Early SUSY searches at the LHC

Alex Tapper

Searching for SUSY at the LHC and interplay with astroparticle physics

Institute of Physics Workshop, 24th March 2010, Imperial College London

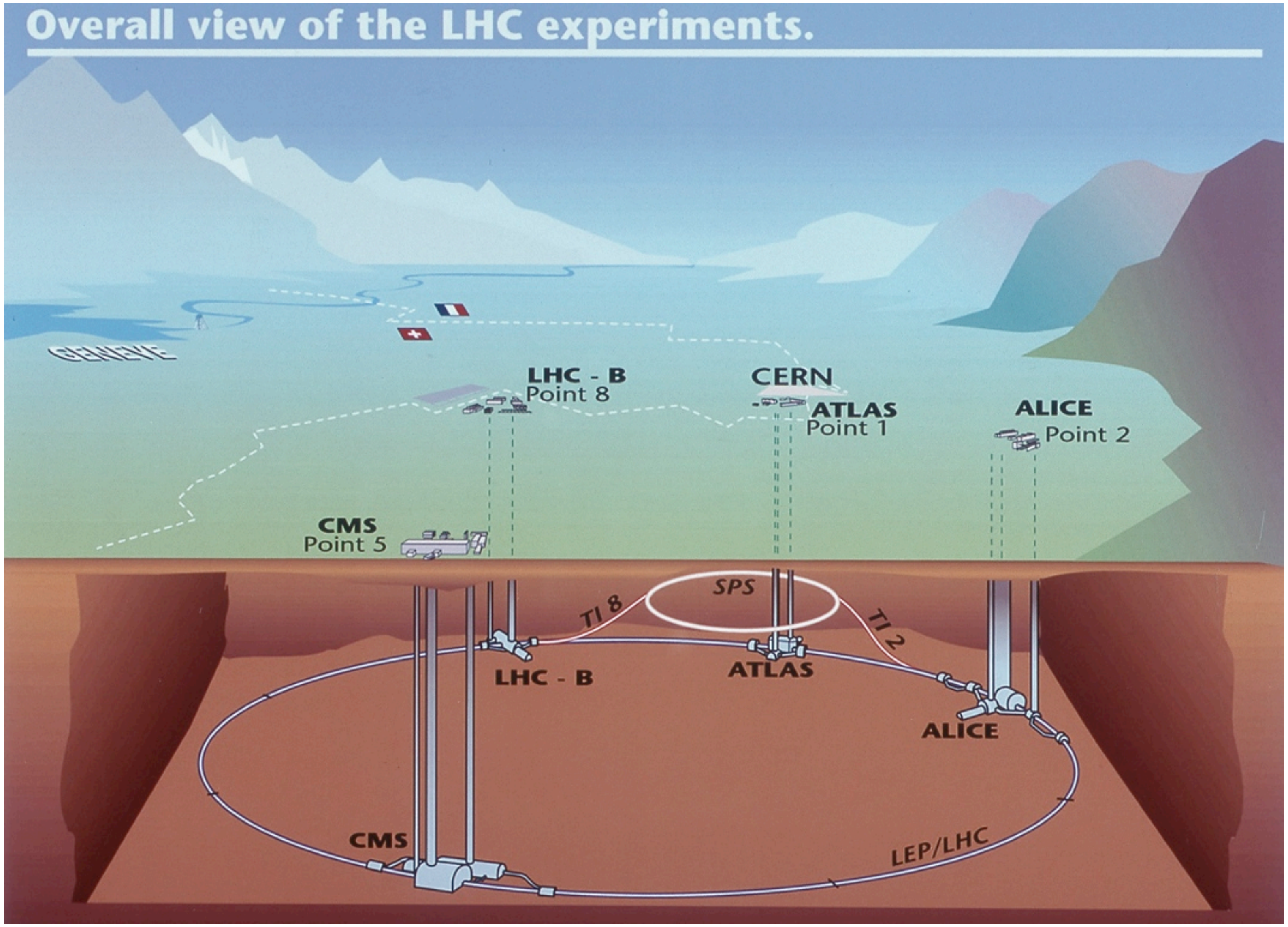
IOP Institute of Physics

Imperial College London

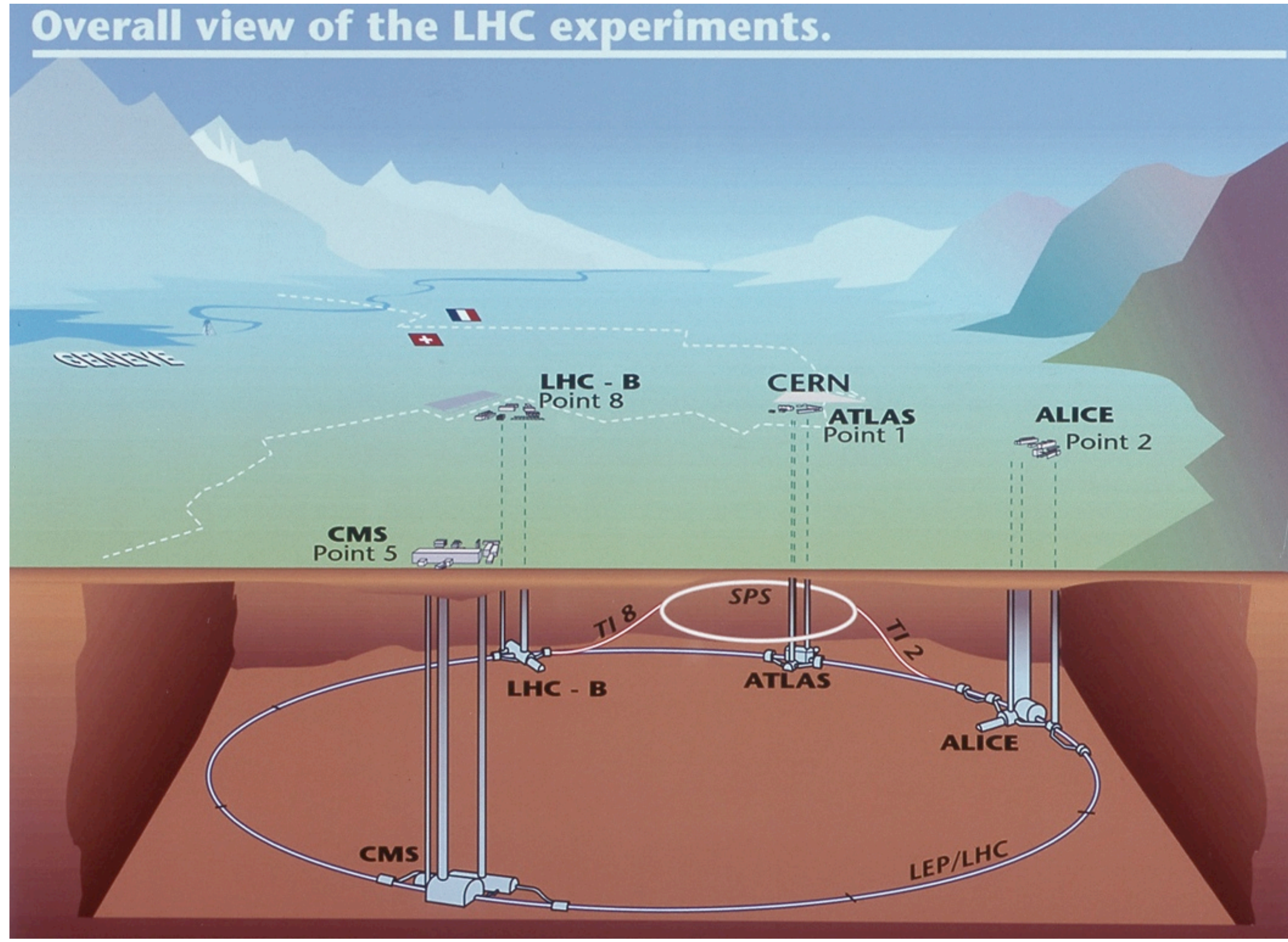
Introduction

- Many different SUSY scenarios investigated by LHC expts
- My brief is to describe plans for early SUSY searches
- What we plan to do with the 2010 and 2011 data
- Covering discovery not really mass, spin etc. determination

The Large Hadron Collider



The Large Hadron Collider



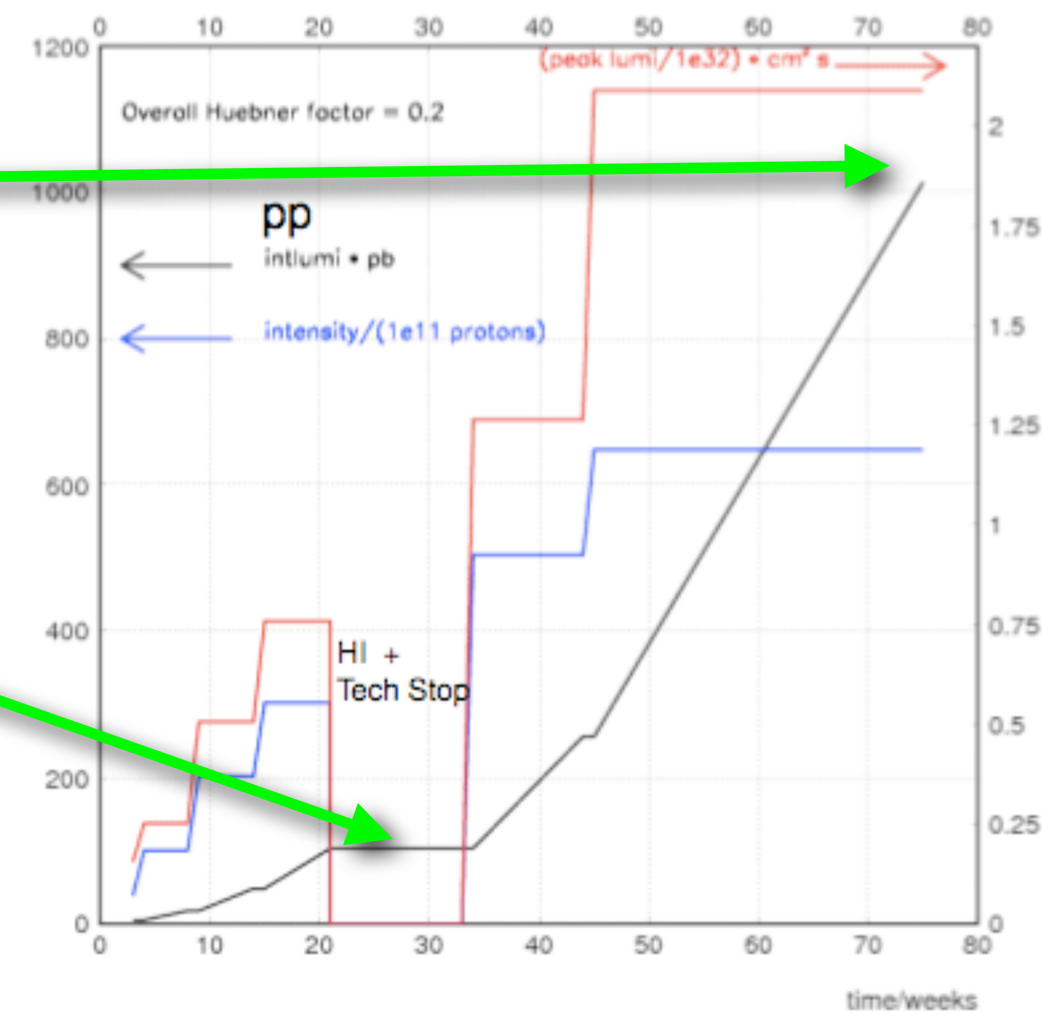
Imperial College London

The Large Hadron Collider

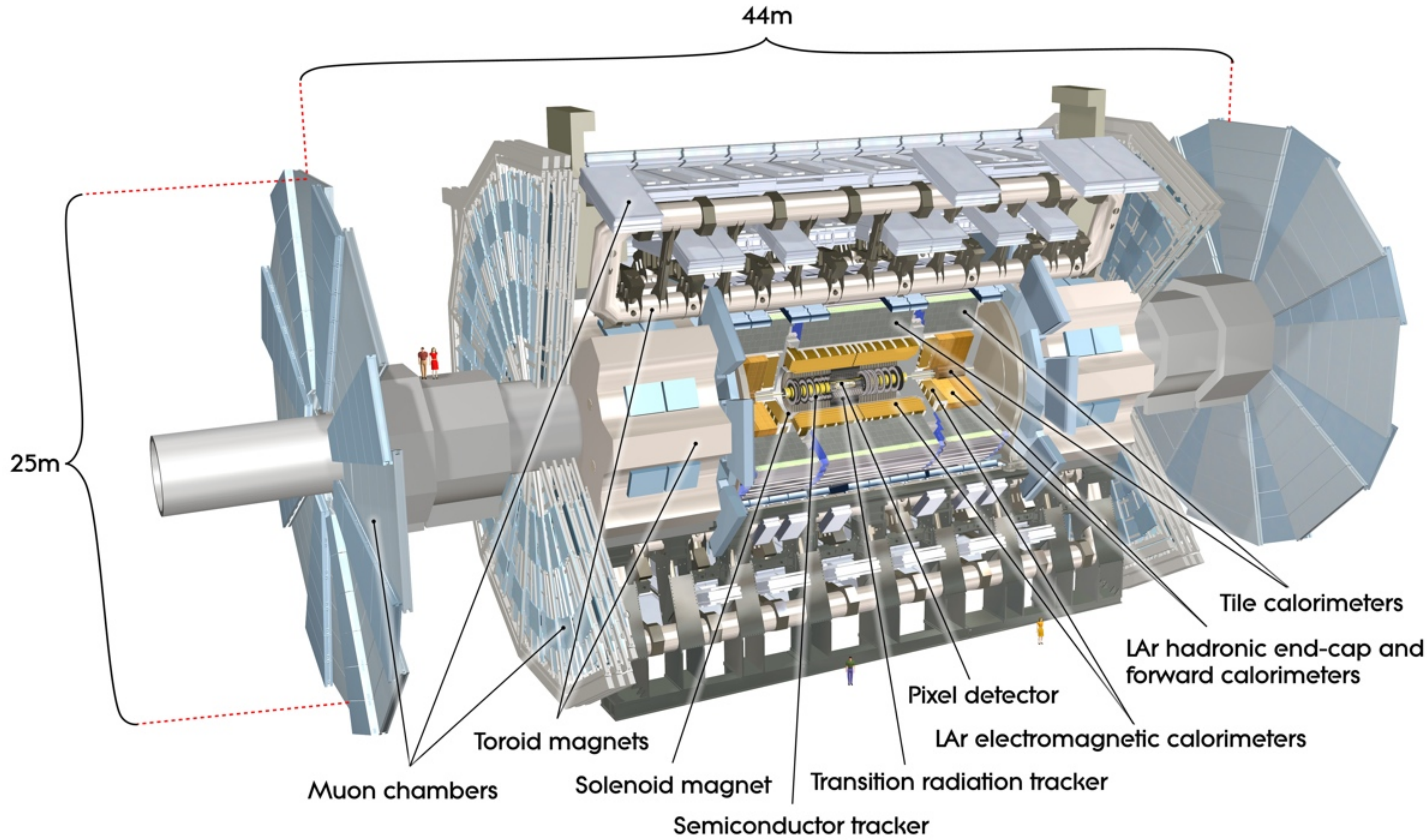
M. Fero-Luzzi

1 fb^{-1} by end of 2011

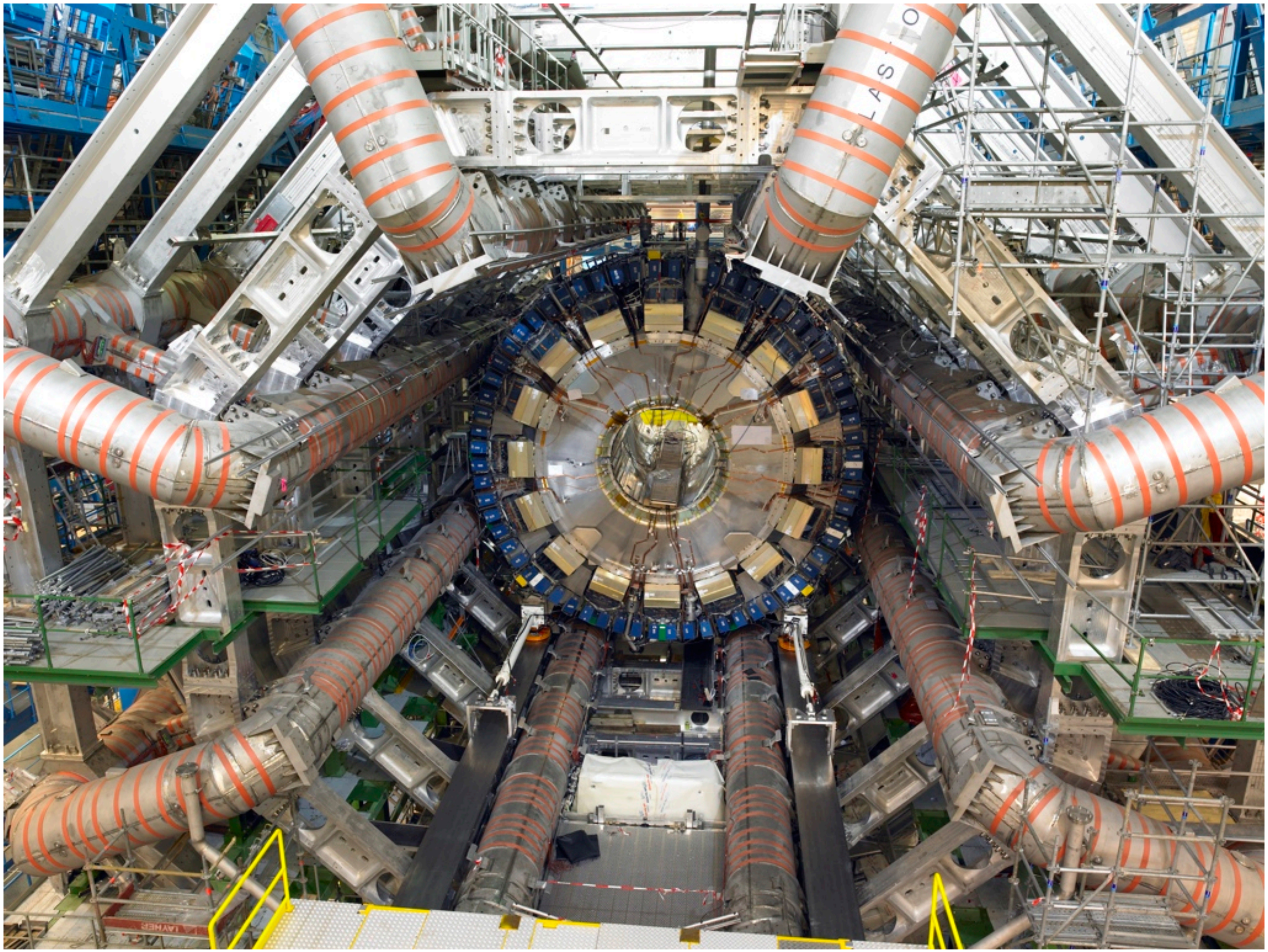
100 pb^{-1} by end of 2010



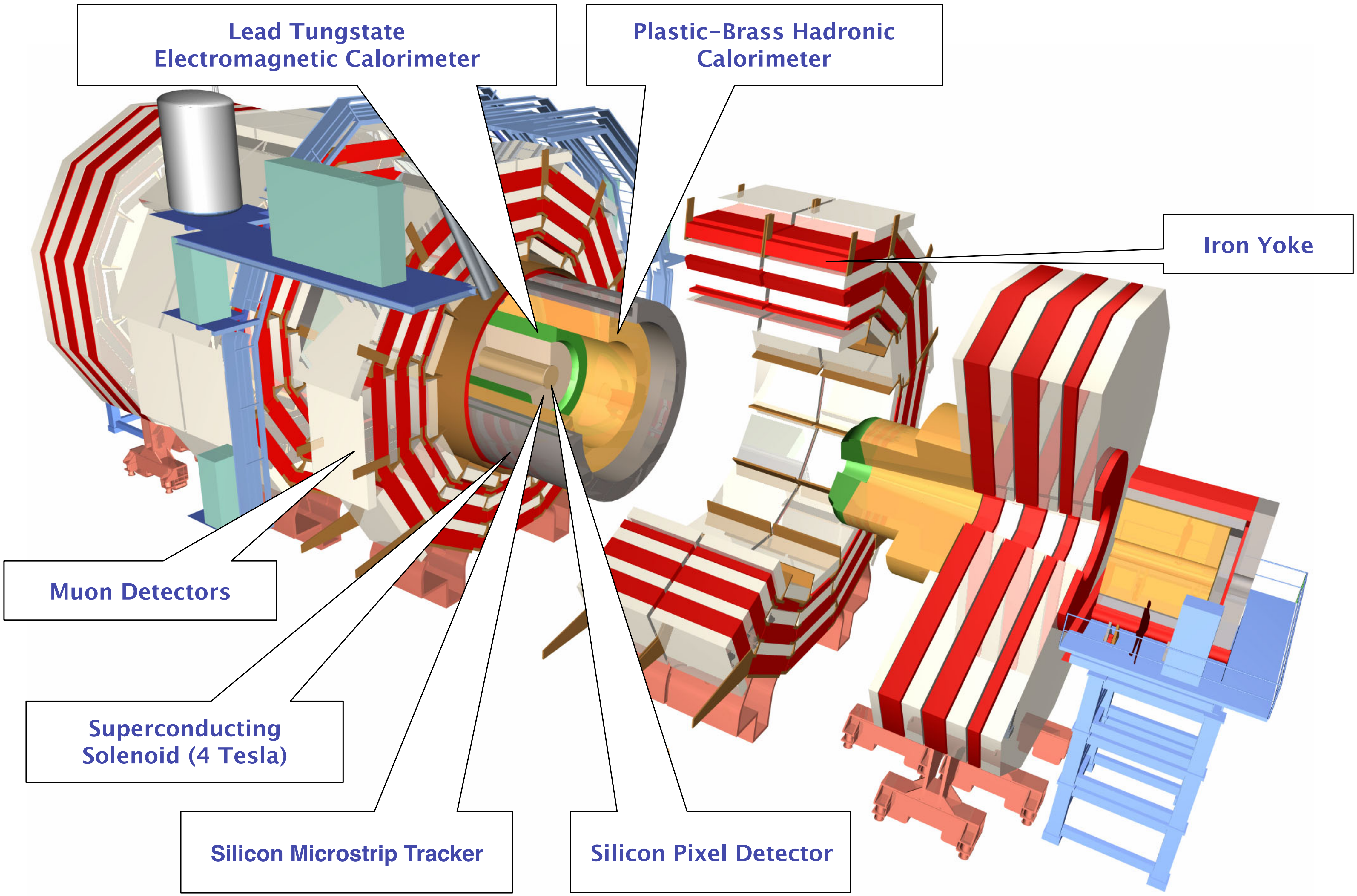
The ATLAS detector



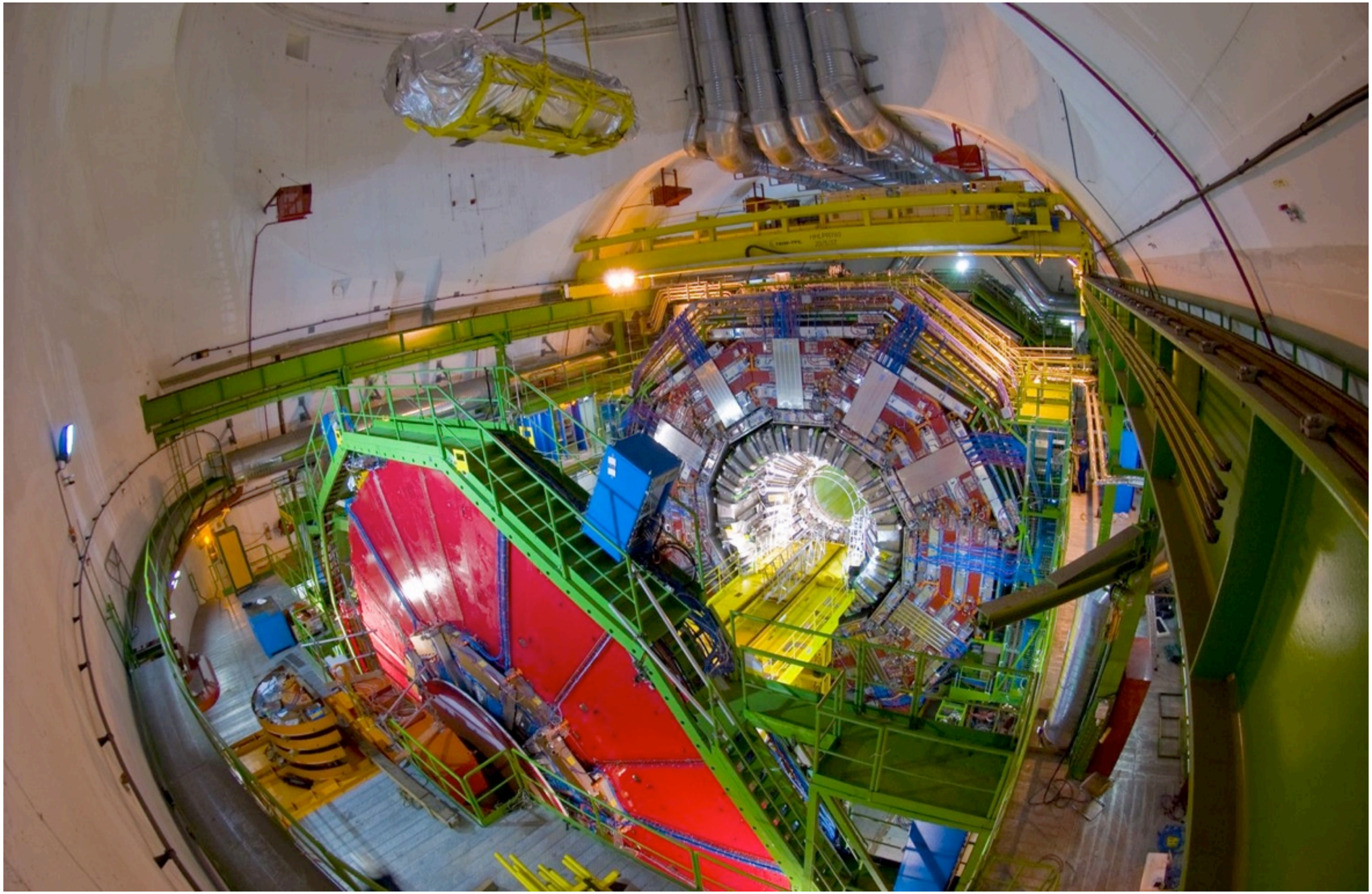
The ATLAS detector



The CMS detector

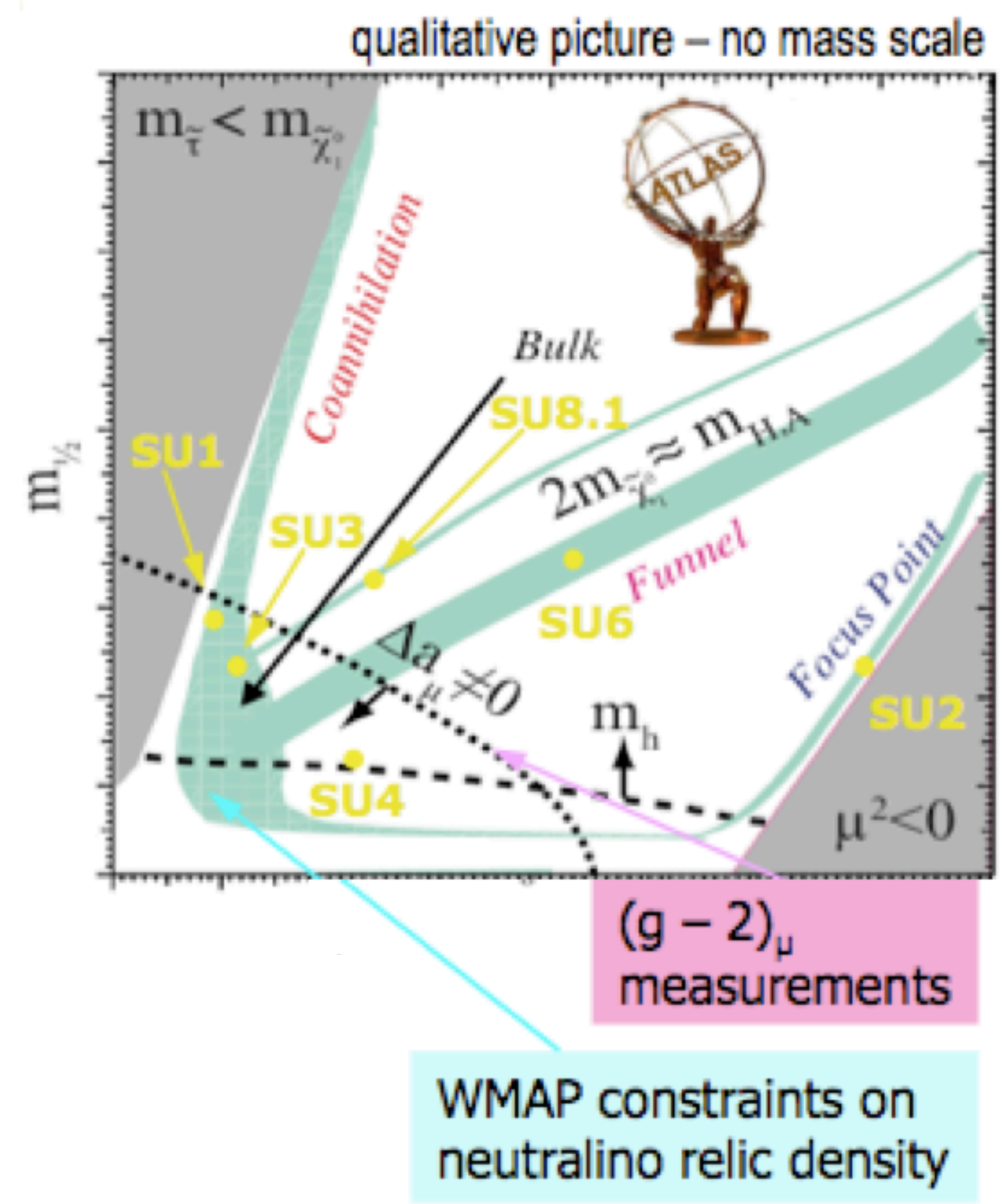


The CMS detector



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

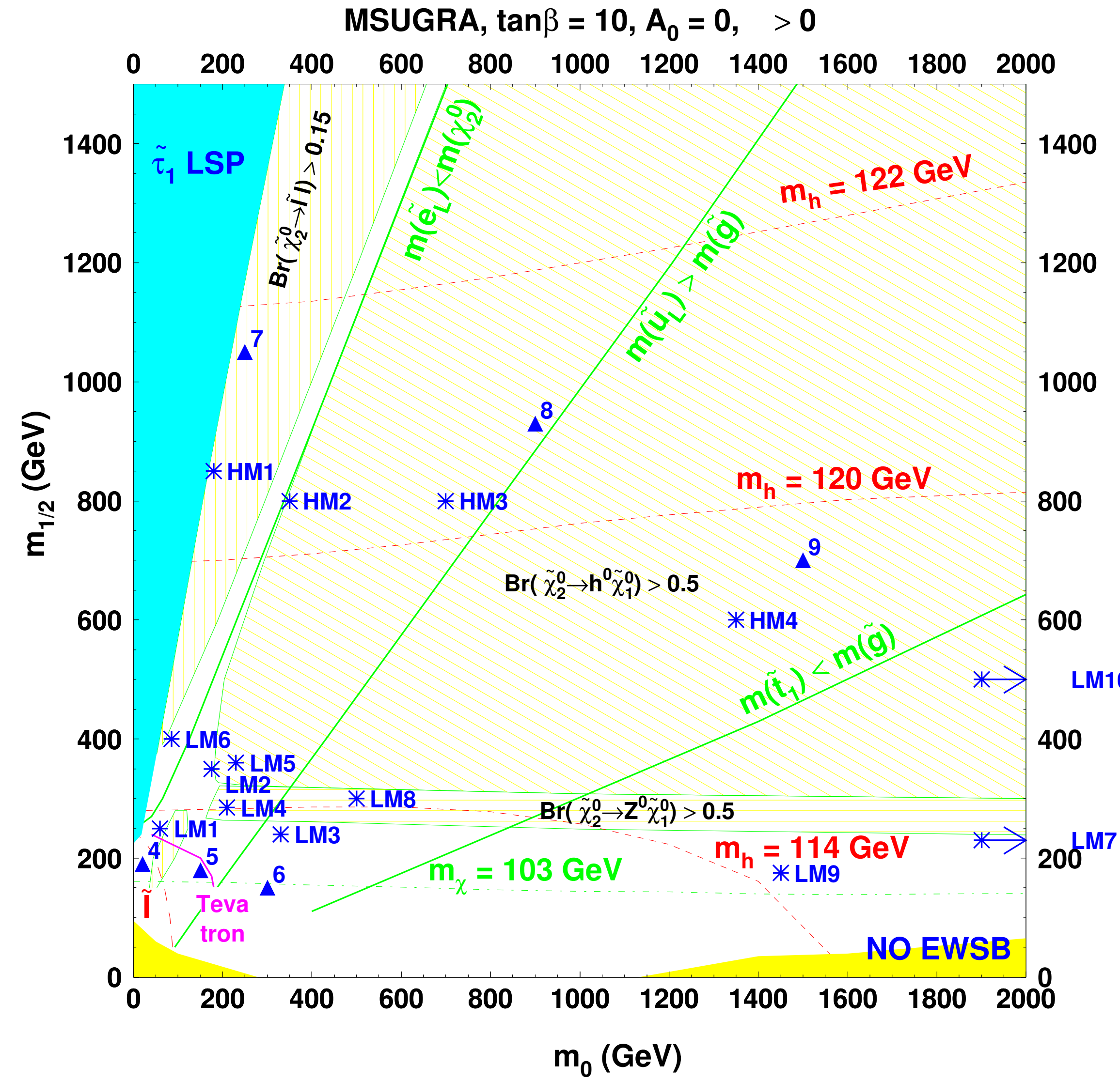


Full details of benchmark points in backup slides

Imperial College London

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
  - LM0 and LM1 for CMS

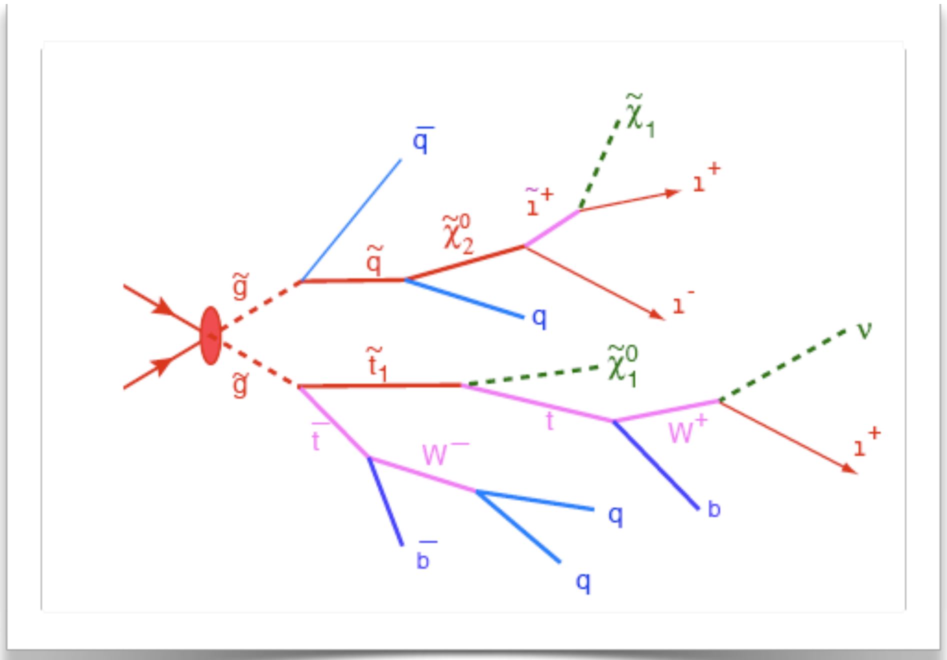


J. Phys. G: Nucl. Part. Phys. 34 (2006)

Full details of benchmark points in backup slides

Imperial College London

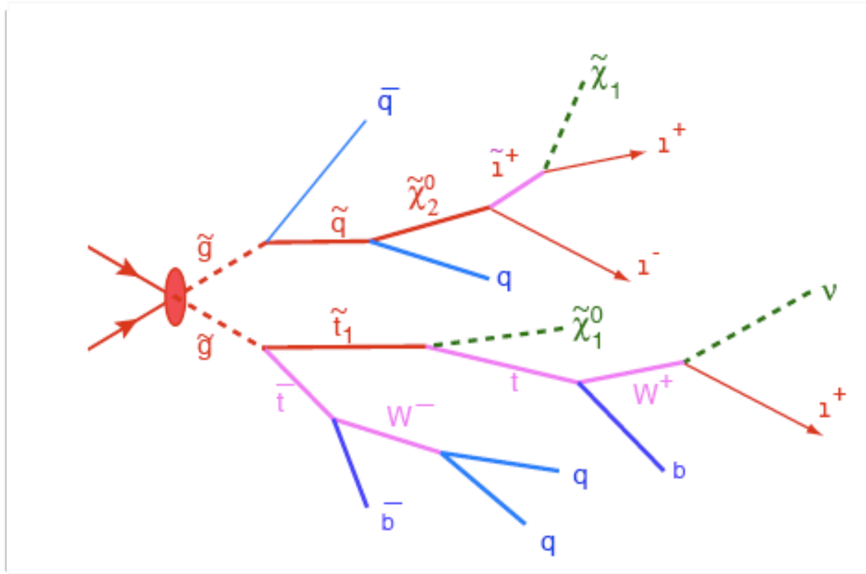
Search strategy



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

Imperial College London

Search strategy



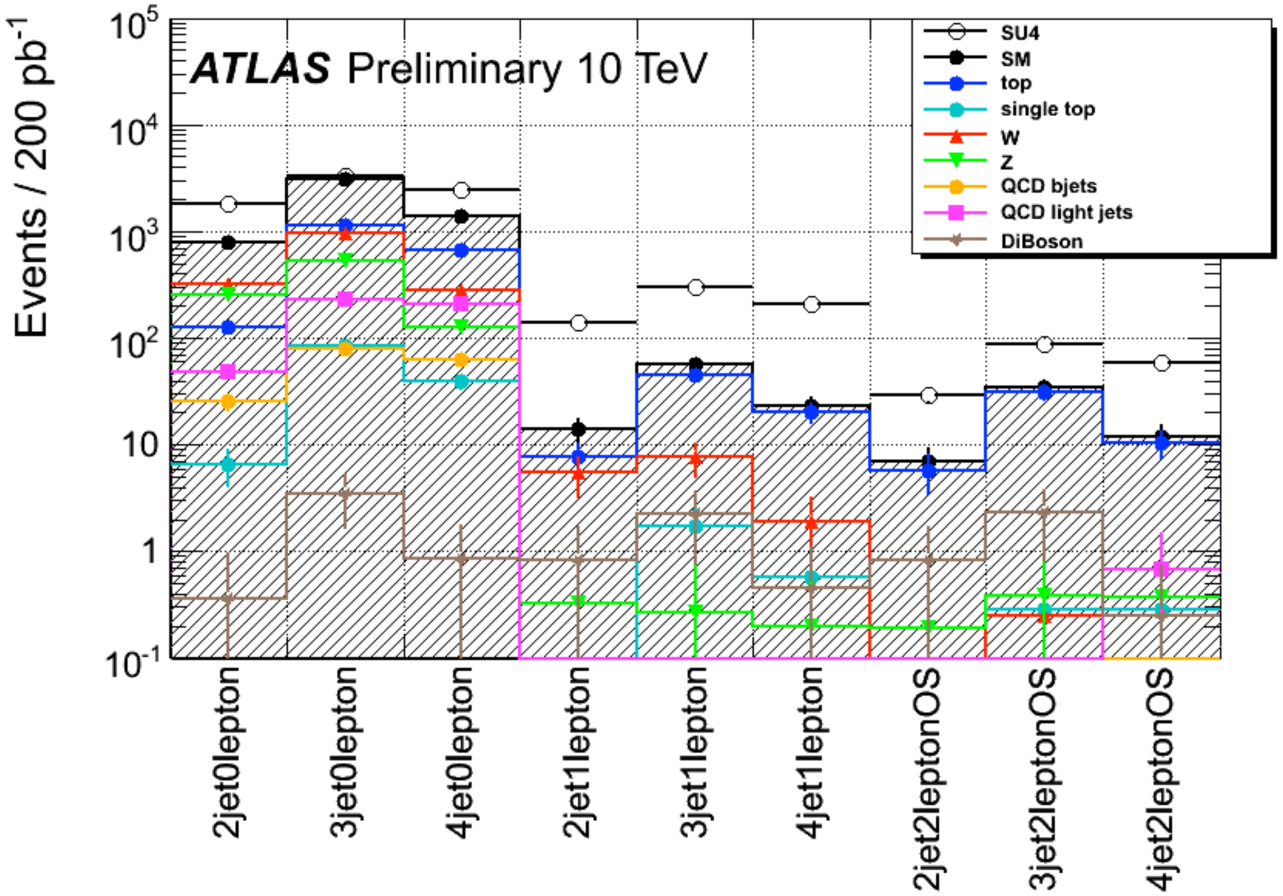
- Production
  - Squark and gluino expected to dominate
  - Strong production so high cross section
  - Cross section depends only on masses
  - Approx. independent of SUSY model
- Decay
  - Details of decay chain depend on SUSY model (mass spectra, branching ratios, etc.)
  - Assume R_P conserved ➔ 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

- How might such a generic search look?

ATL-PHYS-PUB-2009-084

  - 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
- Measuring backgrounds is the key ➔

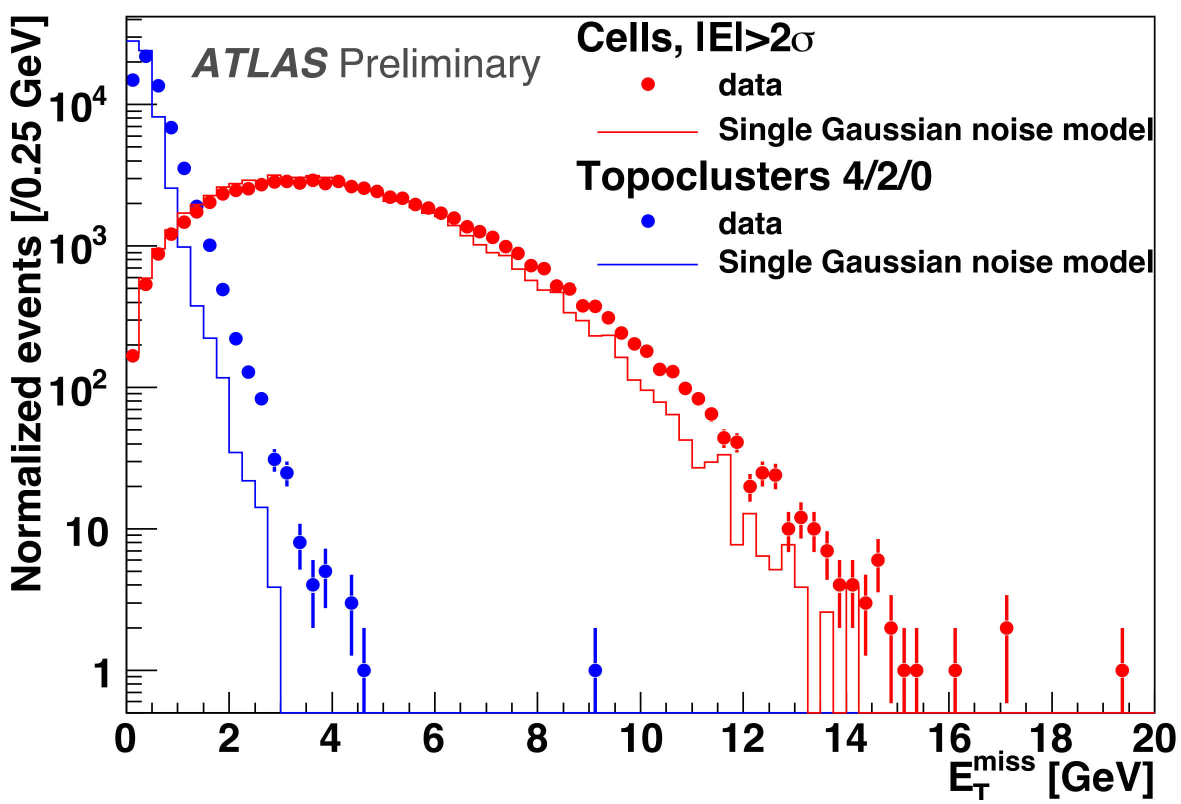
Imperial College London

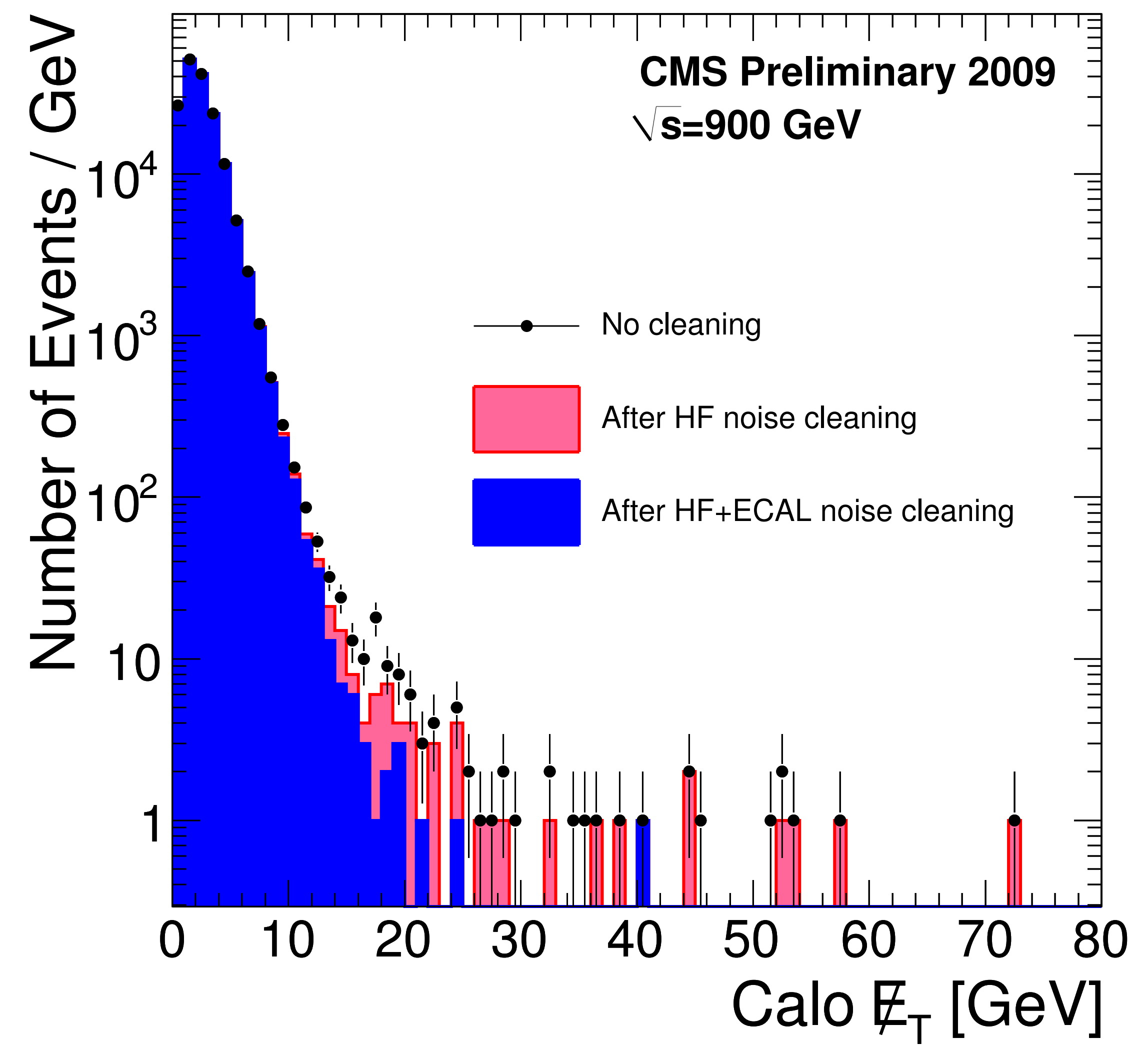
Backgrounds

- 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 ➔ results from 2009 pilot run
- Beam related
  - Beam-halo muons (and cosmic-ray muons), beam-gas events
  - Data and simulation already ➔ measure in situ too

Commissioning and calibration

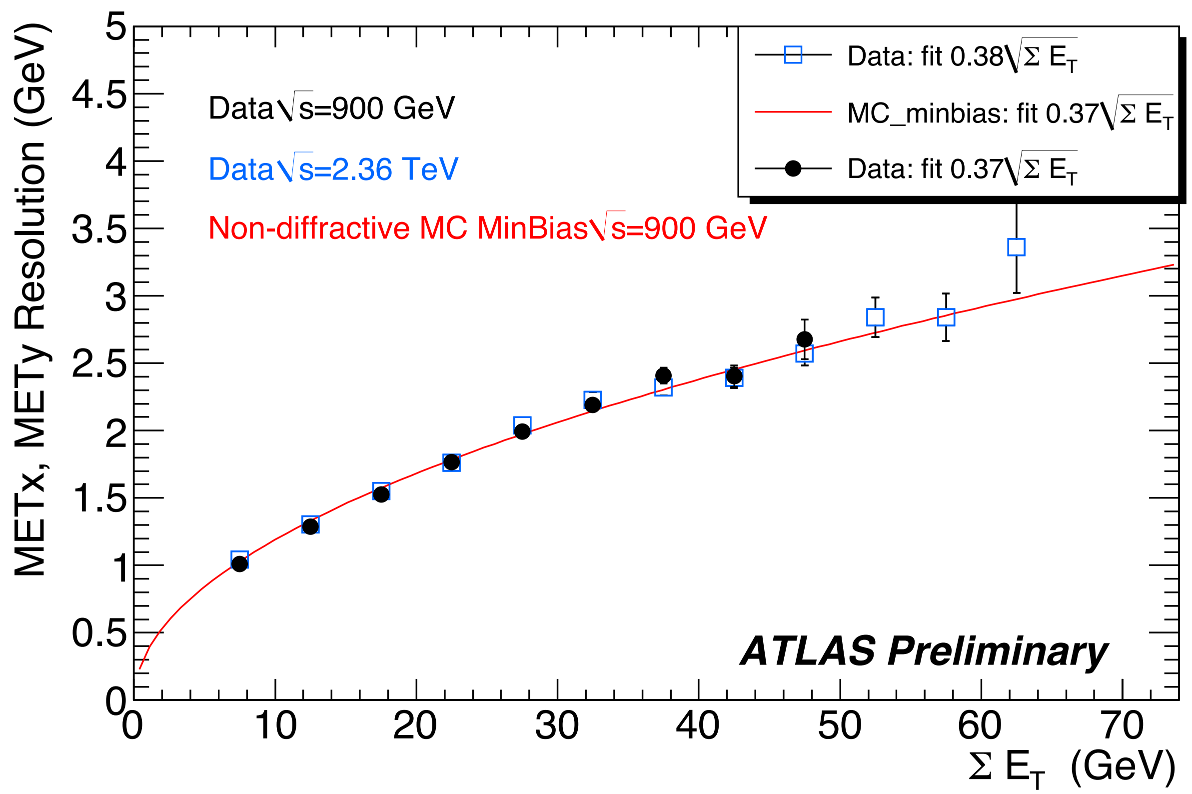
- Universal astonishment at how well the simulation describes the data
- Detector noise under study ➔ promising start in understanding

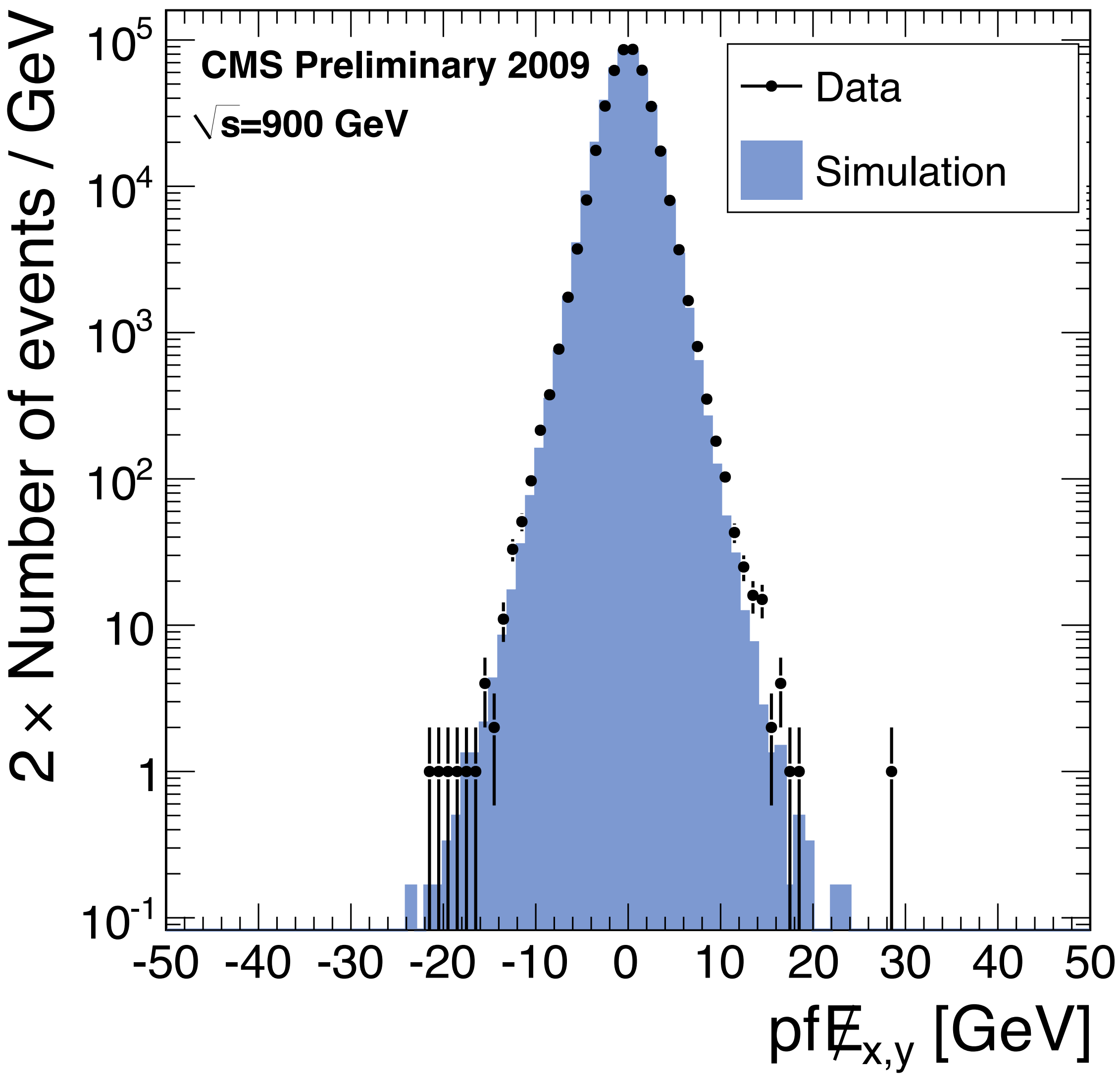




Commissioning and calibration

- Universal astonishment at how well the simulation describes the data
- Resolutions well described by simulation

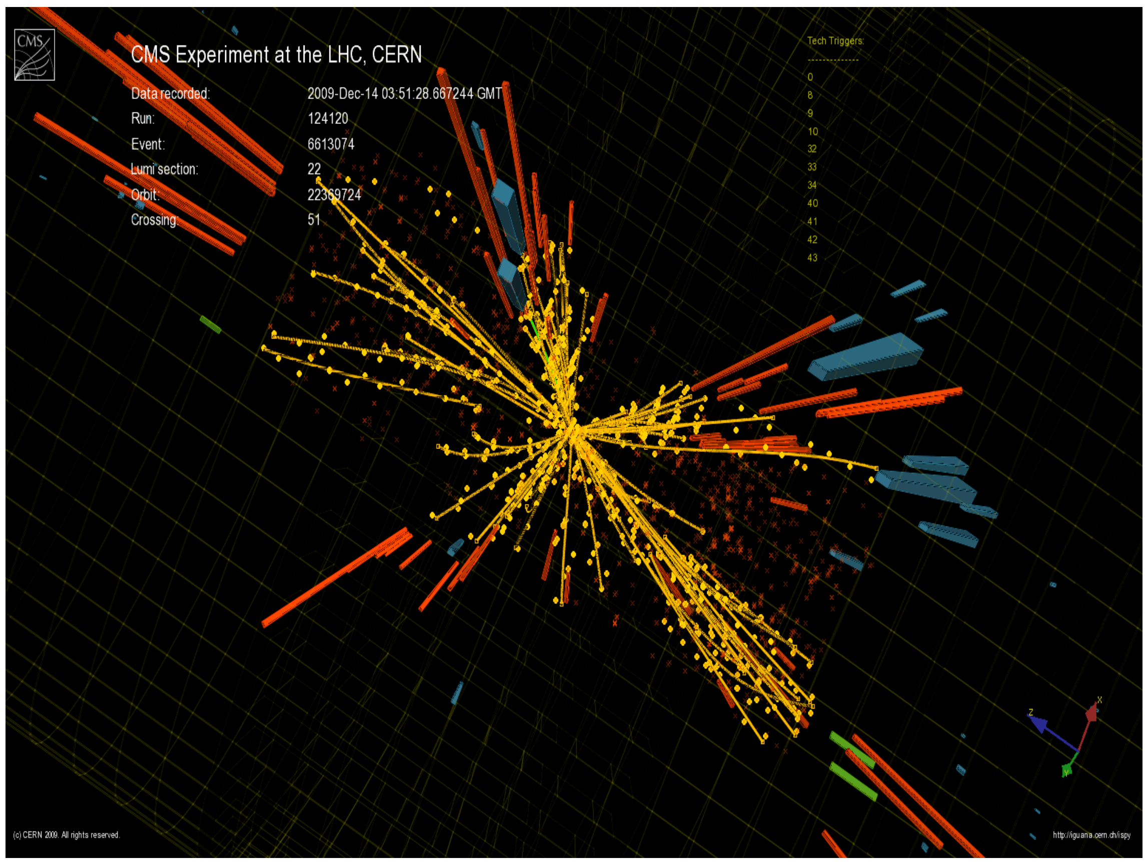


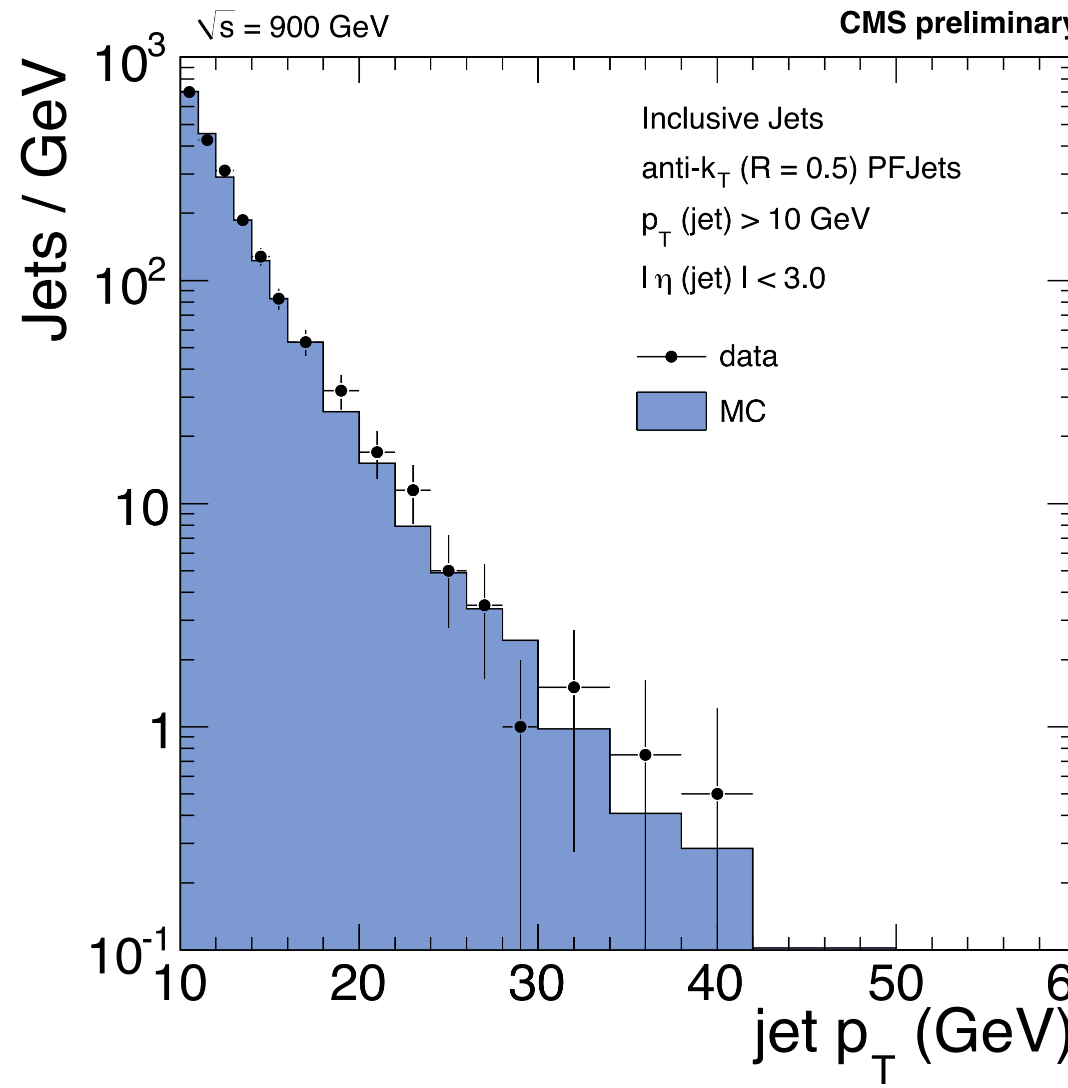


Imperial College London

Commissioning and calibration

- Universal astonishment at how well the simulation describes the data
- Higher-level objects looking good ➔ jet p_T spectrum





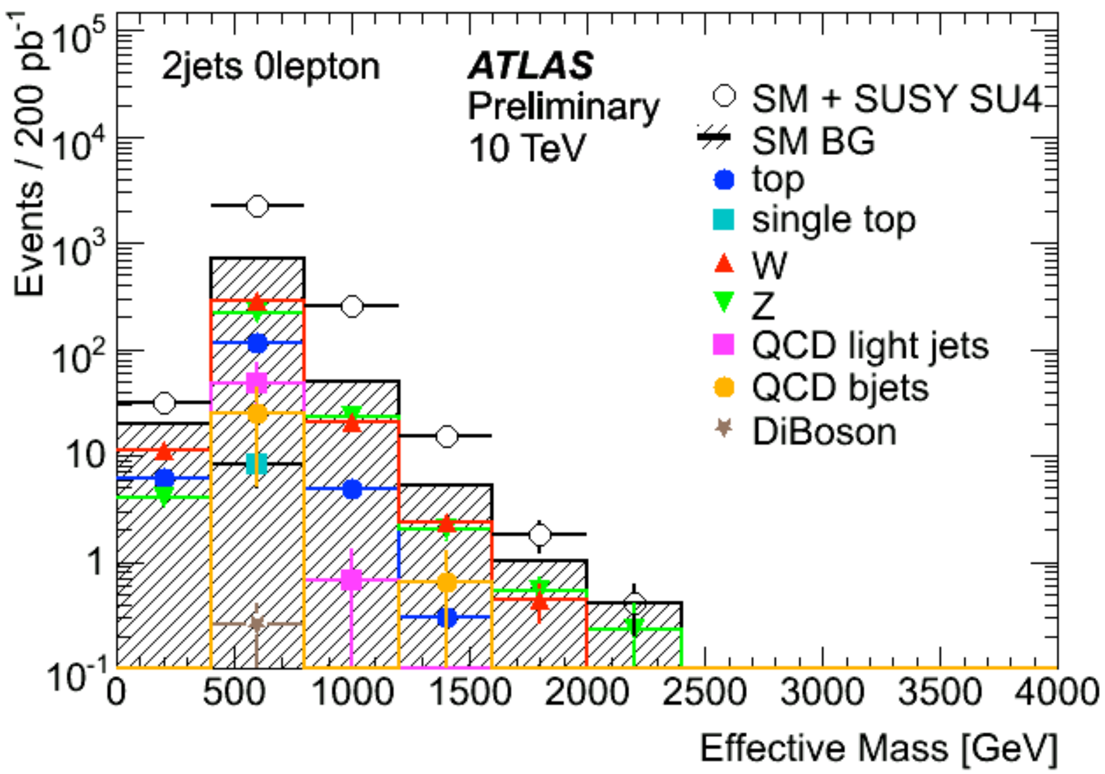
Imperial College London

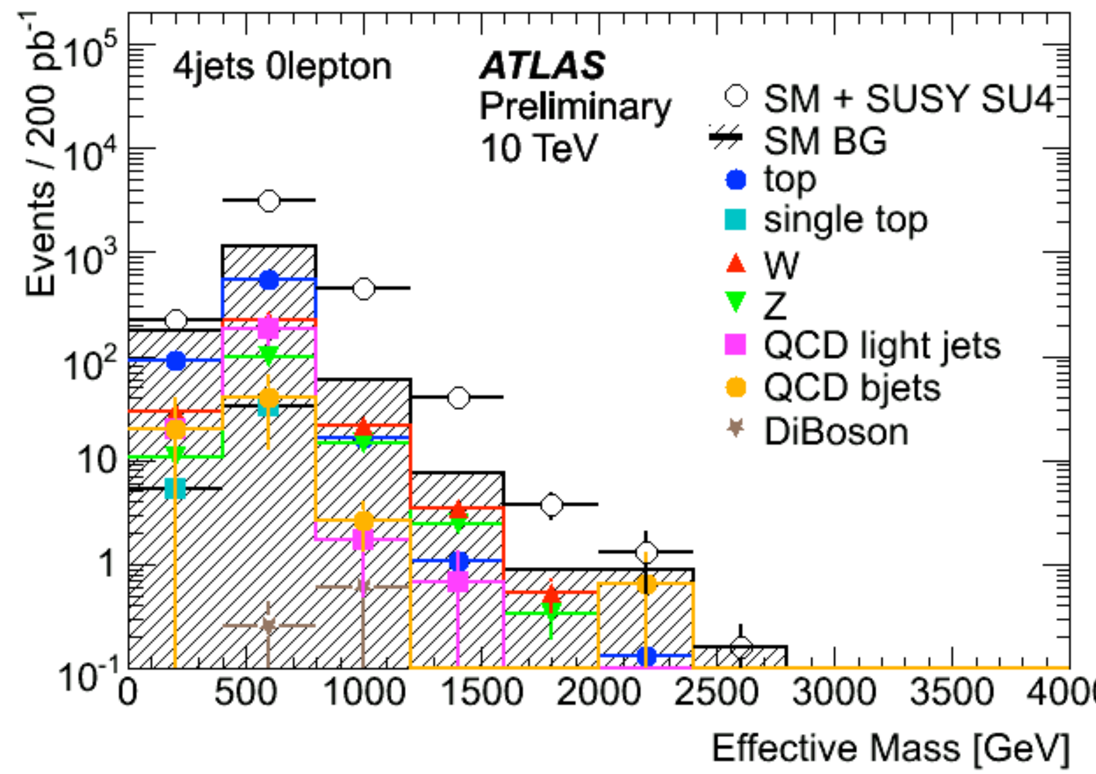
Physics backgrounds

- 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

ATL-PHYS-PUB-2009-084



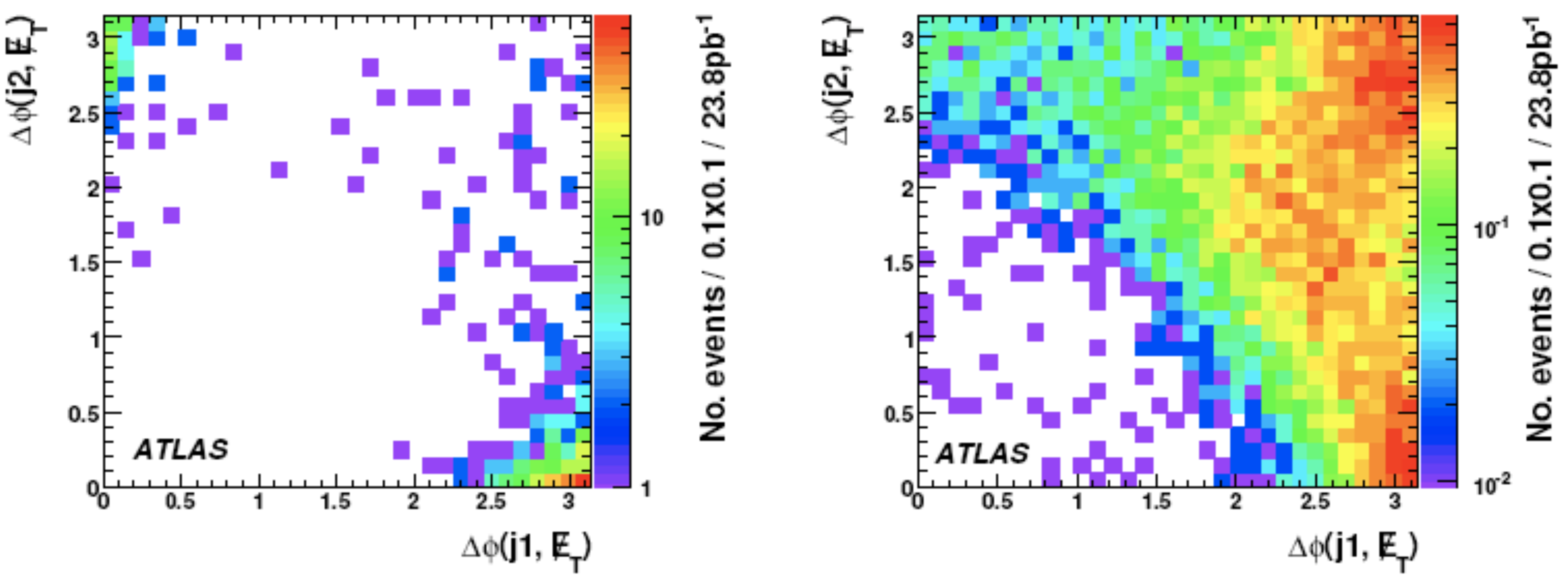


- All-hadronic search highly sensitive to SUSY
- But suffers from many backgrounds
- Nice examples of backgrounds both from detector effects and from Standard Model physics

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)



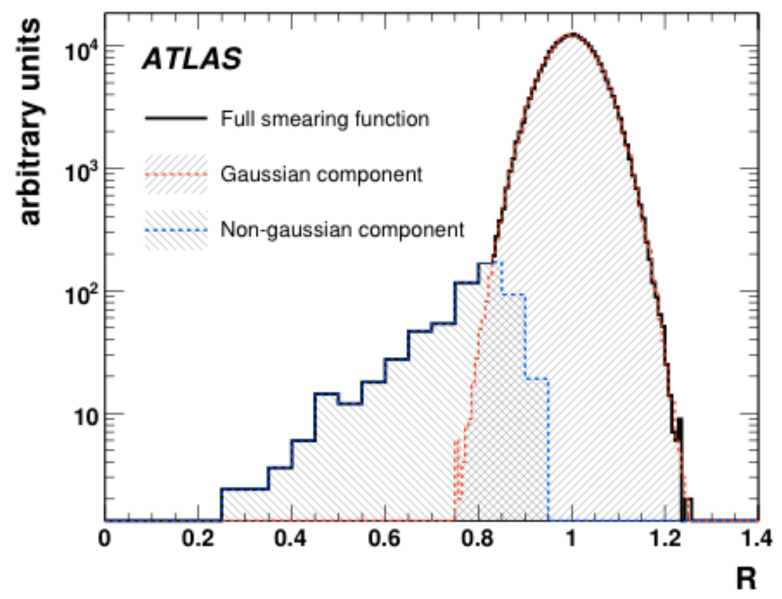
- Several methods developed to predict MET tail from QCD events
  - Matrix methods to estimate from control regions
  - Smearing method ➔

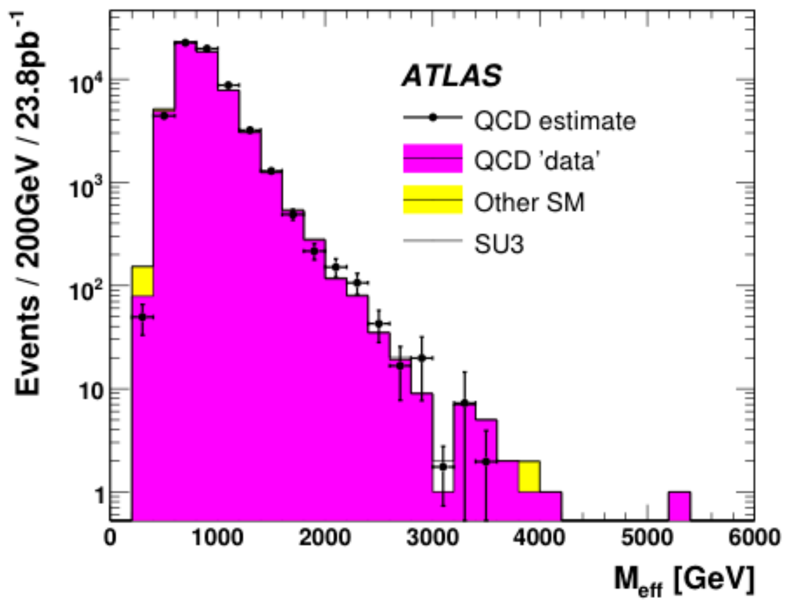
Imperial College London

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

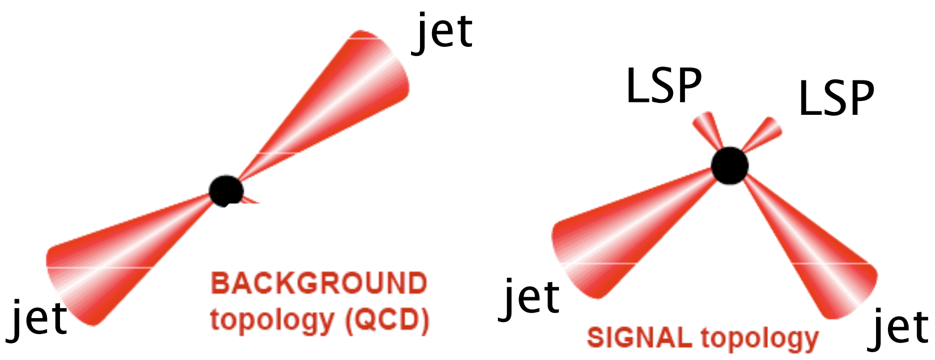




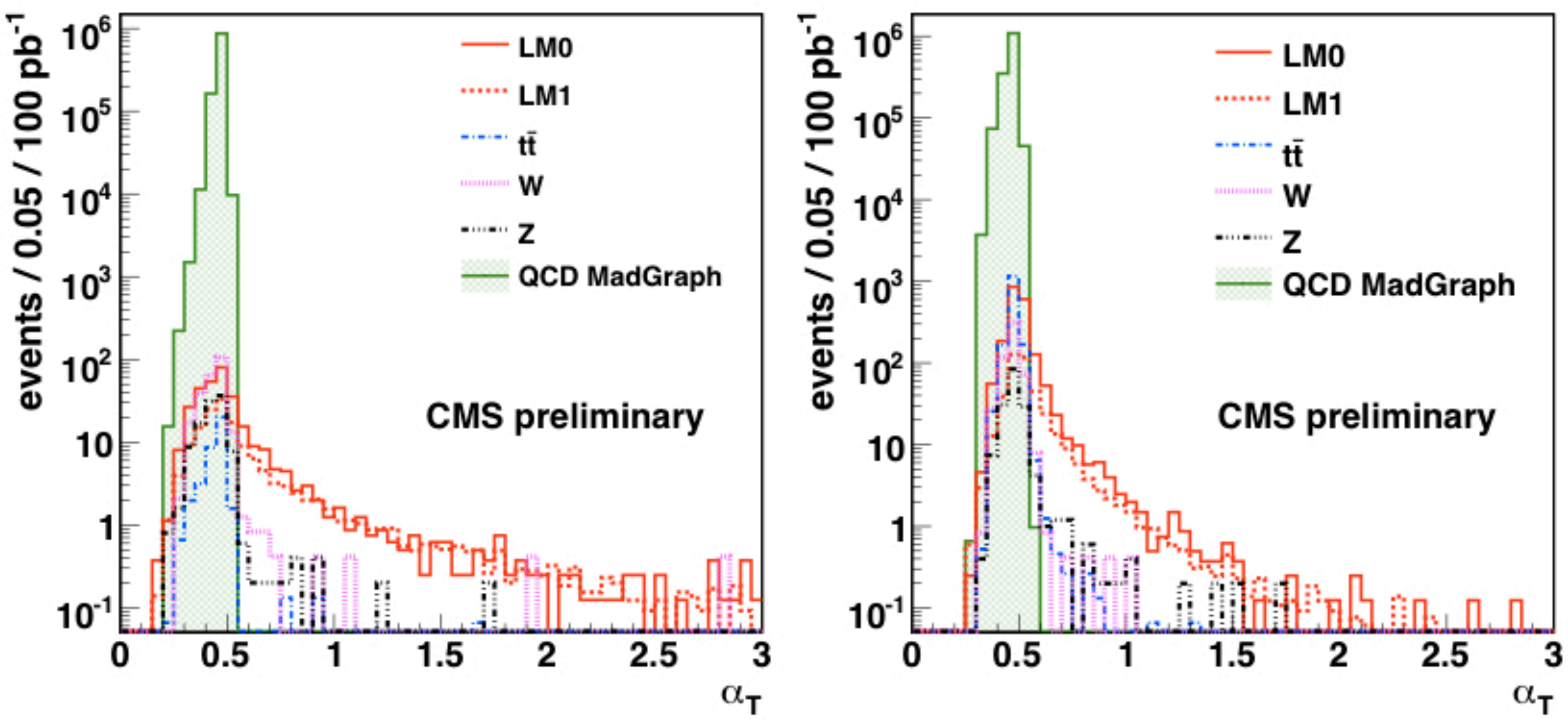
Imperial College London

All-hadronic search

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



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

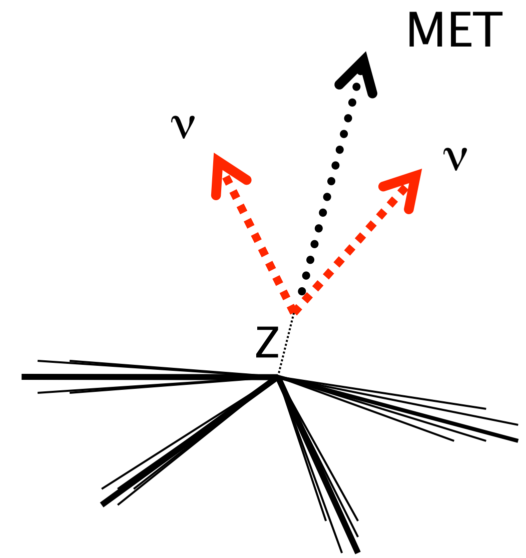


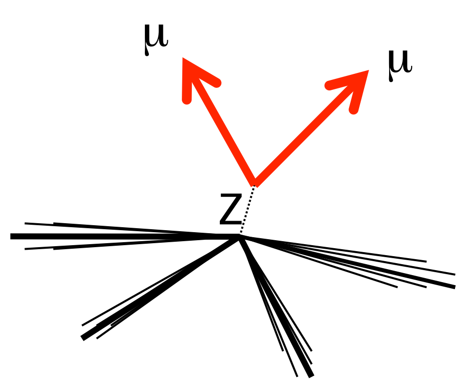
- A novel approach combining angular and energy measurements
- No dependence on MET ➔ robust for early LHC running
- Originally proposed for di-jet events ➔ generalised up to 6 jets
- Perfectly balanced events have α_T=0.5 (cut at α_T>0.55)
- Mis-measurement of either jet leads to lower values

Barr and Gwenlan arXiv:0907.2713

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**

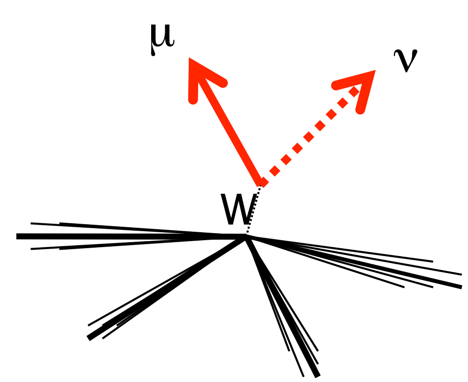




Z → ll + jets

Strength: very clean

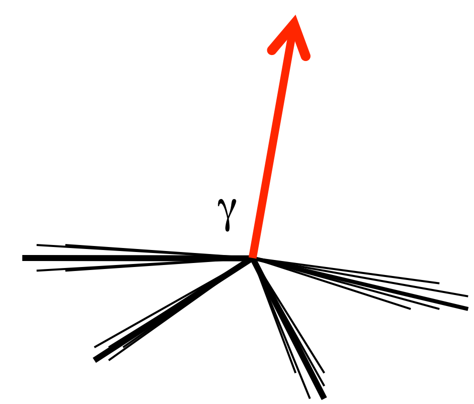
Weakness: low statistics



W → lν + jets

Strength: larger statistics

Weakness: background from SM and SUSY



γ + jets

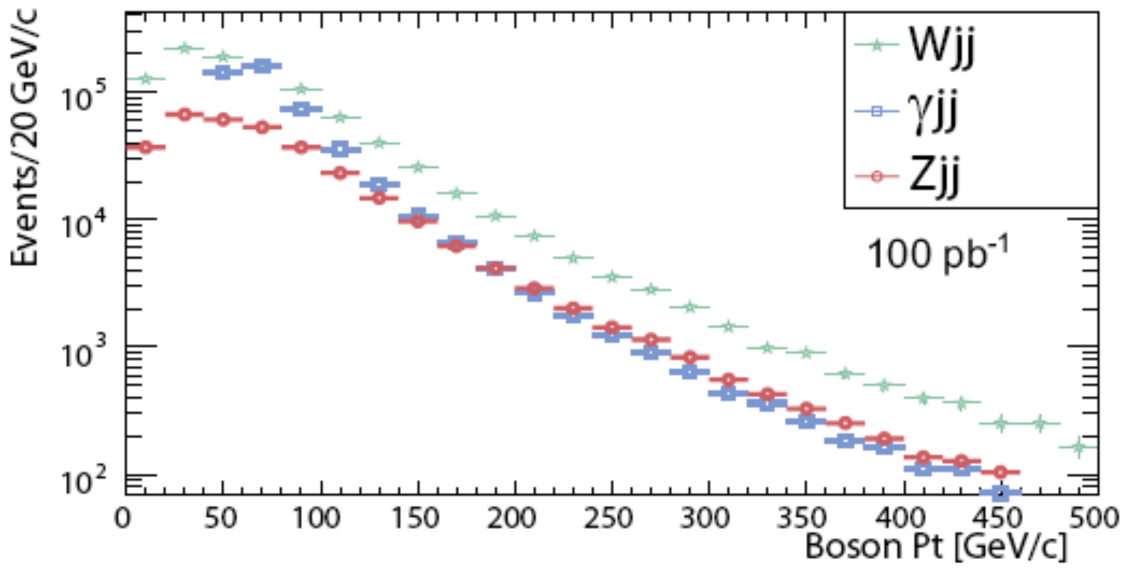
Strength: large statistics and clean at high E_T

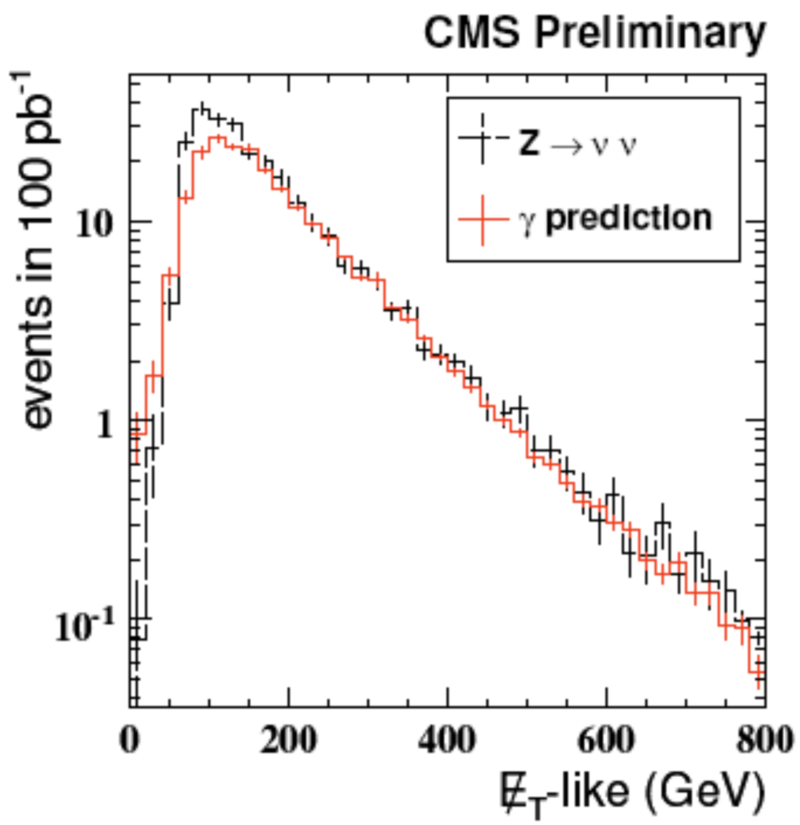
Weakness: background at low E_T, theoretical errors

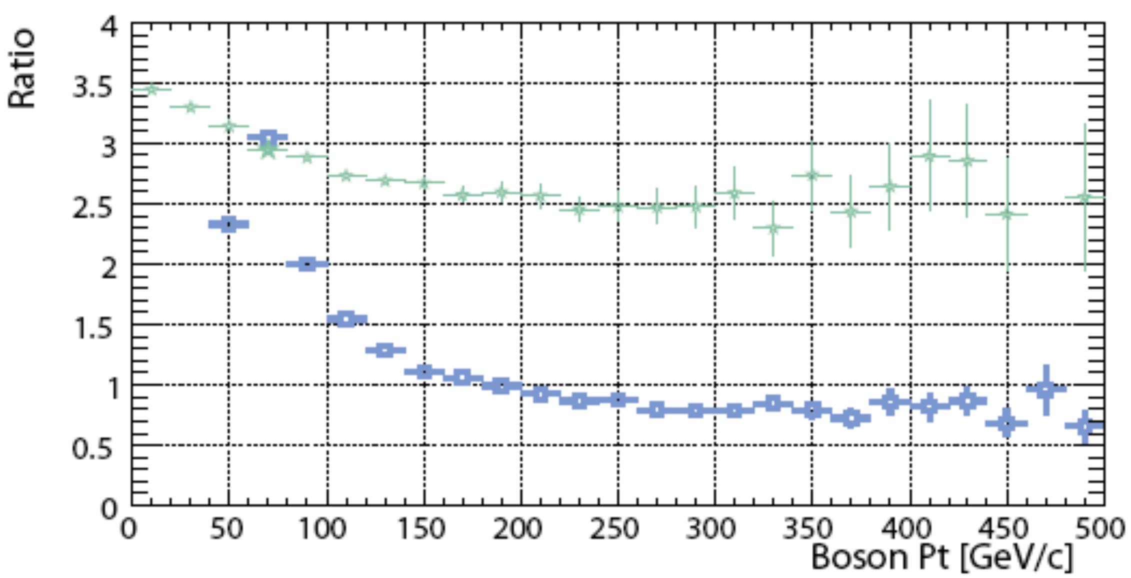
Background estimates

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





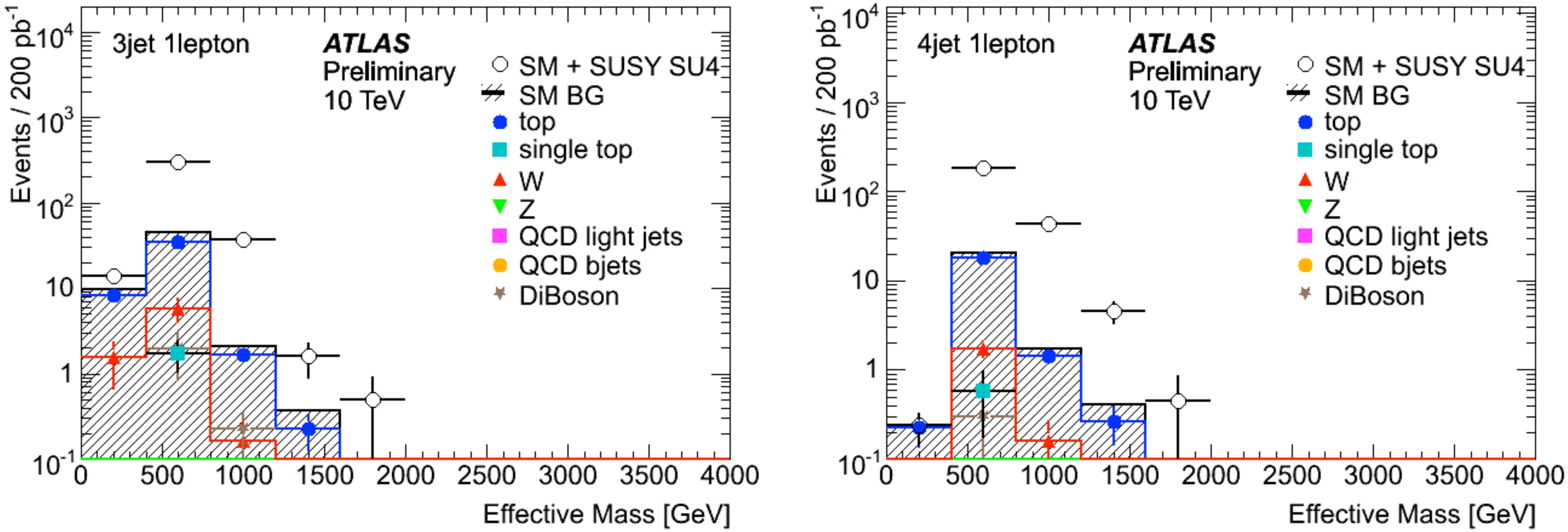


100 pb^{-1} @ 14 TeV COM

Imperial College London

Single-lepton search

ATL-PHYS-PUB-2009-084



- 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

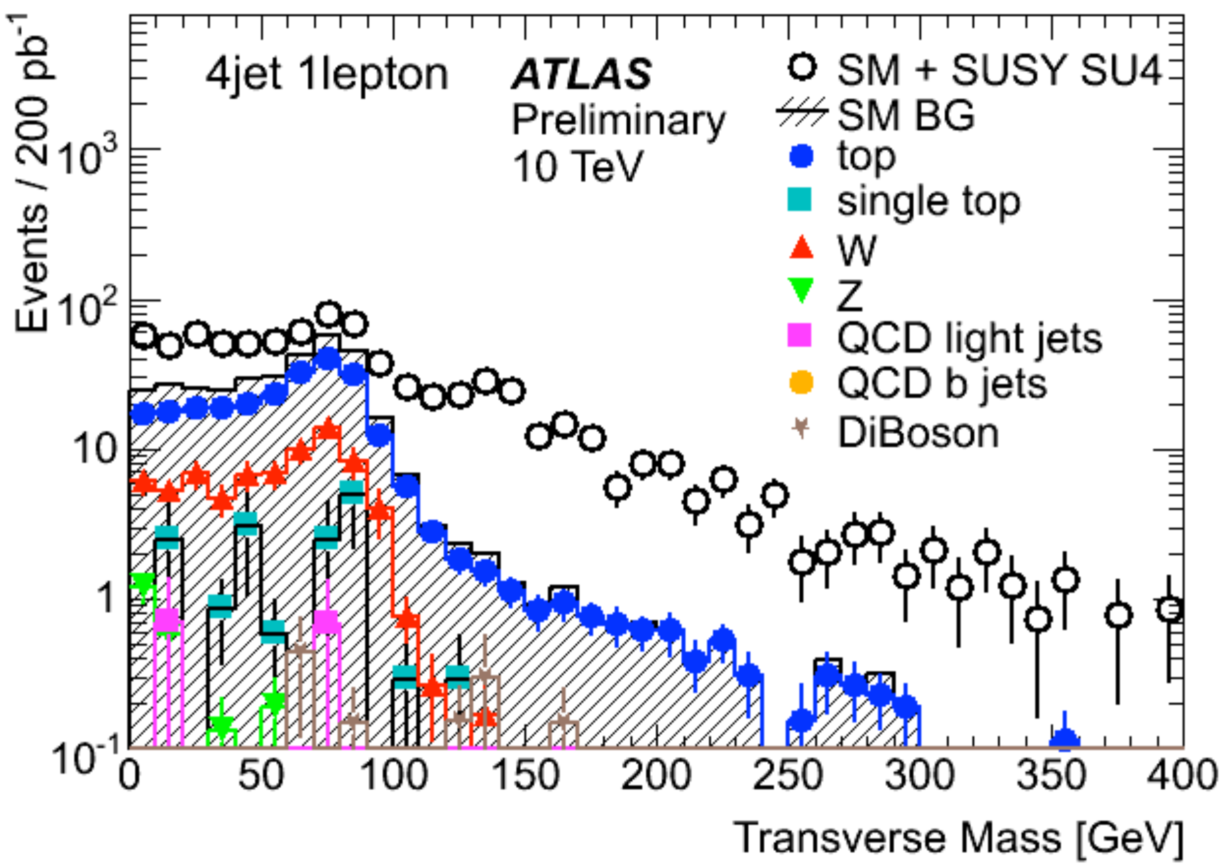
- Data-driven background estimates

ATL-PHYS-PUB-2009-084

  - 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 ➔



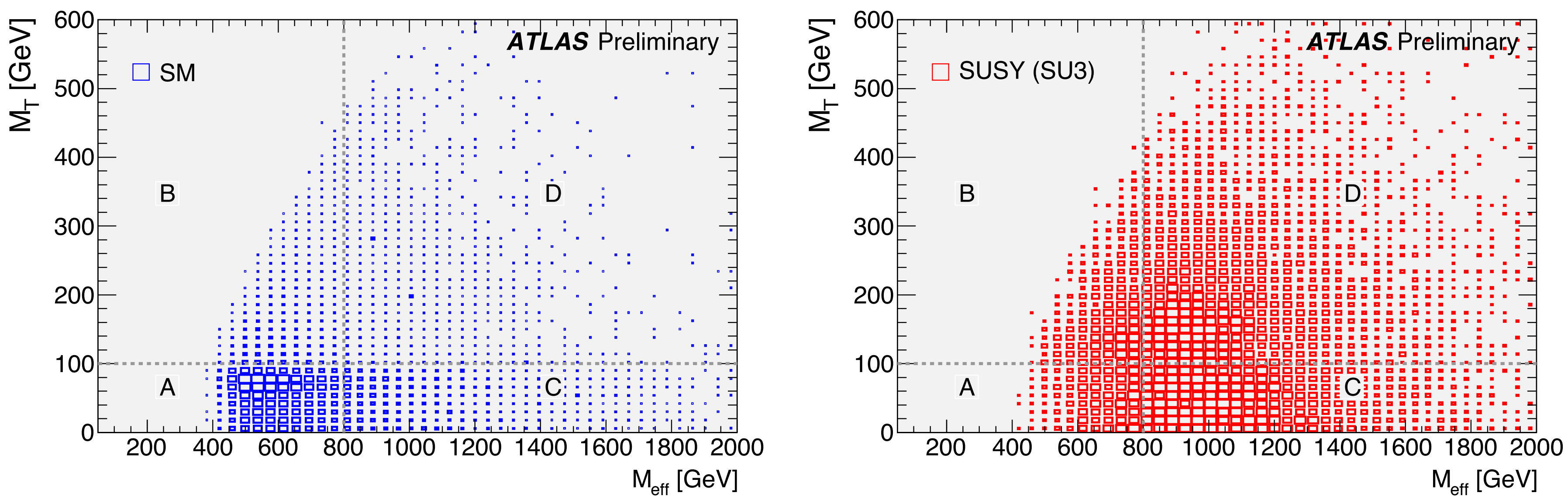
Imperial College London

Background estimates

- “Tiles” method

ATL-PHYS-PUB-2009-077

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



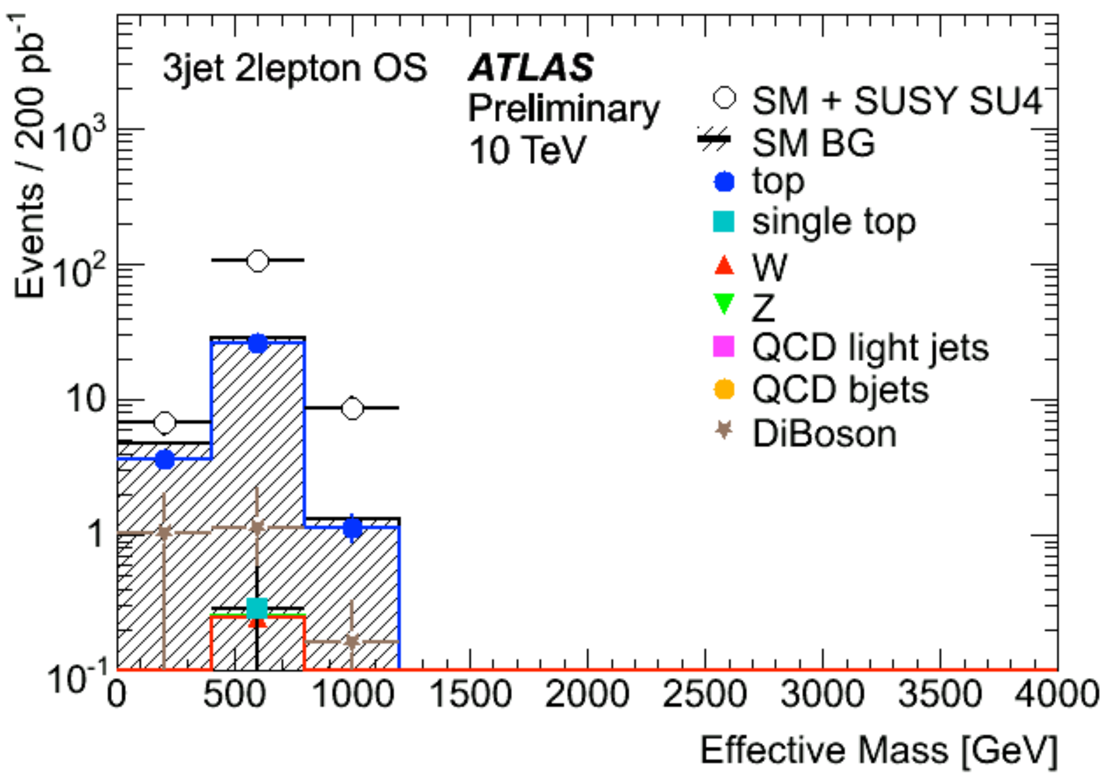
  - Can express N_{evts} in each region in terms of f^{SM} and f^{SUSY}
  - Take f^{SM} from MC for each region and solve the system of linear equations

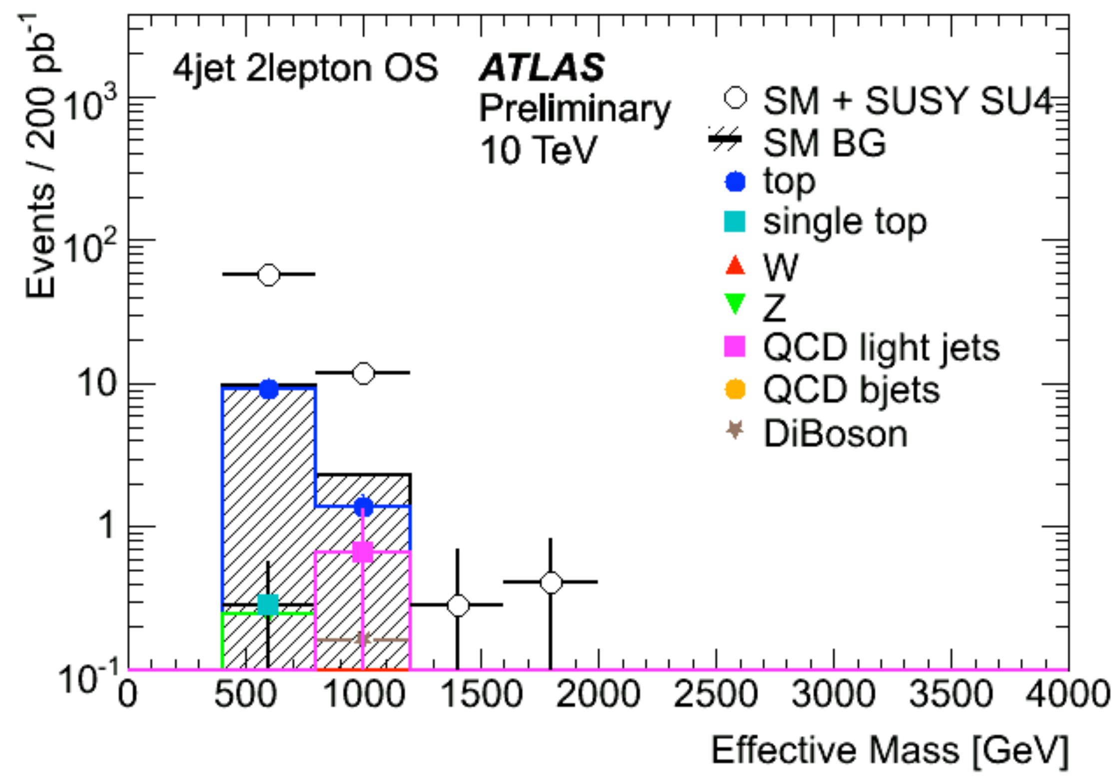
- Predicts the number of SM background and SUSY signal events in each region
- Background prediction not biassed by signal contamination

Imperial College London

Di-lepton searches

ATL-PHYS-PUB-2009-084



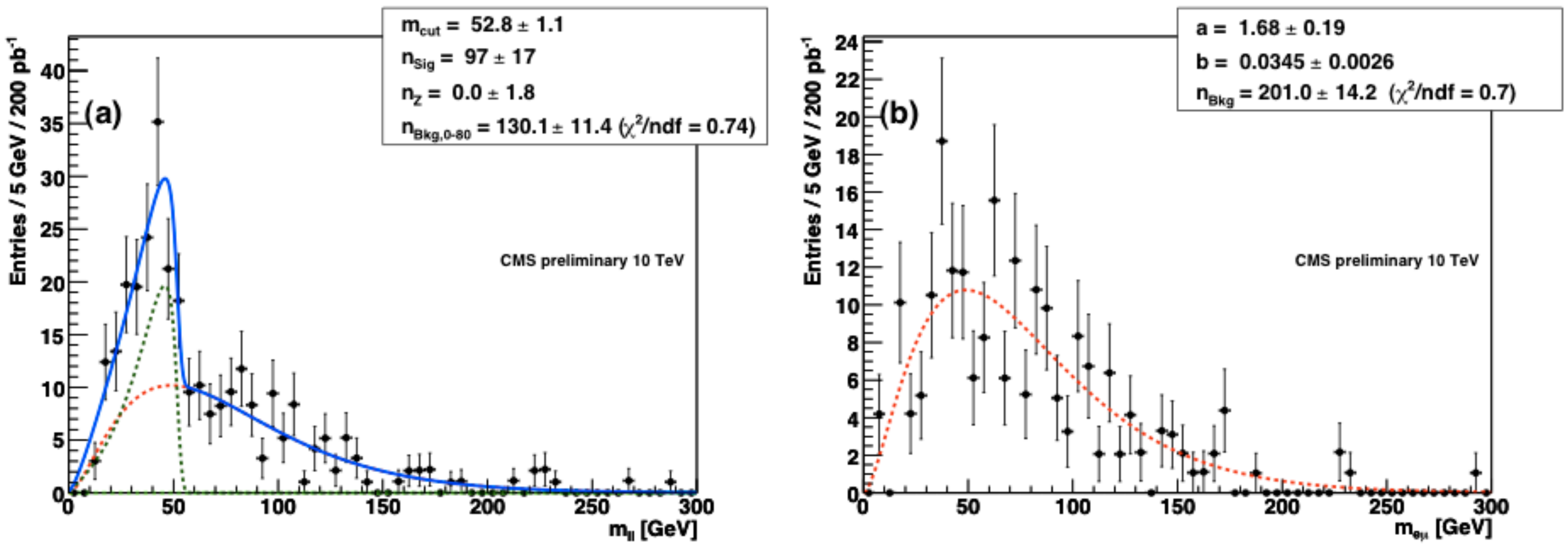


- Low yields but very interesting properties
- Same sign searches
  - Very low Standard Model background rate
  - Backgrounds from charge mis-identified top events (QCD in τ channel)
- Opposite sign
  - Use opposite-sign, opposite-flavour sample to subtract SM background

Imperial College London

Di-lepton searches

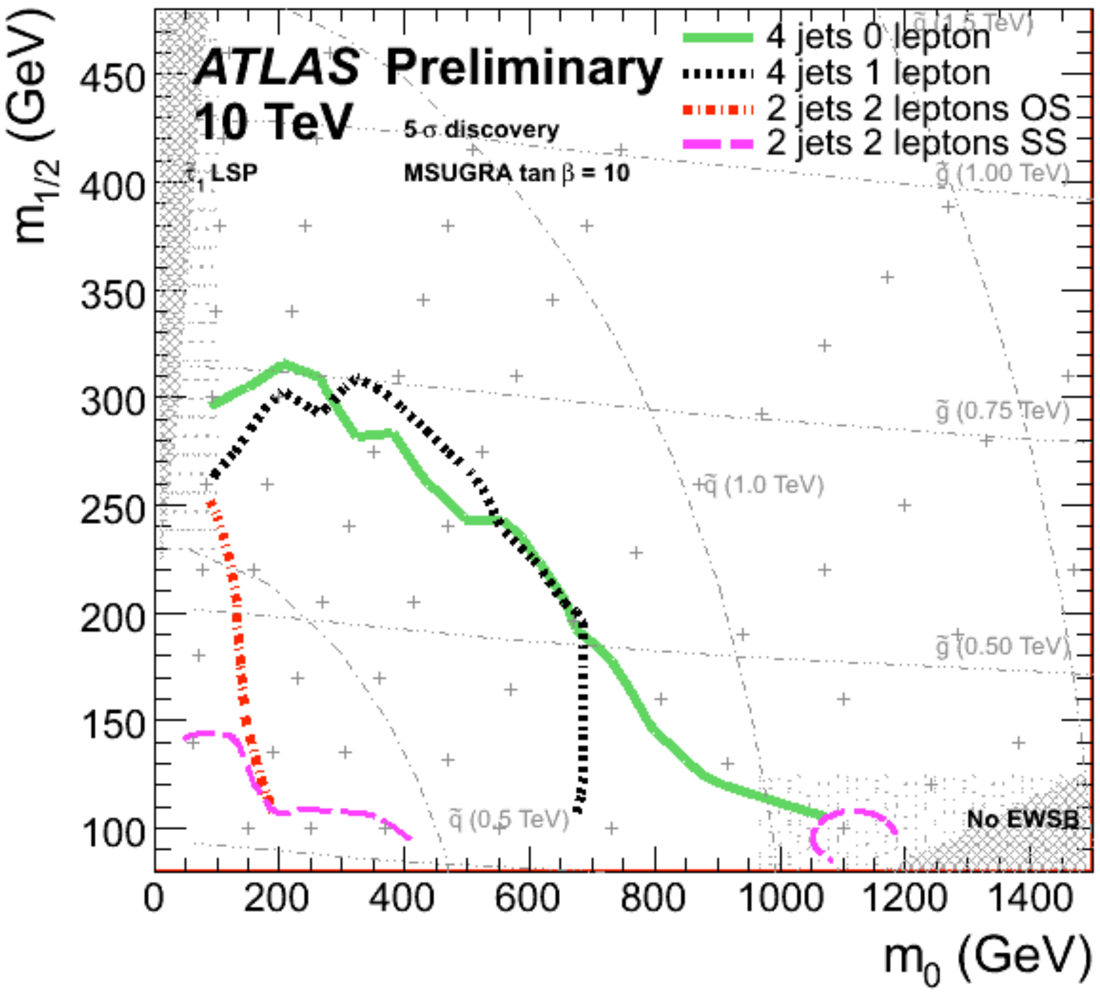
CMS-PAS-SUS-09-002

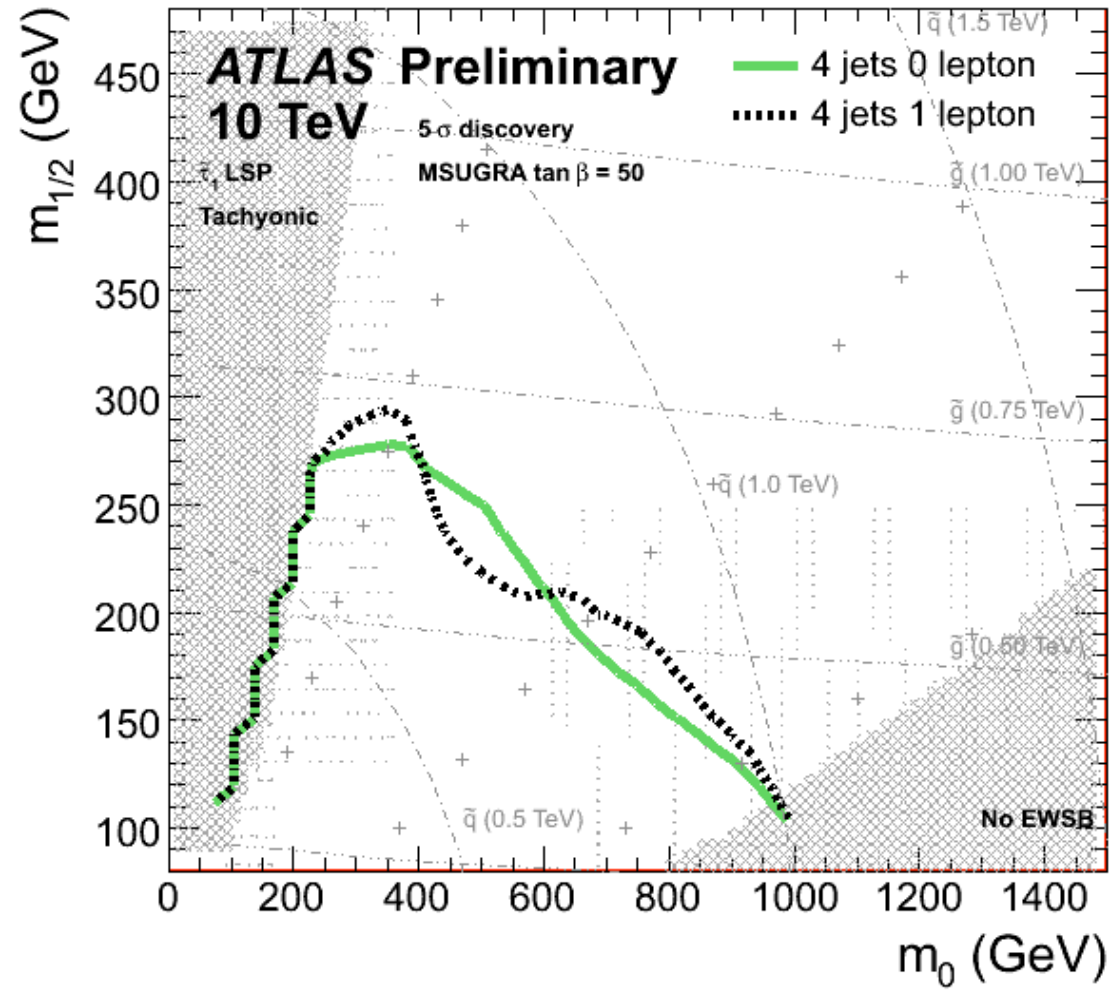


- Fit ee, μμ and eμ distributions simultaneously
  - Resolution function and efficiencies from data
  - 200 pb^{-1} @ 10 TeV
  - Di-leptonic end-point $m_{ll,max}$=51.3 ± 1.5 (stat.) ± 0.9 (syst.) GeV [52.7 GeV]
- Nice example of what could be done with modest dataset

Discovery reach @ 10 TeV

ATL-PHYS-PUB-2009-084





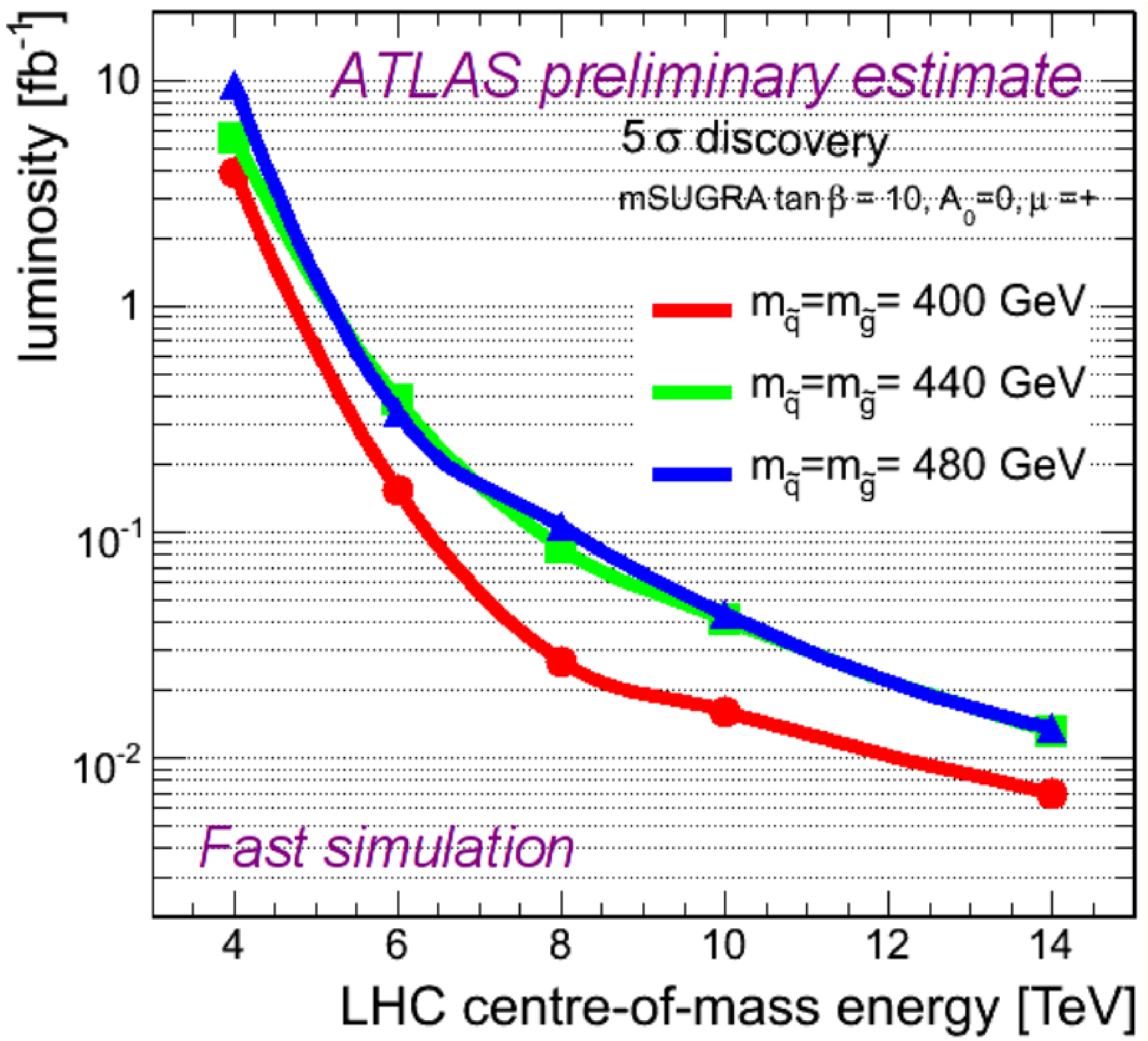
- Scan M_{eff} cut for best sensitivity (50% error on backgrounds)
- All-hadronic and single-lepton searches vie for highest sensitivity
- Clear discovery potential beyond the Tevatron with 200 pb^{-1} @ 10 TeV

Imperial College London

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



Imperial College London

Summary

- Early searches based on robust generic signatures
  - Sensitive as possible to a variety of new physics models
- Detectors in great shape after 2009 LHC pilot run
  - Commissioning progressing well
- A wide range of data-driven techniques developed to measure efficiencies and backgrounds
  - Redundancy builds confidence
- Eagerly awaiting start of 7 TeV LHC collisions next week!
  - LHC should be at the search frontier before the end of 2010

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