A Data-Driven Method to Estimate the Top Pair Background for SUSY Searches

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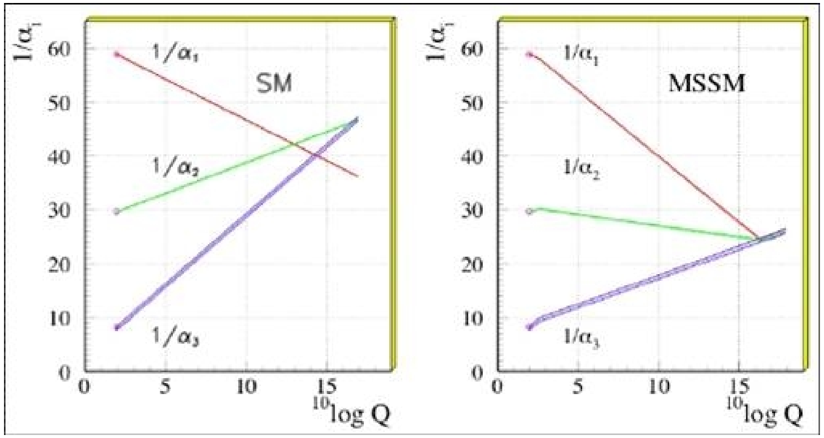
Backgrounds to New Physics?

- TeV-scale SUSY – one attractive extension to the Standard Model
  - ✔ Natural explanation for M_h~100 GeV – addresses the hierarchy problem
  - ✔ Natural candidate for Dark Matter – lightest SUSY particle stable
  - ✔ Consistency with EW-data – coupling unification at GUT scale



- SM particles have **s**particle partners with Δ(spin)=±1/2 (min. extension MSSM)
- Gauge boson- and Higgs partners mix (gauginos and Higgsinos)
  - ⇨ four neutralinos (χ^0_i) and two charginos($\chi^\pm_i$)
  - – Sfermions also mix (according to their mass ie. 3rd generation different)

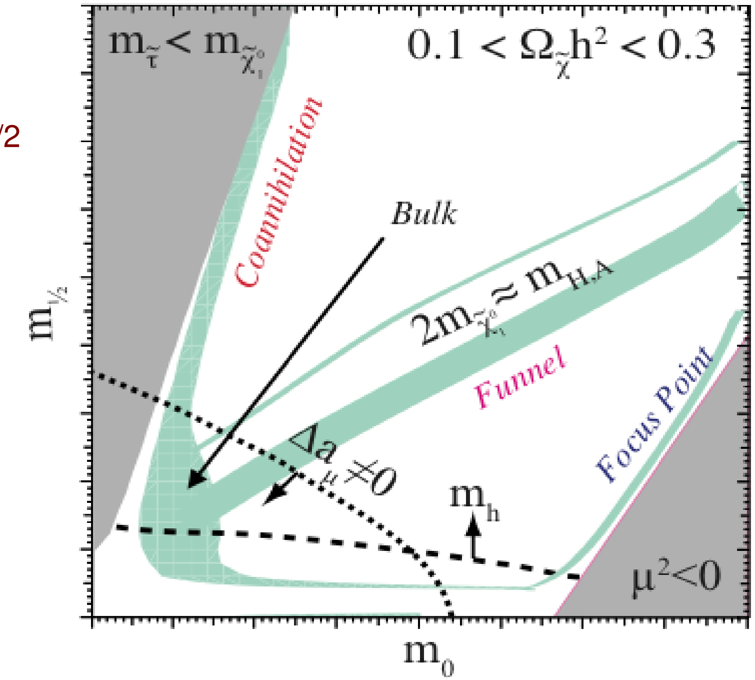
"If new physics <10^6 GeV is not SUSY, it quacks very much like it"
John Ellis, CERN*

*hep-ph/0203114

SUSY a signal scenario

- MSSM is simplest general SUSY model (but >100 free parameters)
  - Arbitrary choice gives FCNC, proton decay, etc.
  - mSUGRA: gravitational interactions -> unified couplings and masses at GUT scale $[m_0, m_{1/2}, A_0, \text{sign}(\mu), \tan(\beta)]$
- Typically good discovery reach in m_0-$m_{1/2}$ plane
- Only parts of parameter space give correct relic density
- Don't "trust" mSUGRA
  - Use it for benchmarking
  - Choose a few representable points for detailed studies

Qualitative plot – no mass scale



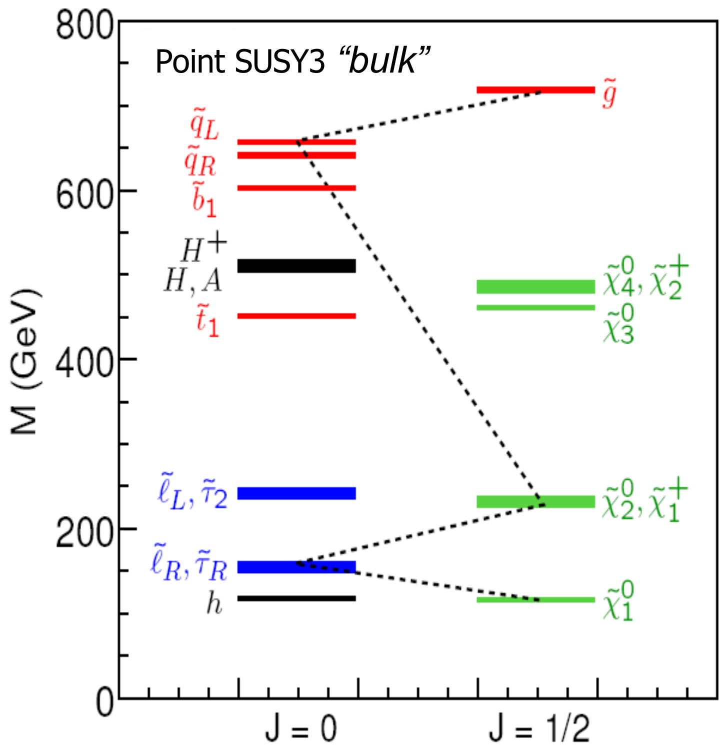
SUSY event signatures

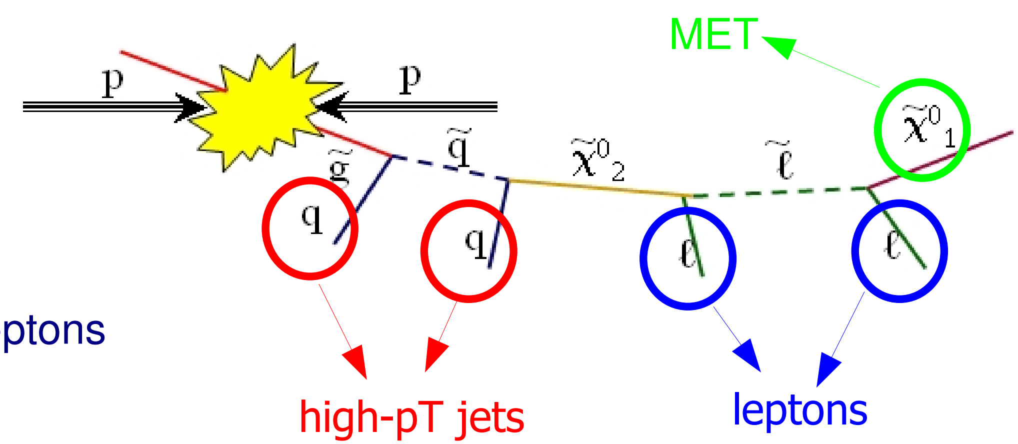
- Squark and gluino production dominates at LHC

$$R = \left(-1\right)^{3B-3L-2S}$$

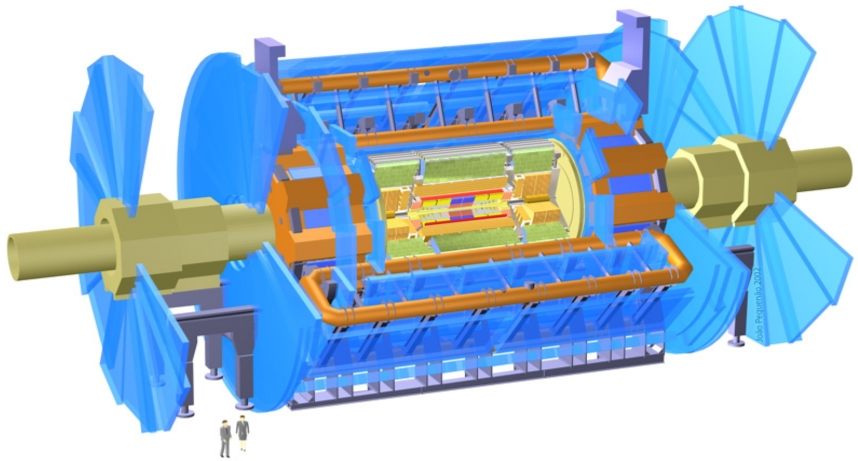
gluino & squark pair production | lightest SUSY particle stable

- Complex SUSY phenomenology
  - High mass objects cascade decay to $\chi^0{}_1$
- Smoking gun of SUSY
  - Large missing tr. energy (MET)
  - High transverse momentum jets
- # isolated leptons gives natural separation between analyzes
  - Focusing on **signatures** with two leptons (e or μ) + jets + MET





ATLAS a multi-purpose detector



Overall length: 44 m
height: 25 m
weight: 7000 tons

- LHC operation goals
  - Beam commissioning in May 2008
  - 14 TeV collisions in July 2008
  - Push towards $10^{32}cm^{-2}s^{-1}$ end of 2008
  - Integrated luminosity $1fb^{-1}$ -> 1-2 months of data-taking

- Muon system
  - Toroid magnets
  - 3 layers of drift tubes, strip chambers and resistive plate chambers
- Calorimetry
  - LAr-lead EM calorimeter
  - Steel-tile (/LAr-Cu) hadronic calorimeter
- Inner detector
  - 3 layers of silicon pixels (r=5-24 cm)
  - 4 layers microstrip-tracker (r<55 cm)
  - Straw tube tracker (r<108 cm)

- ATLAS commissioning
  - Cosmic data taken daily w/ full DAQ
  - Ready for collisions in May 2008

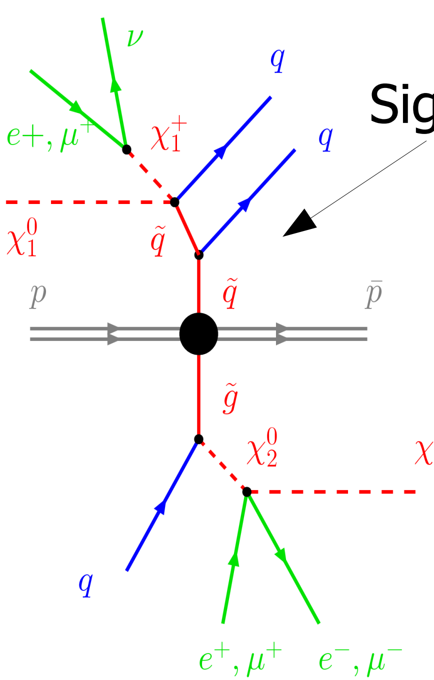
Real='real isolated'

SM di-lepton signatures

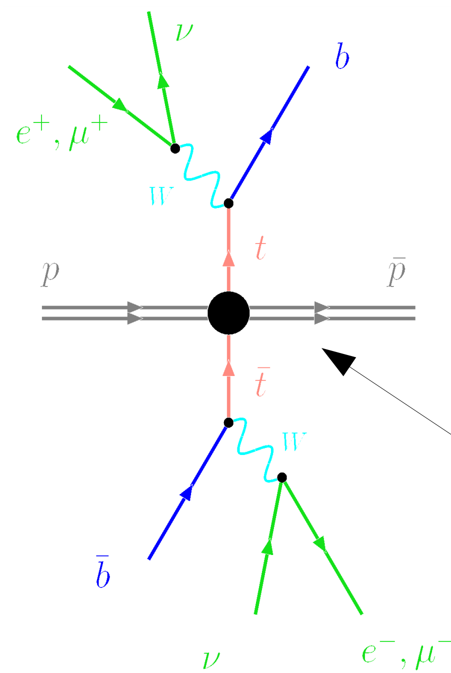
Process	+	-
Z→ll	Cross-section	No real MET
Di-boson	Real MET	Low cross-section
tt→ll	**Real MET,high mass**	
W→lν	Cross-section, real MET	No 2nd real lepton
QCD	Cross-section	No real MET/leptons
tt→l	Real MET,high mass	No 2nd real lepton

Fake leptons (W→lν, QCD, tt→l)

- Top pair production has similar signature
  - Largest background
  - Expectations from simulation
- Experience of analysis techniques from Tevatron valuable



Signal



Background

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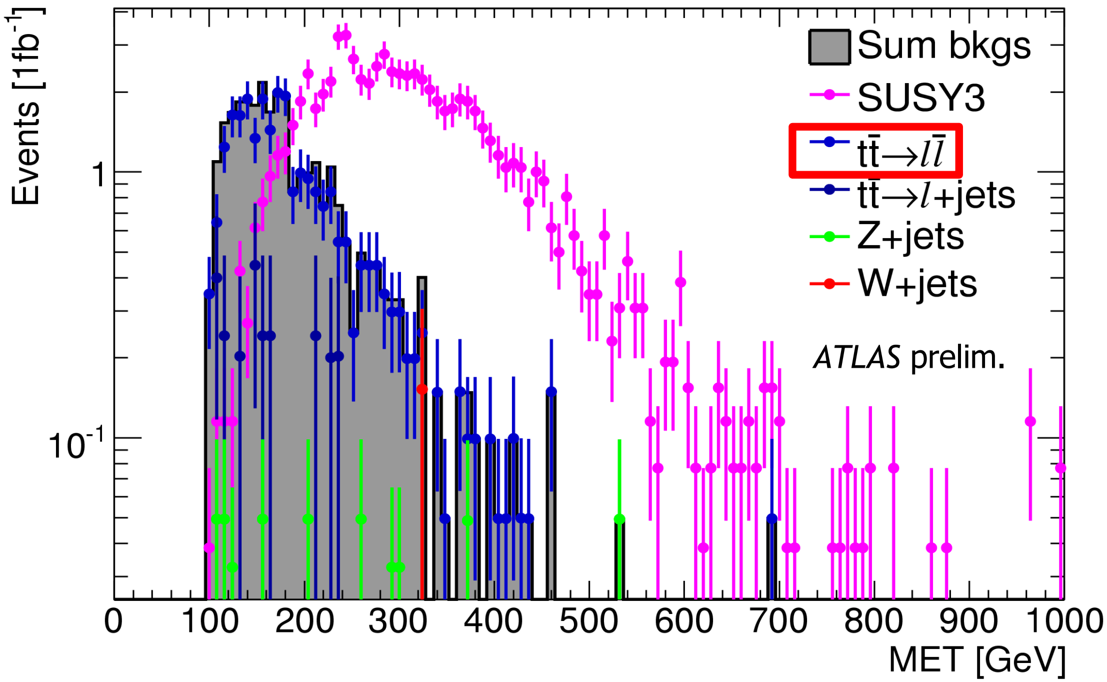
ATLAS preliminary results

Signal region selection

- Select events with high mass scale
  - Clean signature -> one dominating background in opposite lepton charge sign mode

"Standard SUSY" selection

lepton(s) OR jets+MET trigger
2 OS leptons (e or μ) pT>20 GeV
>3 jets pT>(100,50,50,50) GeV
Missing energy>max(100,0.2Meff)



Source	Events (%)
Top ll+jets	24
Top l+jets	2
W+jets	0
Z+jets	0
SUSY3	73
Total # events	109

Question

For a given integrated luminosity, how can we estimate the tt→ di-lepton background from data?

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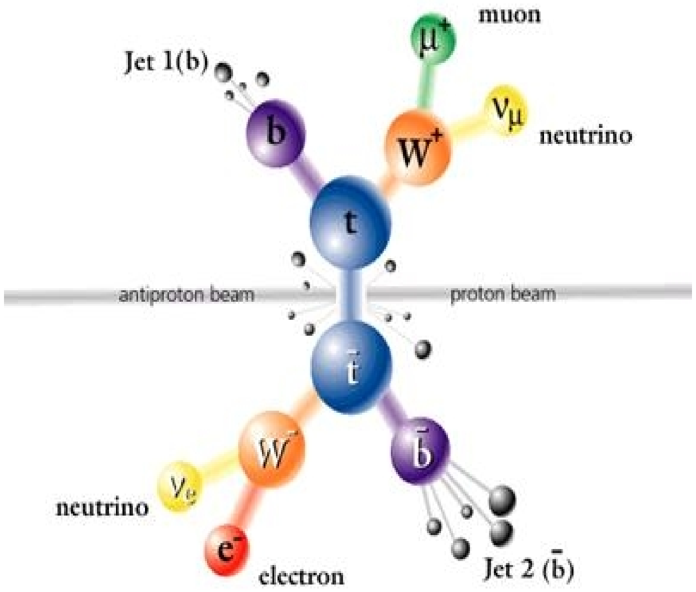
tt clean control sample

- Strategy based on selecting a sample dominated by the background process

1. Apply "standard" SUSY selection
2. Form b-jet pairs
   - Consider all combination of 4 leading jets as input to the following equations



quartic equation
2,4-fold ambiguity
(sets of ν-momentum)

$$p^i_{\nu_1}, p^i_{\nu_2}$$

$$\begin{cases} m^2_{W_1} = \left(p_{l_1} + p_{\nu_1}\right)^2 \\ m^2_{W_2} = \left(p_{l_2} + p_{\nu_2}\right)^2 \\ m^2_{t_1} = \left(p_{l_1} + p_{\nu_1} + p_{b_1}\right)^2 \\ m^2_{t_2} = \left(p_{l_2} + p_{\nu_2} + p_{b_2}\right)^2 \\ MET_x = \left(p_{\nu_{1x}} + p_{\nu_{2x}}\right) \\ MET_y = \left(p_{\nu_{1y}} + p_{\nu_{2y}}\right) \end{cases}$$

3. If it exist a pair of jets giving a real solution: consider event as a "tt like"
4. **Number of (b-)jet pairs** discriminates between tt and other processes

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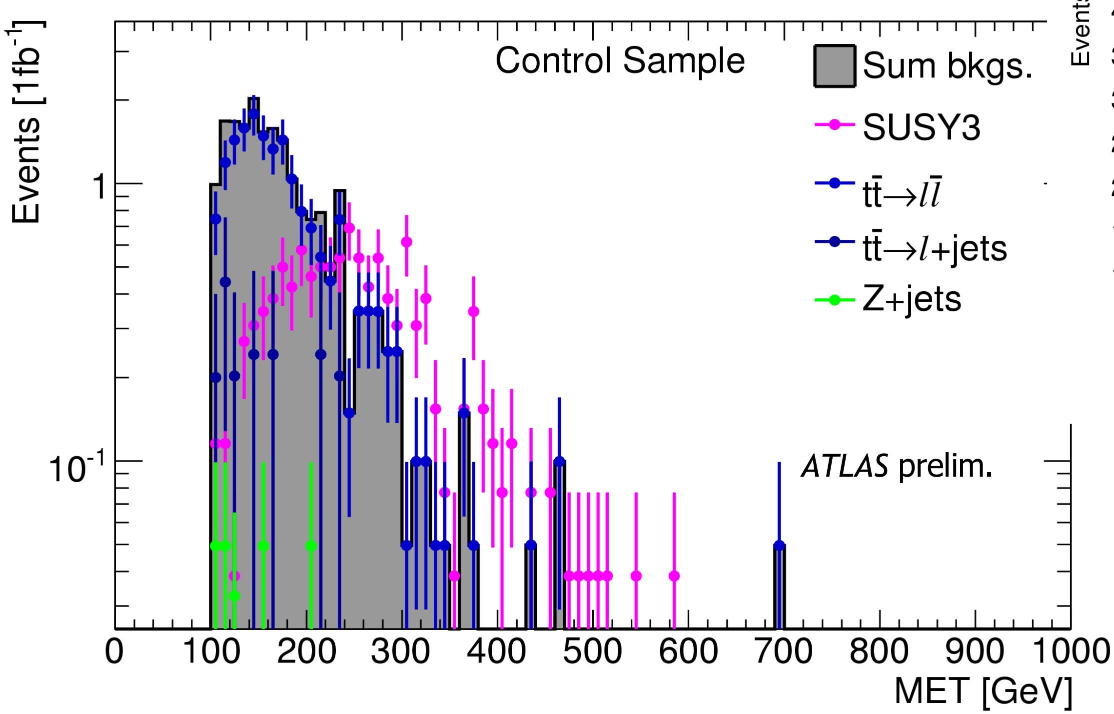
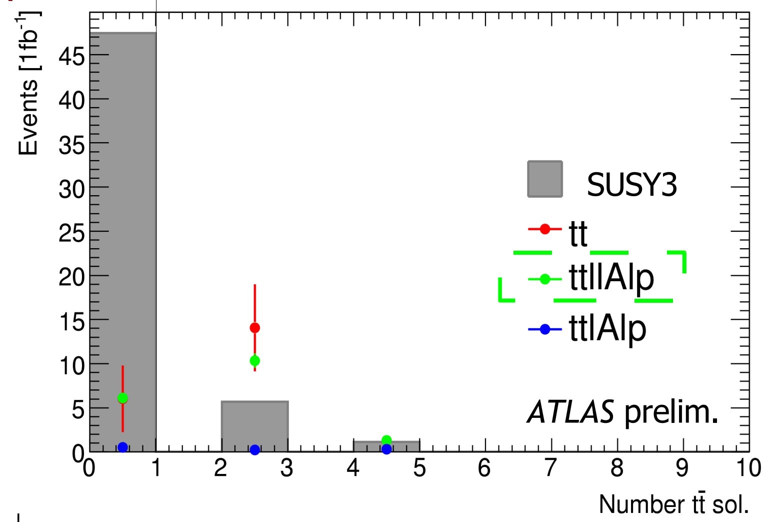
ATLAS preliminary results

tt control sample composition

- Control sample is dominated by tt→di-lepton events



> # b-jet pairs >0 (⇔#sol>0)



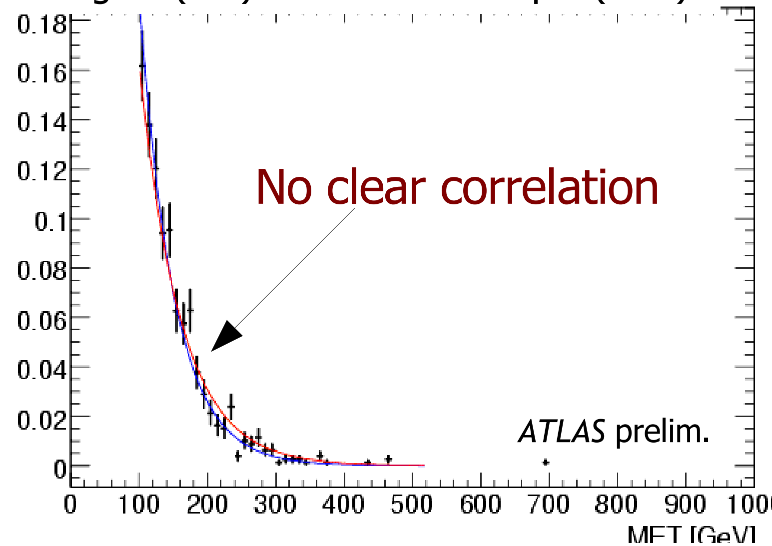
Source	Events (%)
Top ll+jets	58
Top l+jets	6
W+jets	0
Z+jets	1
SUSY3	36
Total # events	30.6

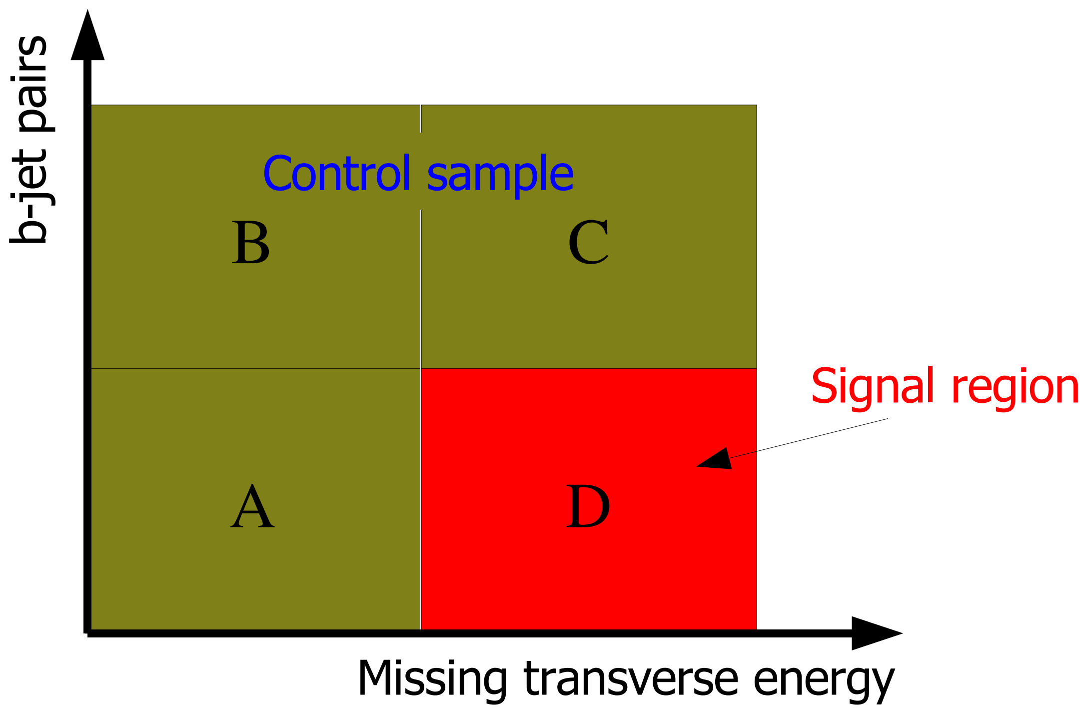
- Potentially large signal contamination
- tt dominated sample obtained from collider data
  - But how much is expected in the signal region?

tt normalization

- Normalize background prediction using uncorrelated variable
  - Here: missing transverse energy
  - Simple scaling into signal region

Comparison of MET in signal (red) and control sample (blue)





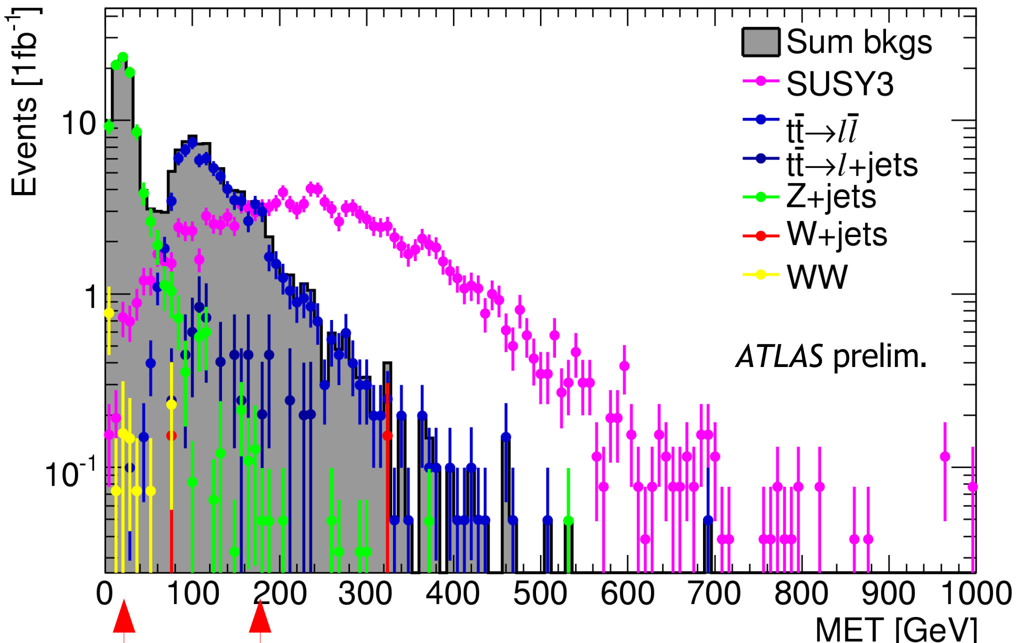
Normalization factor

$$D = C \times \frac{A}{B}$$

ATLAS preliminary results

tt normalization region

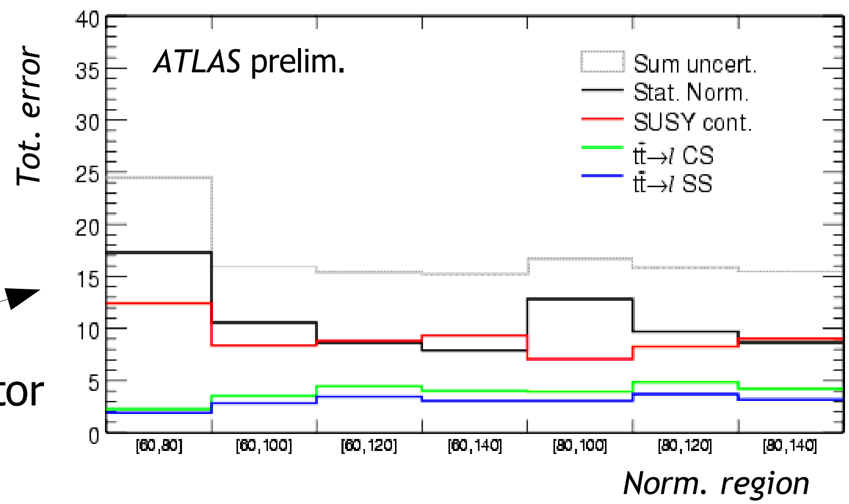
- Normalize background prediction in region with low expected signal contribution
  - Subtract other backgrounds



Norm. region

- Understanding low MET region
  - Z background heavily suppressed vs. signal contamination
  - Perhaps an iterative approach once data exist

Sys. uncertainty:
total error on the normalization factor



Note: some MC samples have gen. cuts

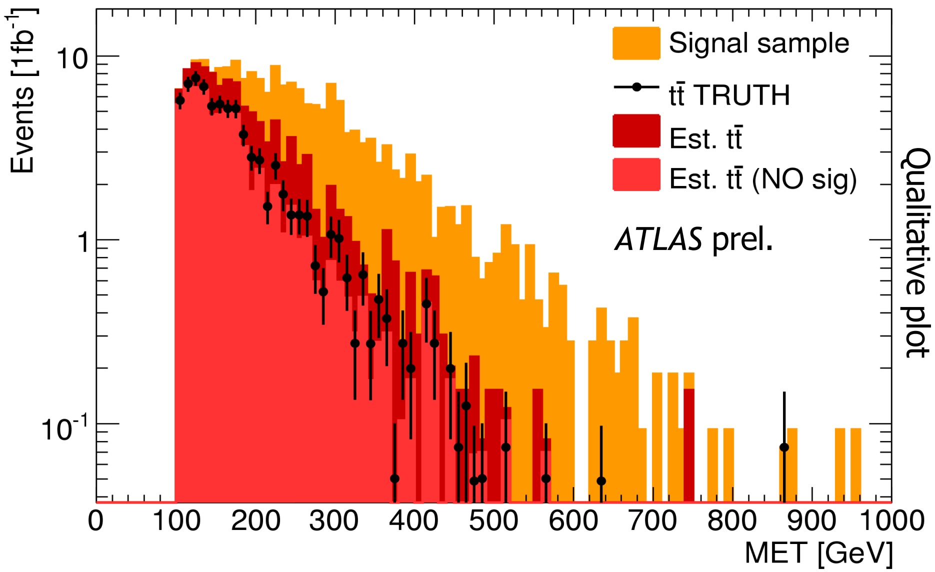
ATLAS preliminary results

tt estimation expected performance

- Estimate tt in “data cocktail” of events
  - Compare with MC truth

Process	Yield (%)
“true tt”	**100** (by def.)
Estimated tt	**90**
Including SUSY3	**122**

- Signal contamination
  - Clearly very model dependent
  - Inverse proportional to mass scale
  - Important -> **result is conservative**
- Systematics also input to searches
  - Result is expected uncertainty of tt
  - More “realistic” reach predictions



Sys. Uncertainty	(%)
Stat. Control Sample	20
Correlation of MET and # b-jet pairs	20
Semi-leptonic tt contribution	4
Jet Energy Scale	9
Jet Energy Resolution	1
MET Scale	1
Leptons via τ	1

Conclusion

- A method to estimate the tt → di-lepton background to SUSY-like signatures
  - Data-driven background estimations are crucial for discovery claims
  - Based on kinematic reconstruction of top pair events
  - Feasible after ~1fb^{-1} of collected data
  - Mass scale dependent signal contamination -> but method is conservative!
- Generic method for any BSM search
  - With same signature
- Part of a larger group-wide effort to provide methods/ideas for early searches
  - Important to have many different cross-checks for each source background
- Many systematic uncertainties are studied (tot. uncertainty ~30%)
  - Dominating source: statistical uncertainty of the control sample
  - Detector resolutions appears to have less effect

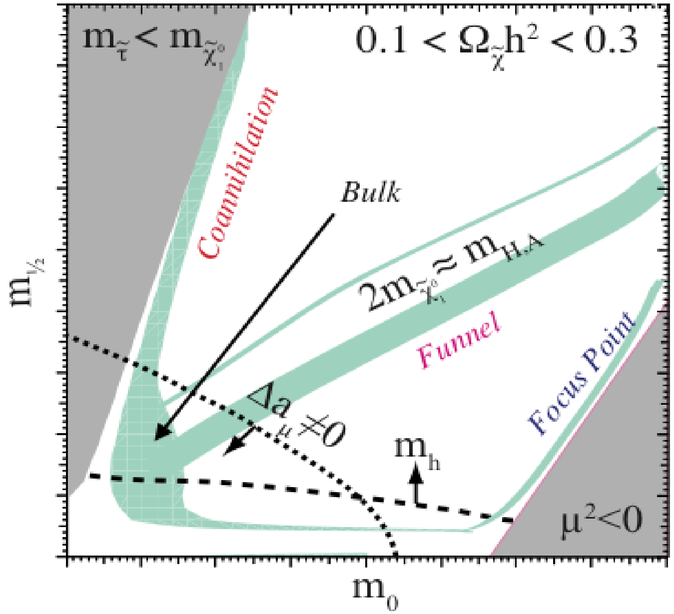
Backup slides

Benchmark Points mSUGRA

- Benchmark points in mSUGRA space
- Different annihilation processes leads to correct relic density

Point	m_0 (GeV)	$m_{1/2}$ (GeV)	A_0	$\tan(\beta)$	$\mathrm{sign}(\mu)$	σ_{LO} (pb)
SU1 – Coannihilation	70	350	0	10	+	6.8
SU2 – Focus	3550	300	0	10	+	4.9
SU3 – Bulk	100	300	-300	10	+	19.3
SU4 – Low Mass	200	160	-400	10	+	280
SU6 – Funnel	320	375	0	50	+	4.5

Qualitative plot – no mass scale



- Wide range of signatures
- Important for generic discovery potential

IsaJet 7.71

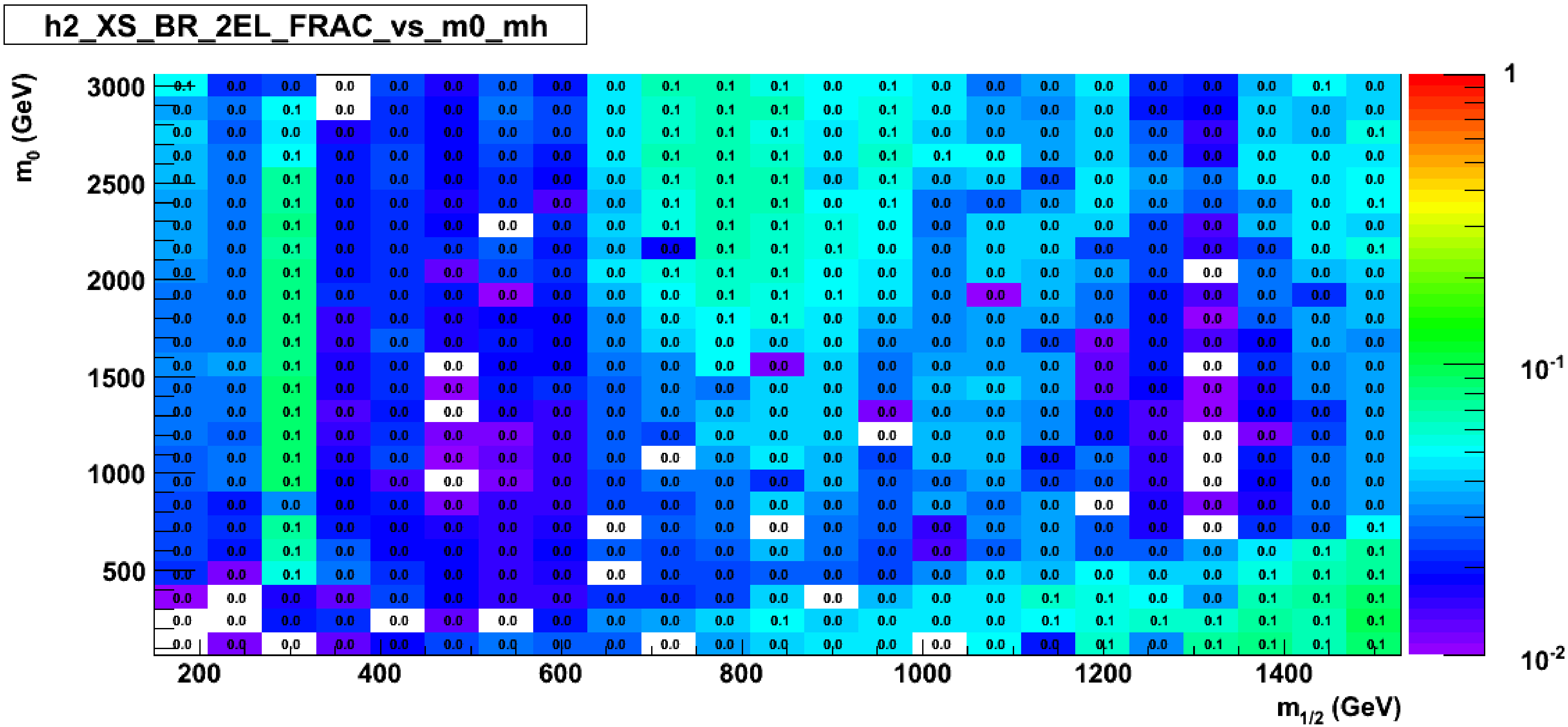
http://atlahttp://www.usatlas.bnl.gov/twiki/bin/view/Projects/AtlasSusyPoints

Systematics

- Uncertainties from Monte Carlo specific sources are not applicable (1^{st} order)
  - Ex. cross-sections cancels -> using data
  - From Monte Carlo
  - Sample composition from data (Z and QCD must be estimated from data)
- Correlation of MET and number of b-jet pairs
  - Fit the MET distributions and take nominal difference
- Detector performance related systematics
  - Nominal uncertainty is (very) luminosity dependent
  - Jet Energy Scale and resolution
  - Electron/Muon Scale and resolution
  - MET resolution

mSugra dilepton signal

- Overview of the SUSY di-electron production cross-section



$$\frac{\sigma\left(SUSY \rightarrow ee + X\right)}{\sigma\left(SUSY\right)}$$

2 electrons pT>X GeV
IsaJet 7.74

mSUGRA typical reach