - Single Top
  - V + jets : Vector boson associated with additional jets
  - Dibosons : WW/ZZ/WZ production



MULTIVARIABLE ANALYSIS

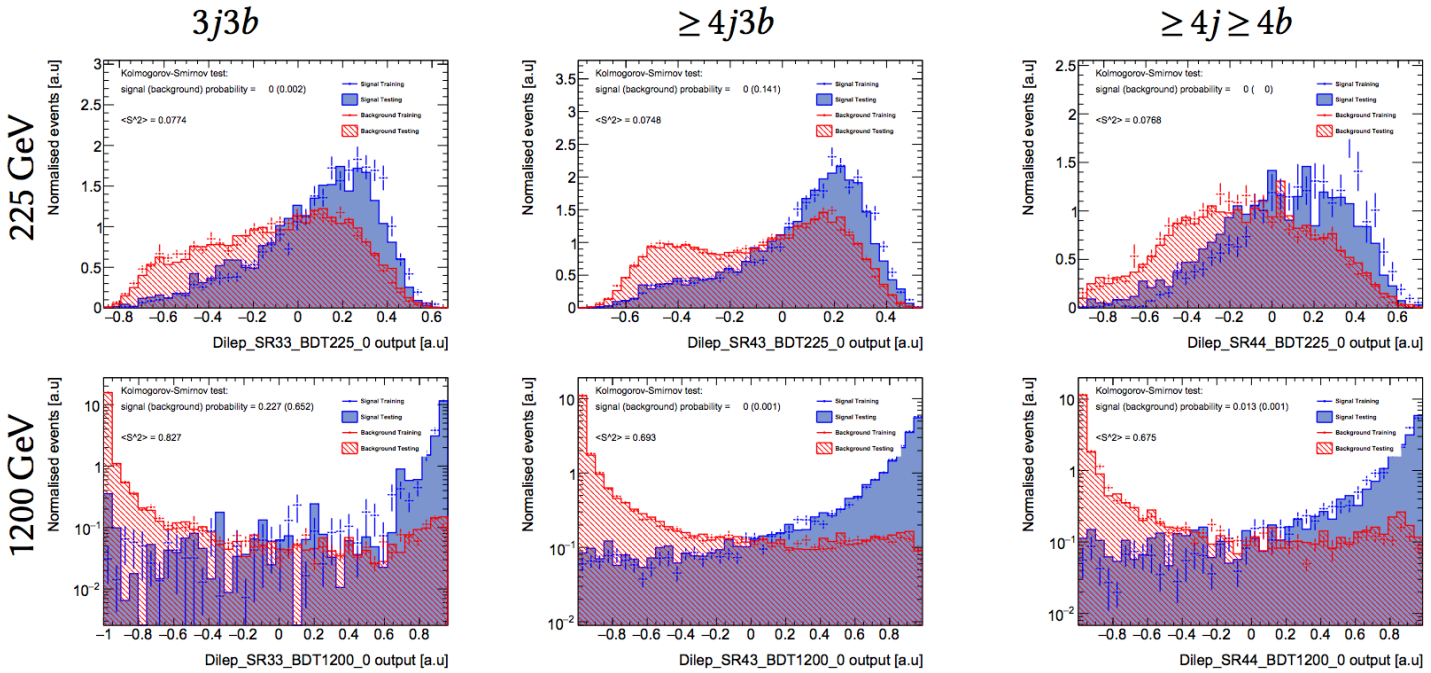


- How to distinguish signal from backgrounds?
  - Directly affect the sensitivity
  - In the data, almost 99% events are backgrounds
  - In most cases, a single variable would not be powerful enough
- Use several variables together to get more separation power
- One of the most common method: Boost Decision Tree
  - Combine several variables to one classification output.
- Variables used in this analysis are mostly exploit the event's angular topology and kinematics, for example:
  - M_max_pt_jb: the invariant mass of a jet and a b-tagged jet pair with maximum transverse momentum.
  - dE_j3_vs_l2: the difference of energy between the 3rd jet and 2nd lepton (sorted by transvers momentum)

variables \ SR	$3jex3bex$
1	M_max_pt_jb
2	dE_j3_vs_l2
3	E_j3
4	dM_j2l1_vs_j1j3l2met
5	dR_j2_vs_j1l2met
6	pt_b1
7	pt_max_dEta_lb

CLASSIFICATION BDT

- Trained against signal (H+) and all backgrounds.
- Trained separately for every mass point and signal region.

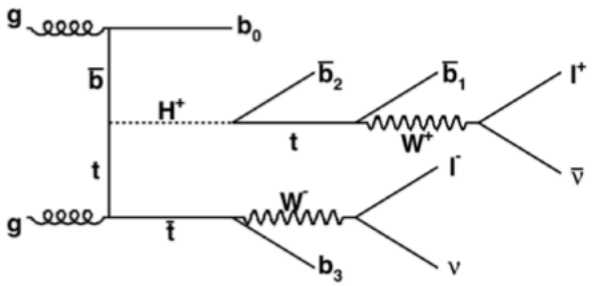


EVENT RECONSTRUCTION

The idea is using truth-match, mapping the b-partons and Jets. This is so called Right(Correct) match. Beside this, we can also assume mappings different from the "Right" one, and all these are so called Wrong match. We can then use the "Right" match as signal and the "Wrong" match as background to train a BDT, which is named "Reconstrucion BDT".

Signal: H+ with right combination.

Background: H+ with wrong object assignments.

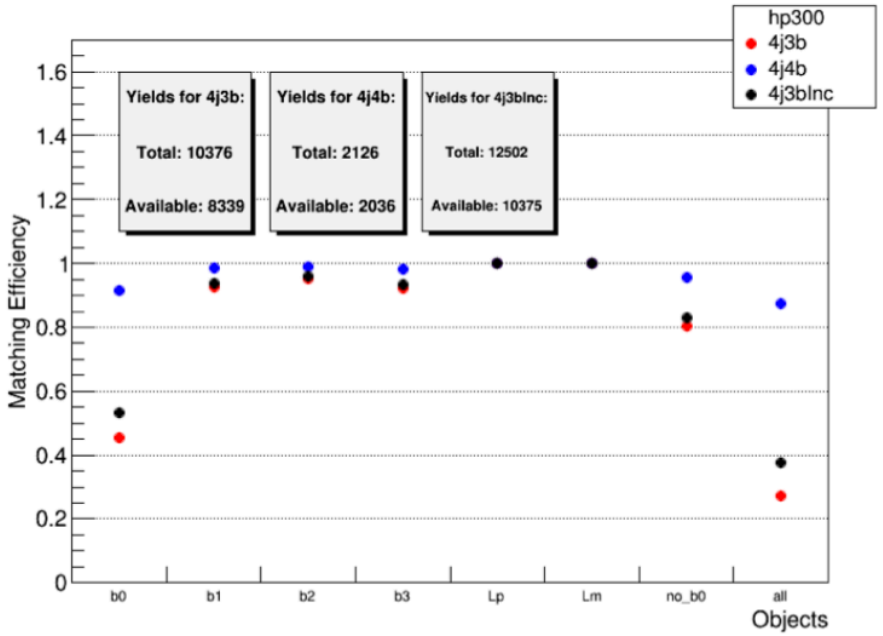


H^+ Dilepton Feynman Diagram

It's totally different from the BDT in previous slide!

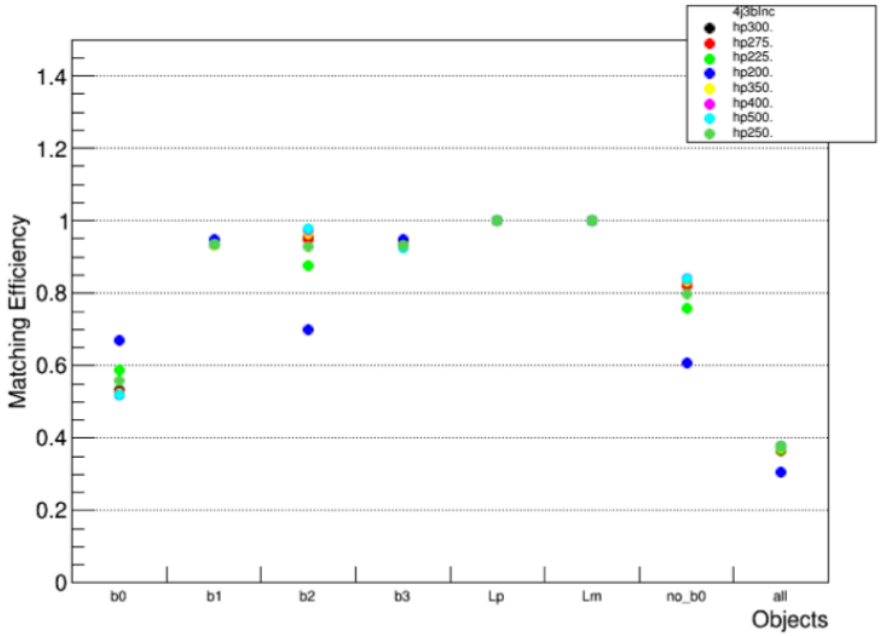
EVENT RECONSTRUCTION

Matching eff. for different objects at 300GeV



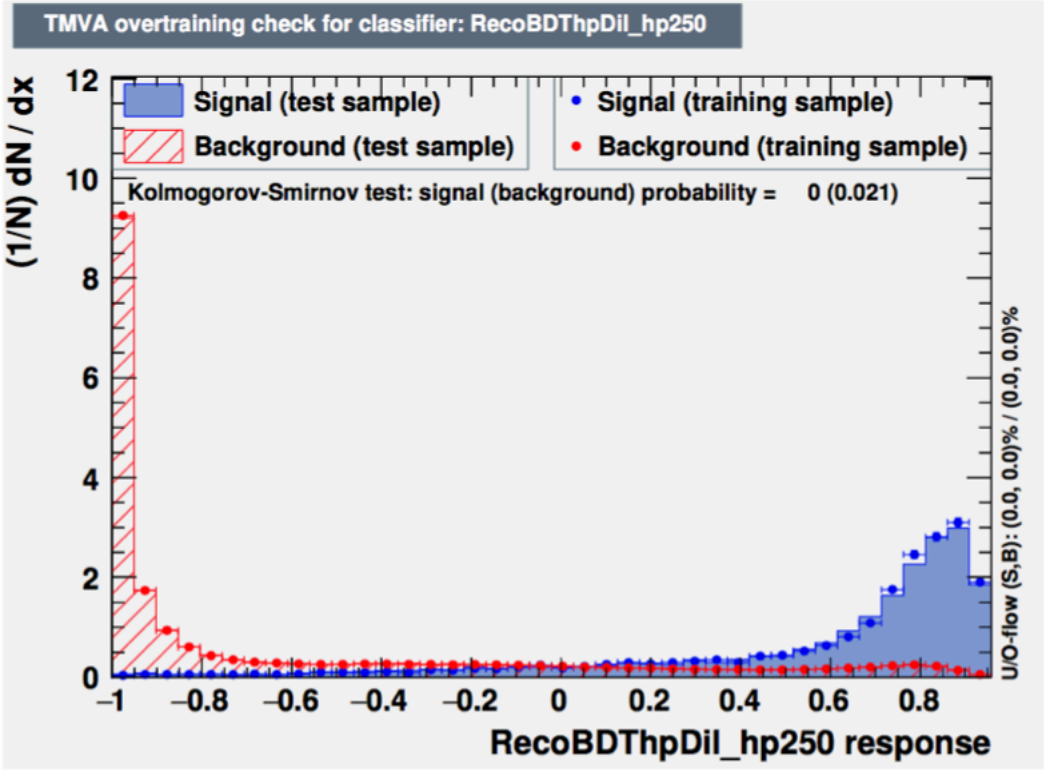
Matching Eff. H^+300GeV

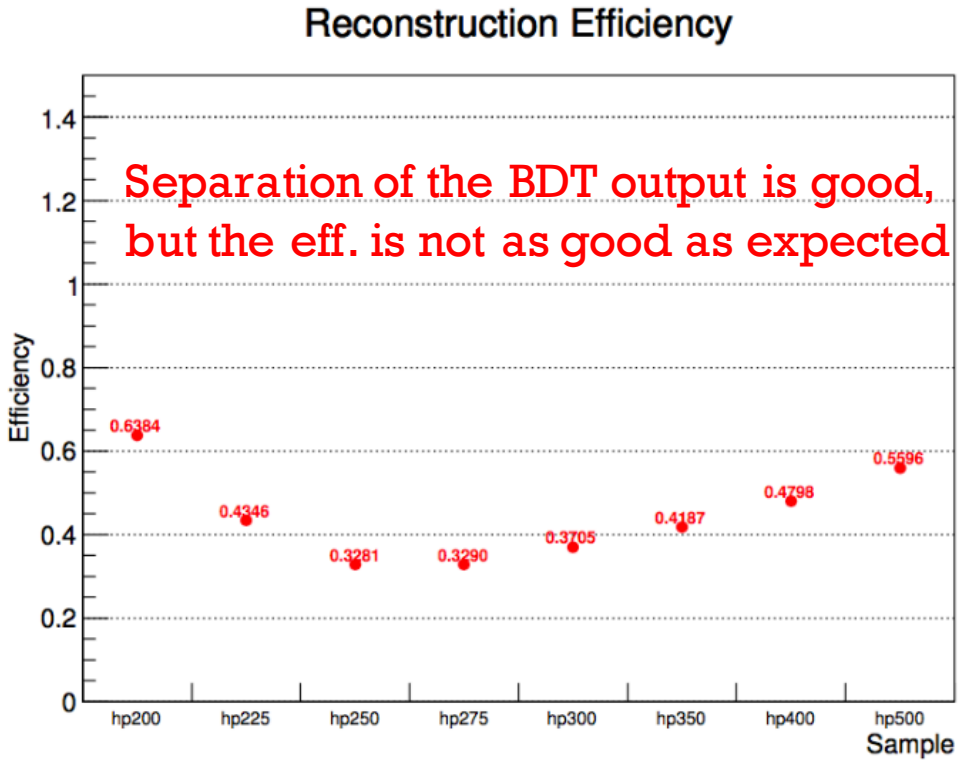
Overall Matching eff. for different H+ mass



Matching Eff. Overall

EVENT RECONSTRUCTION



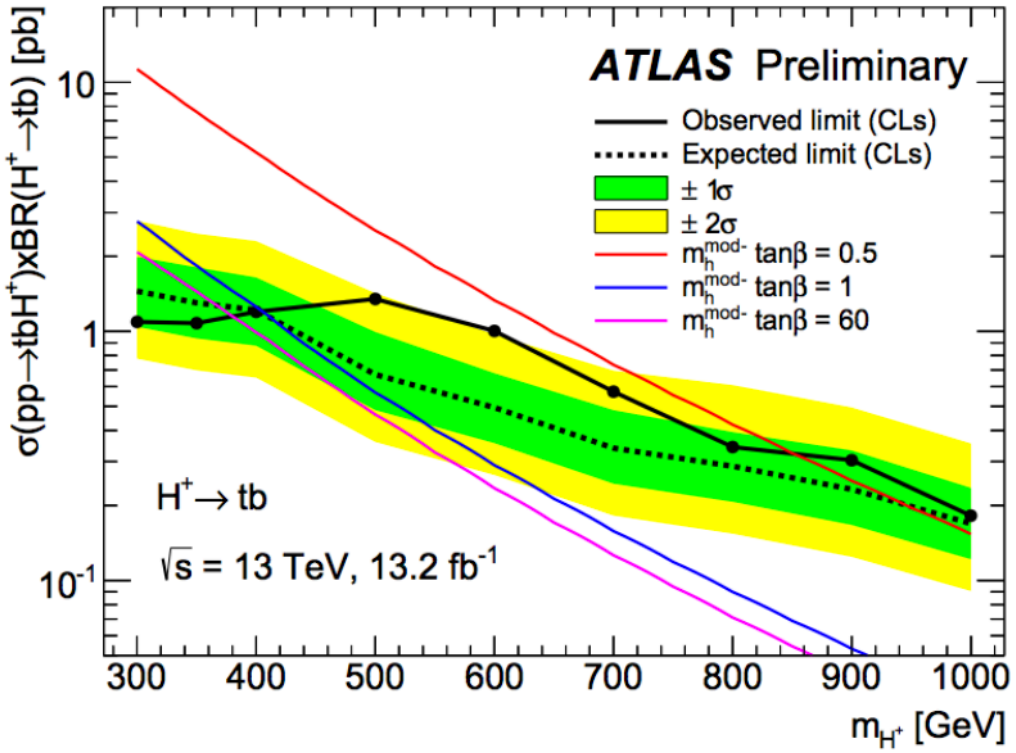


H^+250GeV

Reconstruction Eff.

NOT used in the final analysis!

FINAL RESULT



(b) 13 TeV ICHEP limits

Reduction:

- Only single lepton channel
- Mass range reduced to 300 GeV ~ 1000 GeV

Result:

- Agree with SM expectation within 2σ
- No significant excess
- Largest significance @ 500 GeV

SUMMARY

- We expect new physics beyond SM theory.
- The observation of a charged Higgs boson would be a direct evidence
- LHC and ATLAS detector provide us a powerful tool.
- The analysis using 13.2 fb-1 data is presented.
  - Split events into SR/CR to gain sensitivity
  - Multivariable technique (BDT) is used to have better separation
  - The attempt to reconstruct full event topology
  - The result agrees with SM expectation within 2σ
- First RunII Paper (with 36.1 /fb data) has been approved and would be published soon.
- My work has moved to ttH->multi-lepton analysis.