Early SUSY analyses with ATLAS

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Early analyses at the LHC

The LHC will start producing high-energy collisions in the next months

Large uncertainties on the data-taking parameters:

- Energy (ies)
- Integrated luminosity
- Luminosity profile

However, with a baseline expectation of $\sqrt{s} = 7$ TeV and 200 pb^{-1} of integrated luminosity, we can expect to cover areas of new physics not explored by the Tevatron

Low mass SUSY is an example where we may be able to say something new

Combined performance and physics groups in ATLAS have developed a program of work aimed at taking advantage of this possibility

Explain today the path through which we plan to address SUSY searches based on the data we will collect in 2010

Before starting searches for new physics

With the first few pb^{-1} of data, the Collaboration will perform the basic work for understanding of detector performance.

Once the reconstruction of the basic building blocks for physics analysis:

Jets, electrons, muons, $\not{E}_T$, ...

under reasonable control the first physics analyses will start

Start with simple analyses of basic SM processes which can be based on a limited level of detector understanding, and in parallel continue the commissioning work

As detector understanding improves and statistics cumulates more sophisticated analyses will become possible

Aim at detailed measurements of Standard Model cross-sections and first searches when integrated lumi is of order 100 pb^{-1}

SUSY production at the LHC

Production dominated by strongly interacting sparticles: $\tilde{q}$, $\tilde{g}$

$\tilde{q}$ and $\tilde{g}$ production cross-section $\sim$only function of their masses, $\sim$independent of details of SUSY model

Show LO Cross-sections for two ATLAS benchmark points (fHERWIG) and NLO (MC@NLO) for top

$\sqrt{s}$ (TeV)	σ_{SUSY} (pb) SU3	σ_{SUSY} (pb) SU4	σ_{tt} (pb)
7	1.9	36	148
10	6.5	103	374
14	18.9	264	827
$m_{\tilde{g}}$ (GeV)	717	413	172.5
$m_{\tilde{q}}$ (GeV)	620	410	

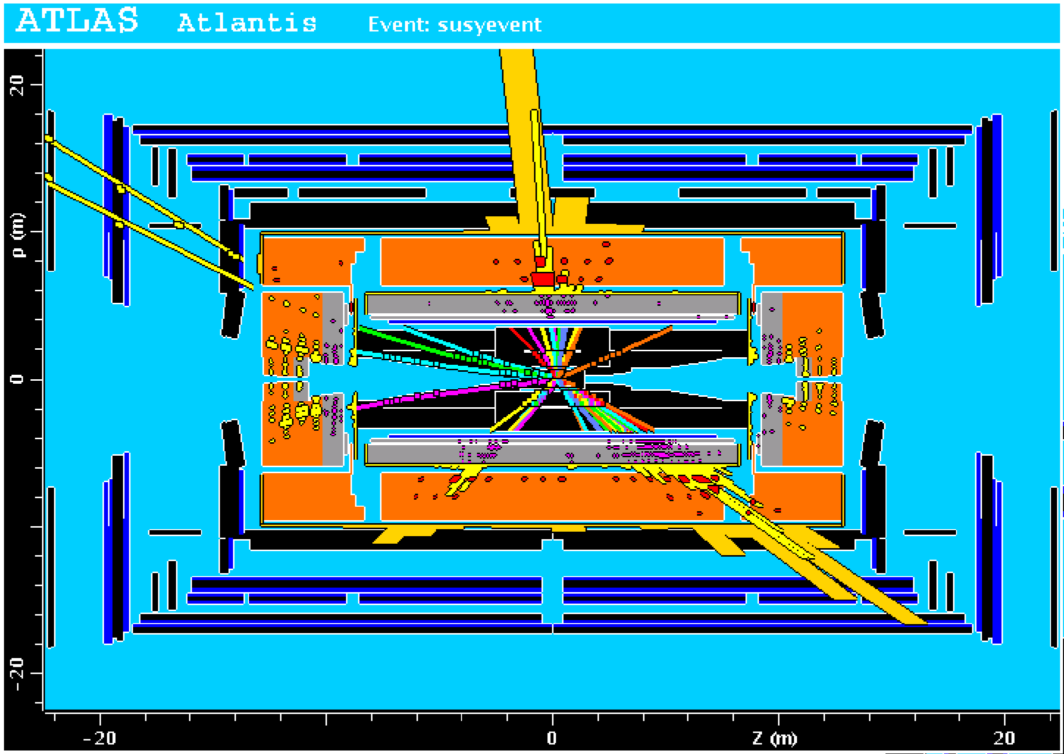
SU3: $m_0 = 100\,\text{GeV}$, $m_{1/2} = 300\,\text{GeV}$, $A_0 = -300\,\text{GeV}$, $\tan\beta = 6$, $\mu > 0$.

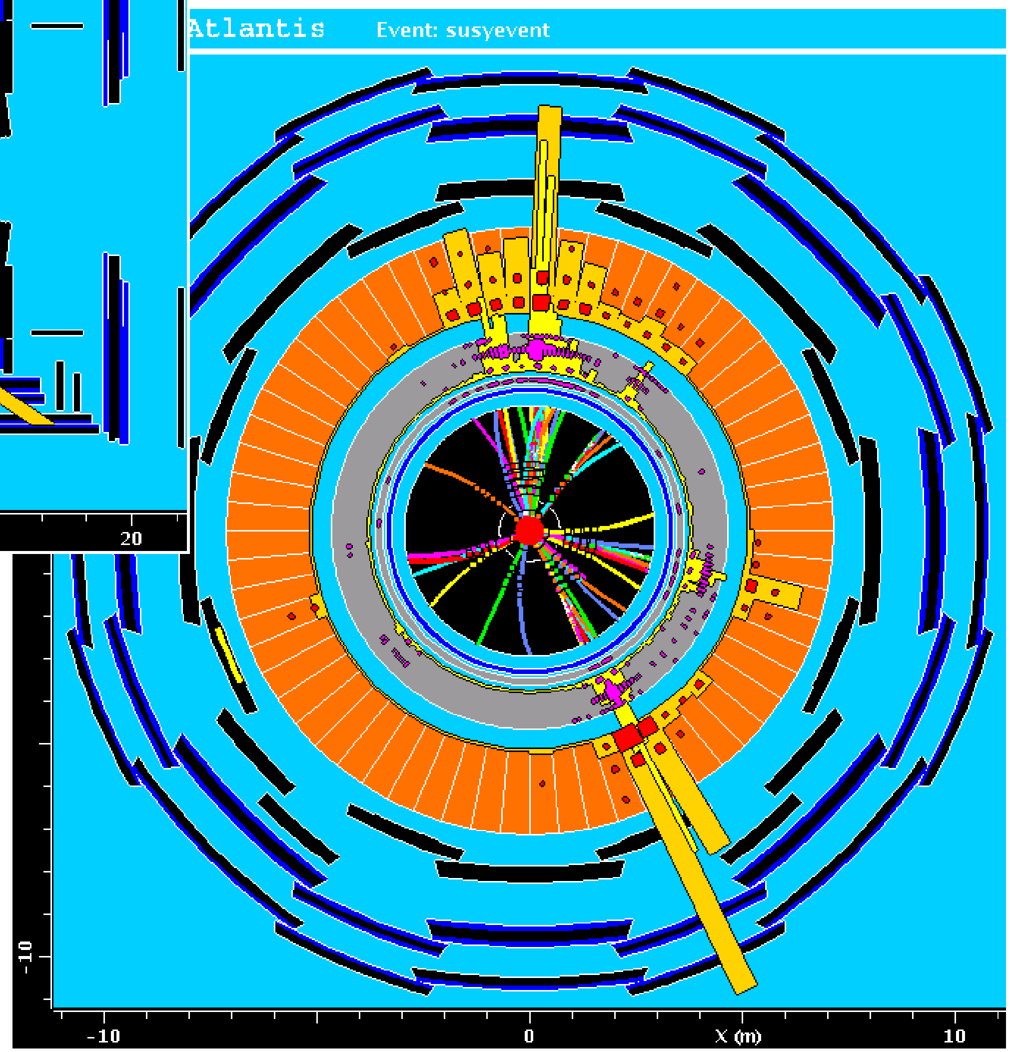
SU4: $m_0 = 200\,\text{GeV}$, $m_{1/2} = 160\,\text{GeV}$, $A_0 = -400\,\text{GeV}$, $\tan\beta = 10$, $\mu > 0$.

Squarks and gluinos are typically the heaviest sparticles

$\Rightarrow$ If R_p conserved, complex cascades to undetected LSP, with large multiplicities of jets and leptons produced in the decay.

A SUSY event in ATLAS





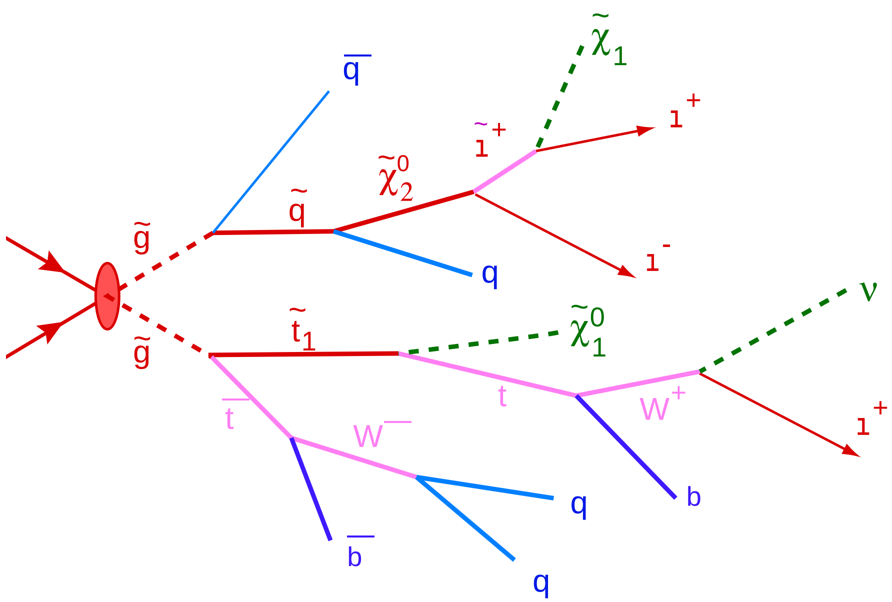
Multi-jet event in Bulk Region

- 6 jets
- 2 high-pt muons
- Large missing E_T

SUSY discovery: basic strategy

Basic assumption: discovery from squark/gluinos cascading to undetectable LSP

Details of cascade decays are a function of model parameters. Focus on robust signatures covering large classes of models and large rejection of SM backgrounds



- $\not\!\!E_T$: from LSP escaping detection
- High E_T jets: guaranteed if squarks/gluinos if unification of gaugino masses assumed.
- Multiple leptons (Z): from decays of Charginos/neutralinos in cascade
- Multiple τ-jets or b-jets (h): Often abundant production of third generation sparticles

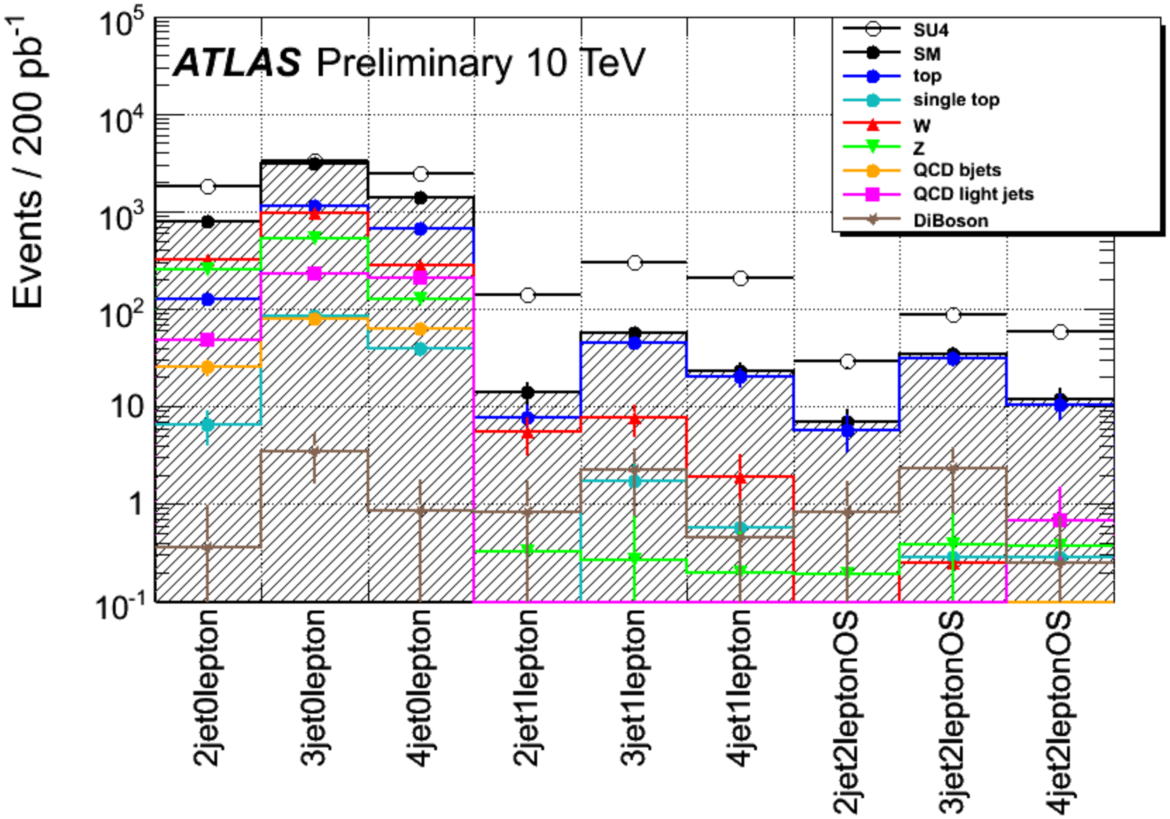
Define basic selection criteria on these variables for RPC SUSY with $\tilde{\chi}_1^0$ LSP

Optimisation of criteria on parameter space: define set of topologies, and for each define sets of cuts aimed respectively at high and low SUSY masses

Basic analysis cuts

For $\sqrt{s} = 10$ TeV and on 200 pb^{-1} define on low-mass point basic analysis cuts:

Perform analyses requiring 2, 3 or 4 jets ans 0, 1 or 2 leptons in the event



- P_T cuts on jets and leptons depending on topology
- $\not{E}_T > 80$ GeV
- Cut on $\Delta\phi(jet_i, \not{E}_T)$
- Cut on ratio between $\not{E}_T$ and $M_{\text{effective}} \equiv \Sigma_{i=1}^{4} p_T^{\text{jet},i} + \Sigma_{i=1} p_T^{\text{lep},i} + \not{E}_T$
- Transverse sphericity $S_T > 0.2$

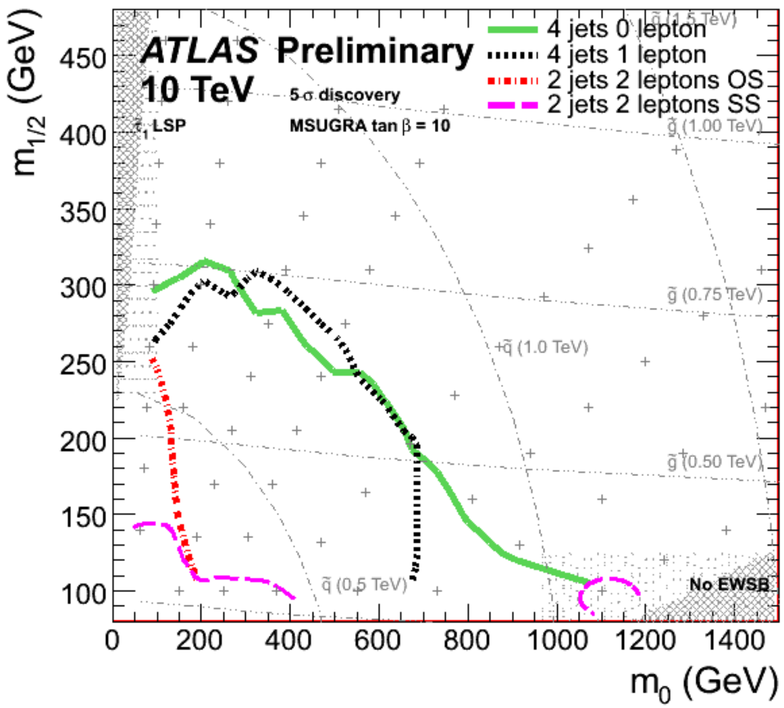
SUSY signal: SU4 point: $m_{\tilde{q}} \sim m_{\tilde{g}} \sim$ 410 GeV (ATL-PHYS-PUB-2009-084)

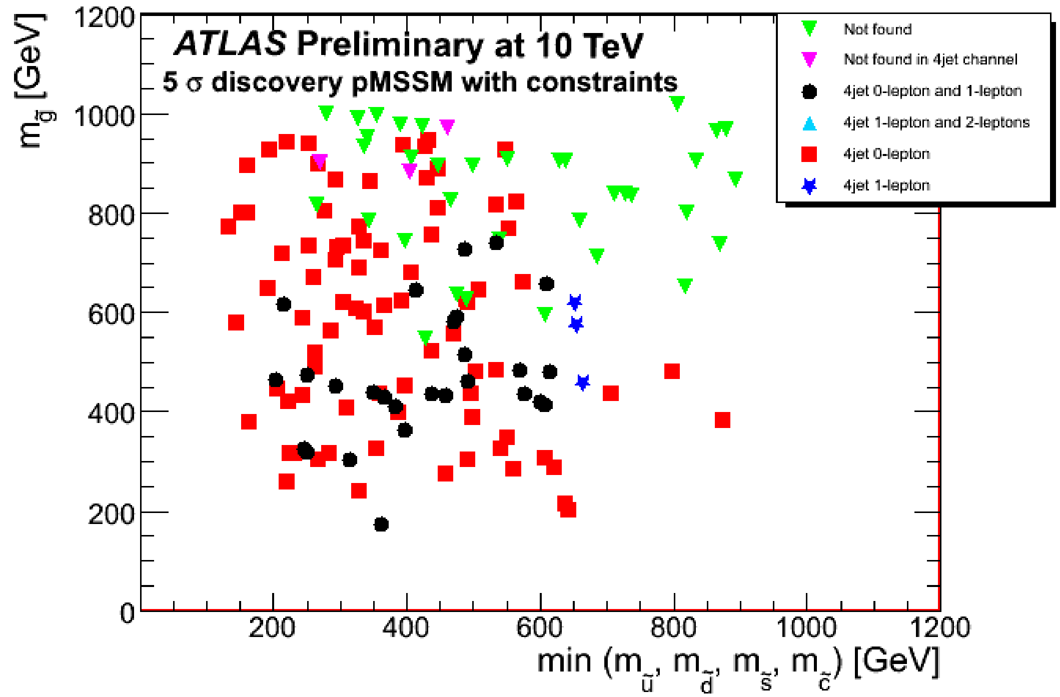
Observe good S/B background in most of the studied channels

In paramters space further optimise statistical significance through additional cut on $M_{\text{effective}}$

Reach in parameter space (200 pb^{-1}, 10 TeV)

Grid in MSUGRA space, and set of 'no prejudice' MSSM points(Tom Rizzo et al.)



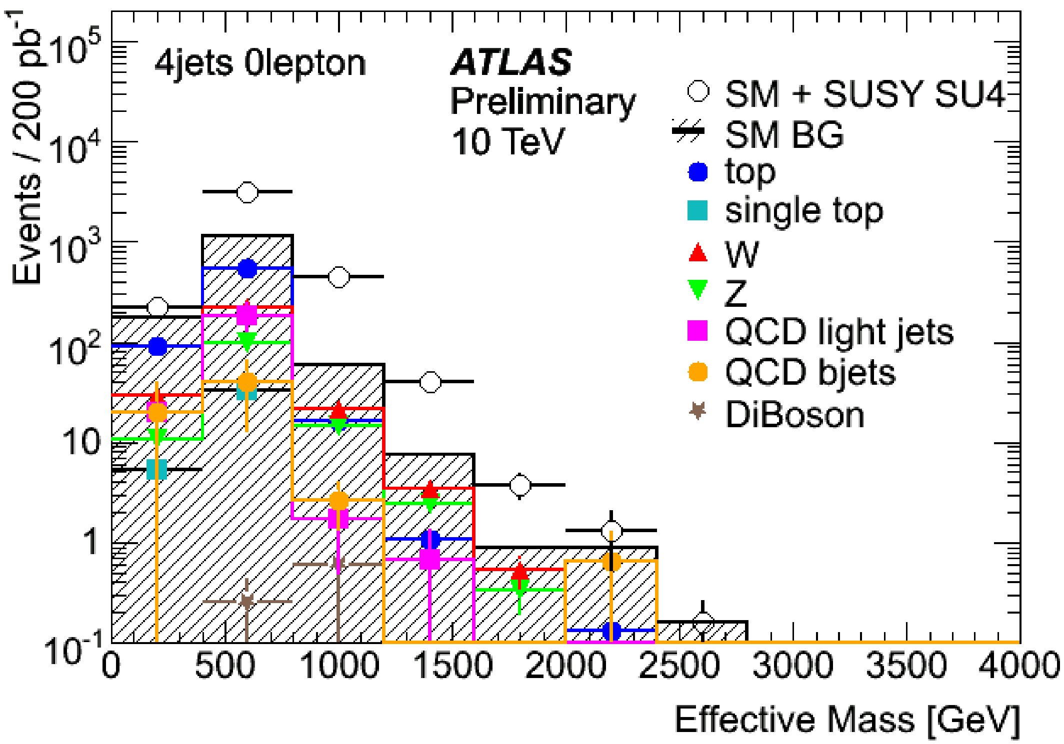


Reach strongly dependent on assumed value of systematic uncertainty on background evaluation

Assume for this study 50% uncertainty on all backgrounds

Techniques for assessing backgrounds and evaluating uncertainties are the key to SUSY analysis $\Rightarrow$ Discuss examples today

0 lepton + jets analysis



Large statistical significance, but many backgrounds to keep under control

- QCD
- top
- W+Jets
- Z+Jets

QCD background particularly insidious as:

- Multijet QCD cross-section not well known
- $\not{E}_T$ from difficult-to-model instrumental effects

Look in detail at $\not{E}_T$ measurement ATLAS and data-driven estimate of QCD backgrounds

Etmiss and SUSY

Etmiss is experimentally difficult variable, as it requires summing over all the detector

Any inhomogeneity in the detector performance/calibration reflects onto it

Need first of all understand measurement of the gaussian 'core' of the Etmiss distribution from fluctuations in detector response

Next all the possible sources of high $\not{E}_T$ events need to be understood and accounted for:

- Detector malfunctioning (dead cells, noisy cells...)
- Beam Halo
- Cosmic rays
- Events where particles end up in insensitive parts of the detectors
- ....

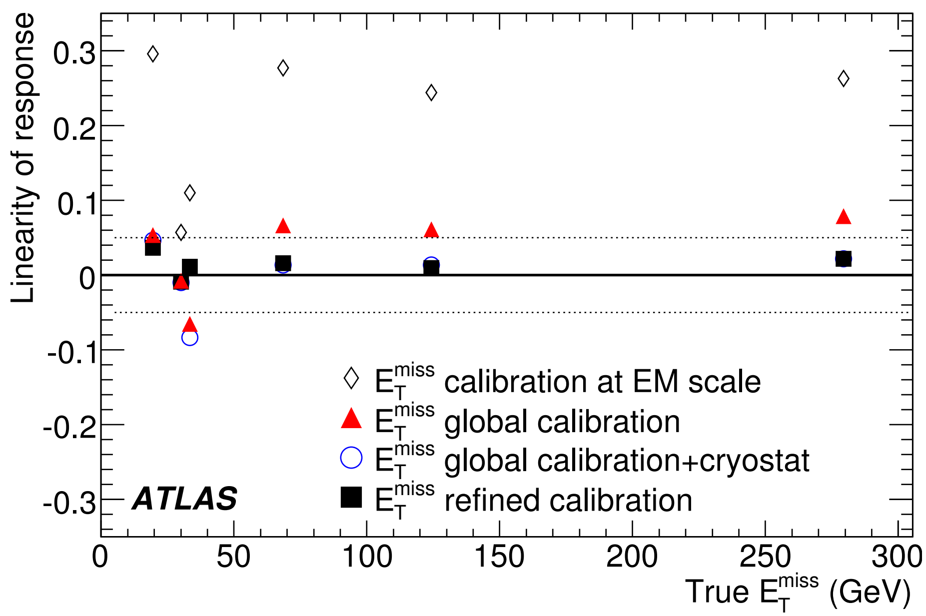
Performance of $\not{E}_T$ experimental measurement

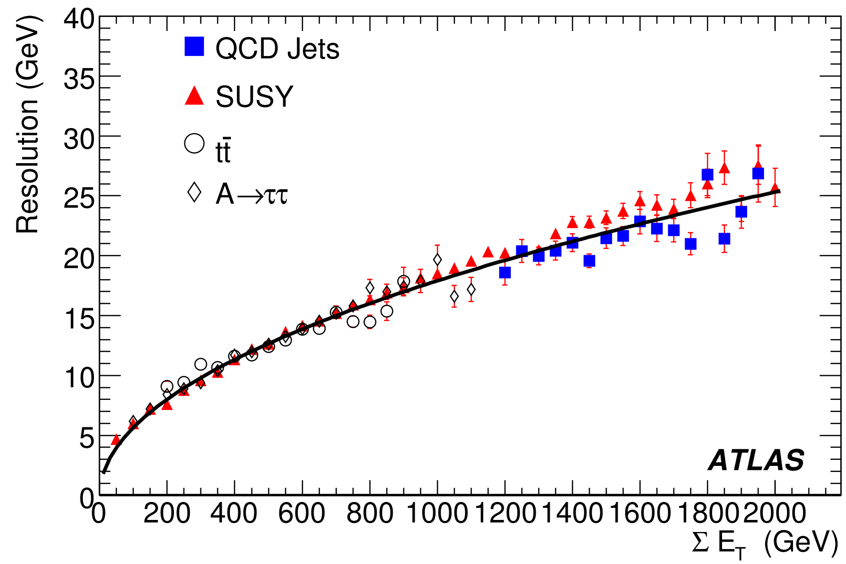
$\not{E}_T$ measurement based on assumption that all the energy is measured in the calorimeters or seen as muons in the spectrometers

Multi-step procedure correcting for experimental effects, starting from vector sum of E_T deposition in calorimeter cells

Measurement resolution estimated on MC by plotting the difference between true and estimated $\not{E}_T$ separately on each of the components

Resolution can be fitted as $0.57 \cdot \sqrt{\sum E_T}$



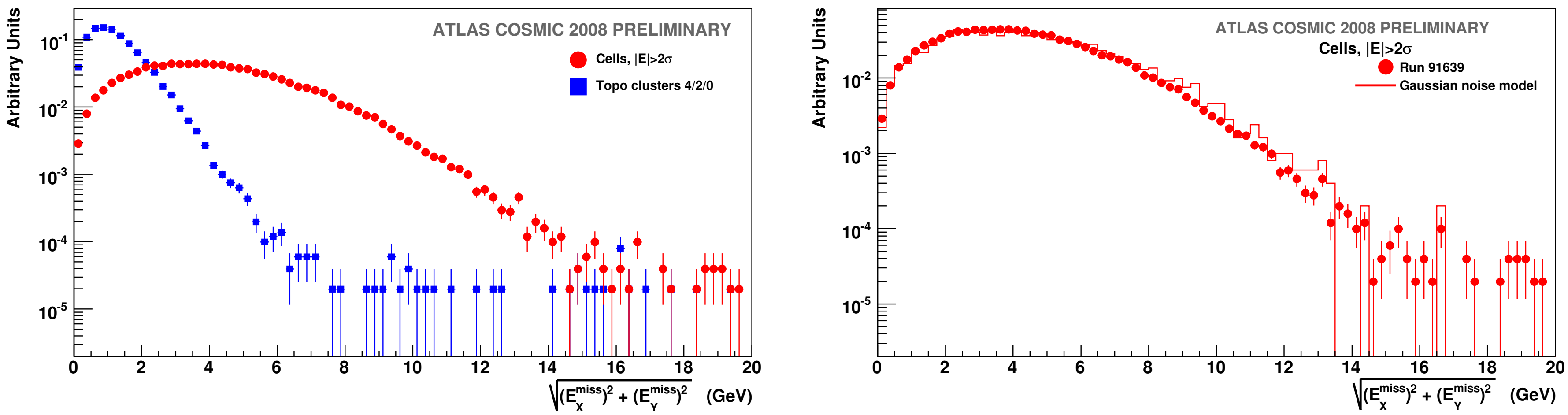


Etmiss commissioning with random events

Basic check: look at random triggers, and plot $\not{E}_T$ distribution

Use two different algorithms for cell noise subtraction: simple cut at 2σ, 3-D energy clusters (topoclusters)

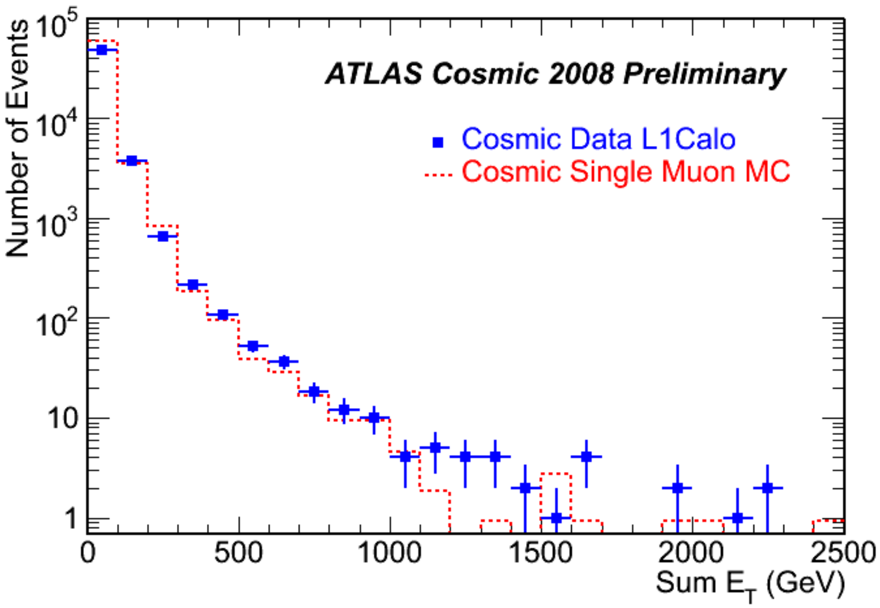
Much narrower distribution for topoclusters

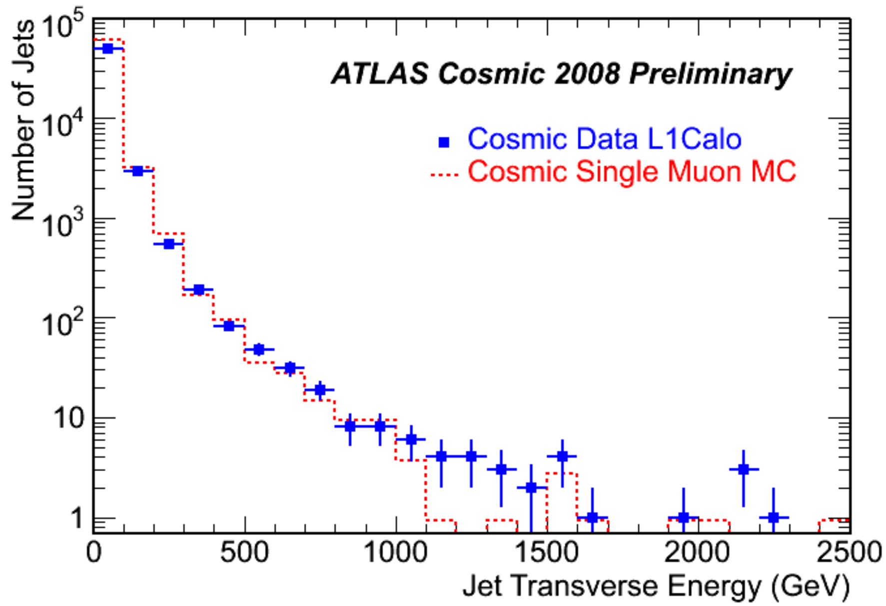


Observe excellent agreement between measured $\not{E}_T$ and simple gaussian model of noise in calo cells (tail now understood as detector mafunctioning)

Good stability observed over 1.5 months period

Fake Etmiss: cosmic rays



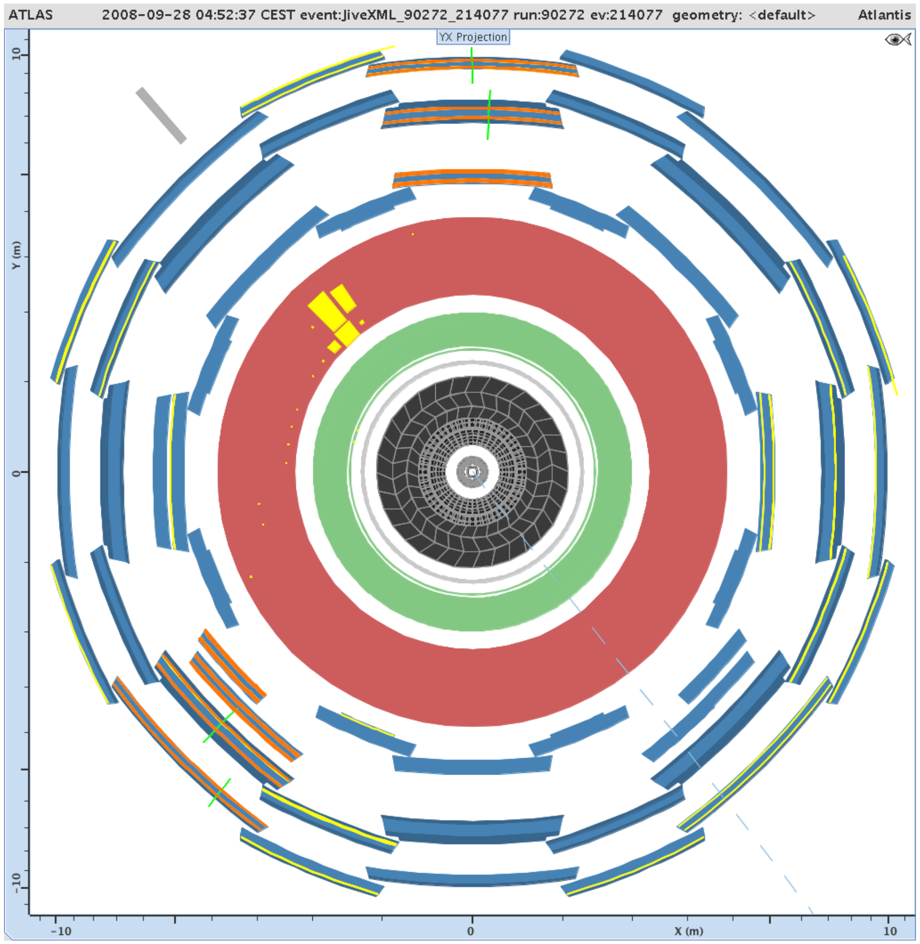


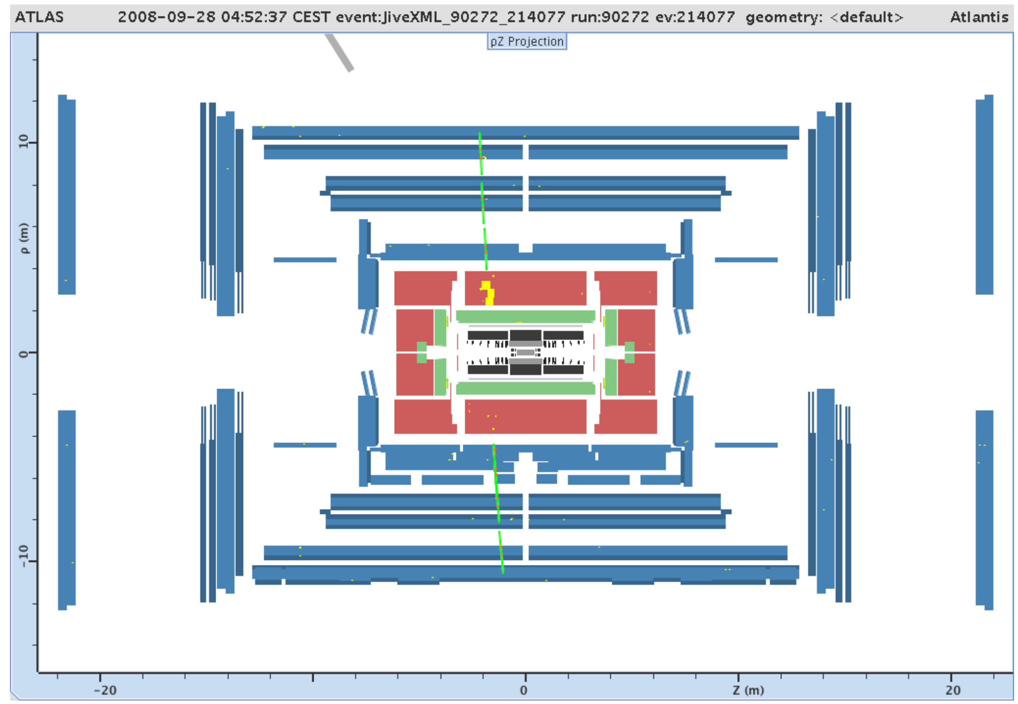
High energy cosmic ray muons undergoing hard bremsstrahlung can produce localised high-energy dposit in calorimeter, and thence fake $\not{E}_T$

Observe good agreement with detailed simulation

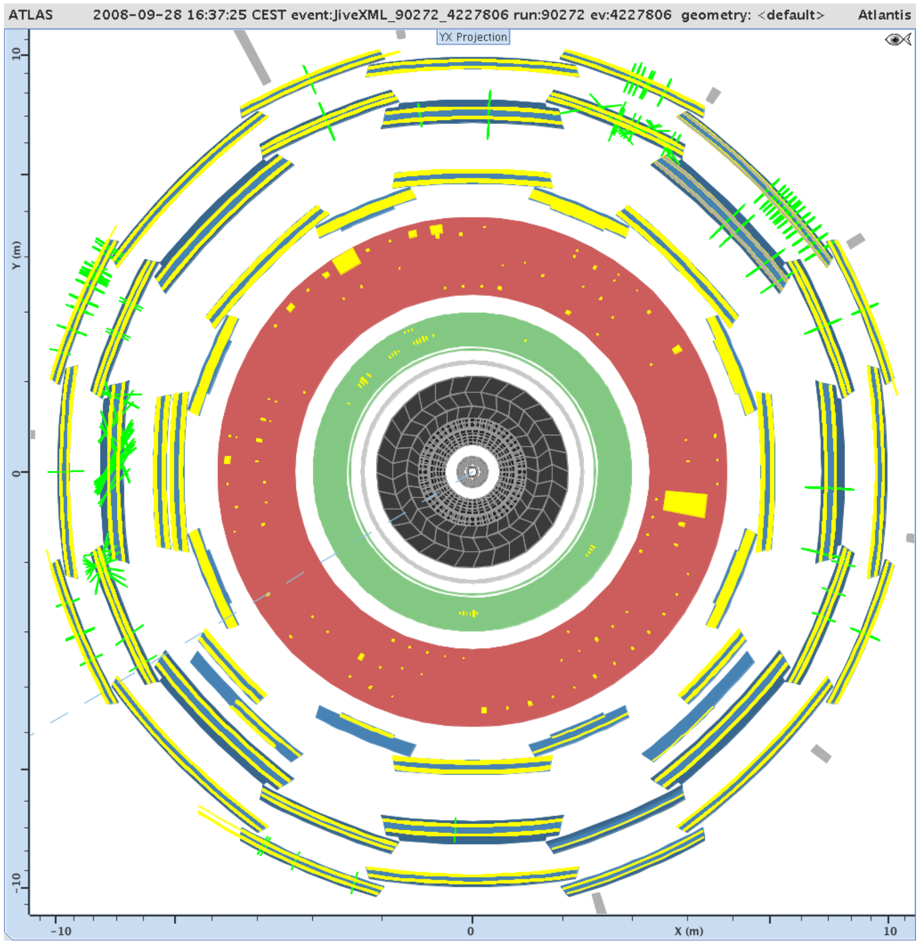
Discrepancy in tails due to MC statistics and from cosmic ray air showers not modelled in MC

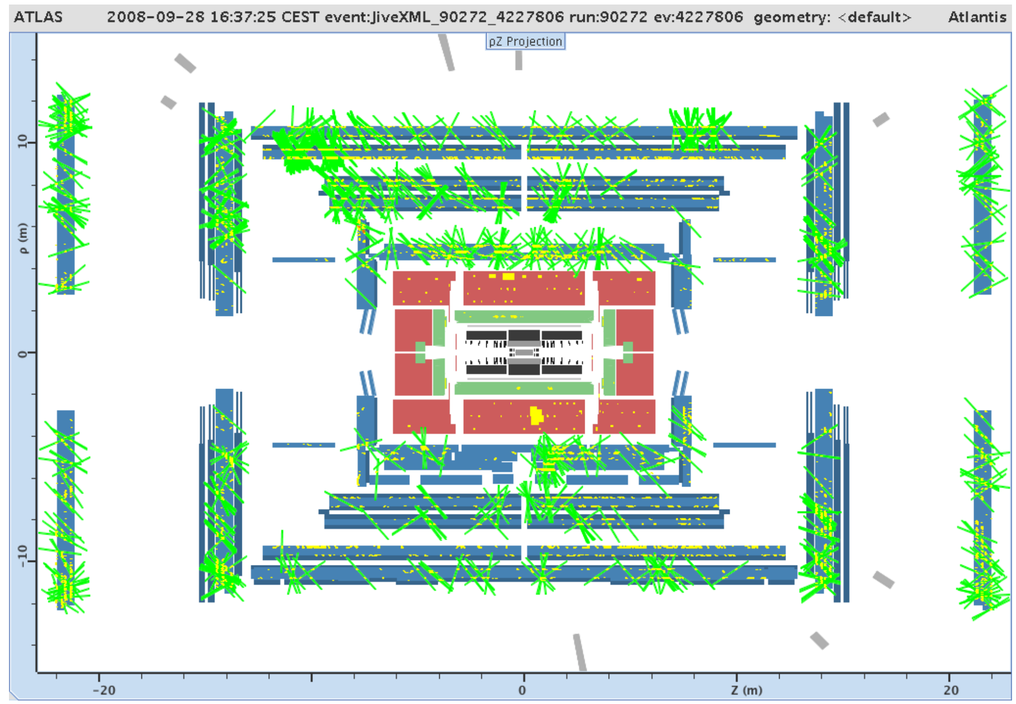
TeV event from single cosmic ray muon



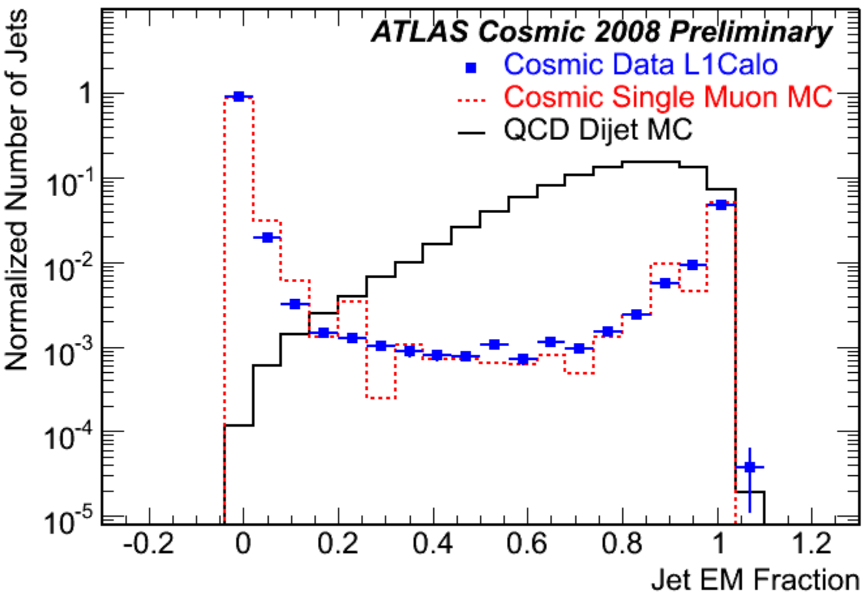


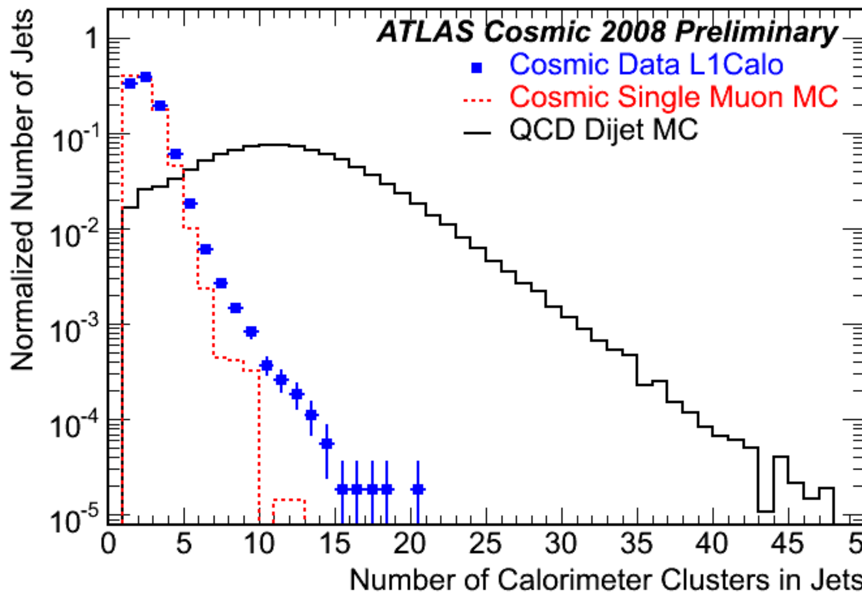
TeV event from cosmic ray air shower





Cleaning cuts for cosmic rays



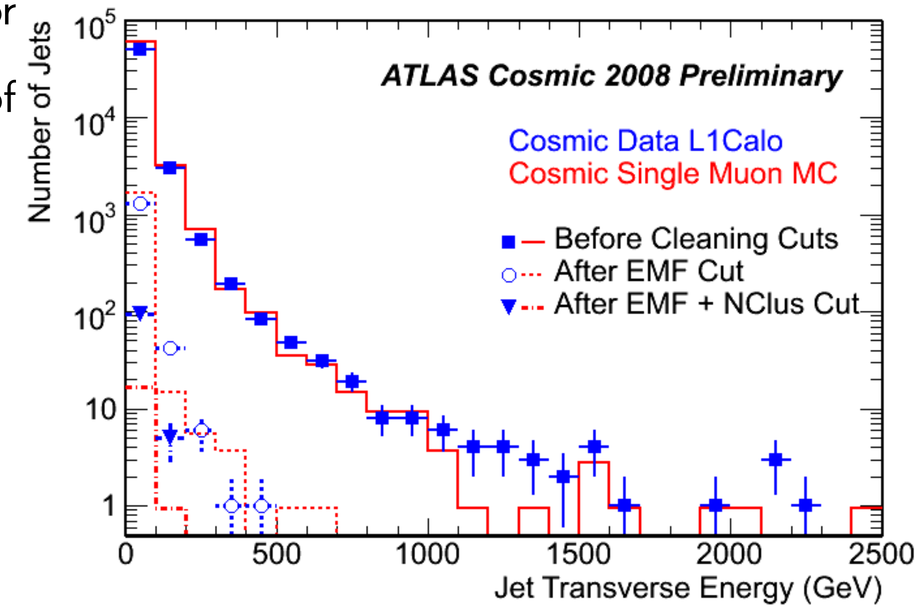


Jet EM fraction (F_{EM}) : Typically 0 or 1 for muons undergoing bremsstrahlung in Tilecal of LARG

Number of clusters (N_{clus}) : lower for cosmics

Resulting rejection after requiring:

- $0.2 < F_{EM} < 0.97$
- $N_{clus} \geq 7$



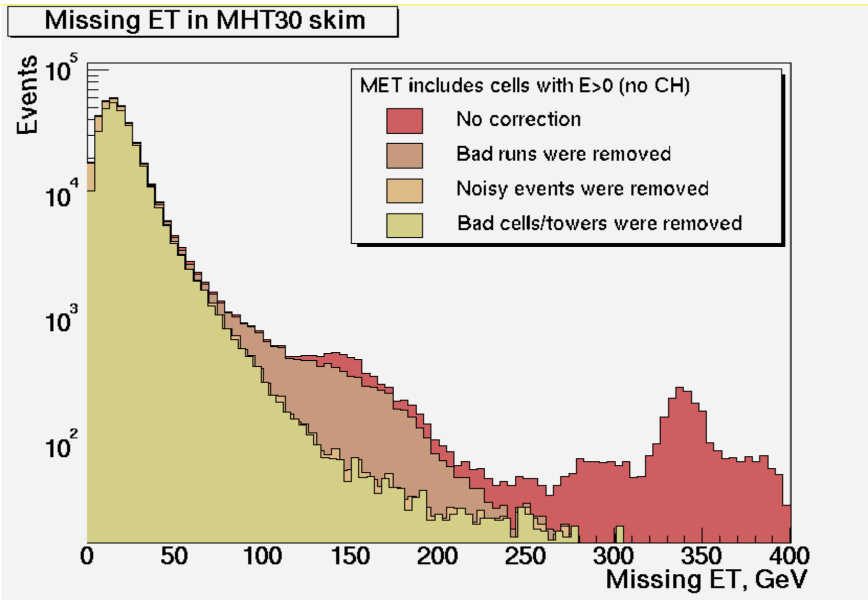
Cleaning of detector malfunctions in $\not\!\!E_T$ sample

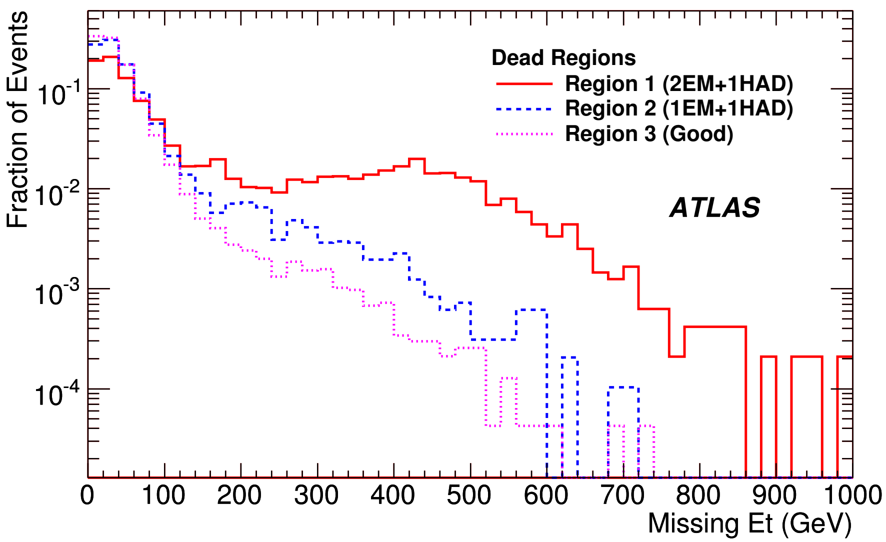
$\not\!\!E_T$ from mismeasured multi-jet events:

Populated by detector and machine problems

Example of $\not\!\!E_T$ cleaning in D0

- Reject runs with detector malfunctioning
- Reject events with noise in the detector
- Remove bad cells





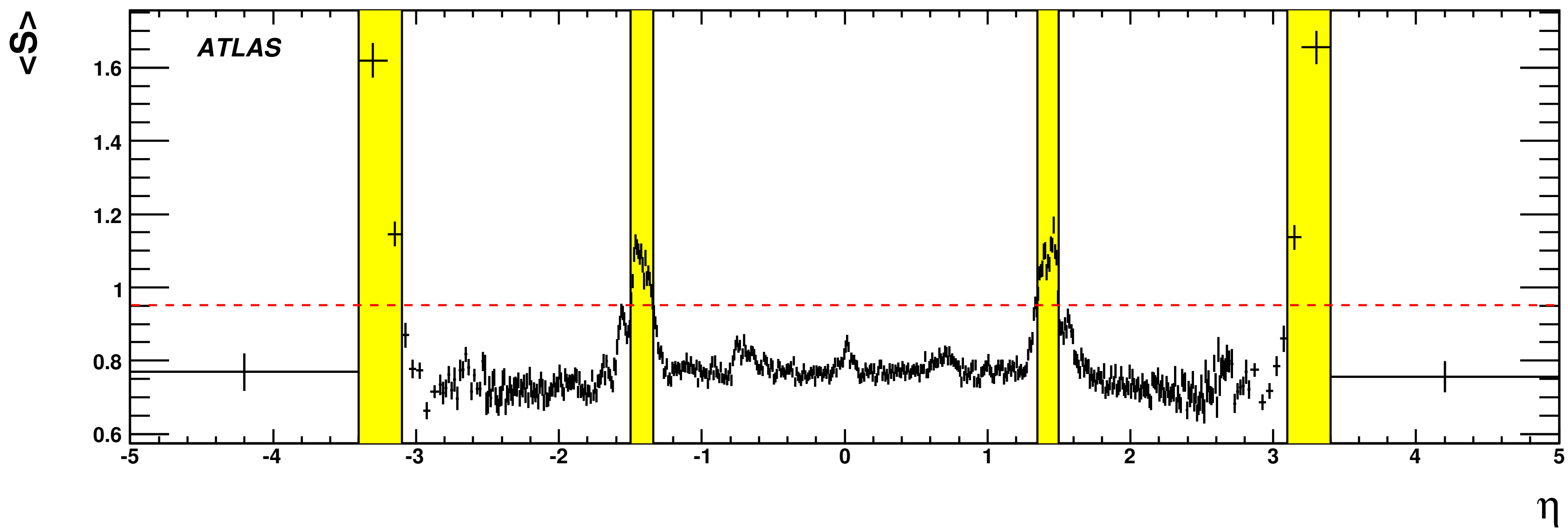
ATLAS example: assume a few HV channels dead in calorimeters

Tools being prepared to monitor and correct event-by-event, very active area of work

Instrumental background: definition of fiducial region for jets

Use a sample of 2-jet events ($p_T > 280$ GeV), apply basic cuts to reject events containing neutrinos

- For each event calculate $S = \not\!\!E_T/\sqrt{\Sigma\, E_T}$, $\propto \not\!\!E_T$ significance
- For each jet in the event, take $\eta(jet)$, and fill one entry in the plot
- For each bin in η calculate the average value of S



Observe rise in significance for events with jets at interface between calorimeters

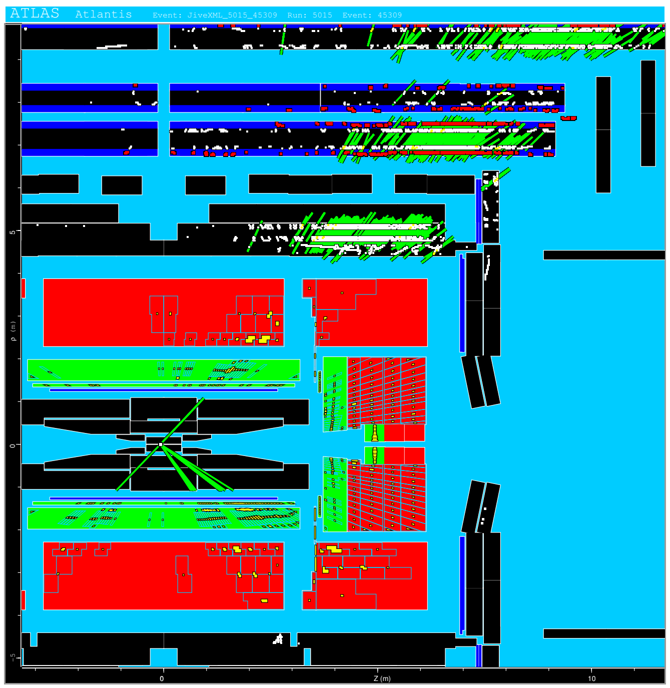
Reject high $\not\!\!E_T$ events with a jet falling in yellow regions

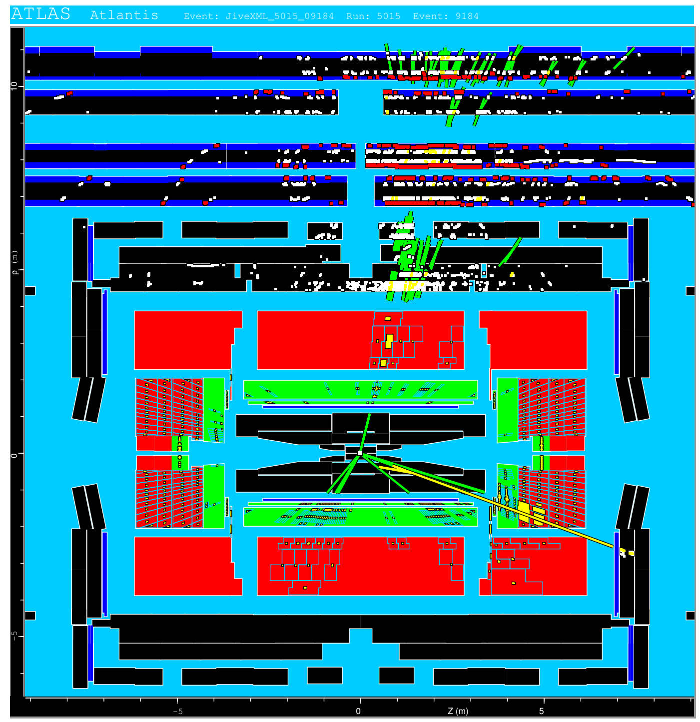
Instrumental background: beyond fiducial cuts

Scan fully simulated jet events in ATLAS ($P_T(jet) \gtrsim 500$ GeV) with

$\Delta \not{E}_T > 250$ GeV (F. Paige, S. Willocq)

$\not{E}_T$ from: Jet leakage from cracks, Fake muons from cracks, Jet punch-through





Problematic events characterised by large occupancy in muon chambers.

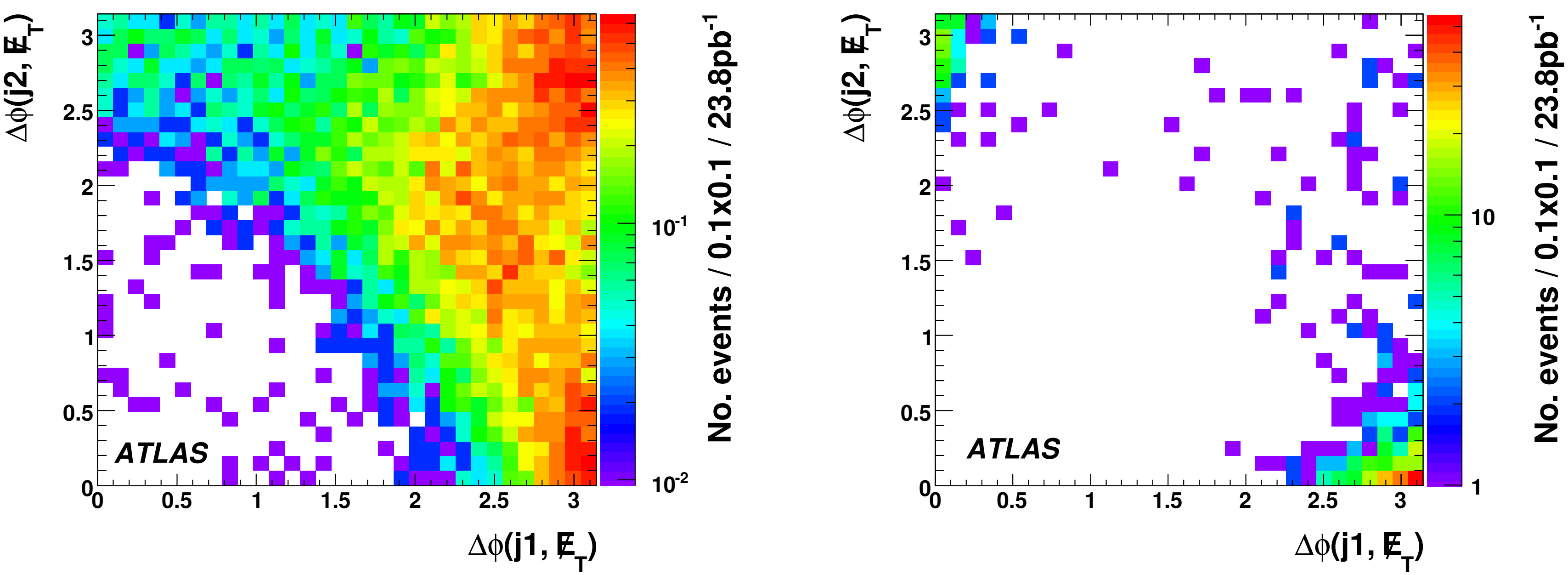
Can develop criteria based on the muon chambers to further reduce tails

Instrumental background: Rejecting specific topologies

Next step is rejection of topologies which likely to yield instrumental $\not{E}_T$

One jet is undermeasured, expect that $\not{E}_T$ be aligned with its p_T. If two-jet events, this will be measured as the second jet in the event

If one jet overmeasured jet energy measurement: $\not{E}_T$ back to back with respect to it



$|\phi^{jet2} - \phi^{\not{E}_T}|$ vs. $|\phi^{jet1} - \phi^{\not{E}_T}|$ Left plot: Signal Right plot: QCD

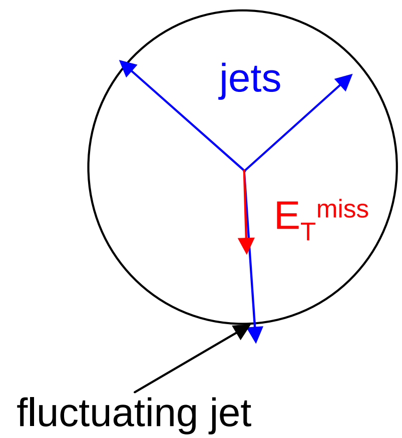
At this point, we are entering the domain of analysis-dependent cuts

Instrumental backgrounds: data-driven estimate

MonteCarlo estimate of QCD background hard. It requires:

- Good MonteCarlo simulation of QCD multijets
- Excellent understanding of detector incorporated in simulation
- $\not{E}_T$ is from tails of response: need to simulate huge number of events

$\Rightarrow$ Develop multi-step data-driven estimate



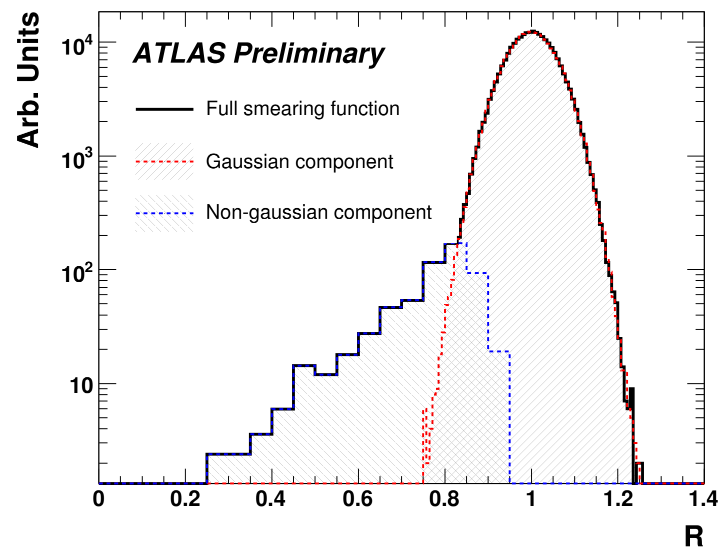
Step 1: Measure the gaussian part of response with balance of γ+jet events

Step 2: Measure the non-gaussian part of response and combine it with the gaussian part

- Require: 3 jets, $p_T(J) > 250, 50, 25$ GeV, $\not{E}_T > 60$ GeV
- One and only one jet parallel to the $\not{E}_T$ vector
- Define the true $P_T(J)$ as: $\vec{p}_T(J, \text{true}) \simeq \vec{p}_T(J) + \vec{\not{E}}_T$

Plot:

$$R_2 = \frac{\vec{p}_T(J) \cdot \vec{p}_T(J, \text{true})}{|\vec{p}_T(J, \text{true})|^2}$$



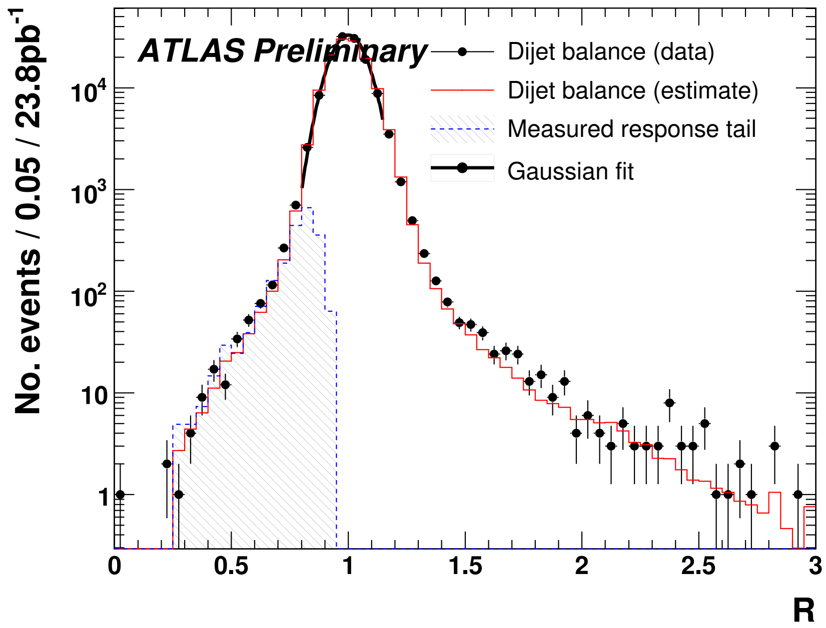
Finally normalize the two estimates from the balance of a sample of 2-jet events

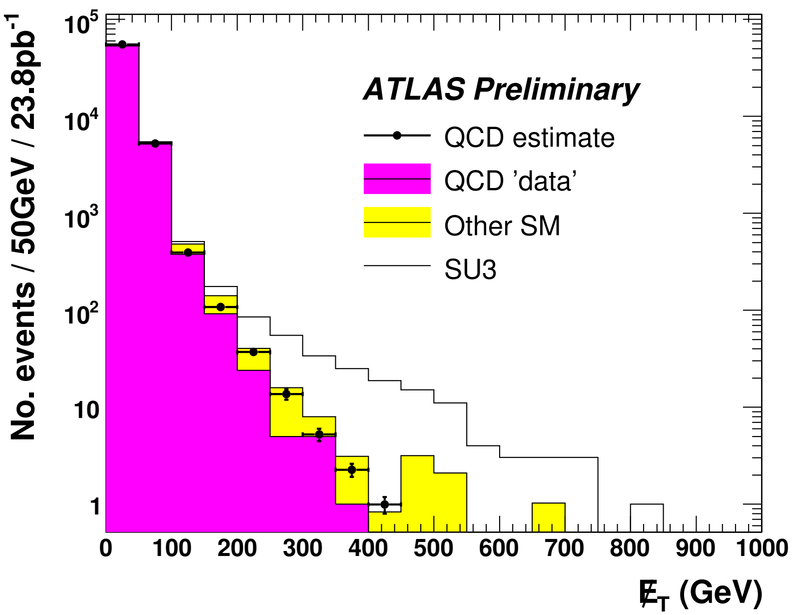
Closure test: compare estimated response curve with 'data' from balance of a sample of two-jet events. Plot for each jet:

$$R_3(j) = 1 + \frac{\vec{\not{E}}_T \cdot \vec{p}_T(j')}{|\vec{p}_T(j')|^2}$$

Step 3: Seed event selection and jet p_T smearing:

Smear according to measured function jet P_T in multi-jet events with low $\not{E}_T$ (‘seed events’)



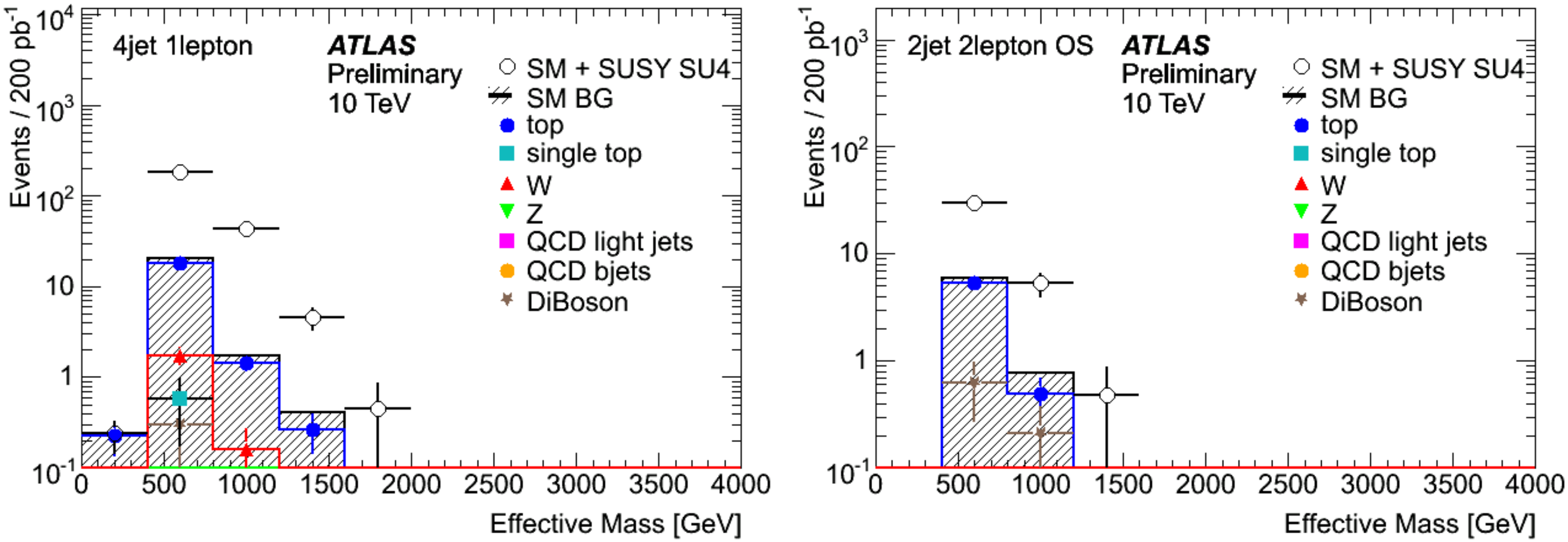


Plot the $\not{E}_T$ distribution for the smeared ‘seed’events is plotted, normalised to simulated QCD events with $\not{E}_T < 50$ GeV

Good agreement between the estimated and ‘data’ distributions

Dominant systematic errors are the P_T bias in event selection and the statistical error on ‘Mercedes’ events.

Backgrounds from processes with real neutrino



Background from: top, $W/Z+$jets important for zero-lepton channels

Once an additional leptons is requested, backgrounds with real neutrinos dominant

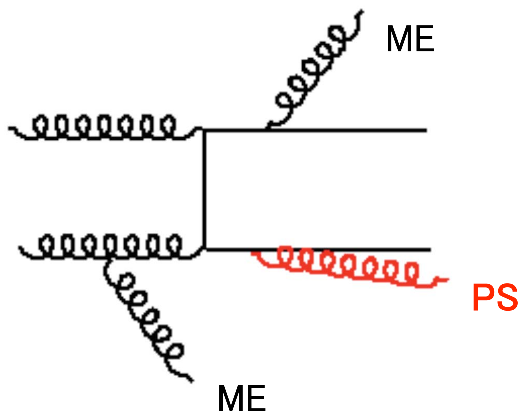
Easier to control than QCD, some kinematic handles available, but still complex work requiring combination of MC and data

SM backgrounds: Monte Carlo issues

SUSY processes: high multiplicity of final state jets from cascade decays

Require additional jets multiplicity to reject EWK backgrounds

Additional jets in $\bar{t}t, W, Z,$ production from QCD radiation



Two possible way of generating additional jets:

- Parton showering (PS): good in collinear region, but underestimates emission of high-p_T jets
- Matrix Element (ME): requires cuts at generation to regularize collinear and infrared divergences

Optimal description of events with both ME and PS switched on

Need prescription to avoid double counting

Detailed comparison with data on IVB's with jets necessary to validate MC

Additional issue: absolute normalisation essentially unknown from MC: need data

Data driven background estimates

Predict amount of SM events in kinematic region where signal expected (signal region) based on understanding of SM in region where SM dominant (control region)

Many variations on idea. Main methods explored are:

- Substitution methods: identify in data decay products of SM, and replace them with new particles making it look like signal
- Multi-variable methods: identify more than one discriminant variable, and predict BG shape based on playing one variable against the other

Rely on identifying pure samples of BG, either through reversal of analysis cuts or through explicit kinematic reconstruction of BG topology ($Z \to \ell\ell$, 'topbox')

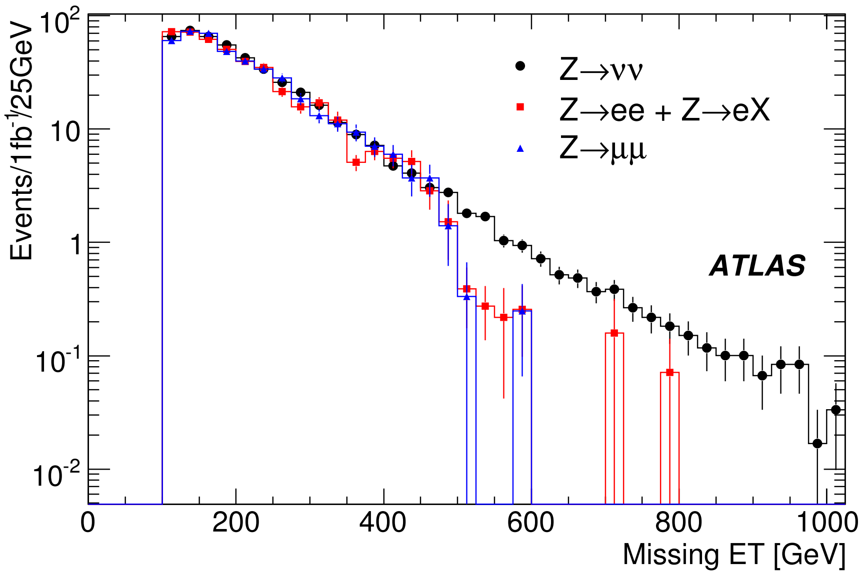
In all cases mix of MC and data, in different proportions:

- With cleaner control samples, need less MC, but high statistical error on data
- If control sample increased through looser selection, additional systematic from increased use of MC
- Can use data for both shape and normalisation or only for normalisation

Data driven estimates: $Z \to \nu\nu +$ jets

Select samples of $Z \to \mu\mu(ee, eX)$+multijets from data

Apply same cuts as for SUSY analysis (4 jets+Etmiss), remove leptons and calculate $\not{p}_T$ of events from the vector sum of their momenta (normalized to 1 fb^{-1})



Number of $N_{Z\to\nu\nu}$ per $\not{E}_T$ bin calculated from $N_{Z\to\ell\ell}$ applying corrections for:

- Fiducial for leptons (P_T and η cuts)
- Kinematic cuts to select pure Z sample
- Lepton id efficiency
- $BR(Z \to \nu\nu)/BR(Z \to \ell\ell)$

First two from MC, last one from data

Low statistics at high $\not{E}_T$, improve precision through fit of the shape

Main uncertainties from:

• MC used for corrections ($\sim 6\%$) • $\not{E}_T$ scale ($\sim 5\%$) • Statistics of control sample ($\sim 13\%$)

Method under study using shapes from MC and normalisation from data.

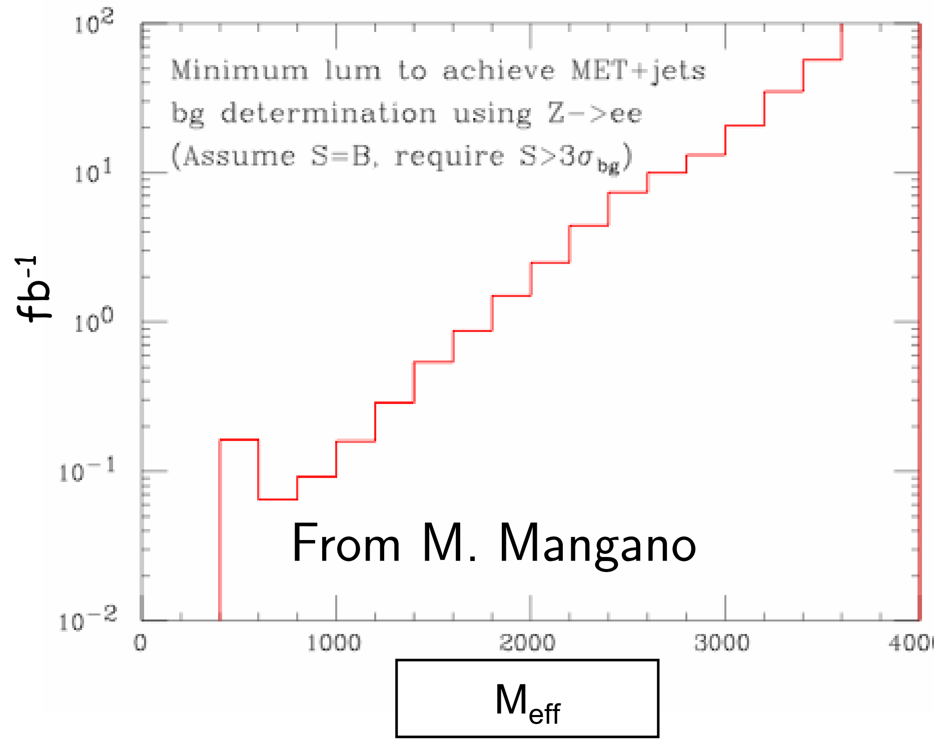
Normalisation needs to be multiplied by $BR(Z \to \nu\nu)/BR(Z \to ee) \sim 6$

Assuming SUSY signal $\sim Z \to \nu\nu$ bg, evaluate luminosity necessary for having $N_{SUSY} > 3 \times \sigma_{bg}$

Stat error on background:

$$\sigma_{bg} = \sqrt{N(Z \to ee)} \times \frac{BR(Z \to \nu\nu)}{BR(Z \to ee)}$$

For each bin where normalisation required, need ~ 10 reconstructed $Z \to \ell\ell$ events. Need to consider acceptance/efficiency factors as well



Several hundred pb^{-1} required. Sufficient if we believe in shape, and only need normalisation. Much more needed to perform bin-by-bin normalisation

Method based on multiple discriminant variables

Basic Principle:

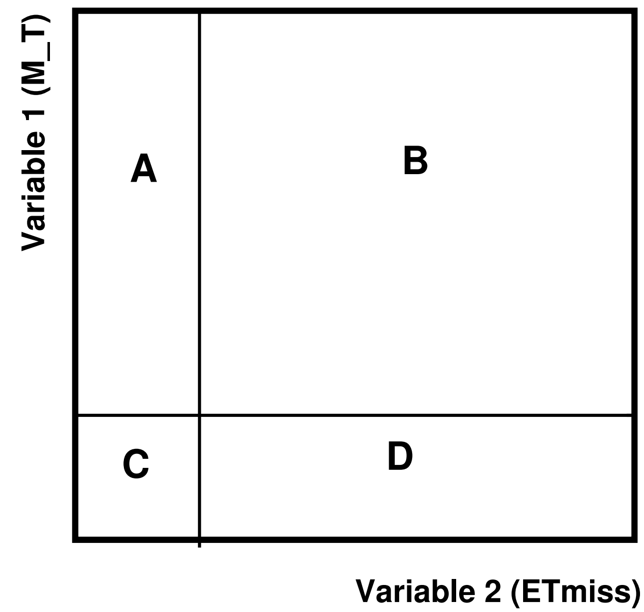
B is *signal region*, ∼no signal in A,C,D

D is *control region*

Estimate of N(B), $N(\tilde{B})$ is calculated as:

$$N(\tilde{B}) = N(D) \times \frac{N(A)}{N(C)}$$

Where $N(X)$ is BG in region X



Some conditions required in order for the algorithm to work:

- The two variables must be independent:

  Shape of variable 1 must be the same in (A+C) and (B+D)

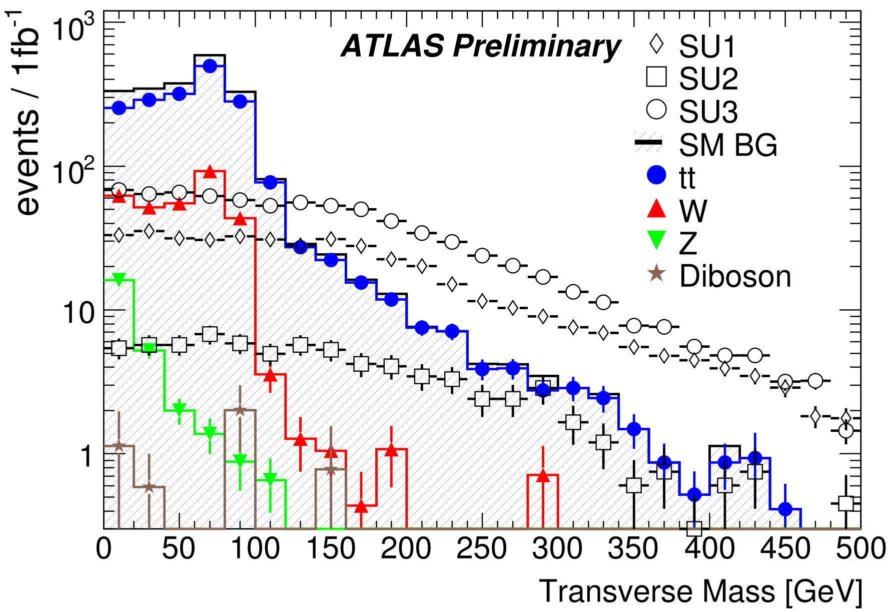
  Shape of variable 2 must be the same in (A+B) and (C+D)

- The contribution of signal in the control regions must be negligible

Conditions only approximately satisfied in most analysis

For low mass SUSY very difficult to find region not contaminated by signal

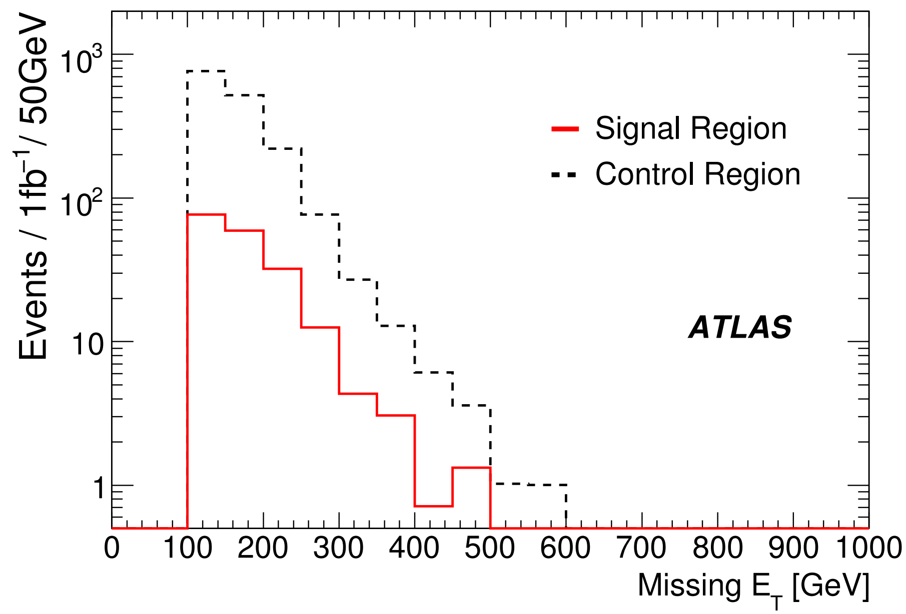
One lepton background evaluation with M_T method



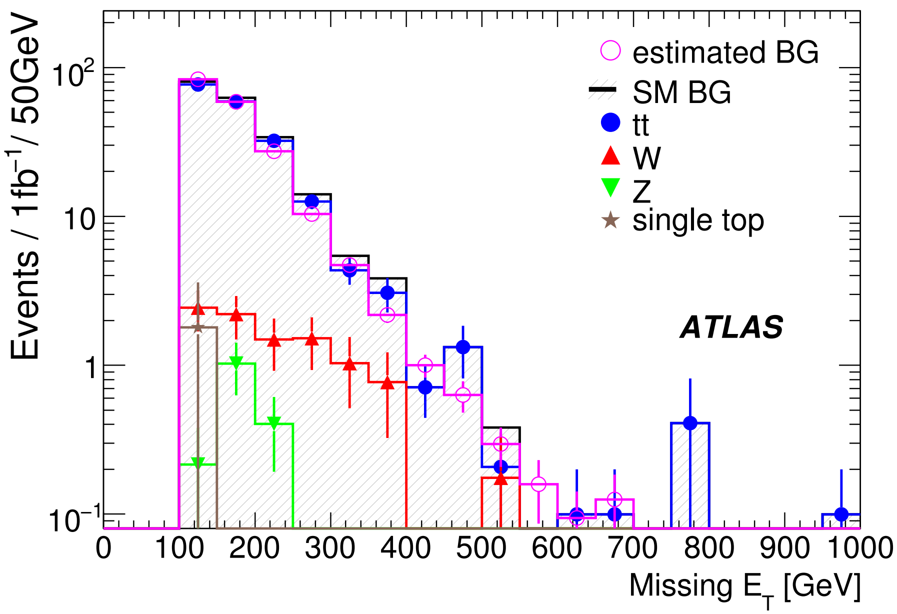
M_T: transverse mass calculated on lepton and $\not{E}_T$: excellent discrimination against $\bar{t}t$, $W+$ jets

Apply method on the $(M_T - \not{E}_T)$ plane

$\not{E}_T$ distributions in signal and control region approximately consistent



M_T method: results without signal

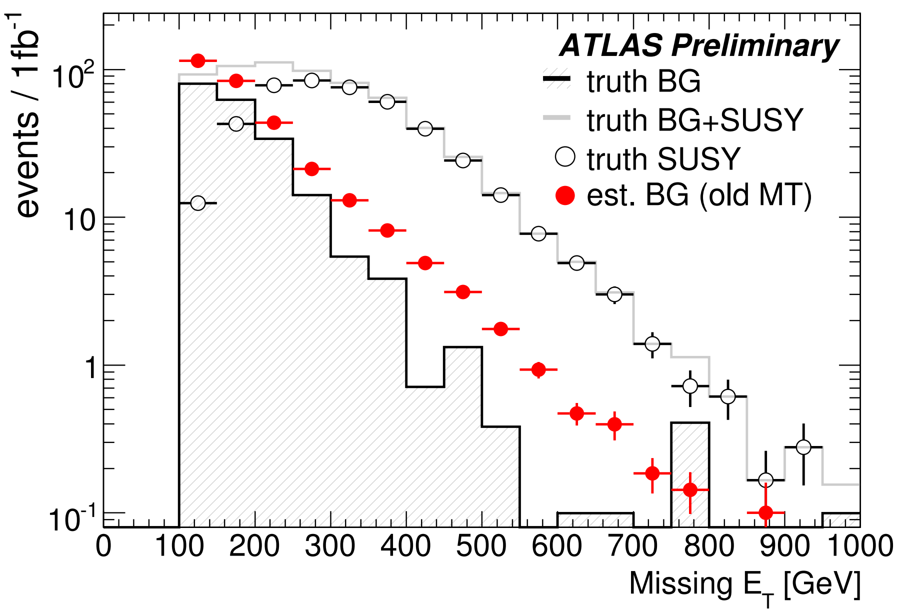


In absence of signal, $\not{E}_T$ distribution in signal region well reproduced by method

Estimated background in absence of signal:

	$\not{E}_T > 100$ GeV	$\not{E}_T > 300$ GeV
True BG	203 ± 6	12.4 ± 1.6
Estimated BG	190 ± 8	9.4 ± 0.7
Ratio(Est./True)	0.93 ± 0.05	0.76 ± 0.11

What if there is signal?



Example: assume SU3 signal.

	$\not\!\!E_T > 100$ GeV	$\not\!\!E_T > 300$ GeV
True BG	203 ± 6	12.4 ± 1.6
Estimated BG	296 ± 10	33.3 ± 1.4
True BG+SUSY	653 ± 8	245 ± 4

Clear overestimate of background, dependent on amount of signal

Work in progress to master the issue of signal contamination, two directions of exploration:

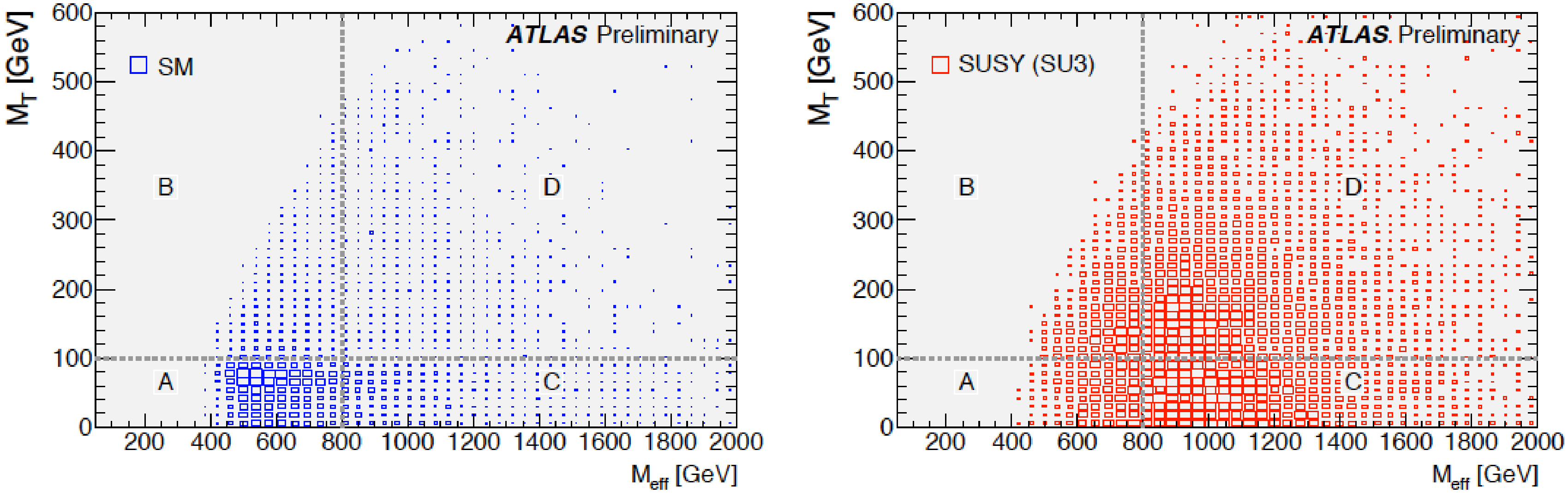
- Iteration procedure: if excess observed, use properties of excess to correct for estimate.

  Example in M_T method: assume that all events observed in signal region are from signal, and with some ansatz on signal shape, extrapolate back in control region

- Combined fit determining the composition of control sample allowing for SUSY contribution: see next slides for an example

Very active field of investigation

The tile method (2×2)



$$N_A = f_A^{SM} N^{SM} \; + \; f_A^S N^S \qquad N_B = f_B^{SM} N^{SM} \; + \; f_B^S N^S$$

$$N_C = f_C^{SM} N^{SM} \; + \; f_C^S N^S \qquad N_D = f_D^{SM} N^{SM} \; + \; f_D^S N^S$$

The four quantities f_A^{SM}, f_B^{SM}, f_C^{SM}, f_D^{SM} are calculated with MC

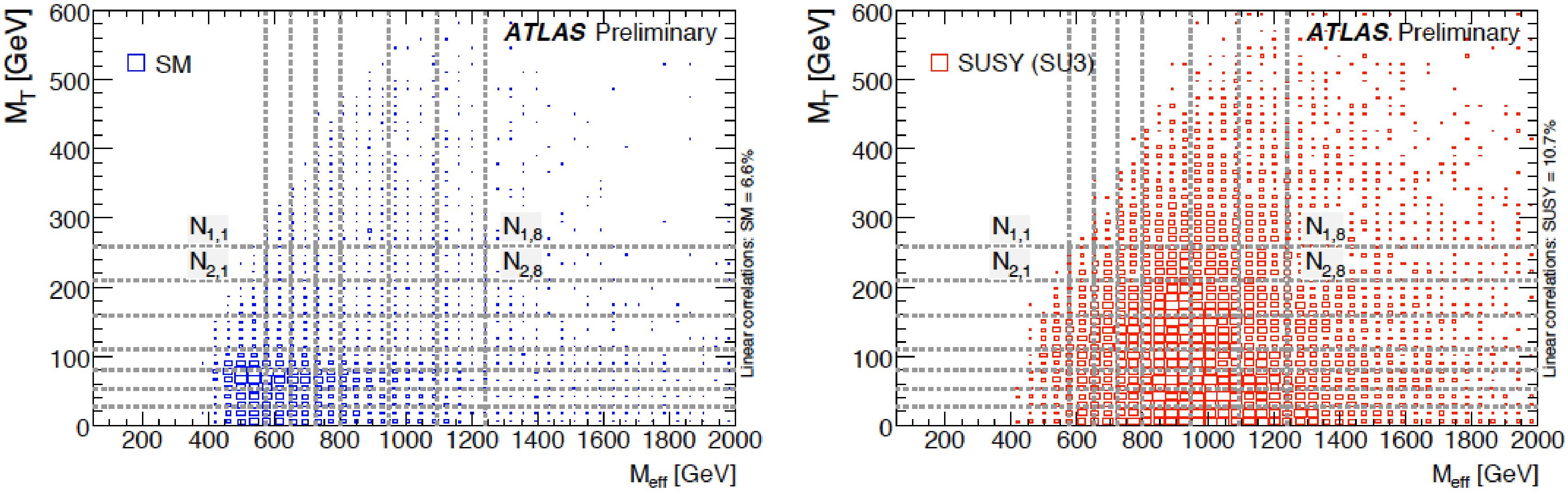
If one assumes independence of $M_{\text{effective}}$ and M_T, f_A^S, f_B^S, f_B^S, f_B^S can be expressed as a function of $f_{M_{\text{effective}}}^S$ and $f_{M_T}^S$ $\Rightarrow$ One is left with a system of 4 equations and four unknowns

No assumption on shape or normalisation of signal

Dependence of the method on the MC for the shapes of the SM backgrounds

Documented in ATL-PHYS-PUB-2009-077

The tile method $(n \times n)$



The method can be extended to $(n \times n)$ tiles

System is now overdetermined: solve it with a likelihood fit

Extension has advantages and drawbacks:

- Information content of the fit improved
- It probes the signal shape in the 2-d space
- May use goodness-of-fit to understand how good BG model
- Increased sensitivity to correct MC description of Standard Model

2-leptons + $\not{E}_T$ + jets inclusive search

Significantly lower reach than other channels, but also lower backgrounds

Different topologies, corresponding to different SM background sources

- Same-Sign Same-flavour (SSSF)
- Same-sign Opposite-Flavour (SSOF)

Gluino Majorana particle, in gluino decay same probability for positive and negative lepton

Very little SM background, dominated by $\bar{t}t$, very sensitive to lepton isolation

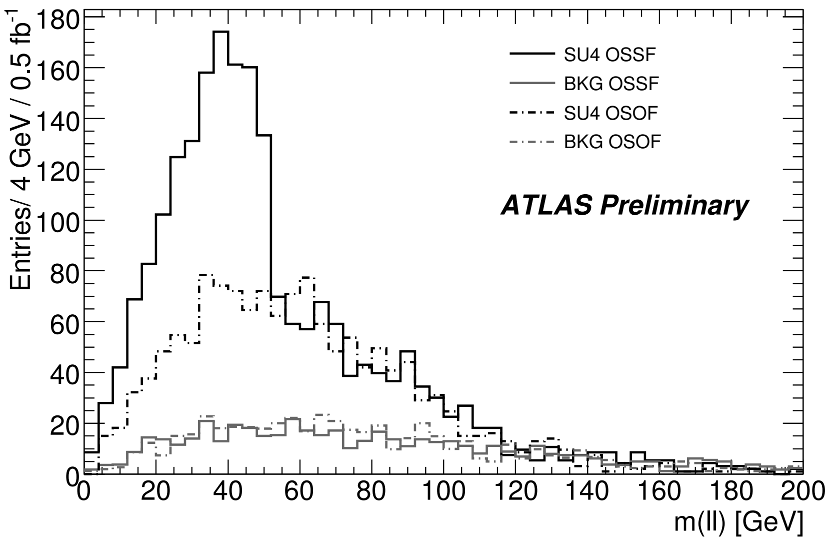
- Opposite-Sign Same-Flavour (OSSF)
- Opposite-Sign Opposite-Flavour (OSOF)

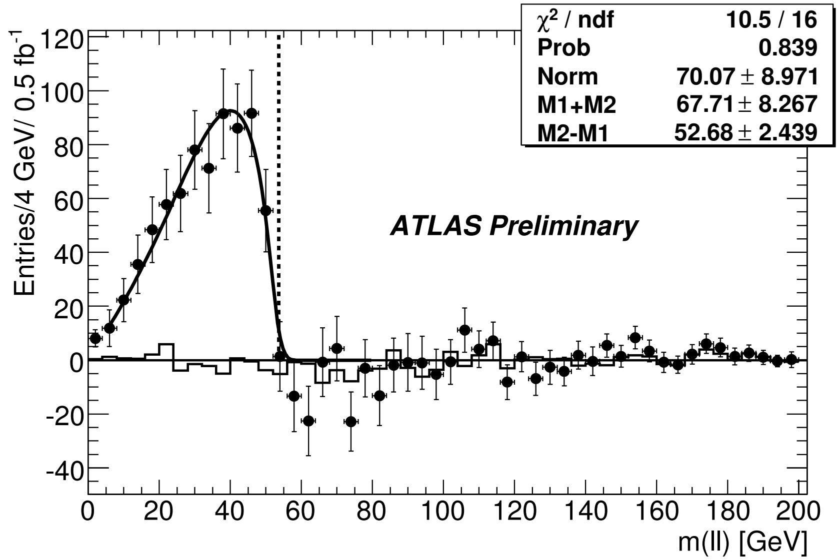
In OS-SF pair two leptons may come from decay of same gaugino $\Rightarrow$

OS-SF invariant mass distribution may exhibit structure, not present in OS-OF pairs

$$\begin{array}{llll}
\tilde{q}_L \longrightarrow & \tilde{\chi}^0_2 & q & \\
 & \hookrightarrow & \tilde{\ell}^{\pm}_{R(L)} & \ell^{\mp} \\
 & & \hookrightarrow & \tilde{\chi}^0_1 \quad \ell^{\pm}
\end{array}
\qquad
\begin{array}{llll}
\tilde{q}_L \longrightarrow & \tilde{\chi}^0_2 & q & \\
 & \hookrightarrow & (Z^*) & \tilde{\chi}^0_1 \\
 & & \hookrightarrow & \ell^+ \quad \ell^-
\end{array}
\qquad
\begin{array}{llll}
\tilde{q}_L \longrightarrow & \tilde{\chi}^+_2 & q' & \\
 & \hookrightarrow & \tilde{\nu}_\ell & \ell^{\pm} \\
 & & \hookrightarrow & \tilde{\chi}^{\pm}_1 \quad \ell^{\mp}
\end{array}$$

Flavour subtraction method





For $\bar{t}t$ and SUSY backgrounds same number of $e^+\mu-$, μ^+e^-, e^+e^-, $\mu^+\mu^-$ pairs

Only $Z/\gamma \to e^+e^-, \mu^+\mu^-$ has same-flavour leptons, strongly reduced by $\not{E}_T$+jets requirement

Fully subtract backgrounds by plotting for each $m(\ell\ell)$ bin: $N(e^+e^-)/\beta + \beta N(\mu^+\mu^-) - N(e^\pm\mu^\mp)$

With $\beta \sim 0.86$ ratio of electron and muon reconstruction efficiencies

Bulk of background uncertainty included in statistical error of subtracted distribution:

$S \equiv (N(OSSF) - N(OSOF))/\sqrt{N(OSSF) - N(OSOF)}$

Main additional systematic comes from uncertainty on β, order 10% with 1 fb^{-1}

For the appropriate parameter values, this might be the fastest discovery channel

Conclusions

Already with the 2010 data we have a chance to explore low mass SUSY production

In ATLAS vigorous program to prepare ourselves to SUSY searches, based on:

- Development of a search strategy based on simple inclusive topologies
- Understanding of detector performance for the reconstruction of the physics objects contributing to these topologies
- Check our understanding through the measurement of key SM processes
- Development of data-driven background estimate methods

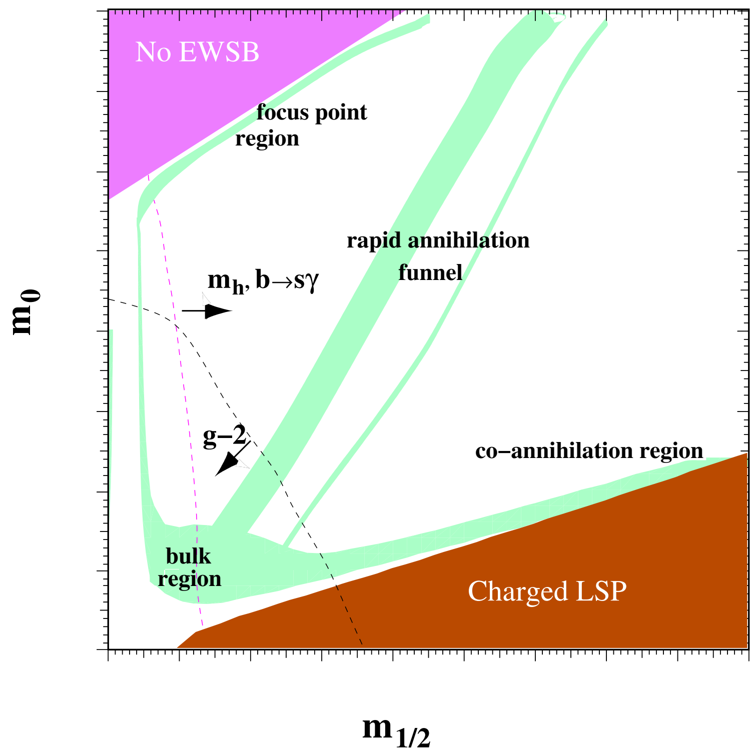
Backup

ATLAS Benchmarks

Large annihilation sross-section required by WMAP data

Boost annihilation via quasi-degeneracy of a sparticle with $\tilde{\chi}_1^0$, or large higgsino content of $\tilde{\chi}_1^0$

Regions in mSUGRA $(m_{1/2}, m_0)$ plane with acceptable $\tilde{\chi}_1^0$ relic density (e.g. Ellis et al.):



- SU3: Bulk region. Annihilation dominated by slepton exchange, easy LHC signatures fom $\tilde{\chi}_2^0 \to \tilde{\ell}\ell$
- SU1: Coannihilation region. Small $m(\tilde{\chi}_1^0) - m(\tilde{\tau})$ (1-10 Gev). Dominant processes $\tilde{\chi}_1^0\tilde{\chi}_1^0 \to \tau\tau$, $\tilde{\chi}_1^0\tilde{\tau} \to \tau\gamma$ Similar to bulk, but softer leptons!
- SU6: Funnel region. $m(\tilde{\chi}_1^0) \simeq m(H/A)/2$ at high $\tan\beta$ Annihilation through resonant heavy Higgs exchange. Heavy higgs at the LHC observable up to ∼800 GeV
- SU2: Focus Point high m_0, large higgsino content, annihilation through coupling to W/Z Sfermions outside LHC reach, study gluino decays.
- SU4: Light point. Not inspired by cosmology. Mass scale ~ 400 GeV, at limit of Tevatron reach

Parameters and cross-sections of benchmark Points

SU1: $m_0 = 70\,\mathrm{GeV}$, $m_{1/2} = 350\,\mathrm{GeV}$, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$.

SU2: $m_0 = 3550\,\mathrm{GeV}$, $m_{1/2} = 300\,\mathrm{GeV}$, $A_0 = 0$, $\tan\beta = 10$, $\mu > 0$.

SU3: $m_0 = 100\,\mathrm{GeV}$, $m_{1/2} = 300\,\mathrm{GeV}$, $A_0 = -300\,\mathrm{GeV}$, $\tan\beta = 6$, $\mu > 0$.

SU4: $m_0 = 200\,\mathrm{GeV}$, $m_{1/2} = 160\,\mathrm{GeV}$, $A_0 = -400\,\mathrm{GeV}$, $\tan\beta = 10$, $\mu > 0$.

SU6: $m_0 = 320\,\mathrm{GeV}$, $m_{1/2} = 375\,\mathrm{GeV}$, $A_0 = 0$, $\tan\beta = 50$, $\mu > 0$.

Signal	σ^{LO} (pb)	σ^{NLO} (pb)	N
SU1	8.15	10.86	200 K
SU2	5.17	7.18	50 K
SU3	20.85	27.68	500 K
SU4	294.46	402.19	200 K
SU6	4.47	6.07	30 K

Particle	SU1	SU2	SU3	SU4	SU6
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42