Searching for new physics at CMS

Gagan Mohanty

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Outline of the talk

- Introduction

Results from 8 TeV

- Extended Higgs sector
  - Charged Higgs boson in top decays
  - High-mass Higgs (m_H > 600 GeV)

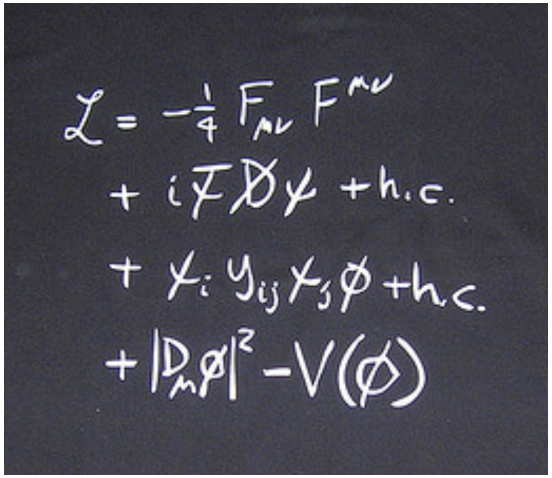
Results from 13 TeV

- Pileup mitigation
- First-generation leptoquarks
- SUSY in fully hadronic channel

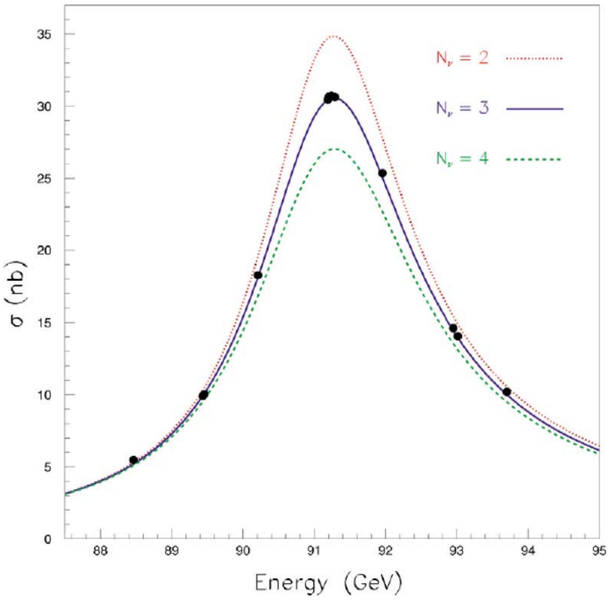
- Summary and outlook

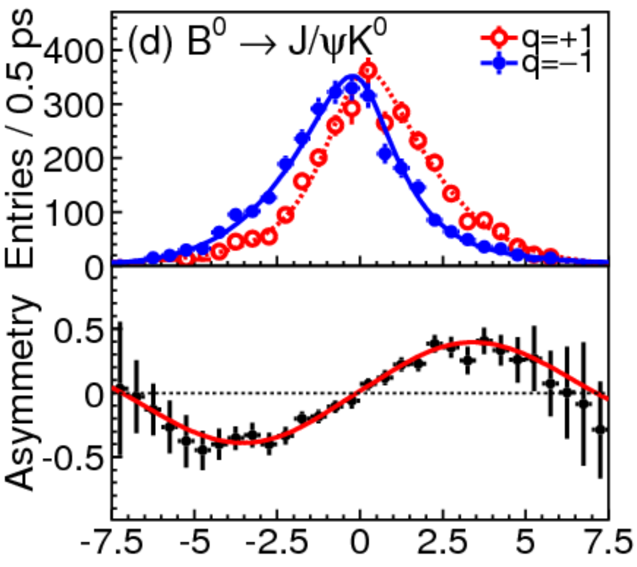
What is the deal?

- Explore new physics beyond

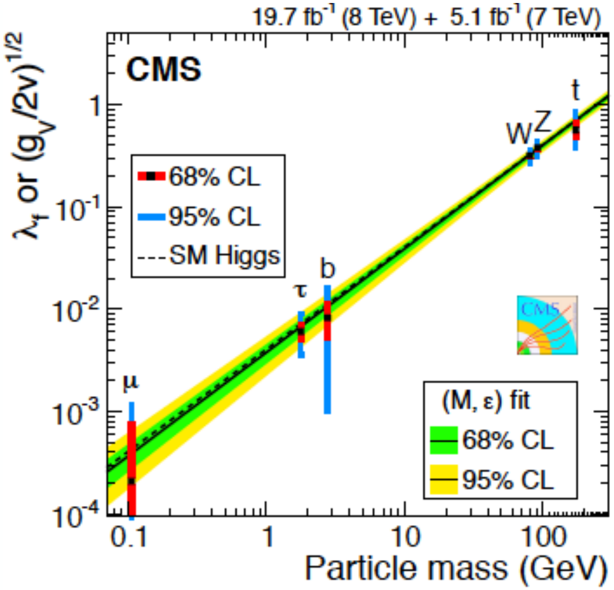


- Experimentally well tested, but not complete





Proper time difference between two B mesons



Any candidates out there?

Supersymmetry

Extra dimension

Extended Higgs sector

New Physics

Extra bosons (W’, Z’ ...)

Leptoquarks

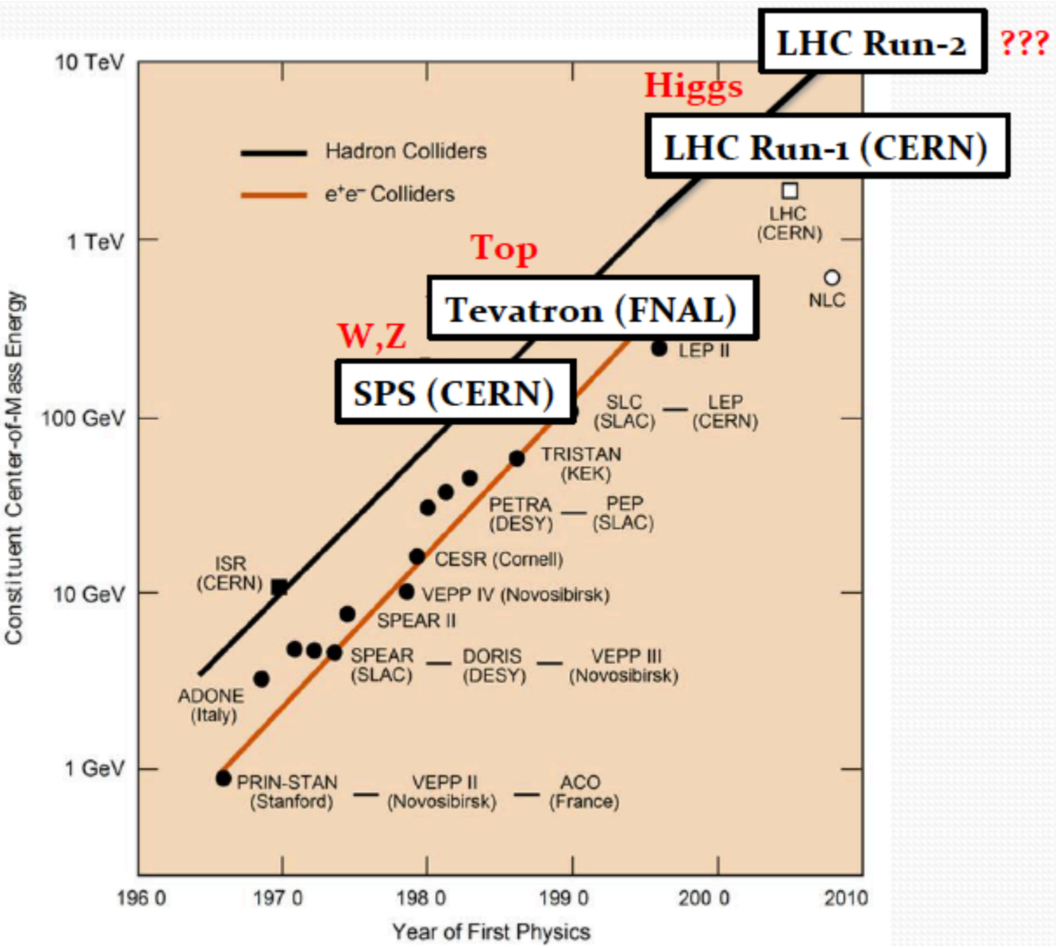
You name it!

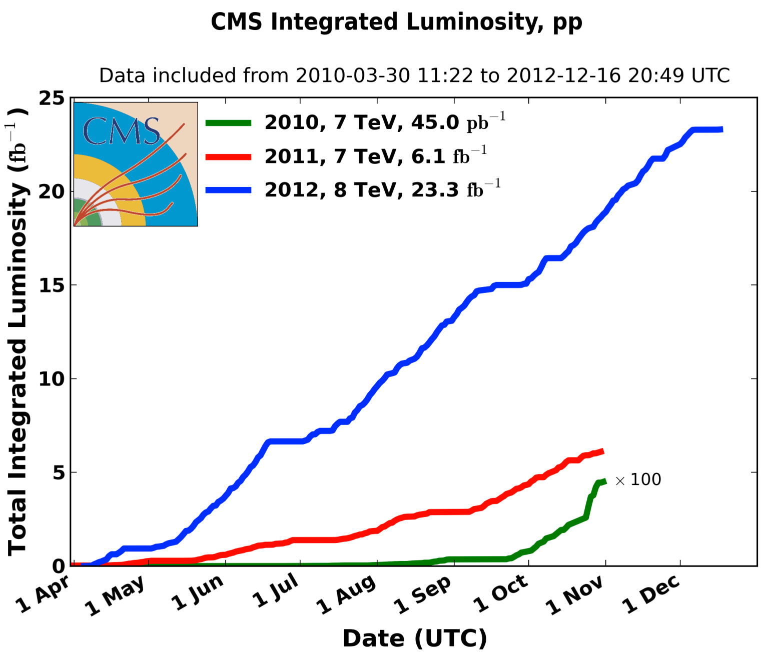
NP at Energy Frontier

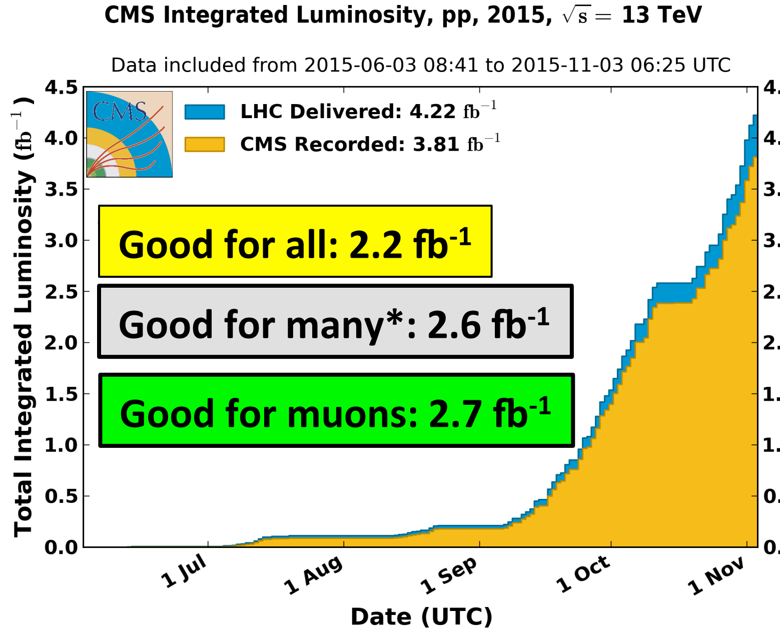
- A play of two equations

$$E = mc^2$$

$$N_{exp} = \sigma . L_{int} . \varepsilon_{det}$$







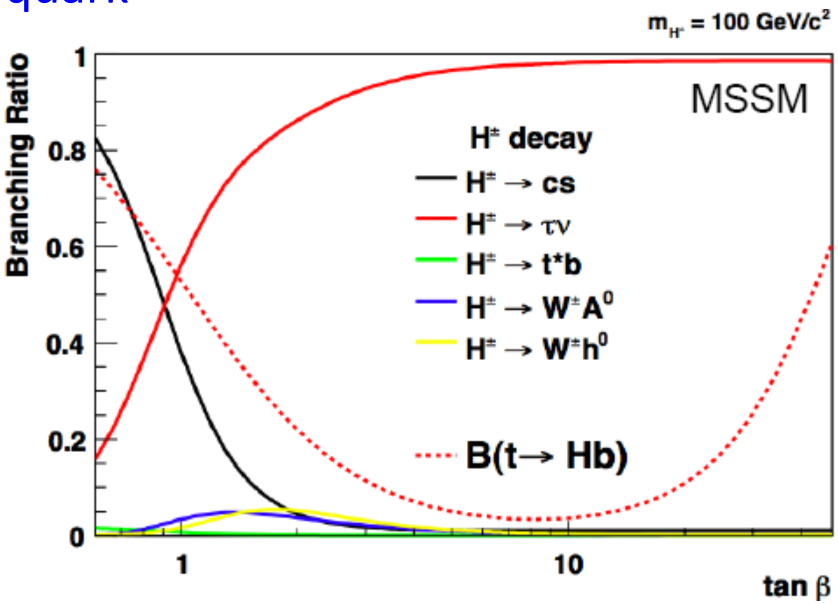
Chasing the charged Higgs boson

- Charged Higgs boson (H^+) appears in various NP models e.g. MSSM, 2HDM
- Its production and decay rates at tree-level depends on two parameters
  1) Ratio of vacuum expectation values of two Higgs doublets (tan β)
  2) Mass of the CP-odd Higgs boson (m_A)

- Two possible production mechanisms for H^+ at the LHC:
  - For $m_H < m_t$, it can appear as a top-quark decay product
  - For $m_H > m_t$, it can directly produced in association with a t and b quark

- Our focus is on the first case, in particular where the charged Higgs boson decays to a charm and an anti-strange quark

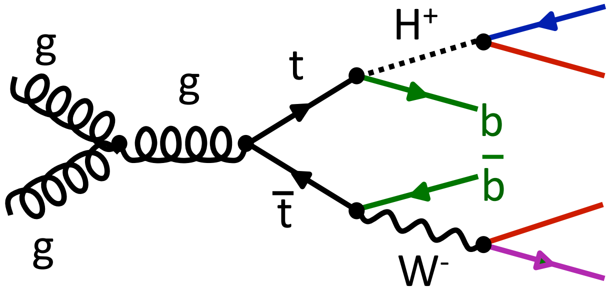
➢ The cs-bar channel is important for the low tan β region



What are we looking after?

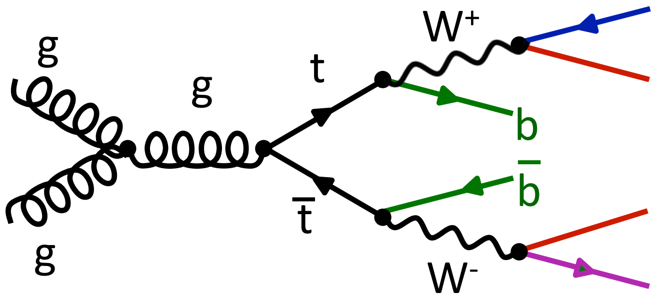
Signal

$$t\bar{t} \rightarrow bH^{+}\bar{b}W^{-}$$



Backgrounds

- ✧ Irreducible SM $t\bar{t} \rightarrow bW^{+}\bar{b}W^{-}$
- ✧ Single top
- ✧ W+jets
- ✧ Z+jets, dibosons and QCD

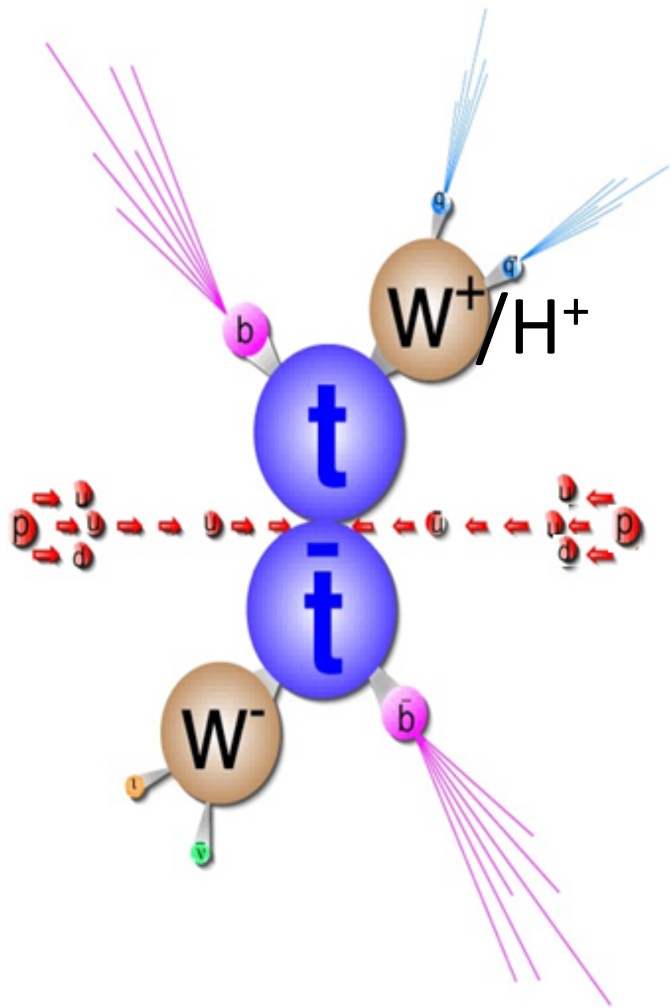


- ❑ Final state comprises a high-p_T isolated lepton, at least four jets (two are b-tagged) and large missing E_T due to neutrino

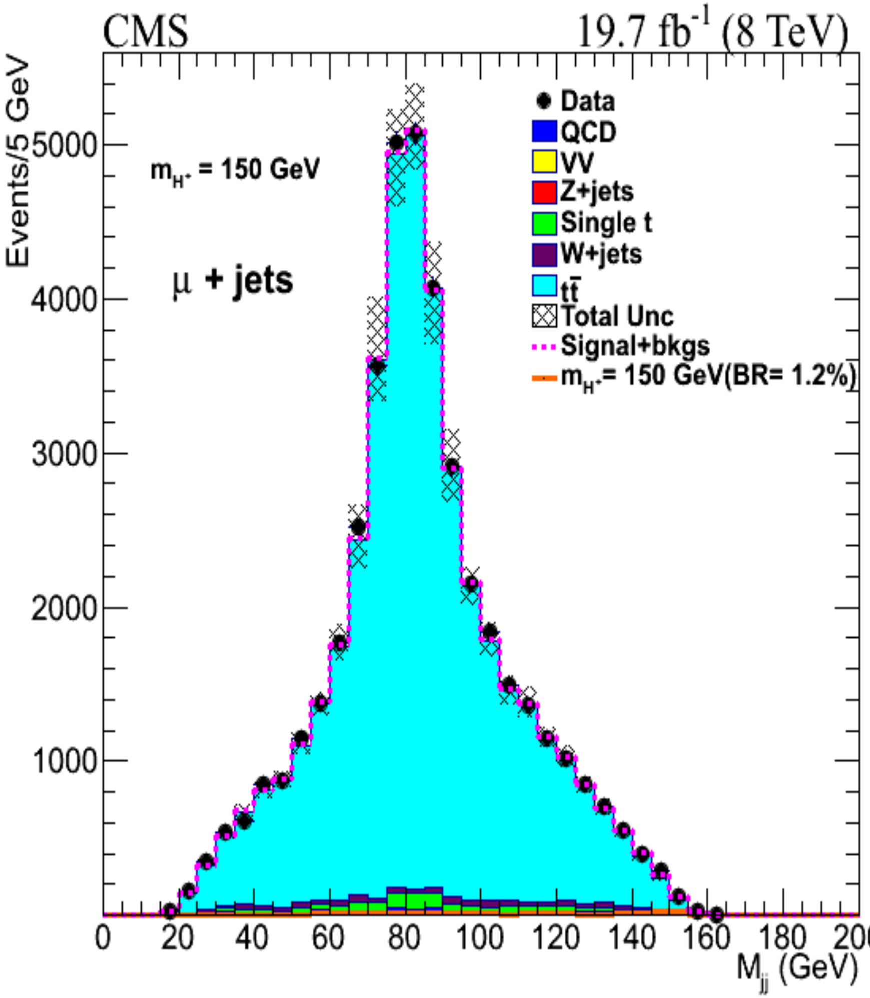
Key point: Kinematic Reconstruction

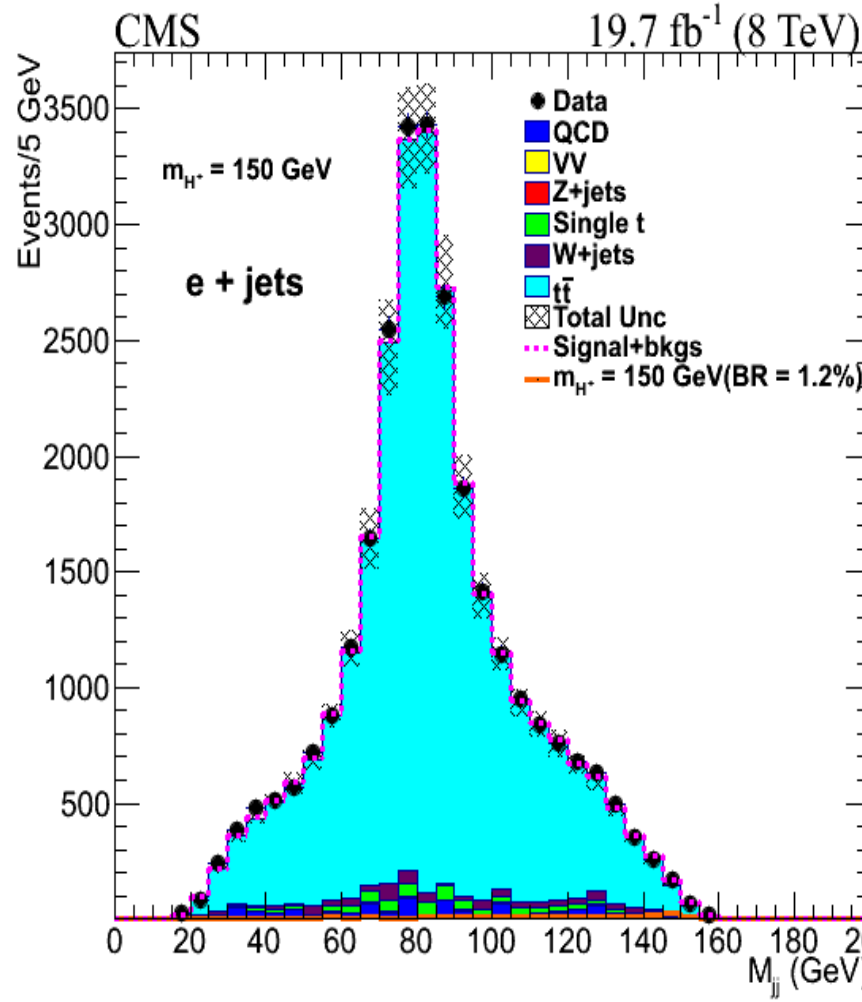
Perform a kinematic fit with the top mass constraint to improve the dijet mass resolution for reconstructing the W or H boson

- ✓ Fit inputs: lepton, all jets passing selection, MET
- ✓ Constrain the mass of both hadronic and leptonic decaying top quarks to their nominal value
- ✓ No constraint is applied on the W mass as we expect H boson in the dijet mass distribution



Final discriminant distribution





$$\Delta N = N_{t\bar{t}}^{BSM} - N_{t\bar{t}}^{SM} = 2x(1-x)N^{WH} + [(1-x)^2 - 1]N_{t\bar{t}}^{SM}$$

Combined limits

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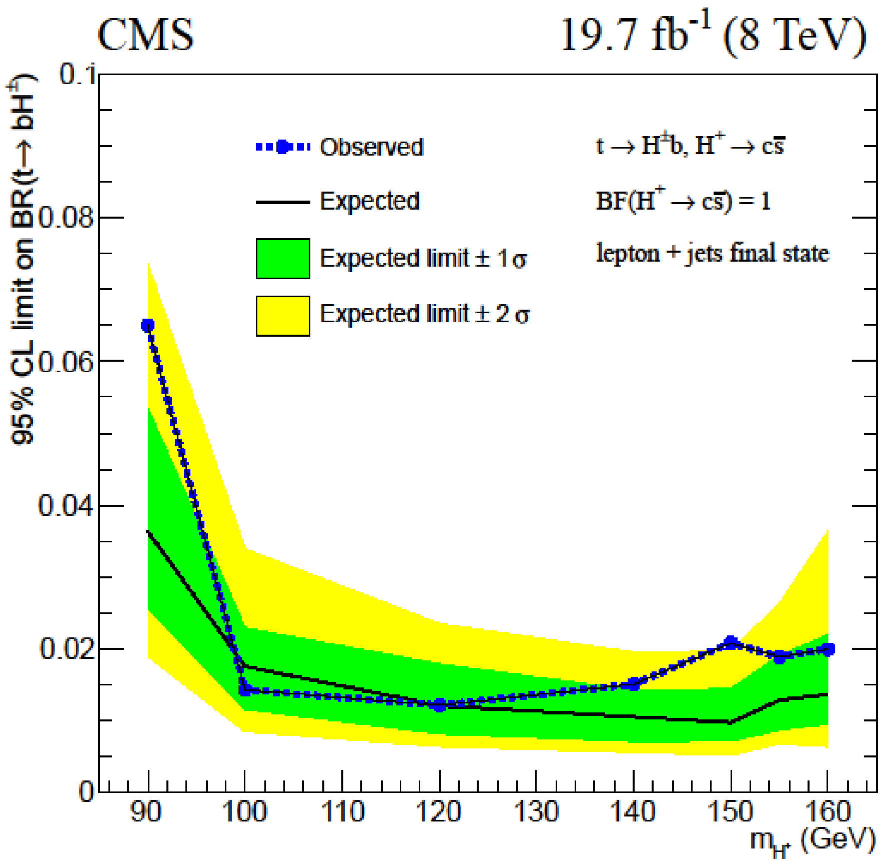
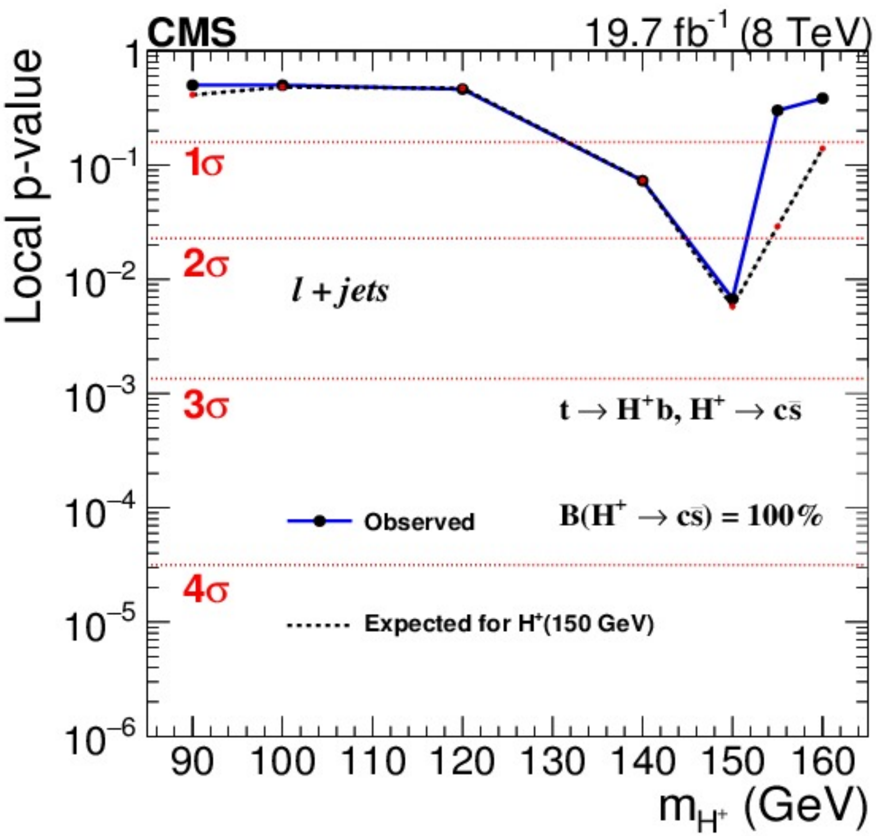


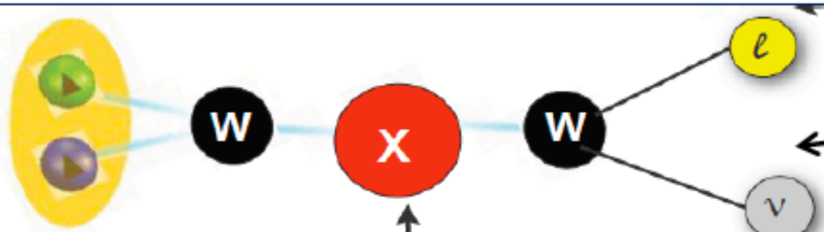


- Most sensitive upper limit across the entire mass range probed
- Would be nice to see the fate of the tiny excess around 150 GeV

High-mass Higgs in WW final state

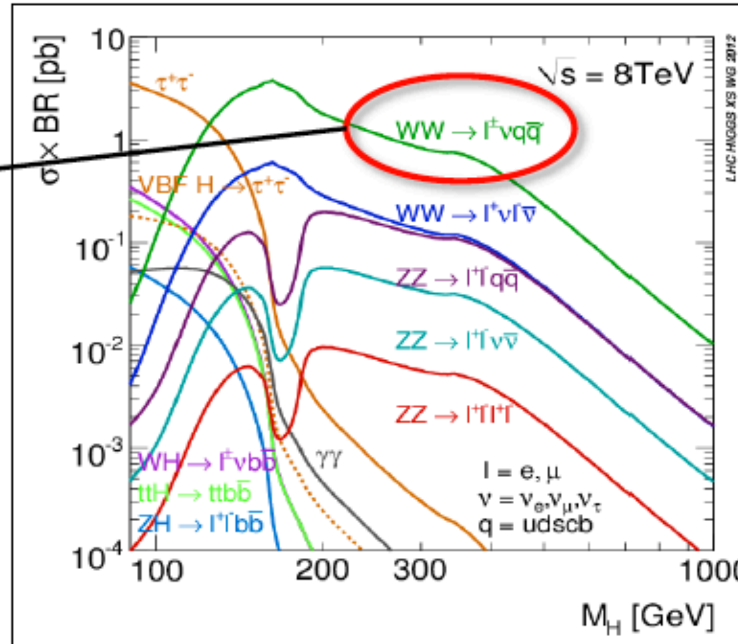
- Search for a SM Higgs-boson decaying into WW → lνqq' in the high mass region (600- 1000 GeV)
- Search is performed in the semi leptonic final state in exclusive jet bins
- Used jet substructure techniques
- This analysis is the benchmark for future analysis of WW scattering

For W p_T > 200 GeV, generally a merged jet.



Use substructure tools to identify hadronic W (or Z)

High mass Higgs as bench mark for a generic WW resonance of M > 600 GeV



Production mechanisms

- Gluon gluon fusion (ggH) & Vector boson fusion (VBF)

Key analysis features

$W \to \ell\nu$

High p_T lepton + high MET

$W \to q\bar{q}'$

High boost, jets merged together to form a "fat jet"

Signature

WW $\longrightarrow$ {l + MET} + merged jet

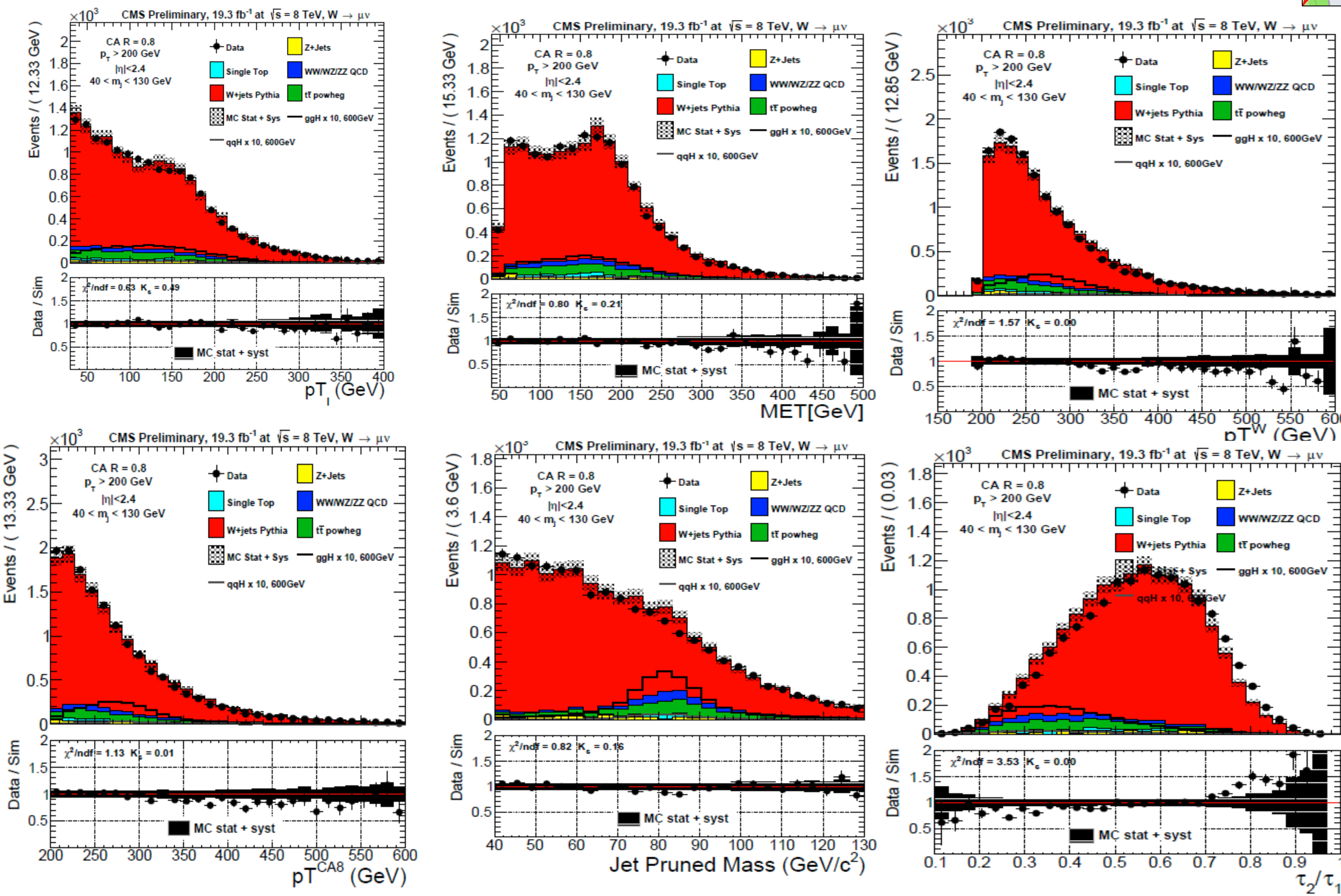
Signal: ggH + qqH, (mH= 600-1000 GeV)
Backgrounds: W+ jets(dominant) ttbar, single top , WW/WZ/ZZ

Use **jet substructure techniques** to identify single jets containing decay products of hadronic W

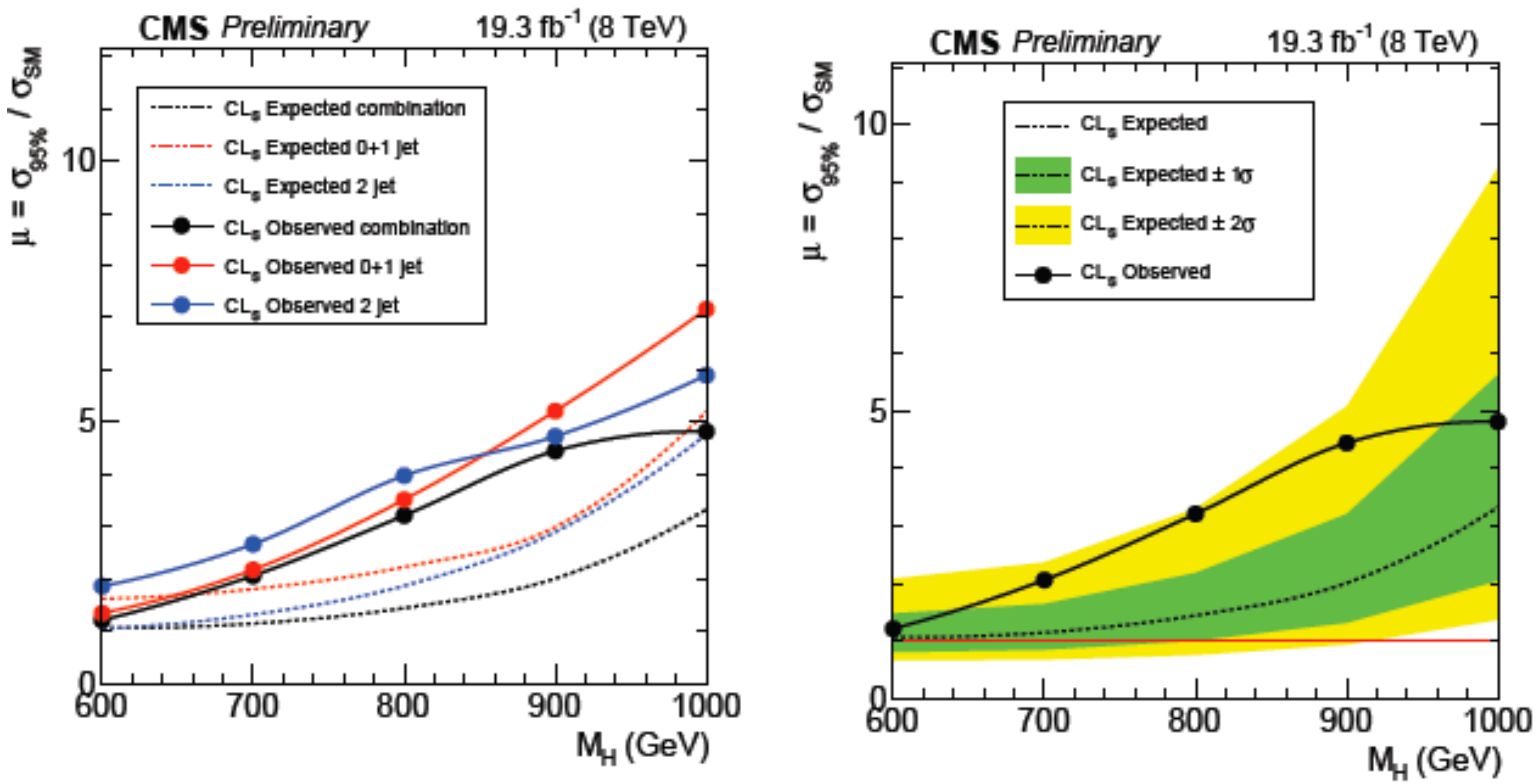
Kinematics: boosted leptonic W back-to-back to a merged jet
Discriminating observables: pruned jet mass(mJ) and three-body mass (mlvJ)
Unbinned shape limits using mlvJ distributions

Background estimation
Data-driven Background extraction using the m_J sideband for W+jets and top enriched control regions

Data-MC comparison in 0+1 jet bin

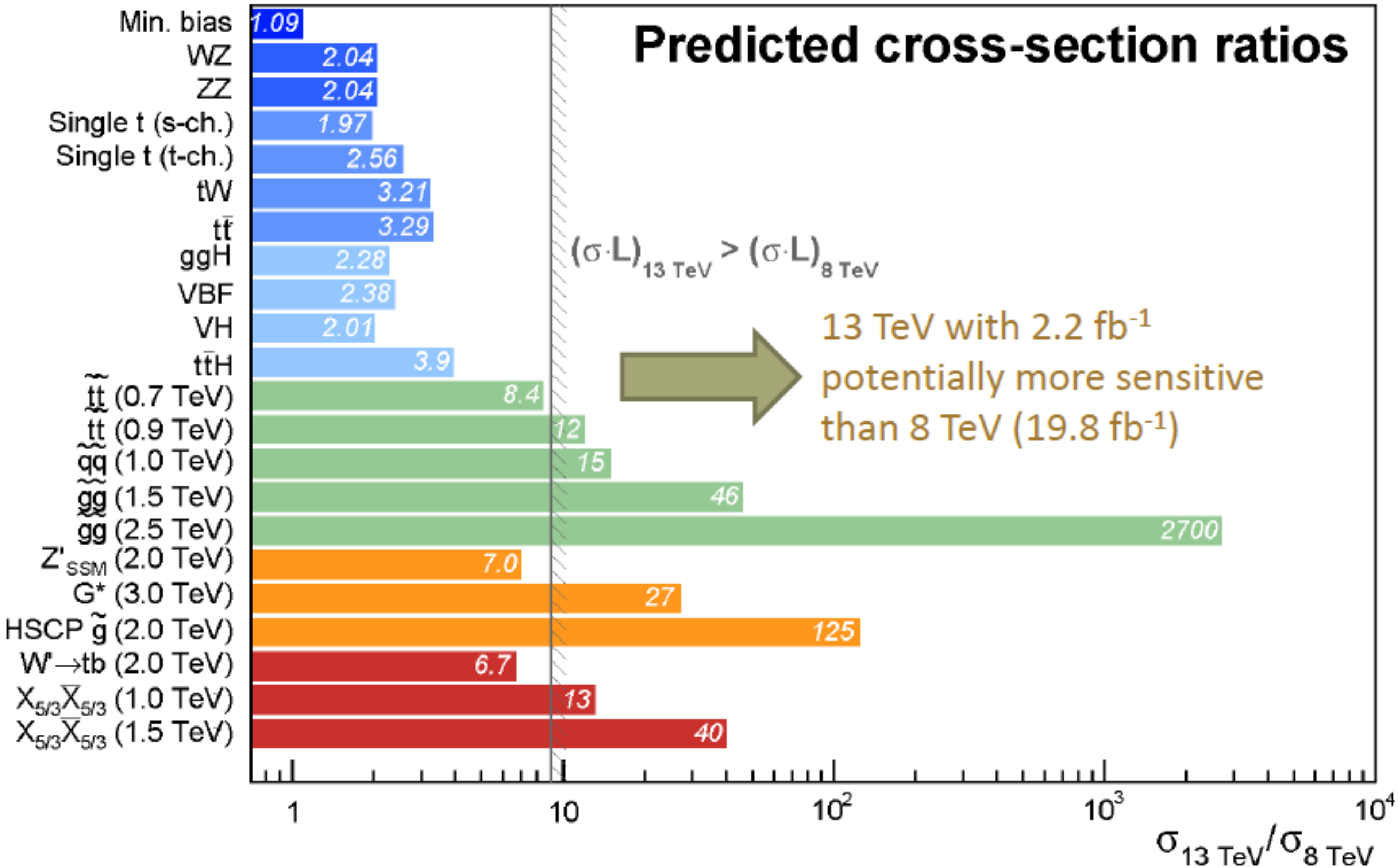


Final Results



- ❑ No significant excess observed in the mass region investigated
- ❑ Watch out the region around 750-850 GeV

Going from 8 to 13 TeV



Before going to physics studies

Pileup mitigation

- Pileup will be one of the main challenges in jet reconstruction in the LHC Run II.
- Contamination from pileup degrades the performance
- Main observables of interest
  - Jet p_T, mass, η, ϕ
  - Jet substructure observables

- We investigated various pileup mitigation tools such as
  - Charged Hadron Subtraction
  - Grooming techniques
  - PUPPI
- Focus on the preparation for Run II of LHC

How do we do it?

- Systematic removal of jet constituents
- Typically used to distinguish heavy fat jets from QCD
- Reduces PU dependence of jet mass
- Studied on fat jets (anti-k_T, R= 0.8)

In this study, we explore different grooming algorithms such as:

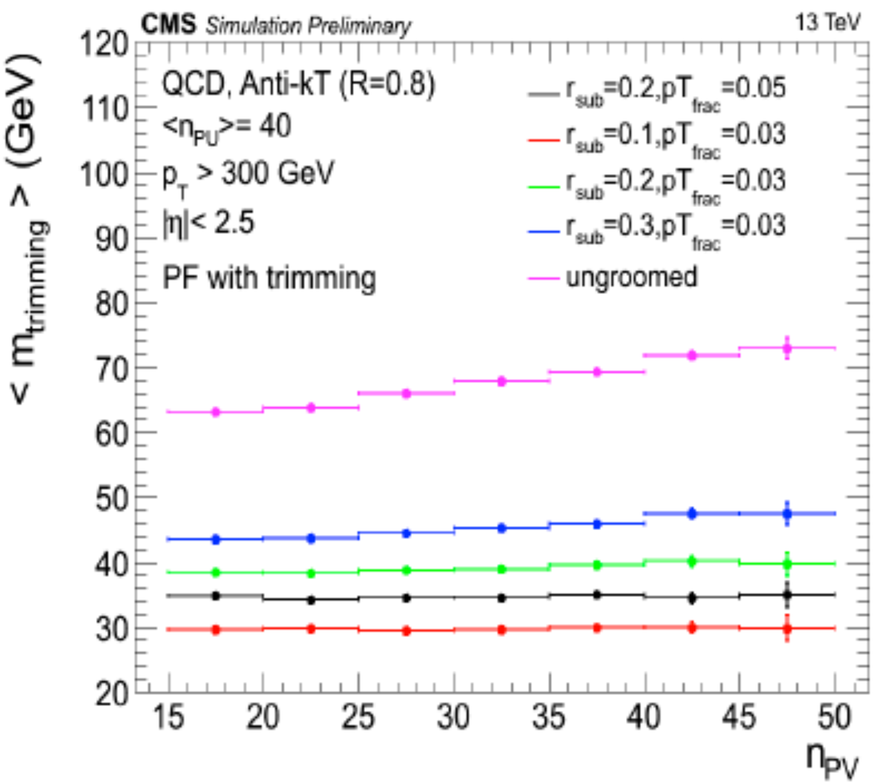
- Trimming (arXiv:0912.1342)
- Pruning (arXiv:0903.5081)
- Soft drop (arXiv:1402.2657)

- Samples used to target the Run II scenario: CSA14(40 PU, 50 ns) @ 13 TeV
  - QCD multijets [p_T > 300 GeV]
  - RS Graviton decaying to WW (m_{grav} = 1 TeV)
- Criteria for comparison:
  - Stability w.r.t. PU
  - Jet mass response and resolution

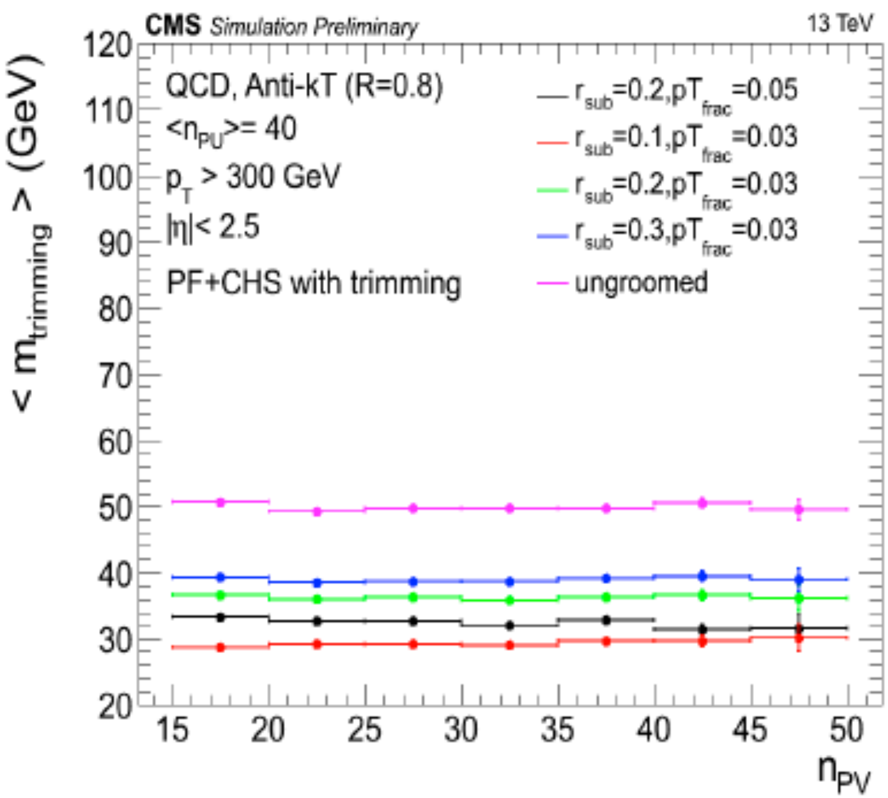
Results from trimming

- Comparison of the trimmed average jet mass vs. PU for various trimming parameters using PF or PF+CHS inputs

PF



PF+ CHS

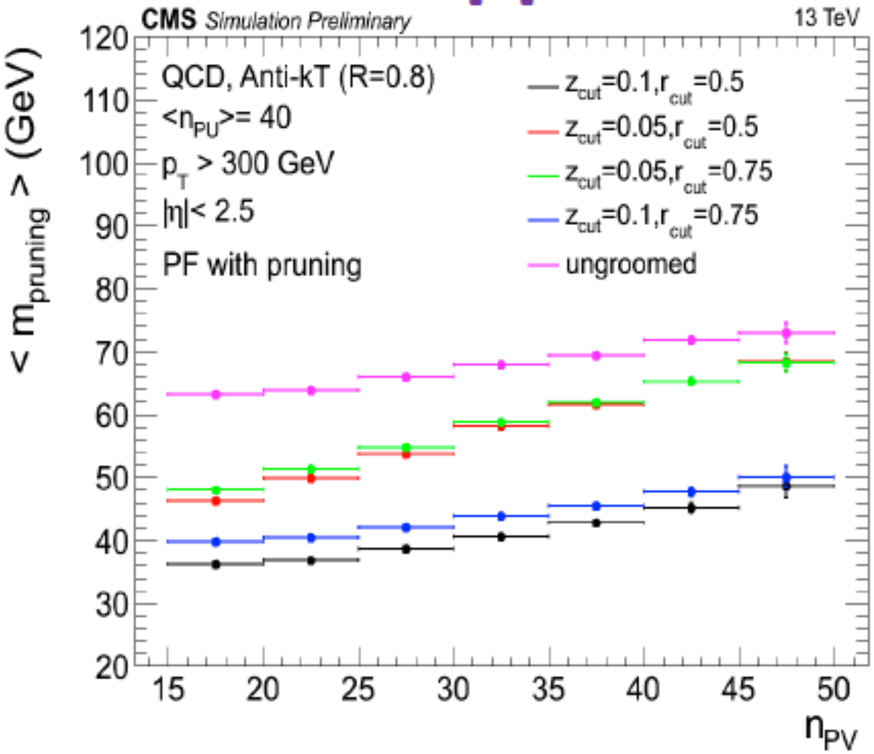


- Trimming is stable against pileup regardless of the input (PF or PF CHS)

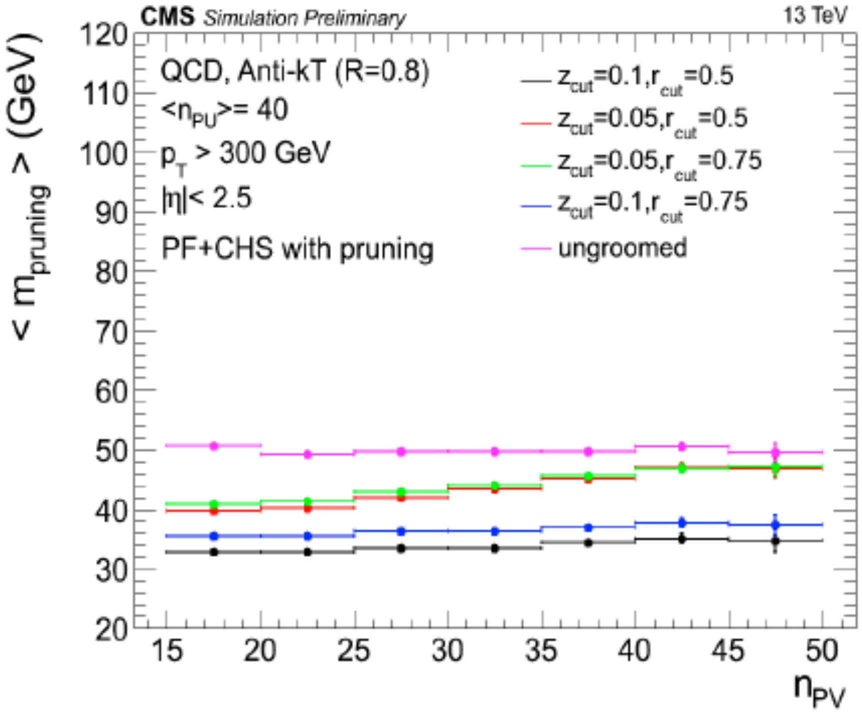
Results from prunning

- Comparison of the pruned average jet mass vs. PU for various pruning parameters using PF or PF+CHS inputs

PF



PF+ CHS

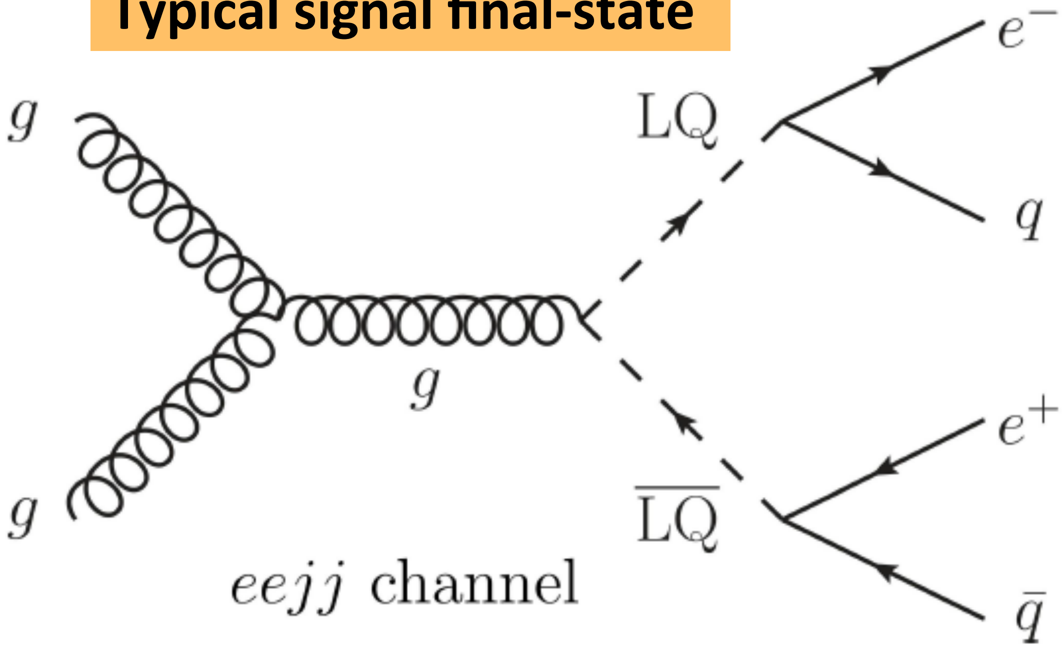


- Mass increases linearly with pile-up
- PF+CHS improves the pileup dependence wrt. to simple PF

Enter the leptoquarks

- Leptoquarks are motivated by many NP models like grand unified theories based on gauge groups including Pati-Salam SU(4) color symmetry, SU(5), SO(10) and so on
- They appear as either scalar or vector bosons carrying both baryon and lepton numbers as well as fractional charge
- Symmetry between quarks and leptons is the key motivation behind the search for leptoquarks

Typical signal final-state



Main Backgrounds:

- DYJets
- ttbar

Other backgrounds:

- Single-top
- W+jets
- γ+jets
- QCD

Estimating QCD background

- One of the trickiest backgrounds to estimate as we don't have a very reliable and sufficiently large MC sample → use data-driven approach
- QCD pollutes the signal region mostly due to jets faking as electrons
- Use a 2 loose-electron control region to calculate its contribution

How to calculate the jet-to-electron fake rate?

A (QCD MC)

exactly 1 loose electron

B (QCD MC)

# of 1 loose electrons that pass the HEEP criteria

if the MC were trustable

Fake rate = B/A

But we do not trust MC, so will determine it from Data

A(Data), small % real electron contamination from W+Jets

exactly 1 loose electron

B (Data) ,large % real electron contamination from W+Jets

# of 1 loose electrons that pass the HEEP criteria

Fake rate = B(corrected for real e)/A

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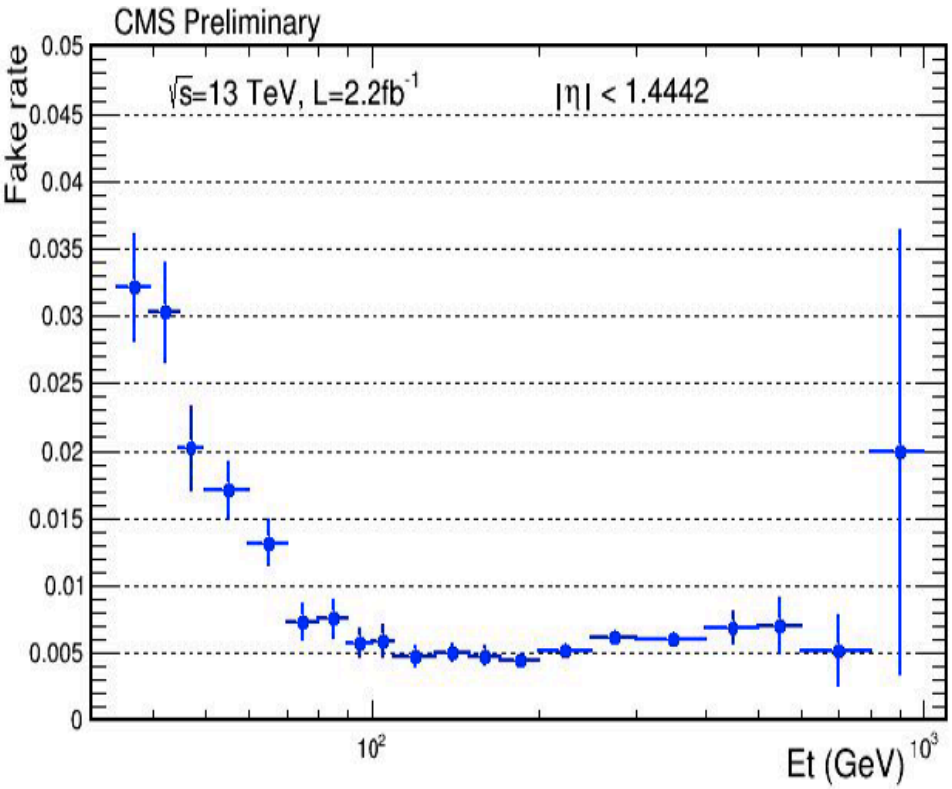
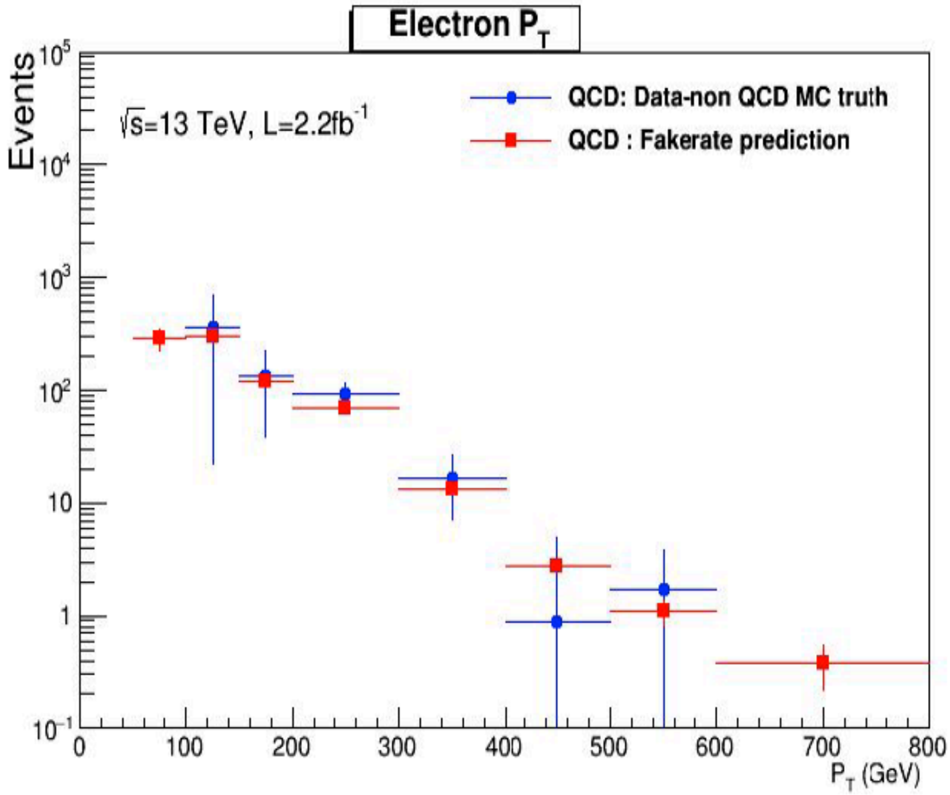
Fake Rate and Closure Test

- Plot on left shows the obtained fake rate as a function of E_T of electrons
- On the right, we compare the predicted QCD contribution from MC with data-driven QCD estimation





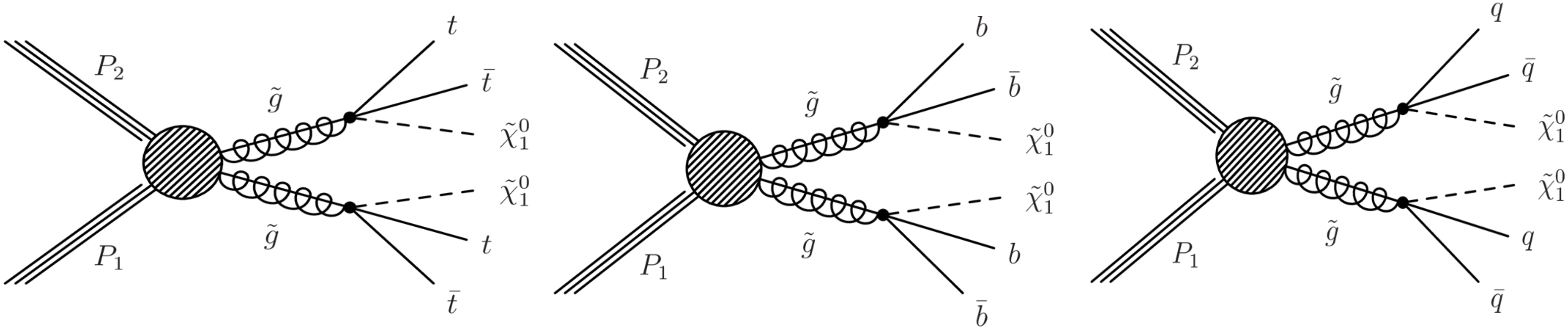
Next steps

➢ For details see Muzamil's poster

- Estimate other backgrounds and finally set limit in case of no excess in data
- Aiming for a combined PAS including the results with 2^{nd} generation LQs

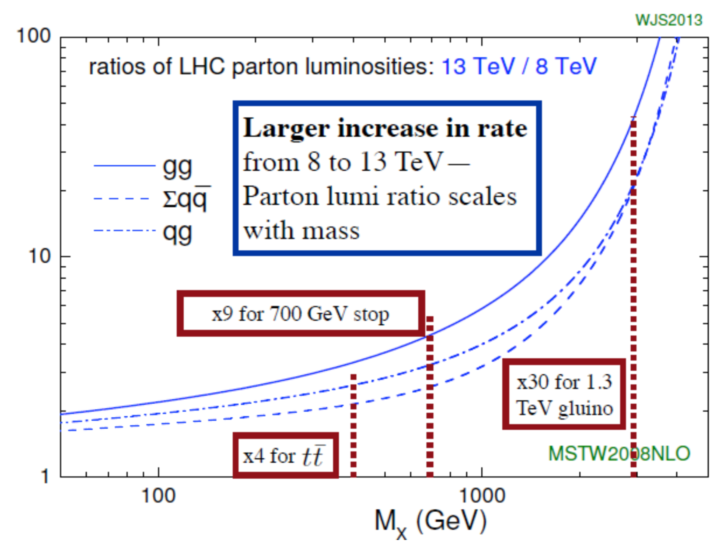
SUSY in fully hadronic channel

- CMS SUSY search results are interpreted in the context of simplified model spectra (SMS)
- Only parameters here are masses of pair-produced SUSY particles (e.g., gluinos), the LSP mass and the production cross section



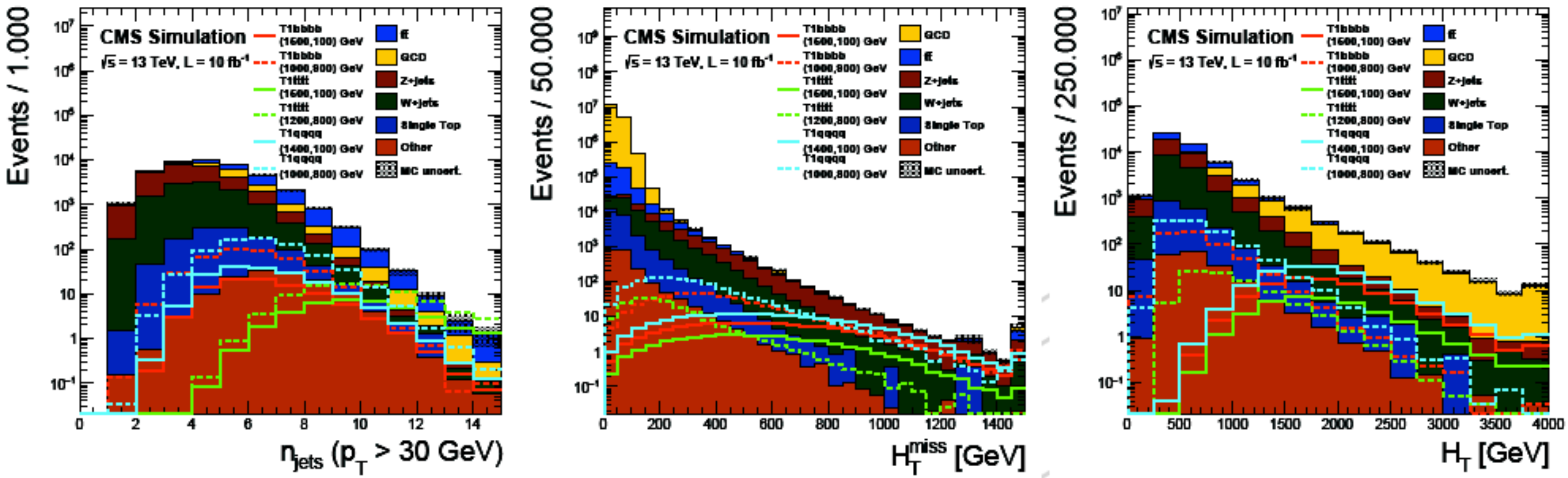
What special about gluinos?

- Higher rate of production
- High particle multiplicity



Search Strategy

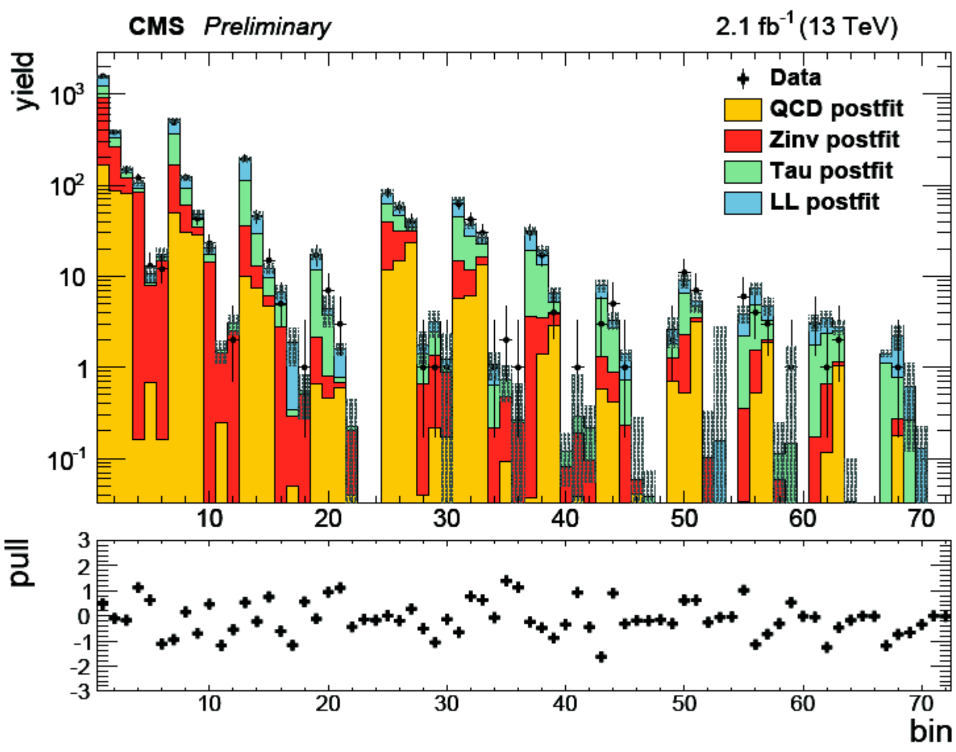
- Each of the discriminating variables exhibits a good signal-to-background rejection

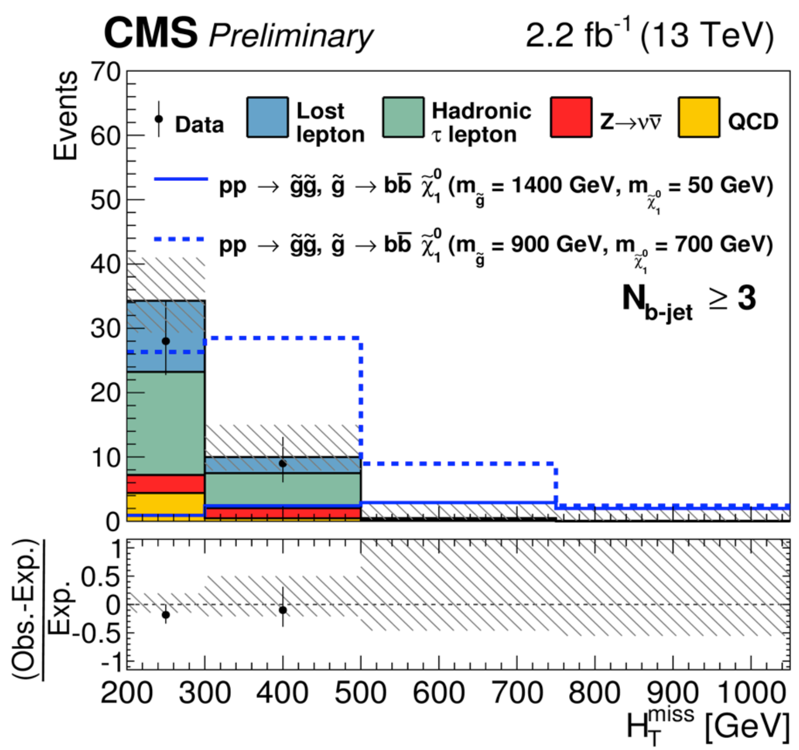


- To maximize sensitivity, search is performed in the bins of H_T, missing H_T, N_{jet} and $N_{b\text{-}jet}$
- Our strategy is to keep it
  - general: if natural SUSY does not look like an SMS model we don't want to miss it
  - simple: we can probe a new territory with the early data

Excess, excess: where are you?

- Plot on left shows the overall agreement between data and expected SM background in all 72 search regions ➔ consistency at 2σ level
- Right plot is the missing H_T distribution

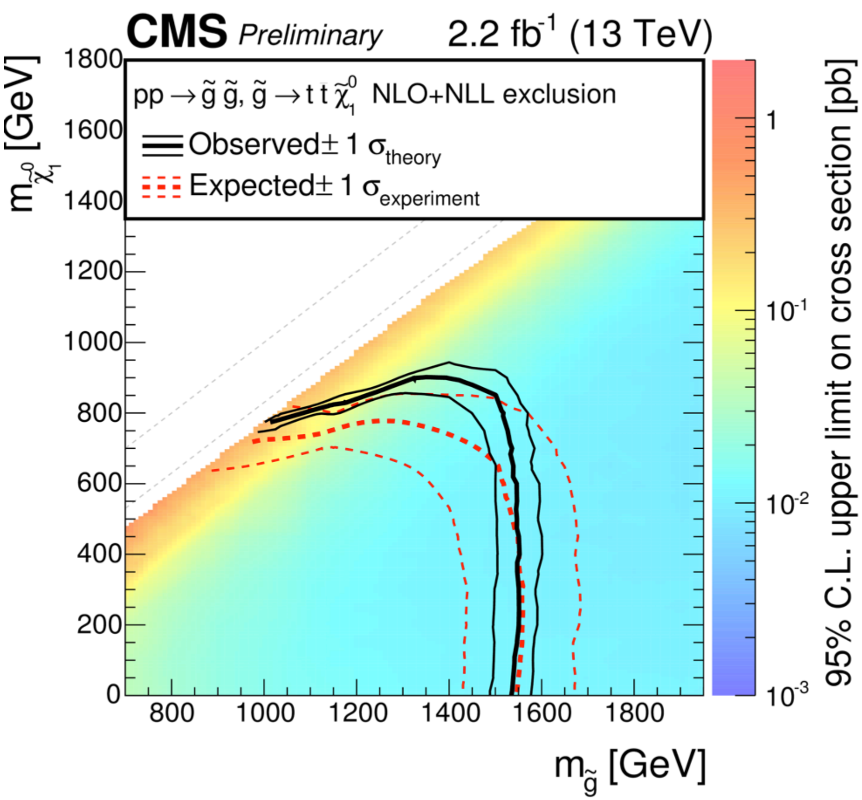


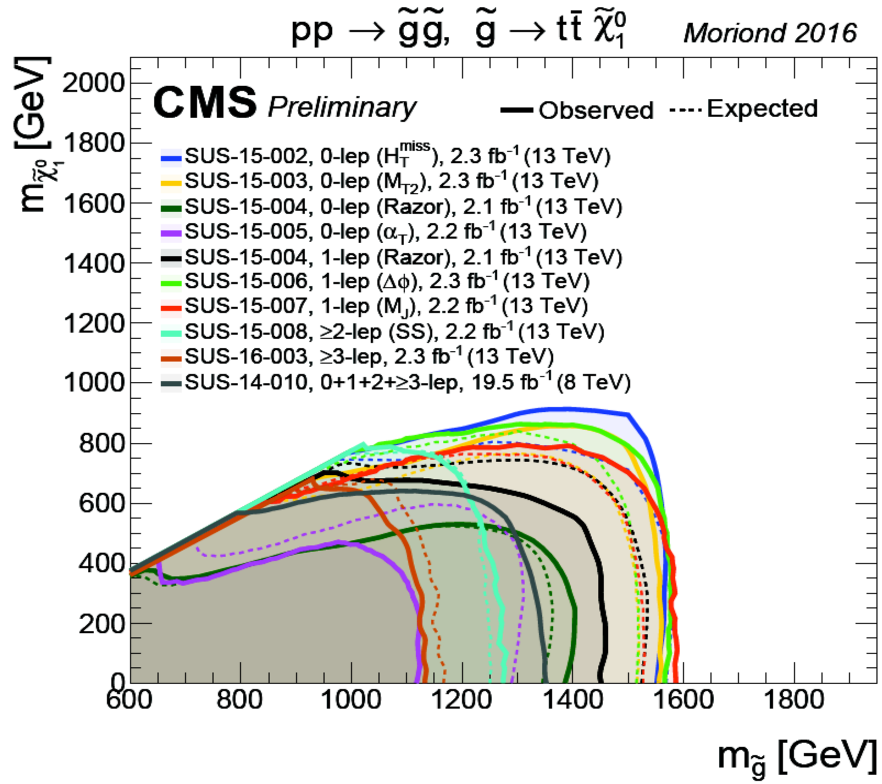


If there were a signal ...

Impressive limits…

- Limits from our study is the most stringent one over the entire parameter space





- More details to follow in Bibhu's talk

Summary

- Briefly summarized several NP searches we are involved in
- No significant excesses any where (SM is in good shape)
- But, of course the fun has just begun