PPAP community meeting, Birmingham, September 17th 2012

Phenomenology

Valya Khoze

IPPP Durham University

Phenomenology in the UK

- Part of the UK Theory effort with its extraordinary tradition and record of scientific excellence

- UK Phenomenology has a world-class reputation

strong UK activity in all areas -- fromm QCD, Electroweak & Higgs to New Physics (Beyond the Standard Model).

- Focused phenomenology effort:

development of new theoretical ideas,
computational tools,
and strong links between Theory and Experimental communities

is mandatory to enable the LHC and other experiments (current and future) to maximise their scientific impact.

Phenomenology in the UK

- Entire UK Theory community: close to 200 academics
  in 20 University groups

- UK Phenomenology: 40 academics (broad counting)
  in 13 University groups

plus

Institute for Particle Physics Phenomenology – 15 academic staff

- a dedicated research centre in particle phenomenology
- partnership between Durham University and the STFC

- Welcome new phenomenology appointments and expansion at

Cambridge (Cavendish), Durham (IPPP), Edinburgh (Higgs Ctr.),
KCL (J.Ellis ERC + new posts), Liverpool, Oxford, RHUL, UCL

The era of the LHC

The era of the LHC

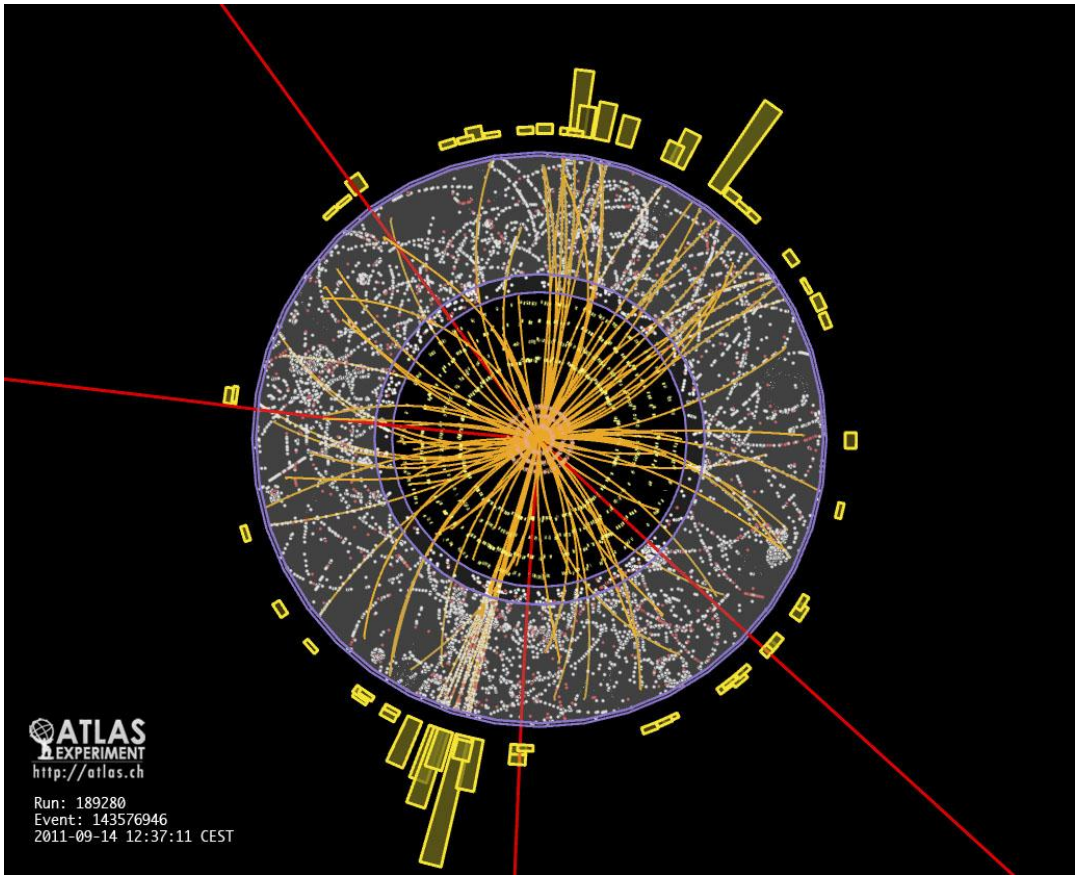
- The LHC is a QCD machine

The era of the LHC

- The LHC is a QCD machine

it collides protons

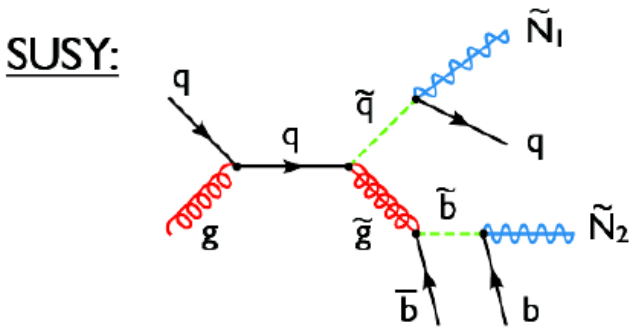
(most of the time)



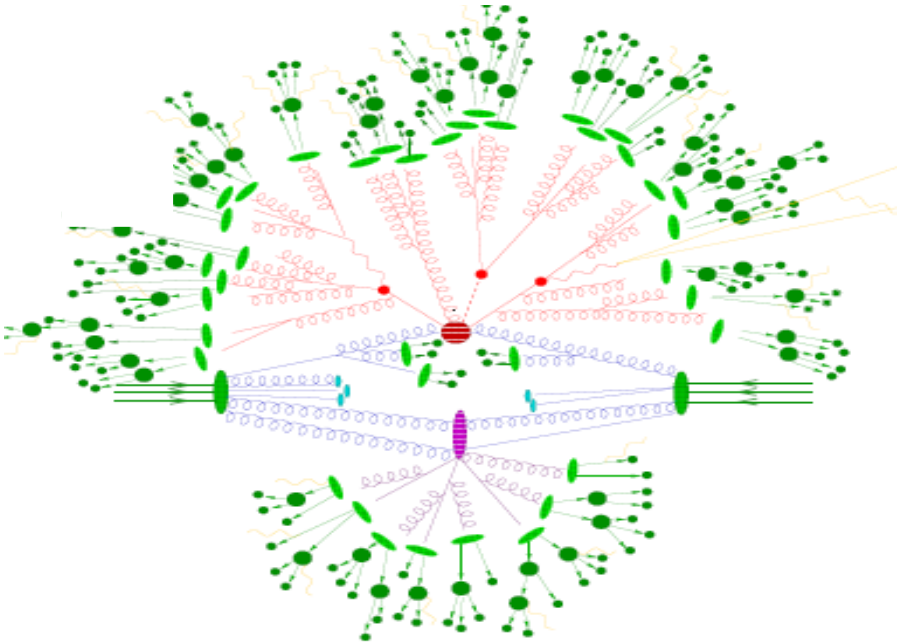
The era of the LHC

- The LHC is a QCD machine

to hope to see this:



need that:



The era of the LHC

- The LHC is a QCD machine

Our role is to provide tools and calculations covering all relevant phenomenological aspects of experimental programme.

Computational techniques & tools include:

- ❖ Parton distribution functions (MSTW and NNPDF)
- ❖ Automated higher-order QCD calculations (BlackHat & Rocket)
- ❖ Jet algorithms and jet substructure, boosted objects.
- ❖ Precision NNLO calculations
- ❖ [Very useful overlap with `Scattering Amplitudes' in `formal' theory]
- ❖ Fully-fledged Monte Carlo event simulations (Herwig (++) and Sherpa)
- ❖ Monte Carlo tuning tools (Rivet & Professor)

UK leads in all these areas.

The era of the LHC

- The LHC is a QCD machine
- It was built to discover New Physics

The era of the LHC

- The LHC is a QCD machine

- It was built to discover New Physics (obviously!) :

➢ The Higgs boson(s)
or other implementations of the Higgs mechanism;

and a) as a consequence of this,
b) at the same time, or c) even before that:

➢ Physics Beyond the Standard Model, such as

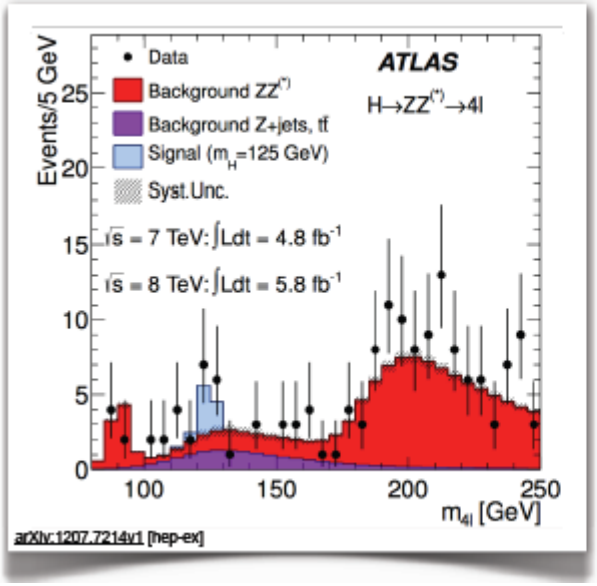
Supersymmetry or
Compositeness or Xtra Dimensions, etc.

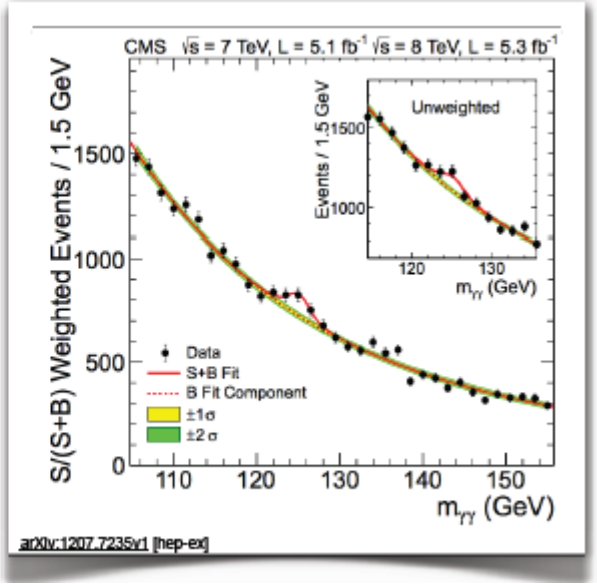
The era of the LHC

- The LHC is a QCD machine
- It was built to discover New Physics
- It discovered the Higgs

The era of the LHC

- The LHC is a QCD machine
- It was built to discover New Physics
- It discovered the Higgs – a triumph!





The era of the LHC

- The LHC is a QCD machine
- It was built to discover New Physics
- It discovered the Higgs – a triumph!

but what kind of Higgs?

Is it the SM Higgs? How SM-like is it?
need Higgs precision-computations & measurements.

The era of the LHC

- The LHC is a QCD machine
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- It discovered the Higgs – a triumph!

- what are its quantum numbers
- is it elementary or composite
- how does it couple to the SM fermions (any deviations from the SM?)
- what mechanism protects its mass (quadratic divergences for the SM Higgs)
- Is it a single Higgs or a part of the extended Higgs sector
- Does it couple directly to new physics (Higgs as the BSM portal)

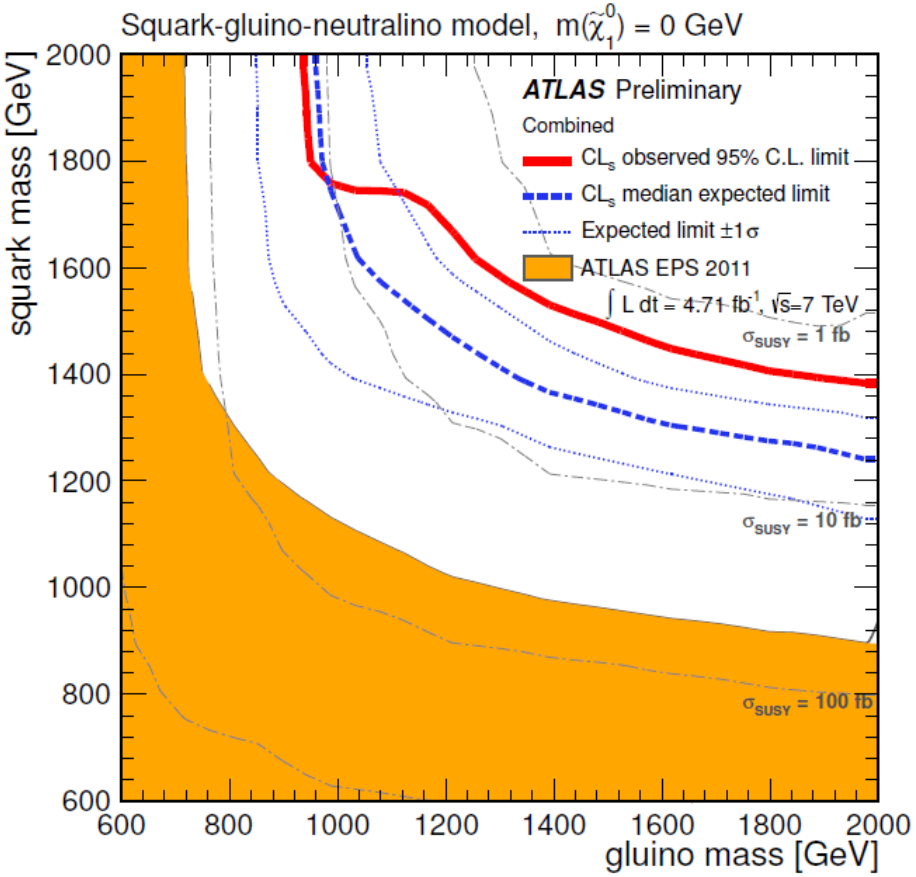
The era of the LHC

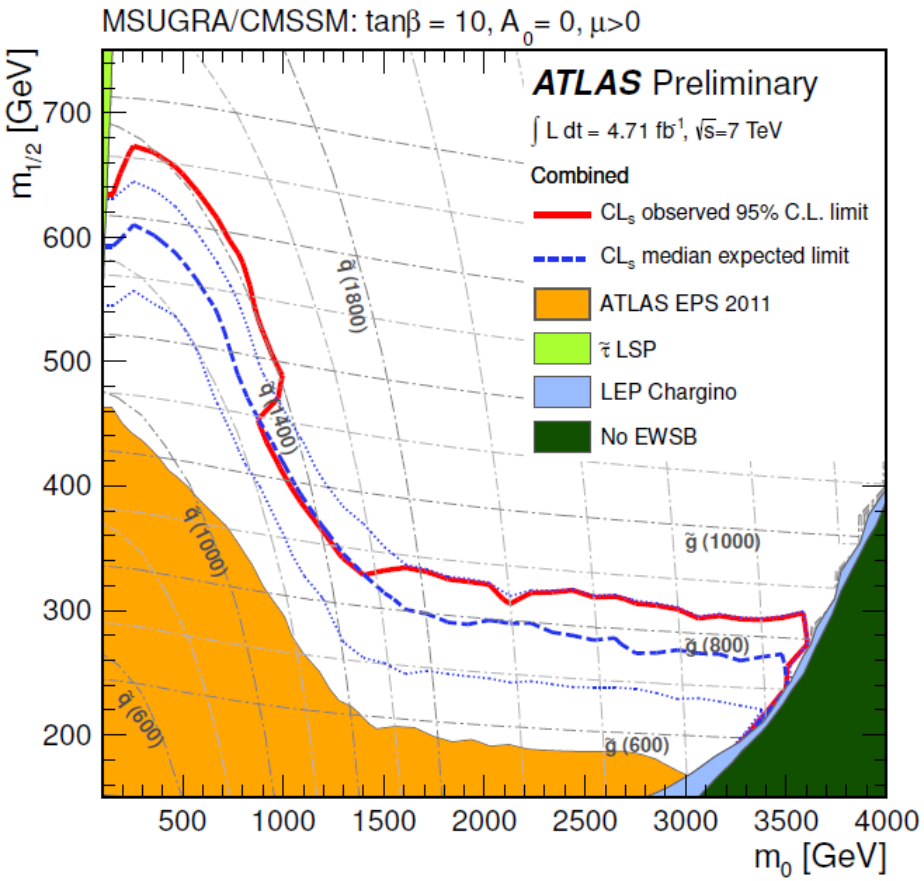
- The LHC is a QCD machine
- It was built to discover New Physics
- It discovered the Higgs
- Direct searches found no New Physics beyond the SM

  ❖ no supersymmetry in `Jets and MET' searches
  ❖ no supersymmetry in `time of flight' searches
  ❖ no supersymmetry

  no gluinos and no (u,d) squarks with masses up to 1.5 TeV

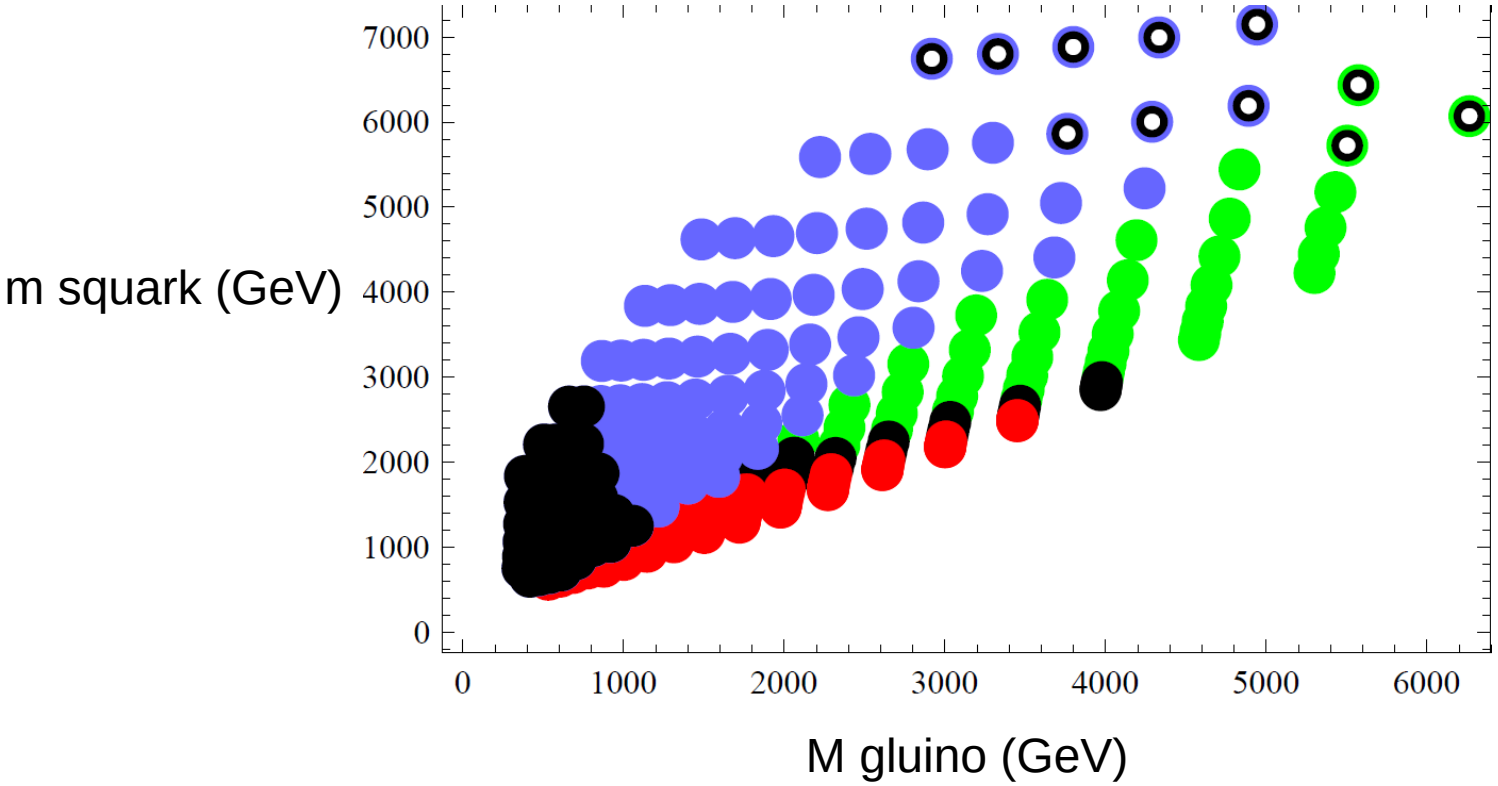
Jets and MET searches of SUSY (ATLAS & CMS)





ATLAS 4.7 fb^{-1} at $\sqrt{s} = 7$TeV complete 2011 sample

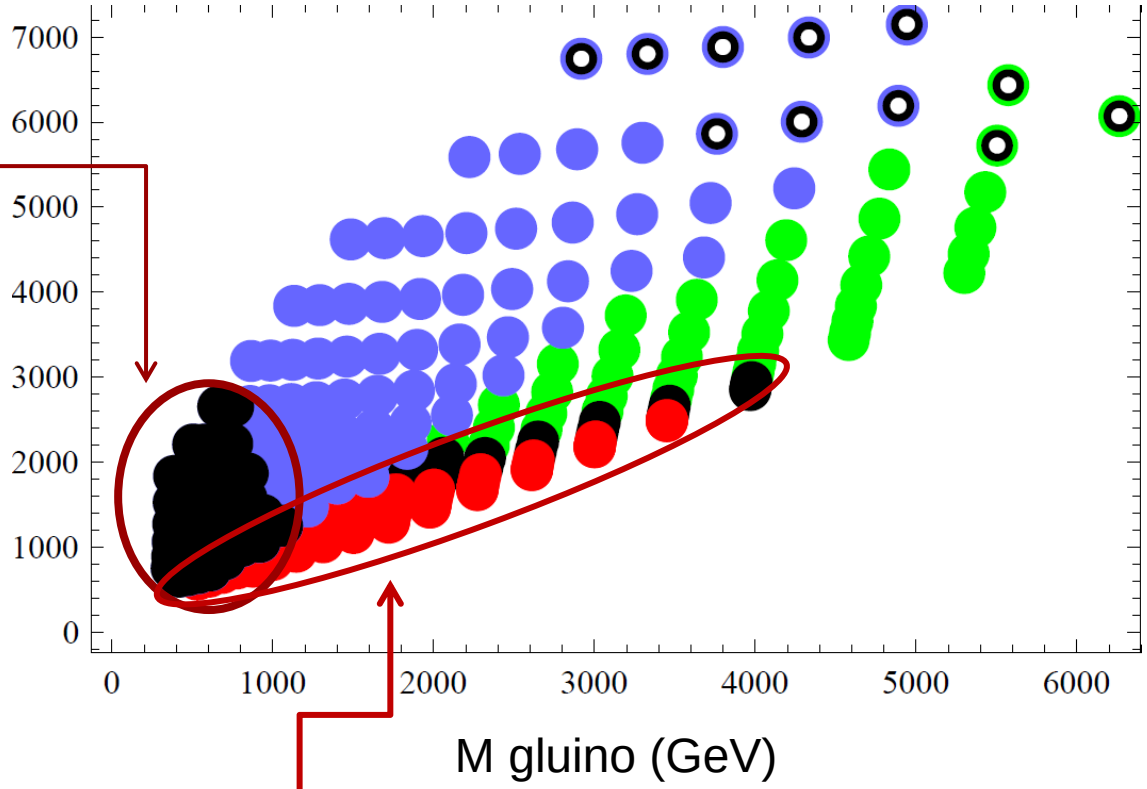
Gauge Mediation



This is an example of vanilla model of supersymmetry – gauge mediation
Theoretically beautiful – calculable, predictive, first-principles theoretical model

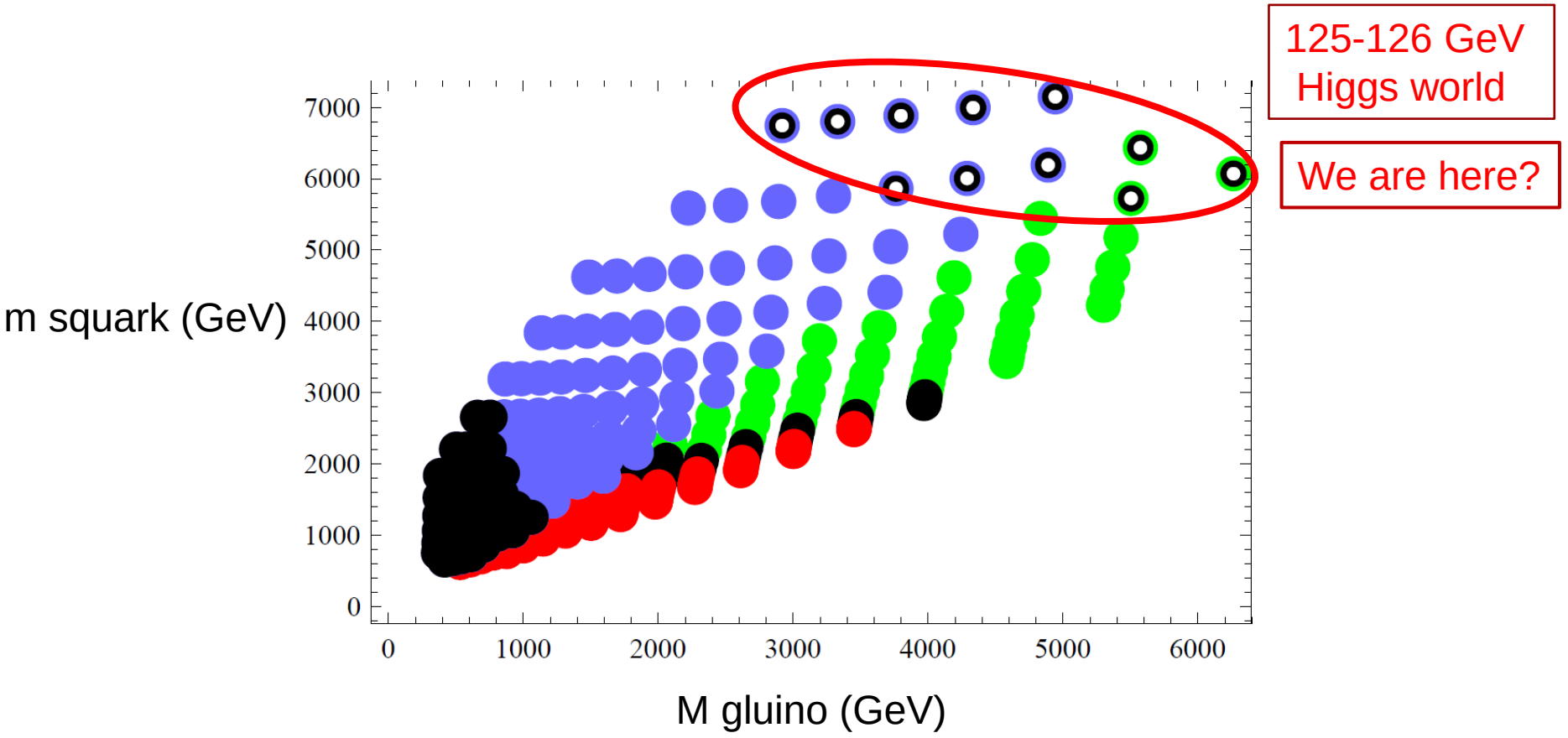
Gauge Mediation

Excluded by Jets&MET searches

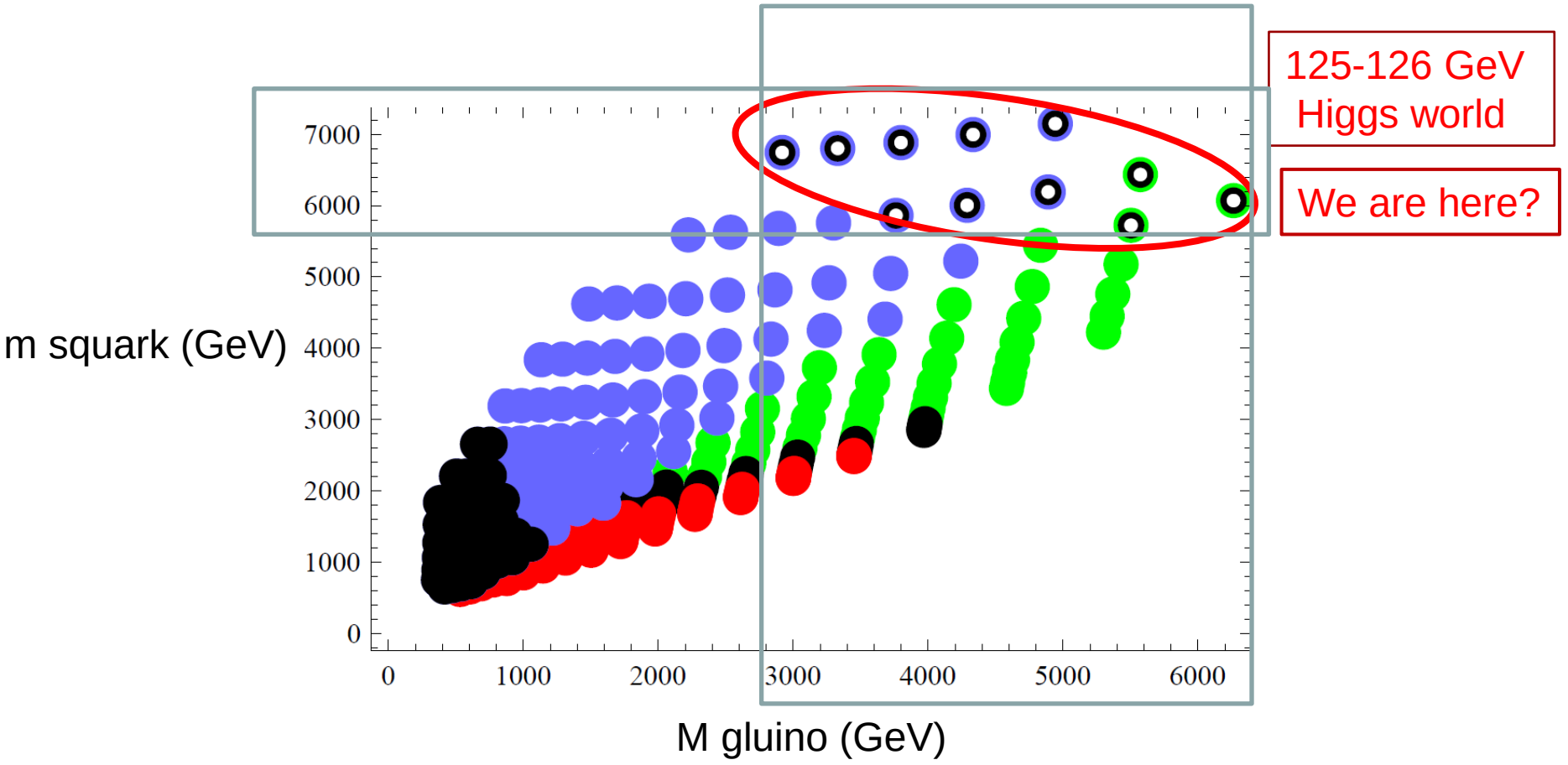


Excluded by long-lived stau > 223 or 314 GeV

Gauge Mediation now - what's left of…



Gauge Mediation now - what's left of…



Most of parameter space now excluded. Not a natural model, fine-tuning, no new physics at TeV scale.

Saving SUSY?

- Very strange that the 125 GeV Higgs is light and looks very much like the Higgs in some SUSY models, except there is no sign of SUSY!?

- Is it time to accept some fine-tuning and a heavier SUSY spectrum?

This solves many of the problems that generic SUSY had (e.g. flavour changing, EDMs) at a stroke, but of course re-introduces some of the hierarchy problem.

Other possibilities for SUSY:

- `Natural SUSY' models
- R-parity violation
- Dirac gauginos
- Additional singlets as in general NMSSM

It's ironic that the solution to the absence of SUSY is to add even more stuff: composite 3rd generation or Higgs, R-parity violating couplings, scalar gluons, or new singlets.

Flavour Physics Questions

What determines the observed pattern of masses and mixing angles of quarks and leptons? Is there a New Physics – driven rational behind the observed hierarchies?

Is there anything beyond Yukawa couplings and mixing matrices which distinguishes the three families?

From Isidori @ Cracow 2012:

The good overall consistency of the SM predictions for flavour-changing processes indicates that there is not much room for new sources of flavour symmetry breaking close to TeV scale, or that the scale of New Physics is very high.

New flavor-breaking sources at the TeV scale (if any) are highly tuned

Flavour Physics

Studies of minimal flavour violation models and models of partial compositeness

Main idea: very small but detectable corrections to the SM in specially selected flavour-violating observables.

Push forward the precision in the most clean observables:
Lepton Flavour Violation and EDMs.

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- It was built to discover New Physics
- It discovered the Higgs
- Direct searches found no New Physics beyond the SM

❖ No SUSY and no other signs of new physics - no non-SUSY
❖ Exotica: heavy objects are probed up to masses 2-3 TeV
❖ No new physics hints from heavy flavour either

No new BSM physics at the TeV scale:
This was unexpected – but it brings a very important input to our field.

The era of the LHC

- The LHC is a QCD machine
- It was built to discover New Physics
- It discovered the Higgs
- Direct searches found no New Physics beyond the SM
- BSM physics is pushed further away (for now)

that's just the beginning. 14 TeV will be essential. LHC upgrades and future experiments are essential.

THERE IS MORE TO COME

From Altarelli - Summary talk at Planck 2012:

The Standard Model works very well

So, why not find the Higgs and declare particle physics solved?

Because of both:

Conceptual problems

- Quantum gravity
- The hierarchy problem
- The flavour puzzle
- .....

and experimental clues:

- Neutrino masses
- Coupling unification
- Dark matter
- Baryogenesis
- Vacuum energy
- some experimental anomalies: $(g-2)_\mu$, ...

Some of these problems point at new physics at the weak scale: eg
Hierarchy
Dark matter (perhaps)

insert here your preferred hints

Neutrino Phenomenology

Neutrino masses and mixing angles require new physics (BSM). Understanding their origin is one of the main challenges.

With the discovery of theta13 in 2012 (Daya Bay, RENO, T2K, MINOS, DoubleCHOOZ) → try-bimaximal mixing pattern is now severely disfavoured because of the large value of theta13.

Are theta12, theta13 and theta23 just three random numbers => anarchy in the lepton sector ? (Anthropic selection and the end of `symmetric way'?)

Studies of possible discrete symmetries plus corrections which can explain the observed values of neutrino mixing.

Studies of leptogenesis and resonant leptogenesis.

Studies of the link between leptogenesis and low-energy CP-violation.

Neutrino Phenomenology

Long baseline neutrino physics

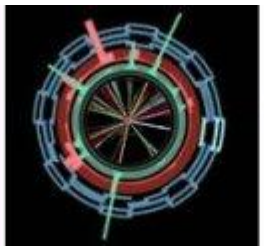
- Determining the mass hierarchy
- Discovering CP-violation
- Measuring parameters with precision.

Low energy neutrino factory

Neutrinoless double beta decay

Durham University

Institute for Particle Physics Phenomenology



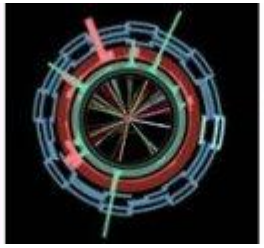
IP3

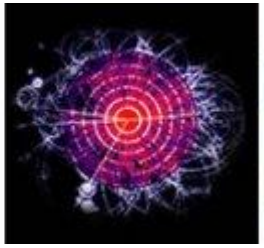
A DEDICATED RESEARCH CENTRE IN PHENOMENOLOGY

The Institute's main objective is to deliver world-class research in phenomenology and to provide a forum for interactions between UK experimentalists and theorists.

Durham University

Institute for Particle Physics Phenomenology





IP3

Workshops: as a vital part of its engagement with the wider UK particle physics community, each year IPPP organises an extensive series of workshops http://www.ippp.dur.ac.uk/Workshops/

IPPP organised/sponsored more than 185 workshops, conferences and schools for graduate students (theory and experiment).
In 2011 the IPPP organised a total of 17 meetings
In 2012 already 12 meetings with more on the way.

[get in touch!]

Durham University

Institute for Particle Physics Phenomenology

IP^3

Associateships: each year up to 10 IPPP Associateships funded by Durham University are awarded to UK academics on the basis of scientific excellence bearing in mind the need to balance activity in different areas of phenomenology research.

Applications are welcomed from both theorists and experimentalists in the UK. Each Associateship supports the Associate's research programme and encourages collaborations with the IPPP and the wider UK PP community.

Summary

Particle phenomenology is a high-priority and high-visibility endeavour on a truly international scale.

The UK phenomenology community is at the forefront of all theoretical and computational developments.

Focused phenomenology effort & strong links between Theory and Experiment are mandatory for the success of the entire Particle Physics programme.