Early SUSY searches at the LHC

Alex Tapper

on behalf of the ATLAS & CMS collaborations

- Introduction
- Search strategy
- Searches
- Background estimates
- Discovery reach
- Summary

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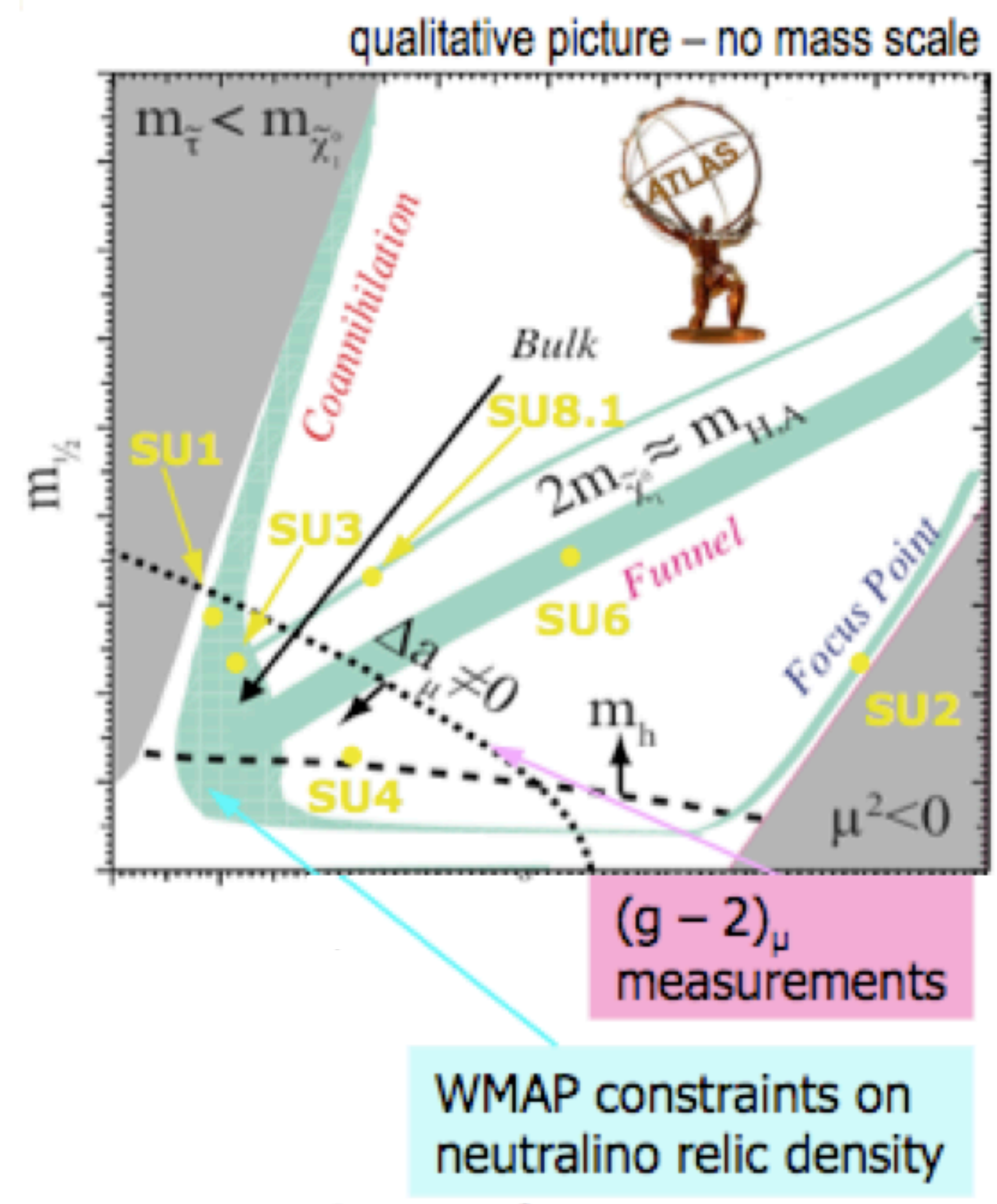
Introduction

- Many different SUSY scenarios investigated by ATLAS & CMS
- My brief is to describe plans for early SUSY searches
- What we plan to do with the 2010 data
  - Stick to studies at 10 TeV centre-of-mass energy and < 1 fb^{-1} of data
  - Some comments on 7 TeV centre-of-mass towards the end
  - Break my own rule only to illustrate some background methods

Search strategy

- Be as model independent as possible
  - But the MSSM has > 100 parameters
  - Need more constrained models
  - Choose a set of benchmark points that are representative of a range of topologies and areas of phase space
  - Range of models
    - MSUGRA (high and low masses)
    - GMSB
    - Split SUSY
  - In this talk MSUGRA at low masses, just above the Tevatron
  - SU4 for ATLAS



Full details of benchmark points in backup slides

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Search strategy

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    - GMSB
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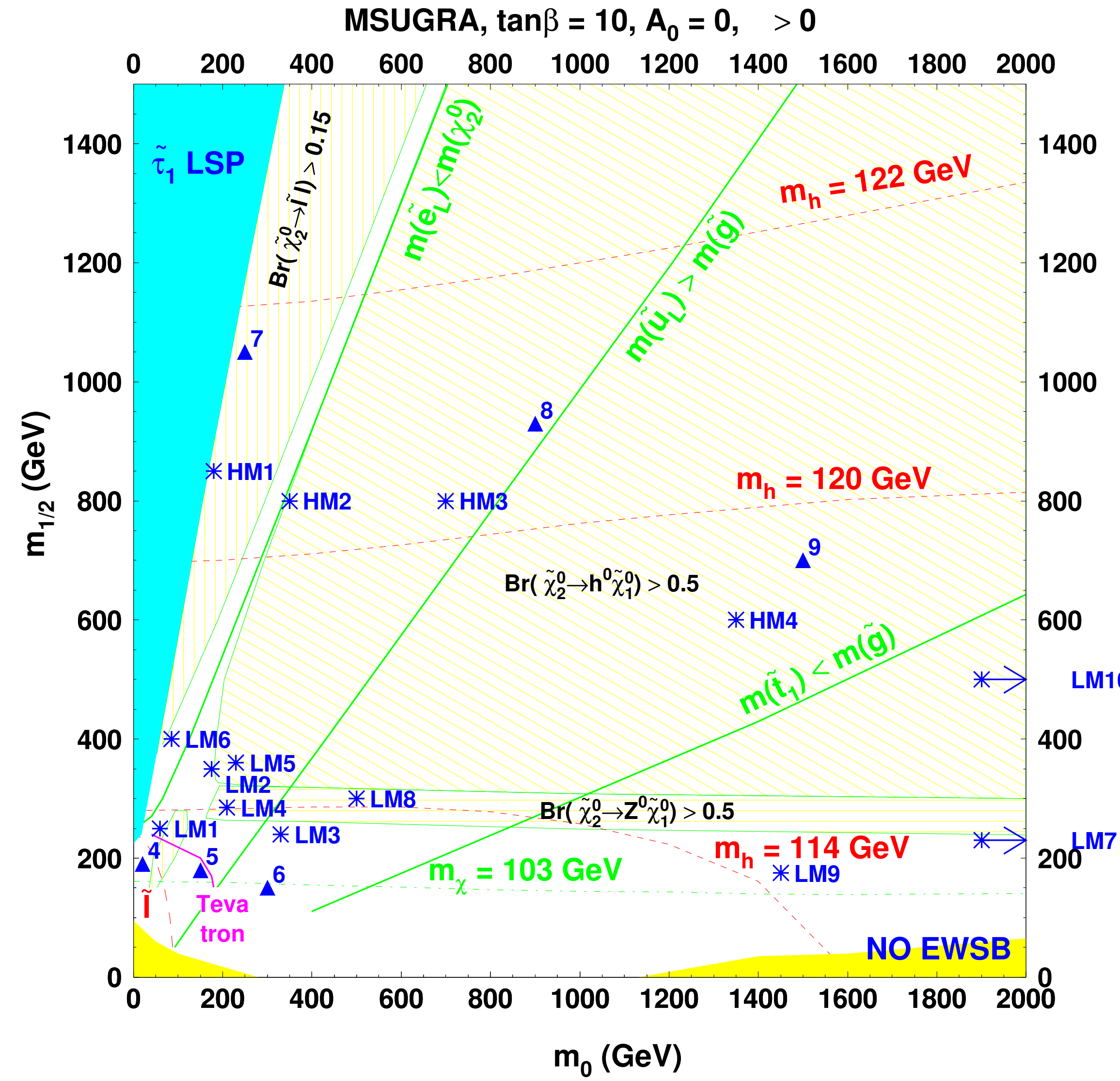
  - LM0 and LM1 for CMS



J. Phys. G: Nucl. Part. Phys. 34 (2006)

Full details of benchmark points in backup slides

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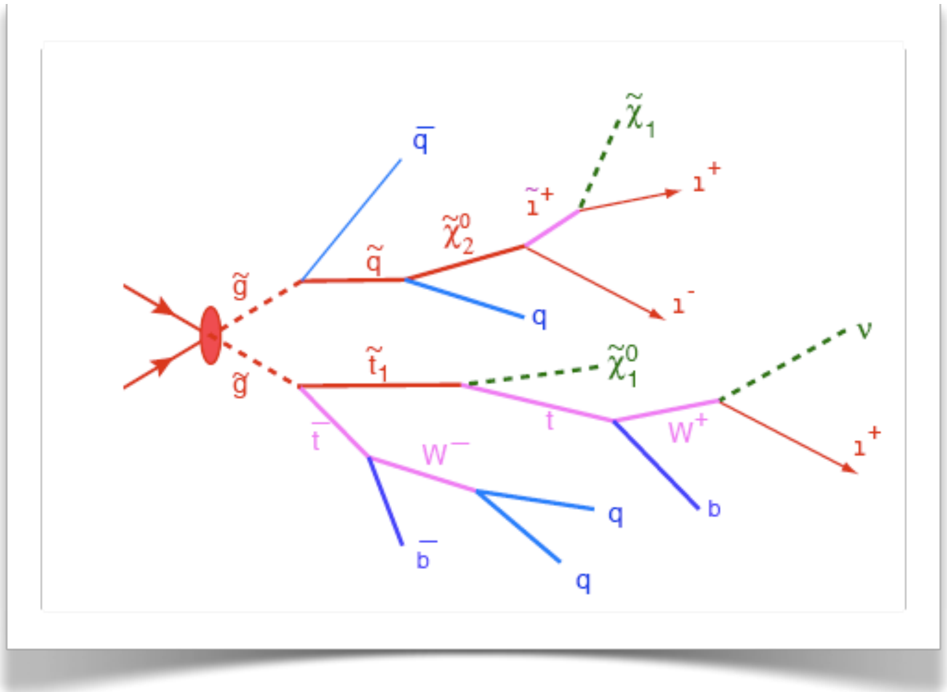
Search strategy



- Production
  - Squark and gluino expected to dominate
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model

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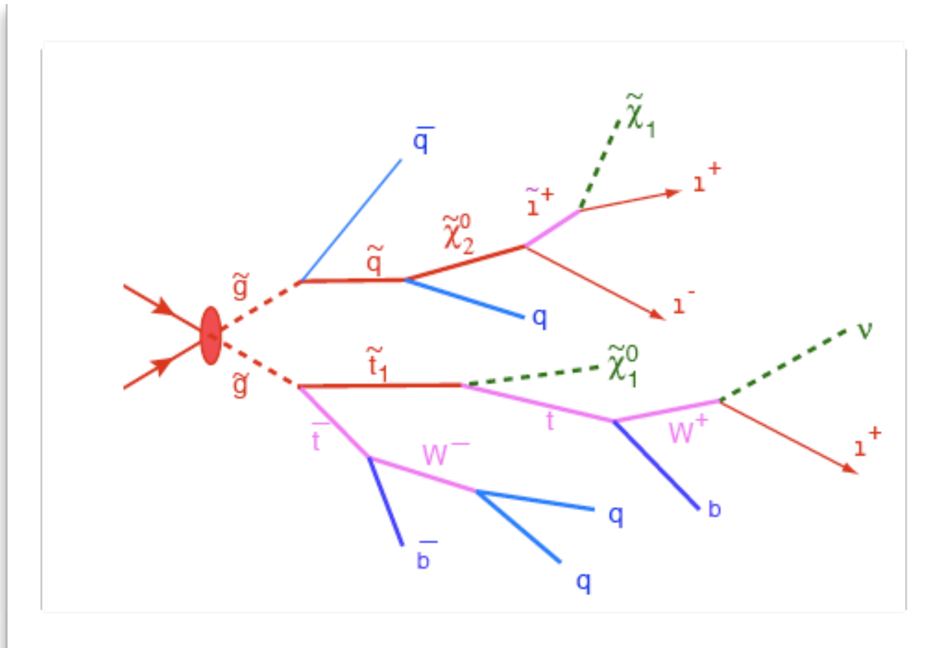
Search strategy



- Production
  - Squark and gluino expected to dominate
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model
- Decay
  - Details of decay chain depend on SUSY model (mass spectra, branching ratios, etc.)
  - Assume R_P conserved ➔ decay to lightest SUSY particle (LSP)
  - Assume squarks and gluinos are heavy ➔ long decay chains
- Signatures
  - **MET** from LSPs, **high-E_T jets** and **leptons** from long decay chain
- Focus on robust and simple signatures
  - Common to wide variety of models
  - Let Standard Model background and detector performance define searches not models

Searches

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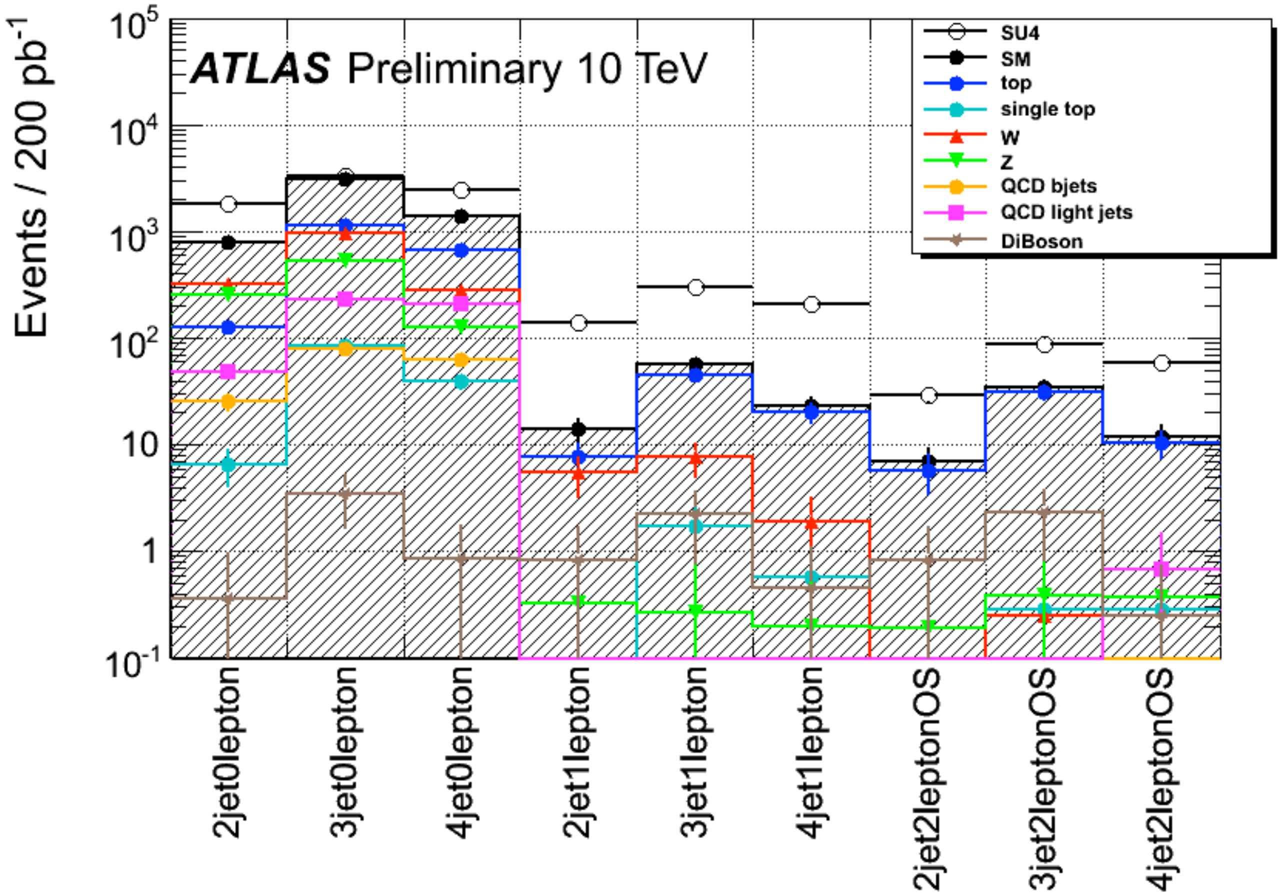
- How might such a generic search look?
  - Simple selection ➔ categorise events by numbers of leptons and jets



- Jet E_T > 100 (40) GeV
- $\Delta\Phi(\text{jet}_i, \text{MET})$ > 0.2 rad
- Lepton E_T > 20 (10) GeV
- MET > 80 GeV
- $M_{eff} = \Sigma E_T^{jet} + \Sigma E_T^{lep}$ + MET
- MET > 0.2-0.3 x M_{eff}
- S_T>0.2
- M_T > 100 GeV

  - Good S/B for most channels (200 pb^{-1} @ 10 TeV COM) but...
  - Backgrounds straight from Monte Carlo
- Key is measuring SM backgrounds from data with systematics

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Backgrounds

- Physics
  - Standard Model processes that give the same signatures as SUSY
  - Cannot rely on Monte Carlo predictions ➔ measure in data
- Detector effects
  - Detector noise, mis-measurements etc. that generate MET or extra jets
  - Commissioning and calibration (see previous talks)
- Beam related
  - Beam-halo muons (and cosmic-ray muons), beam-gas events
  - Data and simulation already ➔ measure in situ too

Backgrounds

- Data-driven background estimates are the key challenge in early SUSY searches
- General idea is find a control region where SM is dominant and use this to predict SM background in signal region
- Two approaches pursued:
  - Matrix (ABCD) methods ➔ playing variables off against each other
  - Replacement methods ➔ modify SM with same topology as signal to predict signal
- In both cases need to identify clean SM control region
- Difficult to avoid using Monte Carlo in some way
- Will discuss searches giving examples of data-driven methods ➔

All-hadronic search

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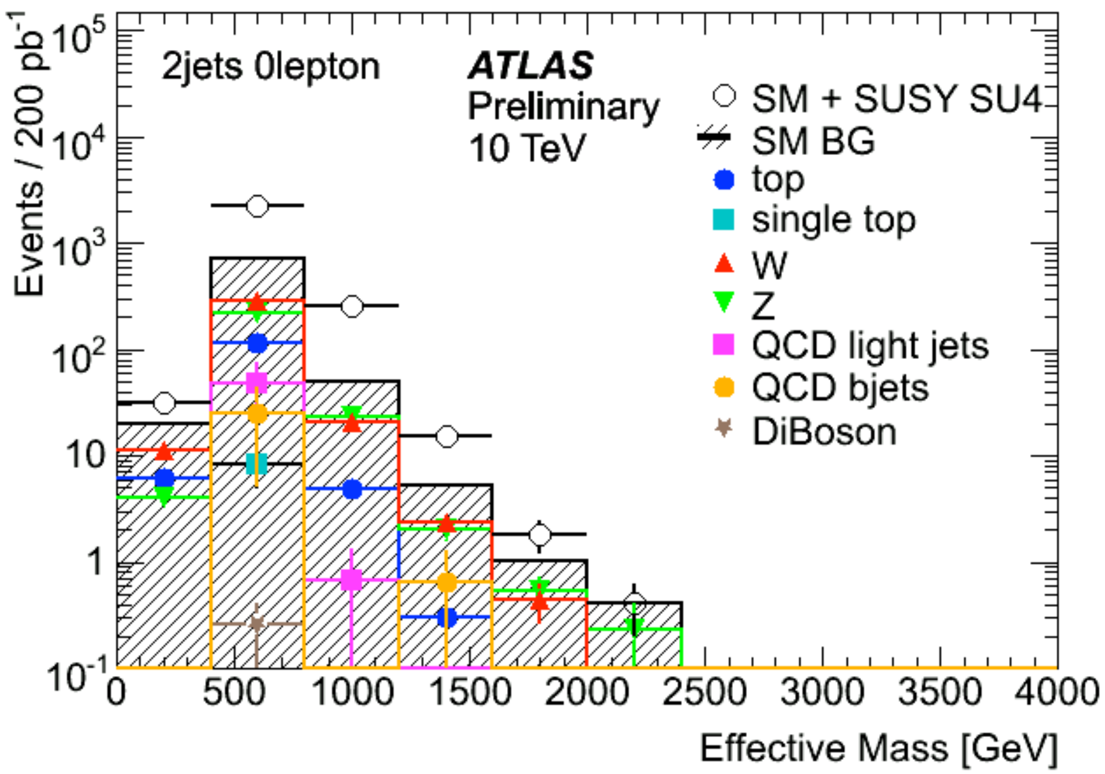
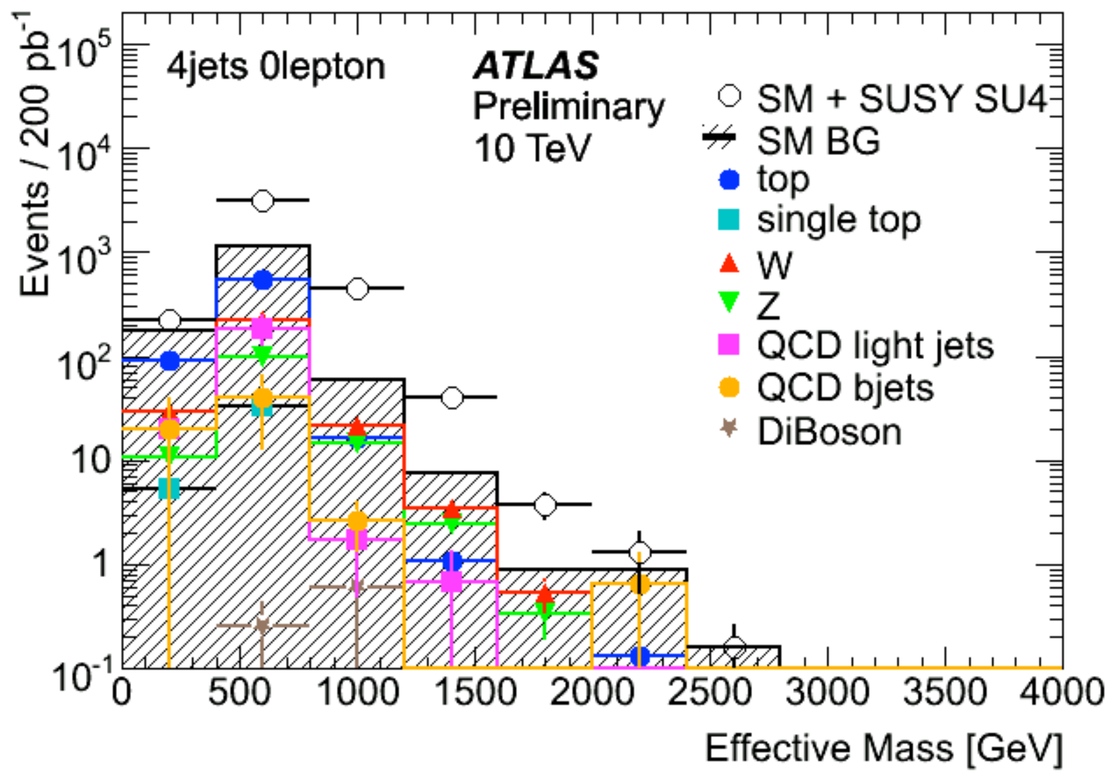


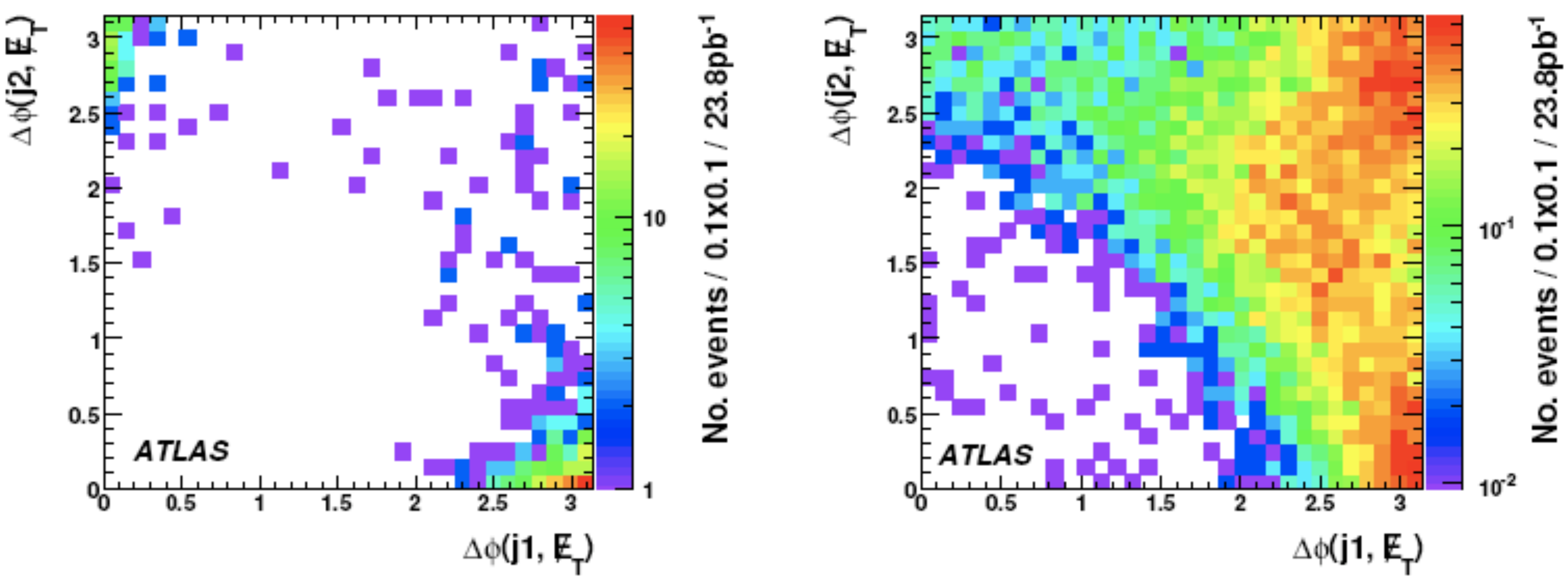


- All-hadronic search highly sensitive to SUSY
- But suffers from many backgrounds
- Nice examples of backgrounds both from detector effects and from Standard Model physics

All-hadronic search

- Mis-measurement of a jet leads to MET along the jet axis
- Remove with $\Delta\Phi(jet_i, MET) > 0.2$ rad

arXiv:0901.0512 (2009)

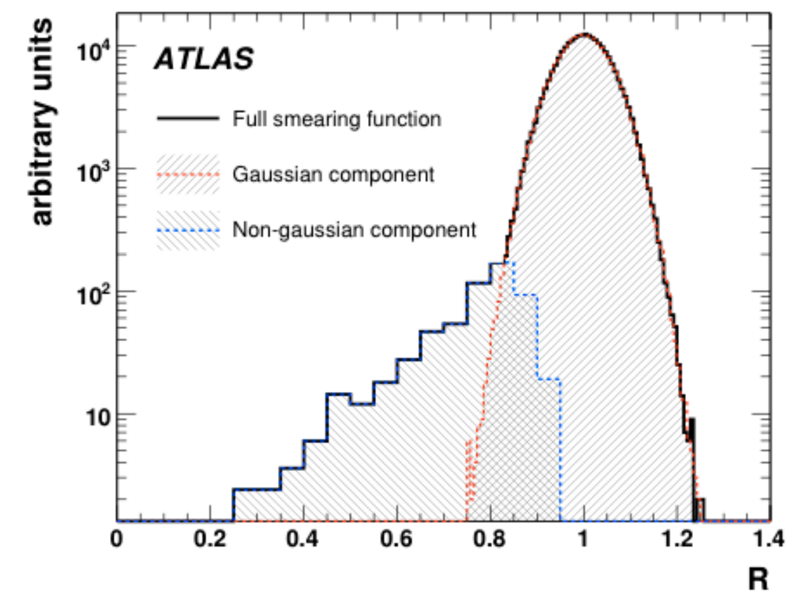


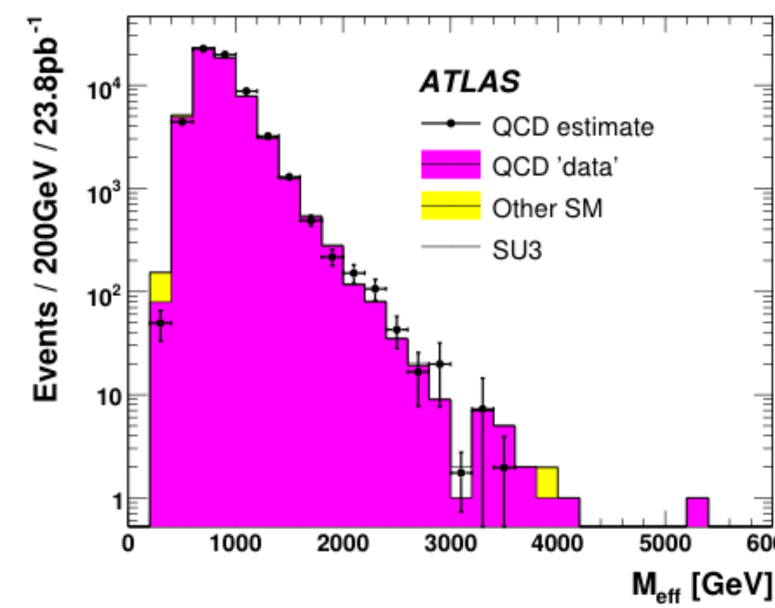
- Several methods developed to predict MET tail from QCD events
  - Matrix methods to estimate from control regions
  - Smearing method ➔

All-hadronic search

arXiv:0901.0512 (2009)

- Derive Gaussian part of smearing function from γ + jet control sample
- Derive non-Gaussian part from Mercedes events, requiring that the MET is co-linear with one of the jets
- Combine smearing functions, normalising with di-jet sample
- Apply smearing function to low MET events to predict the tail in the high MET signal region





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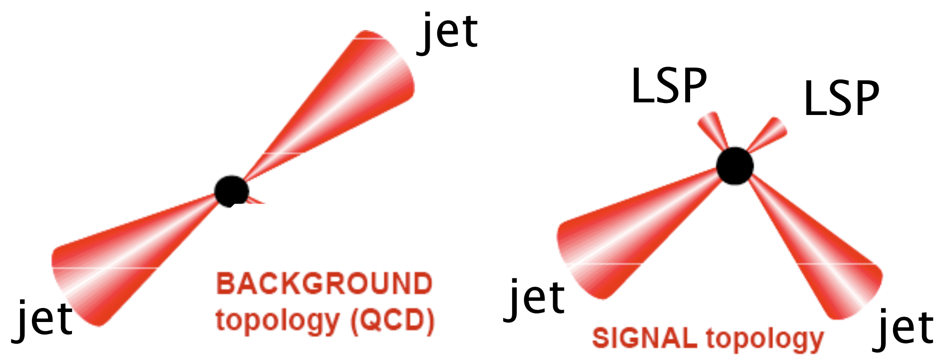
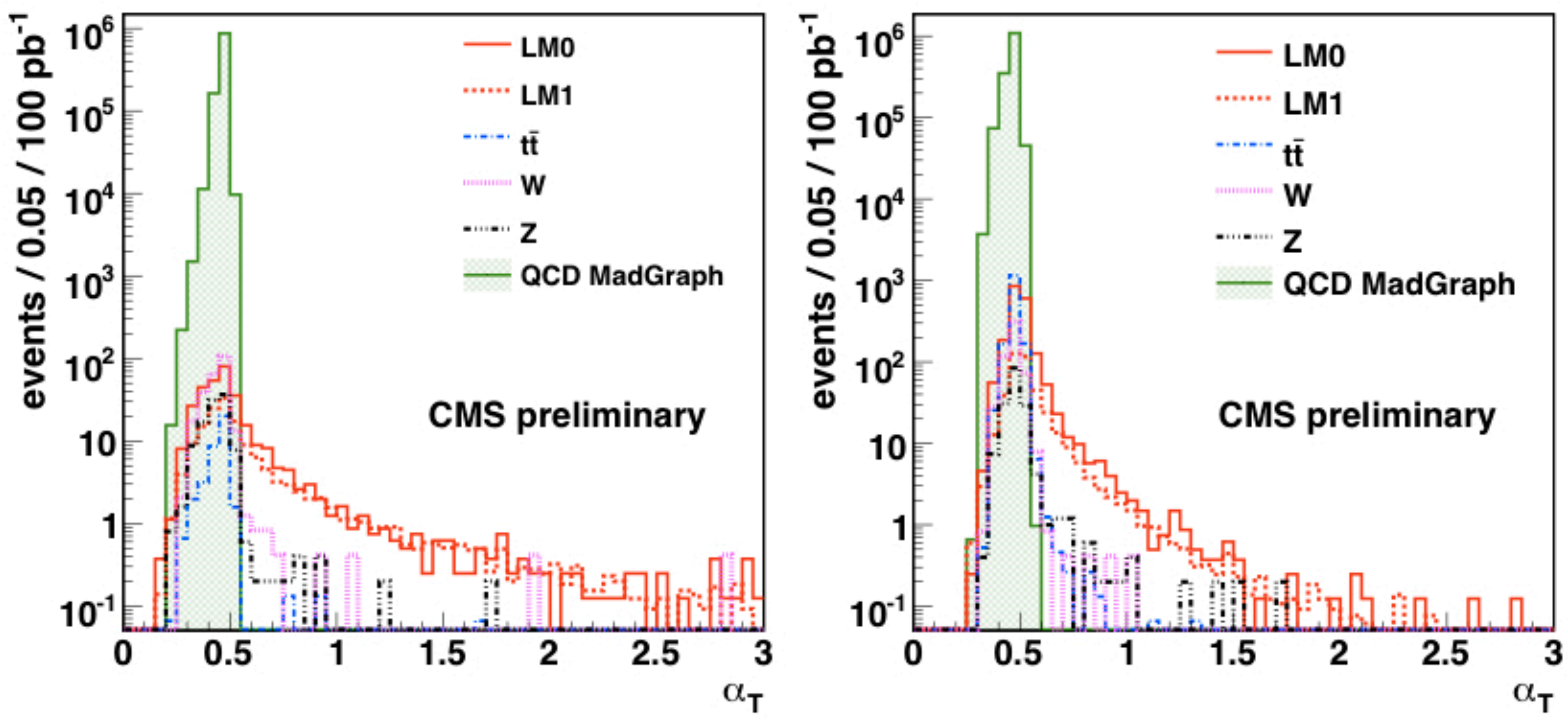
All-hadronic search

PRL101:221803 (2008) & CMS-PAS-SUS-09-001



$$\alpha_T = \frac{E_{T\,j2}}{M_{T\,j1j2}} = \frac{\sqrt{E_{T\,j2}/E_{T\,j1}}}{\sqrt{2(1-\cos\Delta\varphi)}}$$



- A novel approach combining angular and energy measurements
- No dependence on MET ➔ robust for early LHC running
- Originally proposed for di-jet events ➔ generalised up to 6 jets
- Perfectly balanced events have α_T=0.5 (cut at α_T>0.55)
- Mis-measurement of either jet leads to lower values

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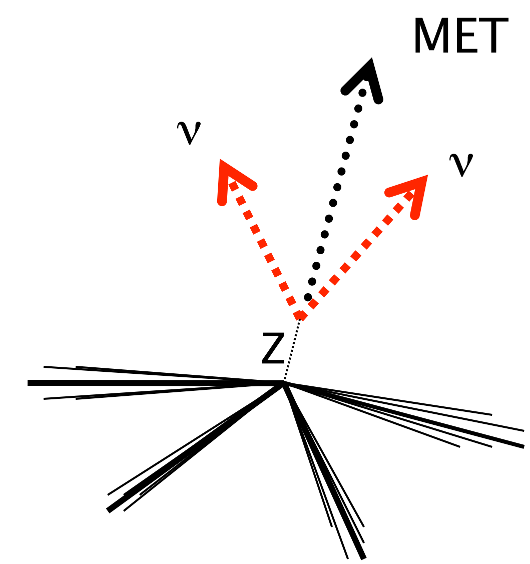
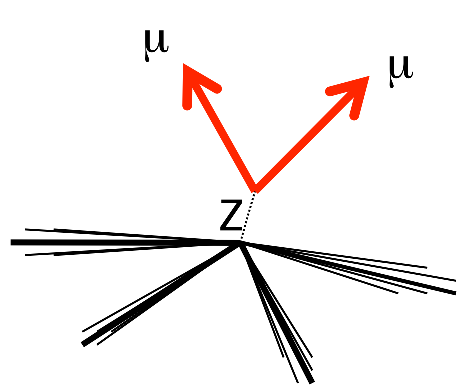
Background estimates

- Data-driven background estimates
  - Find a **control region** in phase space where SM background dominates
  - Use measurements in this region to infer SM background in signal region
  - Example Z → νν + jets ➔ irreducible background
  - **Replacement technique**

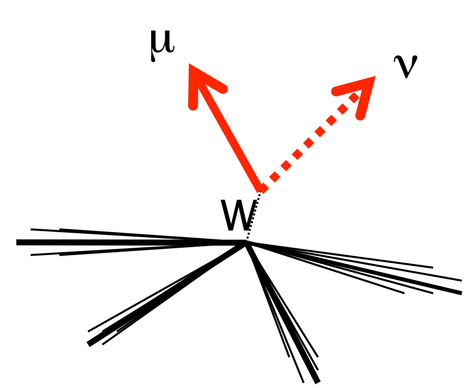




Z → ll + jets

Strength: very clean

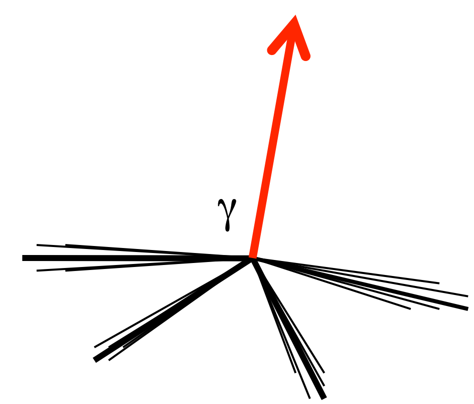
Weakness: low statistics



W → lν + jets

Strength: larger statistics

Weakness: background from SM and SUSY



γ + jets

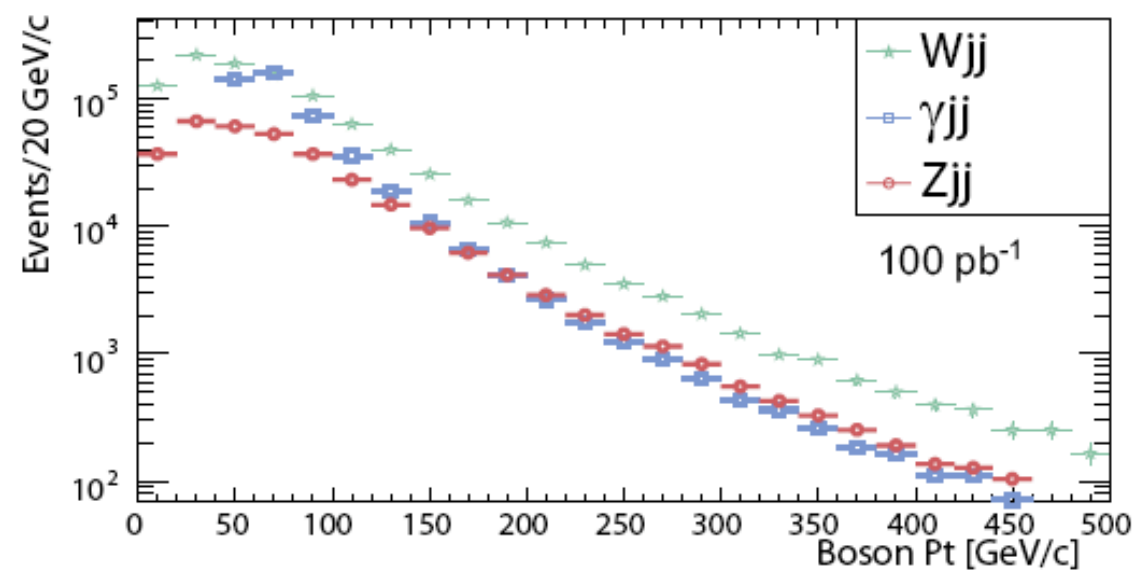
Strength: large statistics and clean at high E_T

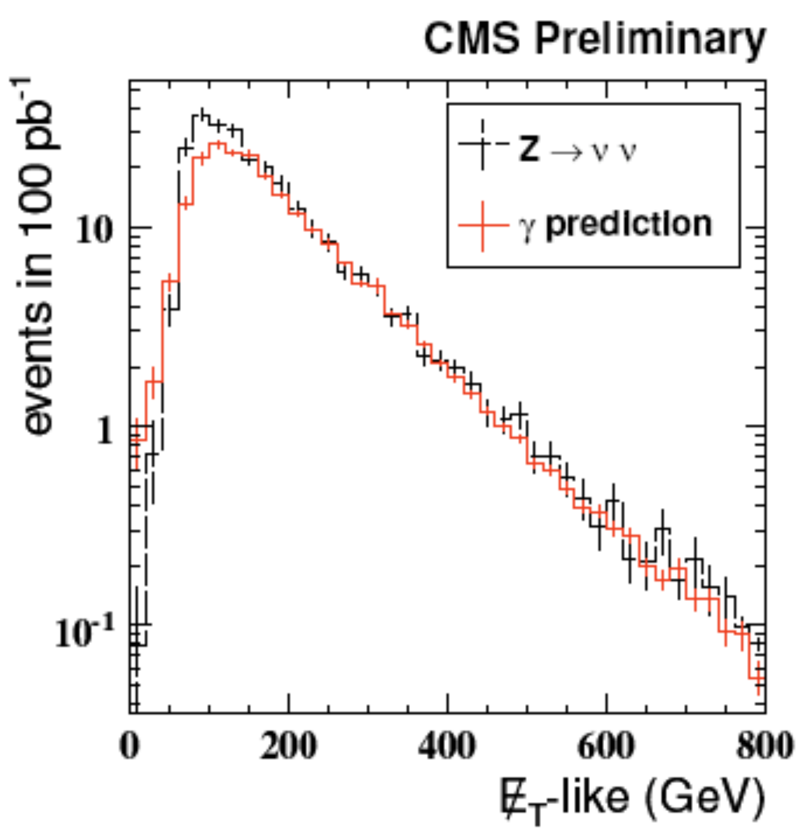
Weakness: background at low E_T, theoretical errors

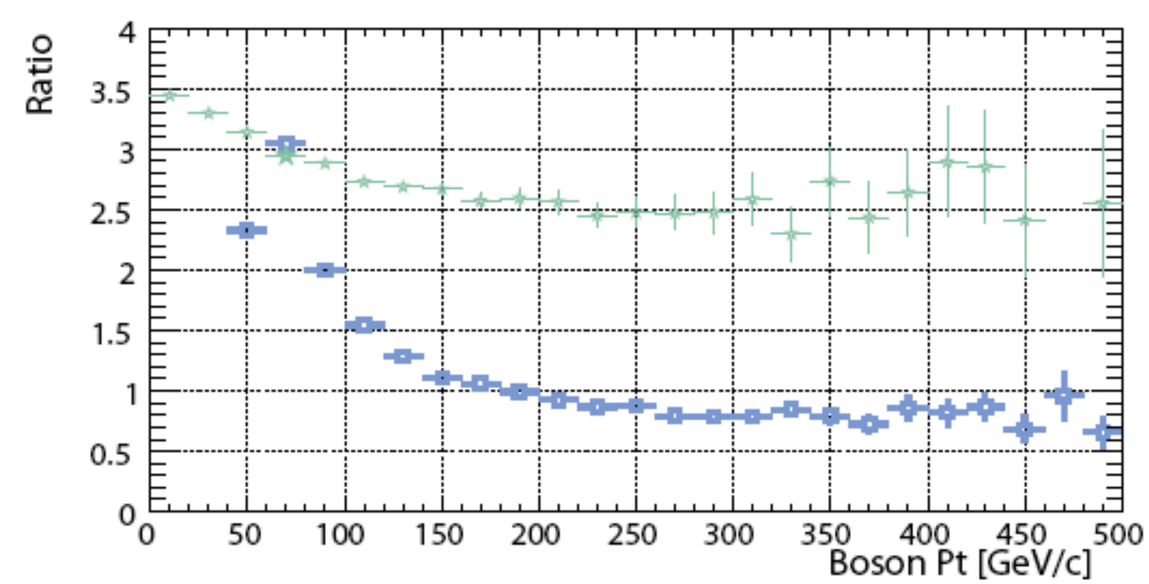
Background estimates

CMS-PAS-SUS-08-002

- Select γ + ≥3 jets with Eγ>150 GeV
  - Clean sample S/B>20
  - Remove photon from the event
  - Recalculate MET
  - Normalise with σ(Z+jets)/σ(γ+jets) from MC or measurements







100 pb^{-1} @ 14 TeV COM

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Single-lepton search

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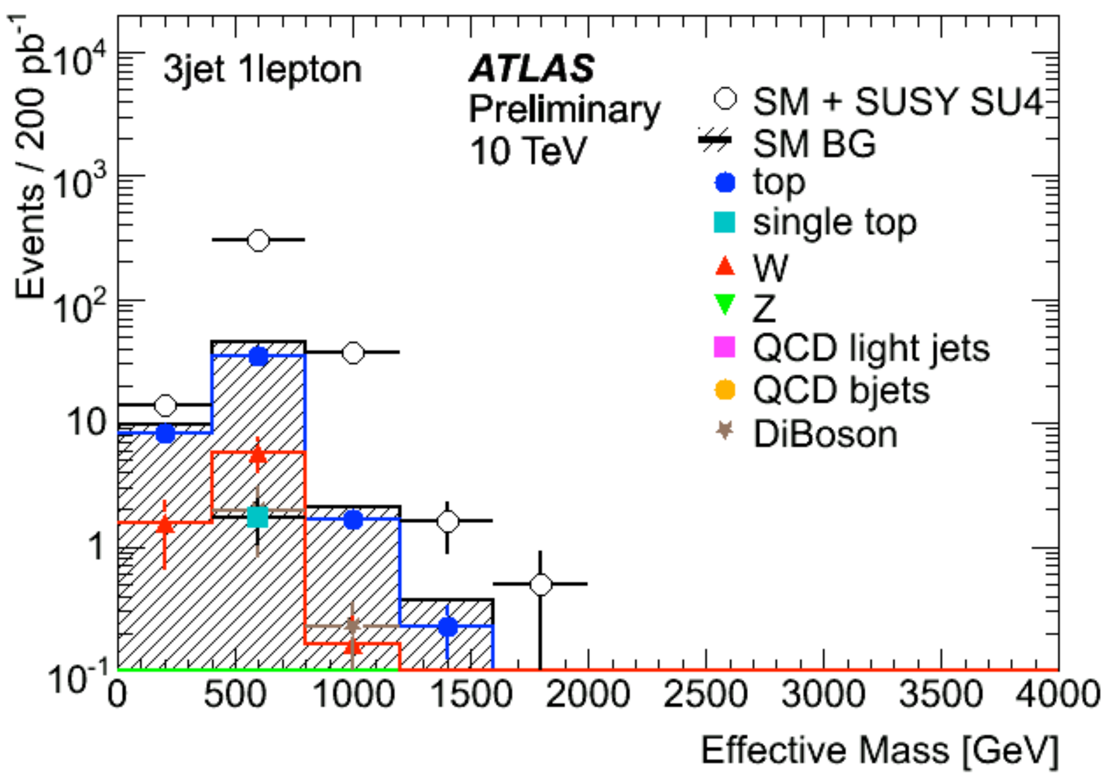

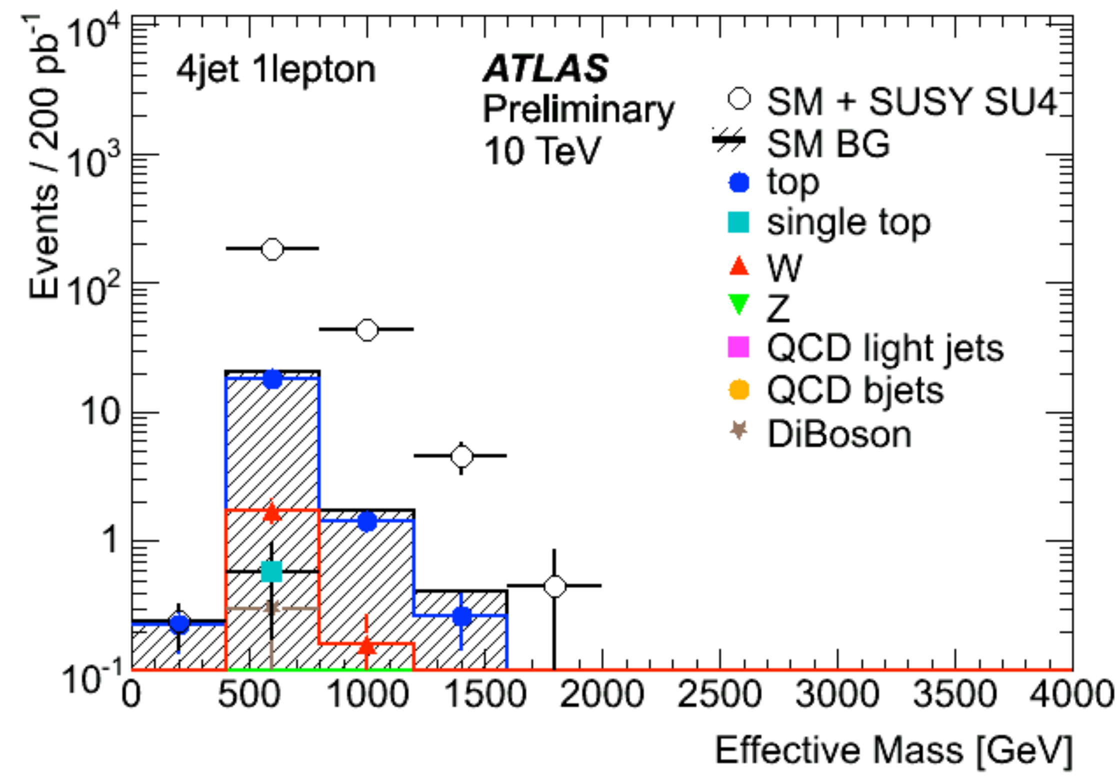

- Requiring one lepton (e or μ) suppresses QCD background powerfully
- Highly sensitive to SUSY
- Backgrounds come from Standard Model processes with neutrinos ➔ real MET
- In particular top and W decays

Background estimates

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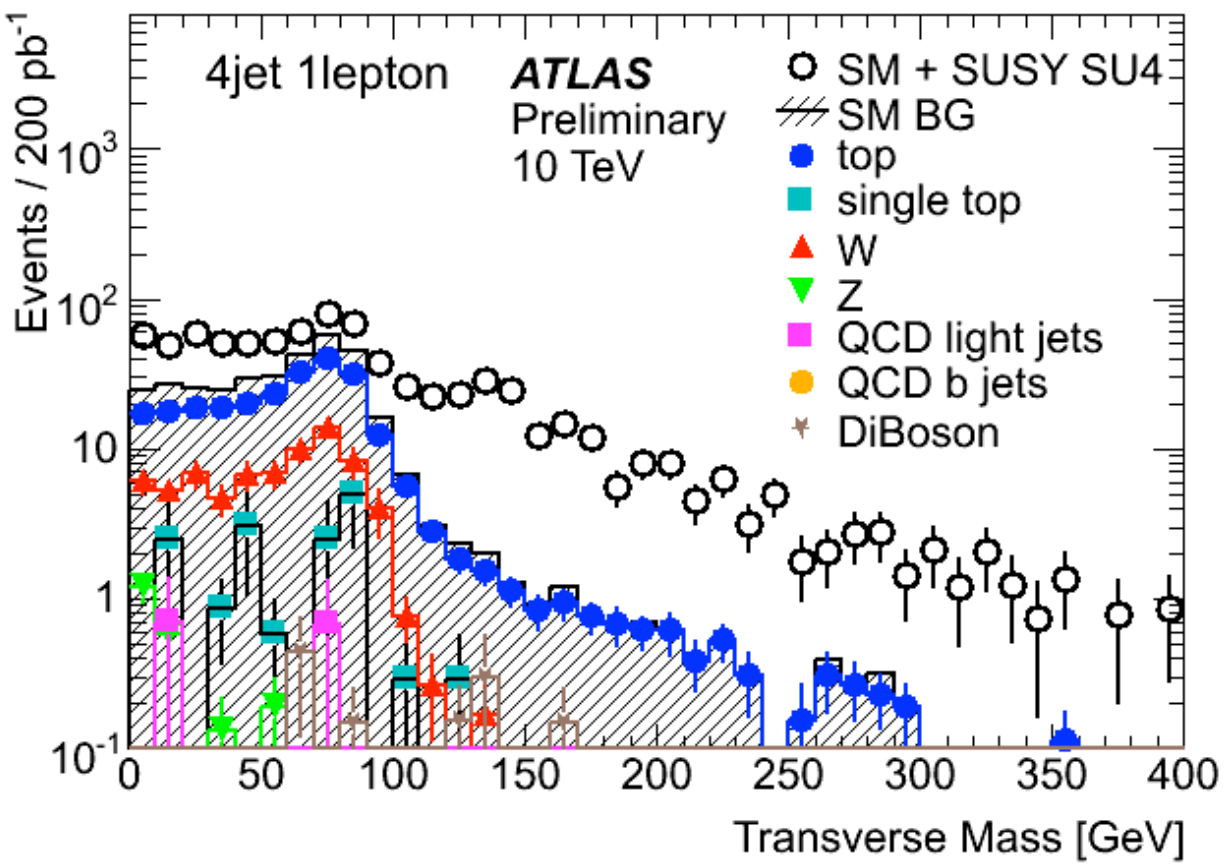
- Data-driven background estimates
  - Find a **control region** in phase space where SM background dominates
  - Use measurements in this region to infer SM background in signal region
  - Example W, top backgrounds to single-lepton search
  - **Playing two discriminate quantities off against each other**

- Well known matrix (M_T) method
  - Use low M_T control region
  - Predict MET spectrum
  - Weaknesses
    - Non-independence of variables
    - Signal contamination
  - More sophisticated methods ➔



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Background estimates

- "Tiles" method

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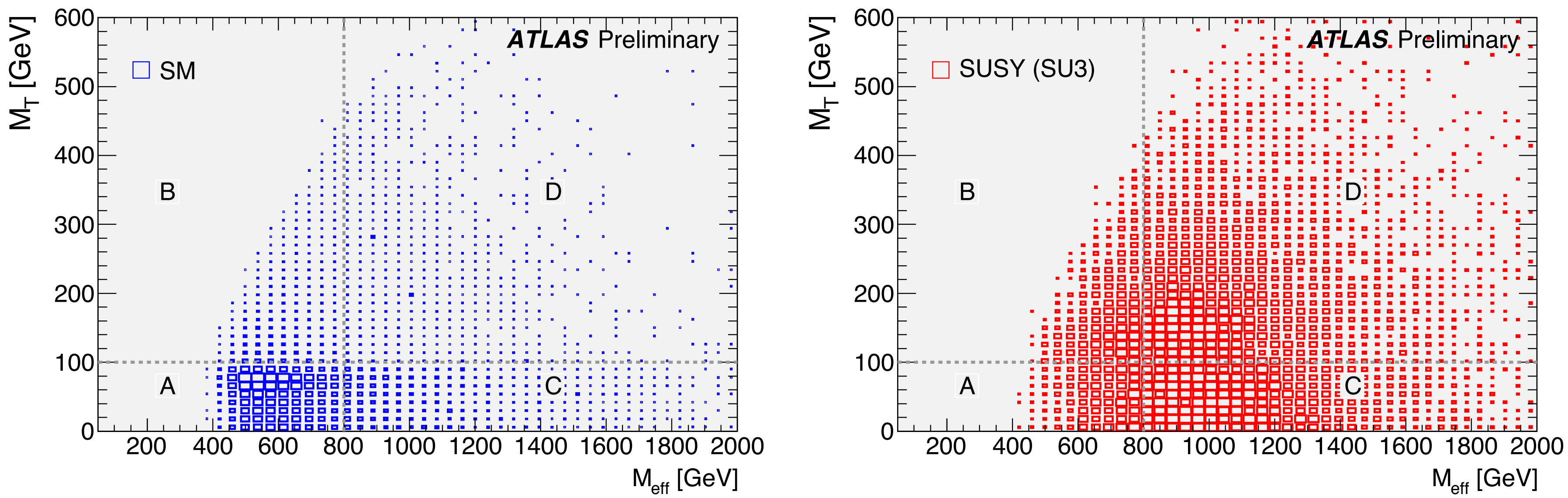
  - Use the Monte Carlo prediction for the shapes of SM backgrounds
  - Assume independence of variables for signal



  - Can express N_{evts} in each region in terms of f^{SM} and f^{SUSY}
  - Take f^{SM} from MC for each region and solve the system of linear equations

- Predicts the number of SM background and SUSY signal events in each region
- Background prediction not biassed by signal contamination

Di-lepton searches

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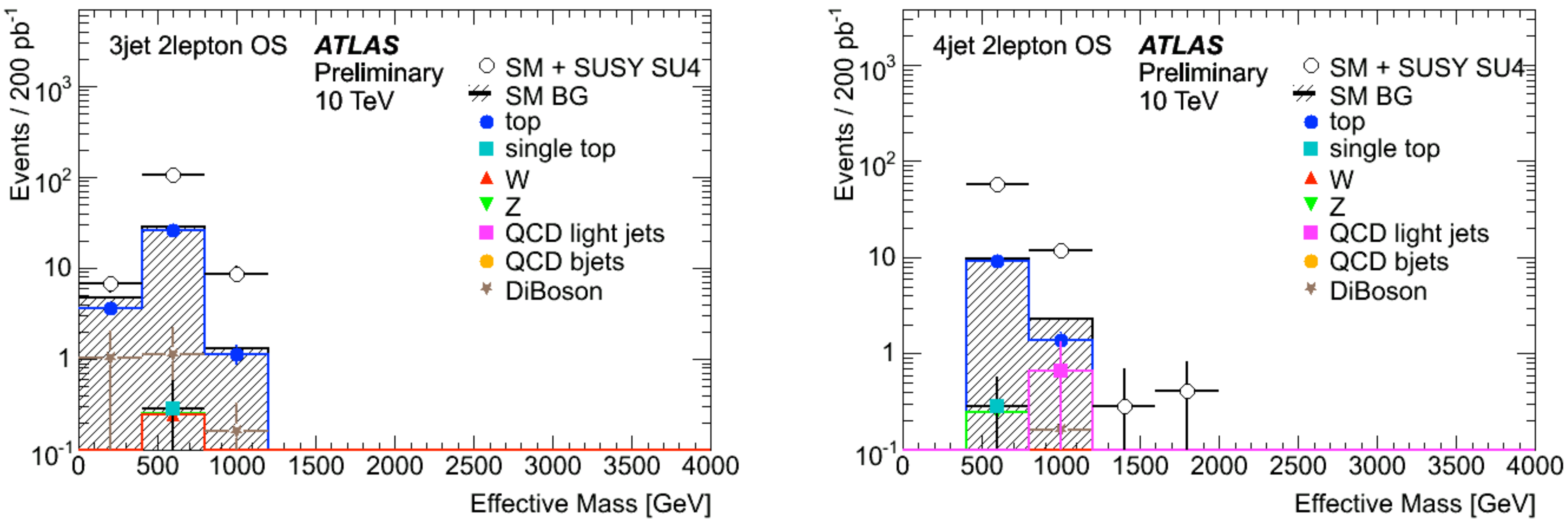

- Low yields but very interesting properties
- Same sign searches
  - Very low Standard Model background rate
  - Backgrounds from charge mis-identified top events (QCD in τ channel)
- Opposite sign
  - Use opposite-sign, opposite-flavour sample to subtract SM background

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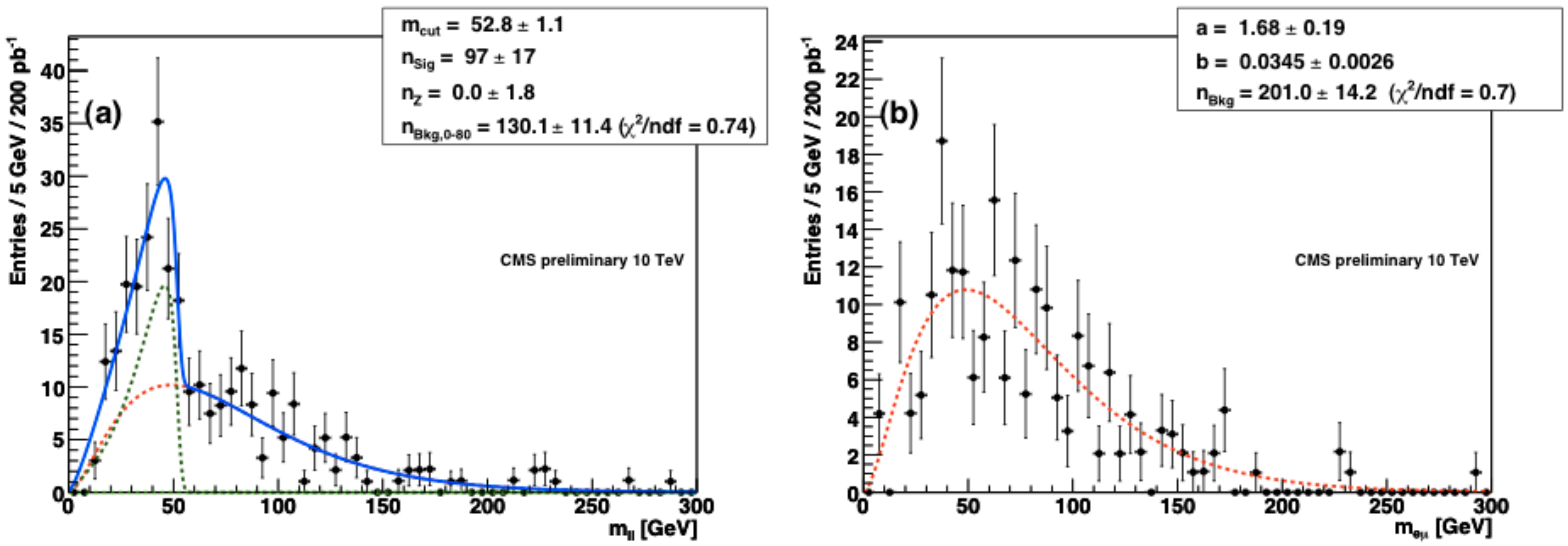
Di-lepton searches

CMS-PAS-SUS-09-002



- Fit ee, μμ and eμ distributions simultaneously
  - Resolution function and efficiencies from data
  - 200 pb^{-1} @ 10 TeV
  - Di-leptonic end-point $m_{ll,max}$=51.3 ± 1.5 (stat.) ± 0.9 (syst.) GeV [52.7 GeV]
- Nice example of what could be done with modest dataset

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Discovery reach @ 10 TeV

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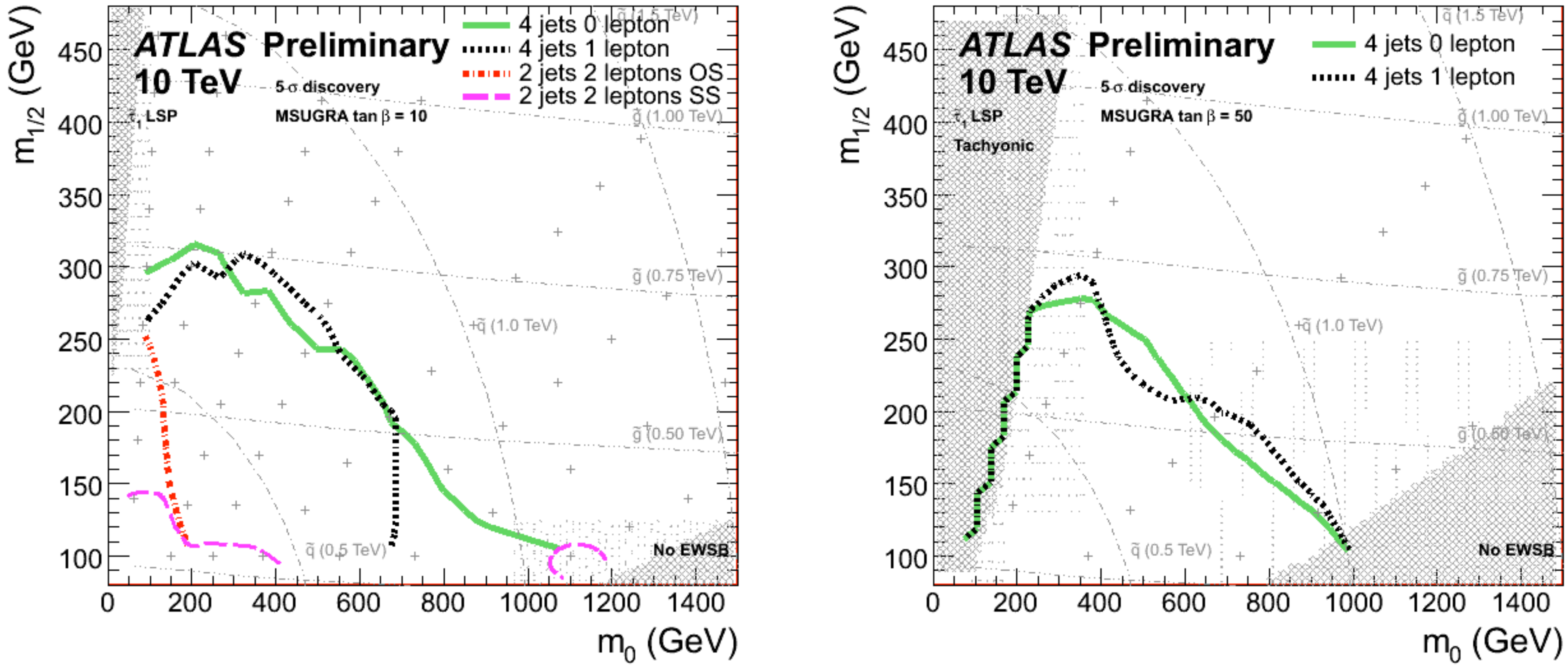
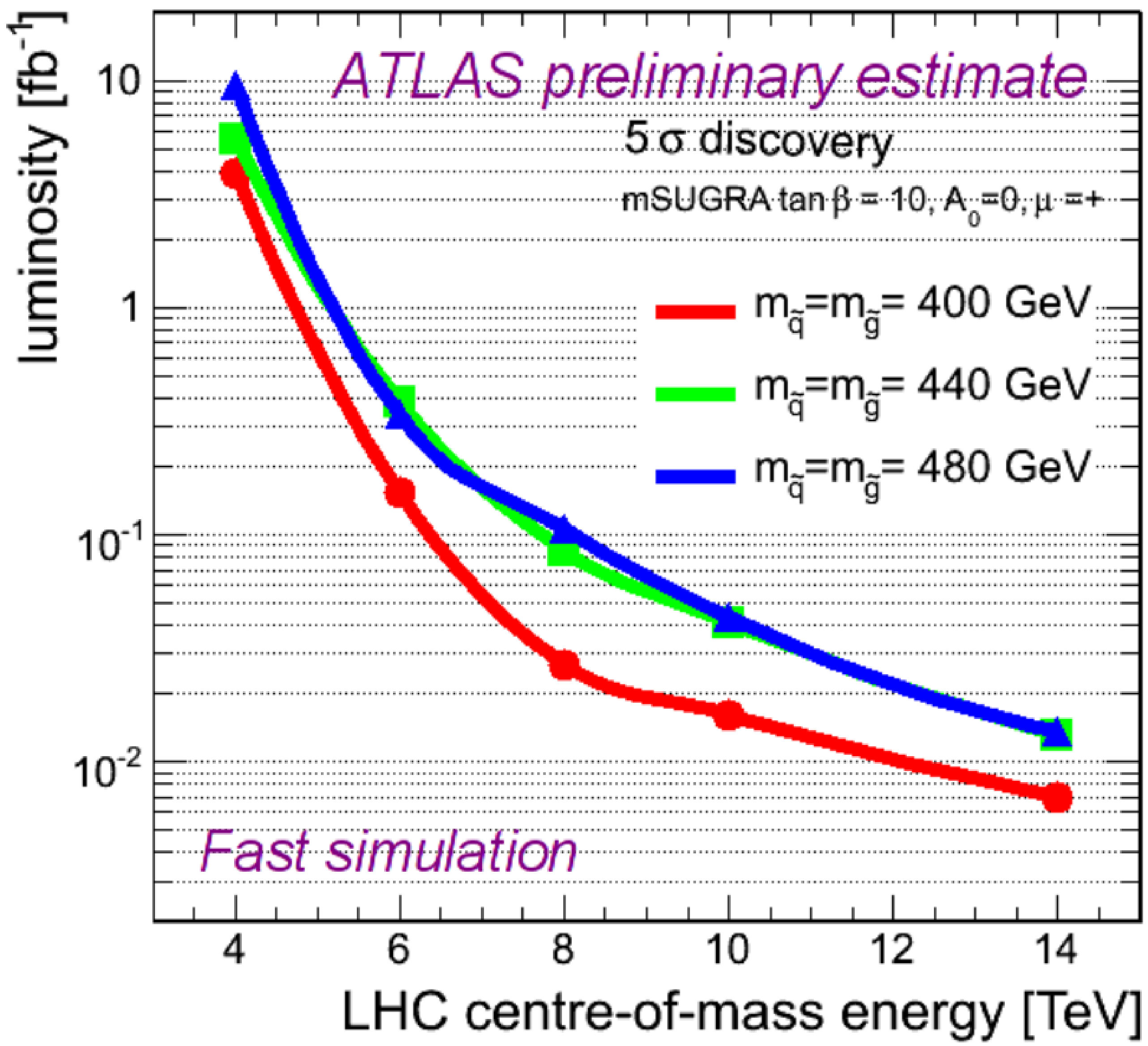


- Scan M_{eff} cut for best sensitivity (50% error on backgrounds)
- All-hadronic and single-lepton searches vie for highest sensitivity
- Clear discovery potential beyond the Tevatron with 200 pb^{-1} @ 10 TeV

Discovery reach @ 7 TeV

Chamonix 2009

- Discovery reach for single-lepton + jets + MET channel
- Need to get above the 400 GeV line to be competitive
- Possible with > 100 pb^{-1} @ 7 TeV
- 10 TeV much better!



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Summary

- Early searches based on robust generic signatures
  - Sensitive as possible to a variety of new physics models
- A wide range of data-driven techniques developed to measure efficiencies and backgrounds
  - Redundancy builds confidence
- Eagerly awaiting LHC collisions!

Backup: Links

- ATLAS latest results
  - https://twiki.cern.ch/twiki/bin/view/Atlas/AtlasResults
- ATLAS Physics TDR
  - http://cdsweb.cern.ch/record/1125884?ln=en
- CMS latest results
  - https://twiki.cern.ch/twiki/bin/view/CMS/PhysicsResults
- CMS Physics TDR
  - http://cmsdoc.cern.ch/cms/cpt/tdr/

Backup: Benchmark points

Low mass (LM) mSUGRA benchmarks

Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
LM0	200	160	–400	10	1	
LM1	60	250	0	10	+	
LM2	185	350	0	35	+	
LM2mhf360	185	360	0	35	+	
LM3	330	240	0	20	+	
LM4	210	285	0	10	+	
LM5	230	360	0	10	+	
LM6	85	400	0	10	+	
LM7	3000	230	0	10	+	
LM8	500	300	–300	10	+	
LM9	1450	175	0	50	+	
LM9p	1450	230	0	10	+	
LM9t175	1450	175	0	50	+	mtop = 175
LM10	3000	500	0	10	+	
LM11	250	325	0	35	+	
LM12						TBD
LM13						focus point, TBD

High mass (HM) mSUGRA benchmarks

Benchmark	m0	m1/2	A0	tanb	sgn(mu)	Notes
HM1	180	850	0	10	+	
HM2	350	800	0	35	+	
HM3	700	800	0	10	+	
HM4	1350	600	0	10	+	

GMSB (GM) benchmarks

Benchmark	Lambda	M_mess	N5	C_Grav	tanb	sgn(mu)	Notes
GM1b	80	160	1	1	15	+	
GM1c	100	200	1	1	15	+	
GM1d	120	240	1	1	15	+	
GM1e	140	280	1	1	15	+	
GM1f	160	320	1	1	15	+	
GM1g	180	360	1	1	15	+	

Particle	SU1	SU2	SU3	SU4	SU6	SU8.1	SU9
$\tilde{d}_L$	764.90	3564.13	636.27	419.84	870.79	801.16	956.07
$\tilde{u}_L$	760.42	3563.24	631.51	412.25	866.84	797.09	952.47
$\tilde{b}_1$	697.90	2924.80	575.23	358.49	716.83	690.31	868.06
$\tilde{t}_1$	572.96	2131.11	424.12	206.04	641.61	603.65	725.03
$\tilde{d}_R$	733.53	3576.13	610.69	406.22	840.21	771.91	920.83
$\tilde{u}_R$	735.41	3574.18	611.81	404.92	842.16	773.69	923.49
$\tilde{b}_2$	722.87	3500.55	610.73	399.18	779.42	743.09	910.76
$\tilde{t}_2$	749.46	2935.36	650.50	445.00	797.99	766.21	911.20
$\tilde{e}_L$	255.13	3547.50	230.45	231.94	411.89	325.44	417.21
$\tilde{\nu}_e$	238.31	3546.32	216.96	217.92	401.89	315.29	407.91
$\tilde{\tau}_1$	146.50	3519.62	149.99	200.50	181.31	151.90	320.22
$\tilde{\nu}_\tau$	237.56	3532.27	216.29	215.53	358.26	296.98	401.08
$\tilde{e}_R$	154.06	3547.46	155.45	212.88	351.10	253.35	340.86
$\tilde{\tau}_2$	256.98	3533.69	232.17	236.04	392.58	331.34	416.43
$\tilde{g}$	832.33	856.59	717.46	413.37	894.70	856.45	999.30
$\tilde{\chi}_1^0$	136.98	103.35	117.91	59.84	149.57	142.45	173.31
$\tilde{\chi}_2^0$	263.64	160.37	218.60	113.48	287.97	273.95	325.39
$\tilde{\chi}_3^0$	466.44	179.76	463.99	308.94	477.23	463.55	520.62
$\tilde{\chi}_4^0$	483.30	294.90	480.59	327.76	492.23	479.01	536.89
$\tilde{\chi}_1^+$	262.06	149.42	218.33	113.22	288.29	274.30	326.00
$\tilde{\chi}_2^+$	483.62	286.81	480.16	326.59	492.42	479.22	536.81
h^0	115.81	119.01	114.83	113.98	116.85	116.69	114.45
H^0	515.99	3529.74	512.86	370.47	388.92	430.49	632.77
A^0	512.39	3506.62	511.53	368.18	386.47	427.74	628.60
H^+	521.90	3530.61	518.15	378.90	401.15	440.23	638.88
t	175.00	175.00	175.00	175.00	175.00	175.00	175.00