Search for SUSY in jets+ MET final state

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Outline

- **Introduction**
- **Analysis Strategy**
- **Background Estimation**
- **Results and Interpretation**

Documentation

Notes:

AN-15-003 or SUS-15-002

PAS Twiki https://twiki.cern.ch/twiki/bin/viewauth/CMS/PhysicsResultsSUS15002

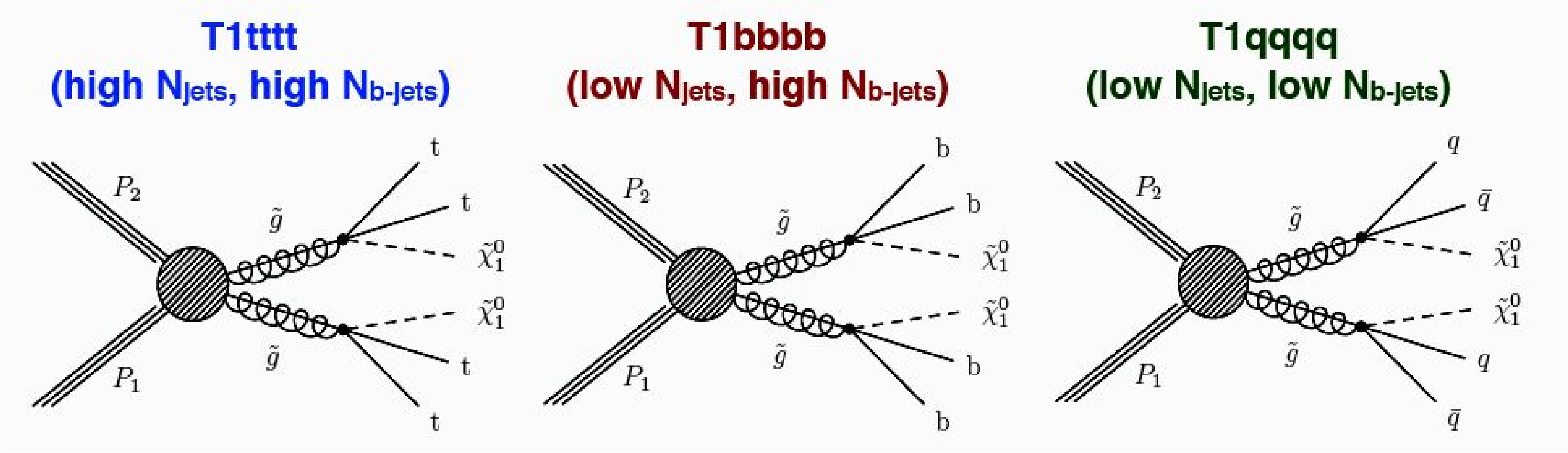
CADI link:

Cadi link

Submitted to PLB

Introduction . . . signal models

- Amongst possible SUSY processes gluino pair production has largest cross section
- Large increase in cross section from 8TeV to 13 TeV
- Fully hadronic analysis targeting pair production of gluinos in the final state of jets + MET
- Signal models targeted are



Introduction … search variables

- Final state comprises jets, b-jets , missing energy and high transverse momentum
- So the search variables are **H_T , H_T^{miss} (MHT) , N_{jets} , $N_{b\text{-}jets}$** defined as follows

Visible energy

$$H_T = \sum_{\text{jets}} |\vec{p}_T|$$

Energy of undetected particles

MHT = $$\not{H}_T = \left| -\sum_{\text{jets}} \vec{p}_T \right|$$

Missing energy

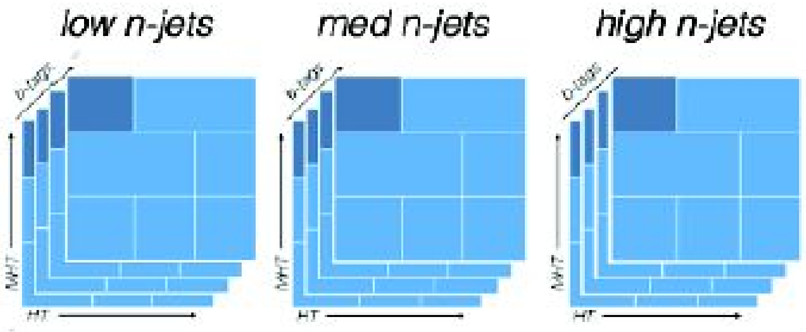
Analysis Strategy . . . Baseline for bkg rejection

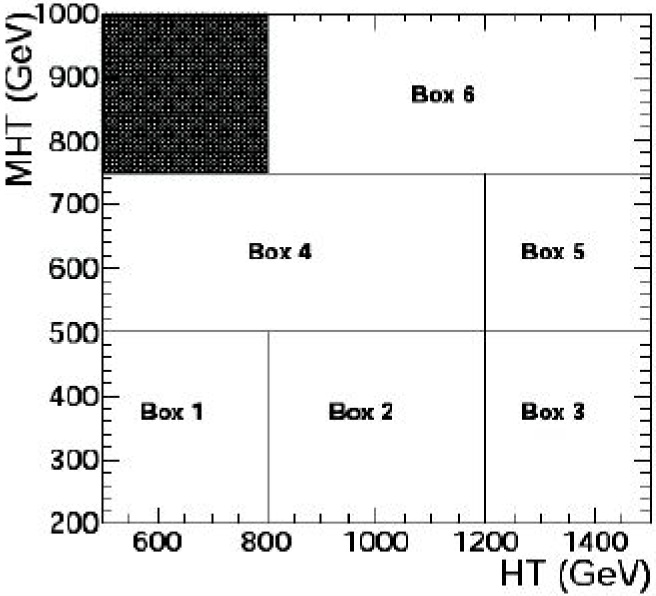
- H_T > 500 GeV
- H_T^{miss} > 200 GeV
- N_{jets} >= 4 , because signal models has minimum 4 jets
- $N_{b\text{-}jets}$ > = 0 , motivated by signal models
- $\Delta\Phi(jet_i, H_T^{miss})$ > (0.5, 0.5, 0.3 , 0.3) for i =1 to 4 to reject QCD
- electron and muon veto, because we are doing all hadronic search
- Isolated track veto , rejects W/top events that fails lepton veto

Analysis Strategy .. binning

3 (N_{jets}) X 4 ($N_{b\text{-}jets}$) X 6 (HT/MHT) = 72 bins total

-
  - N_{jet}: $4\text{–}6, 7\text{–}8, \geq 9$;
  - $N_{\text{b-jet}}$: $0, 1, 2, \geq 3$;
  - H_{T}: $500\text{–}800, 800\text{–}1200, \geq 1200$ GeV;
  - $H_{\text{T}}^{\text{miss}}$: $200\text{–}500, 500\text{–}750, \geq 750$ GeV.





Background composition

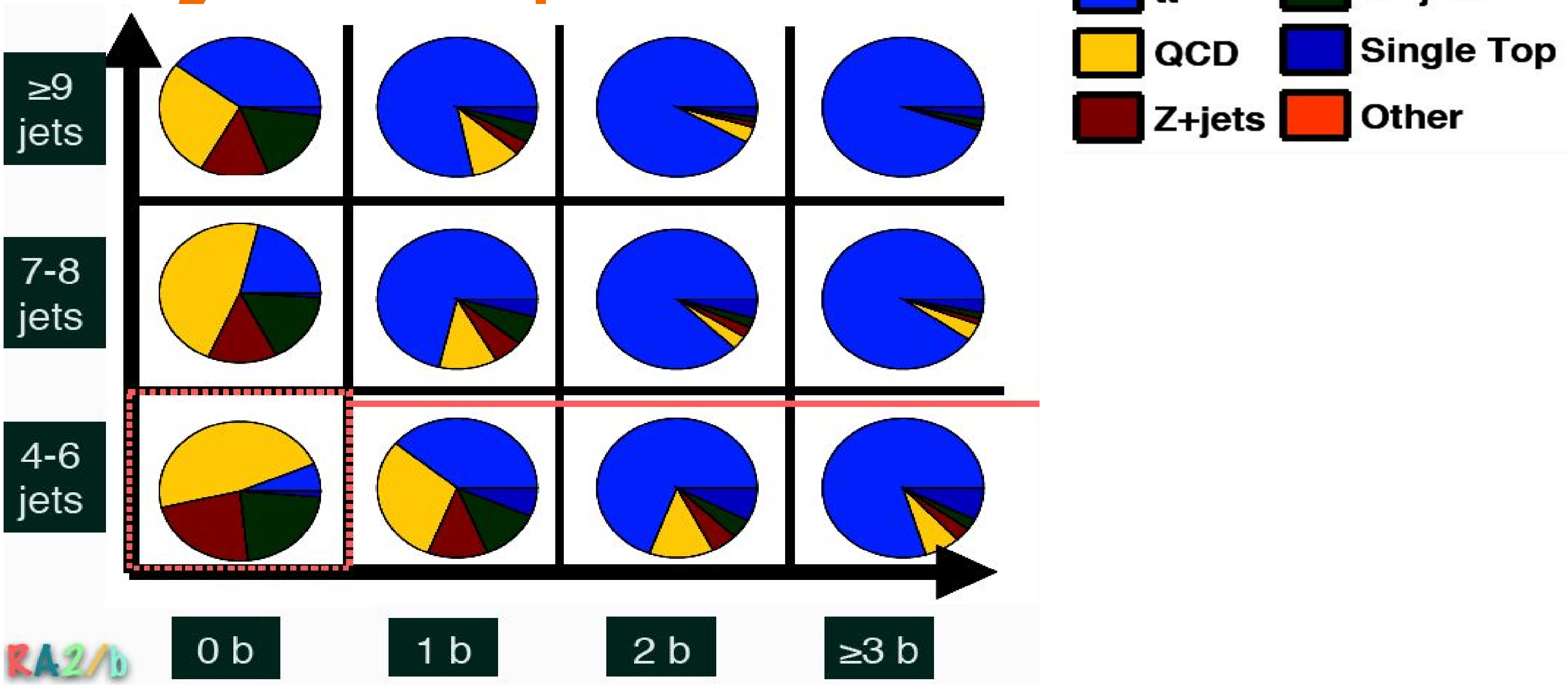


diagram: Jack Bradmiller feld

Introduction . . . to backgrounds

- **Background estimation methods are very important**

In this analysis ,

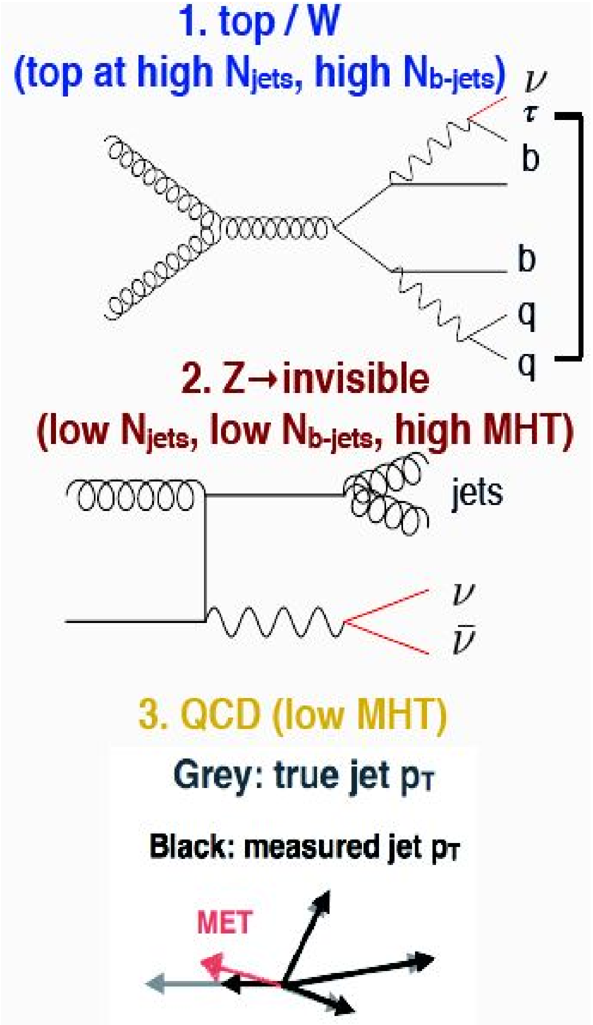
- **W+jets/ top back ground** : Enters search region

when one of the lepton is either **out of acceptance**, **not reconstructed** or **not isolated**

- **Z (to neutrino) + jets back ground: irreducible**
- **QCD background: because it has Fake MET**

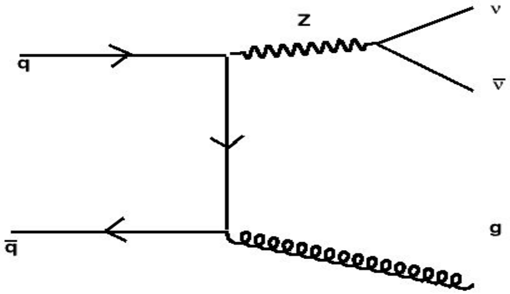
because jet energy is mismeasured ,

$\Delta\Phi(\text{jet}, H_T^{miss})$ will be small for QCD events



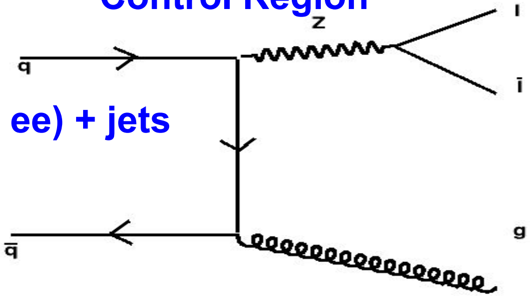
Z (to invisible)+ jets background

Z ($\nu\bar{\nu}$)+ jets



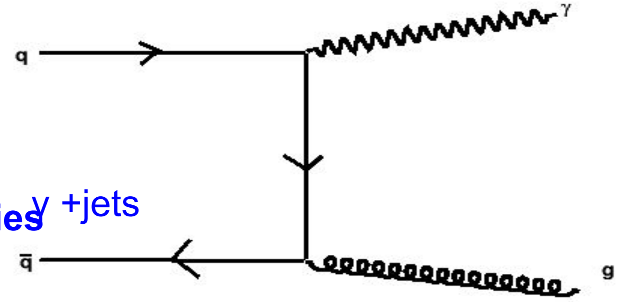
Control Region

Z(ee) + jets



$$N_{Zvv}^{Prediction} = R_{Z/\gamma} * N_{Y+jets}^{data} = R_{Z/Z(ll)} * N_{Z(ll)+jets}^{data}$$

- γ+jets has large statistics ,but higher syst. uncertainties
- Z(ll)+jets has small statistics , but smaller syst. uncertanties
- So combine the two to make hybrid method



Z to invisible background estimation -Hybrid

- For $N_{b\text{-}jets} = 0$ use photon +jets method, 18 bins = 6 (HT/MHT) x 4 (Njet)
- For $N_{b\text{-}jets} > 0$ use extrapolation factors from Zll control sample

Photon +Jets Method:

$$N_{Z\nu\nu}^{Prediction} = R_{Z/\gamma} * N_{\gamma+jets}^{data}$$

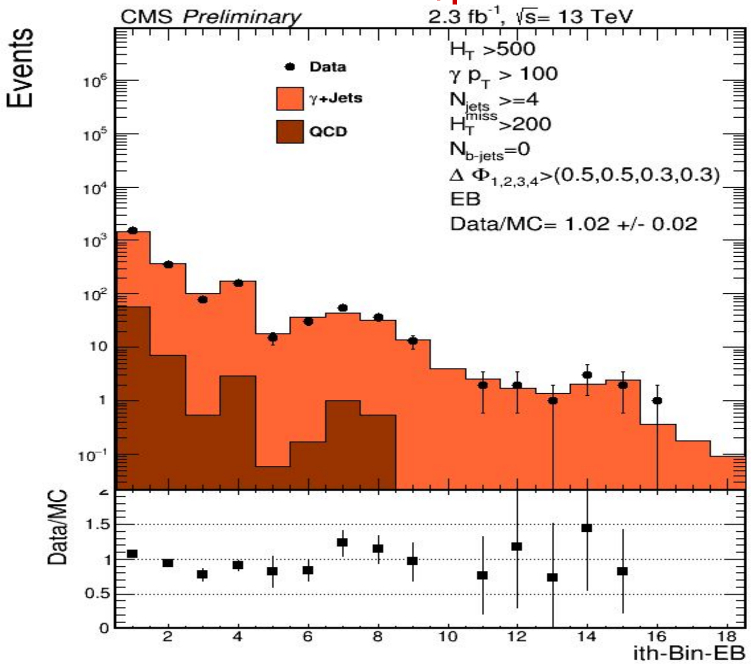
more accurately

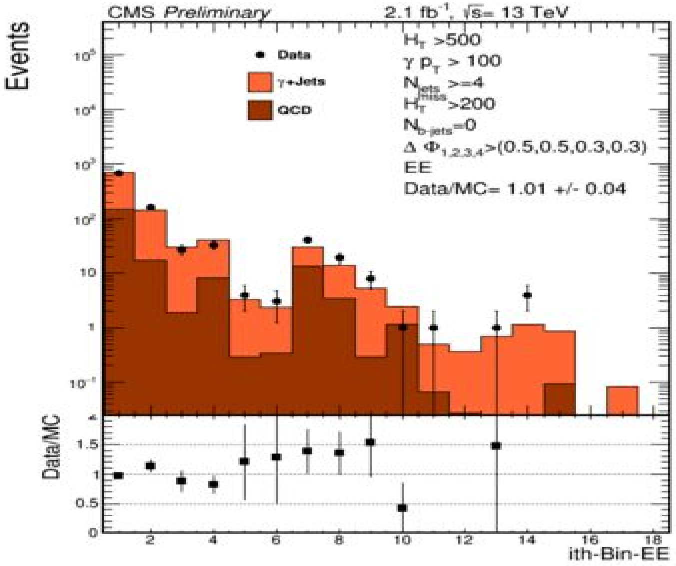
$$N_{Z\nu\nu}^{Prediction} = R_{Z/\gamma} * DR * Purity * N_{\gamma+jets}^{data}$$

DR is the Ratio of $R_{Z/\gamma}$ calculated in Data and MC or DR = $R_{Z/\gamma}$ (data) / $R_{Z/\gamma}$(MC)

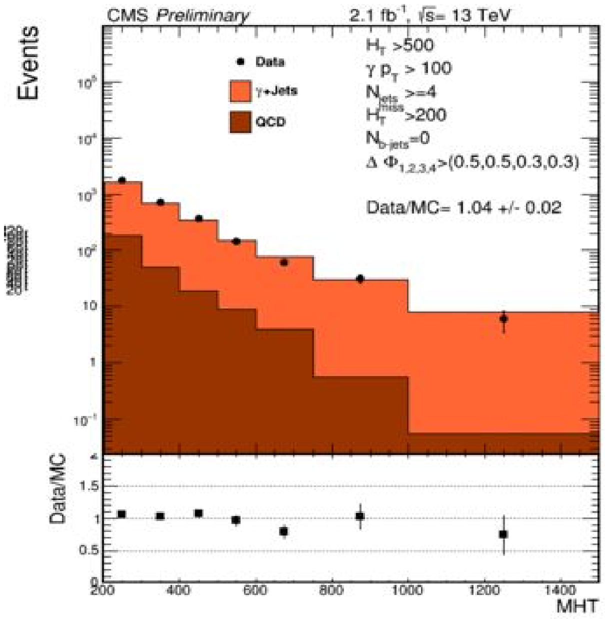
Z to invisible (explain bin)background ...using Photon + jets

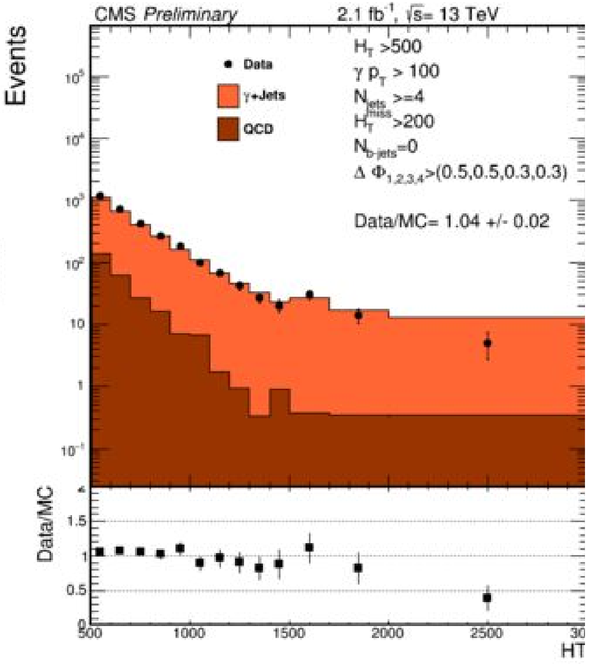
- $N_{Z\nu\nu}^{Prediction} = R_{Z/\gamma} * DR * Purity * N_{\gamma+jets}^{data}$

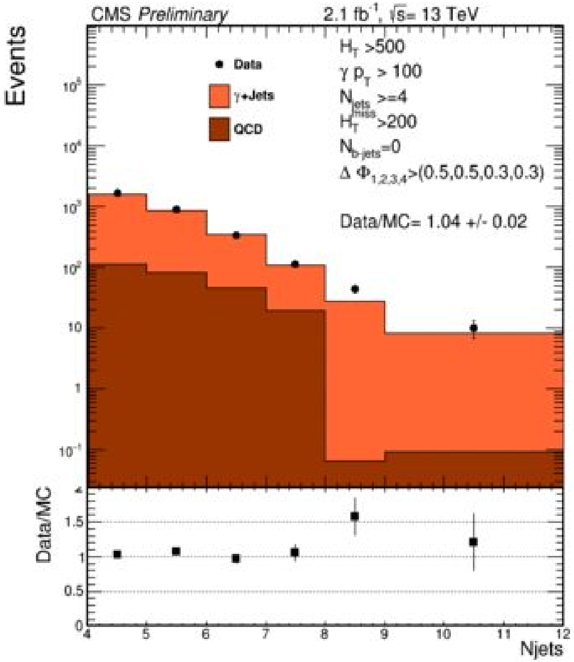




Data/MC in search variabes (control region)

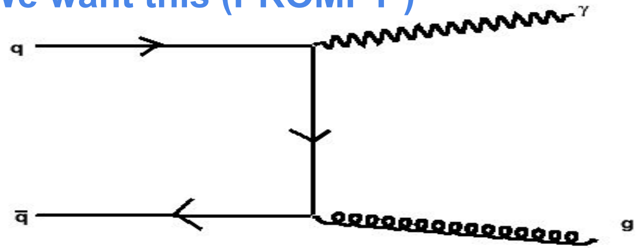




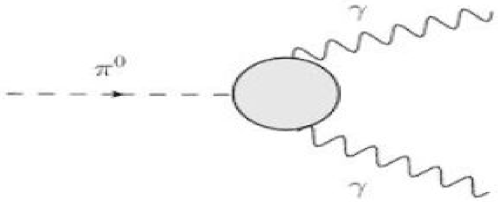


Photon Purity(add bigger font for y)

We want this (PROMPT)

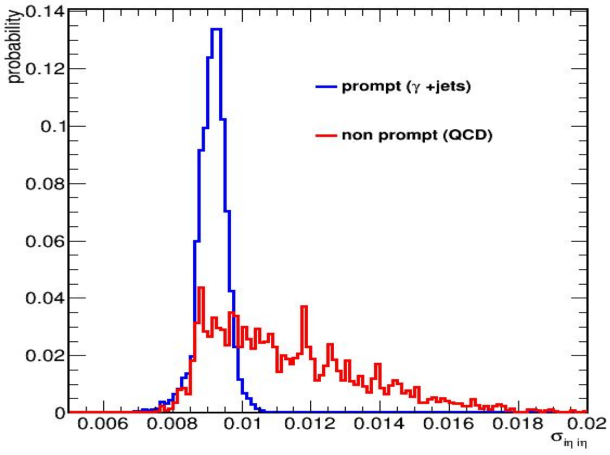


QCD gives this : contamination(NON Prompt)

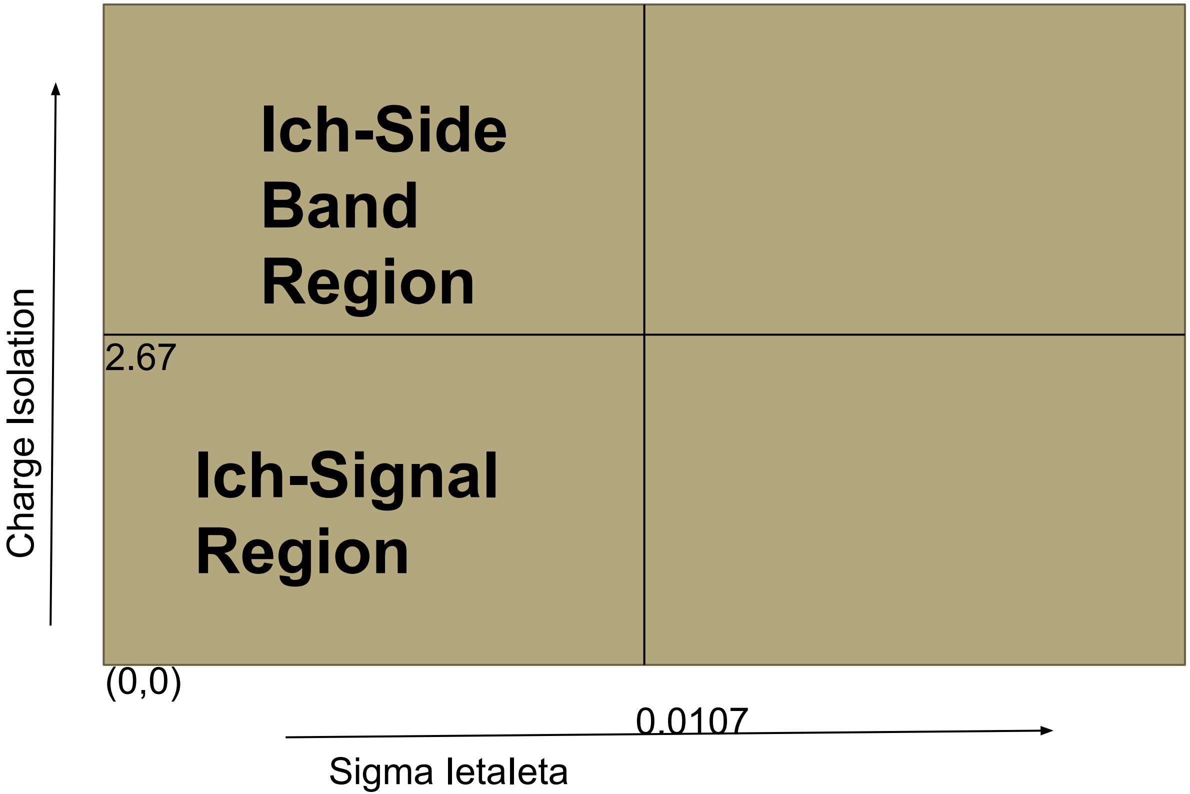


- $\sigma_{i\eta i\eta}$ distribution in the right

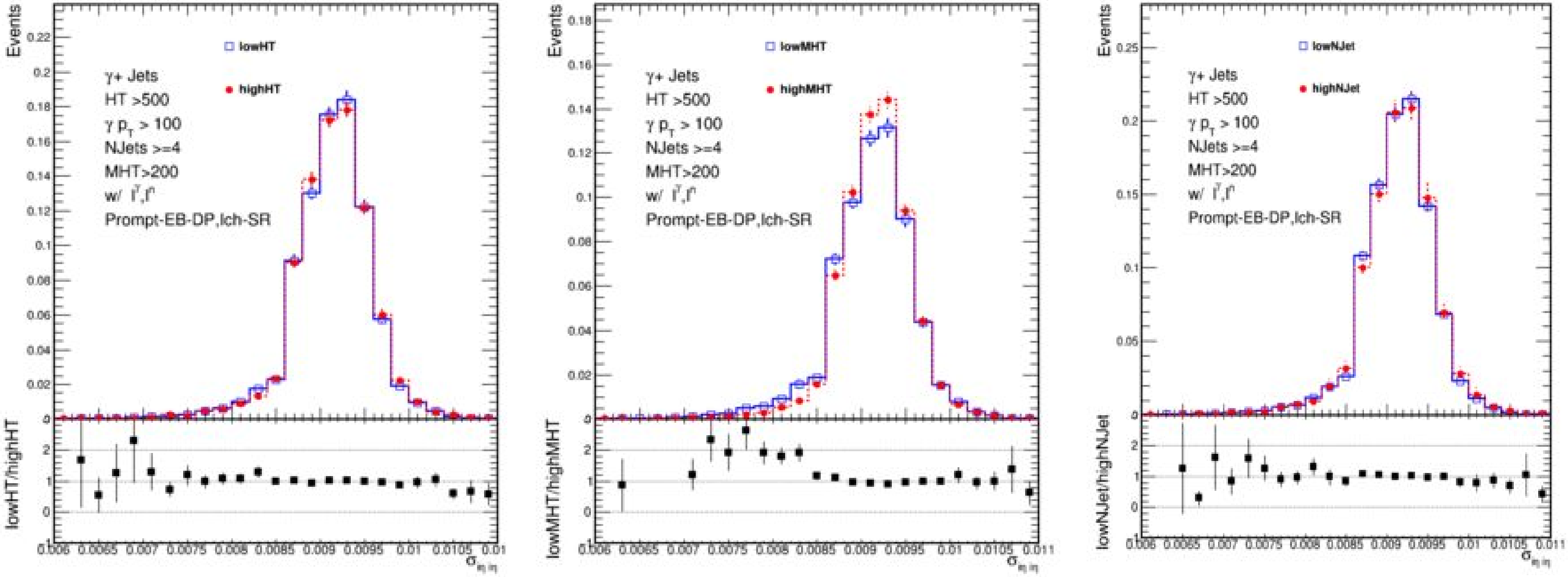
distinguishes between prompt and no prompt



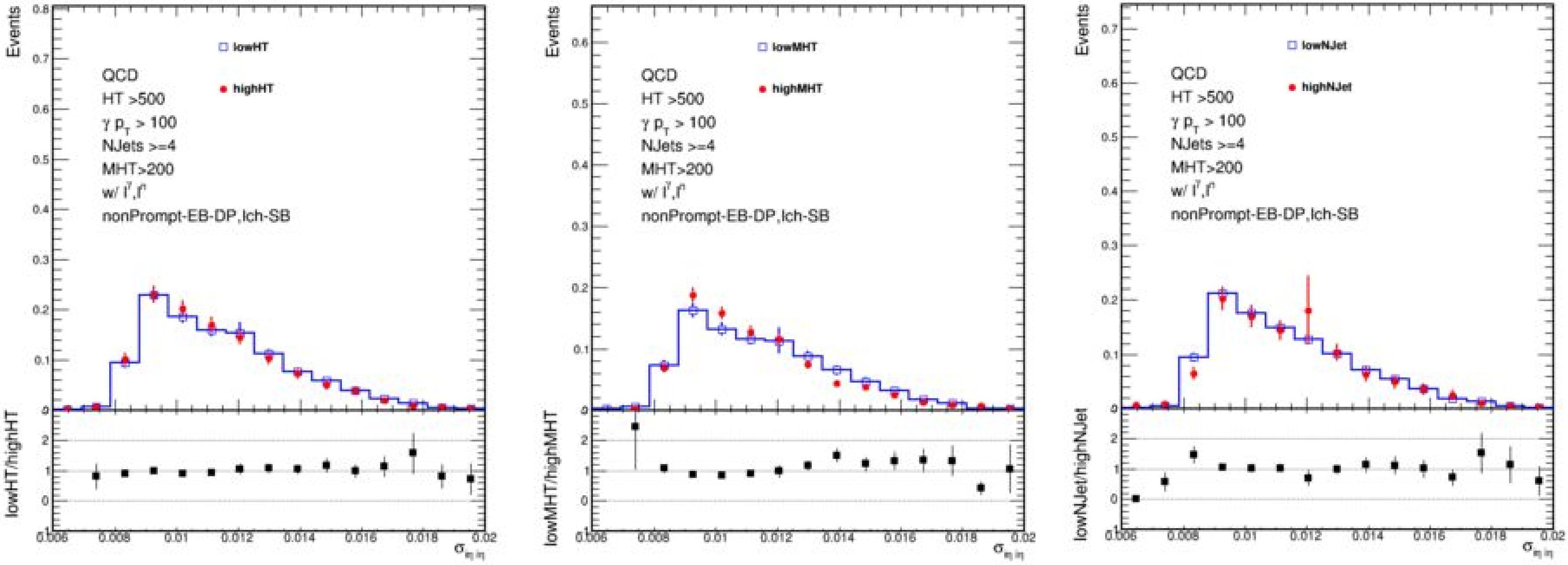
Charged Isolation Side Band and SR



Sigma Ieta Ieta behaviour, prompt, Barrel

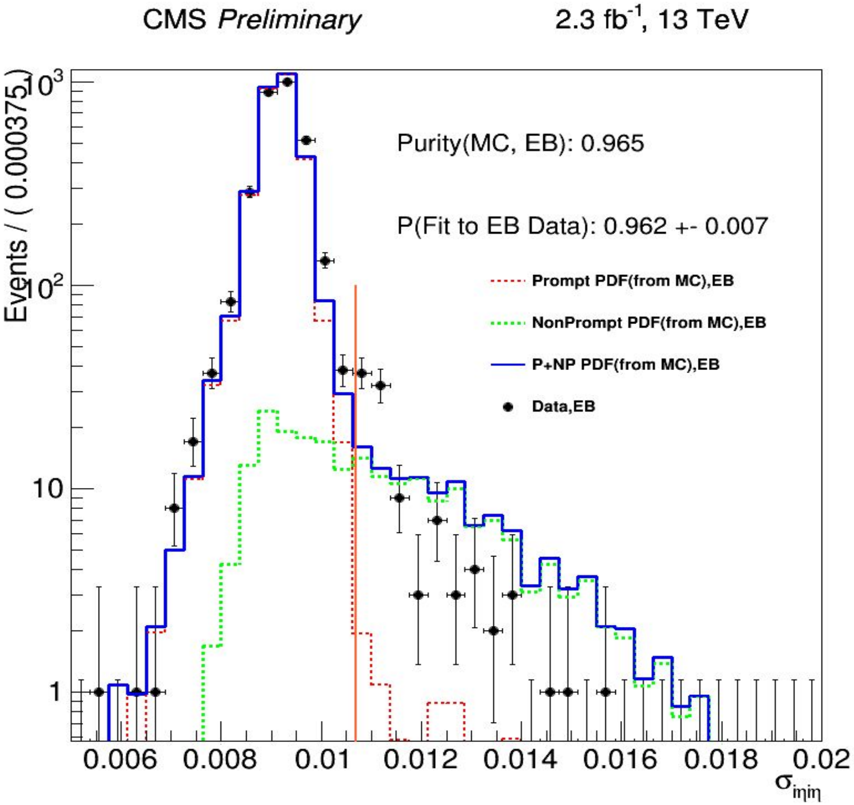


Sigma Ieta Ieta behaviour, non prompt,barrel

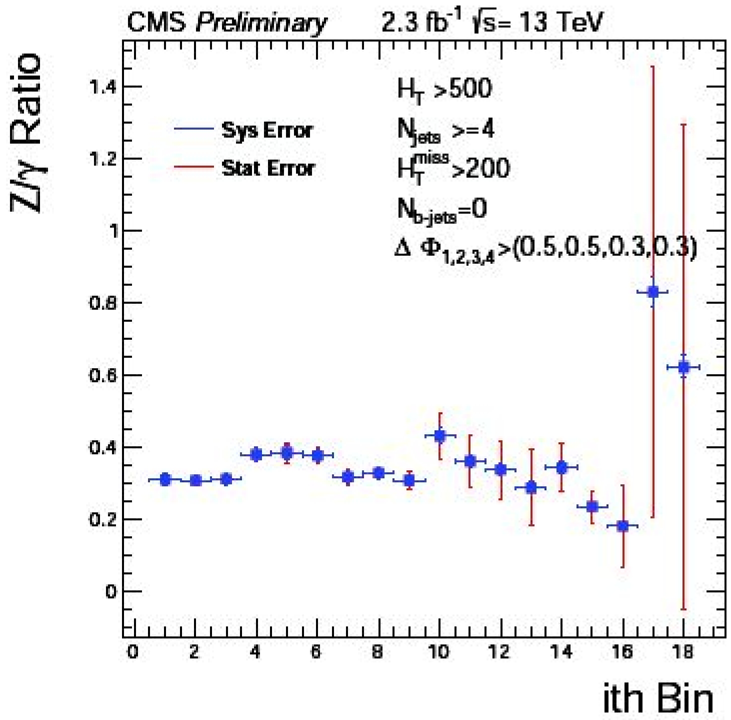


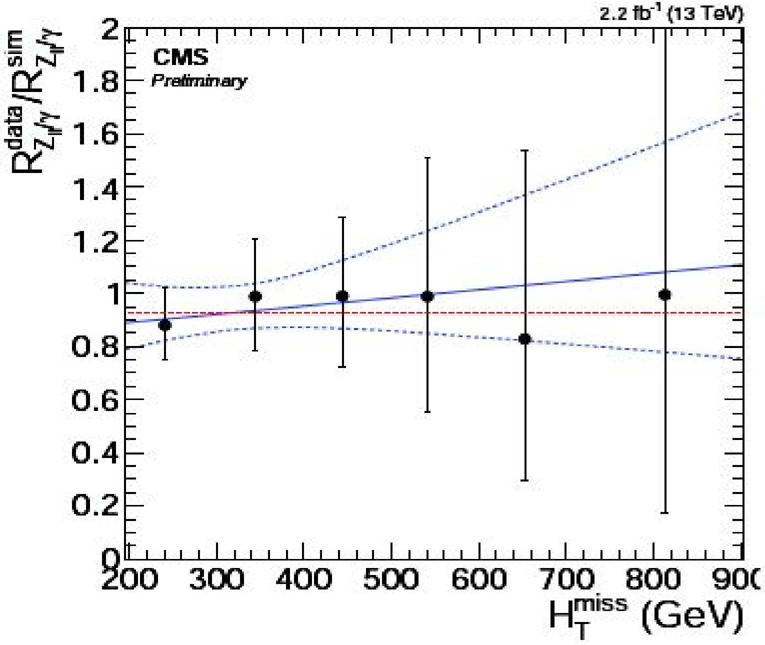
Purity Fits

- Red dotted : Prompt pdf
- Green dotted: non prompt pdf
- Blue : F = Prompt*f+(1-f)*nonPrompt
- Black dots are Data



Z/Gamma Ratio, Double Ratio





b-jet > 0

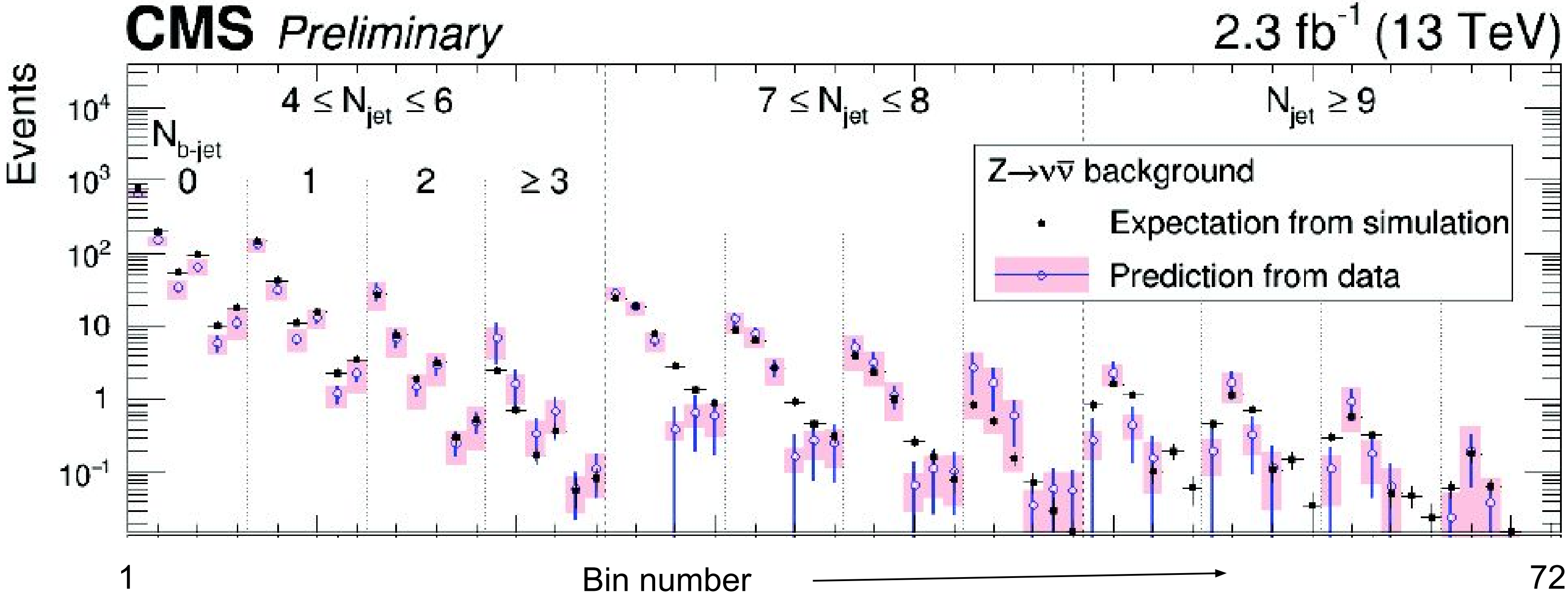
- Use Z ll data to get the b-jet distributions
- That gives you the probability of $N_{\text{b-jets}}$ events from number of 0 b-jets events
- $$N(Z \to \nu\bar{\nu})^{H_T,\, H_T^{miss}}_{N_{jet},\, N_{b\text{-}jet}} = N_{Z\to\nu\bar{\nu}}(\gamma + \text{jets})^{H_T,\, H_T^{miss}}_{N_{jet},\, 0} \cdot \mathcal{F}_{N_{jet},\, N_{b\text{-}jet}}(Z \to \ell^+\ell^-)$$

Extrapolation factors from Z(ll)+jets

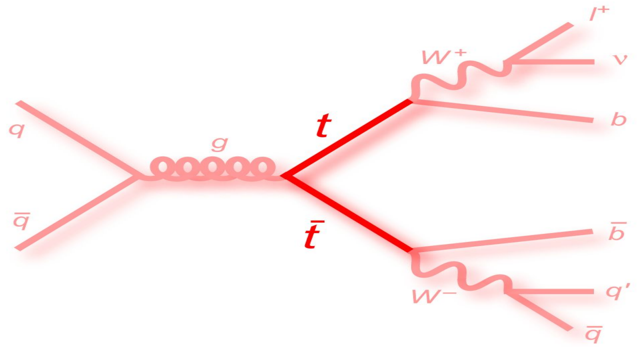
From Photon+jets in 0 b-tags

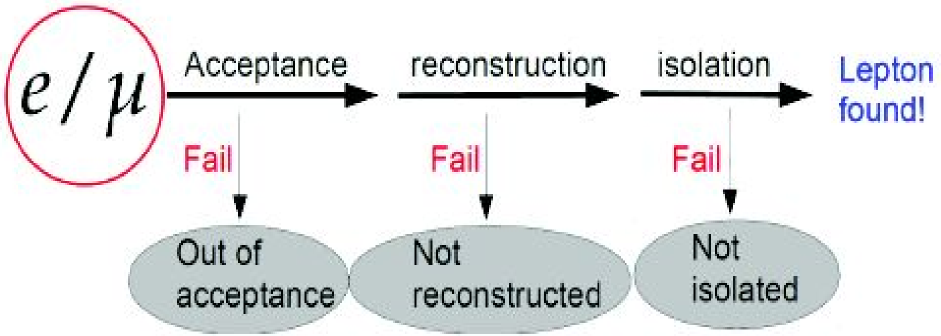
Zinvisible prediction

Lot of difference between data driven prediction and simulation



W+jets /top - lost lepton bkg ,data driven

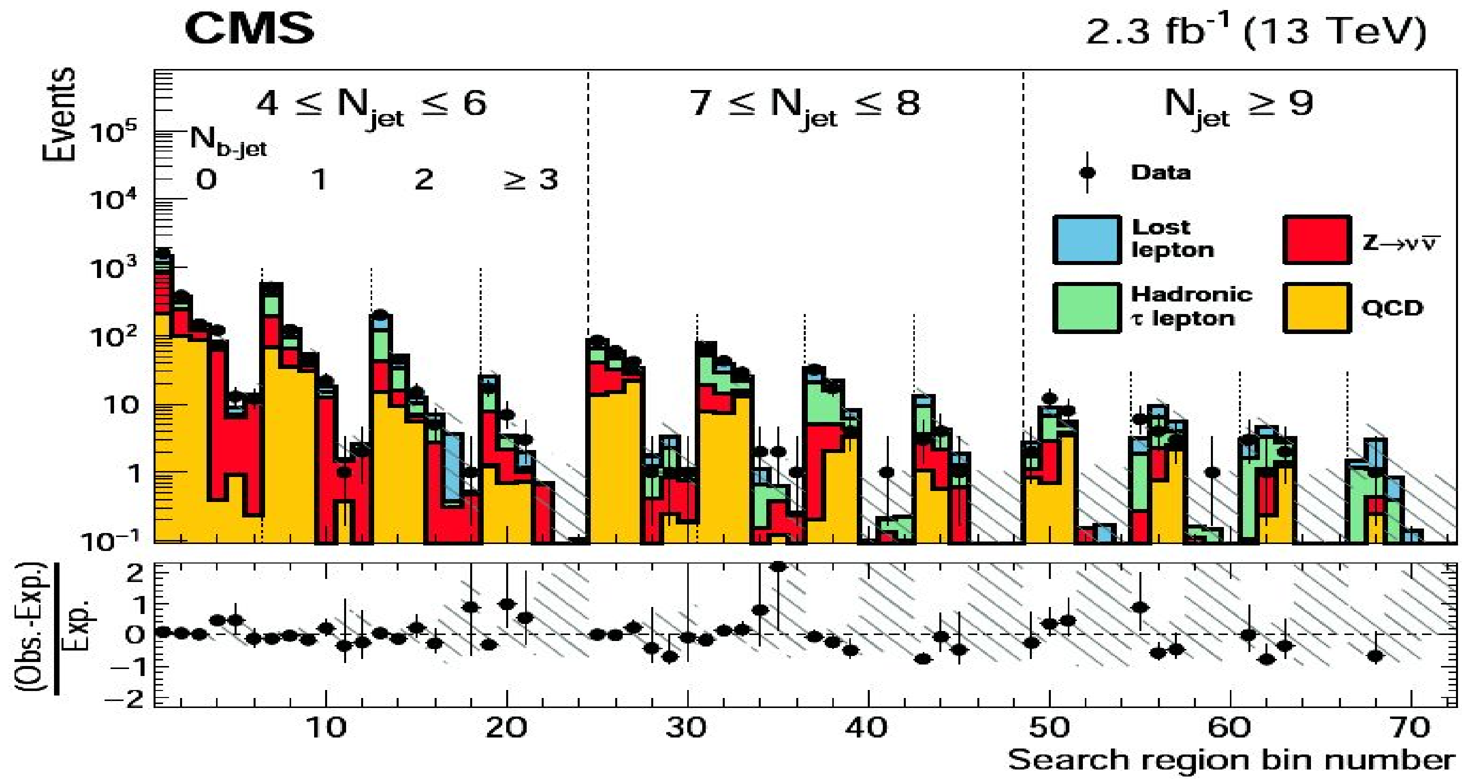




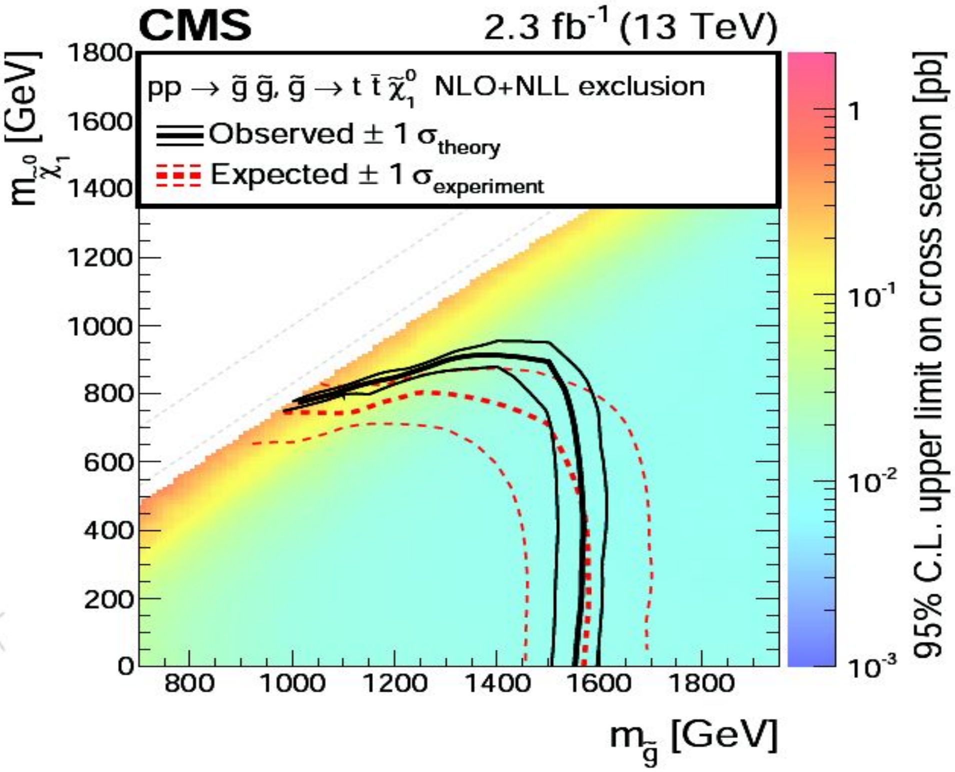
- Enters search region when the lepton fails the lepton veto
- Use the MC information to know the probability($\in_{eff}$) of happening this
- Take a muon control sample of exactly one isolated muon in Data
- Use $\in_{eff}$ to trace back no of leptons that failed the lepton veto
- For example number of muons that fails the isolation

$$!ISO = N_{CR} \cdot \frac{1 - \epsilon_{ISO}}{\epsilon_{ISO}}$$

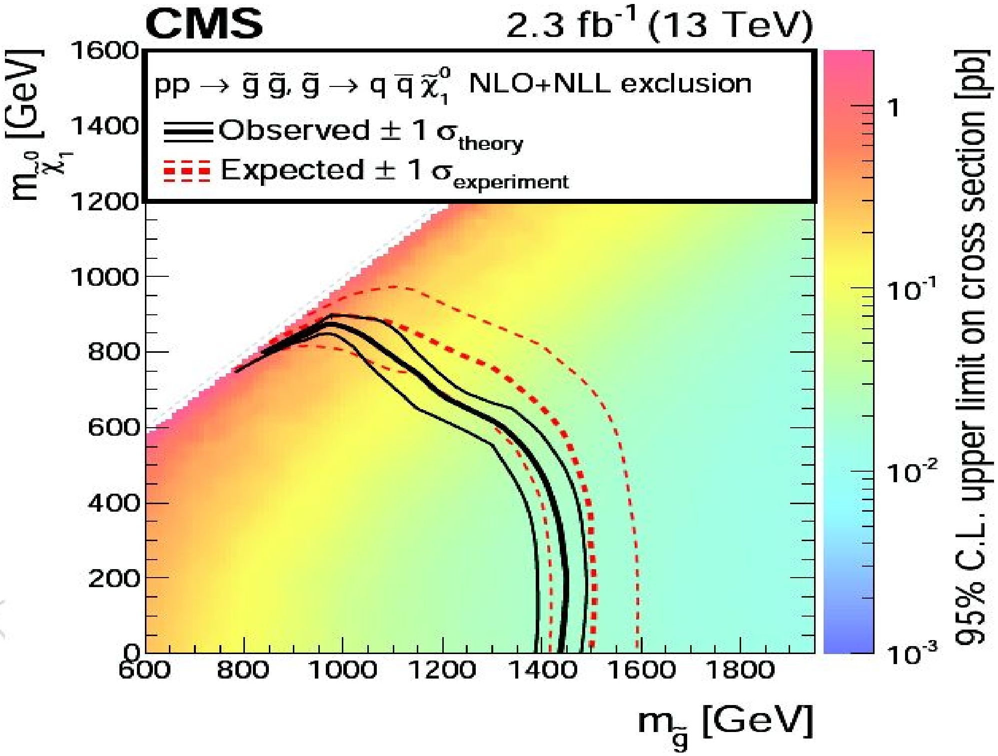
Data vs all predicted background : no excess



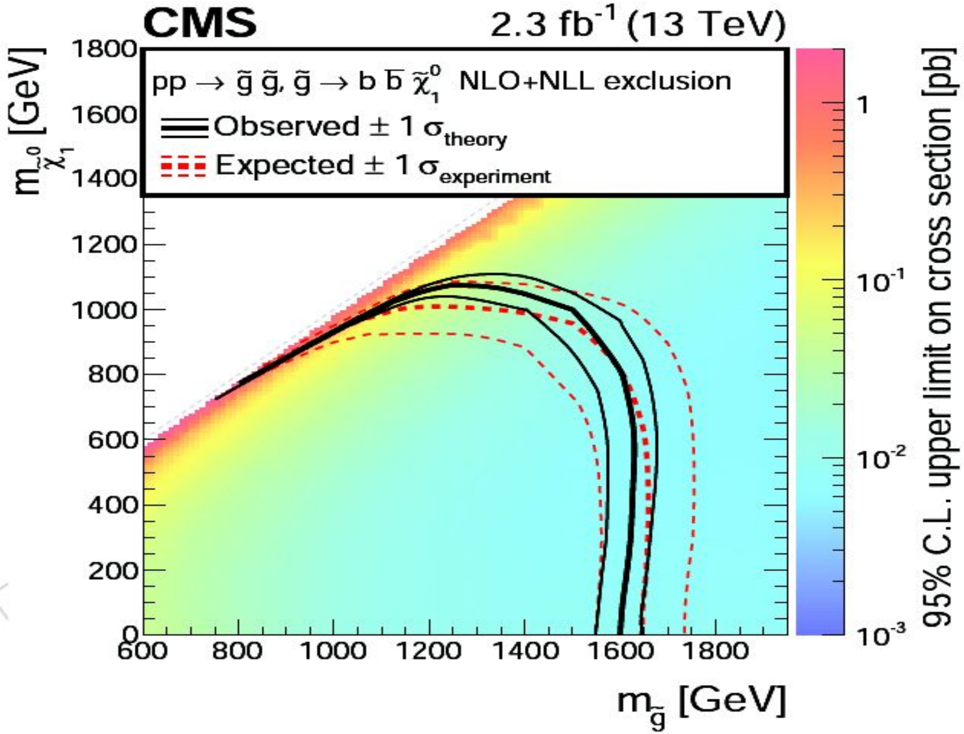
T1tttt limits



T1qqqq limits



T1bbbb limits



Conclusion

- **All the data driven background estimations converged with full data set**
- **Observation in the signal region is consistent with background predictions**
- **Limits significantly extended from Run1 with only 2.3 fb-1 of Data**
- **No observation of excess !**

Back up

Setting limits

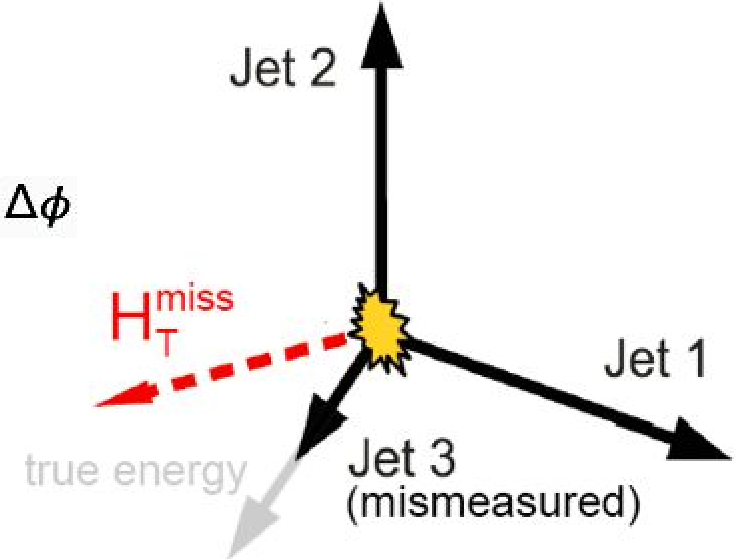
- We use Higgs combination tool to calculate the upper limits
- Its uses a Likelihood ratio as a test statistics $q_\mu = -2\ln\left(\mathcal{L}_\mu / \mathcal{L}_{max}\right)$
- For setting limits, we use the LHC-style CLs approach in the Higgs Combine tool i.e. ratio is the ratio of confidence intervals

$$CL_s = \frac{CL_{s+b}}{CL_b}$$

- We will see the results in the next slide

QCD background

- QCD events do not have real missing energy
- But jet energy can be mismeasured
- This results fake MET region
- This fake MET tends to be alligned with jet
- We reject 90% of events using cuts on low $\Delta\phi$

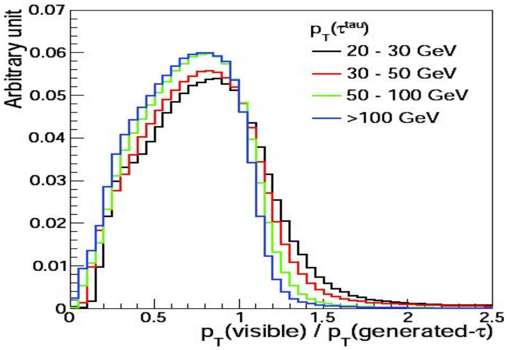


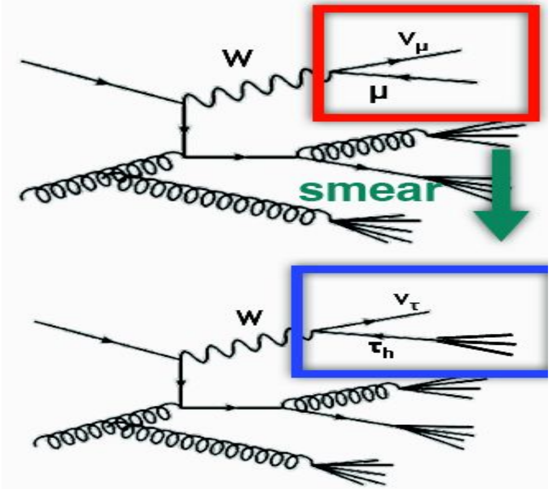
$\Delta\phi(H_T^{miss}, j_{1,2,3,4})$ = Difference of Φ between ith jet and H_T^{miss} vector

- Then we use a control region of events with low Δ Φ
- We use a (high/ low) Δ Φ ratio to go from control region to signal region

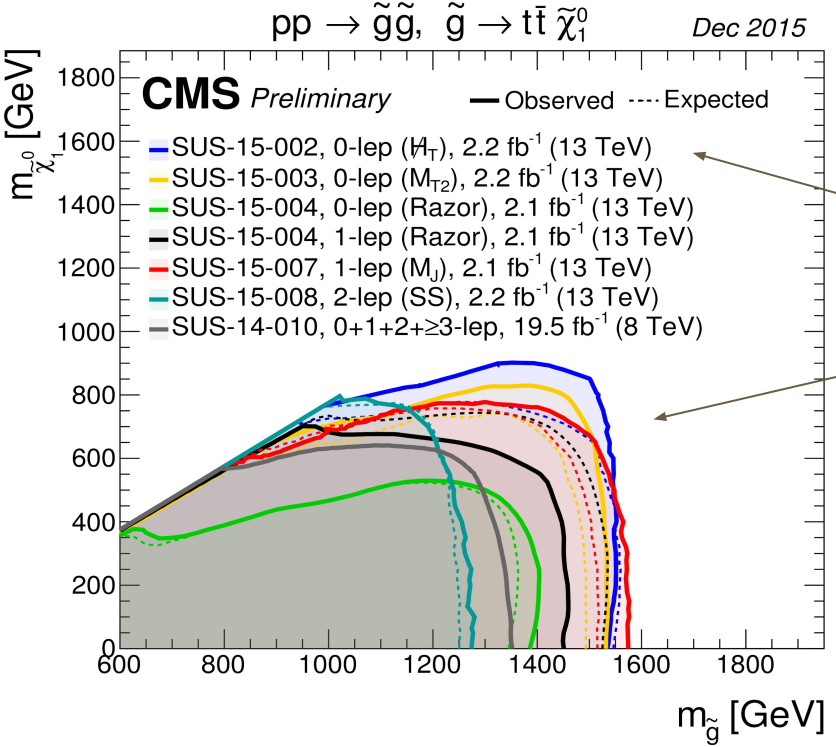
W+jets/top - hadronic tau background

- Results from hadronic decay of tau
- Estimation:
  - Get a response template from MC that maps gen tau to hadronic tau jet
  - Replace gen tau with muon from data after efficieny correction
  - Smear the muon control sample from data with that template to estimate the hadronic tau background



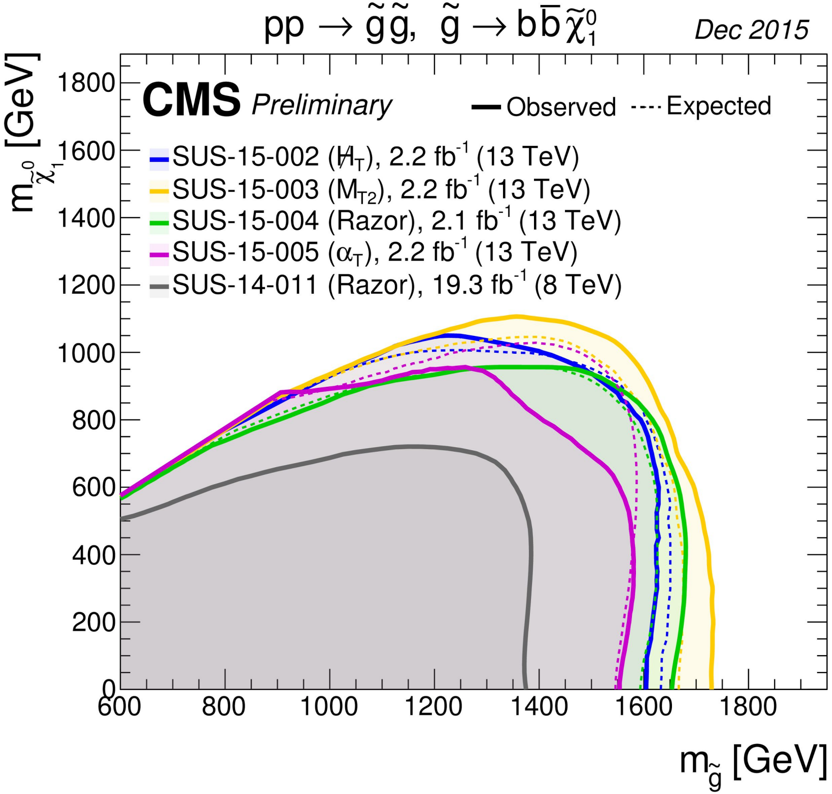


Comparison Limit Plot (T1tttt)

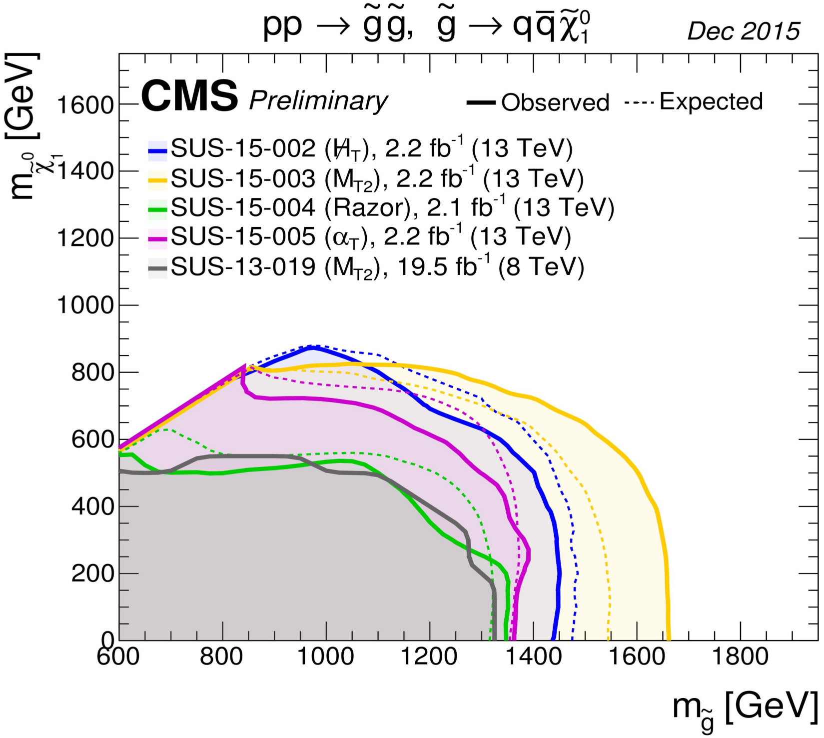


Our limits are competitive:

T1bbbb limits



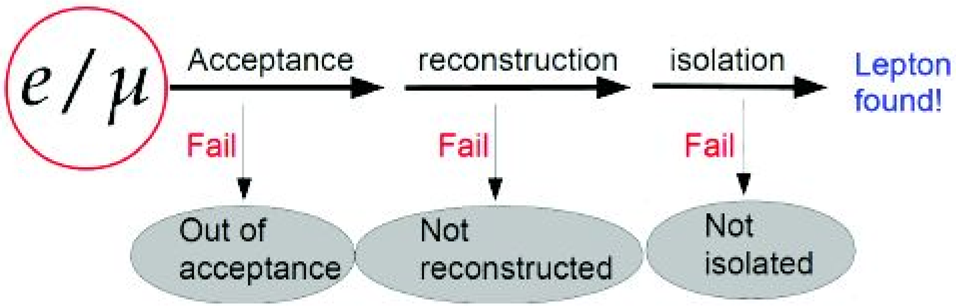
T1qqqq



pp → g̃g̃, g̃ → qq̄χ̃⁰₁
Dec 2015
CMS Preliminary
Observed
Expected
SUS-15-002 (H̸T), 2.2 fb-1 (13 TeV)
SUS-15-003 (MT2), 2.2 fb-1 (13 TeV)
SUS-15-004 (Razor), 2.1 fb-1 (13 TeV)
SUS-15-005 (αT), 2.2 fb-1 (13 TeV)
SUS-13-019 (MT2), 19.5 fb-1 (8 TeV)
m χ̃⁰₁ [GeV]
m g̃ [GeV]
0
200
400
600
800
1000
1200
1400
1600
600
800
1000
1200
1400
1600
1800

W+jets / top - lost lepton background

- **because lepton veto** fails
- Estimation method
  - Take a single lepton control
  - Figure out the probability th
    efficiencies at each stage of identification
  - Take care of control region contamination



- $!\mathrm{Acc} = N_{CR} \cdot \frac{1}{\epsilon_{\mathrm{ISO}}} \cdot \frac{1}{\epsilon_{\mathrm{Reco}}} \cdot \frac{1-\epsilon_{\mathrm{Acc}}}{\epsilon_{\mathrm{Acc}}}$ $\quad !\mathrm{Reco} = N_{CR} \cdot \frac{1}{\epsilon_{\mathrm{ISO}}} \cdot \frac{1-\epsilon_{\mathrm{Reco}}}{\epsilon_{\mathrm{Reco}}}$ $\quad !\mathrm{ISO} = N_{CR} \cdot \frac{1-\epsilon_{\mathrm{ISO}}}{\epsilon_{\mathrm{ISO}}}$

- $$\text{Total Lost Leptons} = \epsilon_{\mathrm{isotrk}} \cdot \sum_{i=e,\mu} \left[\frac{[\epsilon_e^{\mathrm{purity}}]}{\epsilon_{m_T}^i} \cdot \left(\epsilon_{\mathrm{singleLep}}^{\mathrm{purity}} \cdot \left(!\mathrm{Iso}^i + !\mathrm{Reco}^i + !\mathrm{Acc}^i \right) + \mathrm{Lost}^{dilep} \right) \right]$$

Cut	Motivation	Impact
MHT > 200, HT > 500	Get to trigger plateau	Trigger ~95% efficient here
4+ jets (30+ GeV, CHS)	Target high-multiplicity SUSY models Save compressed signal with low-pt cut	$p_T > 30$ GeV cut saves up to 50% more signal w.r.t. cut at 50 GeV
$\Delta\phi$(jets 1-4, MHT) > (0.5, 0.5, 0.3, 0.3)	Suppress QCD by targeting under-measured jets	Rejects > 90% of QCD Favorable signal eff / real-MET BG eff
e/μ veto (pt > 10 GeV, veto/medium ID, mini iso)	Suppress top/W $\rightarrow \ell\nu$	> 95% efficient for hadronic signal
Leptonic track veto ($p_T > 5$ GeV, $m_T < 100$ GeV, track iso)	Reject more top/W $\rightarrow \ell\nu$ events with lower-pt leptons, leptons failing mini iso	Rejects 30% of lost e/μ events, ~90% of which have 5-10 GeV leptons
Hadronic track veto ($p_T > 10$ GeV, $m_T < 100$ GeV, track iso)	Suppress top/W $\rightarrow \tau\nu \rightarrow$ had+MET	Rejects 30% of hadronic tau BG

Cut flow Signals

Cut	T1tttt (1500, 100)	T1tttt (1200, 800)	T1bbbb (1500, 100)	T1bbbb (1000, 900)	T1qqqq (1400, 100)	T1qqqq (1000, 800)
Start	141.9	856.4	141.9	3253.8	252.9	3253
$N_{\text{jet}} \geq 4$	141.8 (1.00)	854.8 (1.00)	137.3 (0.97)	1624 (0.50)	244.9 (0.97)	2549 (0.78)
$H_T > 500$ GeV	141.7 (1.00)	706.1 (0.83)	137.3 (1.00)	654.8 (0.40)	244.8 (1.00)	1390 (0.55)
$H_T^{\text{miss}} > 200$ GeV	125.8 (0.89)	311.9 (0.44)	124.2 (0.91)	534.8 (0.82)	221.2 (0.90)	904.1 (0.65)
μ veto	80.49 (0.64)	202.4 (0.65)	123.1 (0.99)	521.3 (0.97)	220.8 (1.00)	902.6 (1.00)
e veto	51.54 (0.64)	135.14 (0.67)	122.0 (0.99)	512.0 (0.98)	218.5 (0.99)	894.9 (0.99)
μ track veto	50.74 (0.98)	129.9 (0.96)	121.5 (1.00)	500.07 (0.98)	217.8 (1.00)	888.9 (0.99)
e track veto	49.32 (0.97)	120.0 (0.92)	119.9 (0.99)	478.8 (0.96)	215.0 (0.99)	868.8 (0.98)
Had. track veto	48.27 (0.98)	112.0 (0.93)	119.4 (1.00)	472.0 (0.99)	213.9 (1.00)	852.2 (0.98)
$\Delta\phi$ cuts	39.08 (0.81)	87.76 (0.78)	95.94 (0.80)	373.1 (0.79)	173.0 (0.81)	699.6 (0.82)
Evt. cleaning	38.18 (0.98)	86.27 (0.98)	94.76 (0.99)	369.0 (0.99)	169.9 (0.98)	690.6 (0.99)
			$N_{\text{b-jet}}$ bins			
0 CSVM	0.99 (0.03)	2.46 (0.03)	4.52 (0.05)	25.46 (0.07)	115.9 (0.68)	489.3 (0.71)
1 CSVM	5.31 (0.14)	13.75 (0.16)	20.89 (0.22)	110.8 (0.30)	43.59 (0.26)	163.5 (0.24)
2 CSVM	11.55 (0.30)	27.76 (0.32)	34.51 (0.36)	144.4 (0.39)	9.13 (0.05)	32.81 (0.05)
≥ 3 CSVM	20.33 (0.53)	42.30 (0.49)	34.84 (0.37)	88.34 (0.24)	1.38 (0.01)	5.12 (0.01)

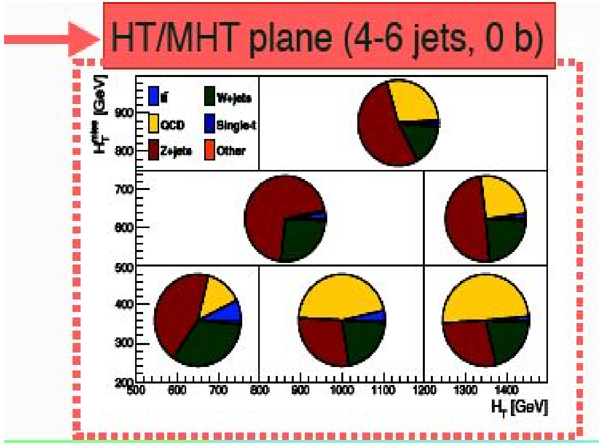
Cut flow Bkg

Table 11: Cutflow and expected yields at 10 fb $^{-1}$ for SM backgrounds, with the baseline se sections listed in Section 3. The efficiency of each cut, calculated with respect to the previ yield.

Cut	$t\bar{t}$	QCD	Z+jets	W+jets
Start	8×10^6	$> 10^8$	6×10^6	2×10^7
$N_{\text{jet}} >= 4$	6×10^6	$> 10^7$	8×10^5	2×10^6
$H_T > 500$ GeV	10^6	$> 10^7$	4×10^4	3×10^5
$H_T^{\text{miss}} > 200$ GeV	46204.02	100718.36	10709.43	35208.73
μ veto	31209.42 (0.68)	100424.34 (1.00)	10693.15 (1.00)	24940.95 (0.71)
e veto	19116.81 (0.61)	99296.67 (0.99)	10607.60 (0.99)	15240.75 (0.61)
μ track veto	17698.28 (0.93)	97798.80 (0.98)	10538.85 (0.99)	14456.57 (0.95)
e track veto	15237.88 (0.86)	93962.19 (0.96)	10272.05 (0.97)	12952.54 (0.90)
Had. track veto	12201.90 (0.80)	91628.84 (0.98)	10133.97 (0.99)	10553.74 (0.81)
$\Delta\phi$ cuts	6946.27 (0.57)	9645.15 (0.11)	7543.35 (0.74)	6101.87 (0.58)
Evt. cleaning	6651.03 (0.96)	4789.70 (0.50)	7477.41 (0.99)	5803.18 (0.95)
		$N_{\text{b-jet}}$ bins		
$N_{\text{b-jet}} = 0$	982.01 (0.15)	2494.63 (0.52)	5743.30 (0.77)	4433.89 (0.76)
$N_{\text{b-jet}} = 1$	2839.90 (0.43)	1575.38 (0.33)	1416.57 (0.19)	1158.09 (0.20)
$N_{\text{b-jet}} = 2$	2298.84 (0.35)	466.97 (0.10)	286.99 (0.04)	190.50 (0.03)
$N_{\text{b-jet}} \geq 3$	530.28 (0.08)	252.71 (0.05)	30.55 (0.00)	20.70 (0.00)

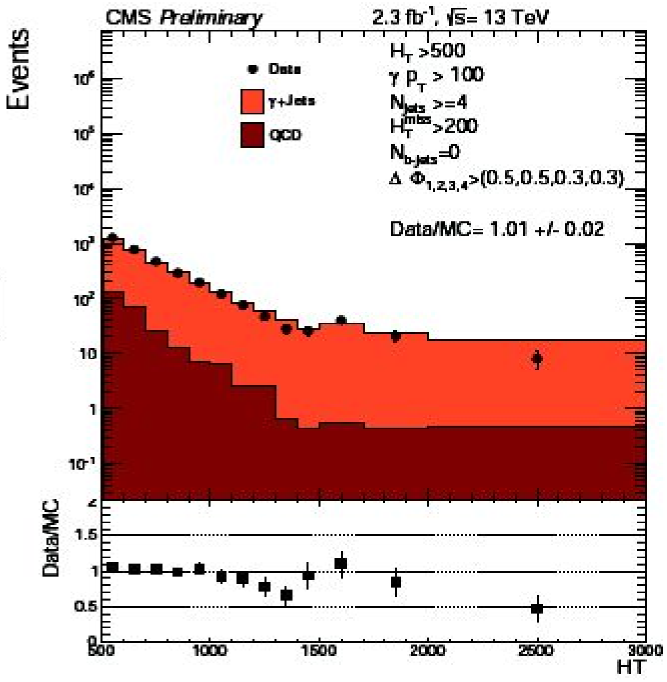
had tau events in bins

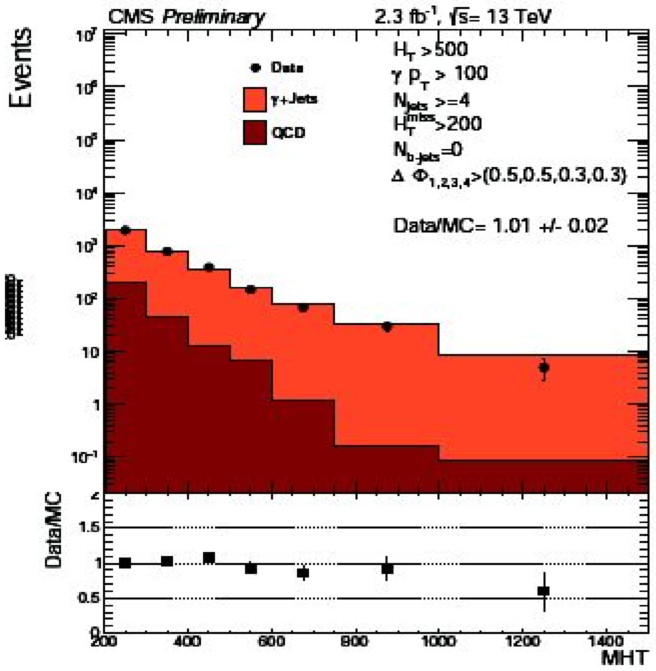
$$N_{\tau_h} = \sum_i^{N_{CS}^{\mu}} \left(\sum_j^{\text{Template bins}} \left(P_{\tau_h}^{\text{resp}} \sum_k w_{\text{b-mistag}}^{\tau_h} \right) \frac{1}{\epsilon_{\text{Trig}}^{\mu} \epsilon_{\text{Reco}}^{\mu} \epsilon_{\text{ISO}}^{\mu}} \frac{1}{\epsilon_{\text{Acc}}^{\mu} \epsilon_{m_T}^{\mu}} (1 - f_{\tau \to \mu})(1 - f_{ll}) \frac{\mathcal{B}(W \to \tau_h \nu)}{\mathcal{B}(W \to \mu \nu)} C_{\text{isotrk}} \right)$$



Photon control region Data/MC plots

- Good data / mc agreement



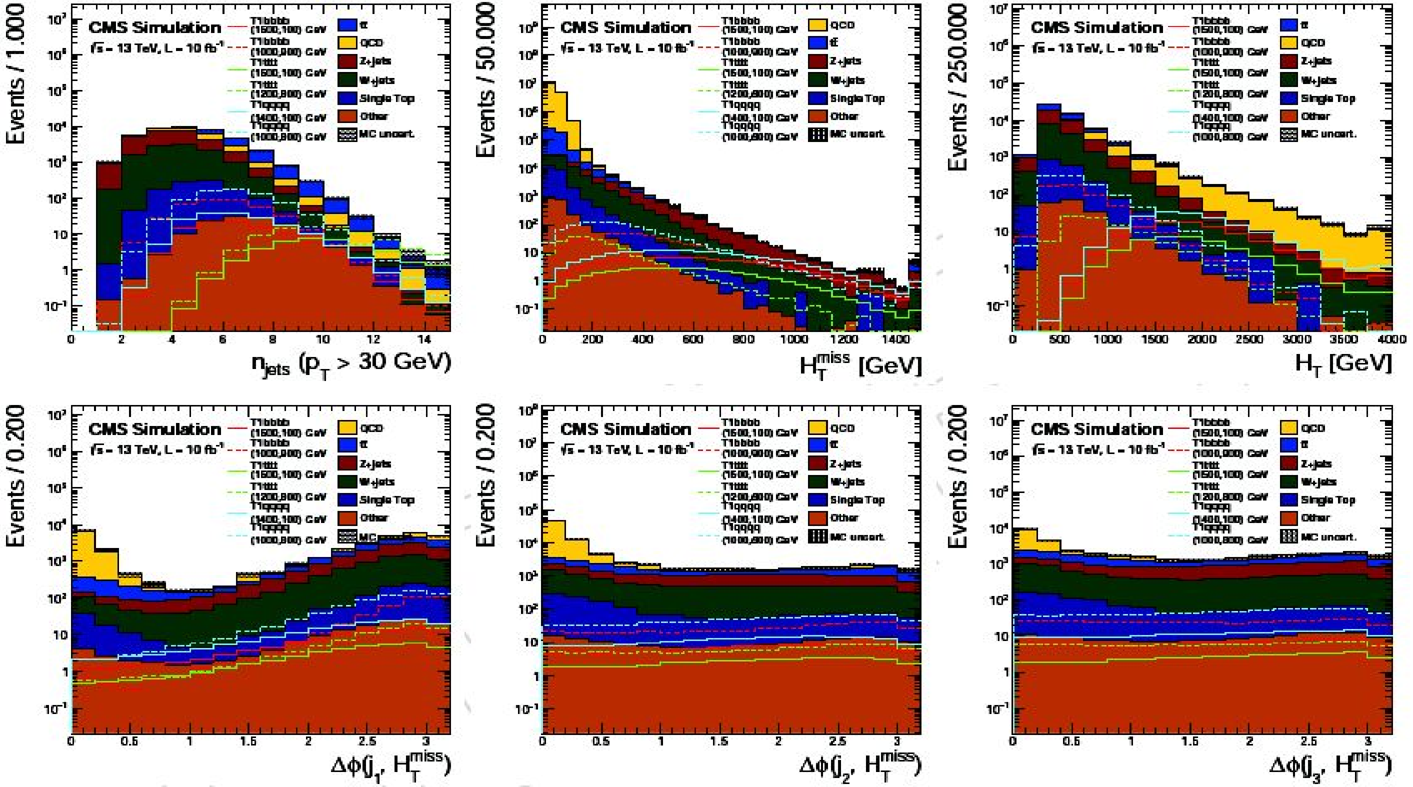


cross section

Table 10: MC FullSim samples for signal SMS model points.

Dataset	σ (pb)	$\int \mathcal{L}\,dt$ (fb^{-1})
SMS-T1tttt_mGluino-1500_mLSP-100_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.014	7268
SMS-T1tttt_mGluino-1200_mLSP-800_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.086	1719
SMS-T1bbbb_mGluino-1500_mLSP-100_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.014	3708
SMS-T1bbbb_mGluino-1000_mLSP-900_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.325	438.5
SMS-T1qqqq_mGluino-1400_mLSP-100_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.025	1958
SMS-T1qqqq_mGluino-1000_mLSP-800_TuneCUETP8M1_13TeV-madgraphMLM-pythia8	0.325	293.0

Kinematics


CMS Simulation
√s = 13 TeV, L = 10 fb⁻¹
T1bbbb (1500,100) GeV
T1bbbb (1000,900) GeV
T1tttt (1500,100) GeV
T1tttt (1200,800) GeV
T1qqqq (1400,100) GeV
T1qqqq (1000,800) GeV
tt̄
QCD
Z+jets
W+jets
Single Top
Other
MC uncert.
Events / 1.000
n_jets (p_T > 30 GeV)
Events / 50.000
H_T^miss [GeV]
Events / 250.000
H_T [GeV]
Events / 0.200
Δφ(j_1, H_T^miss)
Δφ(j_2, H_T^miss)
Δφ(j_3, H_T^miss)

Motivation

- Supersymmetry is a beyond Standard model theory that solves many puzzling issues like
- Hierarchy problem
- Gauge coupling unification
- And possible candidate (neutralino) for dark matter