SUSY Searches in All-Hadronic States with Large MET at the LHC

Michael Tytgat
(on behalf of CMS & ATLAS)
CERN

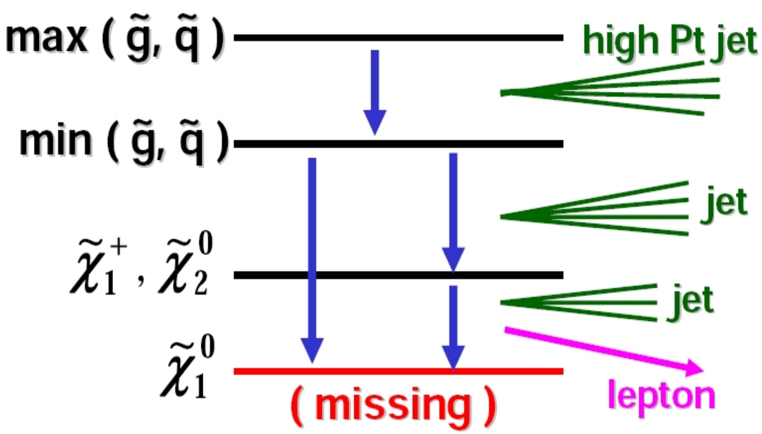
SUSY07

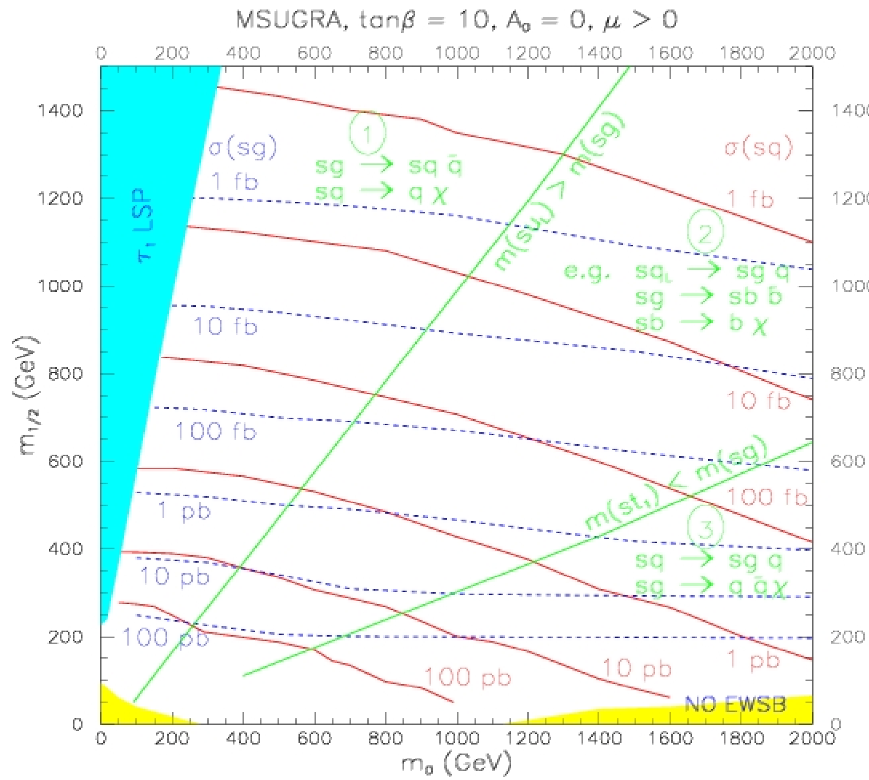
Karlsruhe, Germany

July 26, 2007

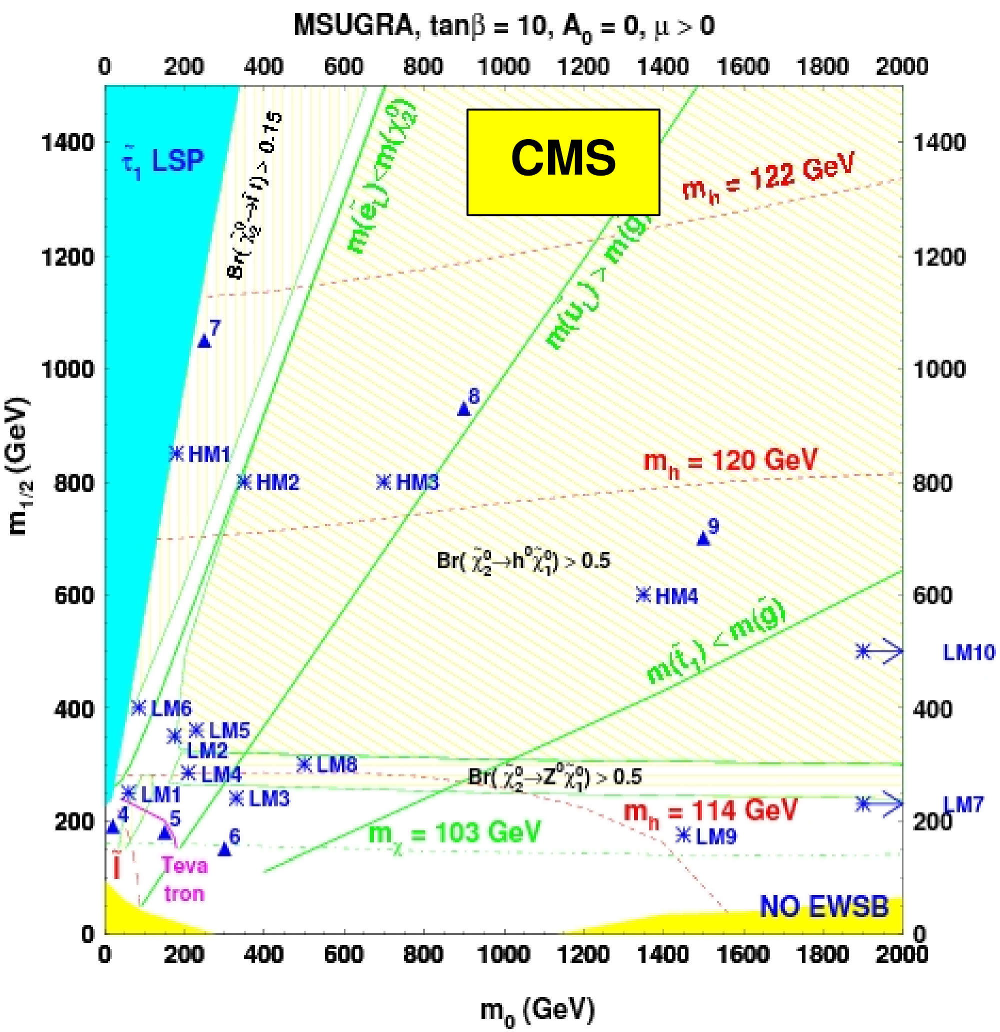
SUSY Signature

- Most SUSY studies in CMS & ATLAS done in the context of :
  - *Minimal Supersymmetric SM* (MSSM) with R-parity conservation
  - *minimal SuperGravity* (mSUGRA) SUSY breaking scenario
- Large cross sections expected at the LHC for squarks/gluinos
- In most cases generic SUSY signature is :
  - multiple jets, often high P_T
  - missing E_T
  - possibly some leptons





mSUGRA Test Points



- 14 benchmark points used in CMS :
  - Low mass points for early LHC running, outside Tevatron reach
  - High mass points for ultimate LHC reach

Point	m_0	$m_{1/2}$	$\tan\beta$	sgn(μ)	A_0
LM1	60	250	10	+	0
LM2	185	350	35	+	0
LM3	330	240	20	+	0
LM4	210	285	10	+	0
LM5	230	360	10	+	0
LM6	85	400	10	+	0
LM7	3000	230	10	+	0
LM8	500	300	10	+	-300
LM9	1450	175	50	+	0
LM10	3000	500	10	+	0
HM1	180	850	10	+	0
HM2	350	800	35	+	0
HM3	700	800	10	+	0
HM4	1350	600	10	+	0

- Similar points used by ATLAS

Inclusive SUSY Searches

- Inclusive SUSY searches especially important for early LHC data :
  - Jets + MET + (0,1,2) leptons (e,μ)
- Robust background estimates are crucial :
  - ttbar, QCD multi-jets, W/Z + jets
  - Data-driven background estimates are essential !
- Typical selection cuts :

ATLAS

- Missing $E_T > 100$ GeV
- ≥ 4 jets, $P_T^{1st} > 100$ GeV, $P_T^{4th} > 50$ GeV
- 0 leptons
- Transverse sphericity > 0.2

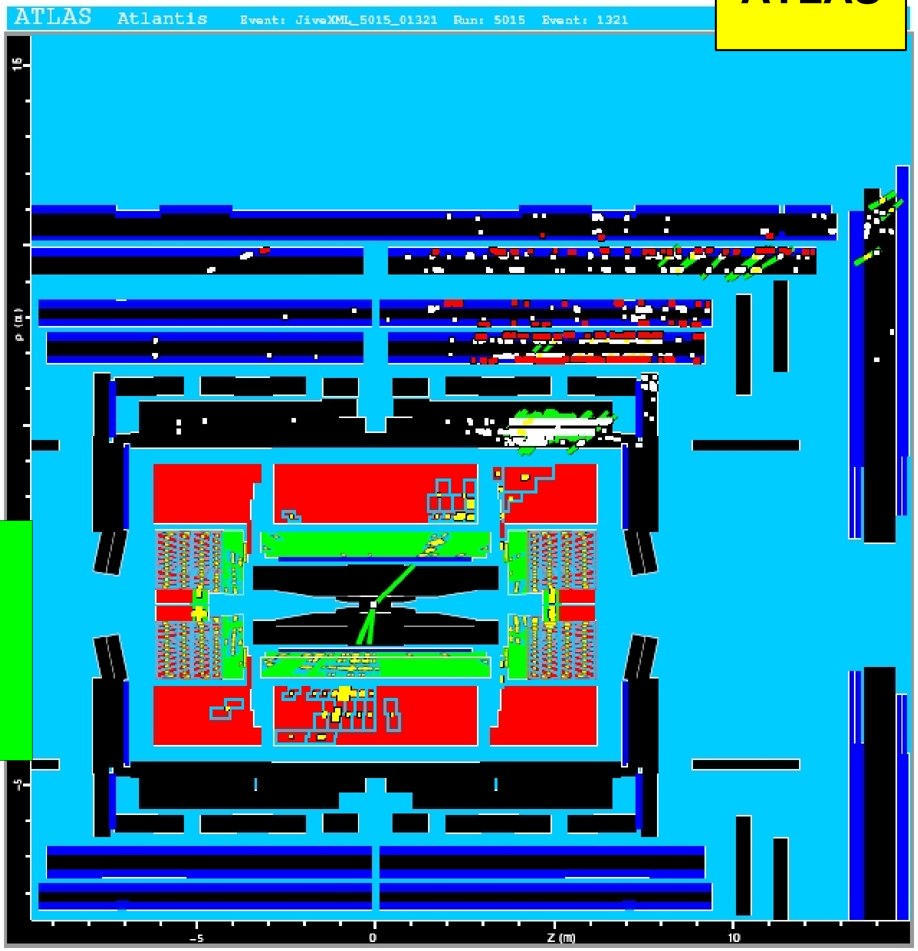
CMS

- Missing $E_T > 200$ GeV + cleanup
- ≥ 3 jets, $E_T > 180, 110, 30$ GeV
- Indirect lepton veto
- Cuts on ΔΦ between jets and MET
- $H_T = E_{T(2)} + E_{T(3)} + E_{T(4)} + MET > 500$ GeV

Missing E_T

- MET is a very powerful tool for SUSY discovery, but also a complex object
- MET will include contributions from :
  - Non-collisional background : beam halo, cosmic muons
  - Detector effects : instrumental noise, hot/dead channels, cracks

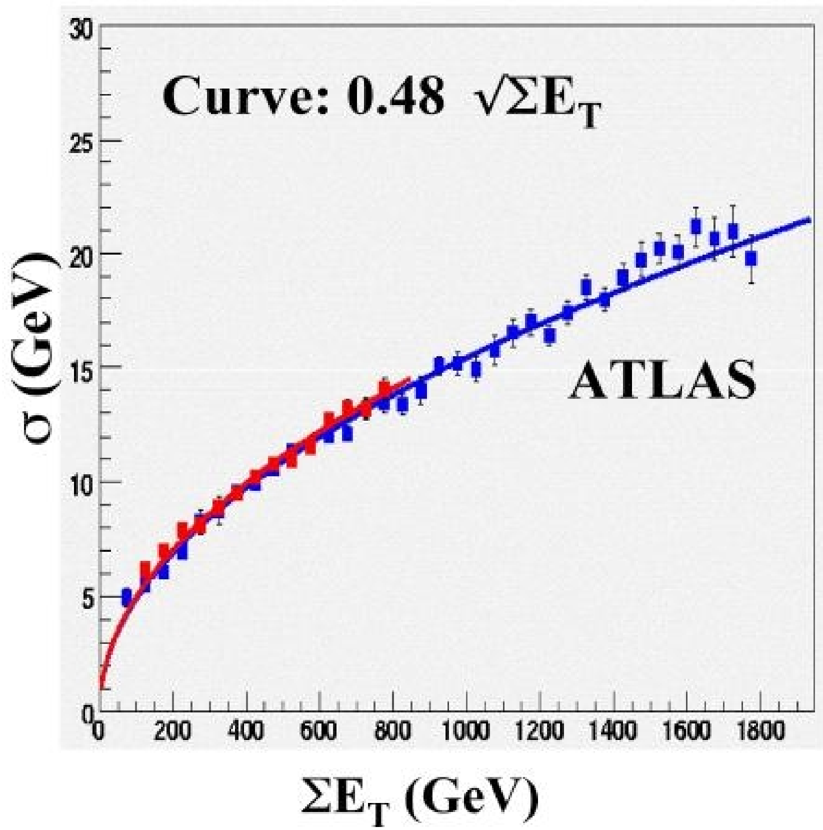
ATLAS

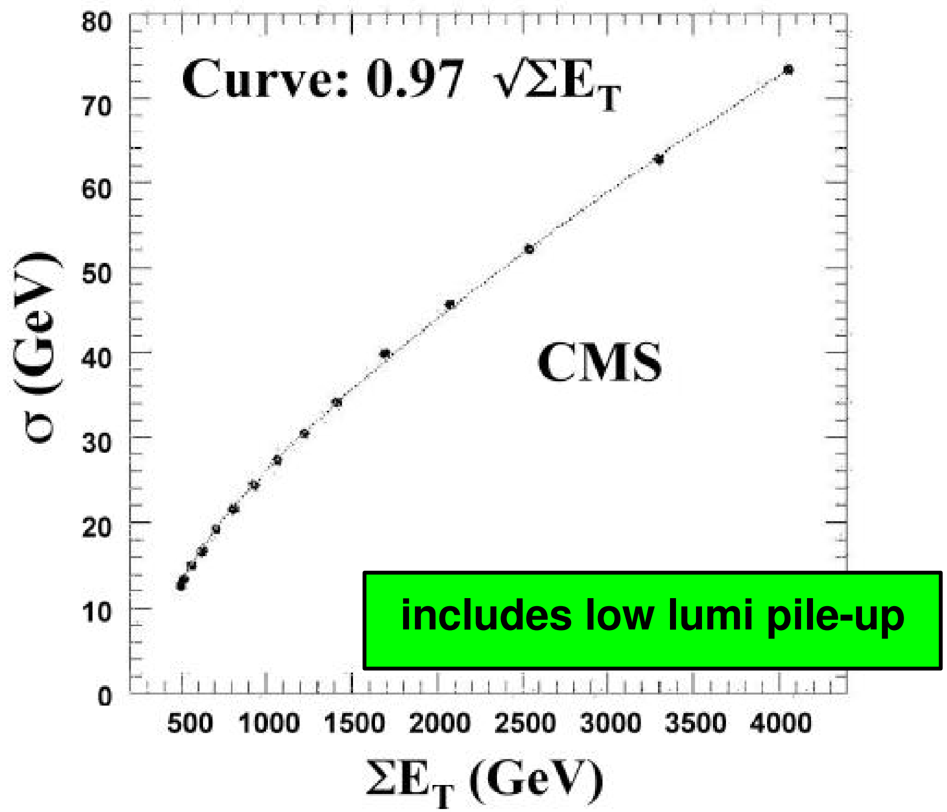


Jet leakage through Hadronic Calorimeter Central Barrel / Extended Barrel crack : MET = 271 GeV

Missing E_T Performance

- Missing Transverse Energy resolution for QCD events :





- Missing E_T performance dominated by calorimeter resolution

Missing E_T Cleaning

- CMS : Apply MET clean up cuts for cosmics and beam halo :
  - ≥1 central jet (|η| < 1.7) with ≥4 tracks
  - ≥1 vertex
  - $F_{em} > 0.1$ (Event Electromagn. Fr.)

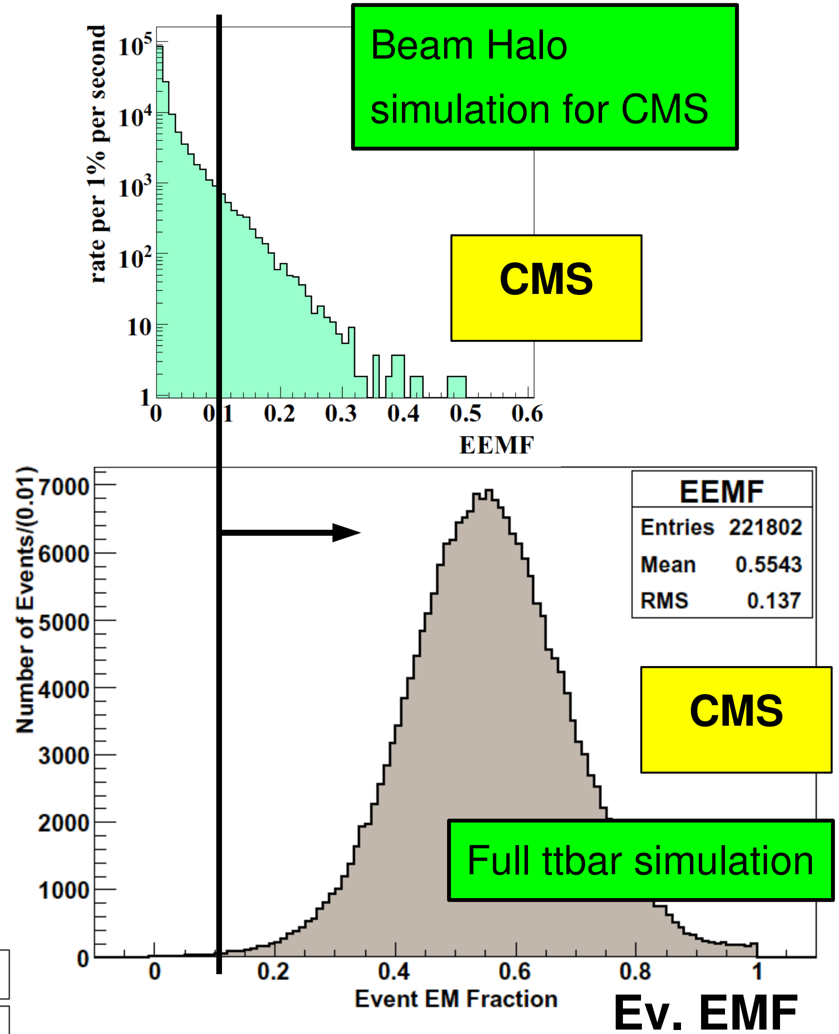
$$\mathrm{EEMF} = \frac{\sum_{j=1}^{N_{jet}} P_{\mathrm{T}j} \times \mathrm{EMF}_j}{\sum_{j=1}^{N_{jet}} P_{\mathrm{T}j}}$$

  - $F_{ch} > 0.175$ (Event Charged Frac.)

$$\mathrm{ECHF} = < \frac{(\sum_i^{tracks} P_{Ti})_j}{P_{Tj}} > |_{N_{jet}}$$

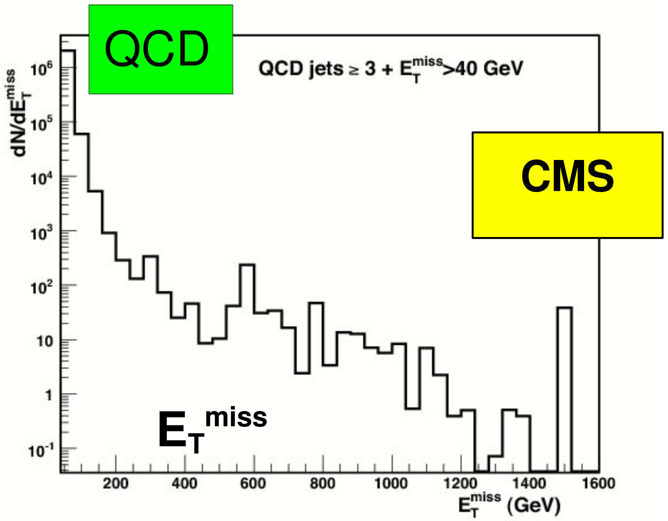
- Effect of cleanup on SUSY sample :

Sample/Requirement	$F_{em} > 0.1$	$F_{ch} > 0.175$	Both(%)
LM1	99.88%	91.32%	91.24%



QCD Cleanup

- SM background in large MET + jets data dominated by QCD
- MET for QCD jets mostly due to jet mis-measurements and detector resolution



$$\delta\phi_1 = |\phi_{j(1)} - \phi(E_T^{miss})|$$
$$\delta\phi_2 = |\phi_{j(2)} - \phi(E_T^{miss})|$$

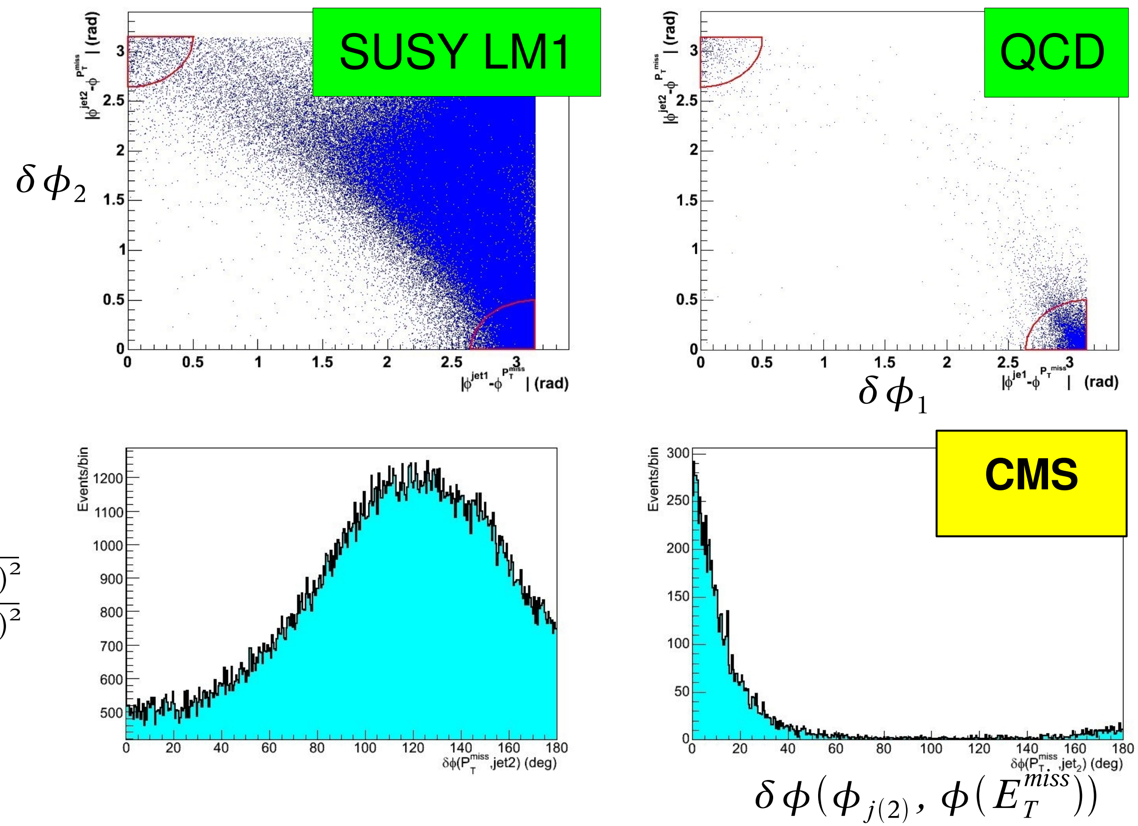
with $R_1 = \sqrt{\delta\phi_2^2 + (\pi - \delta\phi_1)^2}$, $R_2 = \sqrt{\delta\phi_1^2 + (\pi - \delta\phi_2)^2}$

CMS Cuts : $R_{1,2} > 0.5$ rad

$\delta\phi(\phi_{j(2)}, \phi(E_T^{miss})) > 20$ deg

$\delta\phi_{min}(\phi_j, \phi(E_T^{miss})) > 0.3$ rad

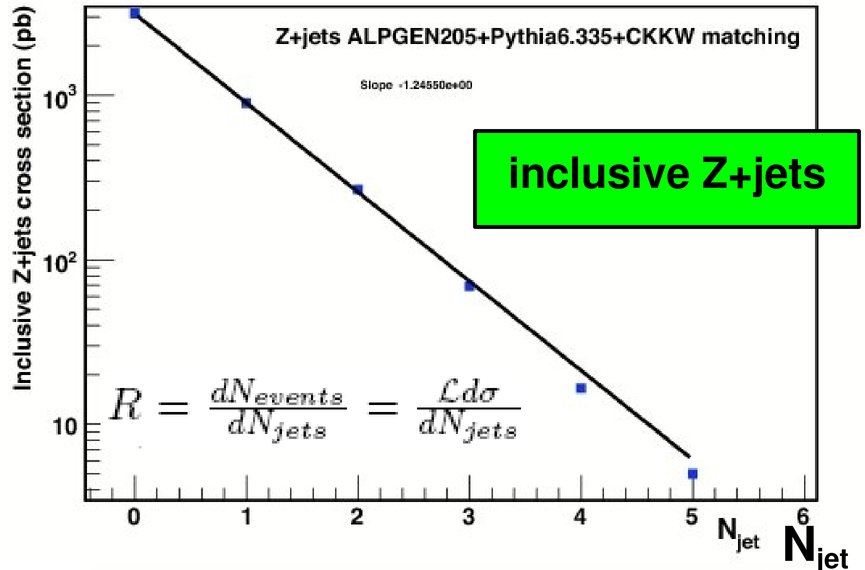
- QCD suppression using topological requirements

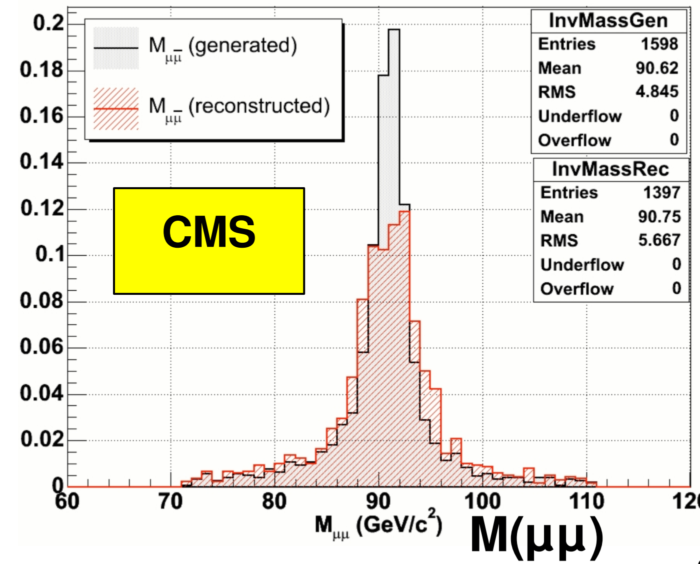


- Efficiency : SUSY LM1 ~ 90 %, QCD ~ 15 %

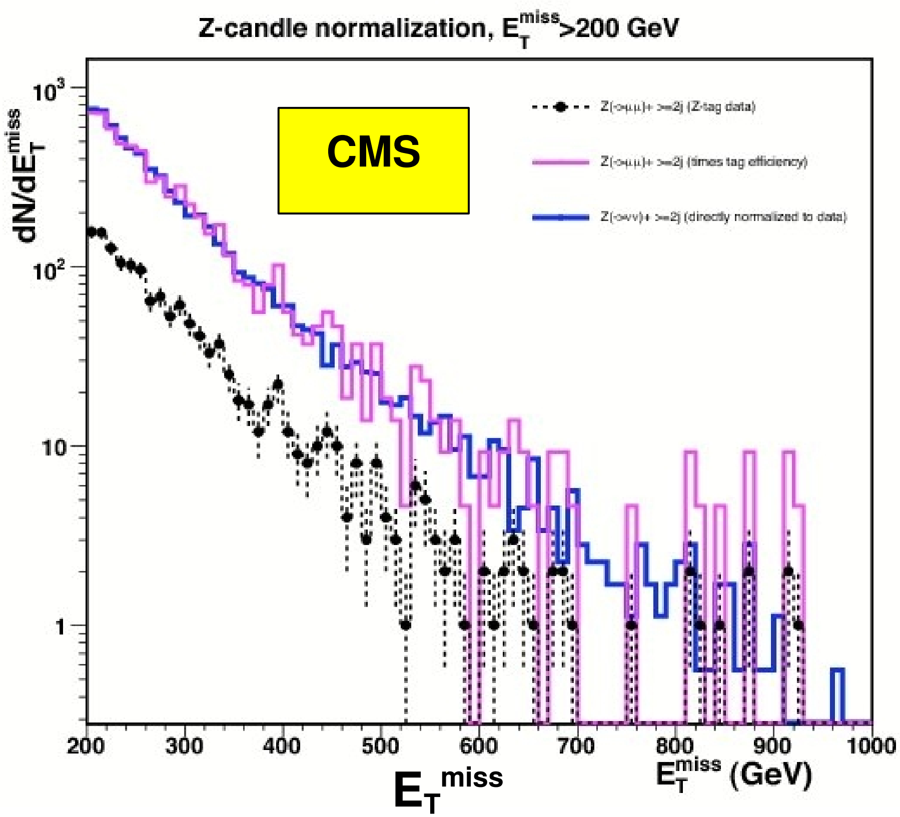
- Large E_T^{miss} and ≥ 3 jets expected from :
  - Z(→νν) + ≥ 3 jets
  - W(→μ(e)ν) + ≥ 3 jets
  - W(→ τν) + ≥ 2 jets (+1 τ-had decay jet)
- $\sigma(Z+N\text{ jets}) \propto \alpha_S^N$
- Measure from the ≥ 2 jets data
  - Z(→ee) + ≥ 2 jets
  - Z(→μμ) + ≥ 2 jets
- Z(→νν) + N jets can be estimated from Z(→μμ(ee)) + N jets
- W + N Jets can be estimated from :

$$\rho \equiv \frac{\sigma(pp \to W(\to \mu\nu)+jets)}{\sigma(pp \to Z(\to \mu^+\mu^-)+jets)}$$

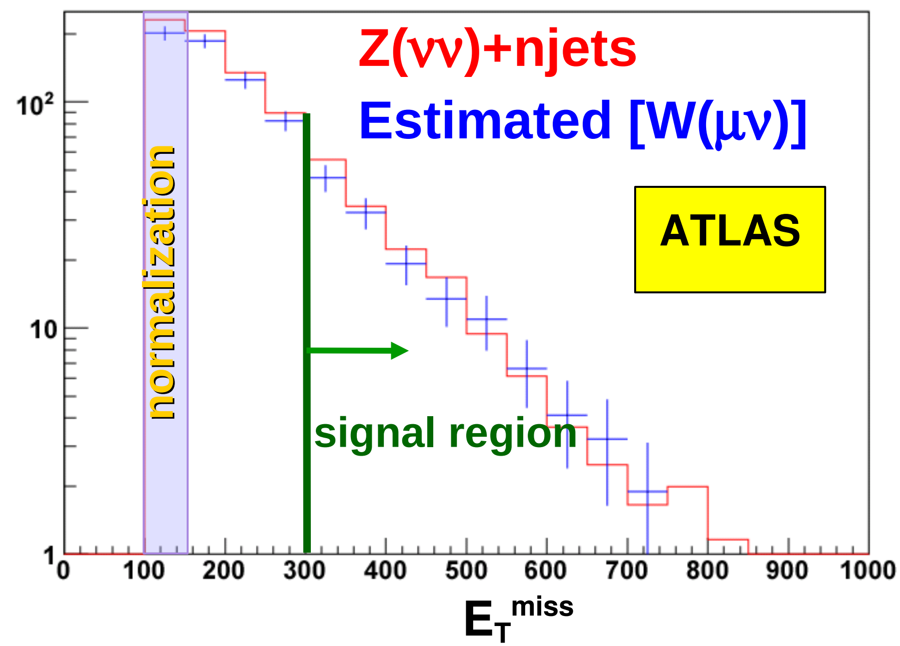




W/Z+jets Background



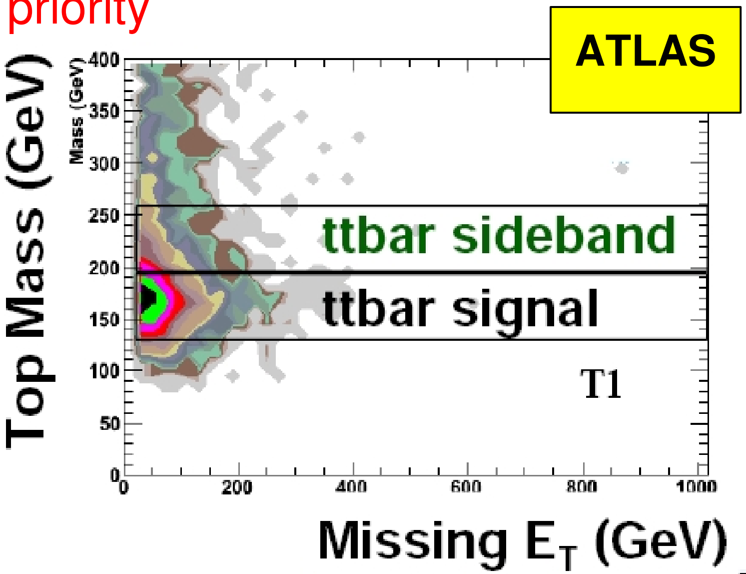
- MC to data normalization avoids systematics due to QCD scale, PDFs, ISR/FSR, jet energy scale ...

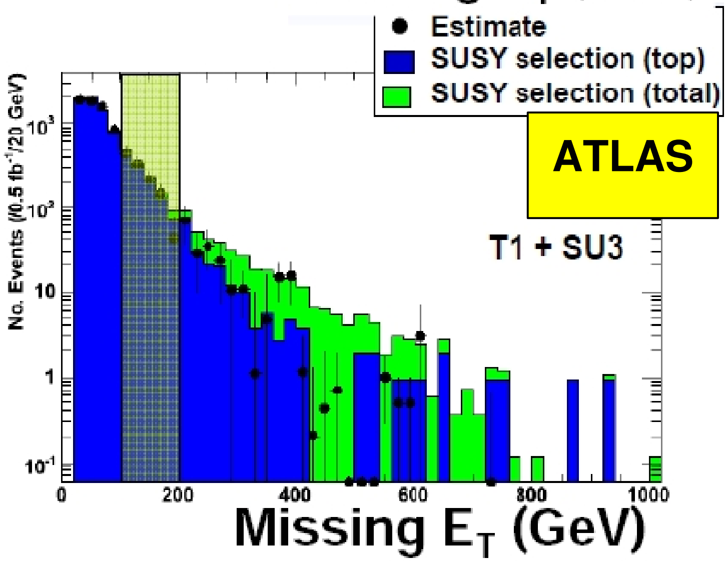


- CMS : Systematic uncertainty dominated by luminosity, measured ratio R and ρ; 5% precision expected with ~1.5 fb-1

ttbar Background Estimation

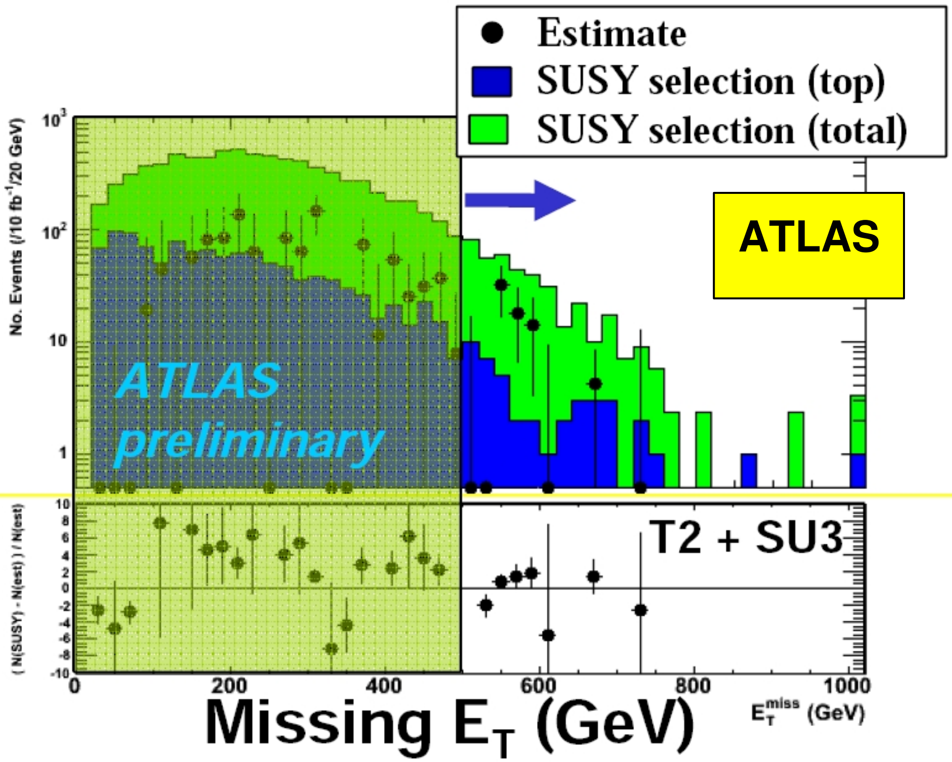
- Estimating top background from data has a high priority
- Find a variable uncorrelated to MET to make a control sample at low MET and to extrapolate to high MET
- Top mass reasonably uncorrelated to MET
- Use semi-leptonic top candidates
- Assume no b-tagging available for early data
  Combinatorial background estimated from the sideband (200-260 GeV) is subtracted from signal region (140-200 GeV)
- Control sample (ttbar signal – sideband) is normalized to data in low MET region where SUSY contribution is small





ttbar Background Estimation

- Apply top background estimation to a high P_T (> 500 GeV) event sample (ttbar + SUSY) corresponding to 10 fb-1, ie. 1 year of statistics at low lumi



- In high MET region (> 500 GeV) :
  - N_{obs} (with SUSY) = 503 ± 22
  - N_{est} (with SUSY) = 7 ± 35

→ Clear excess (13σ) !

Method proves to be valid

Analysis Result @ LM1

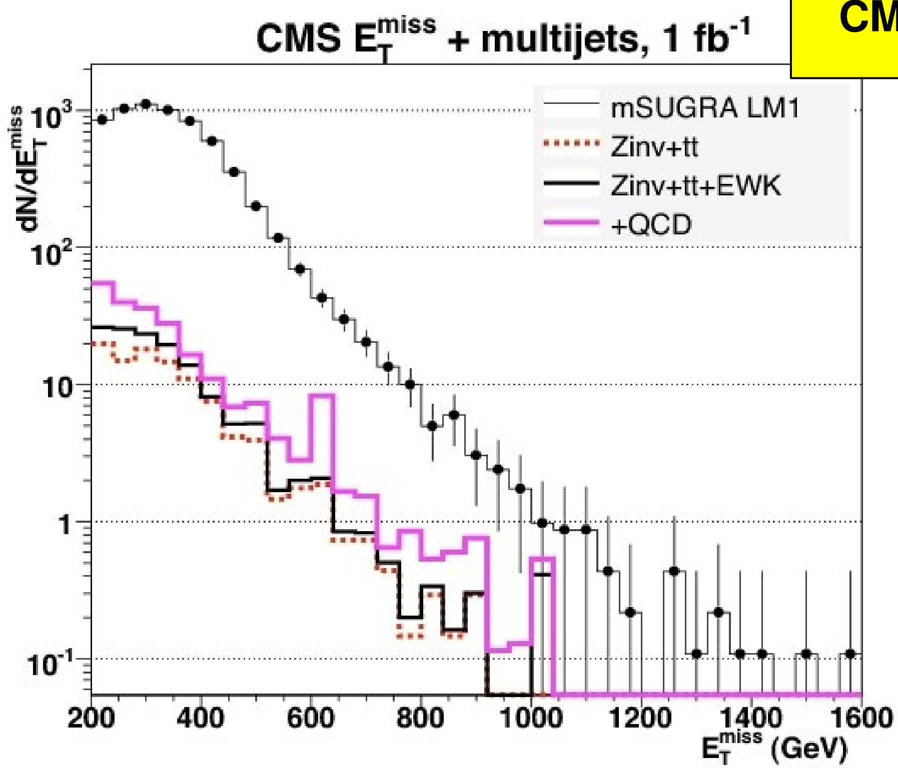
Point	m_0	$m_{1/2}$	$\tan\beta$	$\mathrm{sgn}(\mu)$	A_0
LM1	60	250	10	+	0

$m(\tilde{g}) \approx 600$ GeV
$m(\tilde{q}) \approx 550$ GeV

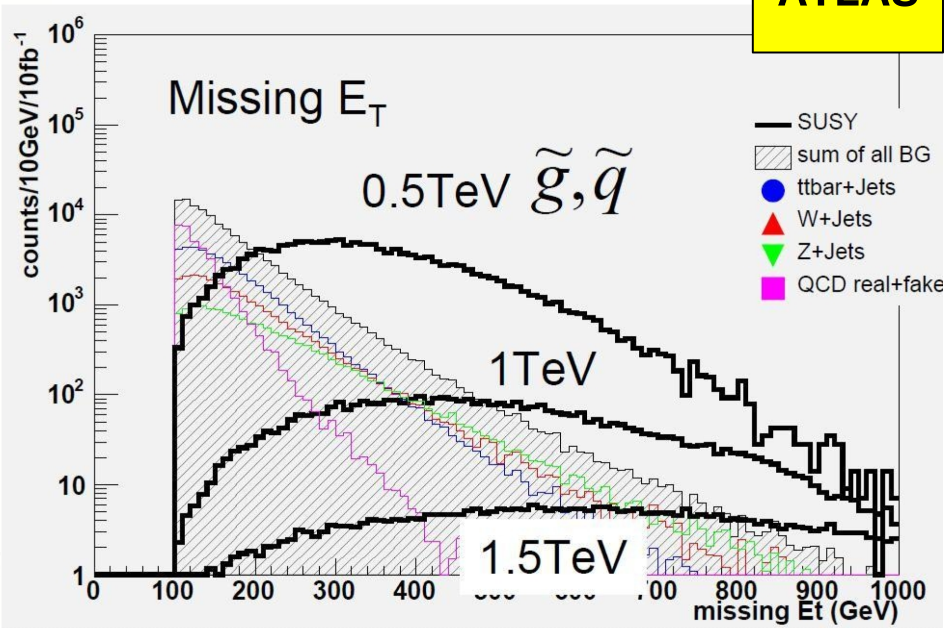
- Efficiency is 13% with S/B ratio ~ 26
- Number of events for 1 fb-1 :

Signal	$t\bar{t}$	single t	$Z(\rightarrow \nu\bar{\nu})$+ jets	$(W/Z, WW/ZZ/ZW)$ + jets	QCD
6319	53.9	2.6	48	33	107

CMS



ATLAS



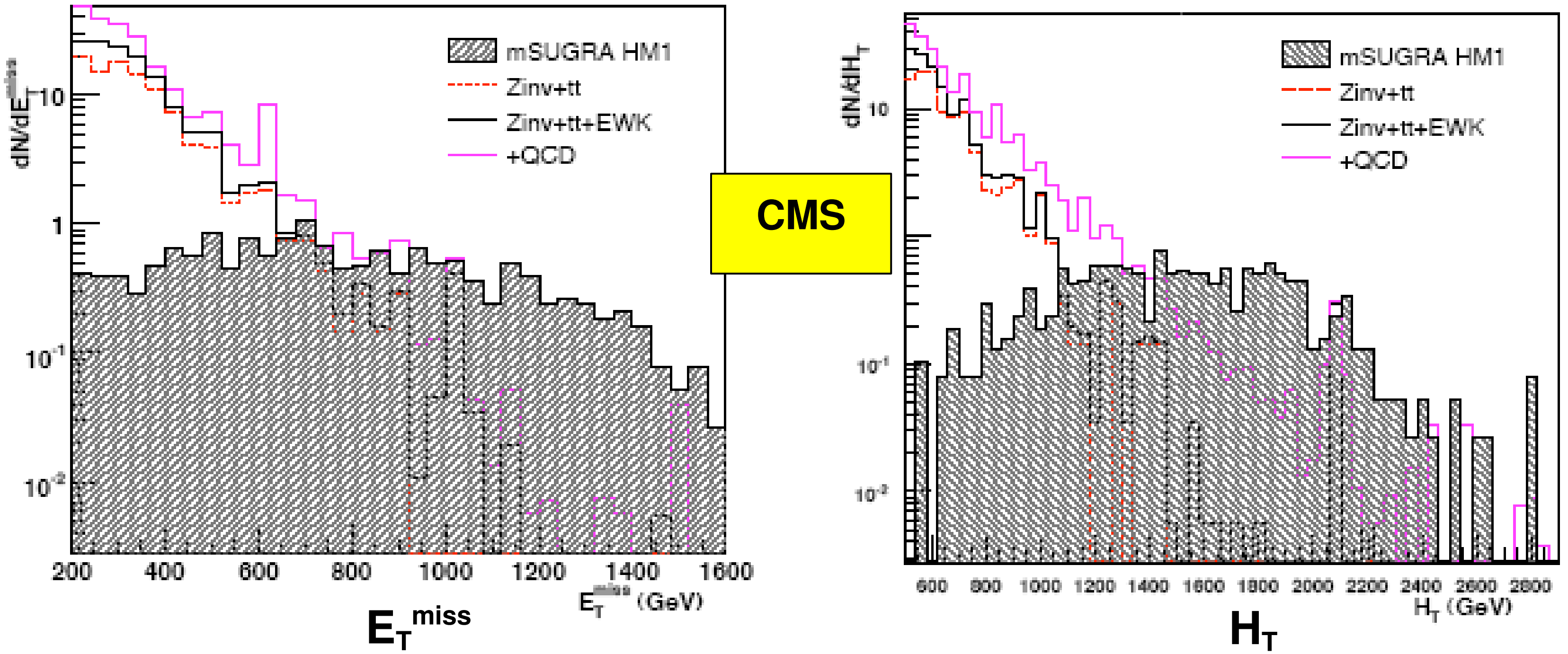
- ~6 pb-1 for 5σ discovery (including syst. uncert. in estimation)

Analysis Result @ HM1

Point	m_0	$m_{1/2}$	$\tan\beta$	sgn(μ)	A_0
HM1	180	850	10	+	0

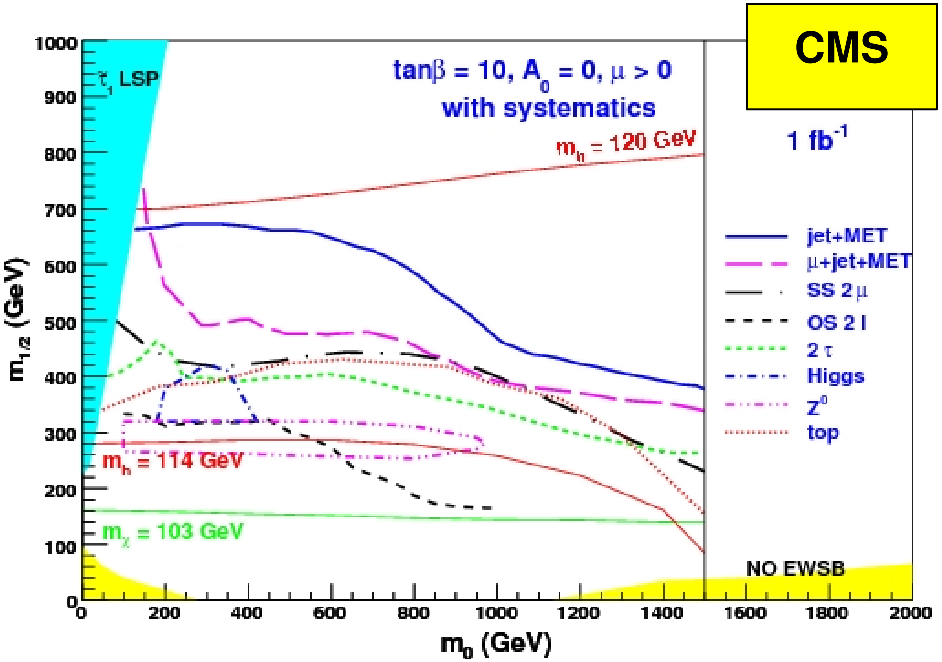
$m(\tilde{g}) \approx 1890$ GeV
$m(\tilde{q}) \approx 1700$ GeV

- Analysis is repeated (1 fb-1) on high mass test point 1 (by using fast simulation FAMOS for signal) with parameters :



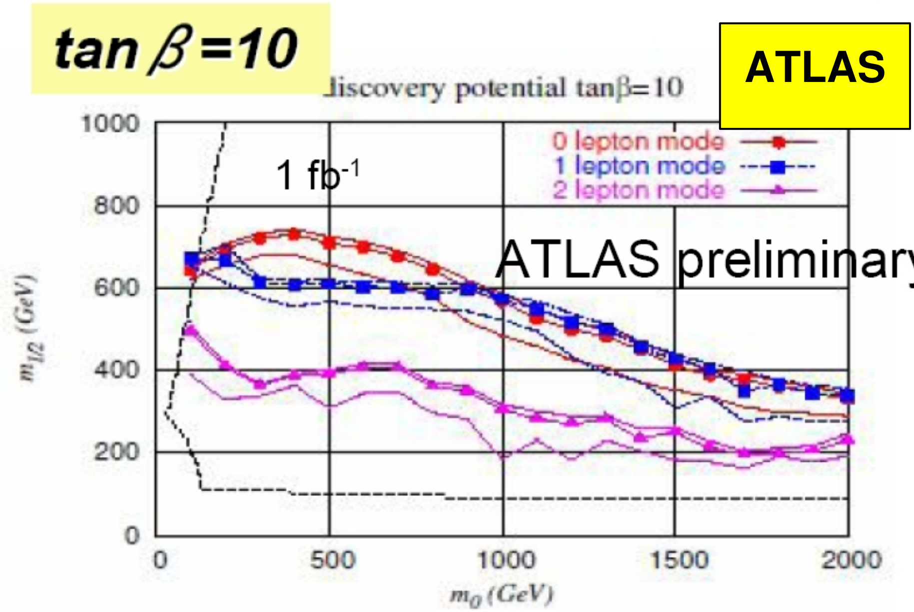
- Overall signal efficiency ~28%; claiming excess signal events is not easy

mSUGRA Discovery Potential

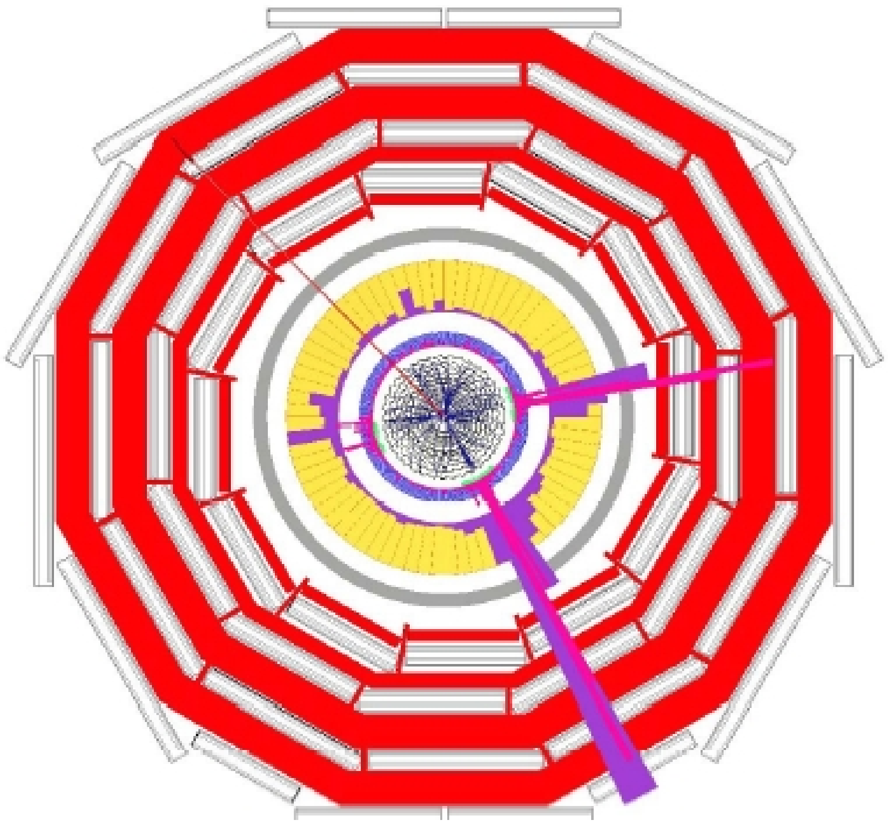


- 1 fb-1 reach tanβ = 10, A_0 = 0, μ > 0
- Systematics do not degrade reach very much up to 10 fb-1

- Best reach is obtained with most inclusive channels

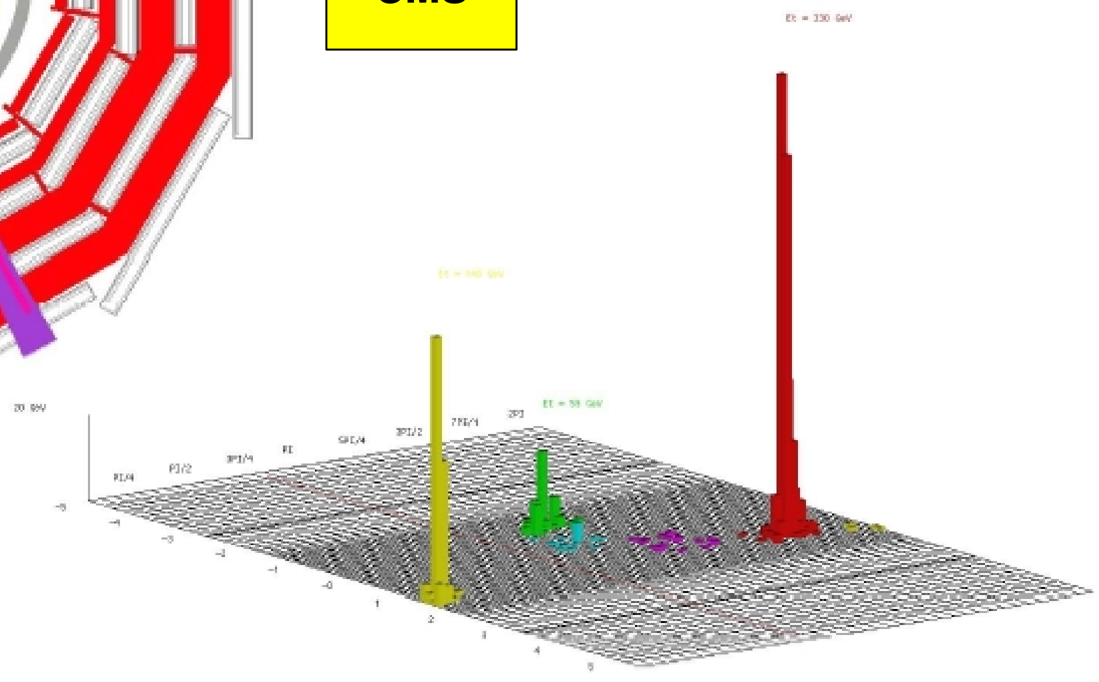


Wish You Were Real ...



- A SUSY candidate event :
  - Leading jets ET = 330, 140, 60 GeV
  - MET = 360 GeV

CMS



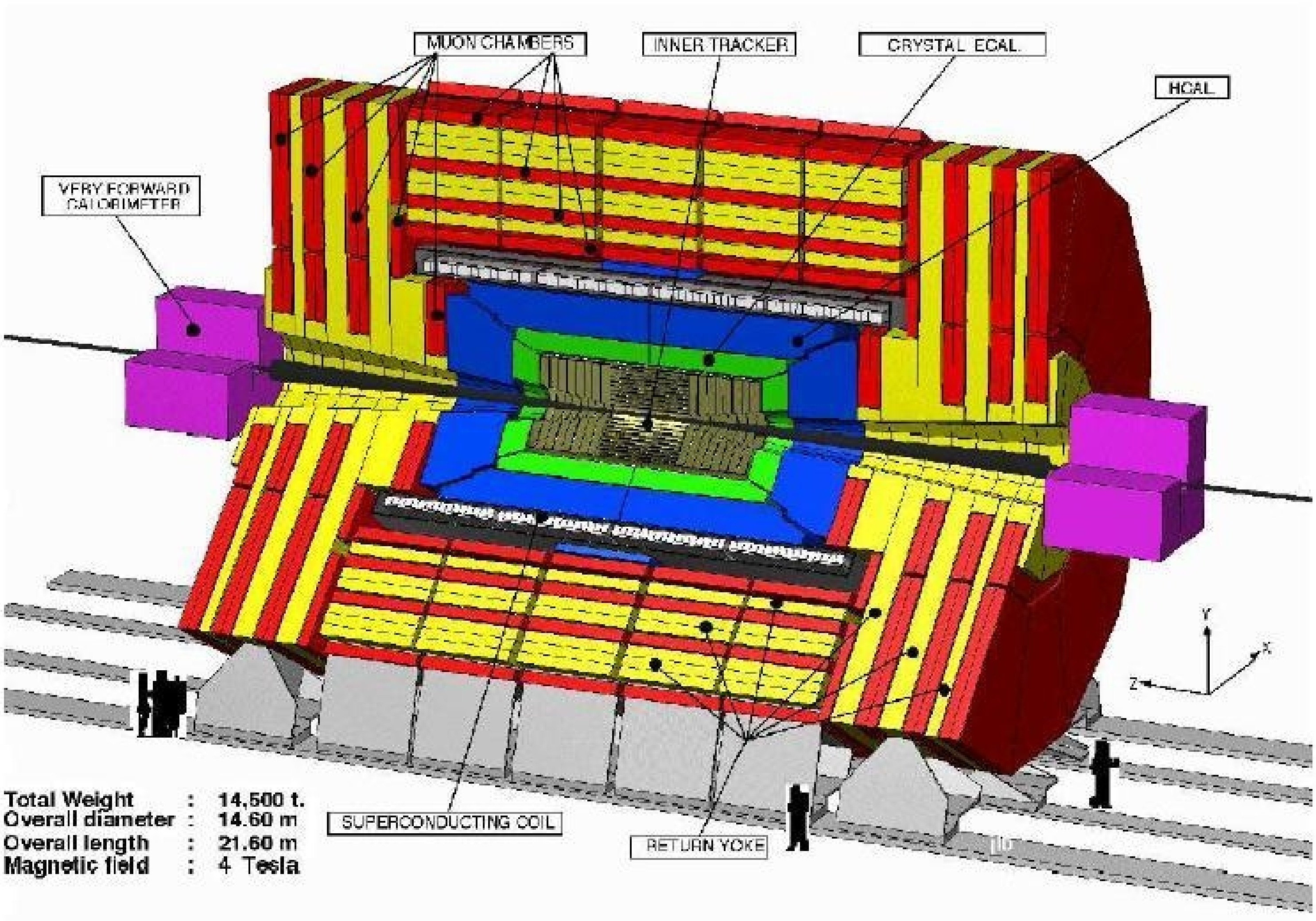
Summary and Conclusions

- Inclusive Jets + Missing E_T searches are important discovery tools for SUSY
- Low mass SUSY should be visible almost immediately
- MET is a powerful SUSY discriminator tool, but needs a thorough understanding
- Background estimates (ttbar, QCD, W/Z) from data-driven methods are crucial and are presently under study in both ATLAS & CMS

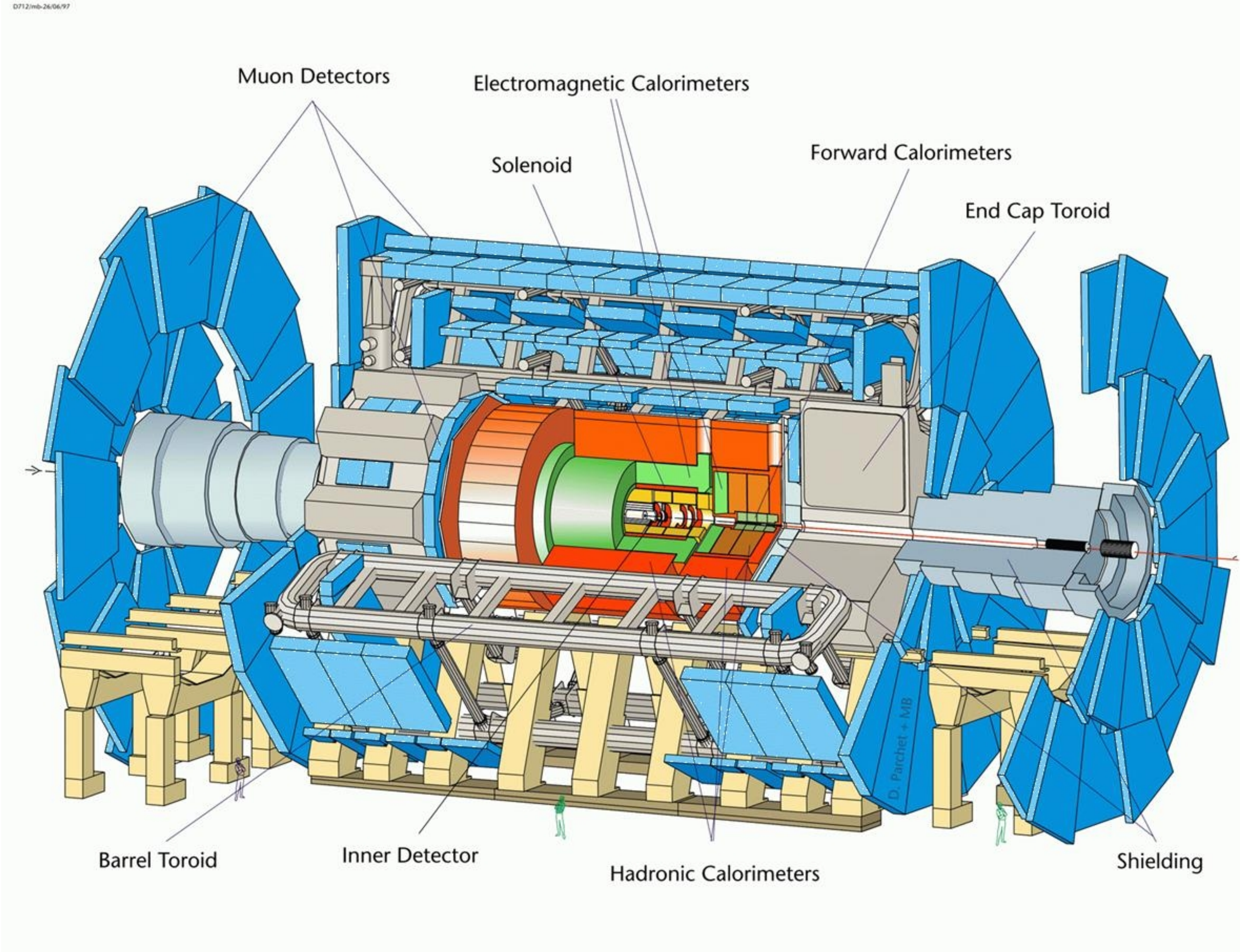
Thanks to S. Asai and D. Tovey for ATLAS plots

Backup Slides

The CMS Detector



The ATLAS Detector



CMS Inclusive Jets + MET Analysis Path

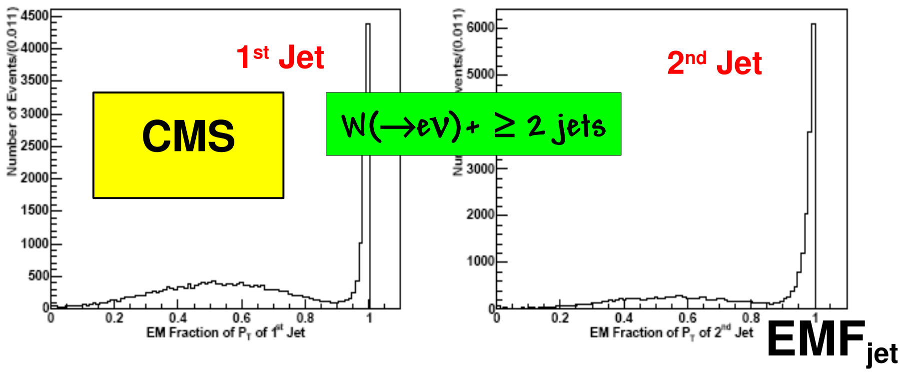
Requirement	Remark
Level 1	Level-1 trigger eff. parameter.
HLT, $E_T^{miss} > 200\,\mathrm{GeV}$	trigger/signal signature
primary vertex ≥ 1	primary cleanup
$F_{em} \geq 0.175$, $F_{ch} \geq 0.1$	primary cleanup
$N_j \geq 3, \lvert\eta_d^{1j}\rvert < 1.7$	signal signature
$\delta\phi_{min}(E_T^{miss} - jet) \geq 0.3$ rad, $R1, R2 > 0.5$ rad, $\delta\phi(E_T^{miss} - j(2)) > 20^\circ$	QCD rejection
$Iso^{ltrk} = 0$	ILV (I) $W/Z/t\bar{t}$ rejection
$f_{em(j(1))},\ f_{em(j(2))} < 0.9$	ILV (II), $W/Z/t\bar{t}$ rejection
$E_{T,j(1)} > 180\,\mathrm{GeV}, E_{T,j(2)} > 110\,\mathrm{GeV}$	signal/background optimisation
$H_T > 500\,\mathrm{GeV}$	signal/background optimisation
SUSY LM1 signal efficiency 13%	

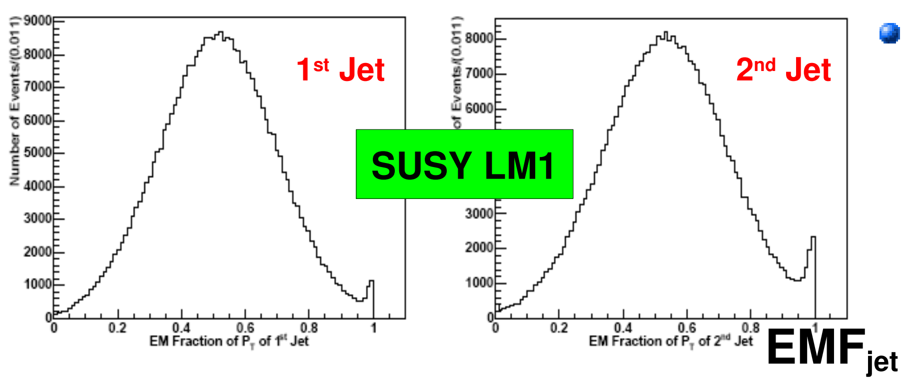
Indirect Lepton Veto

- No explicit lepton identification in inclusive analysis, use *Indirect Lepton Veto* (ILV)
- It uses two parts of the detector : Calorimeter and Tracker

<u>Calorimeter :</u>

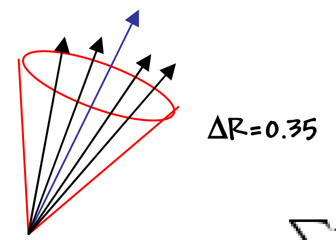
$F_{em,j(1)} < 0.9$ and $F_{em,j(2)} < 0.9$





<u>Tracker :</u>

Track isolation



$$P_{isol} = \frac{\sum_{i \neq \text{Lead Trk}}^{N^{\text{Trks}}} P_T^{i\text{Trk}}}{P_T^{i\text{Lead Trk}}}$$

- When both requirements are applied :
  - ~80% signal efficiency
  - ~50% to ~90% rejection efficiency in W/Z + jets depending on lepton flavour

Systematic Uncertainties

- MET shape :

  Effect of non-Gaussian tails in the jet E_T resolution to MET due to energy mis-measurements by using a bootstrap method; three scenarios :

  - a) 3 jets are under measured simultaneously
  - b) 2 jets are under measured simultaneously
  - c) 1 jet is under measured

  Overall MET shape systematic uncertainty is ~7%

- Jet Energy Scale (JES) :

  absolute jet energy corrections, calorimeter stability, underlying event, relative jet energy corrections

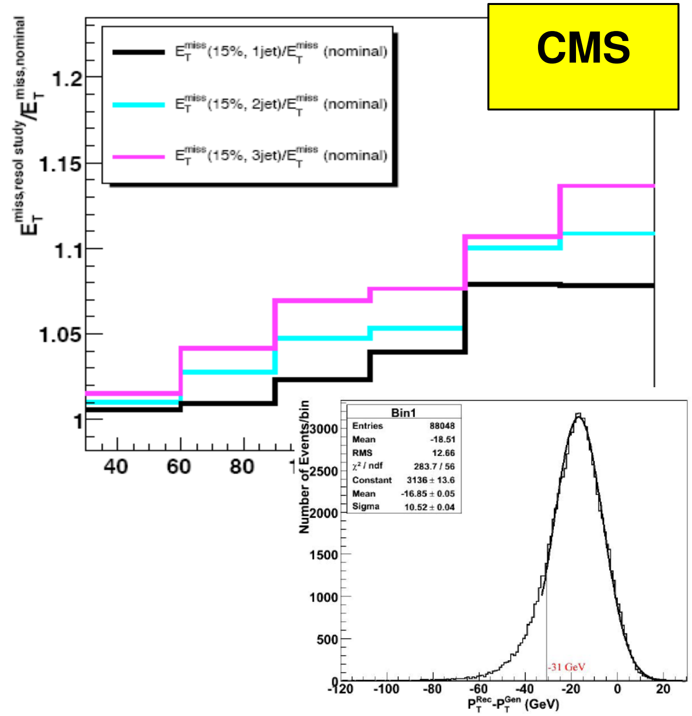
  7% JES uncertainty is taken into account for 1 fb^{-1}

- Luminosity : ±5% uncertainty (candle norm. to data)

- ALPGEN-PYTHIA :

  5% positive uncertainty due to the variation in efficiency of the ILV requirement between ALPGEN and PYTHIA

- Total background syst. uncert. :

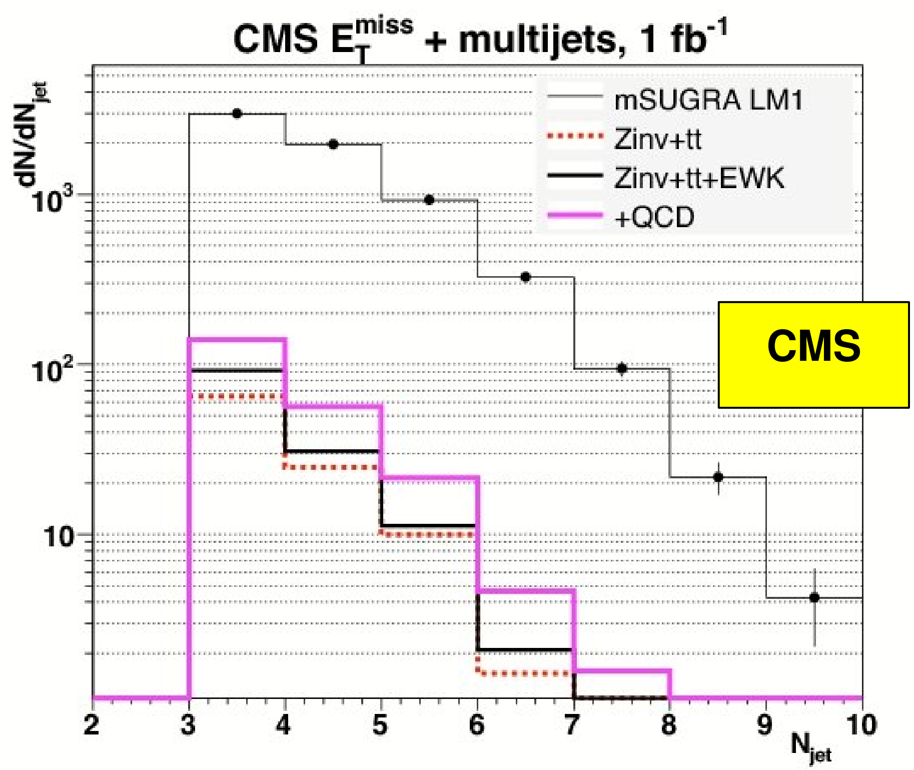


$$p^{\mu,jet}_{scaled} = (1 \pm \alpha) \cdot p^{\mu,jet}_{meas}$$
$$= (1 \pm \alpha) \cdot (p_x, p_y, p_z, E)$$

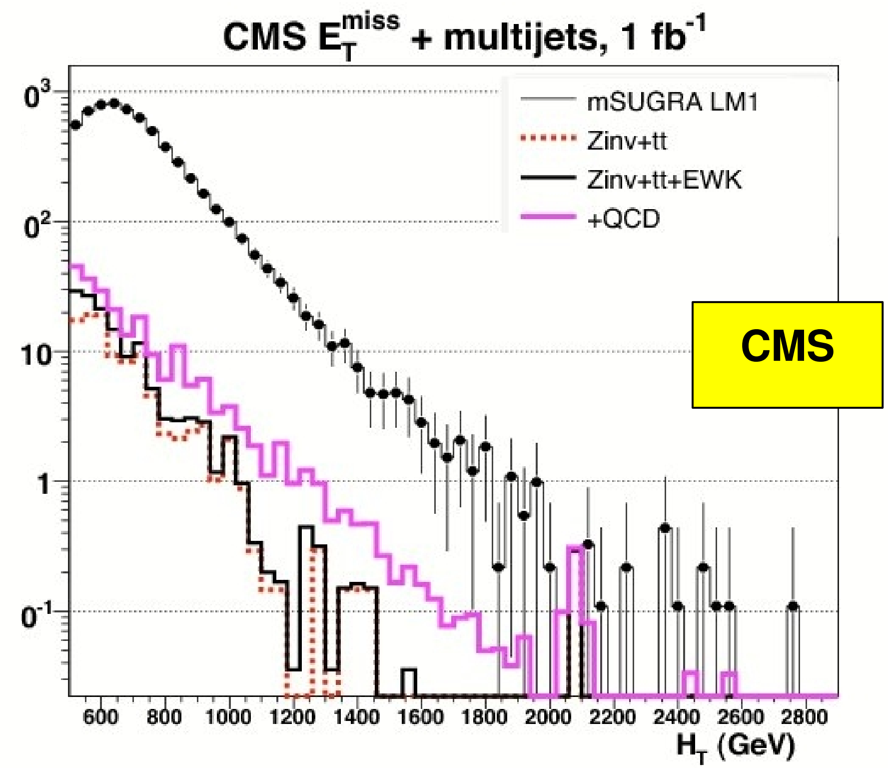
$t\bar{t}$,single top	$Z(\to \nu\bar{\nu})$+jets	$(W/Z,WW/ZZ/ZW)$ + jets	QCD
56 ± 11(sys) ± 7.5(stat)	48 ± 3.5 (all)	33 ± 2.5 (all)	107 ± 25(sys) ± 10(stat)

Analysis Result @ LM1

- Inclusive Jets + MET, 1 fb-1 :



N_{jet}



H_T