Search for new physics at 13 TeV with CMS

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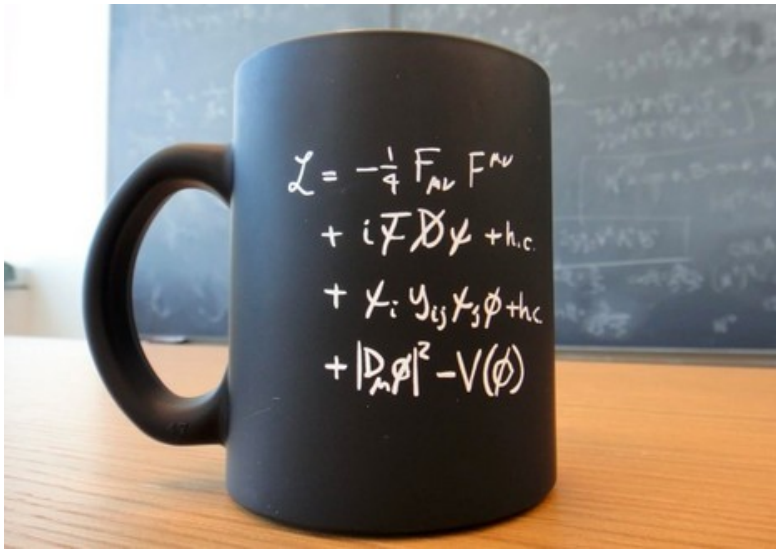
On behalf of the CMS collaboration

Introduction

- The SM was successfully validated by many experimental measurements performed over many years.

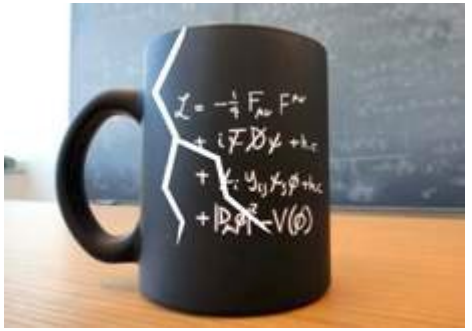


- The LHC results have even more consolidated the SM :
  - with new extremely precise measurements,
  - with the discovery of predicted SM processes/particles : the Higgs boson is the brightest example.

- However the MS is incomplete!
- There are new particles to be found !
- One of the goals of the LHC : probe SM physics and find new physics.

Beyond the Standard Model

- Despite it's successful predictions, the SM suffers from limitations/imperfections :
  - Not predicting the Dark Matter (DM) nor the Dark Energy,
  - No explanation for matter/antimatter asymmetry,
  - No massive neutrinos, no explanation for the observed hierarchy of masses,
  - “Unstable” Higgs mass and fine tuning,
  - Not compliant with the GUT,
  - Etc...



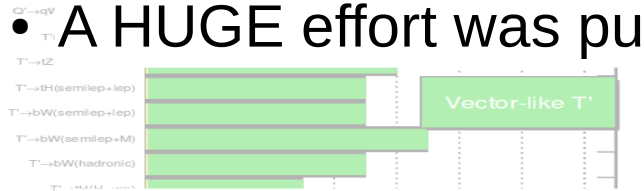
- Many models on the market, proposing solutions to these “problems” :
  - Super-symmetry (SUSY),
  - Extra-dimension,
  - etc...

- How can we search for New Physics at colliders ?
  - Direct searches of new particles ! Many (almost infinite number of) channels, but can be performed inclusively.
  - Indirect searches ! Re-interpretation of precision measurements (anomalous couplings, close signatures). Requires luminosity...

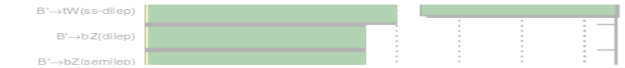
Discussed in this talk

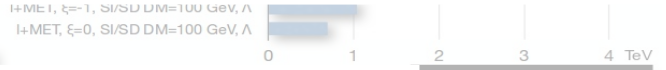
Snapshot of 8TeV BSM results at CMS

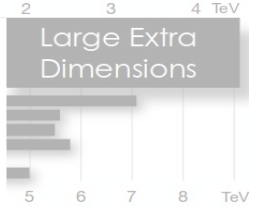
- A HUGE effort was put on direct searches at Run I.



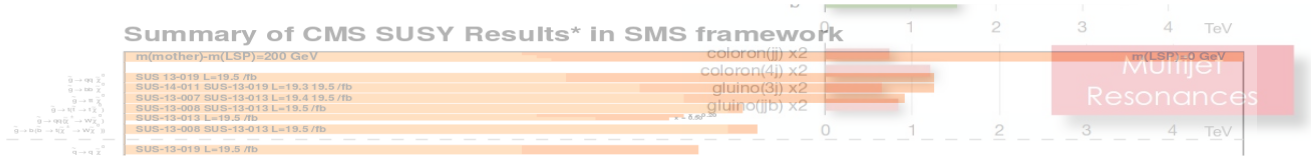
- Many channels/signatures investigated, no clear sign of new physics found so far !

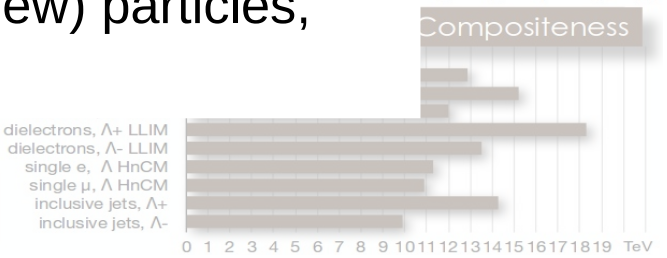






- With LHC run 2 : lot of opportunities.
  - Higher energy : producing (more) heavy (potentially new) particles,
  - Large luminosity : important for rare processes !





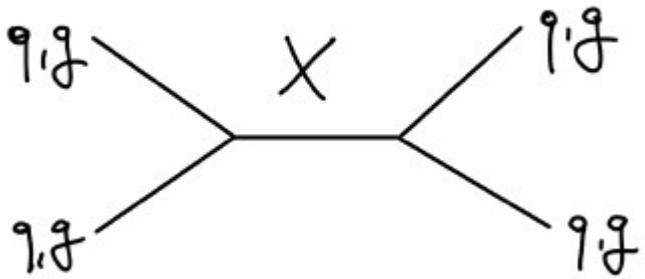
- Current status at 13 TeV : still low luminosity 175 pb^{-1} (here shown mainly results using 42 pb^{-1}).
  - first focus on inclusive searches,
  - validation of the analyses, not enough statistics for almost all searches,
  - but not for all (dijet resonance) !

Search for di-jet resonance at 13 TeV

EXO-15-001

Di-jet resonance search

- Search for heavy particles decaying into 2 jets.



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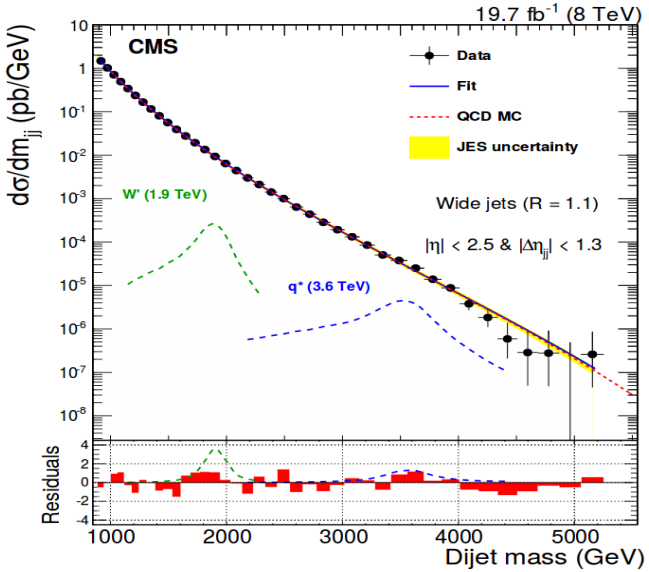


- For narrow resonances : search for a bump in the di-jet mass spectrum.

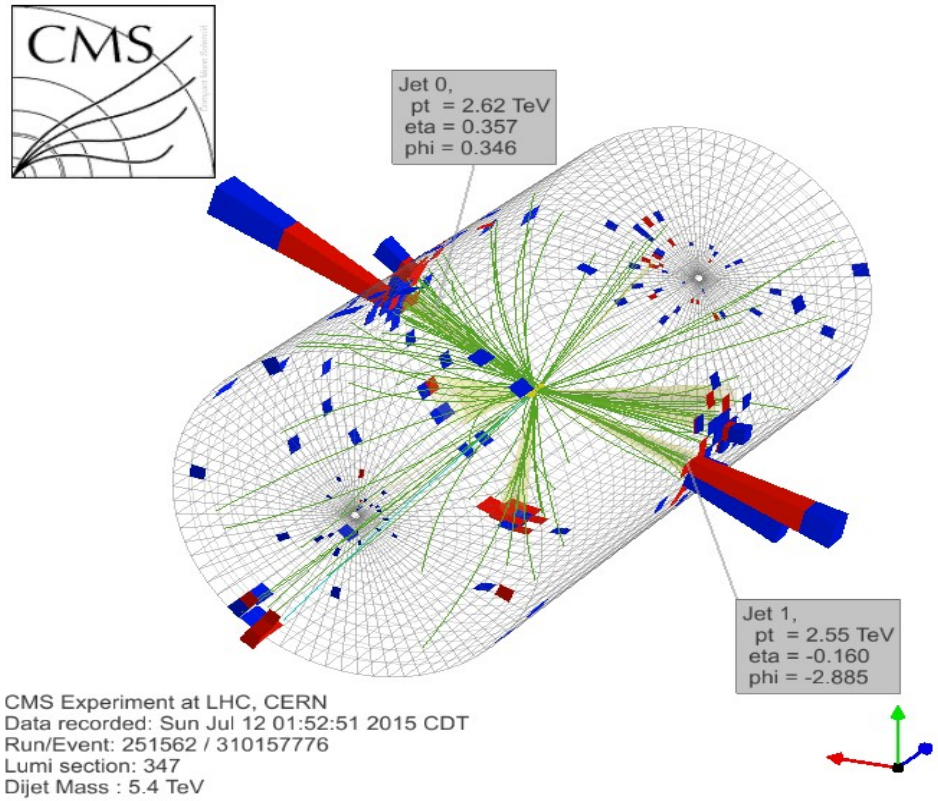
- Inclusive search (well suited for first studies) : sensitive to any resonant particle that produces di-jet.

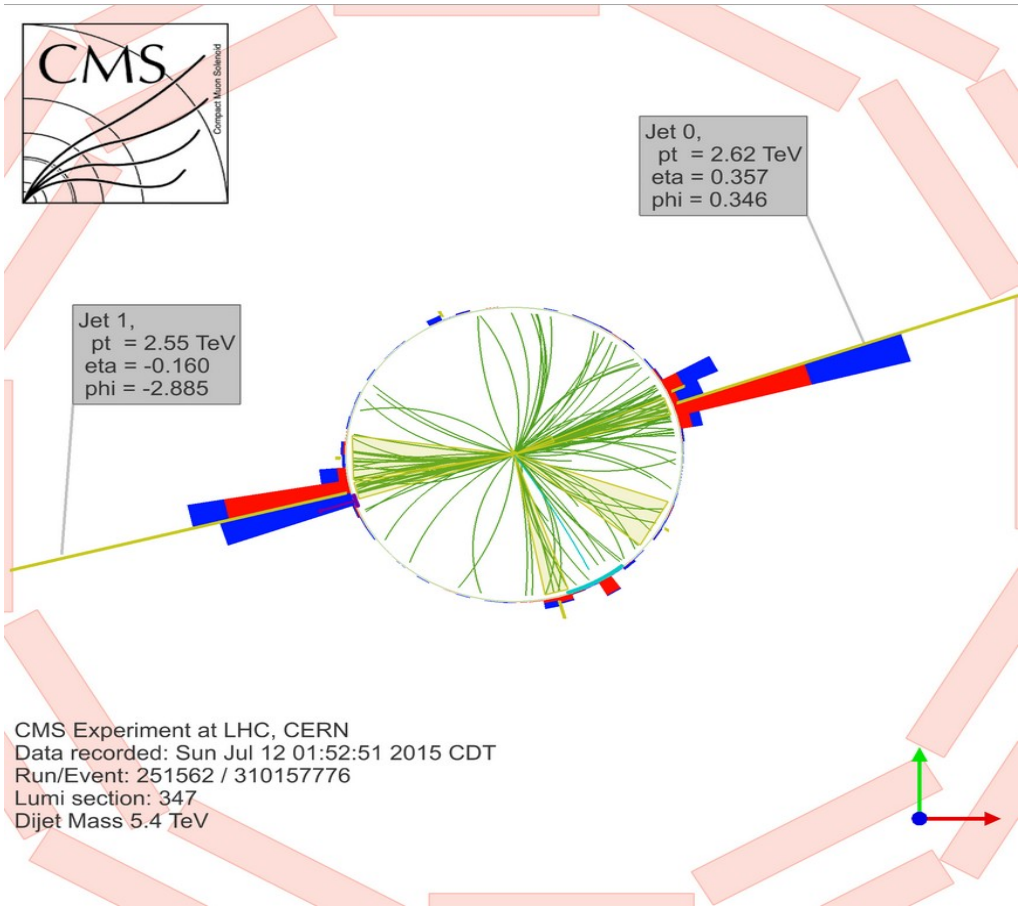
- pp collisions at 13 TeV : new energy scale reachable, expected to have already a better sensitivity for masses > 5 TeV !

Highest di-jet mass events

Dijet mass of 5.4 TeV

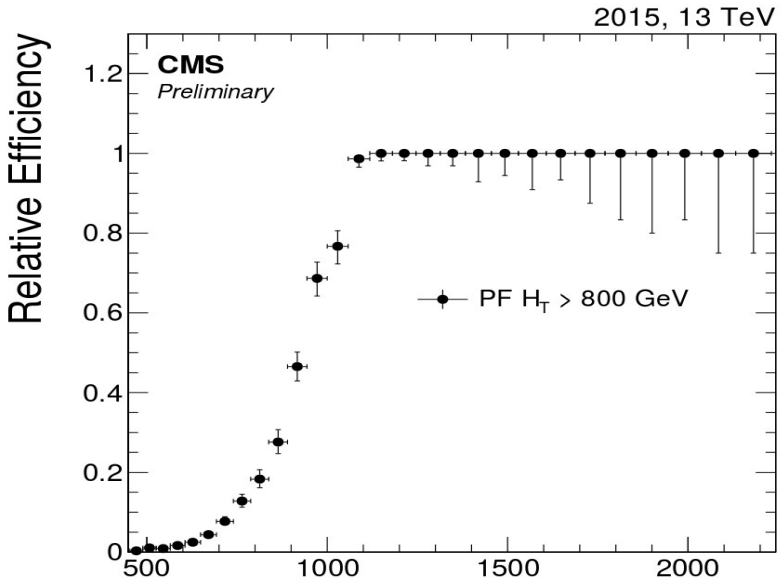
For |Δη|<1.3

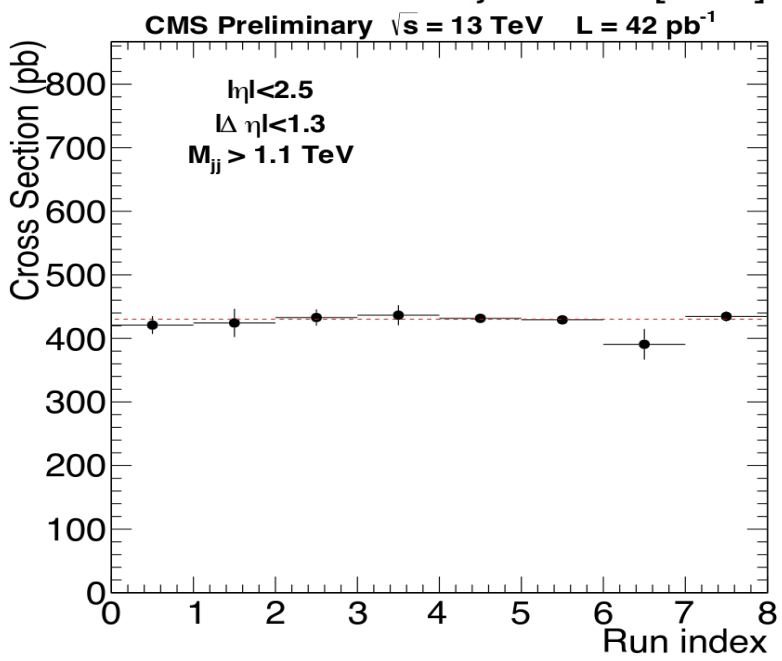




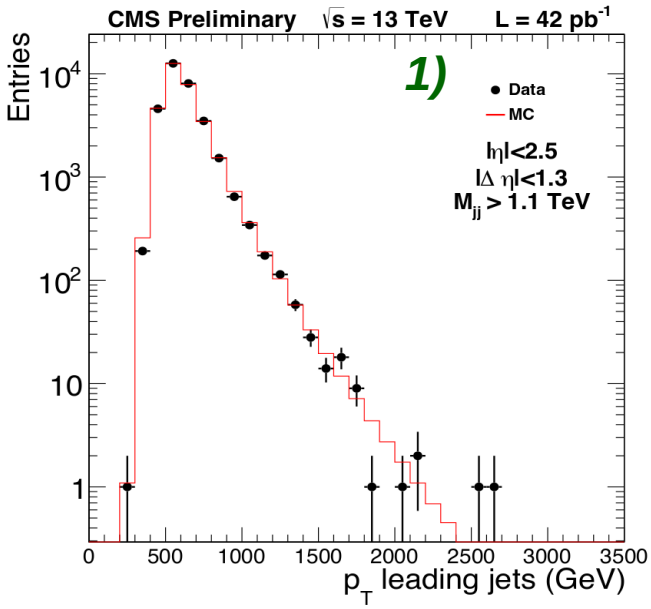
Event reconstruction and selection

- Wide jets reconstruction :
  - Reconstructed jet (ΔR=0.4) with p_T>30 GeV and |η|<2.5,
  - Choose the 2 leading jets as seeds,
  - add jets to the closest leading jet with ΔR<1.1.
- Trigger selection :
  - H_T>800 GeV (H_T= scalar sum of jets p_T),
  - Trigger efficiency from data : reference trigger H_T>450 GeV,
  - Fully efficient >1.1 TeV.
- M_{jj}>1.1 TeV to avoid trigger bias.
- Further suppression of t-channel QCD : |Δη|<1.3.

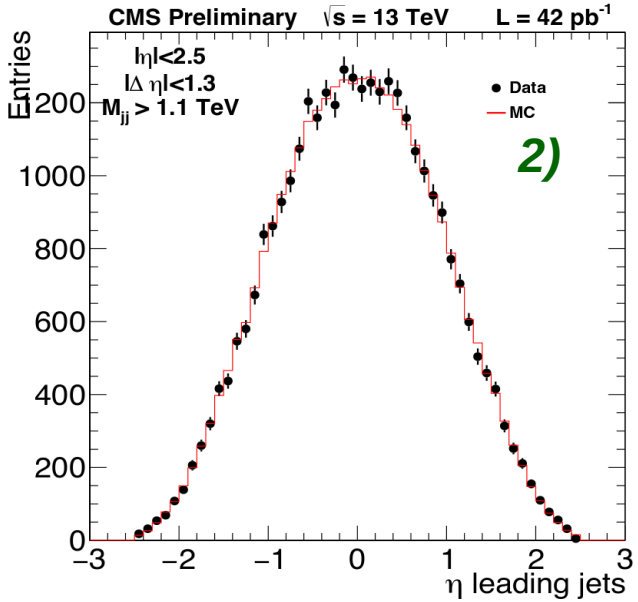


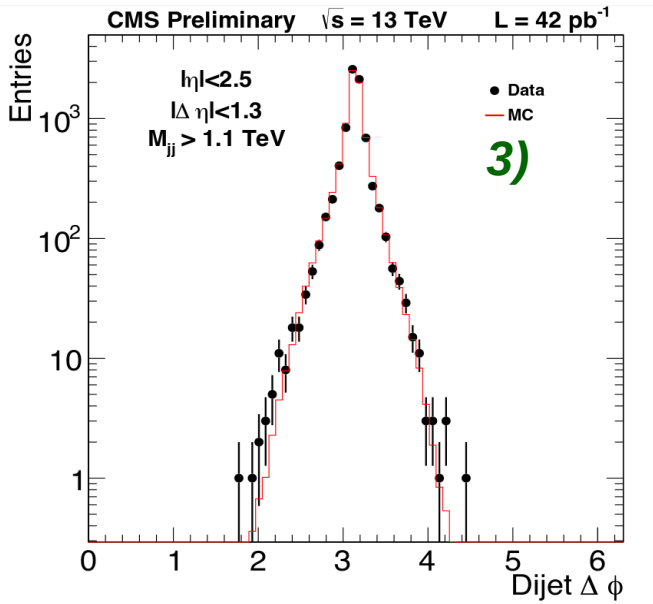


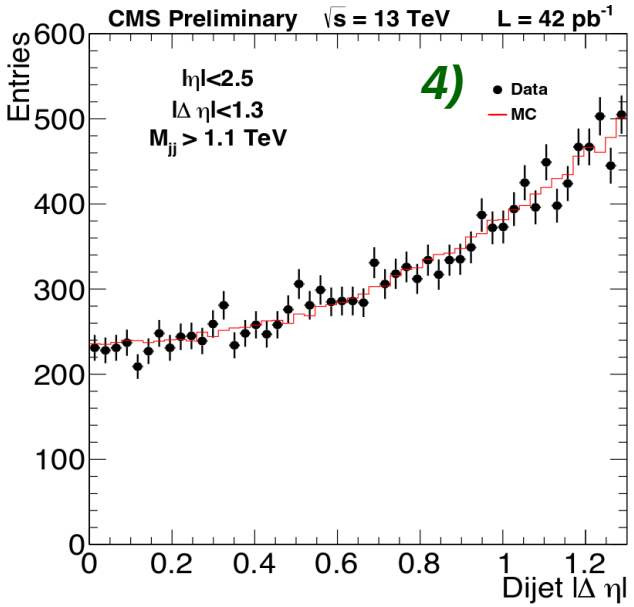
Data-MC comparisons



- Data compared with QCD-Pythia8 :
  - ***1)*** leading jets p_T, ***2)*** leading jet η,
  - ***3)*** Di-jet Δφ, ***4)*** Dijet |Δη|,
  - Excellent agreement between data and MC.



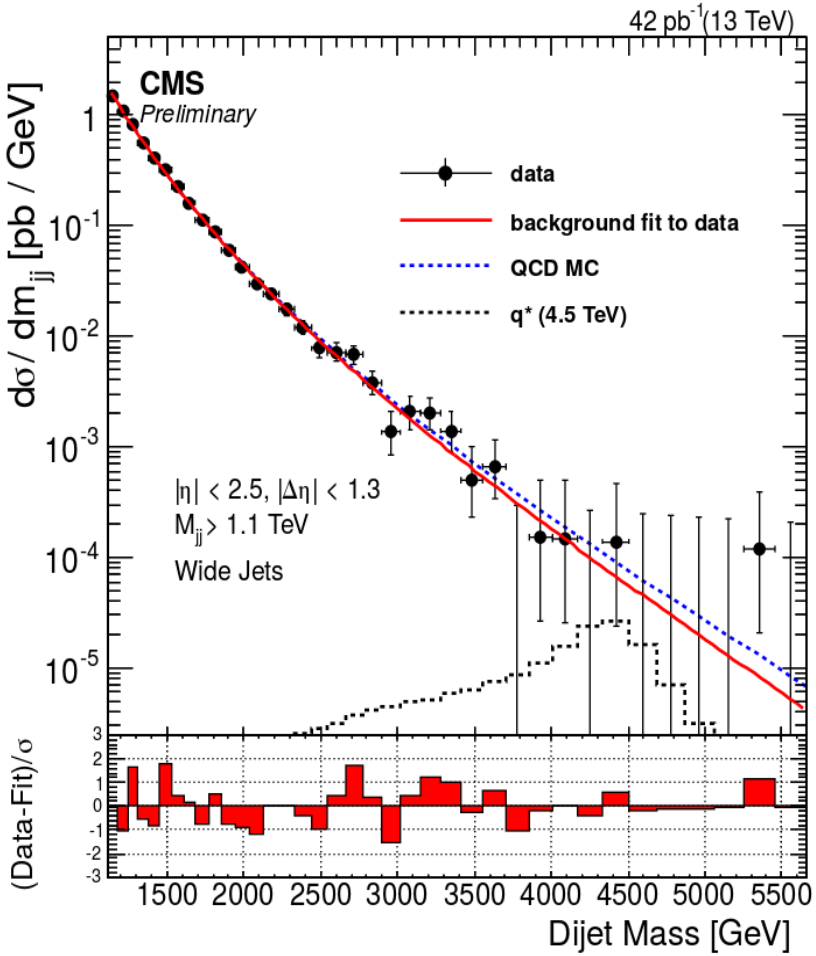




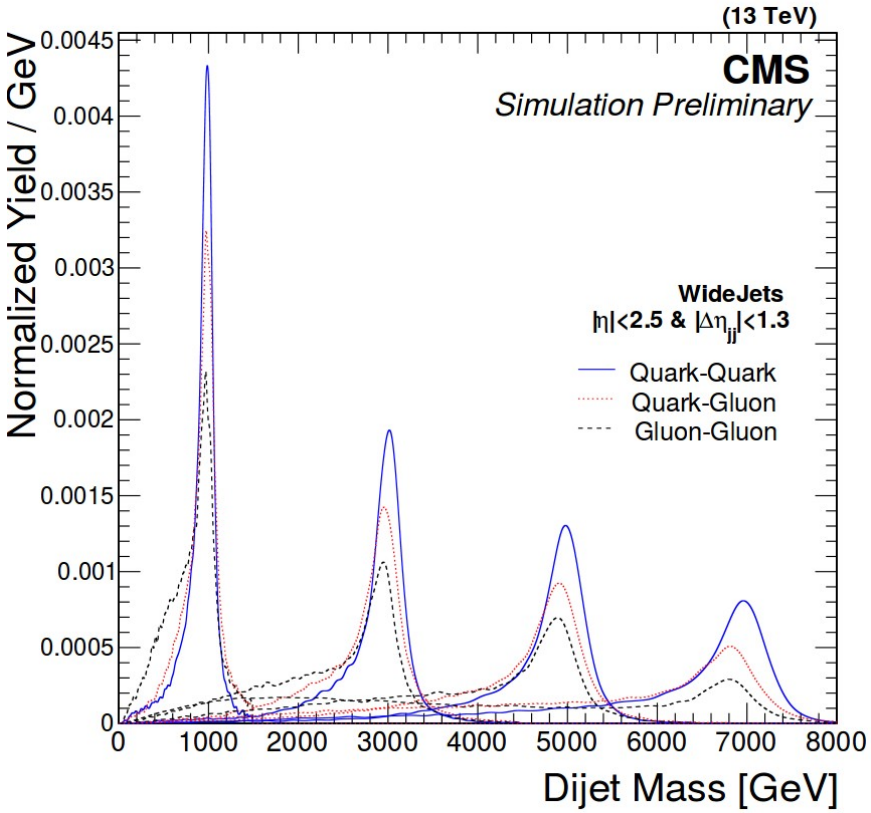
Background fit and signal modelling

Dijet invariant mass at 13 TeV

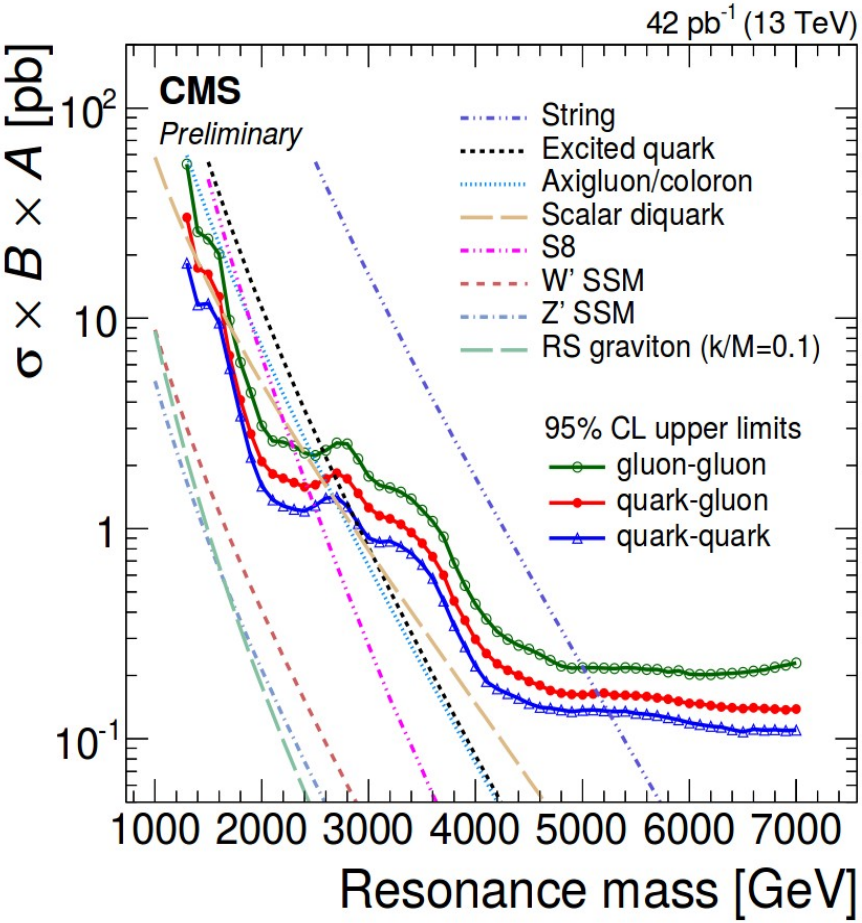
$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2}} \qquad x = m_{jj}/\sqrt{s}$$



- Reconstructed mass for narrow quark-quark, quark-gluon and gluon-gluon resonances.
- For masses from 1 to 7 TeV.
- Low mass tails :
  - from FSR, more pronounced for gluons,
  - At high masses, PDF effects.



Limits on di-jet resonances



- No evidence of new di-jet resonances.
- Exclusion limits are calculated for the 3 different cases : qq, qg and gg.
- Dominant systematics : lumi 12%, JER 10% and JES 5%.
- Exclusion from 2.3 to 5.1 TeV (best exclusion), depending on the model.

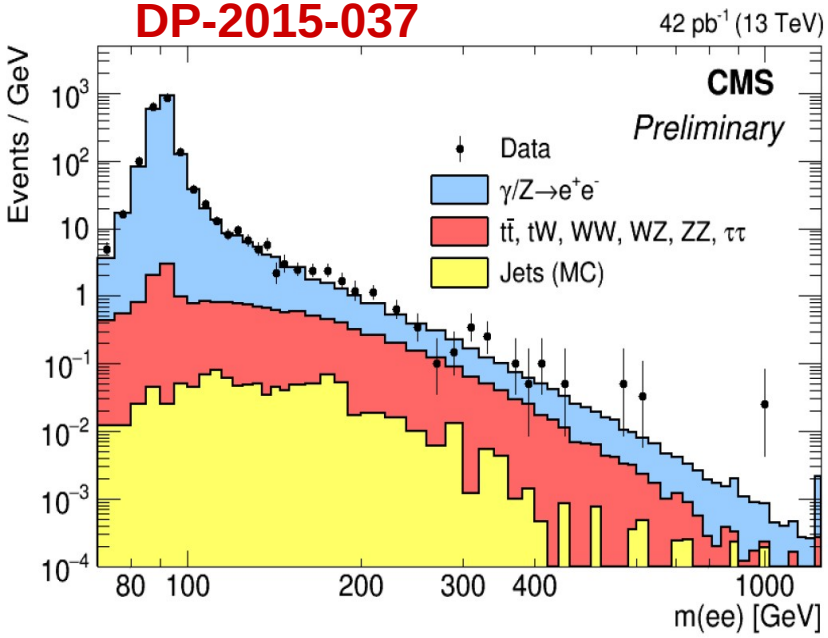
Model	Final State	Obs. Mass Limit [TeV]	Exp. Mass Limit [TeV]
String Resonance (S)	qg	5.1	5.2
Excited Quark (q*)	qg	2.7	2.9
Scalar Diquark (D)	qq	2.7	3.3
Axigluon (A)/Coloron (C)	$q\bar{q}$	2.7	2.9
Color Octet Scalar (s8)	gg	2.3	2.0

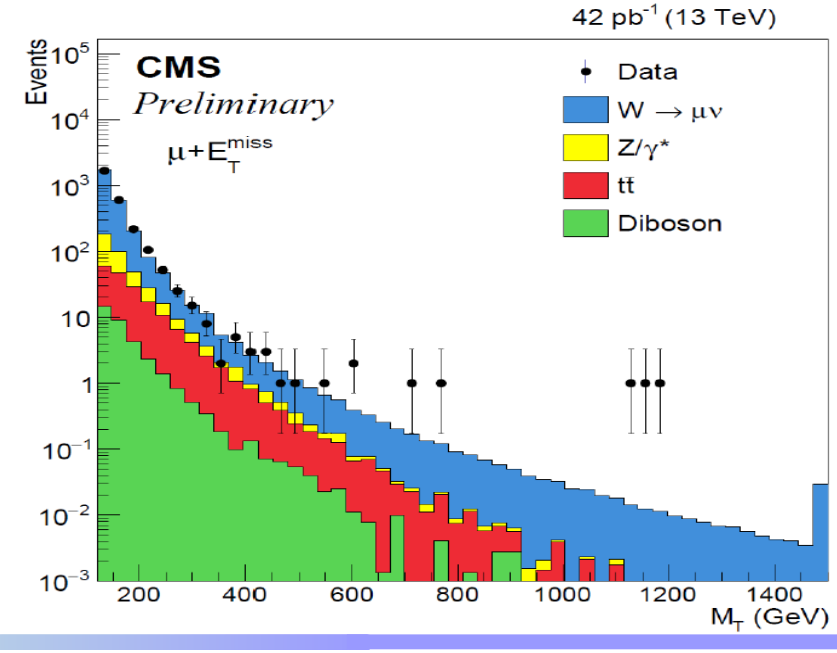
Table 1: Observed and expected 95% CL limits on the mass of various resonances. This analysis excludes the resonances listed at 95% CL between a mass of 1.3 TeV and the limits shown.

Other preliminary results related to resonances

Di-electron and mu+met M_T

DP-2015-037





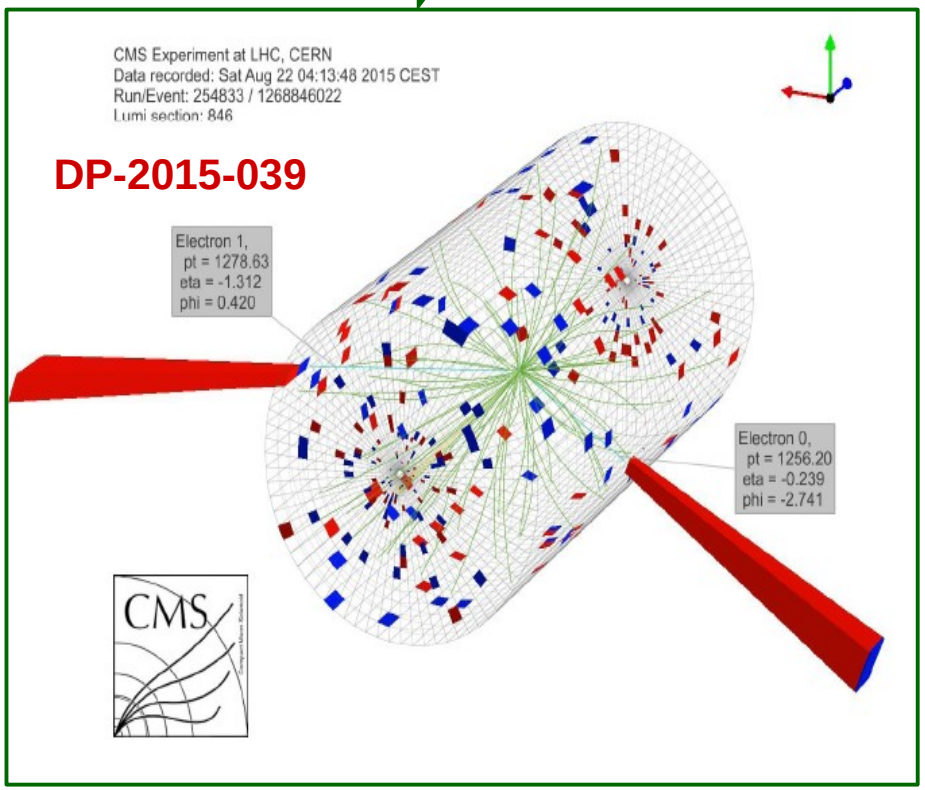
- Di-electron invariant mass spectrum :
  - Good isolated electrons with E_T > 35 GeV and $|\eta|$< 1.4442 or 1.566<$|\eta|$<2.5,
  - One electron with $|\eta|$ < 1.4442,
  - A pair of electrons (no opposite sign requirements),
  - Simulation scaled to the data in the region 60<m_{ll}<120 GeV.

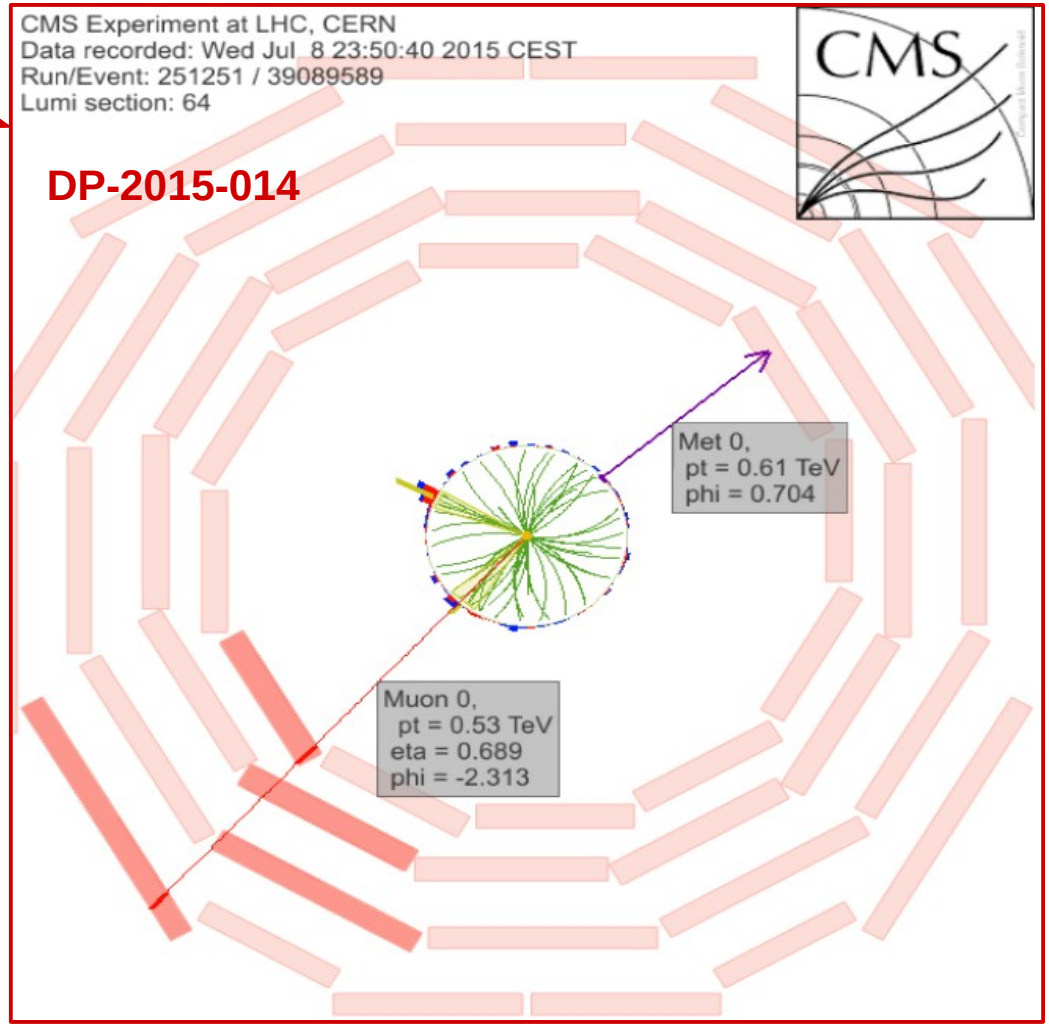
- Transverse mass for μ+MET:
  - Isolated muon with good quality,
  - p_T > 55 GeV, $|\eta|$ < 2.4,
  - Single muon (veto add. muon) with large MET : 0.4<p_T(μ)/MET<1.5,
  - Δφ(μ-MET)>2.5,
  - Simulation scaled to the luminosity.

Good agreement between data and MC

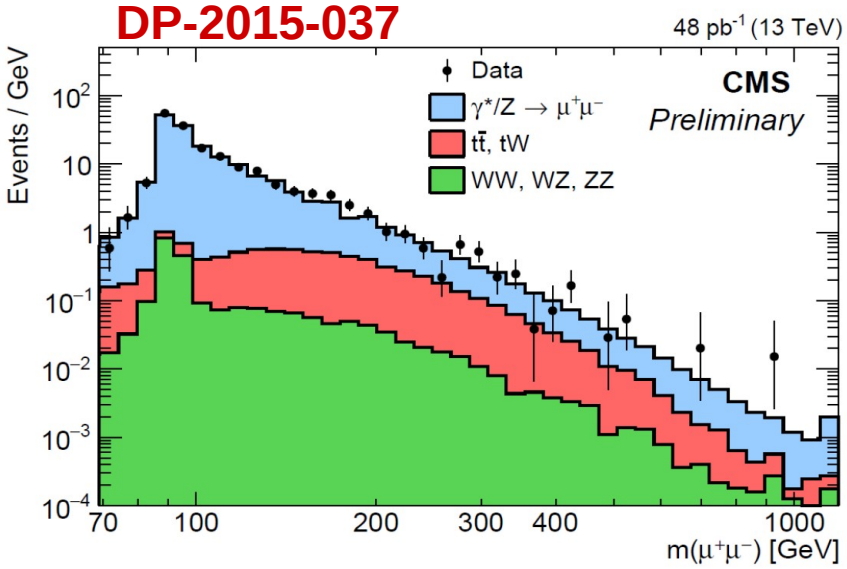
Some events displays for "energetic" events

- Event displays for :
  - Single muon (0.53 TeV) and MET (0.62TeV), M_T=1.1 TeV
  - e+e- of m_{ll}=2.9 TeV (1.3,1.3 TeV)





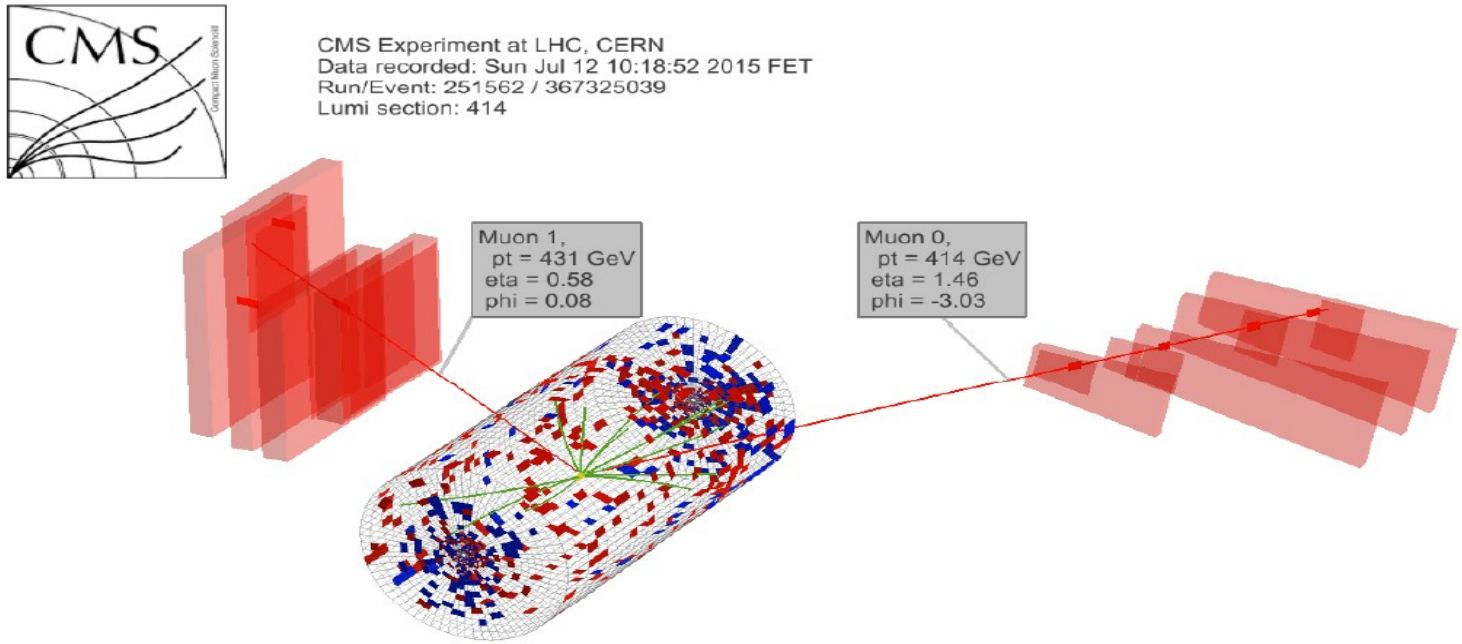
Di-muon events



- Di-muon invariant mass spectrum.
  - Good isolated muons with p_T>48 GeV |η|<2.4,
  - Pair of opposite sign muons,
  - Simulation scaled to the luminosity.

Good agreement between data and MC

- Event display :
  - Di-muon with p_T (431, 414),
  - Invariant mass of 920 GeV.



SUSY investigations :

Commissioning the performance of key observables

DP-2015-035

Investigating SUSY variables

- Not enough luminosity (yet) to be competitive with Run 1 analyses.

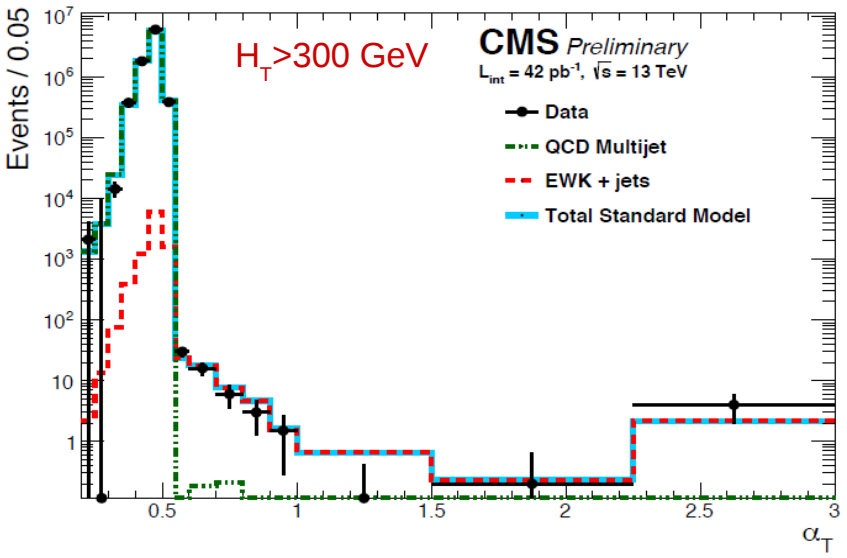
- Preparing SUSY searches : first control plots for trigger and selection efficiencies, background estimations and data-MC comparisons for key observables.

- With first data, focus on “inclusive” searches :
  - All hadronic channels : **α_T**, razor (kinematic specificities of “dijet” events), MT2,
  - Single lepton channels : **$\Delta\varphi$**, sum jet masses,
  - Di-leptonic channels : **same sign**,
  - Photon+met channels.

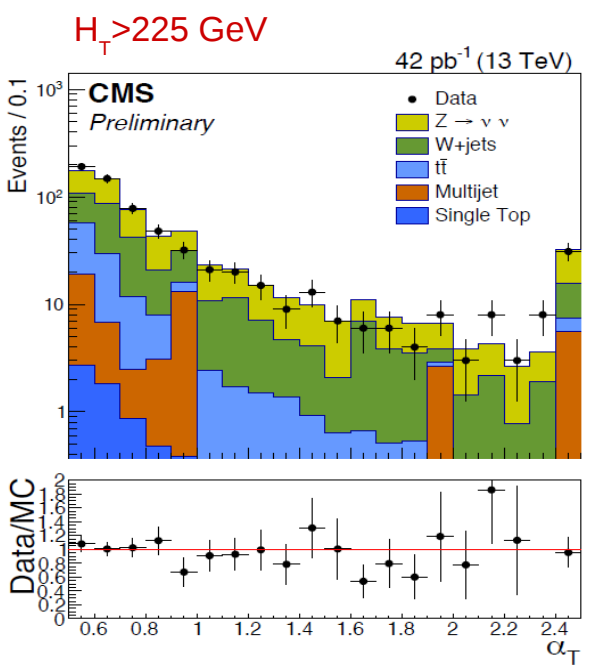
Shown in these slides

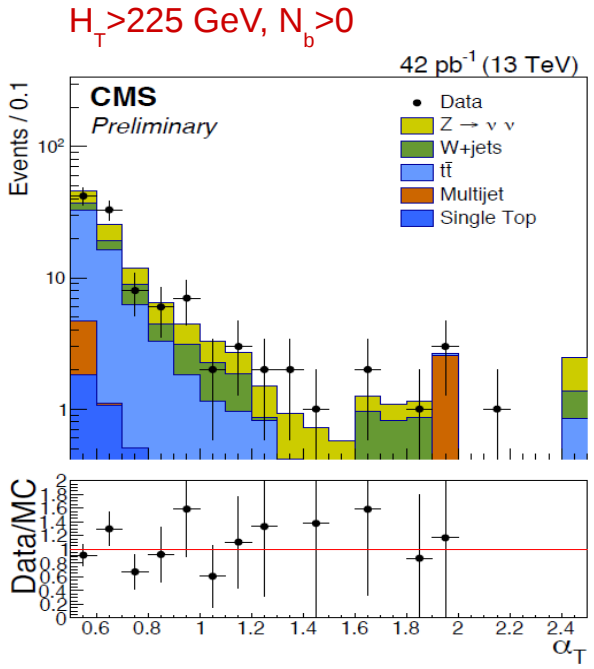
All hadronic channels : example of α_T

- α_T definition : $E_T(j_2)/M_T$
  - For di-jet QCD events, jets are back-to-back in φ : α_T=0.5,
  - Robust against jet mis-reconstruction : imbalance in di-jet => α_T< 0.5,
  - Generalized to multi-jets by merging jets into two pseudo-jets,
  - α_T>0.5 for events with extra MET.



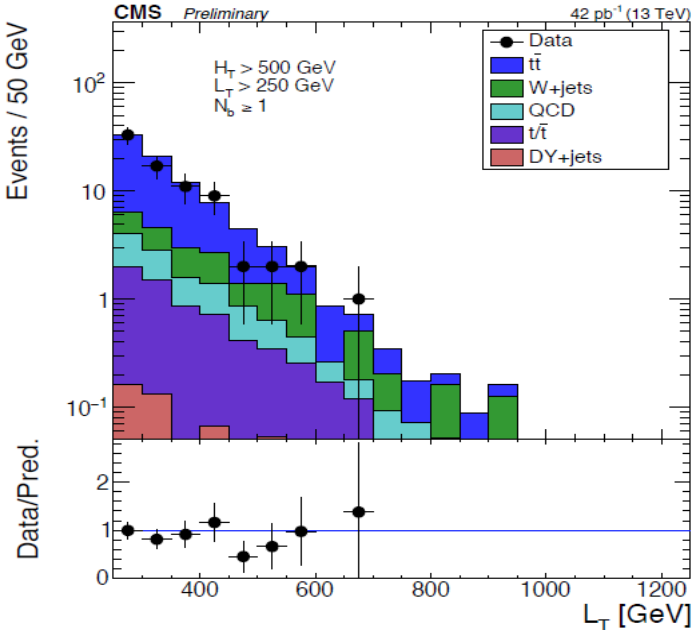
- Event selection :
  - H_T-α_T dedicated triggers,
  - Veto isolated leptons (photons) with p_T>10(25) GeV for leptons,
  - ≥2 jets with p_T>40 GeV, |η|<3, b-tag,
  - H_T>200 GeV, leading jet p_T>100 GeV,
  - α_T > 0.55.

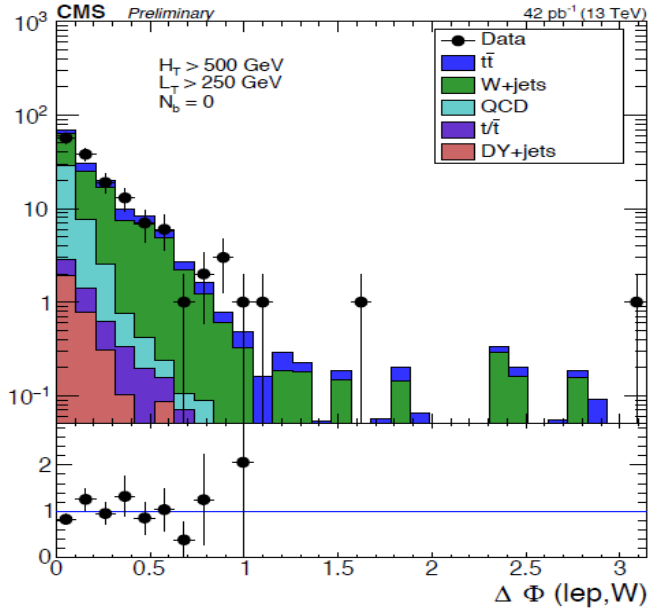




Good agreement between data and MC

Single lepton channels: example of Δφ





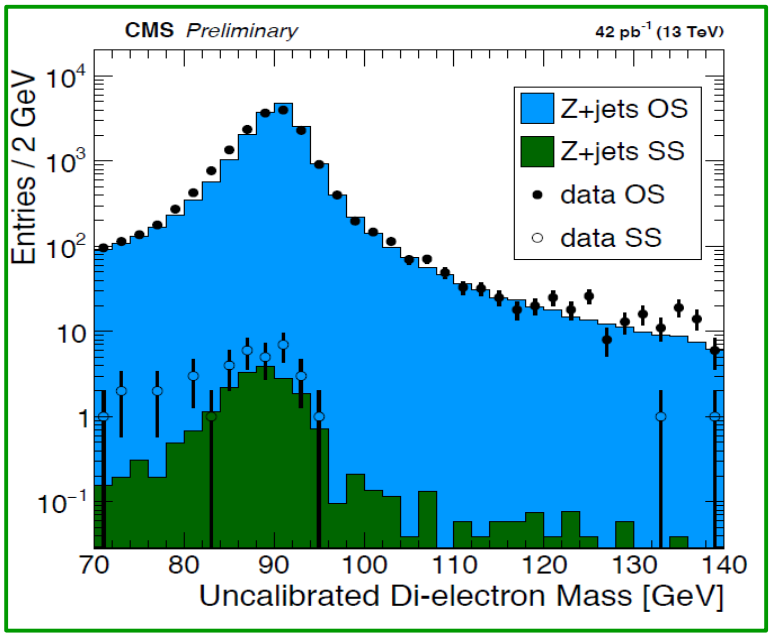
- Definition of Δφ(W,l) : azimuthal angle between W and lepton.
- Sensitive to SUSY signatures with W boson and multiple source of MET (stop pairs->ttbar+neutralinos).
- Performed in multiple bins of H_T, Njets, Nbjets.
- Event selection :
  - Trigger => 1 lepton, H_T>350 GeV, MET > 70 GeV,
  - Exactly one isolated lepton with p_T>25 GeV, |η|<2.4,
  - Veto additional leptons with p_T > 10 GeV,
  - ≥2 jets with p_T > 30 GeV, 2 leading > 80 GeV,
  - H_T>500 GeV, L_T(sum lepton p_T and MET) >250 GeV.

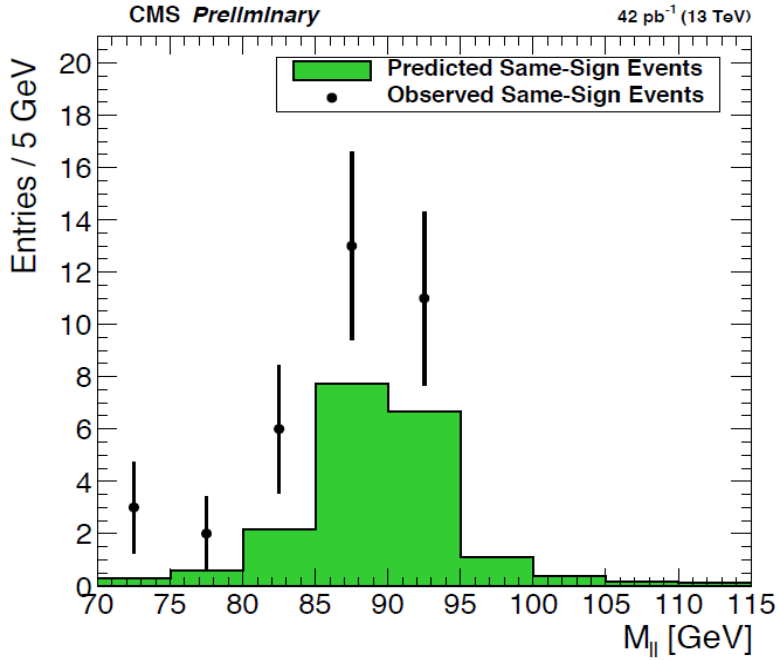
Good agreement between data and MC

Same sign di-lepton

- Same sign di-leptons appear in many BSM processes, but rare in the SM.
- Main background contributions :
  - Charge mis-reconstruction of electrons,
  - Fake-lepton backgrounds from b/c semi-leptonic decays or from misidentification,
  - SM processes with same sign di-lepton (ttbar+V, VV).

- Charge mis-reconstruction estimated using Z mass peak.



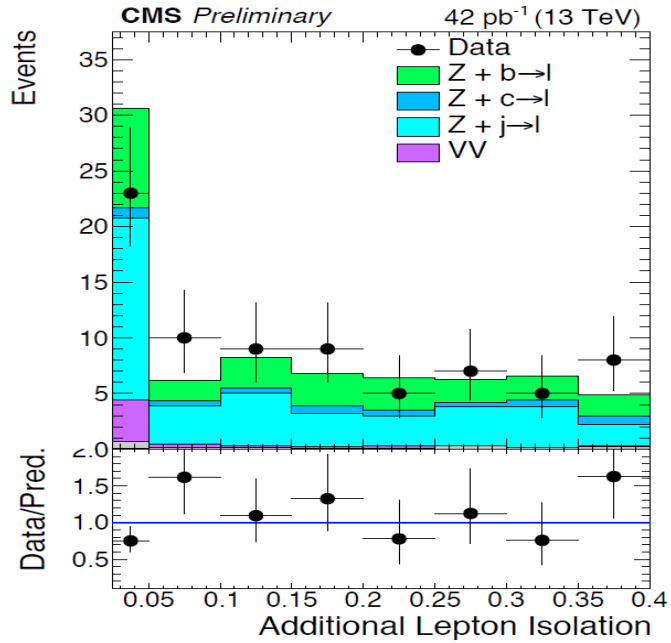


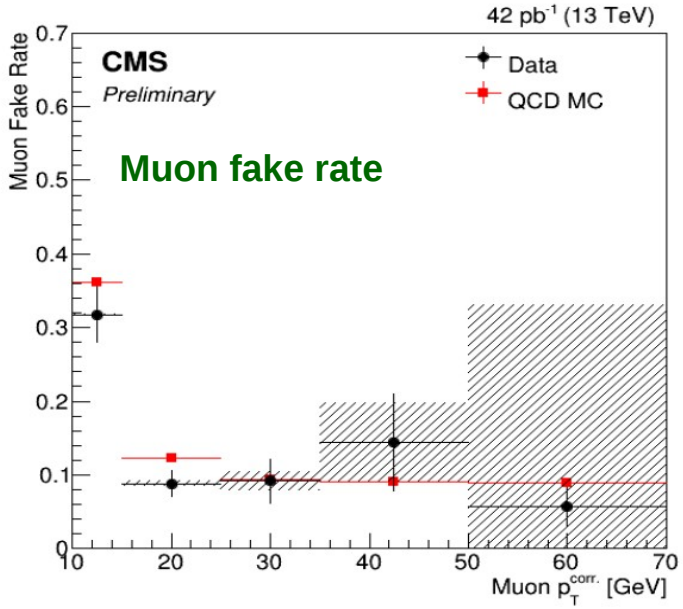
Same sign di-lepton (2)

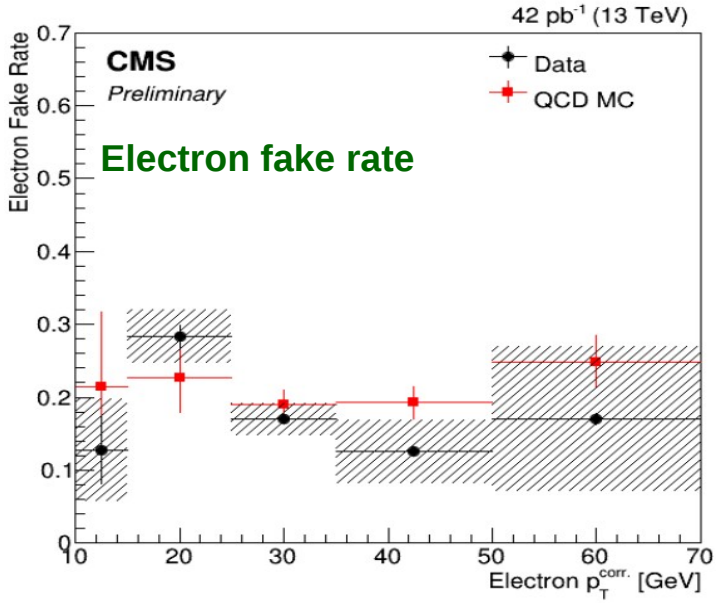
- Fake lepton isolation :
  - From sample enriched in fakes,
  - Select Z(W)+1 additional (fake) lepton,
  - Isolation selection rate of add. lepton => fake rate,
  - Correct for prompt lepton contamination.

- Data-driven estimation compatible with MC predictions.

Z+1 lepton selection





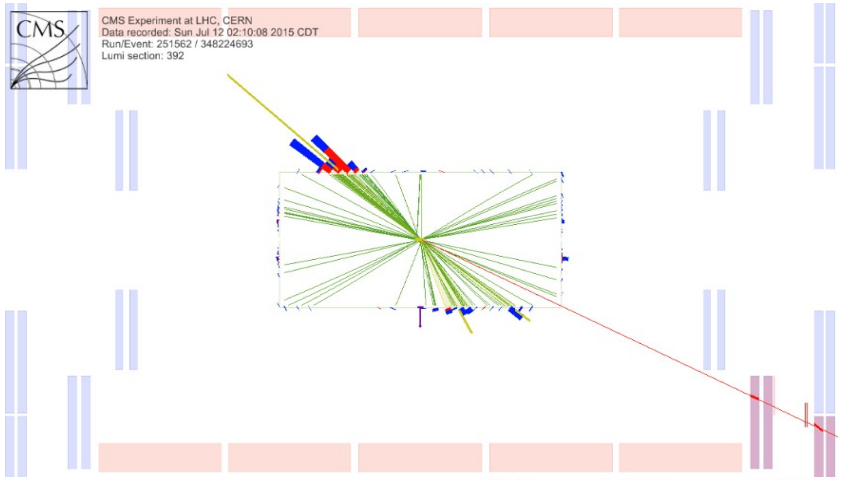


B2G first investigations : W' → tb and ttbar+DM

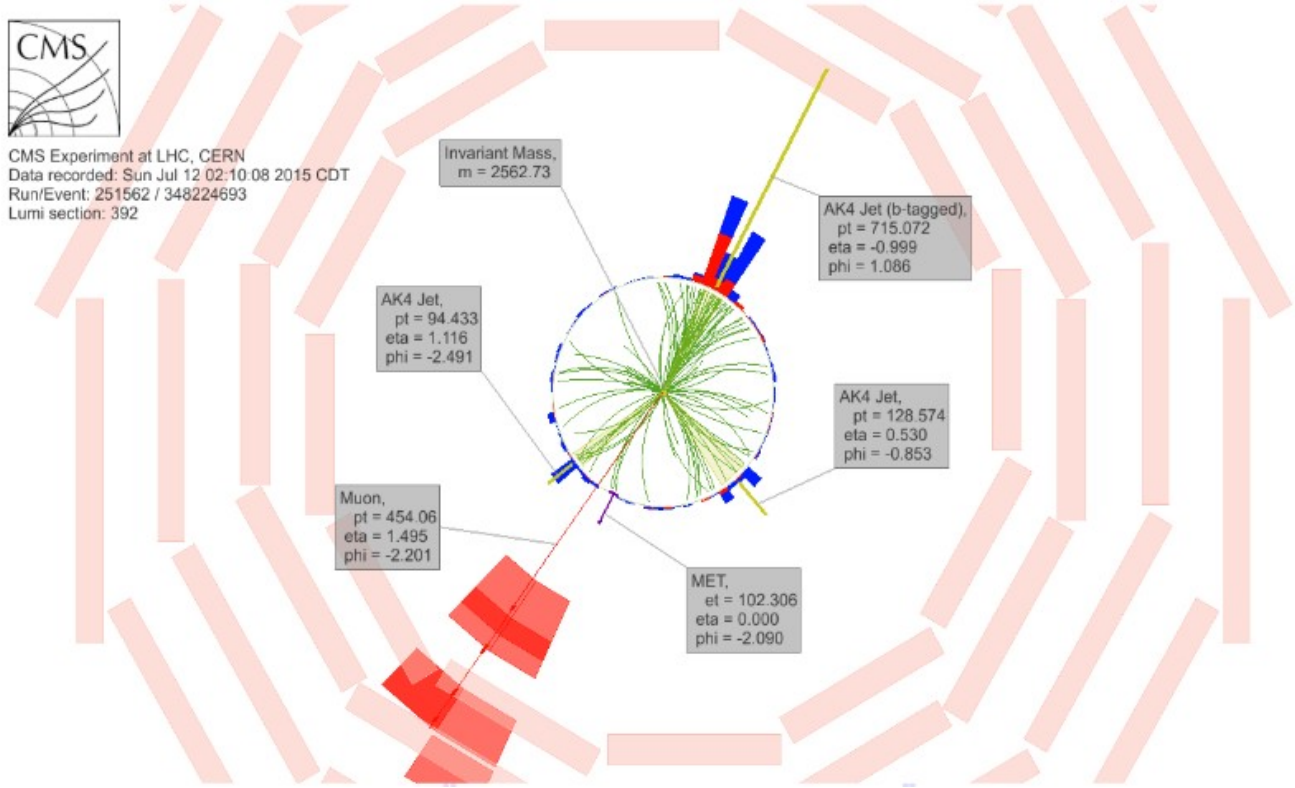
DP-2015-033

Boosted tops presented elsewhere (see talk from Louise Skinnari)

W' event display



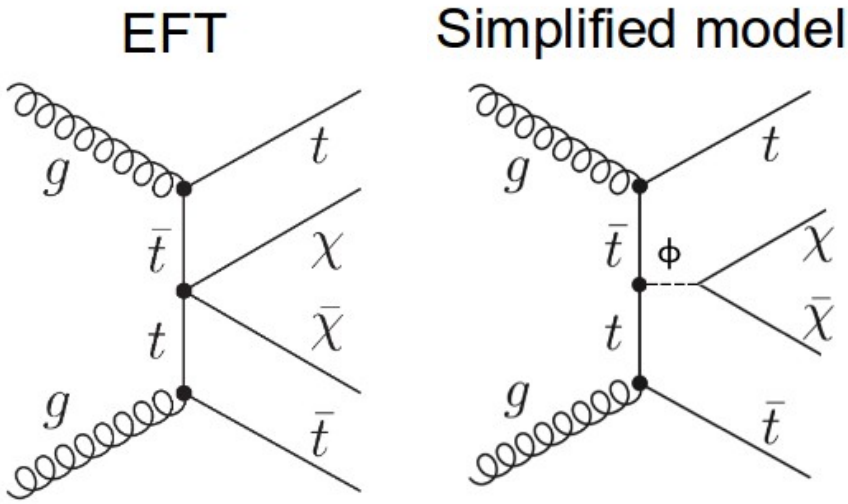
- Candidate of W'→tb at high energy :
  - Single isolated lepton, two jets and large MET.
  - Jet 1 p_T=715 GeV, jet 2 p_T=129 GeV,
  - Muon p_T=457 GeV,
  - MET=102 GeV,
  - Invariant mass = 2.5 TeV.



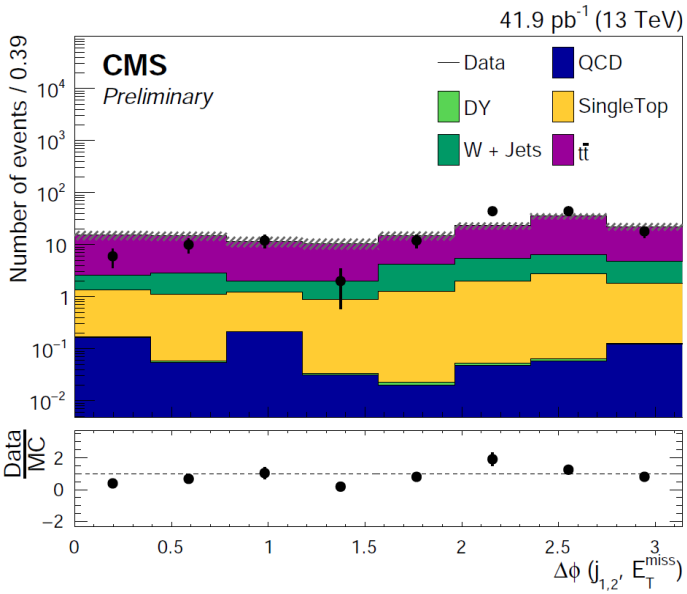
ttbar+met

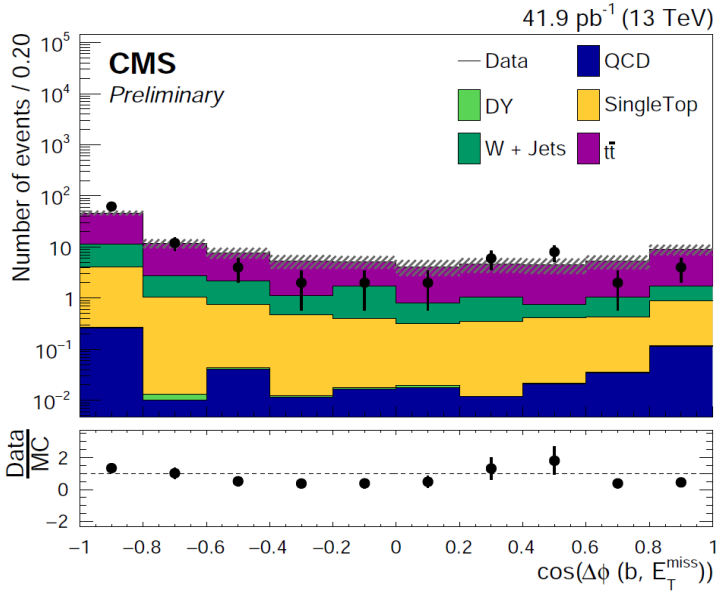
- Search for DM produced in associations with ttbar (single lepton channel).

- Event selection :
  - Good quality isolated leptons (e,μ) with p_T>30 GeV, |η|<2.5,
  - ≥3 jets with p_T>30 GeV, |η|<2.5, ΔR=0.3, one tight b-tag,
  - MET>160 GeV.



- Discrimination : use recoil of ttbar against MET





Good agreement between data and MC

Conclusion

- First 13 TeV data are already used to search for new physics.
- Di-jet resonances searches already **show better sensitivity than Run 1**, for the high mass region.
- For most of the searches, there are not enough statistics to be competitive with Run 1 (yet).
- However, the “commissioning” of analyses already started, and **shows good performances of the CMS detector**.
- **Ready to gather more data ! Exciting moment ahead !**

With more data, who knows, we might be able to find something !

- Some MC based sensitivity studies for further reading (at high luminosity).
- FTR-13-014 : Study of Discovery Reach in Searches for Supersymmetry at CMS with 3000 fb^{-1}.
- FTR-13-016 : Projections of Top FCNC Searches in 3000 fb^{-1} at the LHC.
- FTR-13-024 : Performance studies on the search for 2HDM neutral Higgs bosons with the CMS Phase-II detector upgrades.
- FTR-13-026 : Sensitivity of the prospects for searching for heavy vector-like charge 2/3 quarks at 14 TeV with the upgraded CMS detector.

Backup

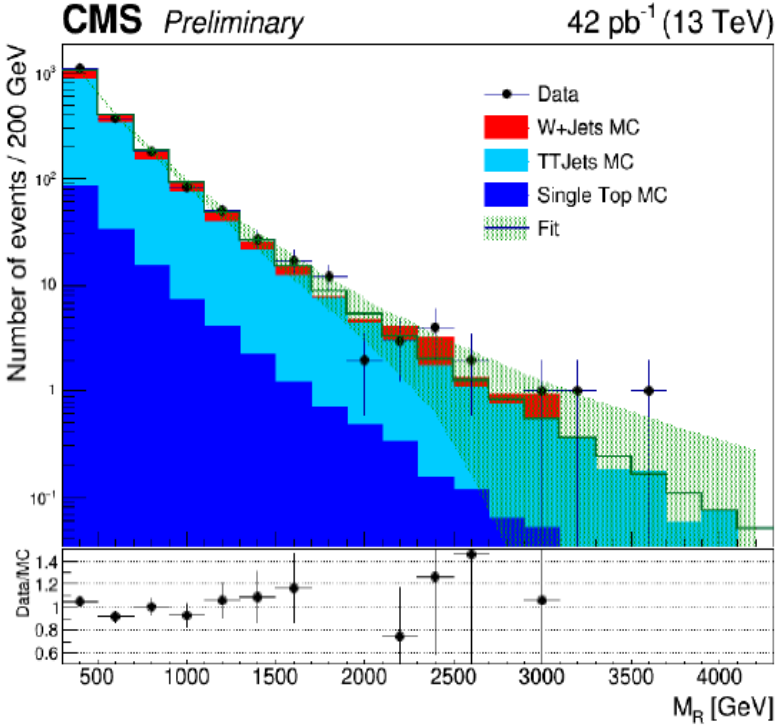
Commissioning of the MT2 and razor variable

- Razor : kinematic end point at new particle mass.
- Single lepton, MET>30 GeV, $30<M_T<100$

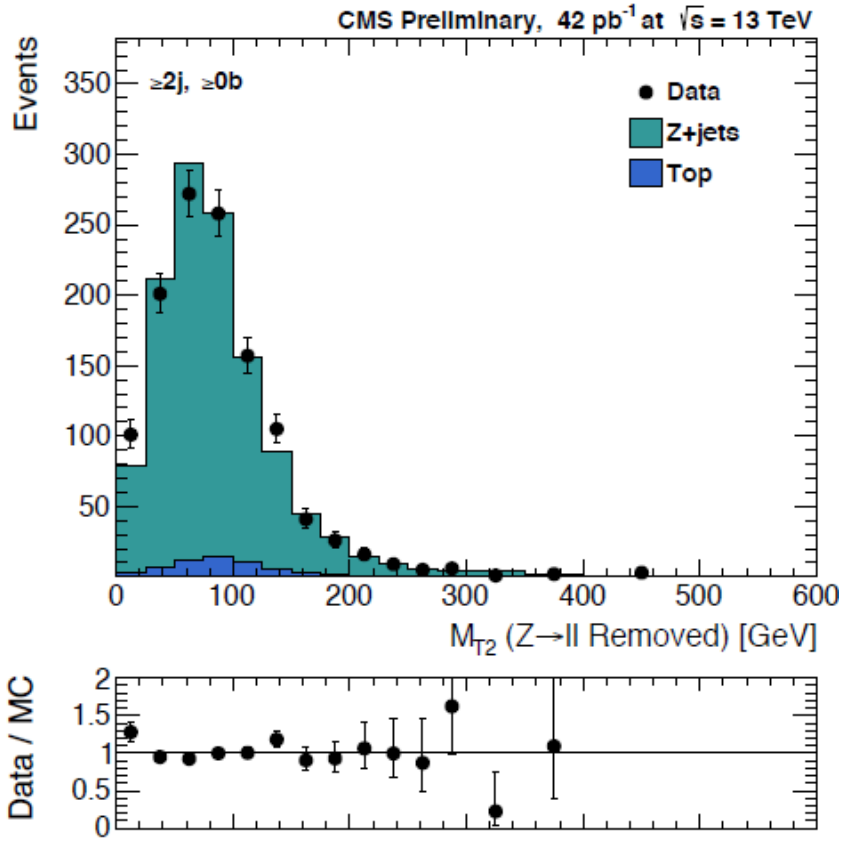
$$M_R \equiv \sqrt{(|\vec{p}(j_1)| + |\vec{p}(j_2)|)^2 - (p_z(j_1) + p_z(j_2))^2} \quad \text{and} \quad R \equiv \frac{M_T^R}{M_R},$$

$$M_T^R \equiv \sqrt{\frac{E_T^{miss}(p_T(j_1)+p_T(j_2)) - \vec{E}_T^{miss}\cdot(\vec{p}_T(j_1)+\vec{p}_T(j_2))}{2}}.$$

ttbar enriched



- MT2 : signatures with MET, new physics populate the tail.
- Estimation of the Z+jets backgrounds in Z-> invisible :
  - dilepton with $p_T(Z) > 120$ GeV,
  - At least 2 jets



Sum jet variable

- Single lepton, 4 jets, 1 b-tag, MET>175 GeV, HT>400 GeV.
- Uses the “sum jet” variable.

$$m(J_i) = \sqrt{p(J_i)^2} = \sqrt{\left(\sum_{\text{objects } n \text{ in } J_i} p_n\right)^2},$$

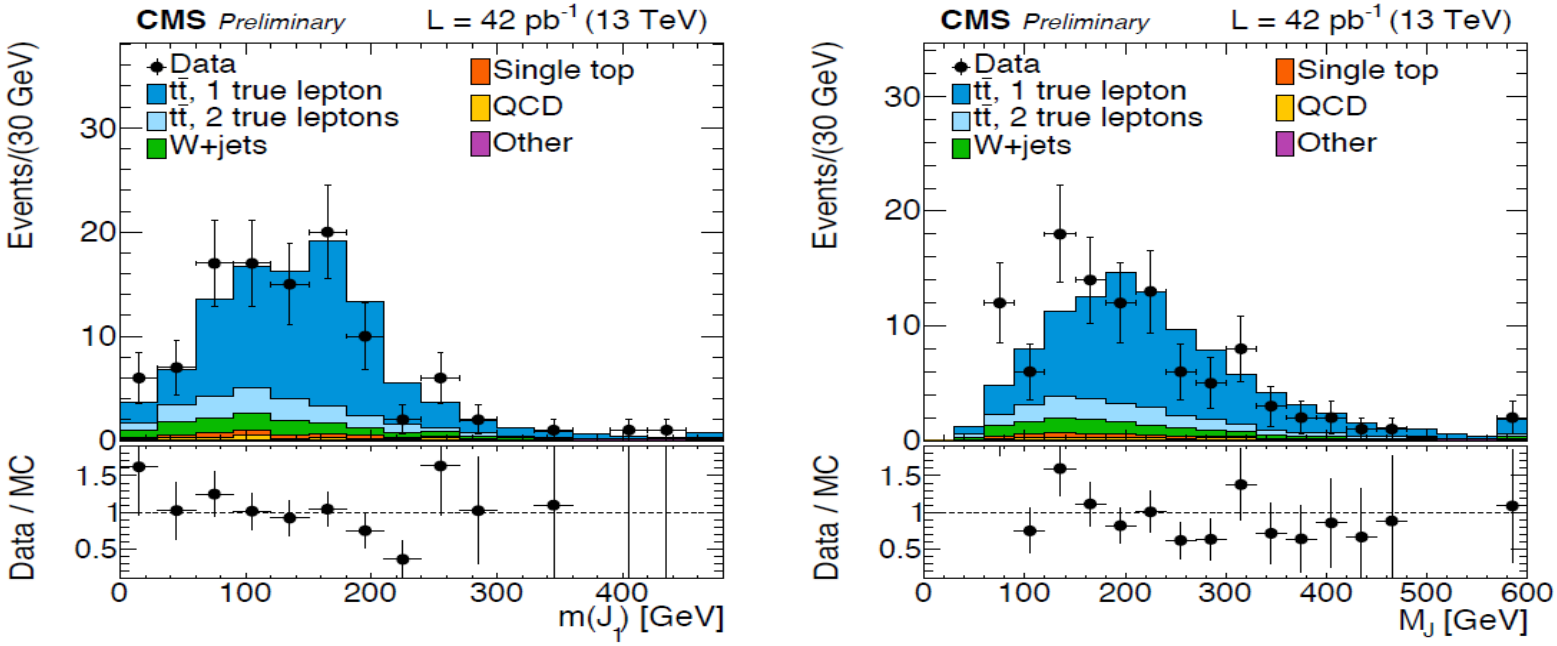
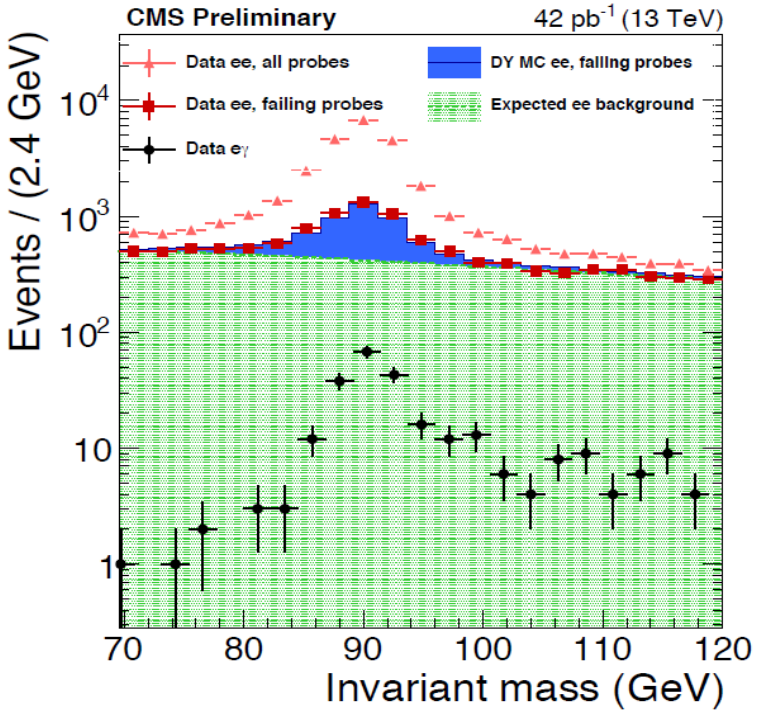


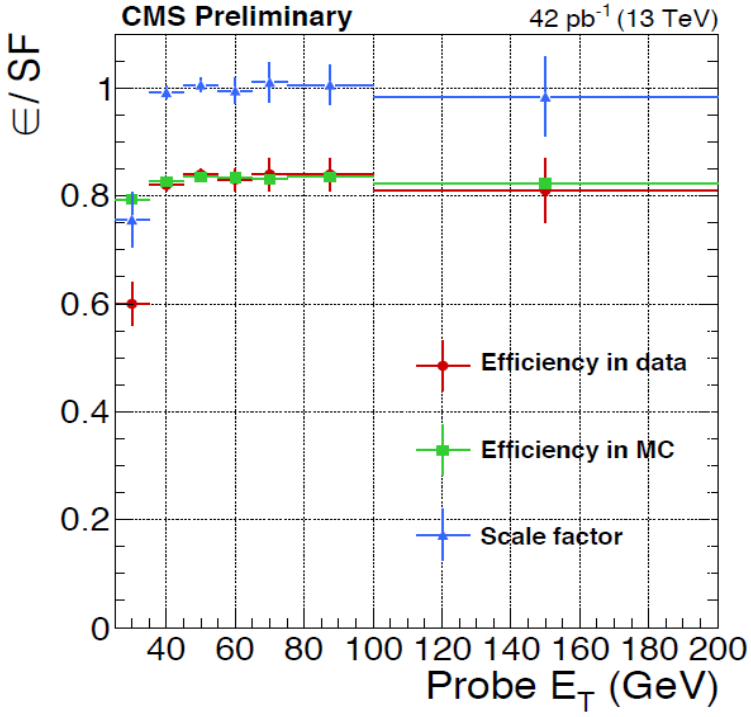
Figure 20: Distributions of (left) $m(\mathrm{J}_1)$ and (right) M_J in a single lepton + jets + $E_\mathrm{T}^\mathrm{miss}$ sample. The overall event yield in simulation is normalized to the number of entries in data.

Di-photon validation

- Signatures with high p_T photons and MET.

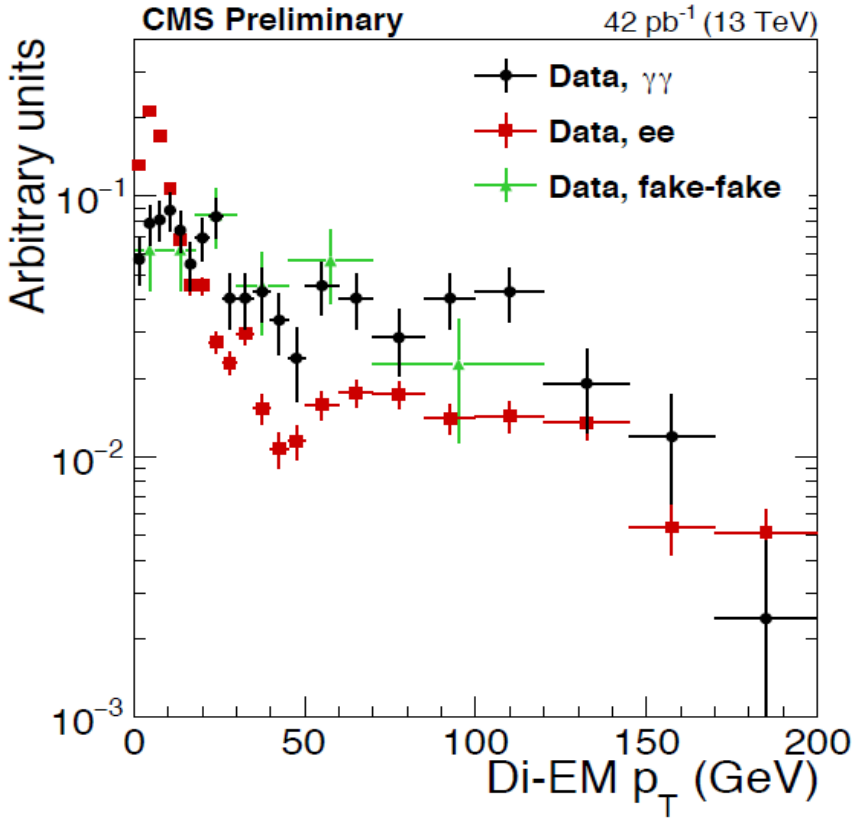
- Di-photon selection:
  - p_T> (34, 22) GeV, with medium ID, in the barrel,
  - Selection efficiencies : tag&probe using Z->ee,
  - Fake photons from electrons : electron-photon invariant mass.

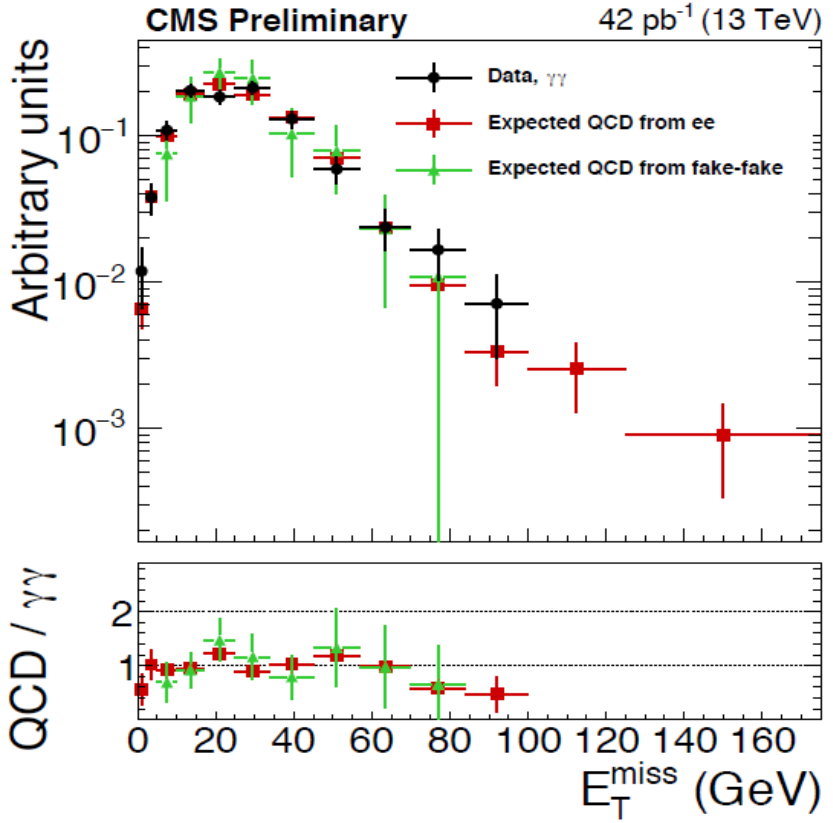




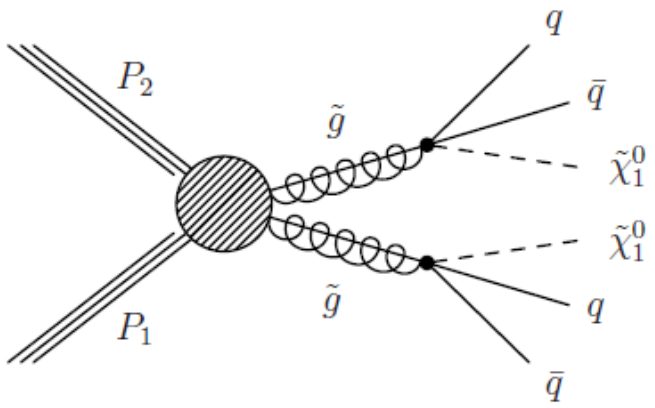
Photons validation

- QCD estimation : uses the poor resolution of MET compare to real di-photon.
- Hadronic activity estimated using p_T of di-EM.
- Fake-fake : di-jets events with high EM fraction.

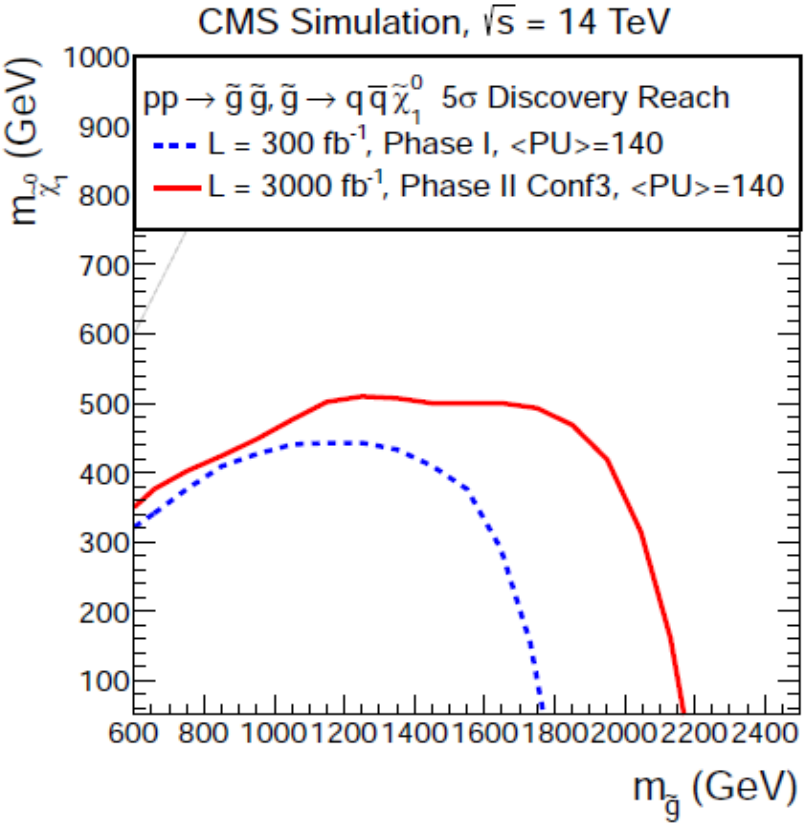




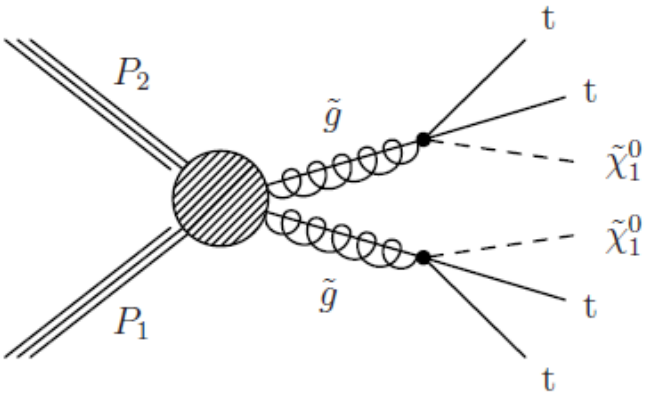
SUSY search with 300 fb^{-1} and 3000 fb^{-1}



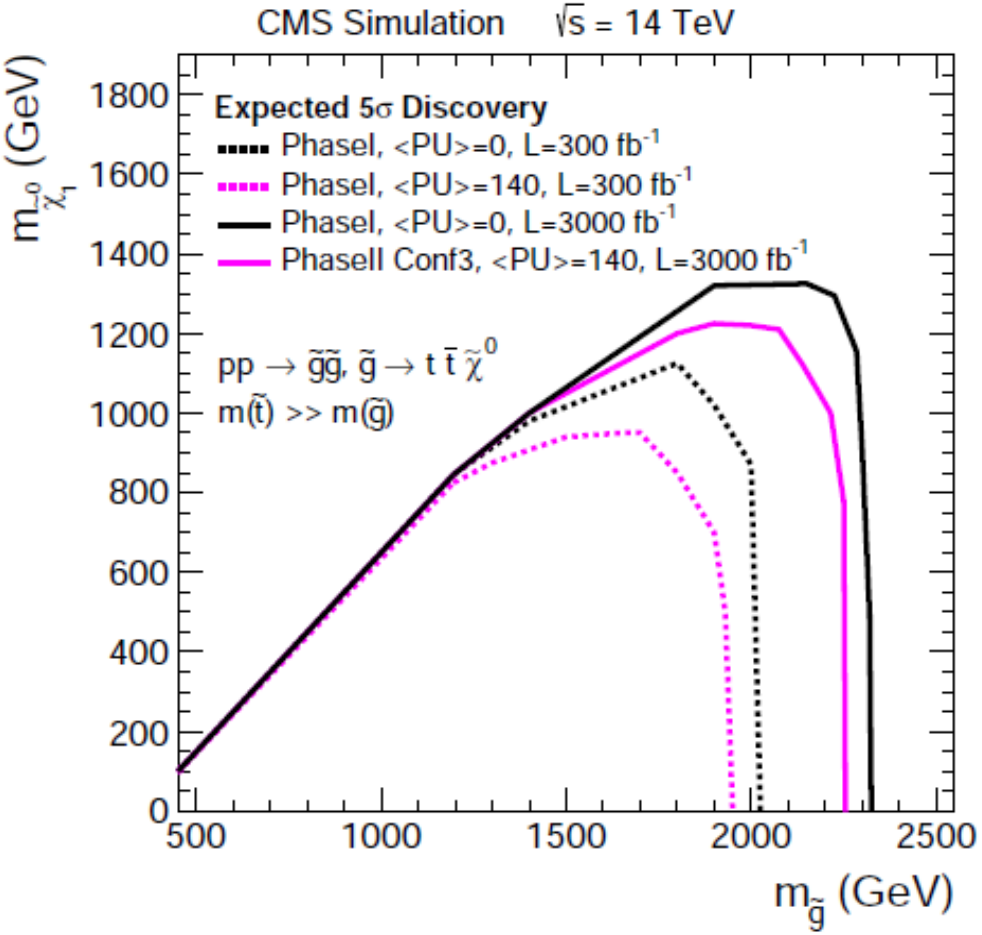
- Signatures with jets and missing energy.



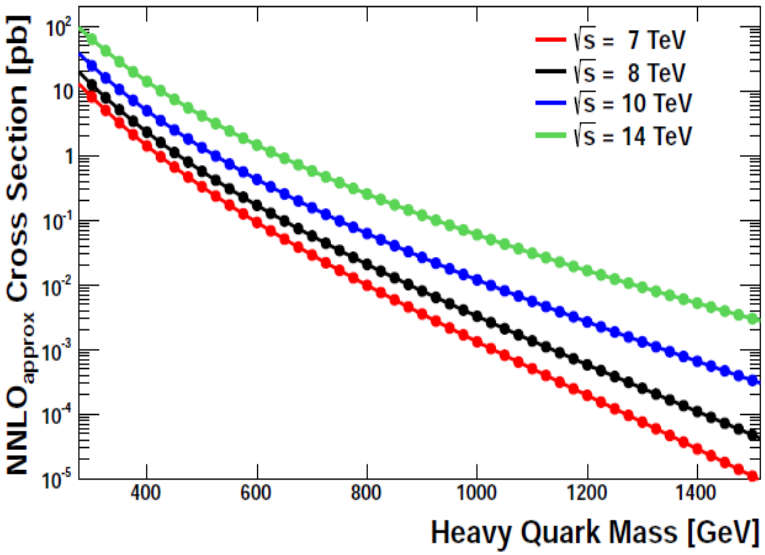
SUSY search with 300 fb^{-1} and 3000 fb^{-1}

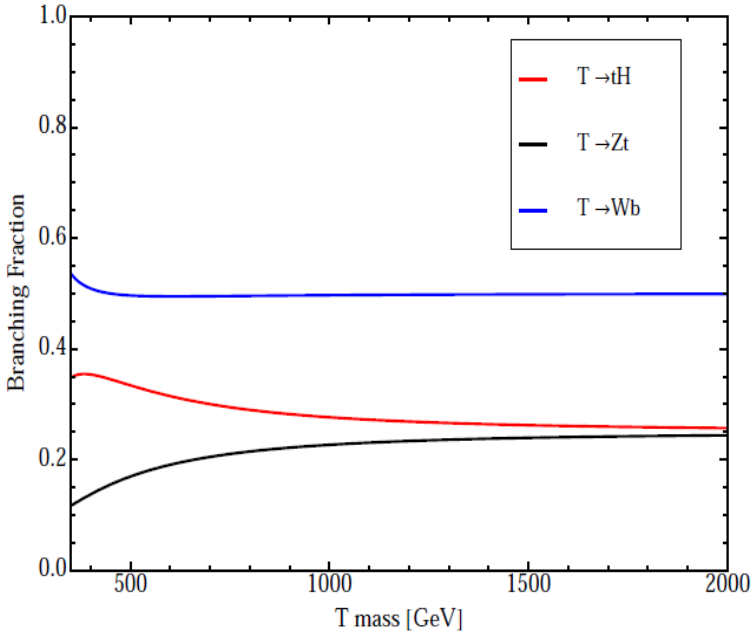


- Search for gluinos decaying into top quarks and LSP.

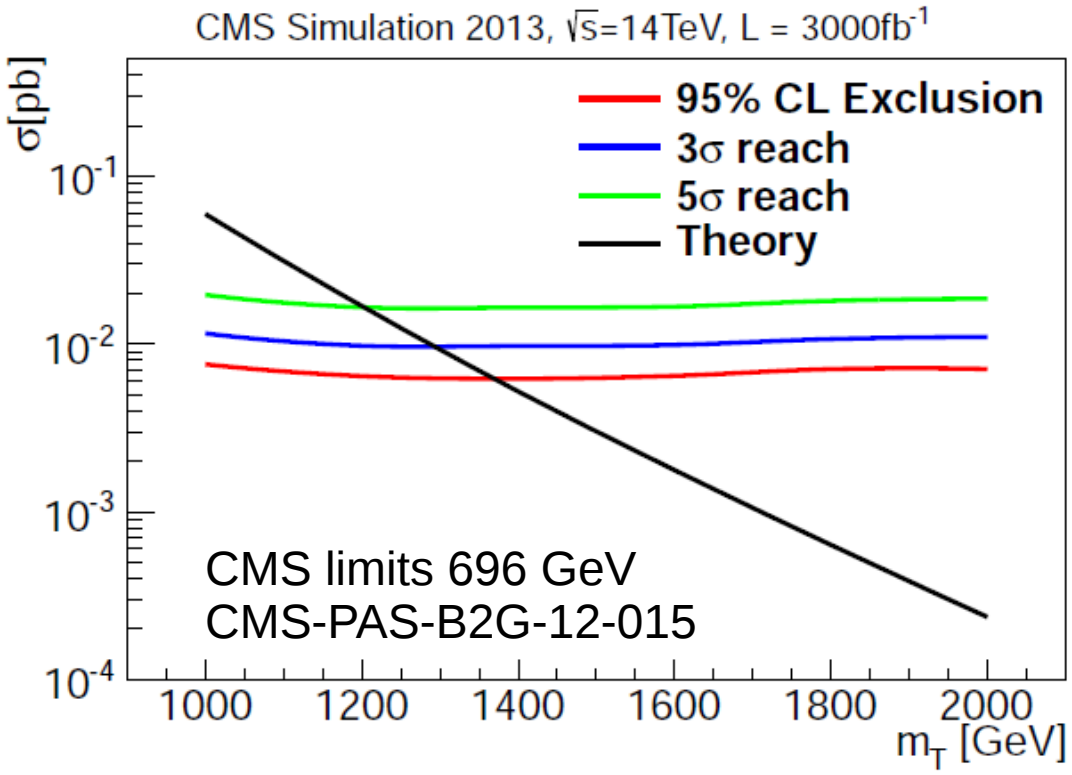


Vector like T quark with 3000 fb^{-1}

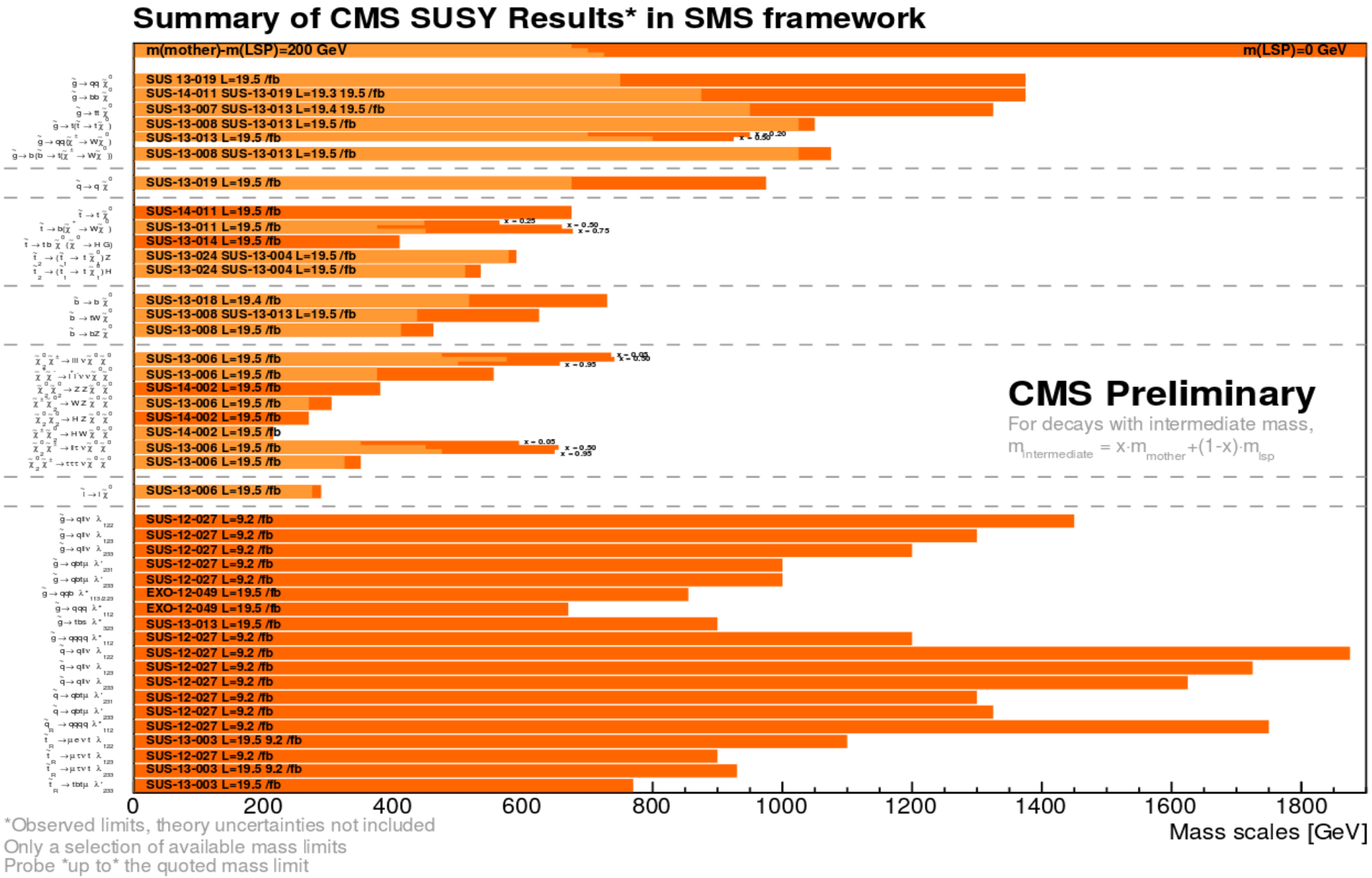




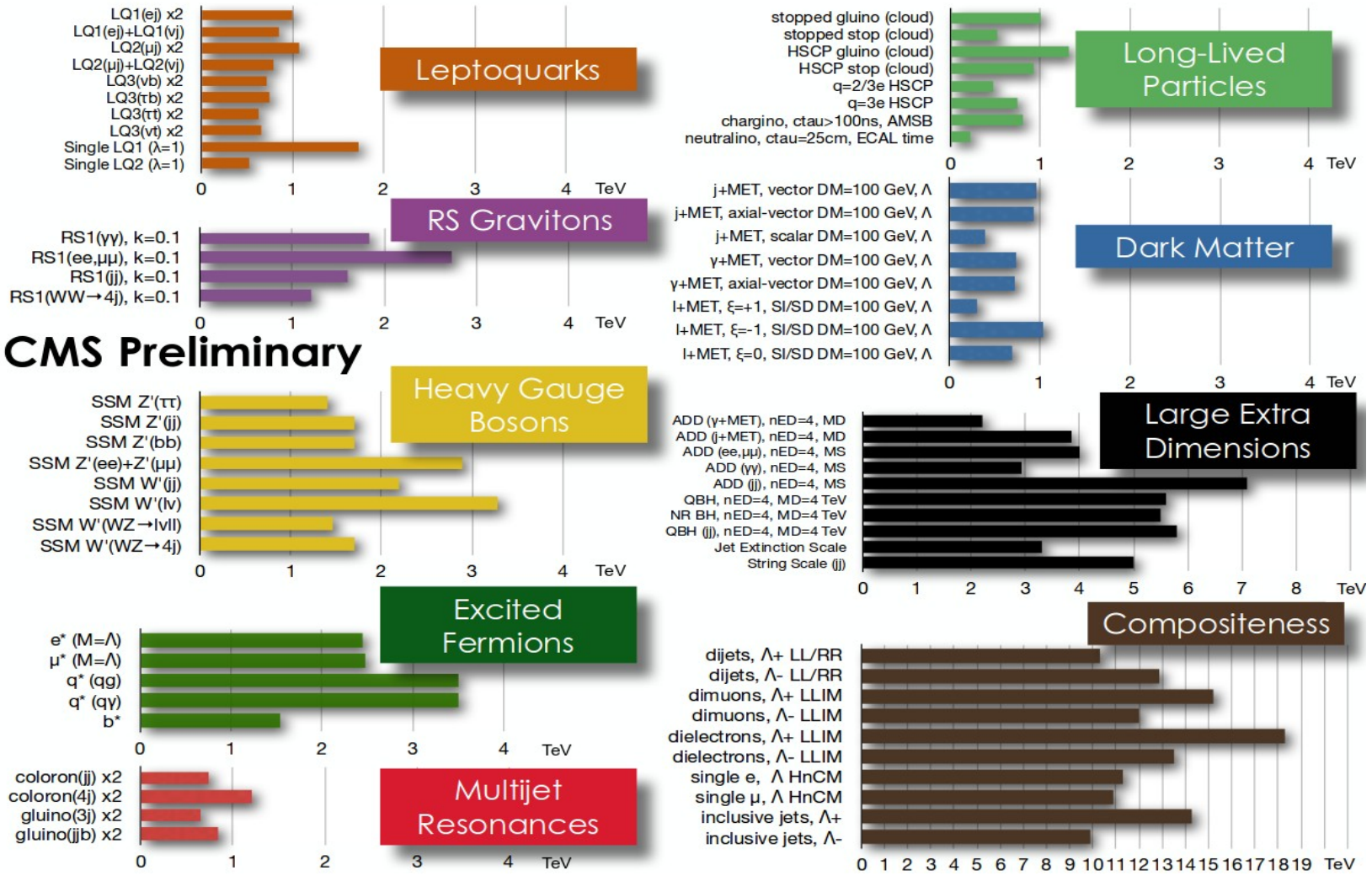
- Pair production of vector like T-> tW, tZ, tH.



SUSY summary 8 TeV



EXO Summary 8 TeV



B2G summary 8 TeV