An early search for supersymmetry in hadronic final states with the CMS detector at the LHC

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1) Signatures, backgrounds and challenges

The minimal supersymmetric extension to the Standard Model (MSSM) predicts scalar and fermion partners to all SM fermions and bosons [1]. MSSM imposes R-parity conservation, which implies pair-production of *s*particles and the existence of a stable, weakly interacting massive particle, known as the lightest supersymmetric particle (LSP). At the LHC, pair-production of heavy squarks and gluinos is expected to dominate. These will decay, potentially via cascades, down to the LSP. In the case of the constrained mSuGra model, the LSP is a neutralino with a mass of order 100 GeV. Hence, mSuGra signatures typically comprise multiple high-p_T jets, leptons and large missing transverse energy (MET).

- CMS will focus on simple, robust signatures for early SUSY searches [2,3].
- The hadronic channel requires **at least two jets and MET** [4,5].
- W+jets, Z+jets and $t\bar{t}$ provide real MET and irreducible backgrounds.
- Of primary concern is the **QCD background** due to its large cross-section.
- QCD can be suppressed effectively by requiring a high energy scale and MET.
- However, its large cross-section and kinematics are not predicted with high precision.
- Presently, it is difficult to model reliably the extreme tails of QCD distributions.
- **Data-driven methods** are extremely important to control QCD and other backgrounds.

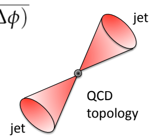
2) Controlling QCD using kinematic variables

- α_T characterises the overall transverse momentum balance of the event [4,5,6].
- Like MET, but dimensionless, α_T is a powerful, robust discriminator against QCD.
- EWK backgrounds must be suppressed and determined using other methods [7].

Di-jet case: $\alpha_T \equiv \dfrac{p_{T2}}{M_T}, \quad M_T = \sqrt{2p_{T1}p_{T2}(1-\cos\Delta\phi)}$

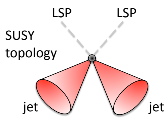
$$\alpha_T = \sqrt{p_{T2}/p_{T1}}\,/\,\sqrt{2(1-\cos\Delta\phi)}$$

For a perfectly measured jet system: $\alpha_T = 0.5$
Event with mis-measured jet(s): $\alpha_T < 0.5$



Extension to multi-jet (>2) case:

$$\alpha_T = \frac{1}{2}\frac{H_T - \Delta H_T}{\sqrt{H_T^2 - (MHT)^2}}$$



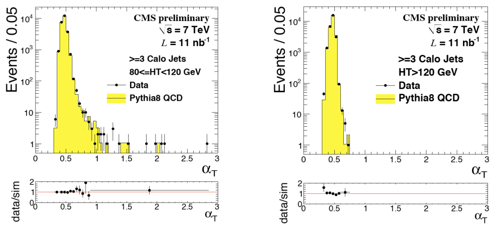
$H_T = \sum_{\text{jets } j} p_T^j, \quad MH_T = |-\sum_{\text{jets } j} p_T^j|$ [8], $\quad \Delta H_T = H_{T\,\text{pseudojet 1}} - H_{T\,\text{pseudojet 2}}$

- Collapse multi-jet system into a di-jet-like system comprising two *pseudo*-jets.
- Jet re-combination scheme minimises ΔH_T in order to maximise the signal yield.
- α_T for multi-jets exhibits comparable behaviour and performance to the di-jet case.

3) Commissioning with 7 TeV data

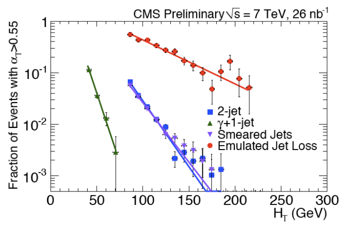
The QCD rejection power of α_T improves, as the edge at $\alpha_T = 0.5$ sharpens with increasing H_T.

- Jets just below the threshold, p_T^{thresh}, that are not considered can result in $\alpha_T > 0.5$.
- This perturbation decreases as the ratio p_T^{thresh}/H_T tends to zero.



α_T distributions from 7 TeV data and simulation, for an inclusive 3-jet sample and two different energy scales (H_T) [9].

It is crucial that the fraction of events with $\alpha_T > 0.55$, $f(\alpha_T > 0.55)$, is a monotonically decreasing function of H_T, so the low H_T region can be used to determine an upper bound on QCD contamination in the signal region.



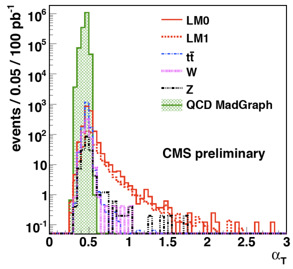
α_T is robust against jet mis-measurement.

$f(\alpha_T > 0.55)$ as a function of H_T for QCD di-jet, γ+jet and artificially degraded events (jet smearing and emulated jet loss) [9].

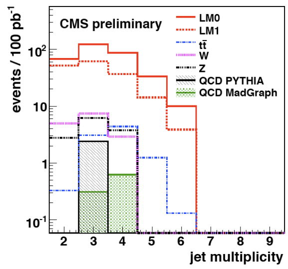
4) Analysis method and yields

Event selection:

- A jet- or MH_T-based trigger, followed by event cleaning to reject instrumental backgrounds.
- At least two high-p_T jets passing acceptance and quality criteria and a lepton/photon veto.
- A high H_T threshold (> 350 GeV), followed by the cut $\alpha_T > 0.55$. (Implicitly, $MH_T > 150$ GeV.)



α_T distributions using an inclusive 3-jet sample for two mSuGra benchmark points (LM0, LM1) and backgrounds, for 100 pb⁻¹ at √s = 10 TeV [5]. QCD is suppressed using the cut $\alpha_T > 0.55$.



Background composition in the various jet bins, for 100 pb⁻¹ at √s = 10 TeV, after all selection criteria are applied, including $\alpha_T > 0.55$ [5].

	LM0	LM1	Total bkgd	QCD bkgd
Exclusive di-jet	68 ± 3	52 ± 1	8.1 ± 1.6	0.0 + 1.0
Inclusive 3-jet	253 ± 6	116 ± 1	30.4 ± 2.6	0.9 ± 0.9

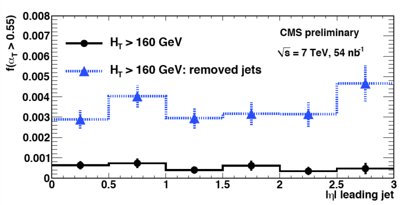
Expected yields for 100 pb⁻¹ at √s = 10 TeV for two benchmark points in the mSuGra parameter space [5].

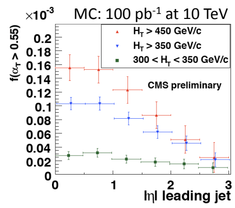
In order to reach the same sensitivity, running the machine at 7 TeV requires approximately three times more integrated luminosity compared to that in a 10 TeV run. This scaling factor is determined using parton luminosity ratios for $q\bar{q}$ and gg interactions [10].

5) A data-driven method to establish an excess

Jets from SUSY processes are expected to be more central than from QCD [11].

This feature can be used to establish an excess over Standard Model predictions.





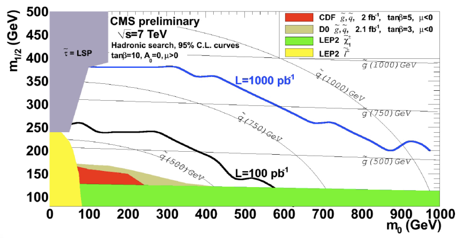
For QCD, $f(\alpha_T > 0.55)$ is **independent of the leading jet** $\boldsymbol{\eta}$ (used as a measure of the centrality of an event) **and** $\boldsymbol{H_T}$ (not shown). This behaviour in η holds even if a jet is artificially removed (to simulate inefficiencies) [9].

In the presence of SUSY, $f(\alpha_T > 0.55)$ exhibits a **negative slope** with increasing values of η, which also **steepens with increasing** $\boldsymbol{H_T}$ [5].

This method can also be used to estimate the QCD contamination in the signal region (low η) by extrapolating from a signal-depleted control sample at high η.

6) Physics reach for 100 pb⁻¹ and conclusions

These results indicate that in the 7 TeV run, the hadronic channel is expected to have sensitivity to regions of SUSY parameter space well beyond the current Tevatron limits with an integrated luminosity of 100 pb⁻¹ [10].



References and acknowledgements

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