ATLAS Results Overview

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Glasgow/Witwatersrand

High Energy Particle Physics Workshop
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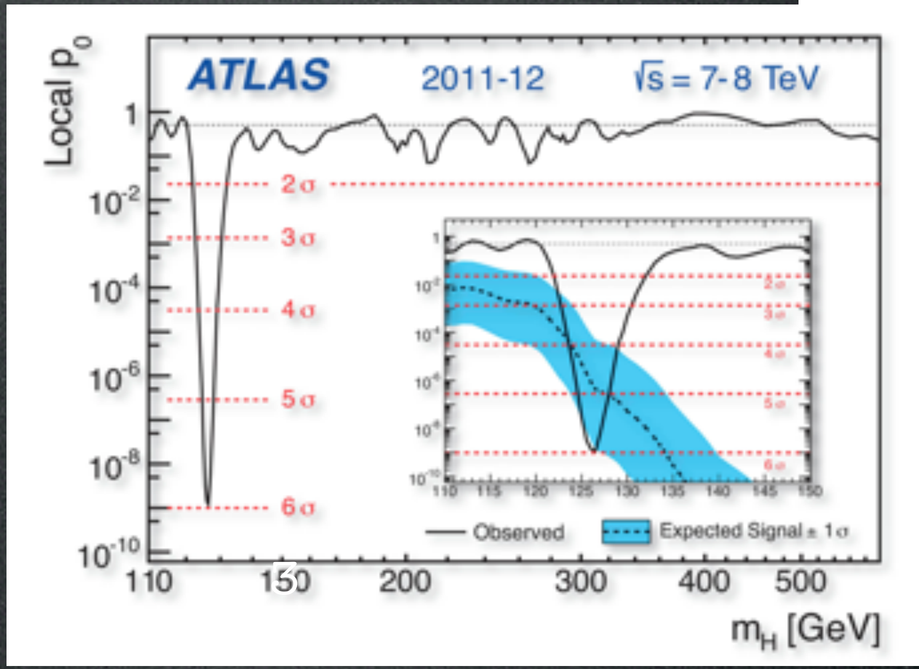
An amazing adventure…

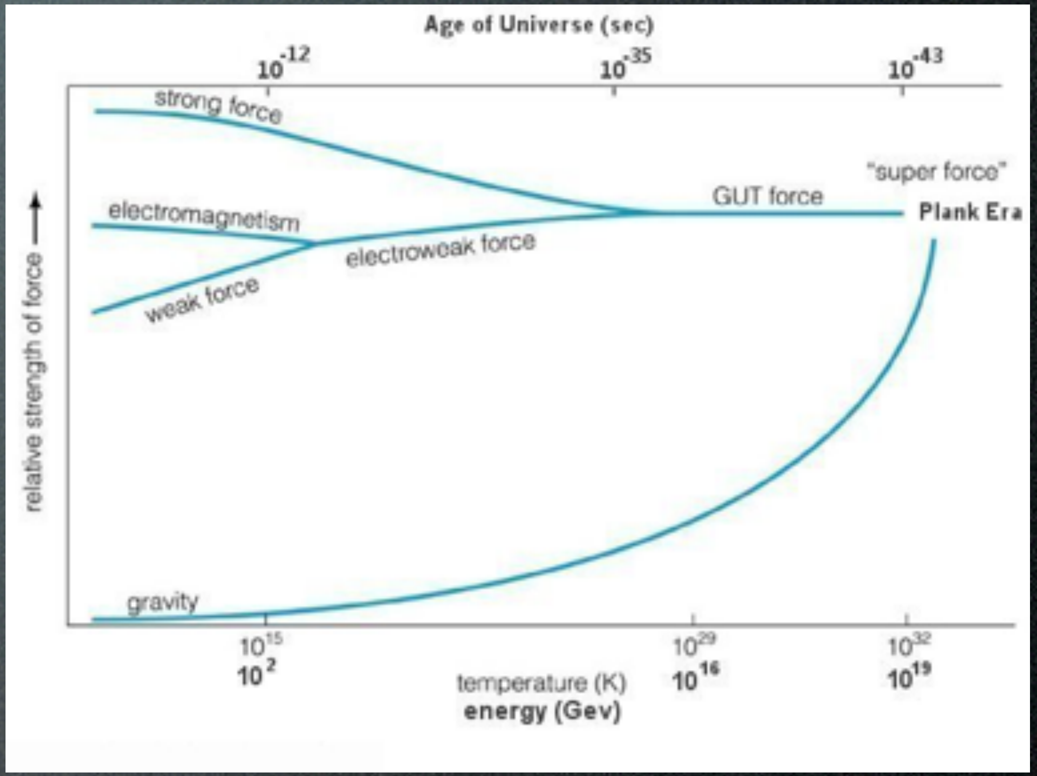
Overview

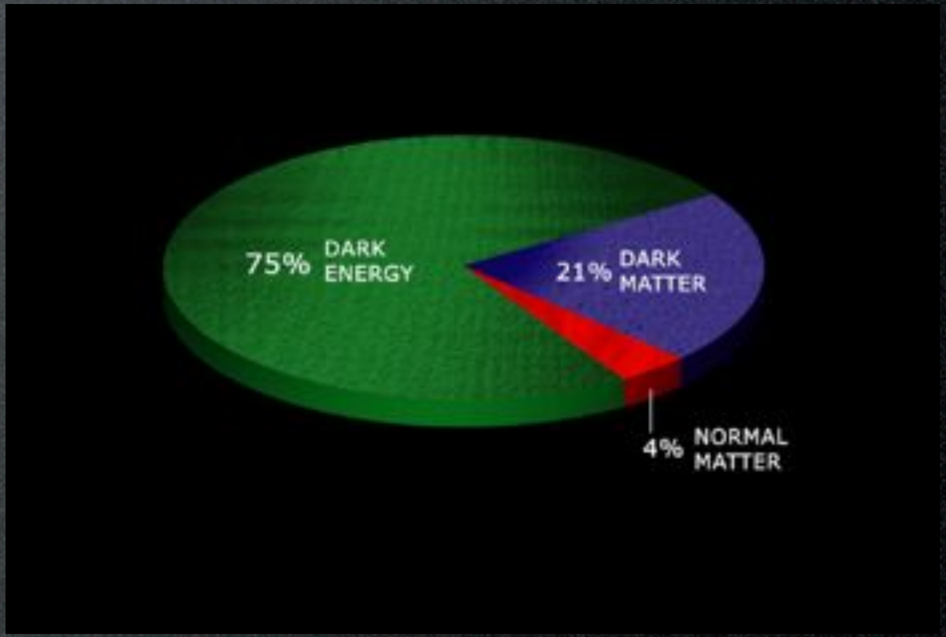
- ATLAS has over 350 published papers (and many more public results).
- Spread over all aspects from detector performance, improving physics object definitions, measurements, searches, prospects after upgrade.
- Only selected highlights.



So, what is left to discover?

- Unification of forces?
- Why theses masses?
- Origin of dark matter, dark energy?
- Matter antimatter asymmetry?
- ...





LHC 13/14 TeV runs will help us to probe a new energy domain.

So, what is left to discover?

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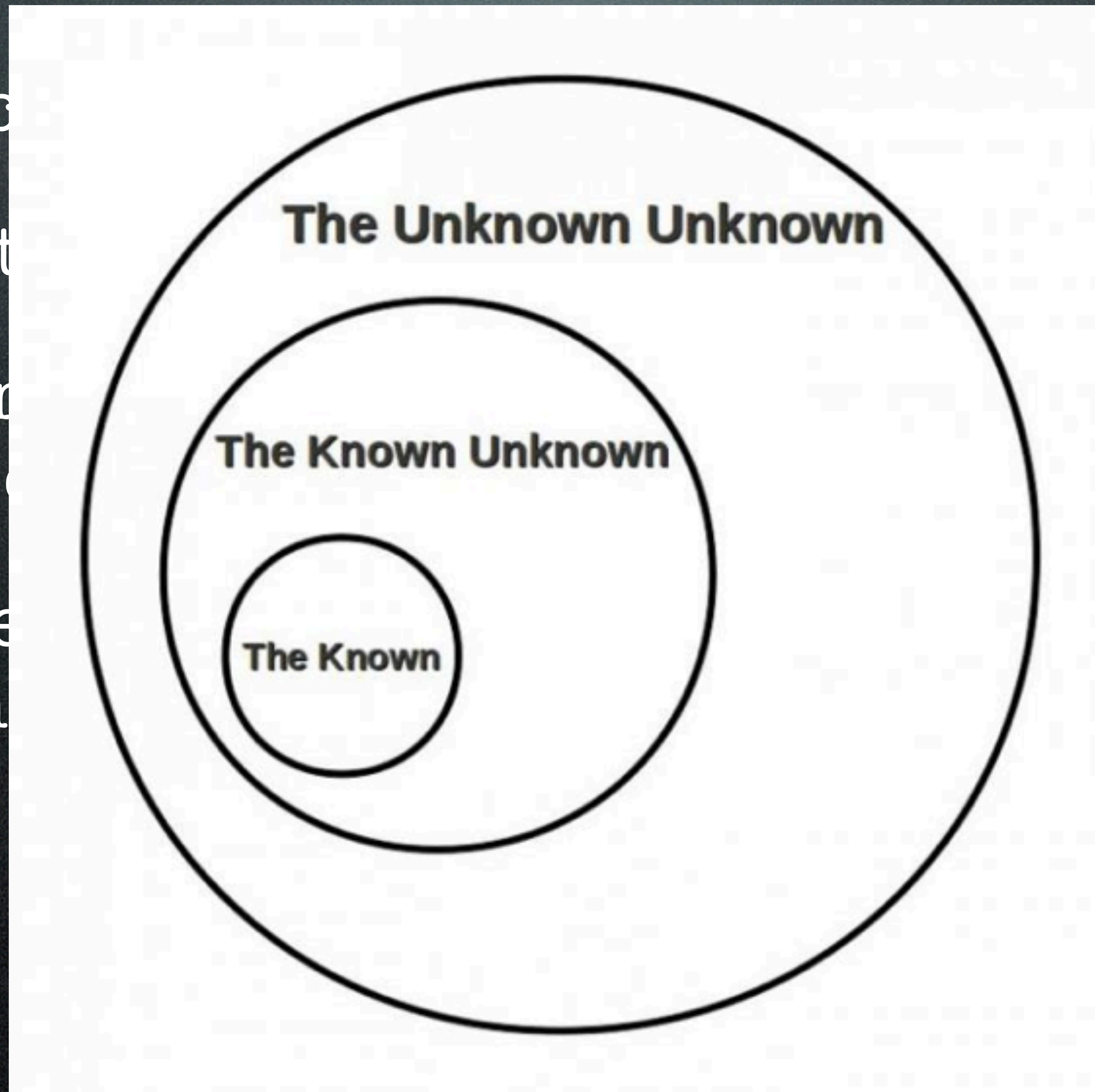
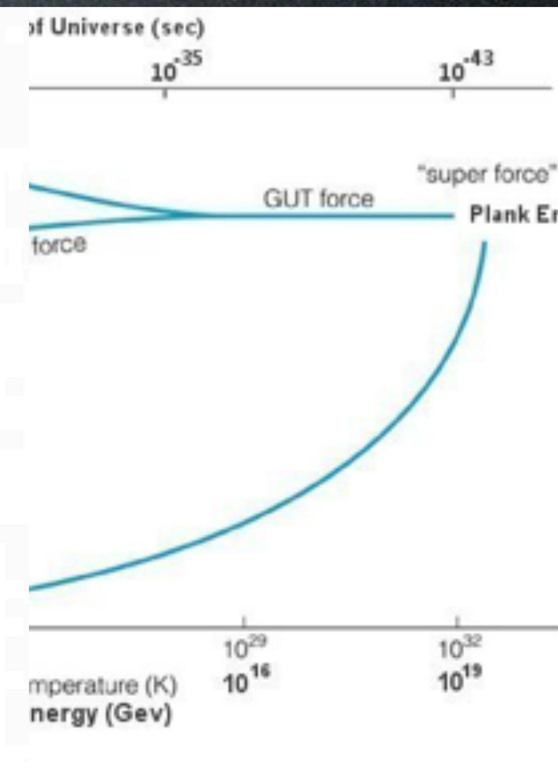
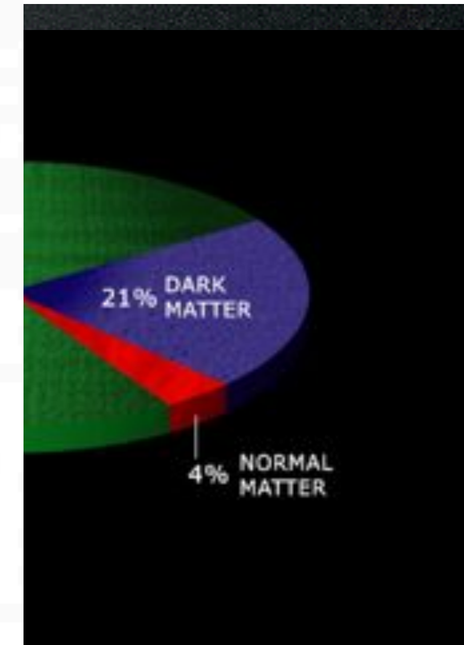
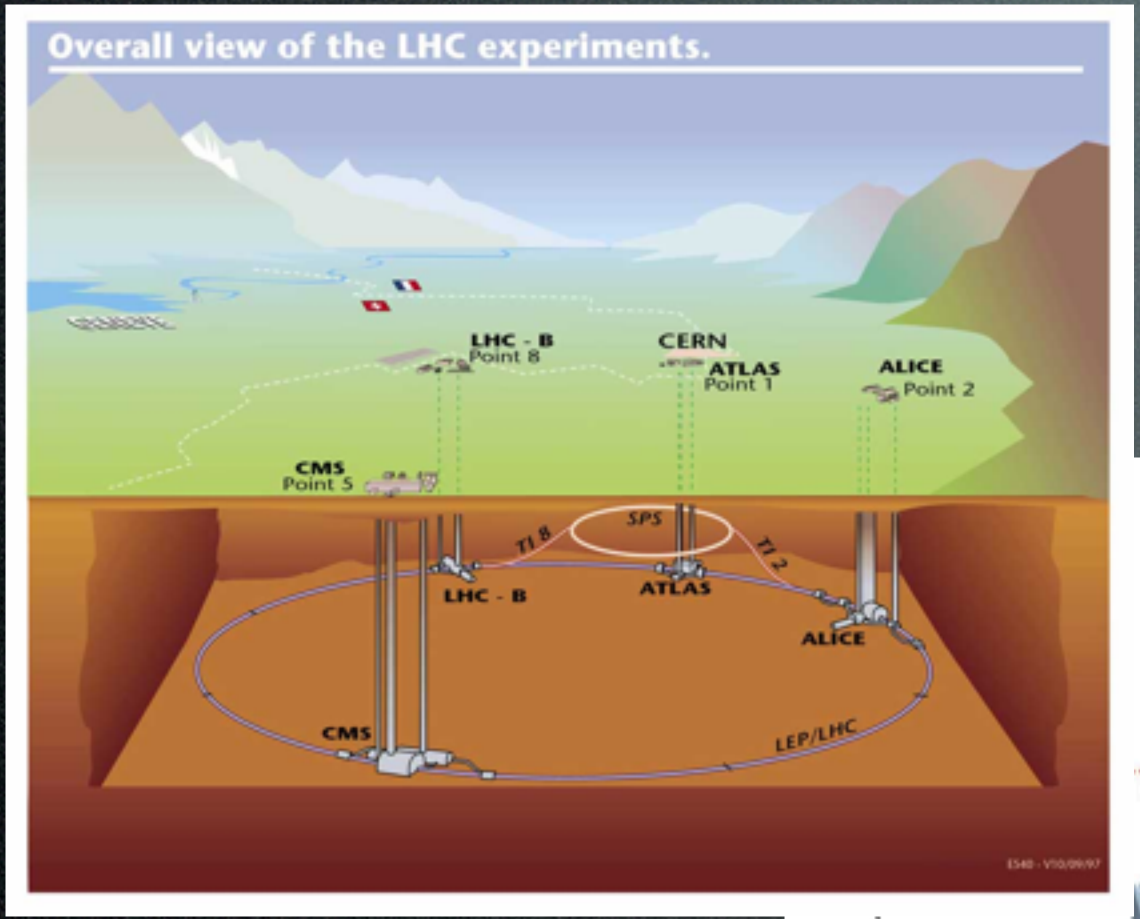




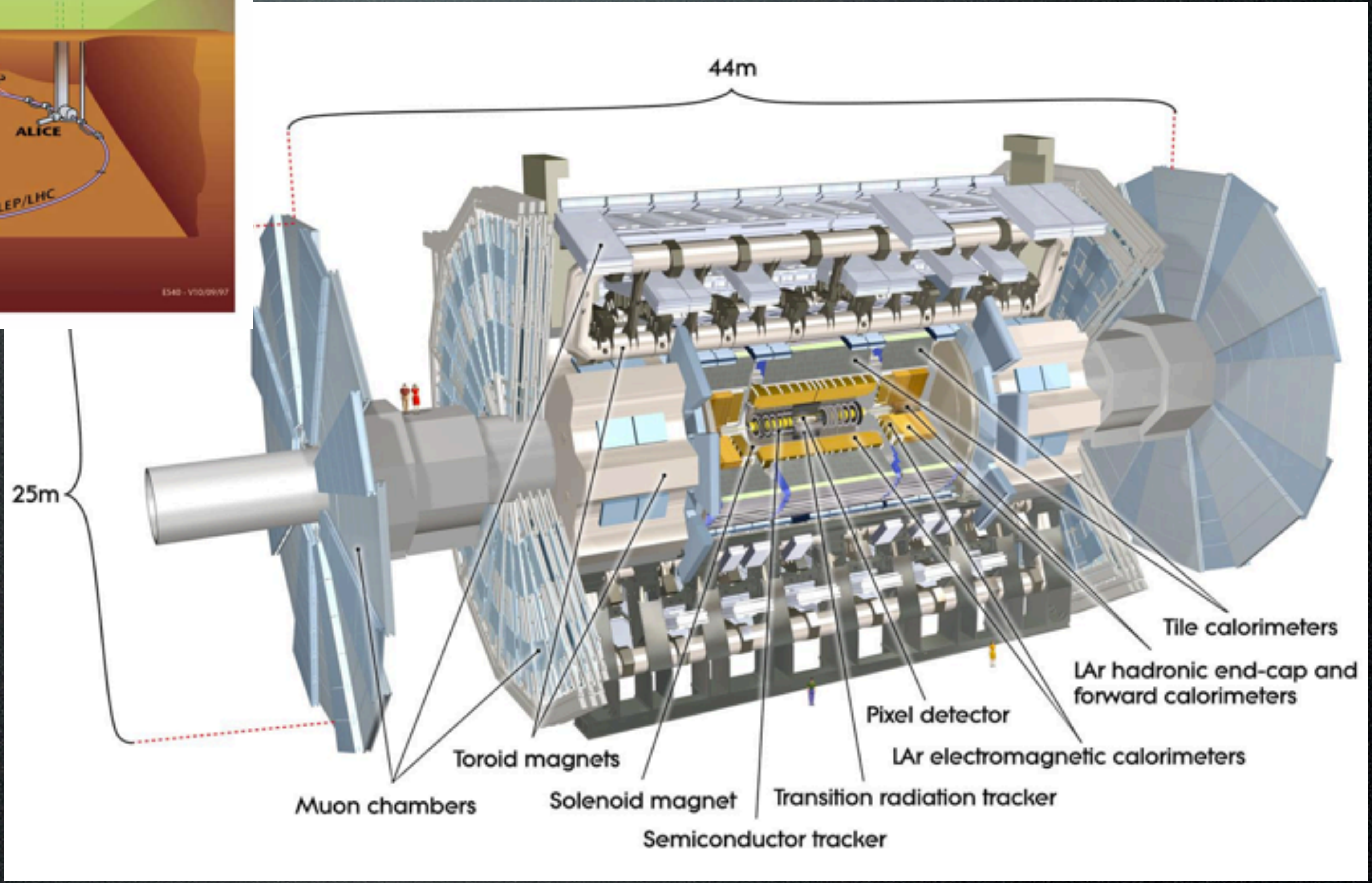


LHC 13/14 TeV runs will help us to probe a new energy domain.

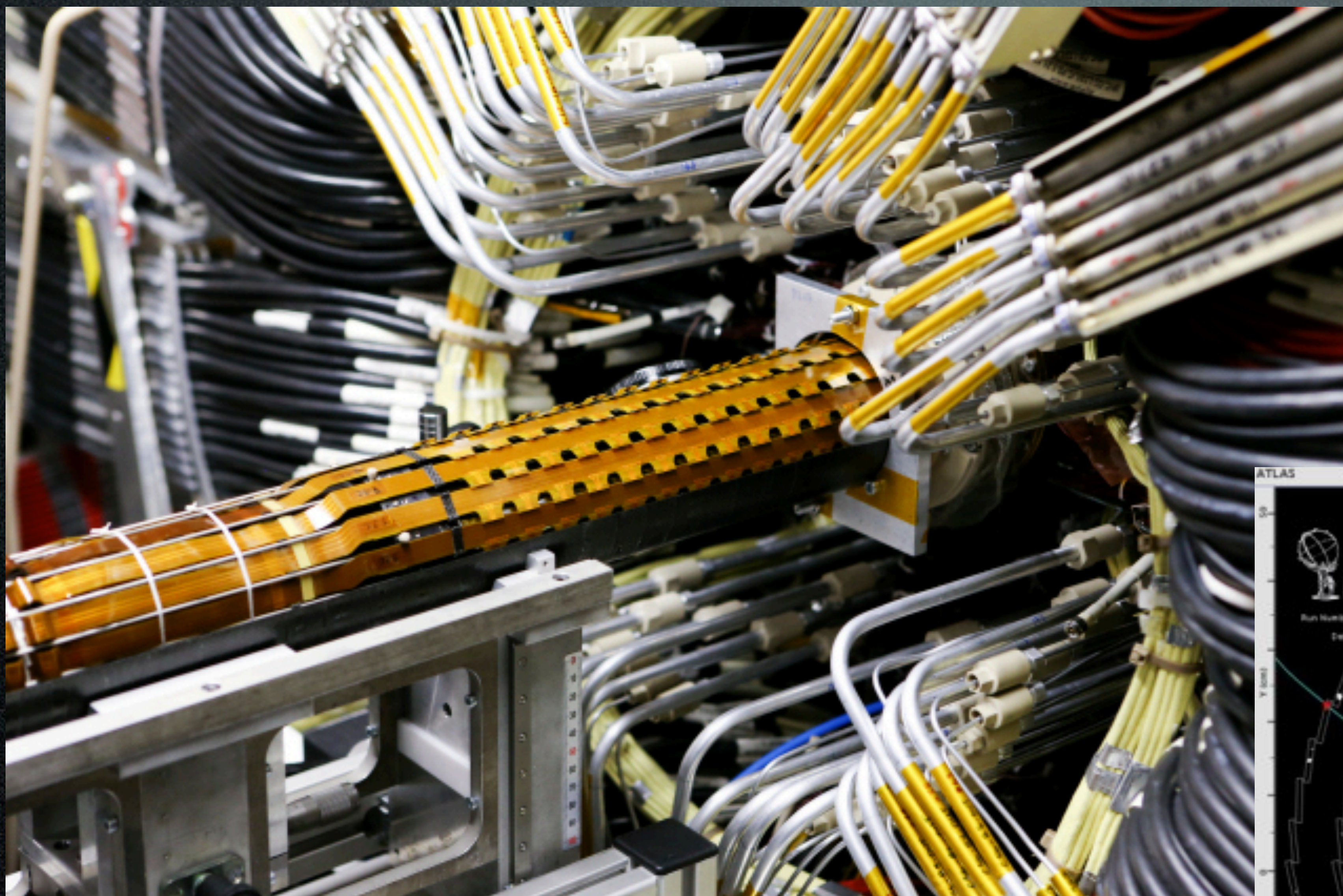
LHC and ATLAS



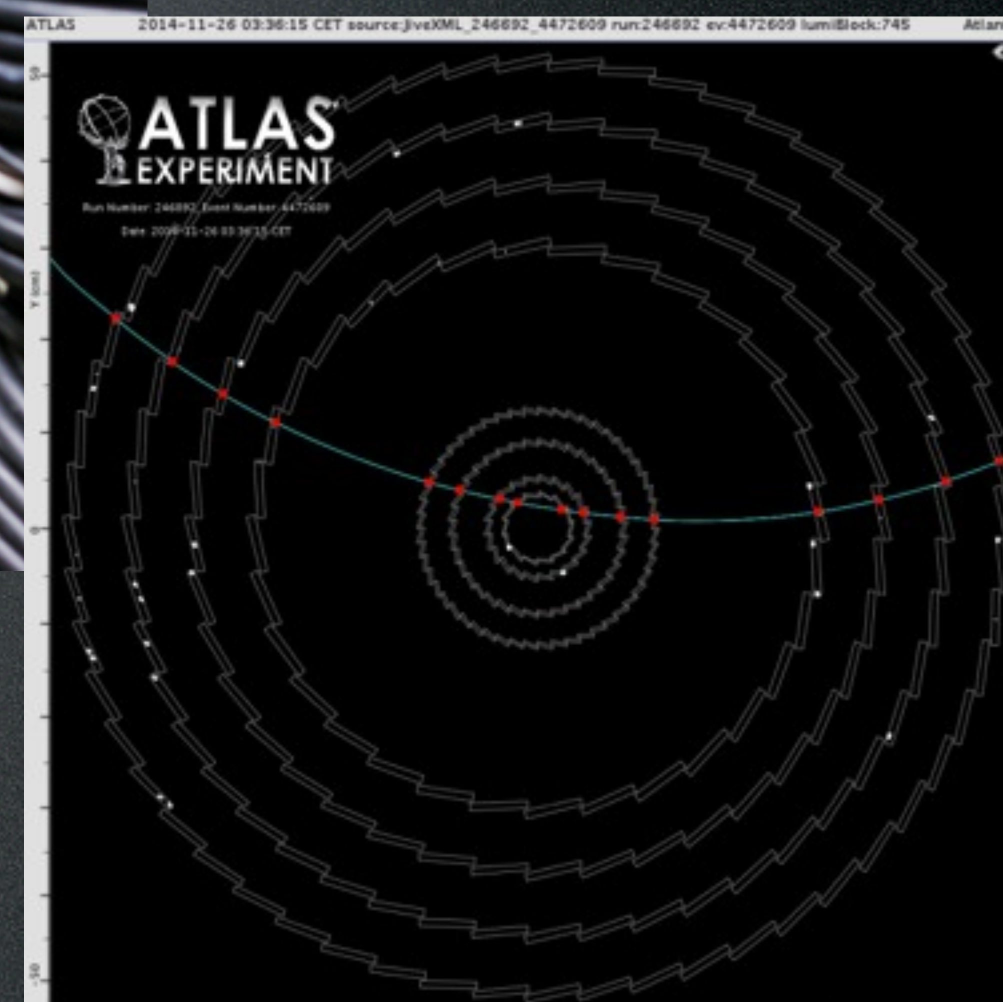
Multi-purpose high resolution detector



What's new: IBL

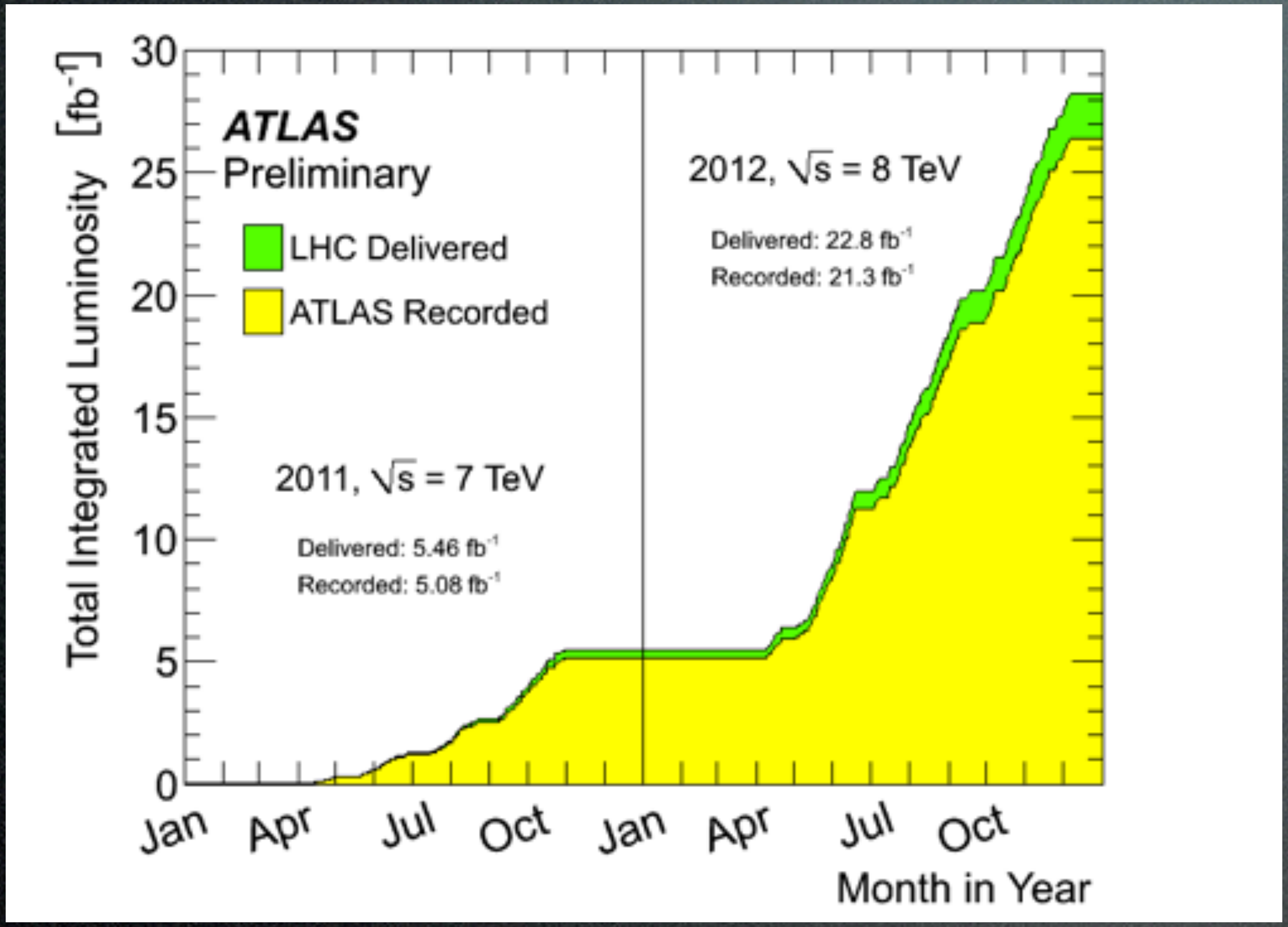


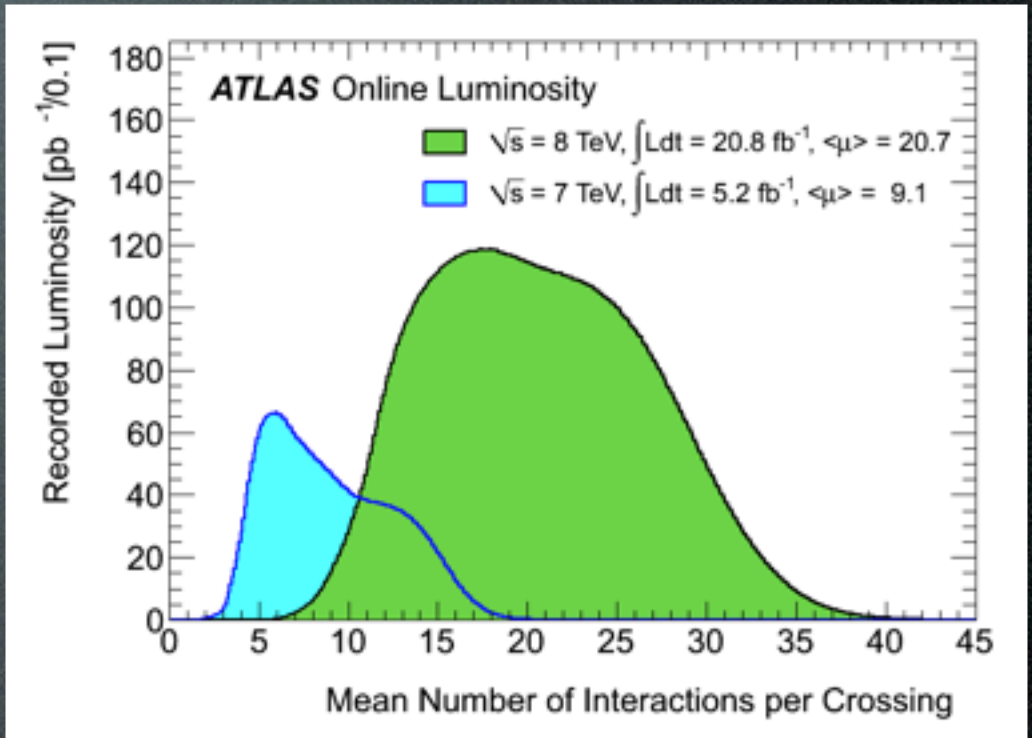
Additional layer
of radiation-damage
resistant pixels

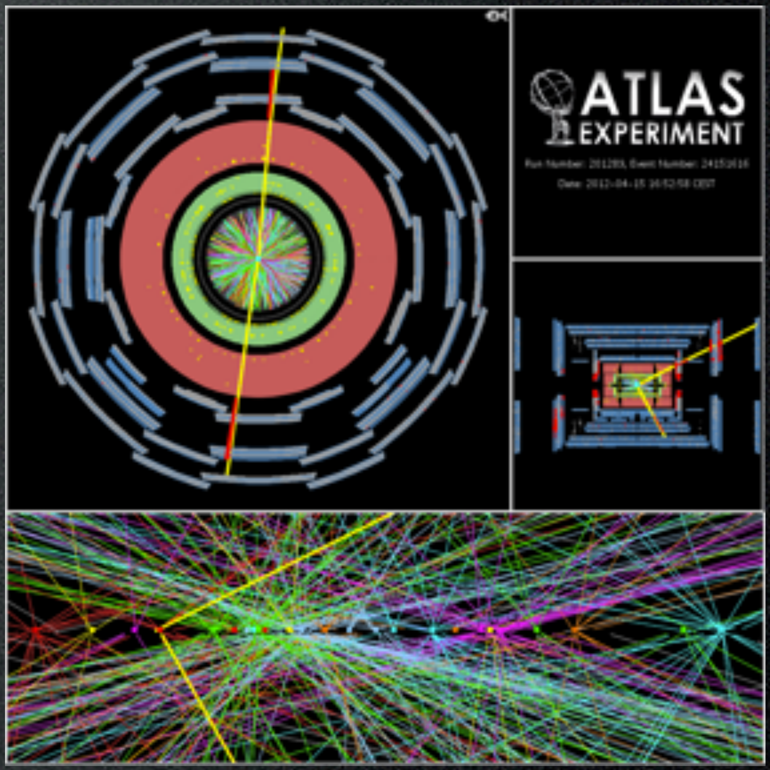


Improved track reconstruction
and b-tagging

A lot of data!





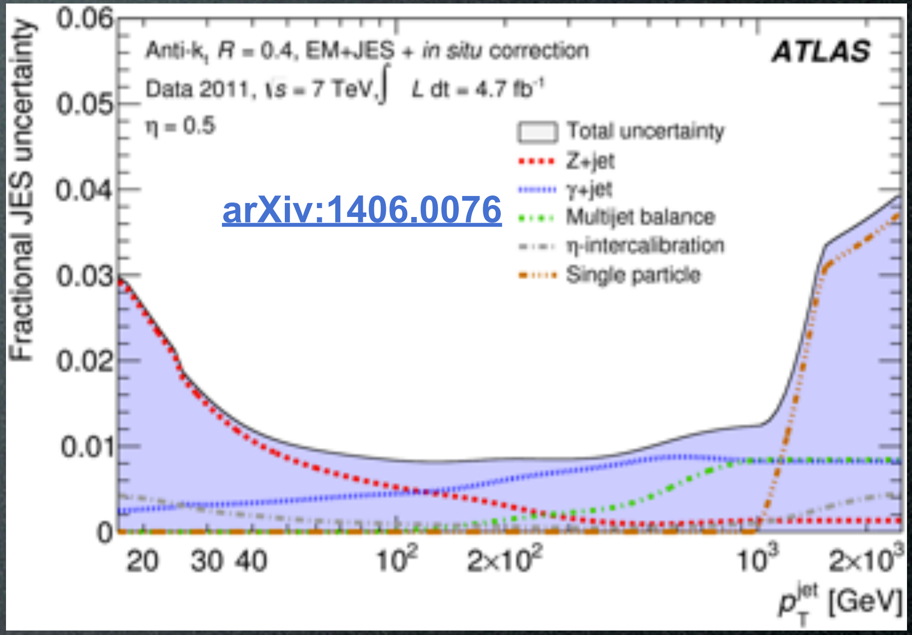


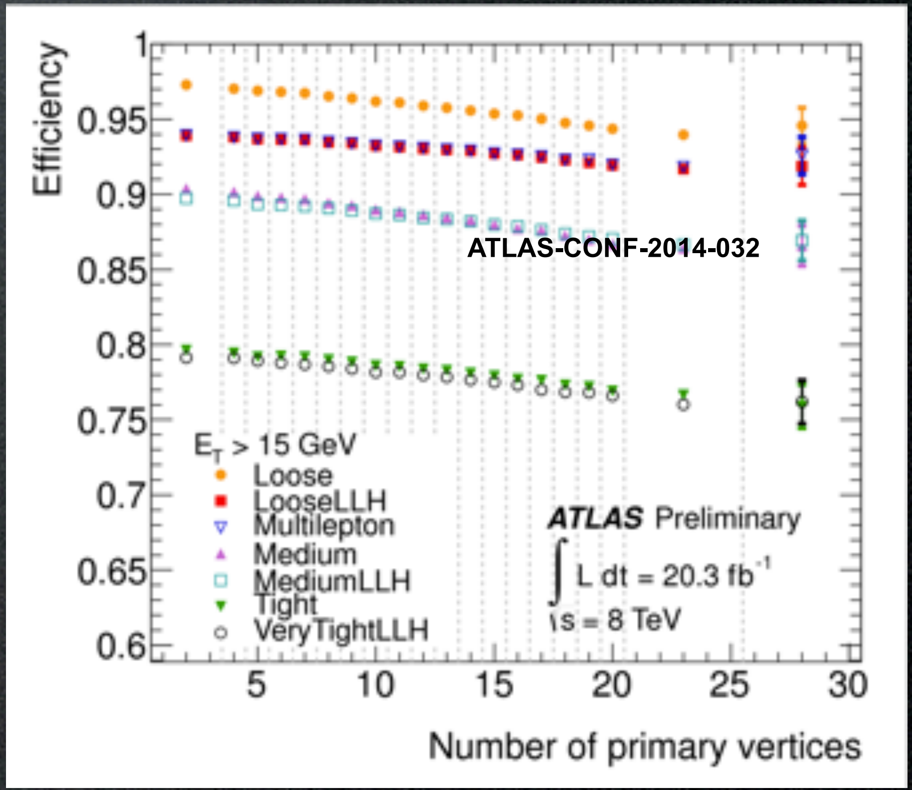
excellent data collection efficiency with <2% luminosity uncertainty.

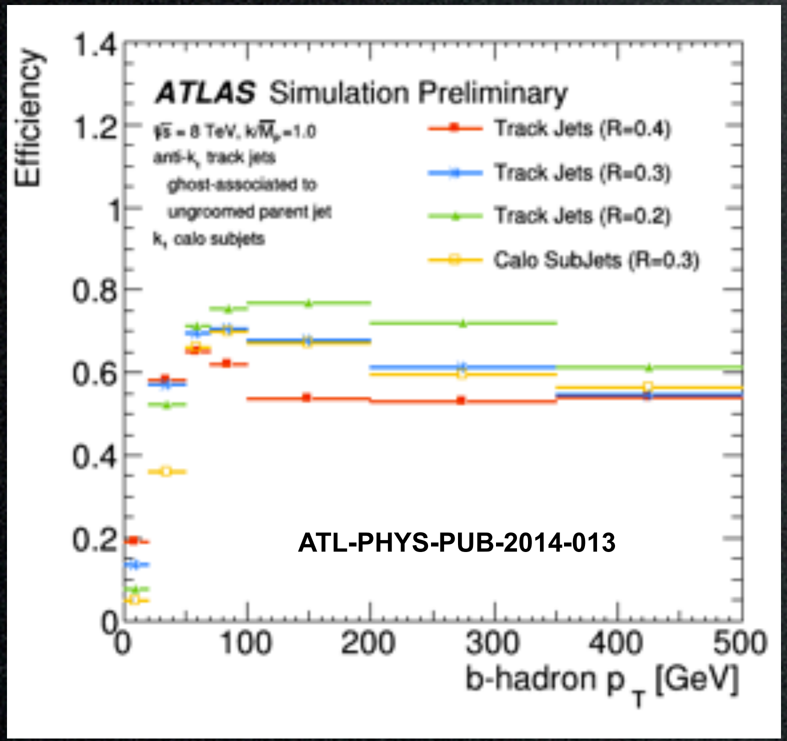
Price of high luminosity: pileup

Physics Object Reconstruction

- Jet energy scale uncertainties are <3% for central jets.
- Different pile up suppression techniques investigated.
- Improved electron and photon identification efficiency and energy scale uncertainty (latter directly helping in Higgs to diphoton measurements).
- Improved muon momentum scale and resolution (benefiting i.e Higgs to ZZ to 4 muons channel)

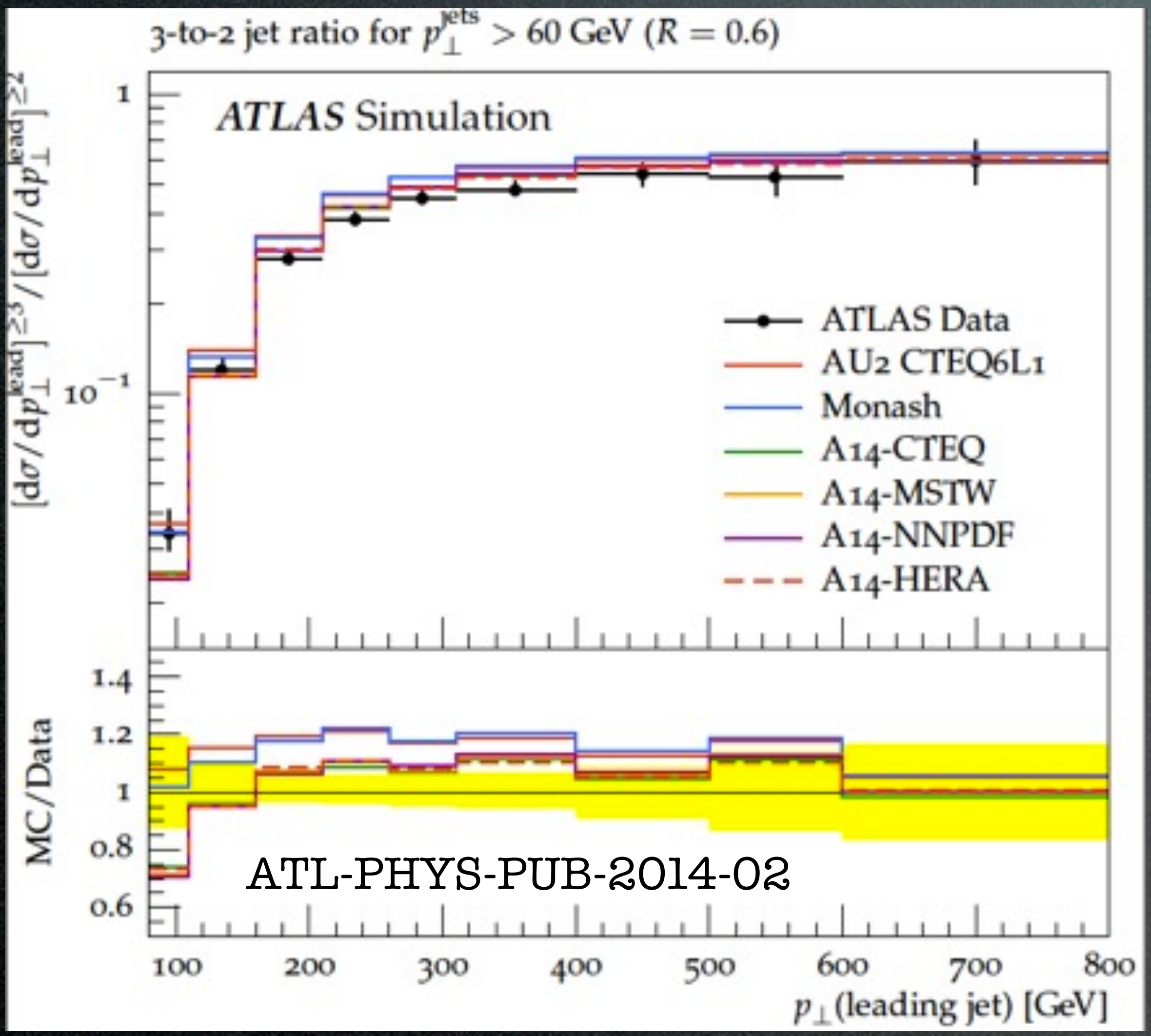


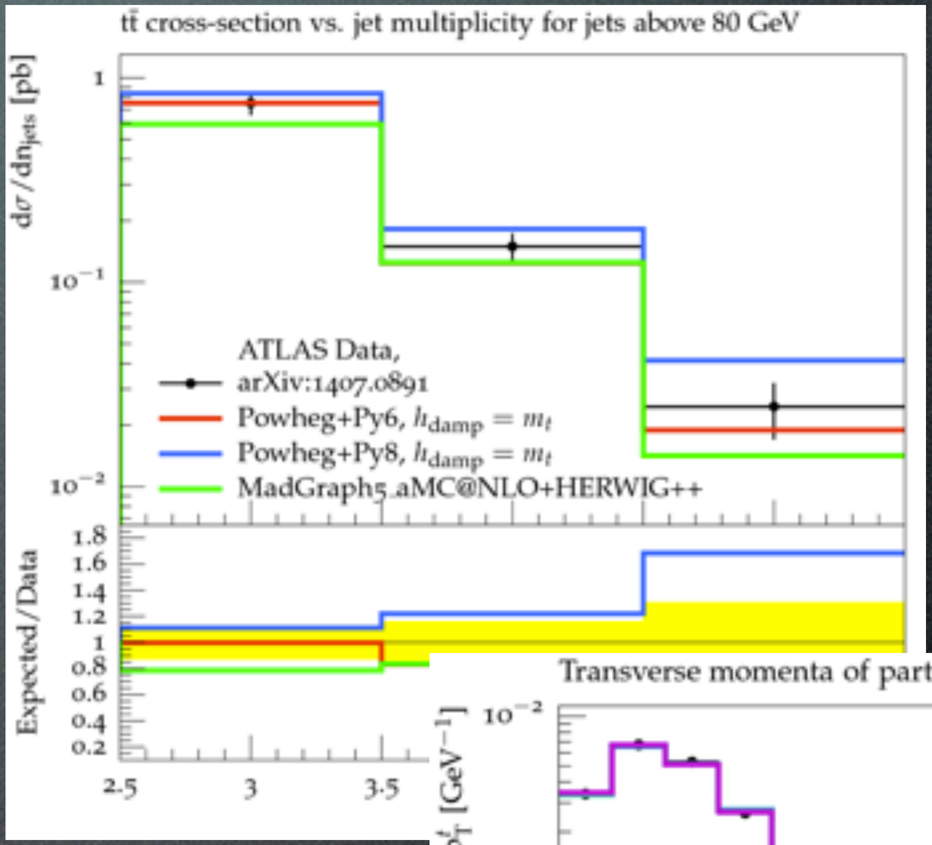


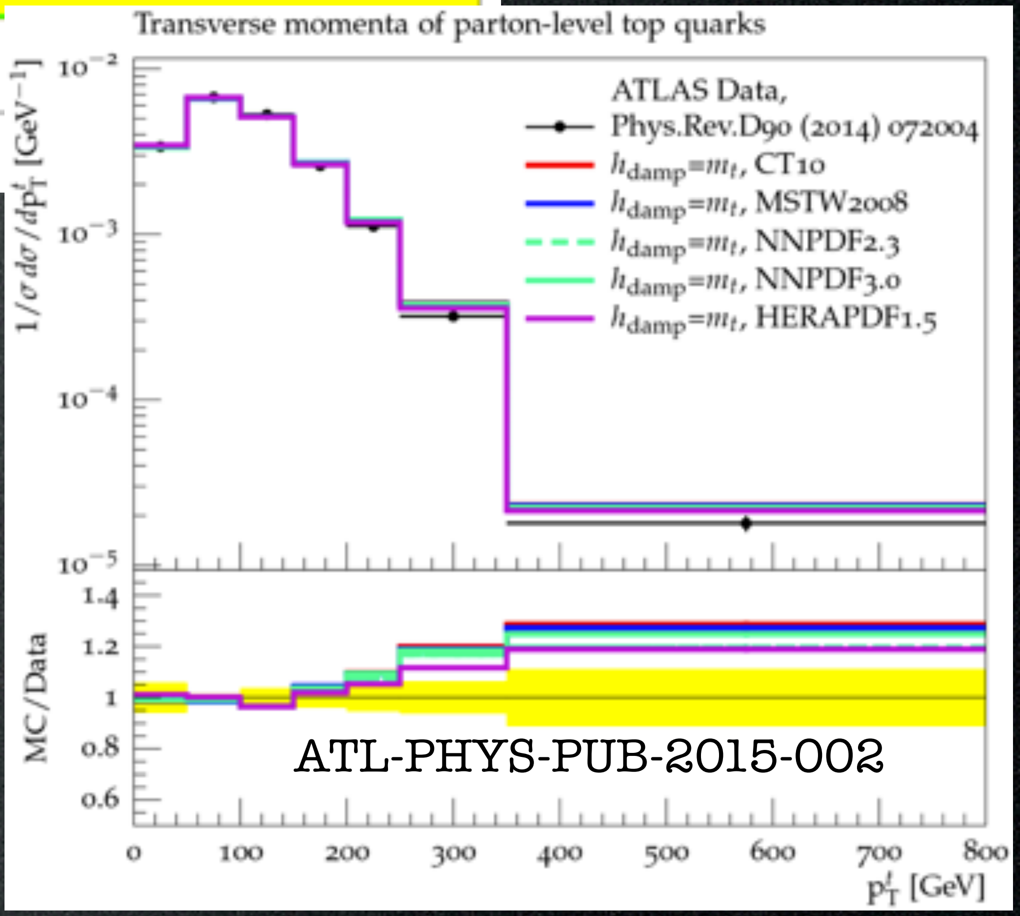


- Multivariate flavour taggers with high performance and small uncertainty.
- Exploring new ideas for b-taggng, i.e using trackjets for small radius jets.

MC tuning/top modelling







Open issues...

New Pythia8 A14 tune: first tune of shower+MPI

Big 5

Big 5

HIGGS BOSON
H
The HIGGS BOSON is the particle of the Higgs mechanism, believed by physicists to reveal how all matter in the universe gets its mass. On July 4, 2012, the CMS and Atlas collaborations at CERN announced a 5-sigma level of certainty that the Higgs boson had been detected with a mass of around 125 GeV.
$10.49 PLUS SHIPPING
LIGHT
HEAVY
Wool felt, fleece with gravel fill for maximum mass.
The PARTICLE ZOO

DARK MATTER
?
DARK MATTER is the name given to material in the Universe that does not emit or reflect light but is necessary to explain observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals 96% of the Universe, yet it remains a mystery as to what exactly it is.
Acrylic felt, wool felt, and fleece with gravel fill for maximum mass.
Packaged in a black opaque bag designed for concealing contents.
LIGHT
HEAVY
$10.49 PLUS SHIPPING
The PARTICLE ZOO

Z BOSON
Z
The Z BOSON is a very massive carrier particle for the weak force. Unlike its siblings the W-/W+ particles, the Z is neutrally charged. Living only 10⁻²⁵ second, the Z quickly decays into other particles. Discovered in 1983, the Z has allowed physicists to further study electroweak theory.
Wool felt with gravel fill for maximum mass.
LIGHT
HEAVY
$10.49 PLUS SHIPPING
The PARTICLE ZOO

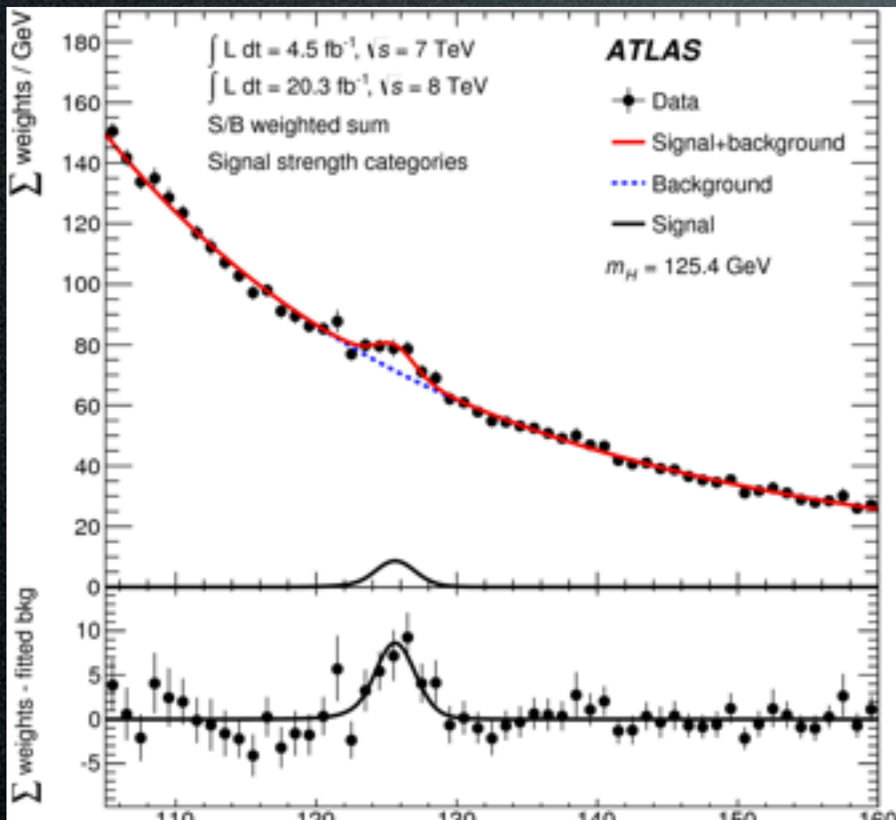
TOP QUARK
t
Discovered at Fermilab in 1995, the TOP QUARK is as short-lived as it is massive. Weighing in at a hefty 175 GeV, its lifetime, a mere 10⁻²⁴ second, is the briefest of the six quarks. Top Quarks are an enigmatic particle whose personal life is sought after by thousands of physicists.
Acrylic felt with gravel fill for maximum mass.
$10.49 PLUS SHIPPING
LIGHT
HEAVY
The PARTICLE ZOO

neutralino
esa
CERN

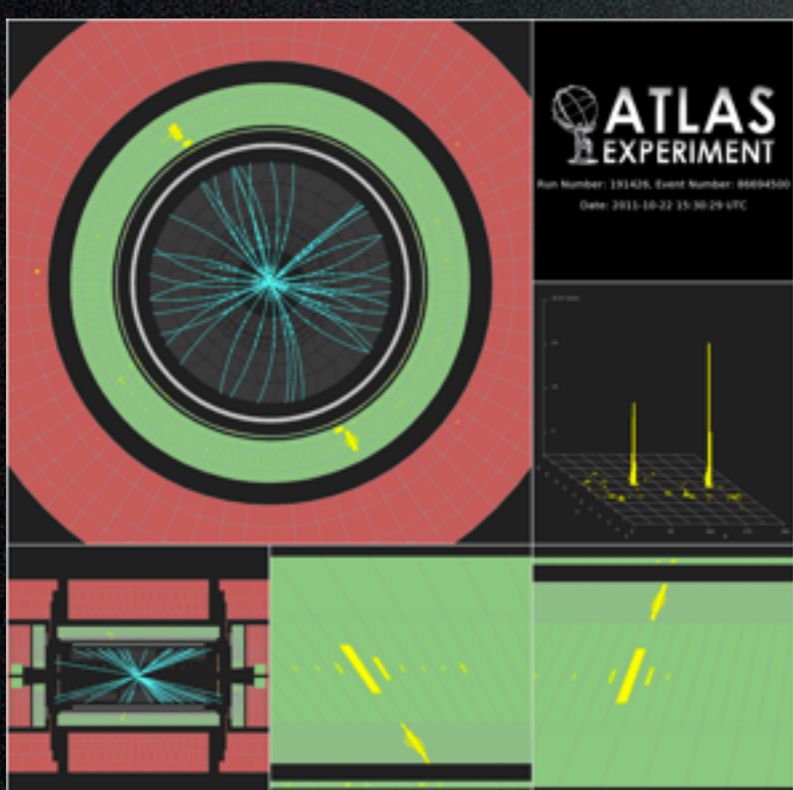
Higgs

Higgs

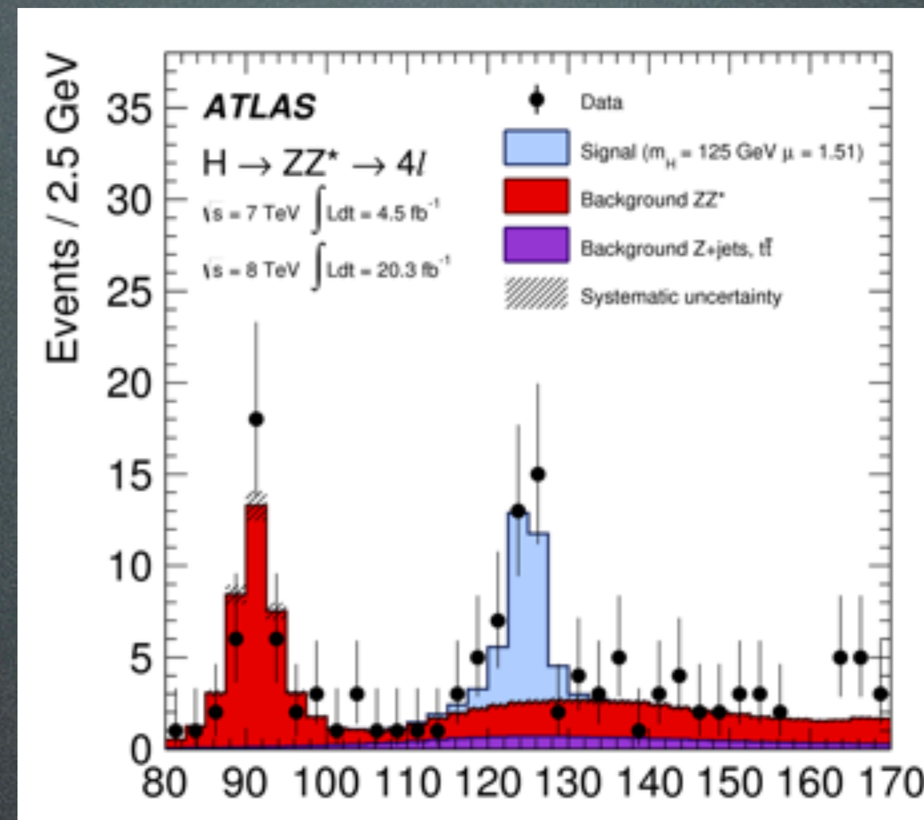
H->$\gamma\gamma$ (5.2σ)



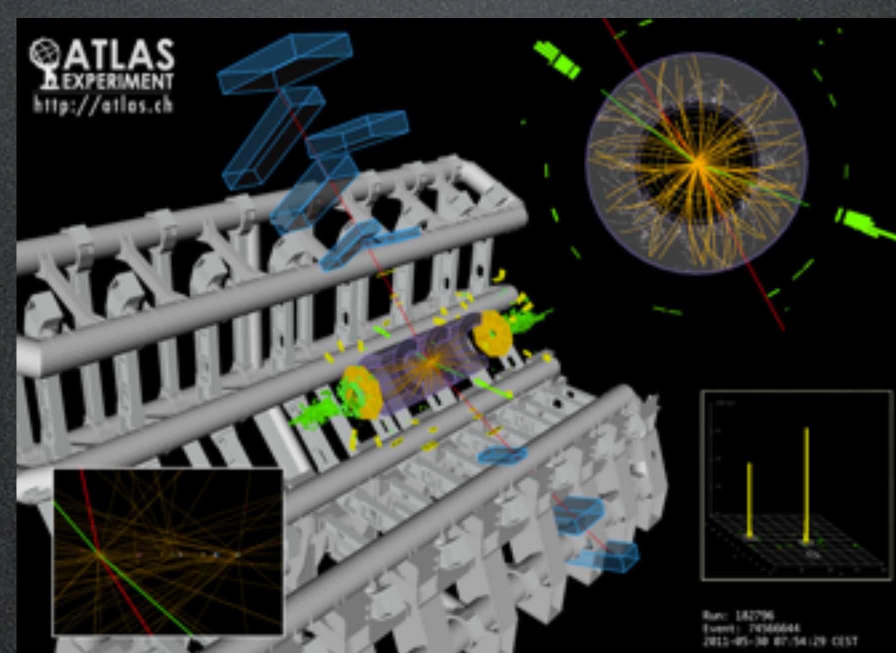
Phys. Rev. D 90 (2014) 112015



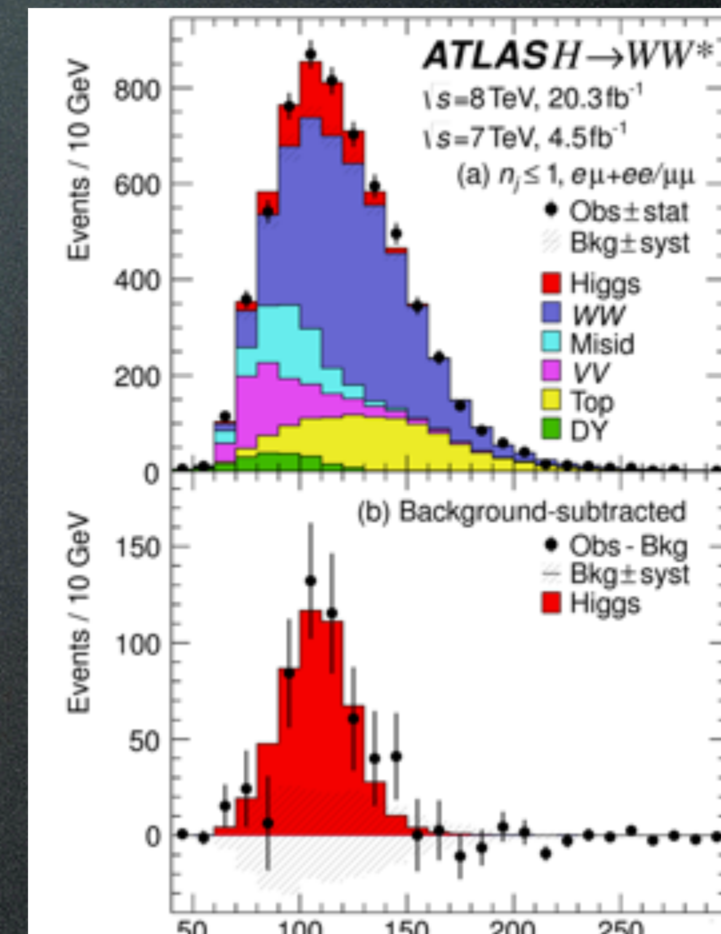
H->ZZ->4l (8.2σ)



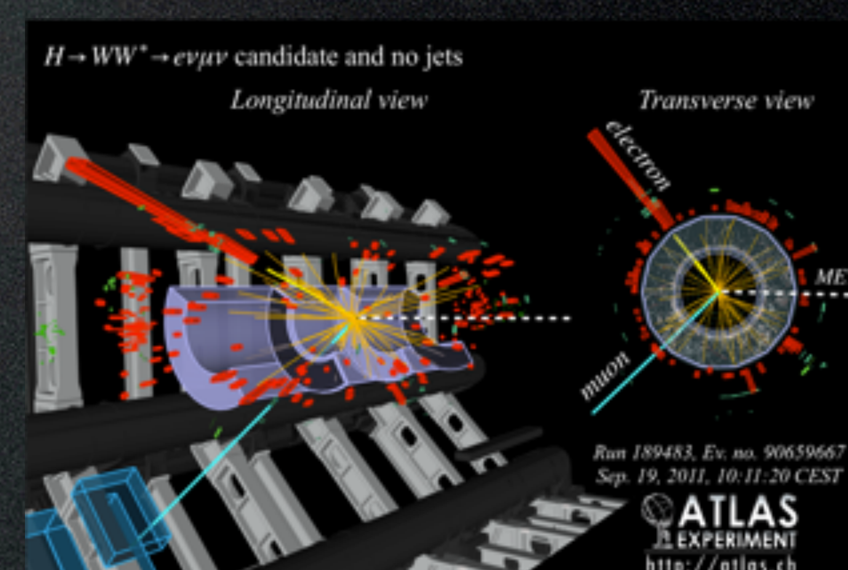
Phys. Rev. D 91 (2014) 012006



H->WW->2l2ν (6.1 σ)



arXiv:1412.2641

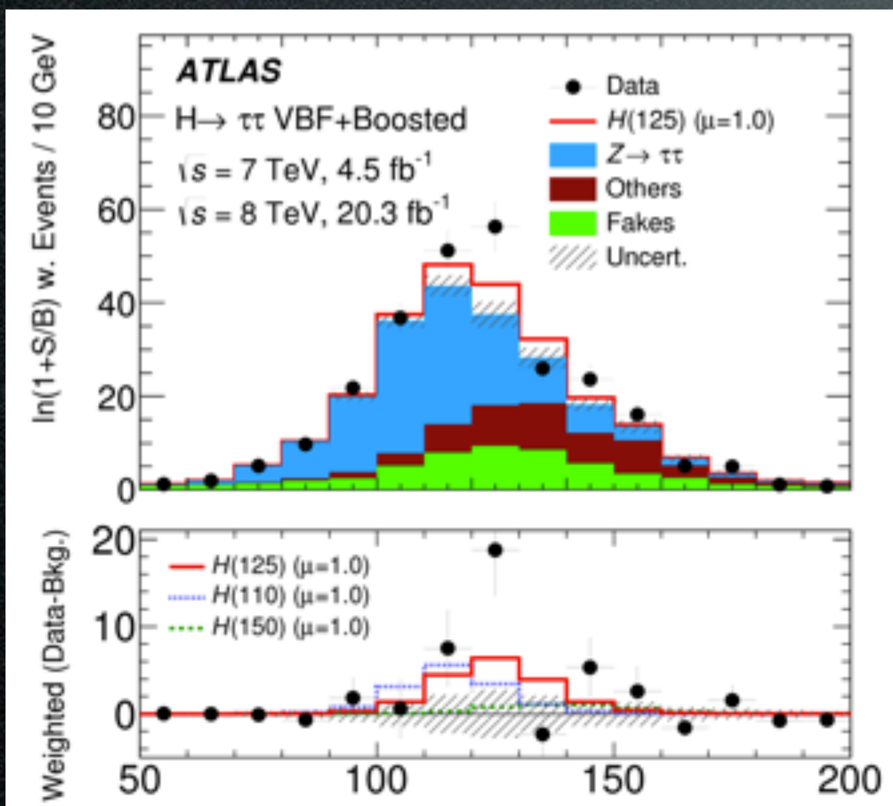


After the discovery

- Obvious question: how do we know it is the SM Higgs?
- Many extensions of the SM predict additional Higgs bosons (with one SM-like Higgs), rule out or find!
- Observe in other channels.
- Precisely measure the properties: spin, parity, width, CP, coupling, cross sections.
- Much more stats in Run 2: Currently ~40 candidates/channel. Run 2 expect ~500/channel.

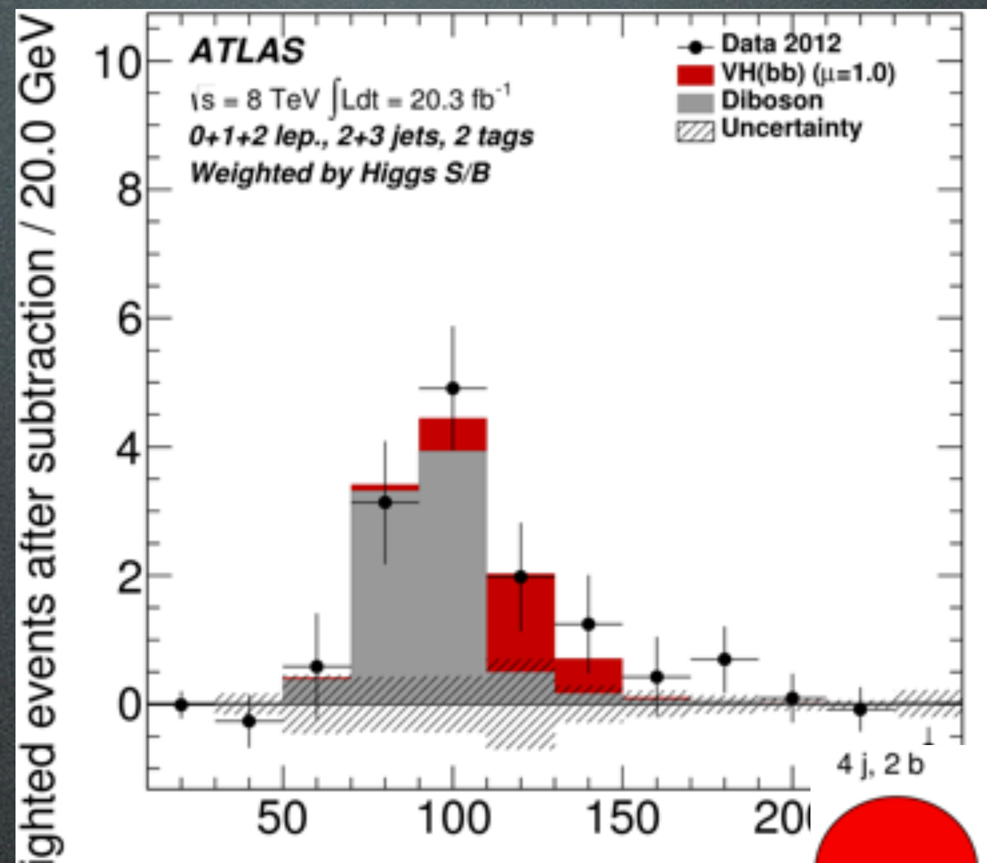
Higgs decaying to Fermions

H->ττ (4.5σ)



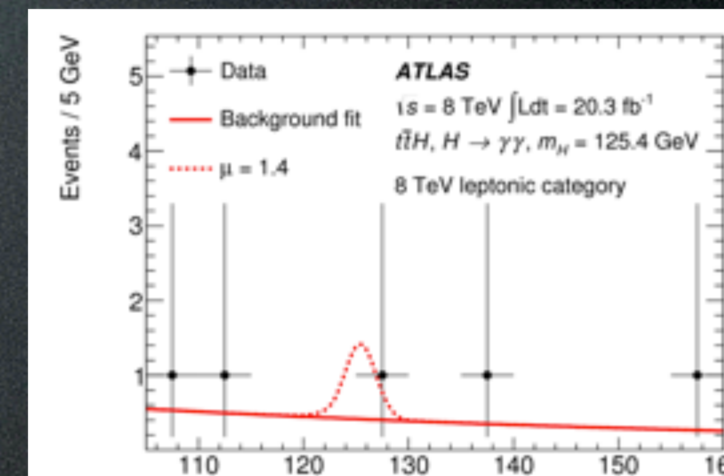
JHEP01(2015)069

(V)H->bb (1.4σ)



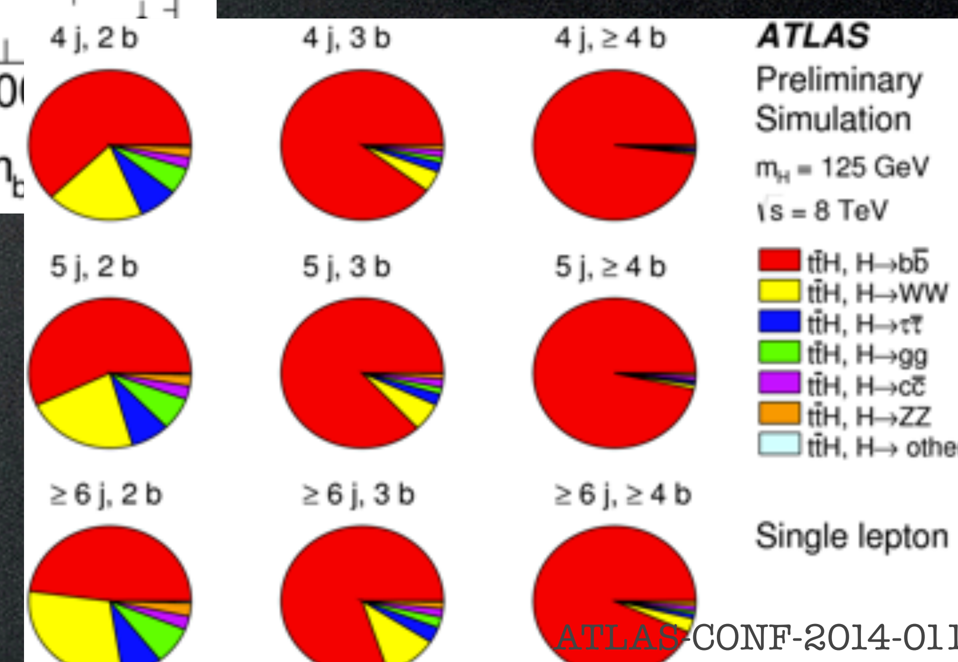
arXiv:1409.6212

(tt)H->γγ



Physics Letters B 740 (2015)

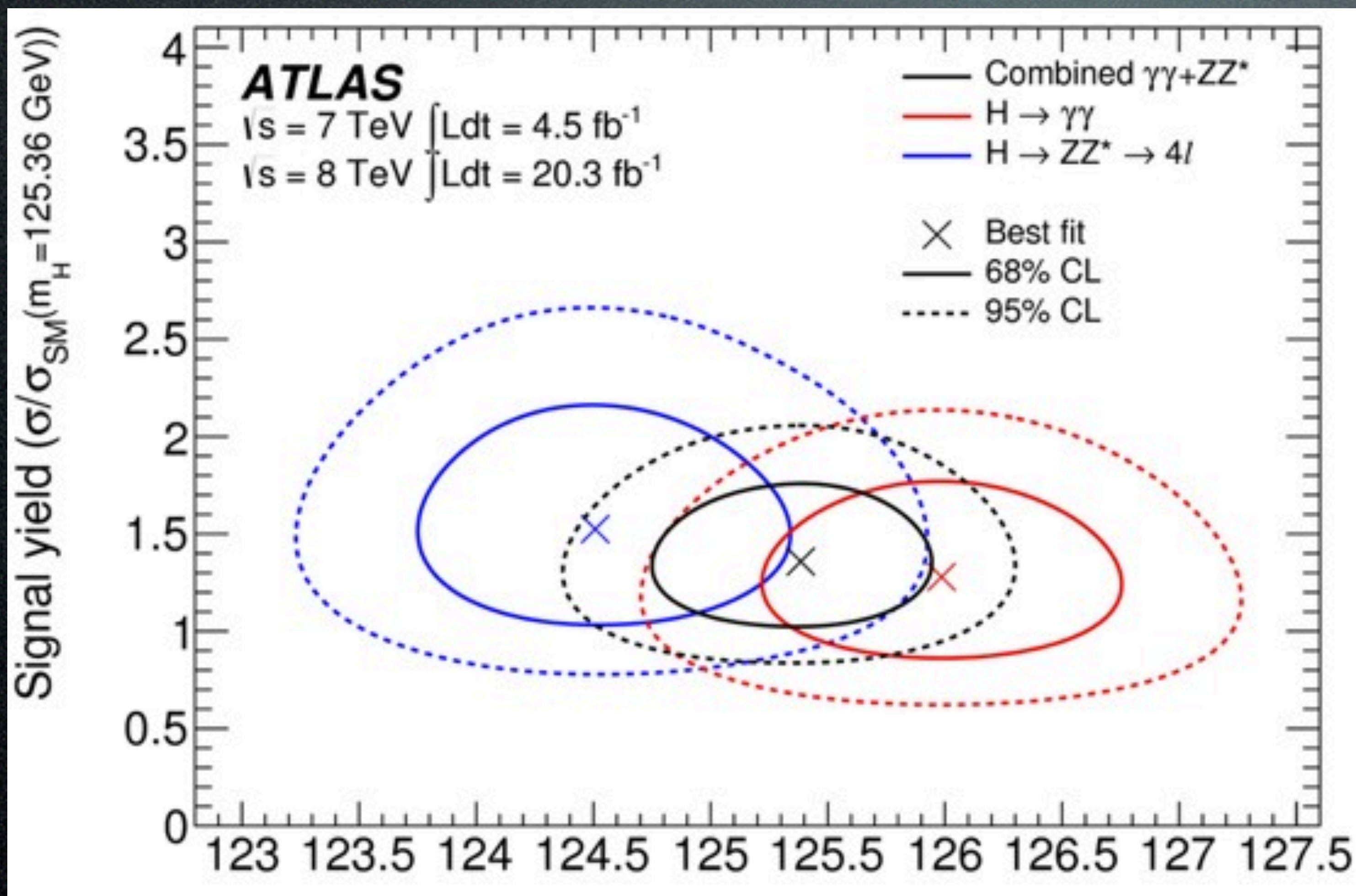
(tt)H->bb



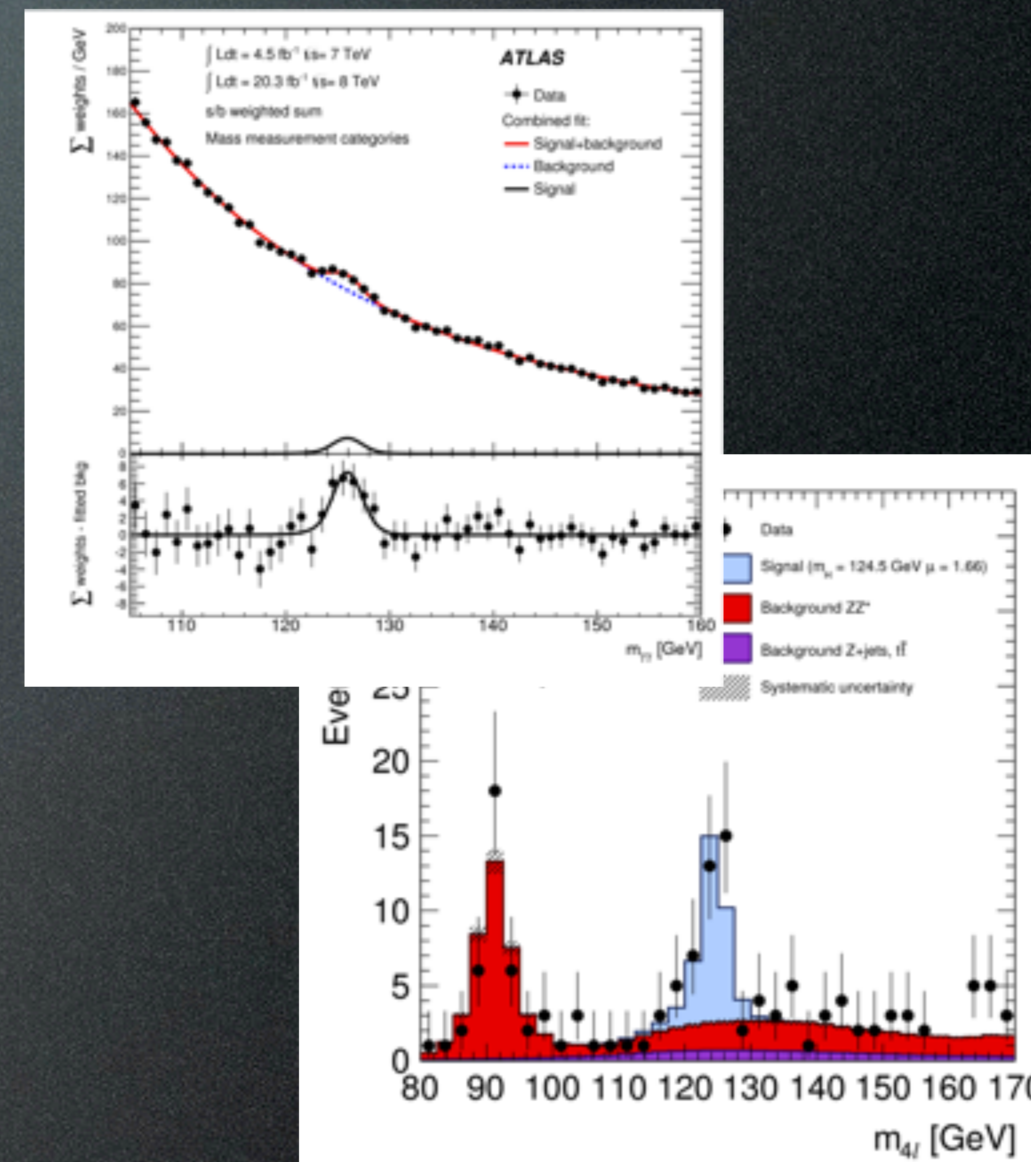
ATLAS-CONF-2014-011

Multi variate analysis to distinguish signal from background

Higgs Mass Measurements

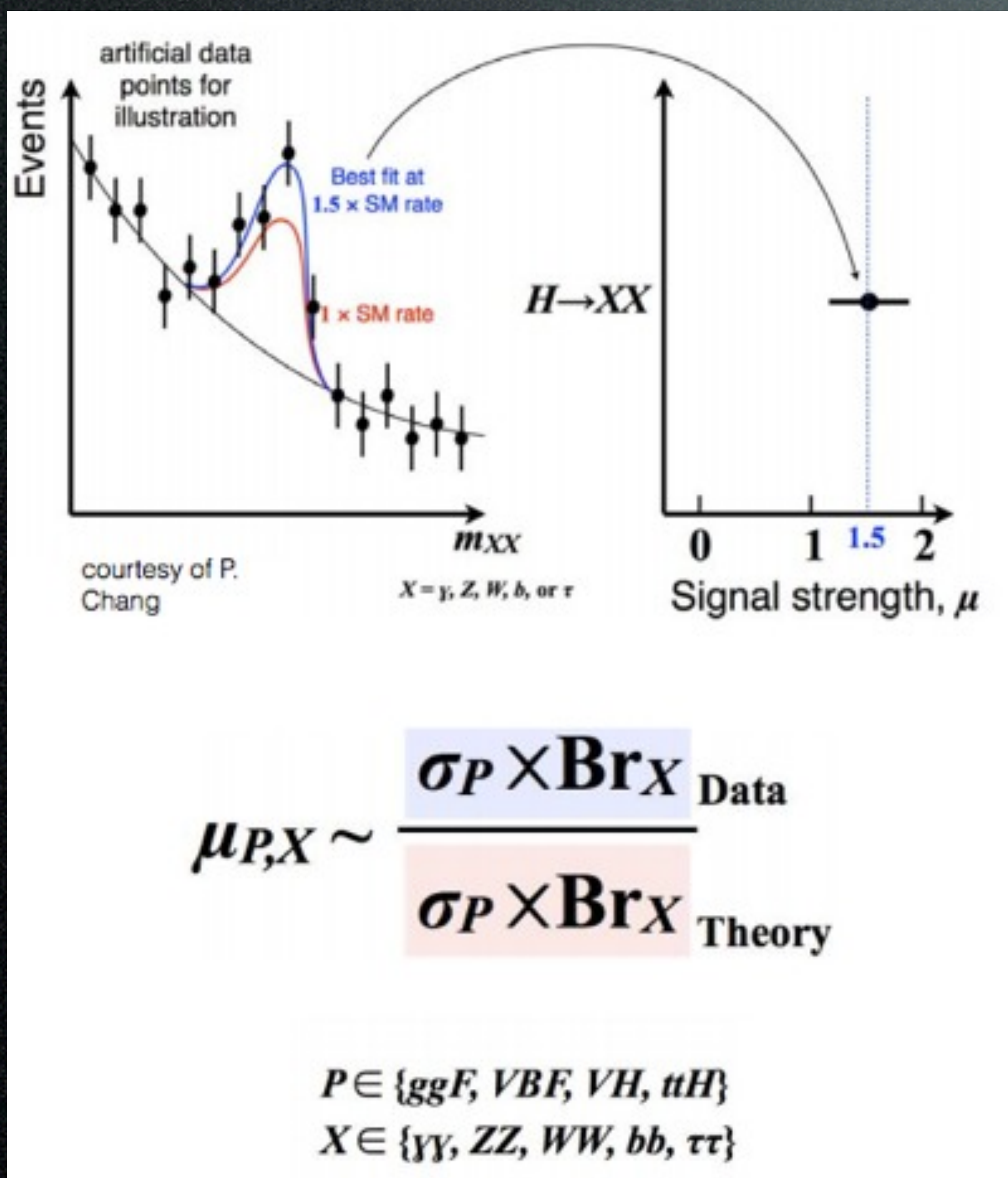


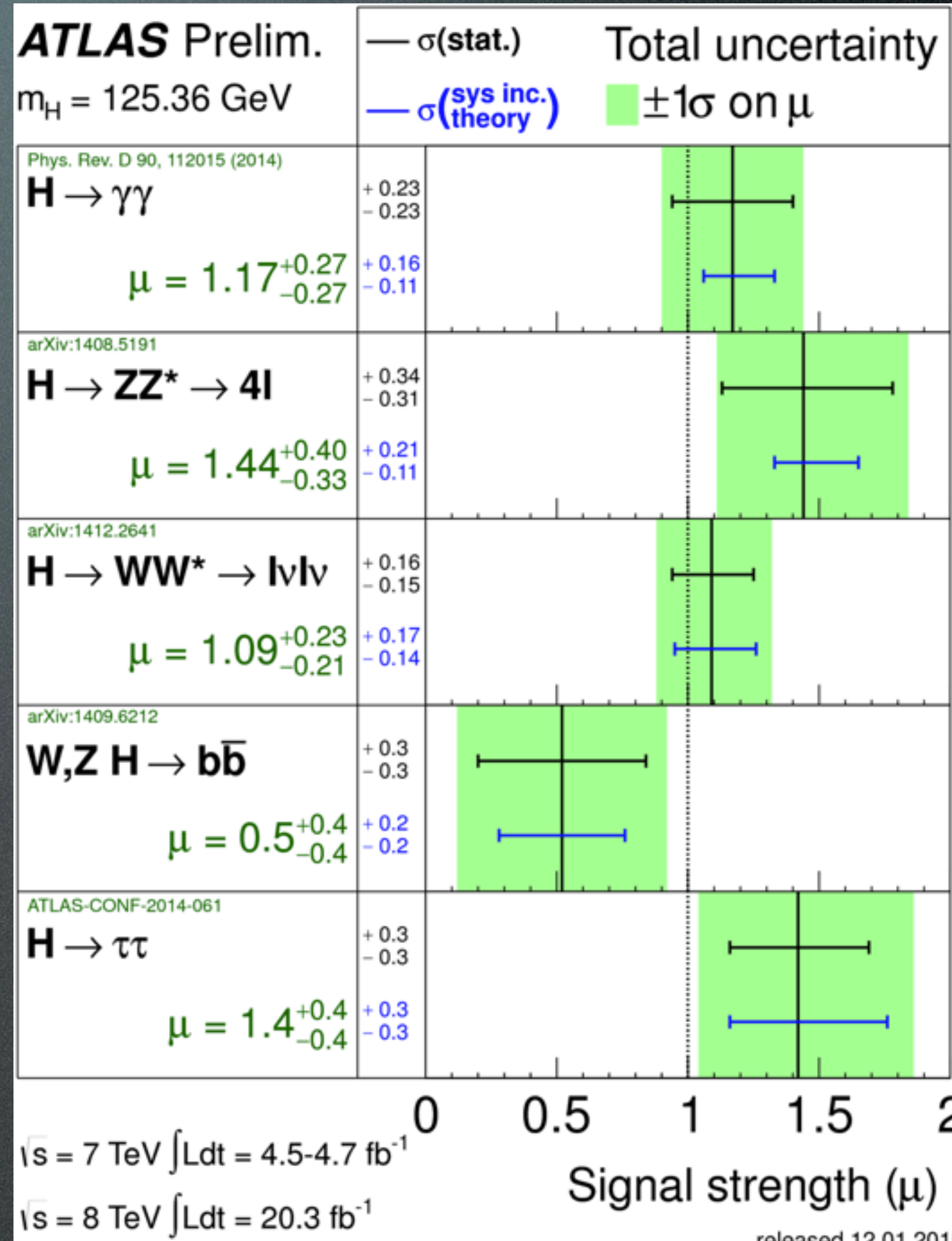
Phys. Rev. D. 90, 052004 (2014)



Measured in high resolution channels, $\gamma\gamma$ and 4l

Signal Strength

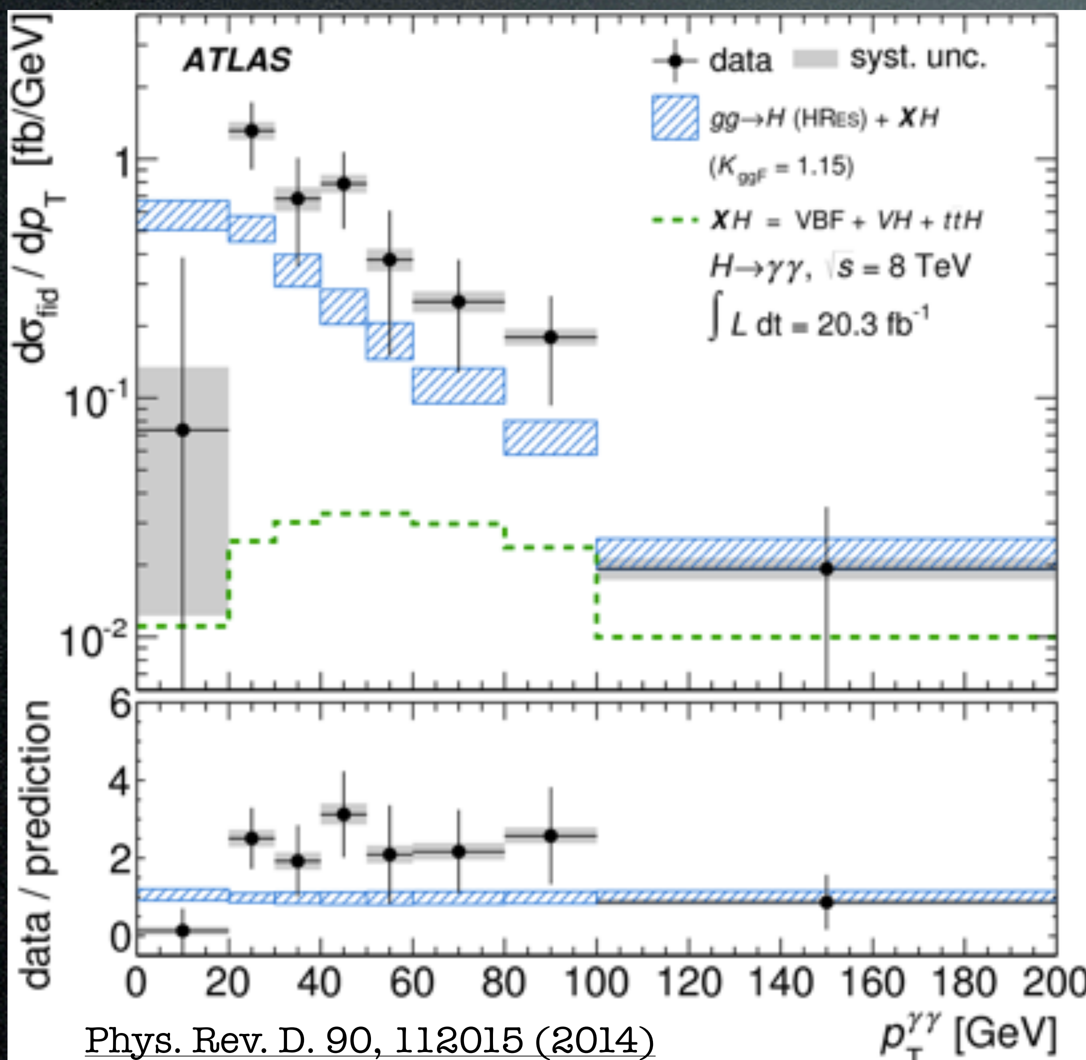




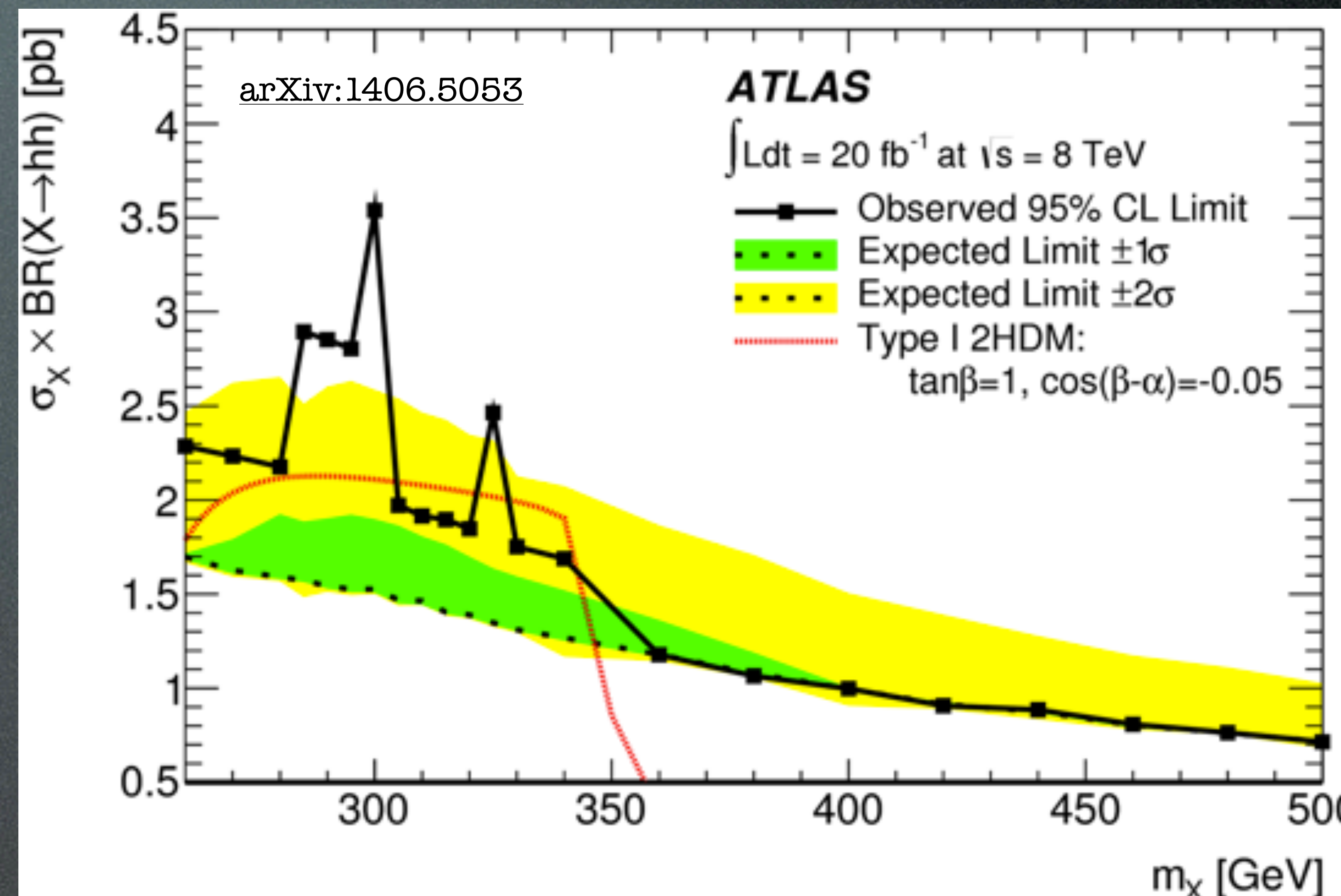
Other Properties

- Spin 0 strongly favoured
- Coupling strengths in measured channels roughly consistent with SM
- CP-odd almost ruled out
- Self coupling not measured

Open Questions?



Mismodelling of Higgs p_T?



A narrow resonance decaying to pairs of Higgs bosons?

More data will help!

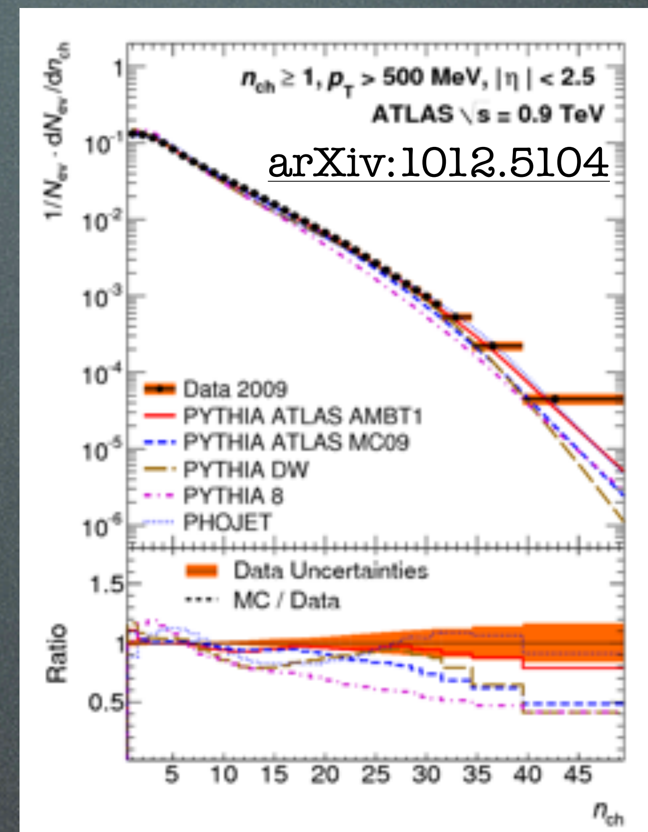
Standard Model

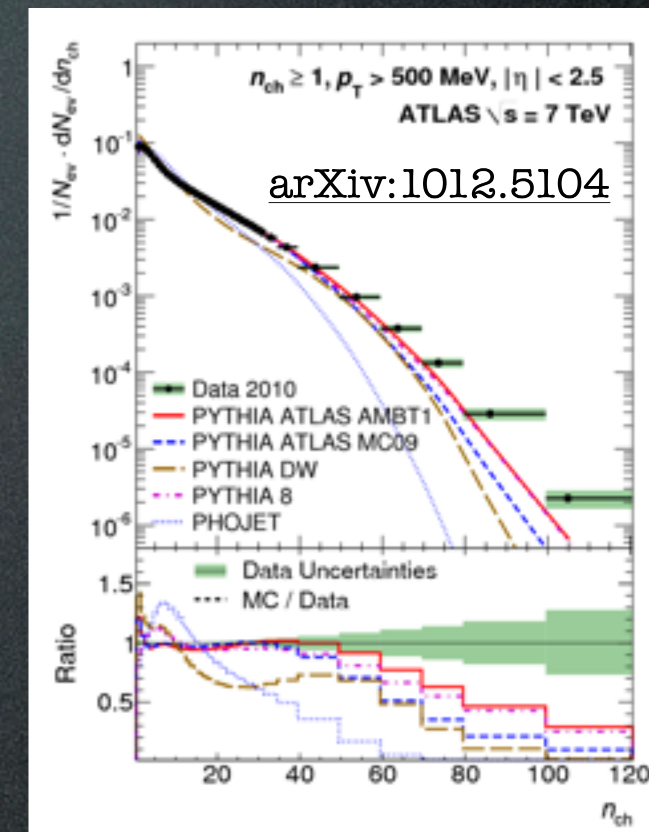
(SM) Measurements

- Wealth of measurements, all consistent with Standard Model predictions.
- Unprecedented Precision measurements with Z,W, Top (they couple most strongly to Higgs).
- Testing QCD at a new energy frontier.
- Measure the free parameters of SM (often indirectly).
- Test and validate MC Generators (input to PDF building as well).
- Essential background to the searches.

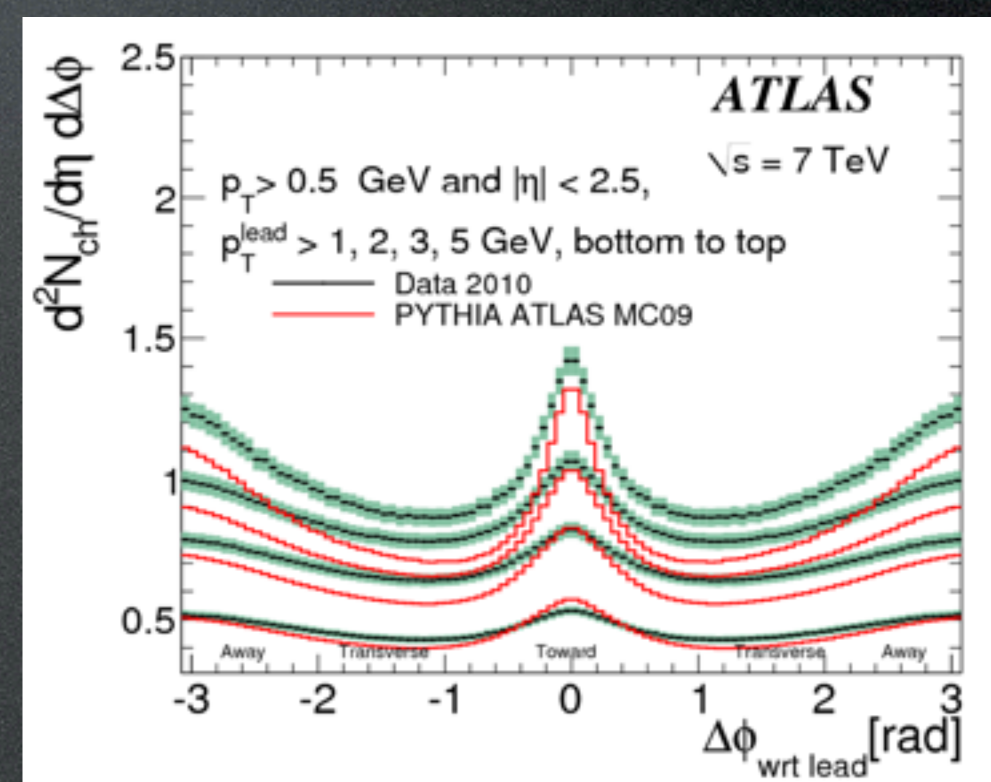
Beginning of the LHC

- Tevatron tunes did not agree with the early minbias and underlying event data.
- Not just at 7 TeV, but also at 900 GeV!

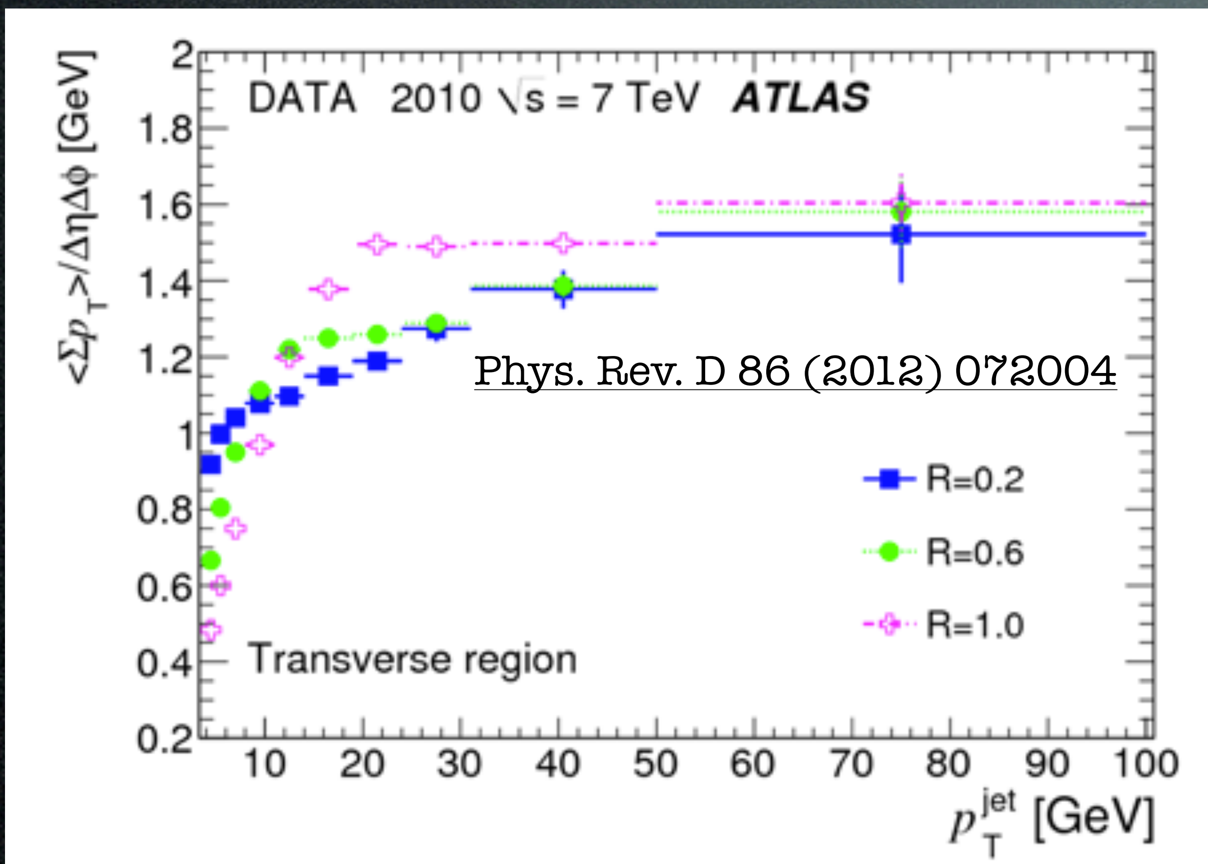




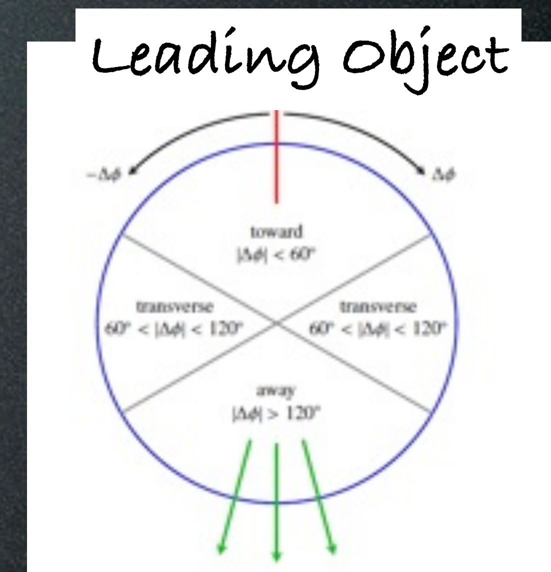
Would be the first results coming out of Run 2 as well!



SoftQCD: W/jet comp

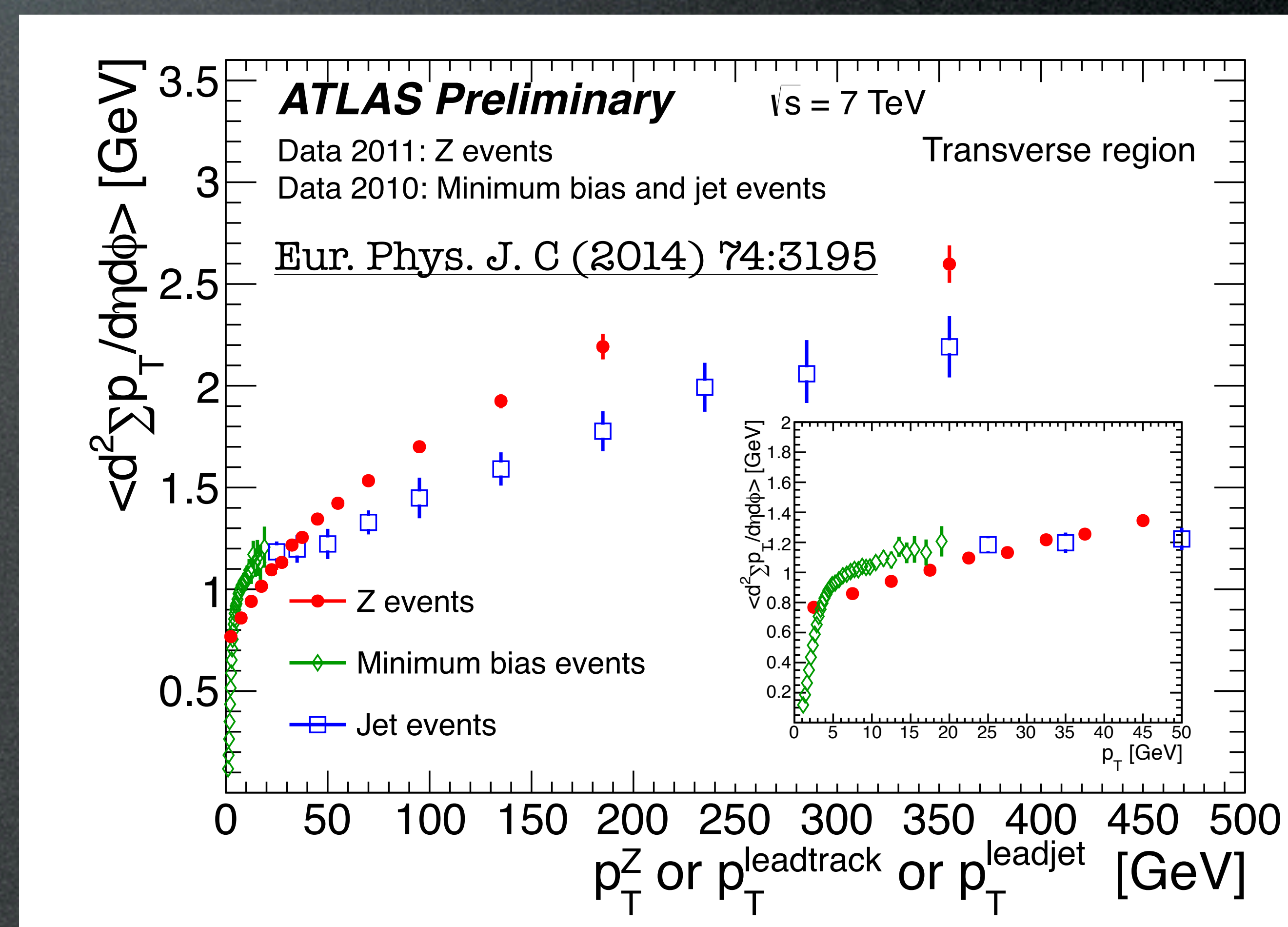


Activity increases with jet radius

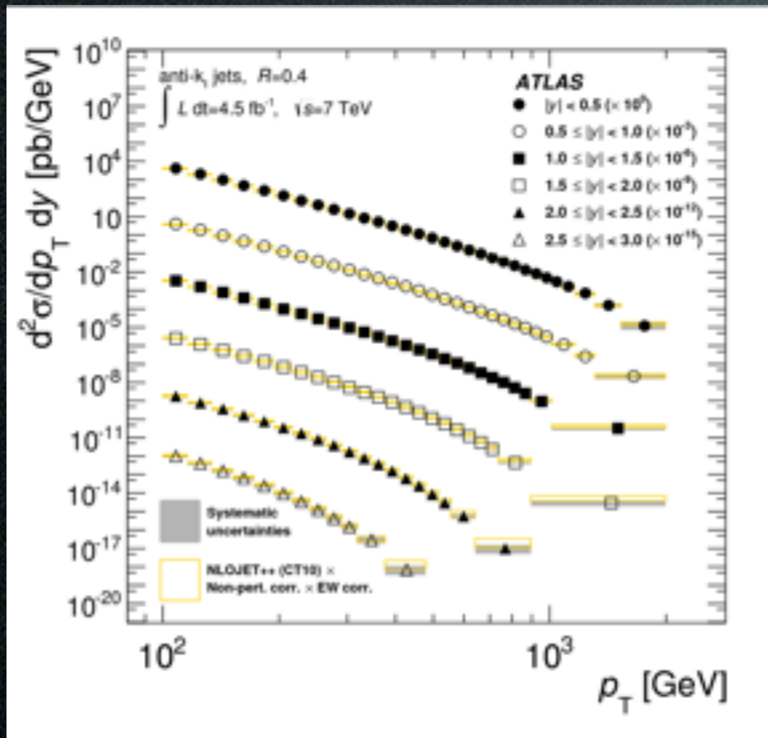


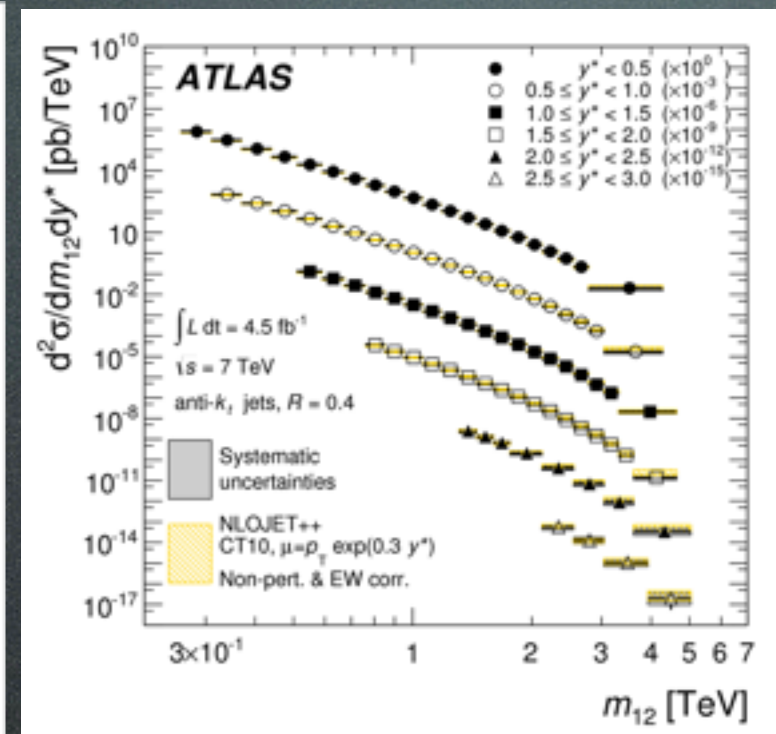
Difference due to selection bias.

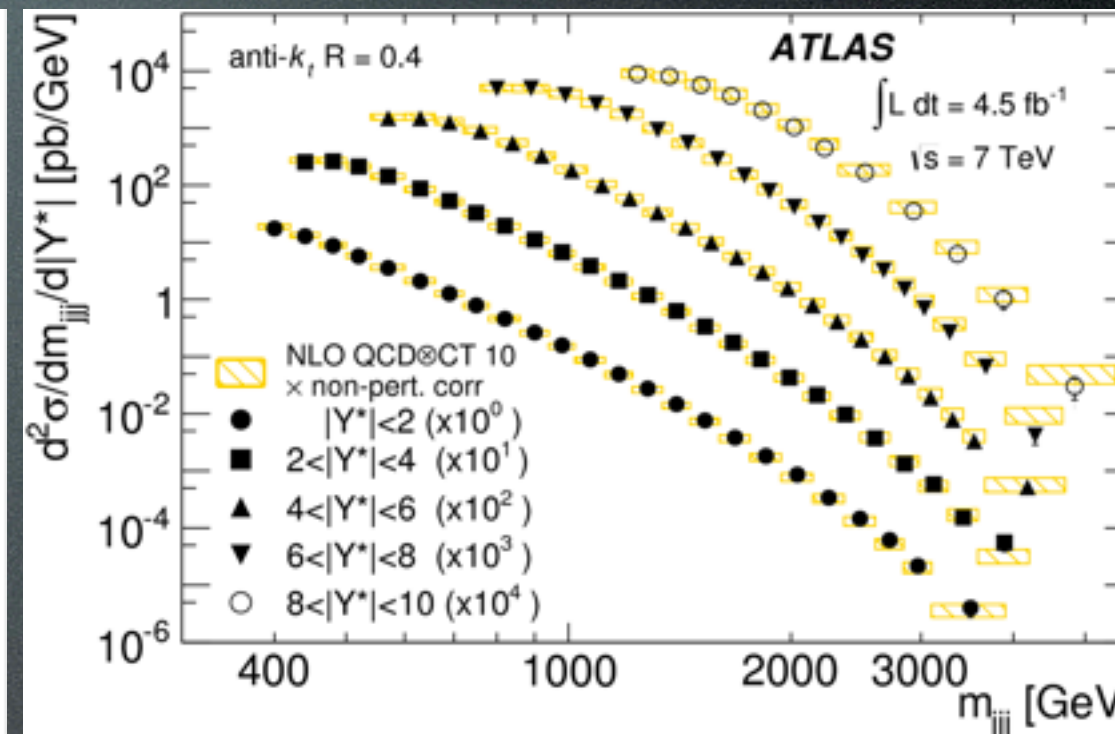
UE activity contaminated by extra jets

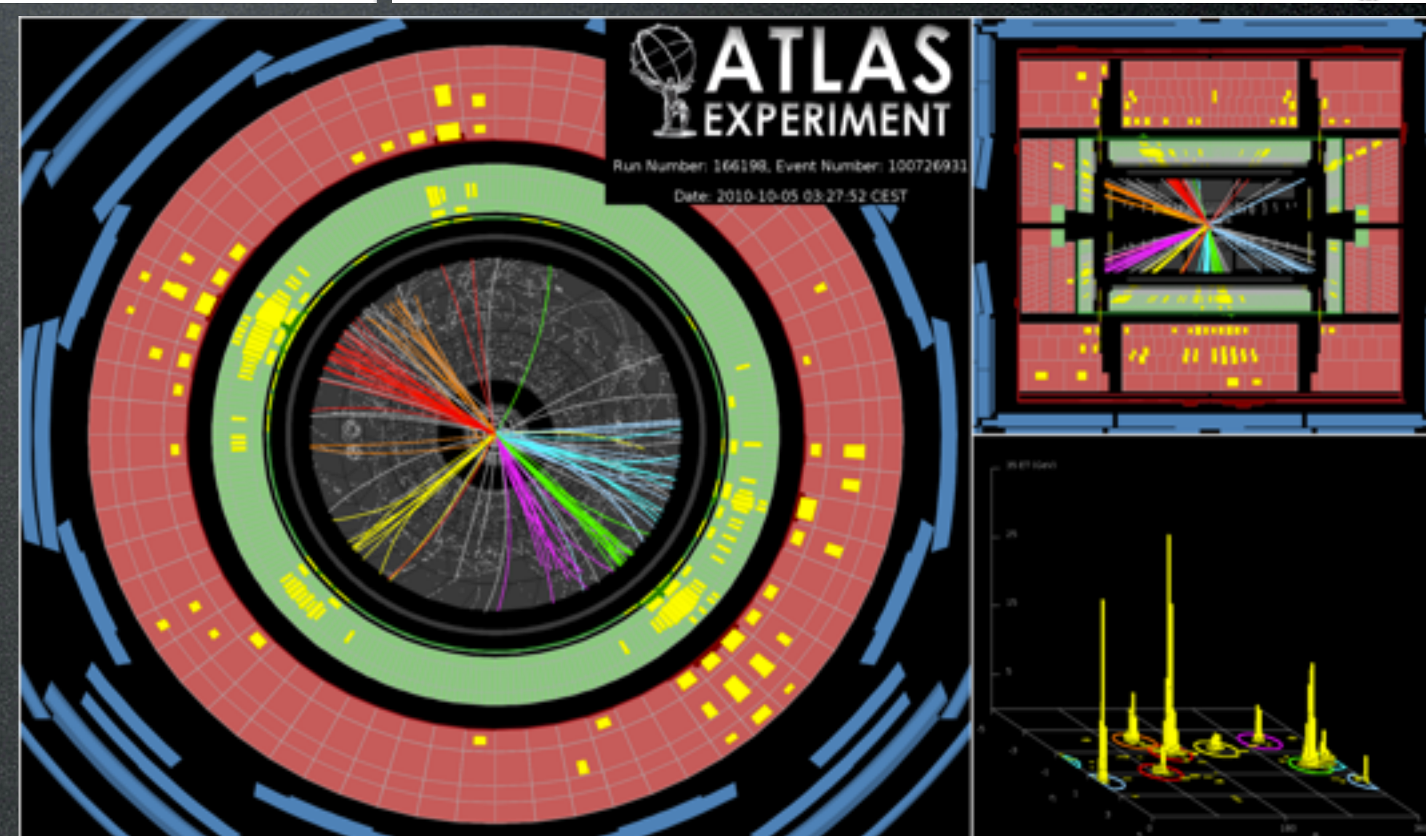


Jet Production





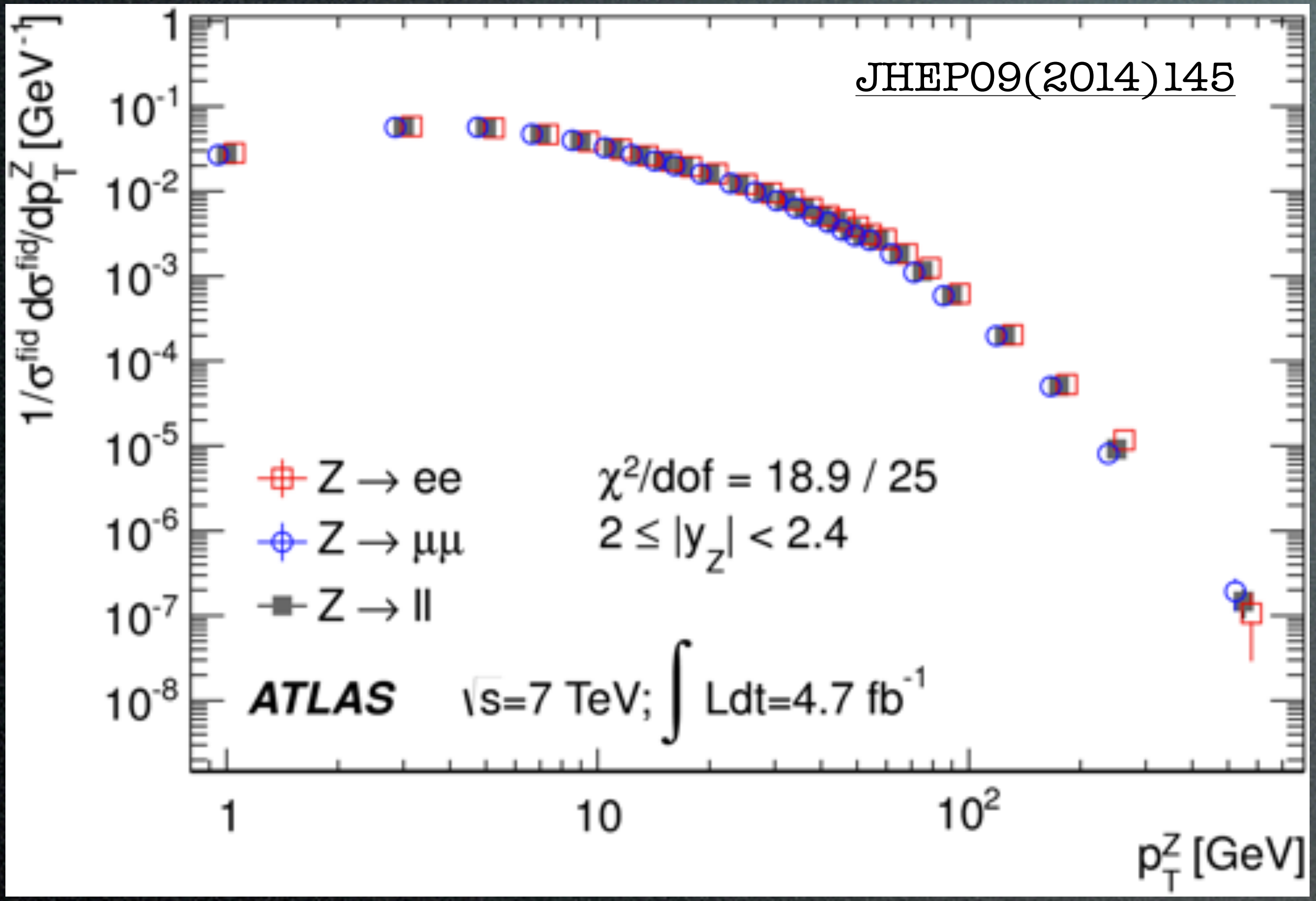


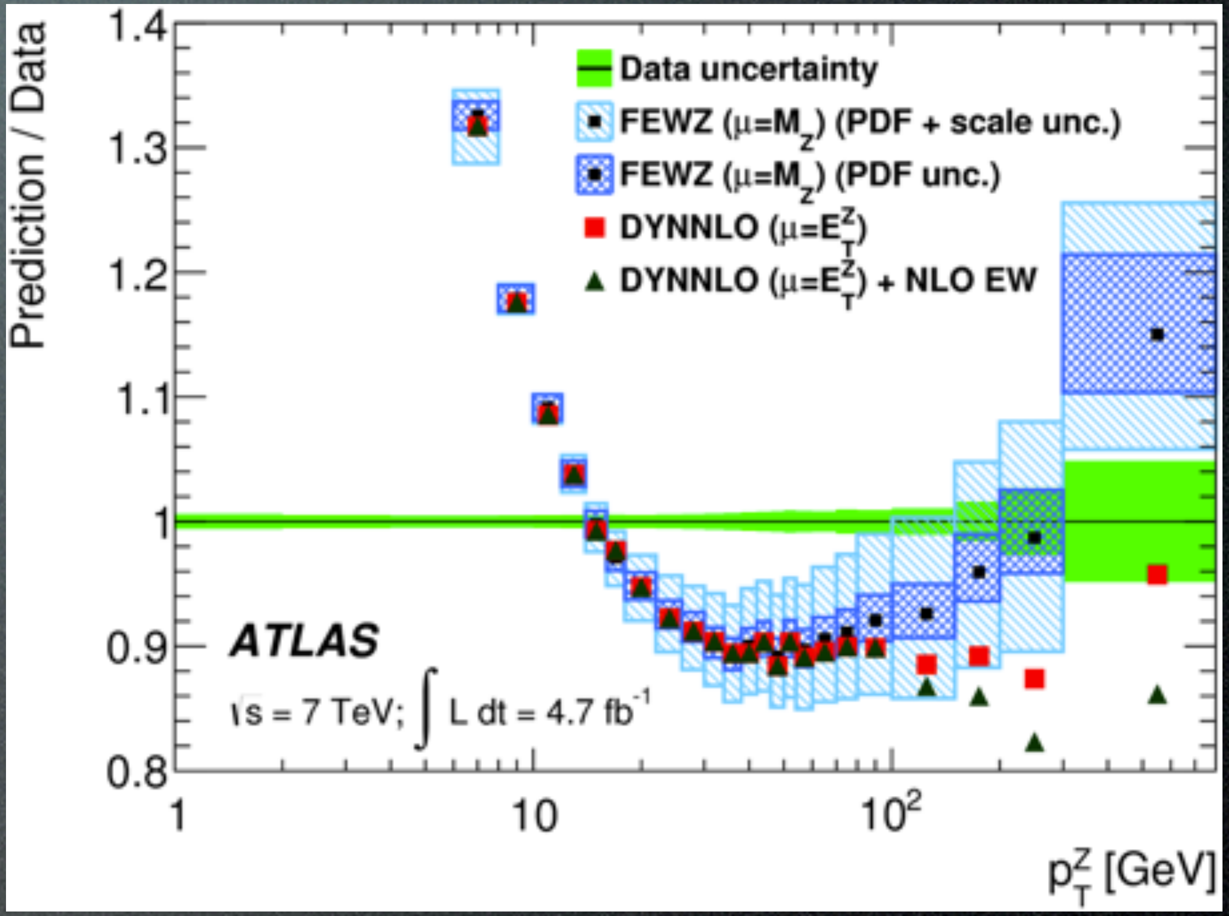


Inclusive, dijet and 3-jet differential cross-sections

Also properties of events with jets extensively studied

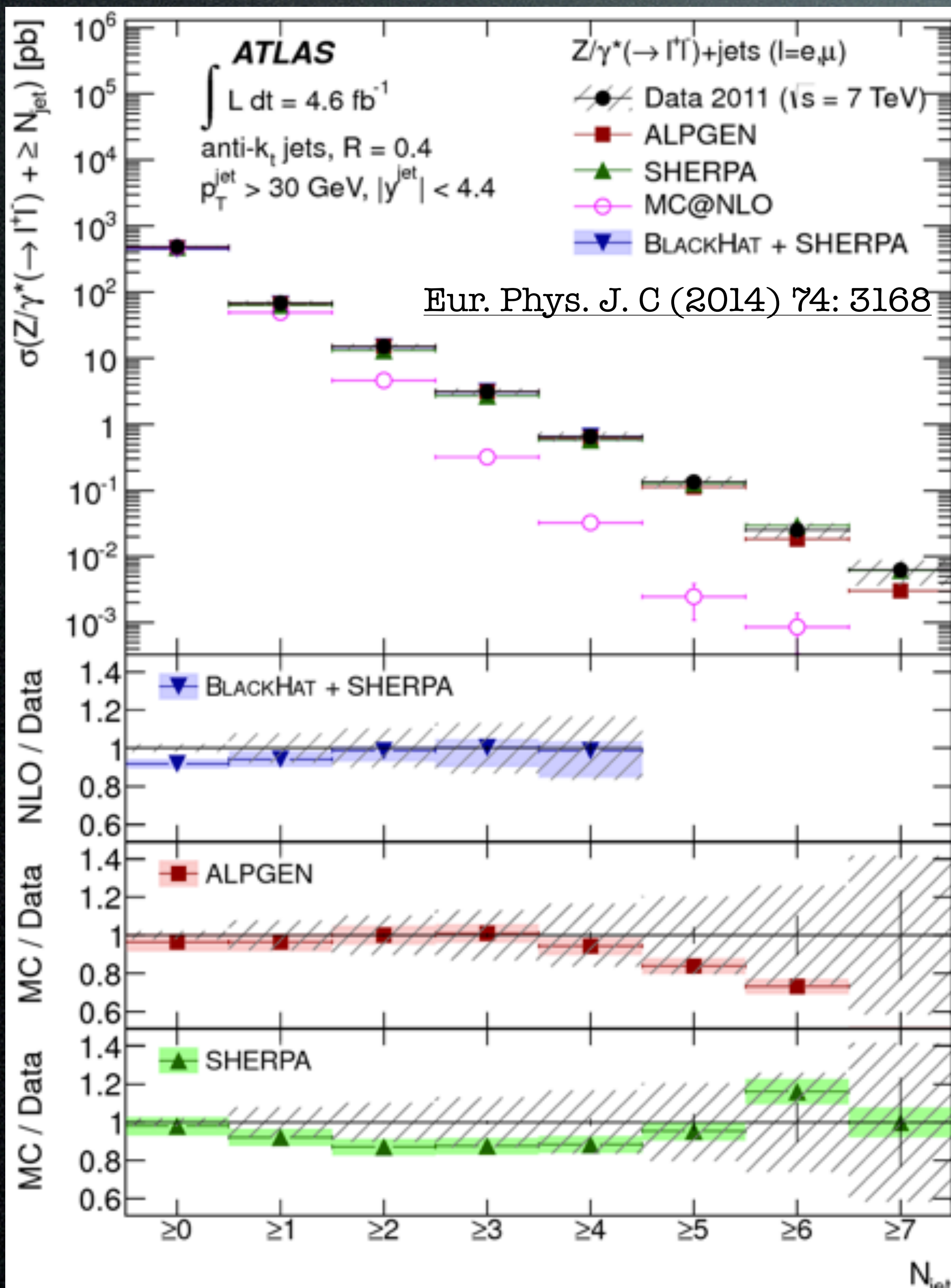
Z Transverse Momentum



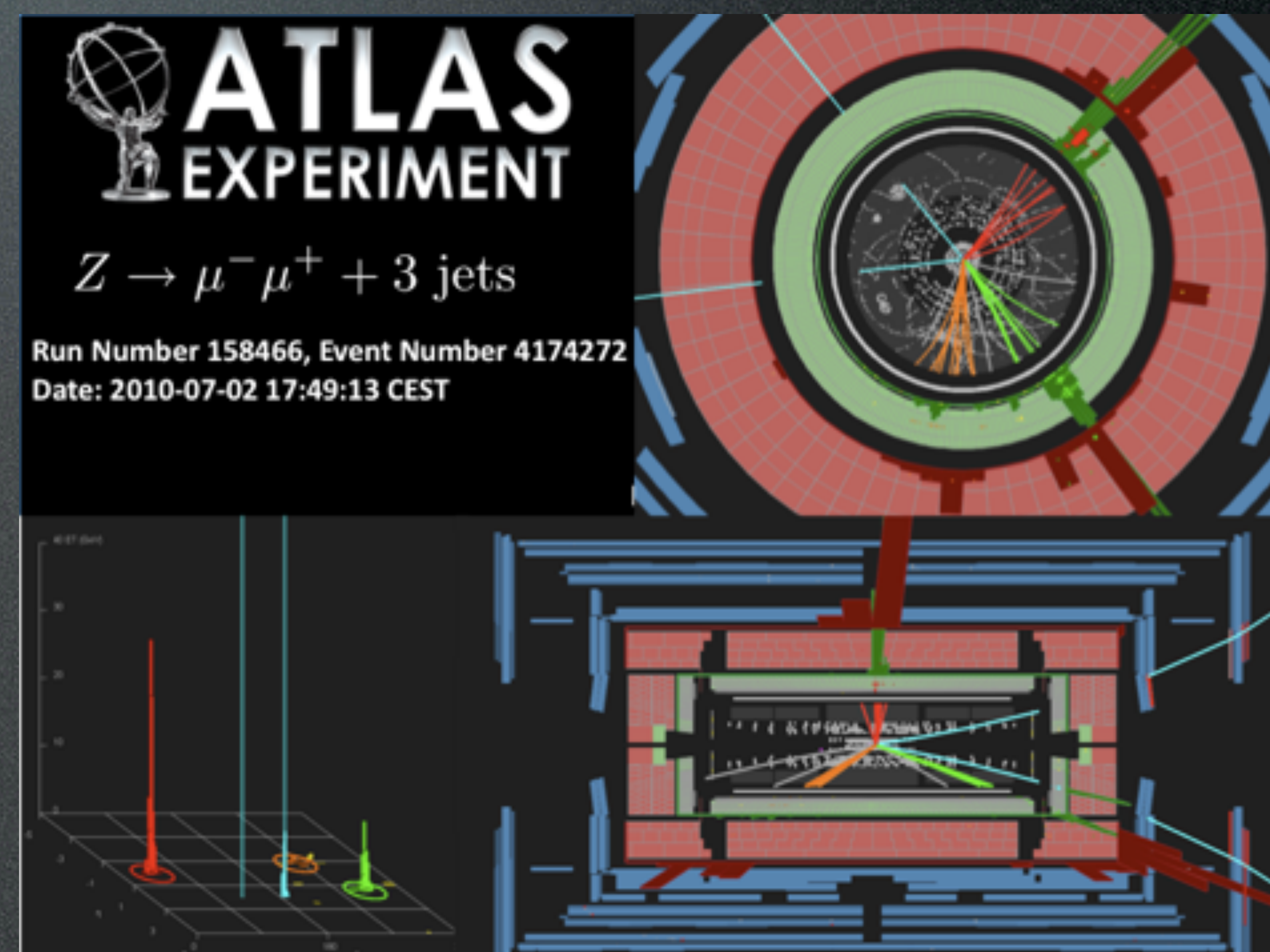


Stringent test of (perturbative) QCD calculations

W/Z+jets Productions

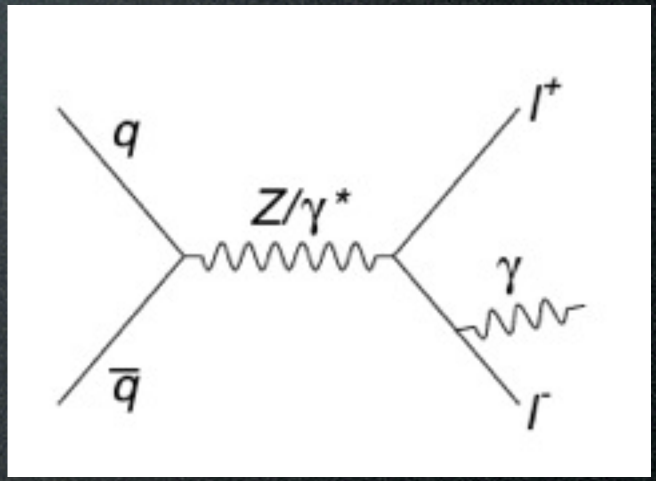


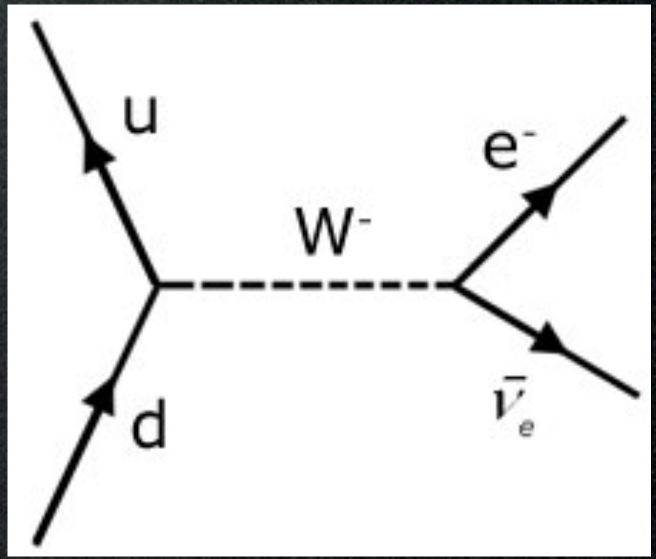
Recoil against hard jet, additional jets from radiation

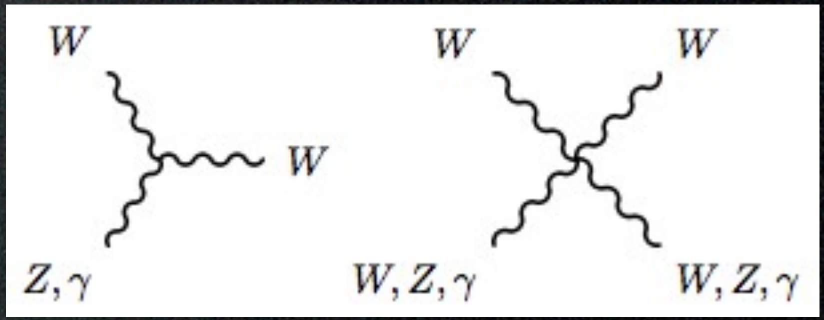


(Electro-weak) Measurements

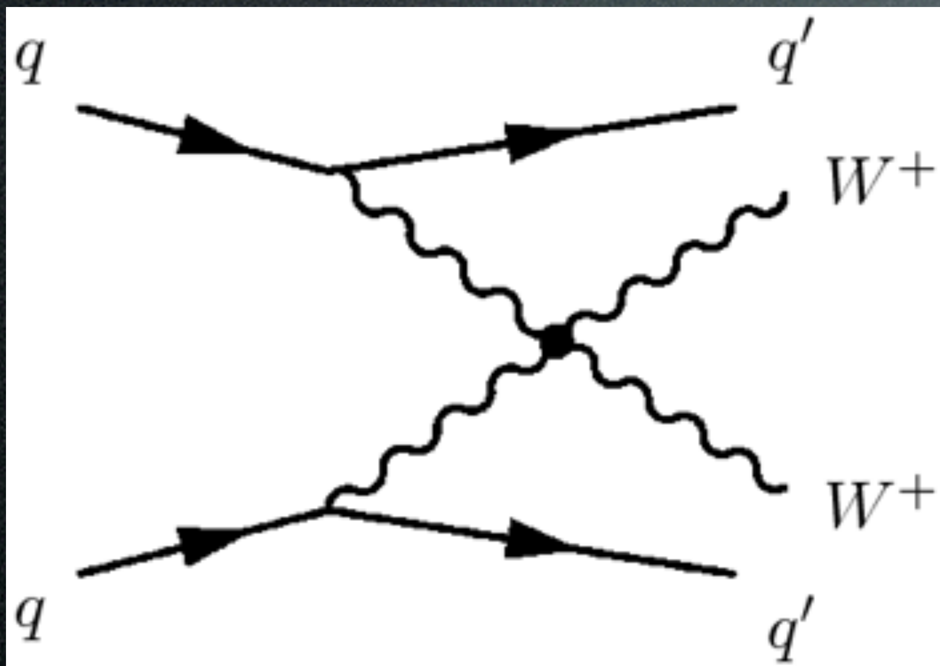
- Involves single or combination of W, Z and isolated γ, cross sections or kinematic observables.
- Reconstructed using leptons, missing energy (and jets).
- Probe triple or quartic self interactions (and set limits): they can be sensitive to new physics.







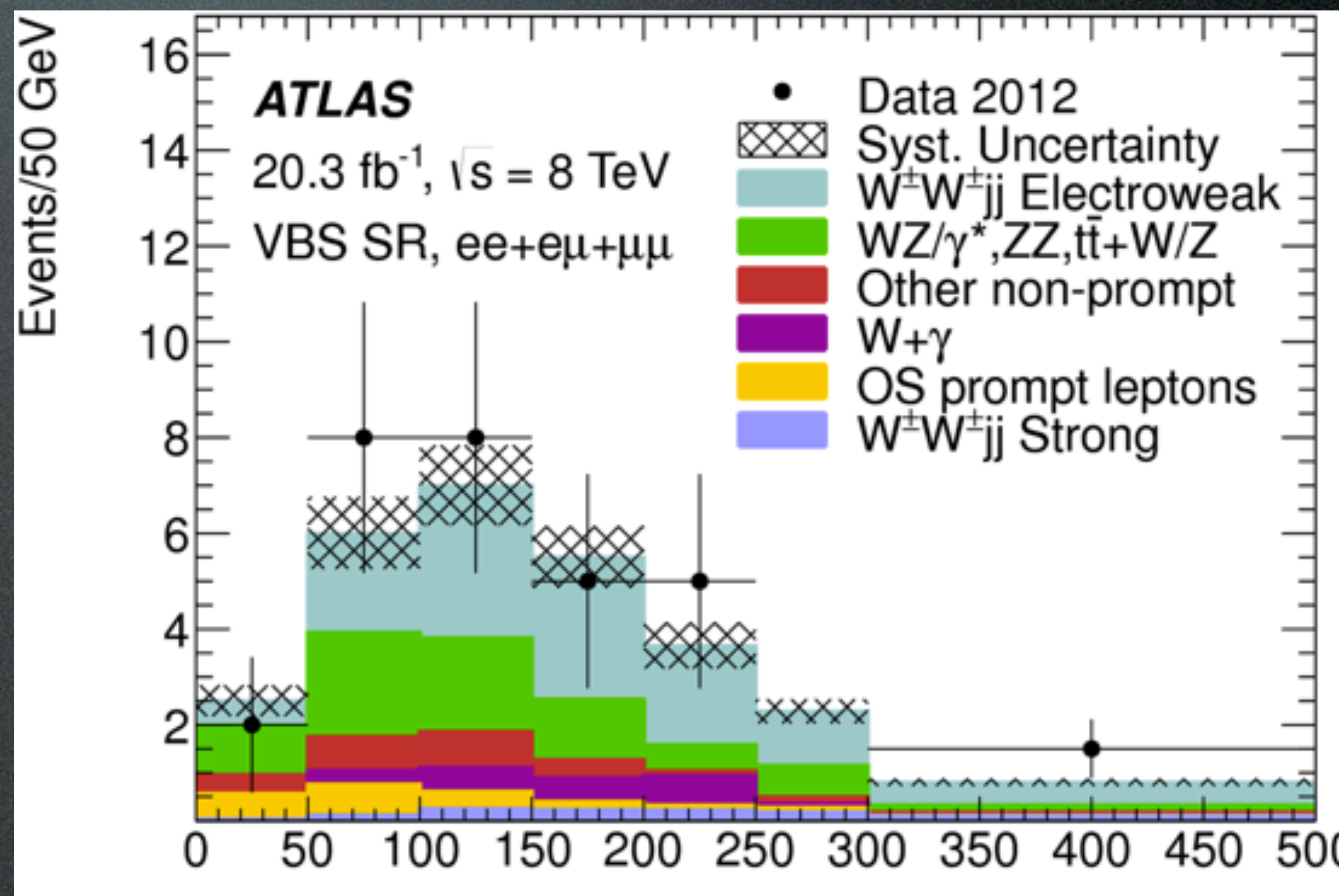
Observation of VBS



Vector Boson Scattering

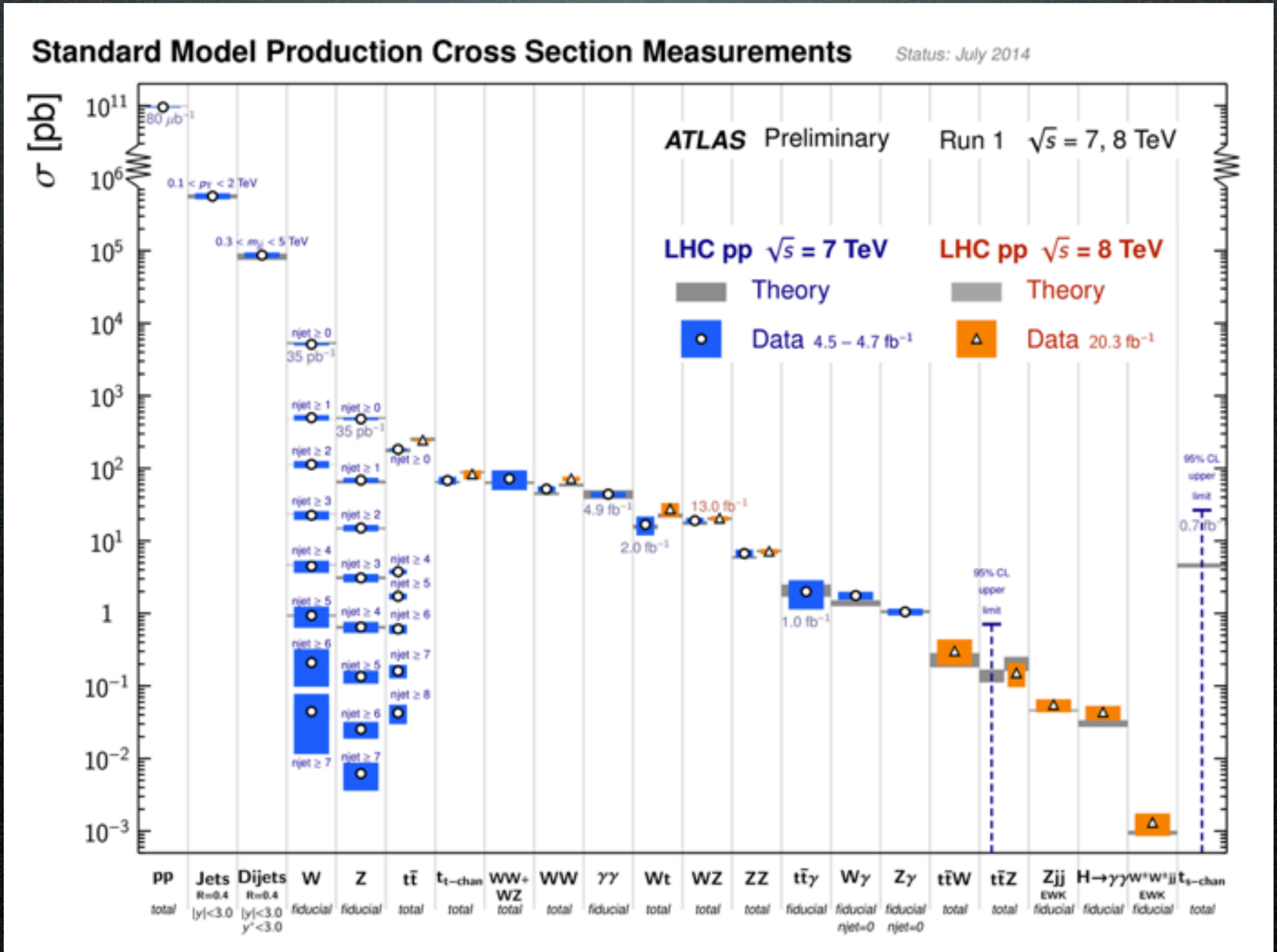
Select events with same charge WW pair + two jets

4.5σ (3.6σ) evidence for (electroweak) WWjj production



Phys. Rev. Lett. 113 (2014) 141803

SM Summary

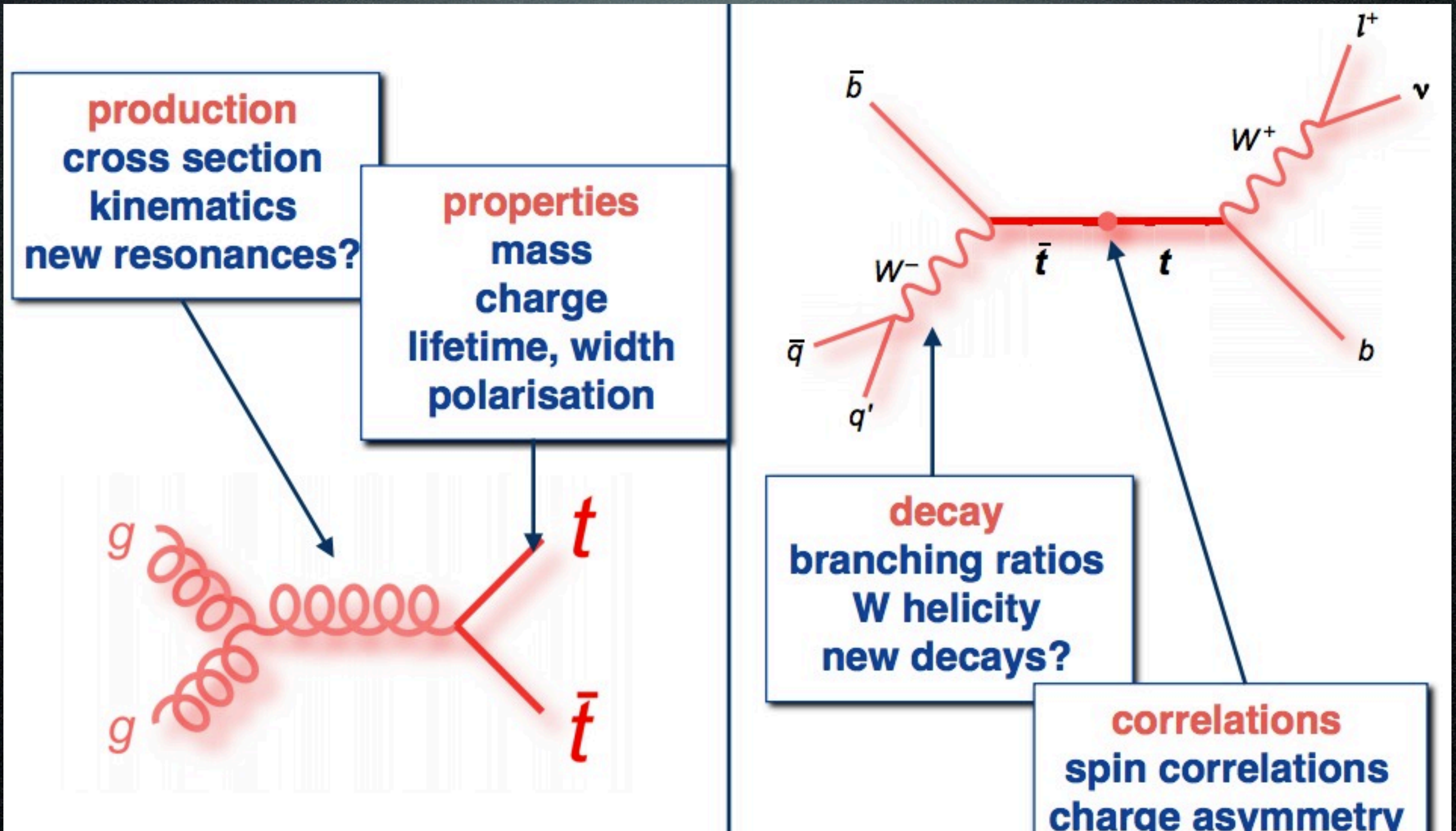

Standard Model Production Cross Section Measurements
Status: July 2014
σ [pb]
ATLAS Preliminary
Run 1 √s = 7, 8 TeV
LHC pp √s = 7 TeV
Theory
Data 4.5 – 4.7 fb⁻¹
LHC pp √s = 8 TeV
Theory
Data 20.3 fb⁻¹
pp
Jets
Dijets
W
Z
tt̄
t_t-chan
WW+WZ
WW
γγ
Wt
WZ
ZZ
tt̄γ
Wγ
Zγ
tt̄W
tt̄Z
Zjj
H→γγ
W±W±jj
t_s-chan

Top

Why Top is Special

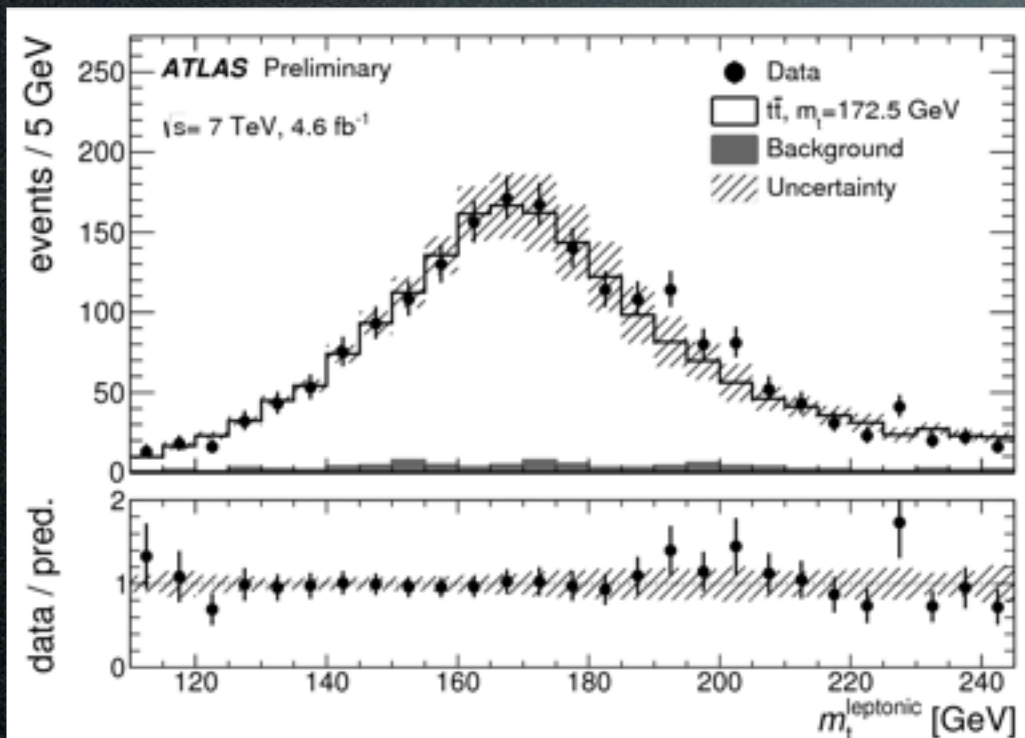
- LHC is a top factory.
- Heaviest elementary particle, no bound state.
- Pair production via strong interaction , single production via weak interaction. Leptonic and hadronic decay modes.
- Large coupling to Higgs.
- Existence of top-partners is one way to resolve the hierarchy problem. New heavy resonance can decay into top-quark pairs.

Top Measurements

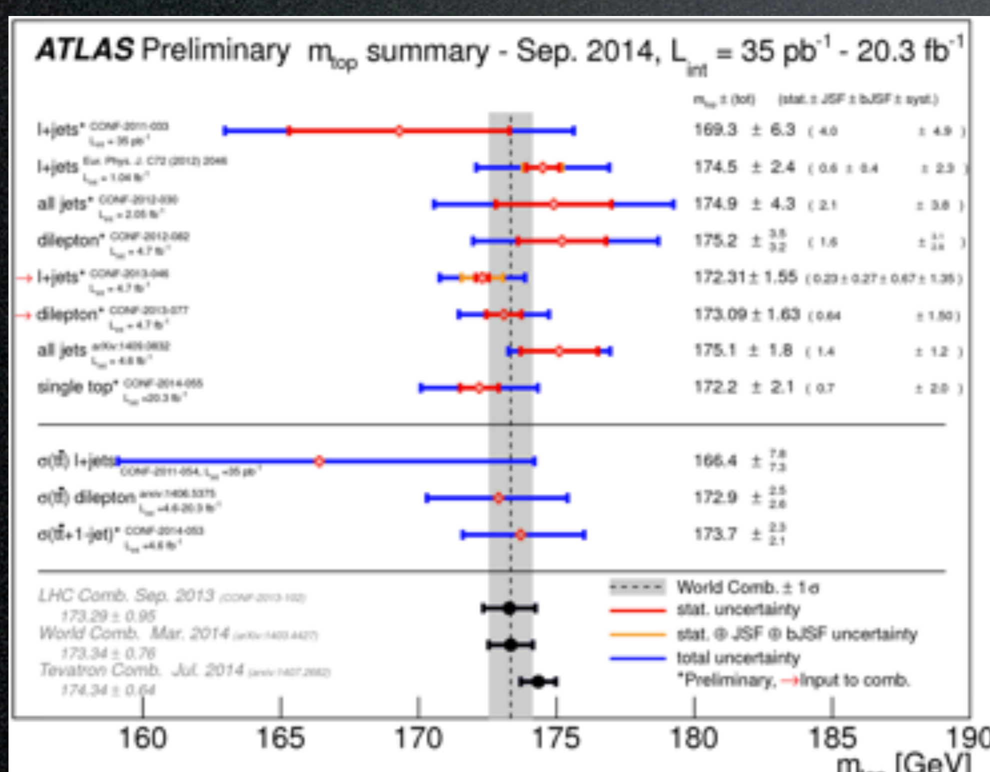


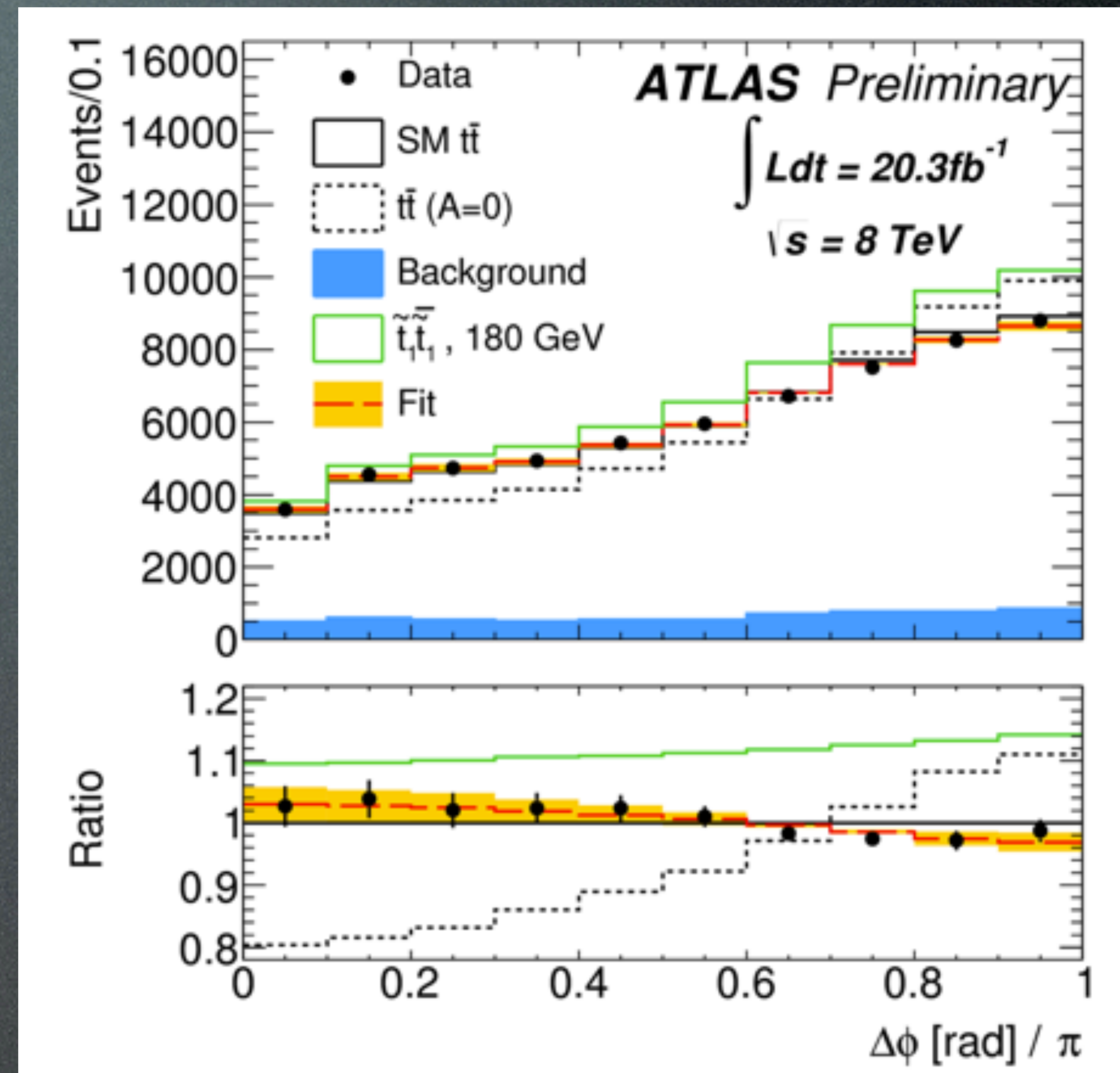
From Jürgen Kroseberg

Top Properties



Top Mass

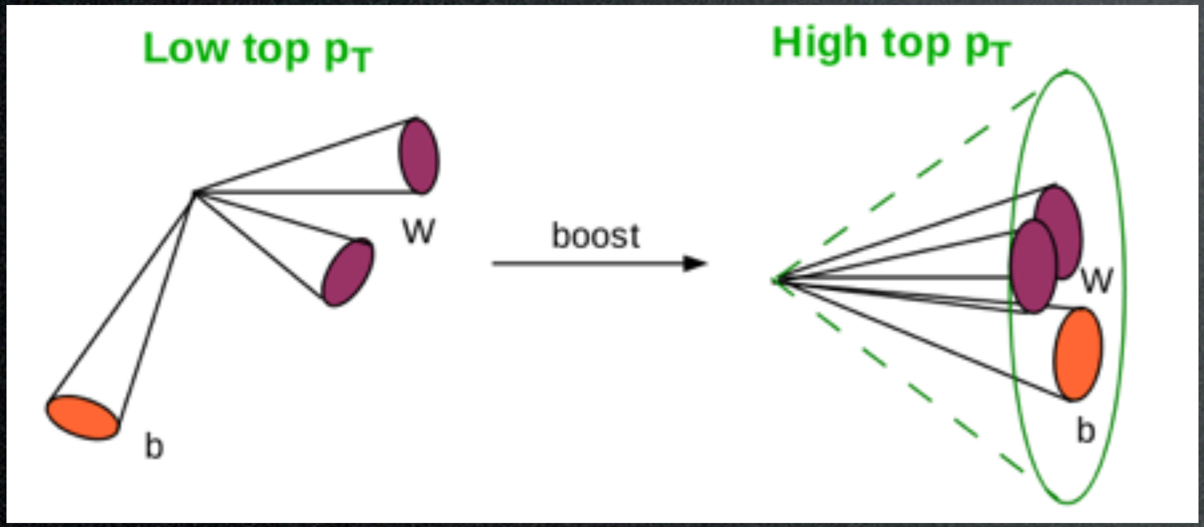




Spin of the top quark at production is transferred to its decay products and can be measured directly via their angular distributions

Boosted Top Quark Jets

The boosted jet coming from top quark (hadronic) decay should be distinguishable from the boosted jet coming from events with no top quarks.



We want to exploit the "substructure" of the large-radius jet to identify original particles

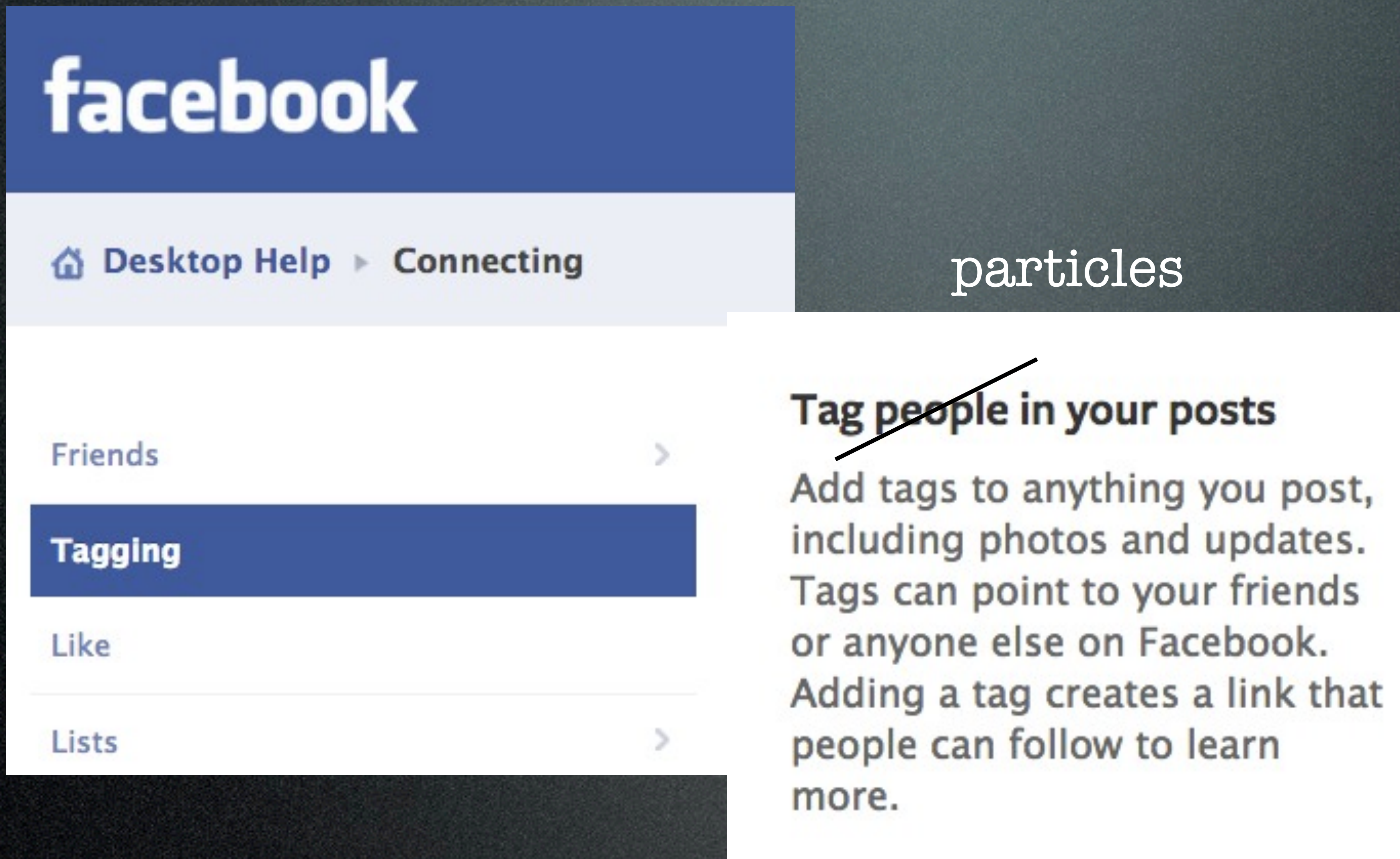
Substructure Techniques

- Jets need to be "groomed".

The large-radius jets not only include particles coming from the interesting decays, but also from pileup, underlying event ....

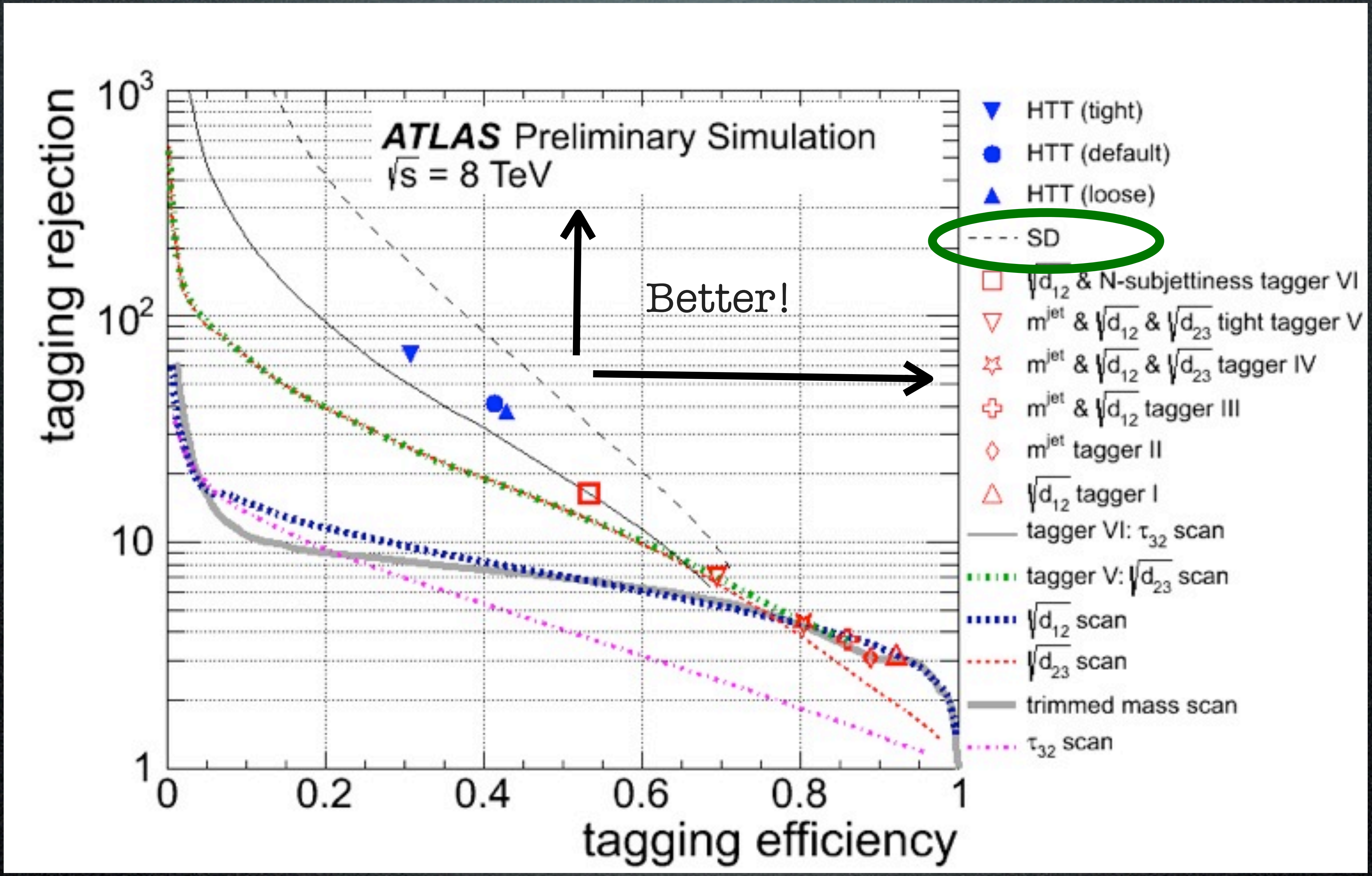
- Need observables which would be sensitive to signal-like or background-like nature of these jets.

Tagging Top or Higgs



- Target is to identify jets resulting from the decay of top quark or Higgs against jets coming from light quark/gluons.

Top-Tagging Comparison

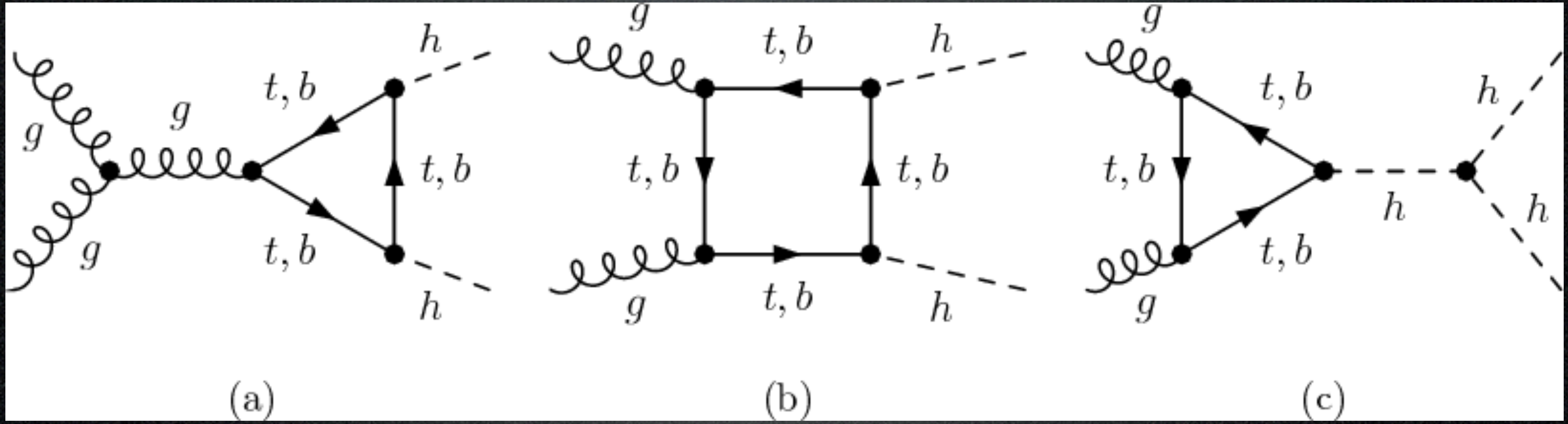


Better top quark finding efficiency at the same rejection of multijets when compared to the HEPTopTagger.

ATLAS-CONF-2014-003

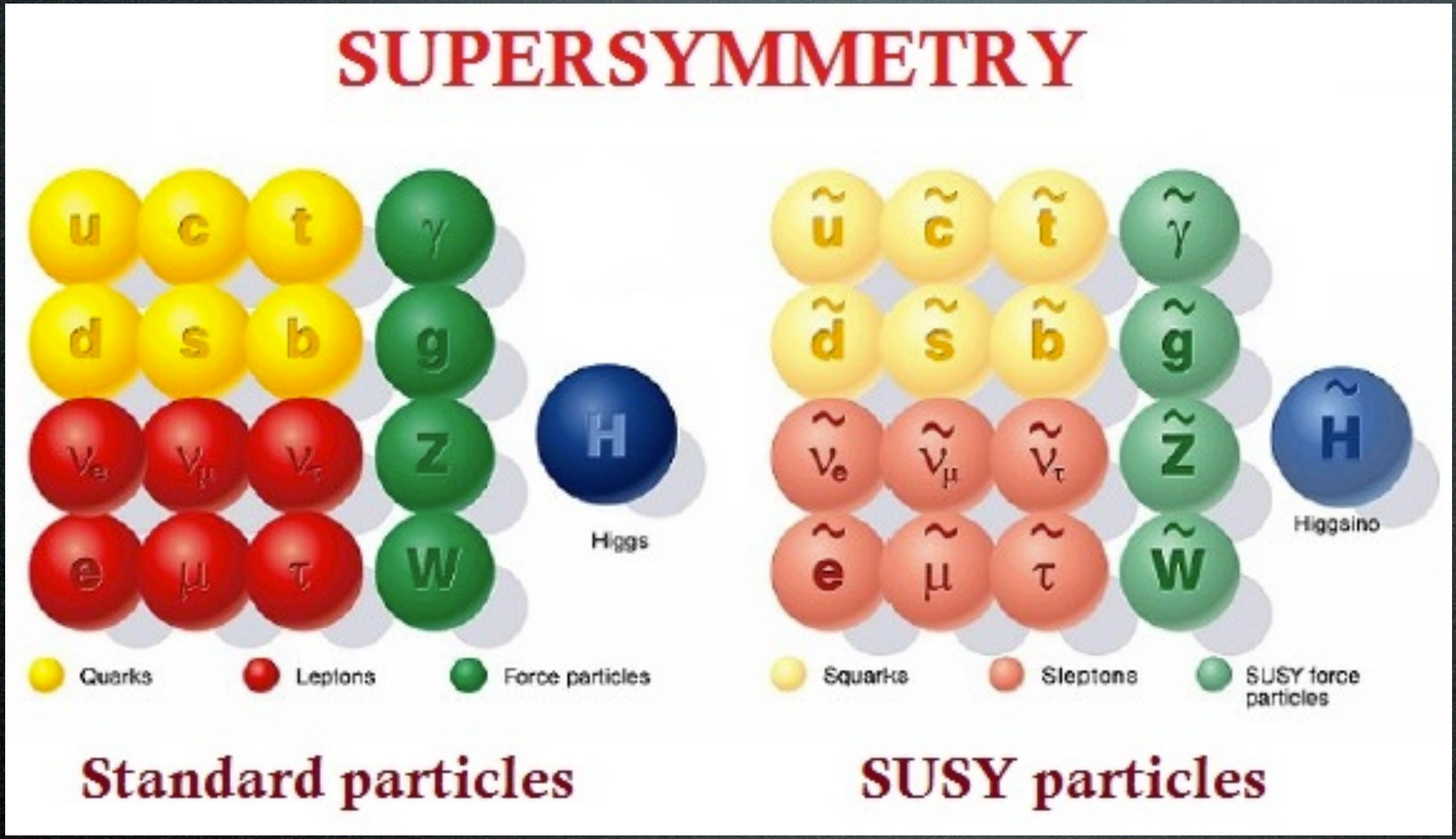
… but also

- New TeV scale particles can result in boosted W/Z bosons decaying hadronically (i.e to jets).
- Boosted di-Higgs decay and self-coupling.



SUSY

SUSY

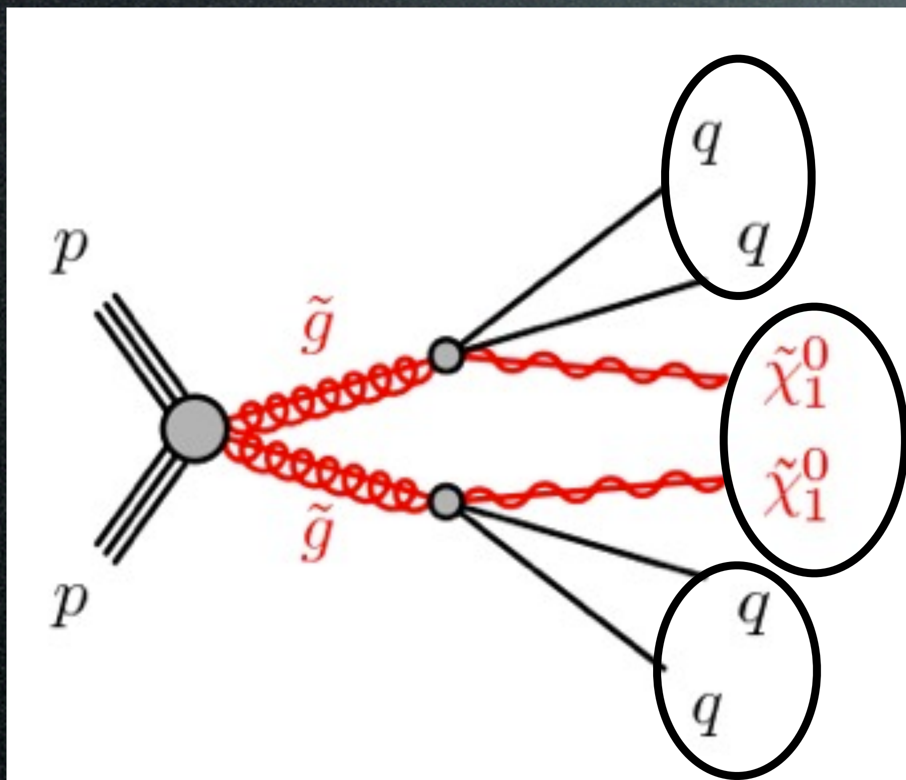


Many Models:
MSSM
mSUGRA
CMSSM
GMSB
...

R-Parity: SM Particle = 1, SUSY Particle = -1

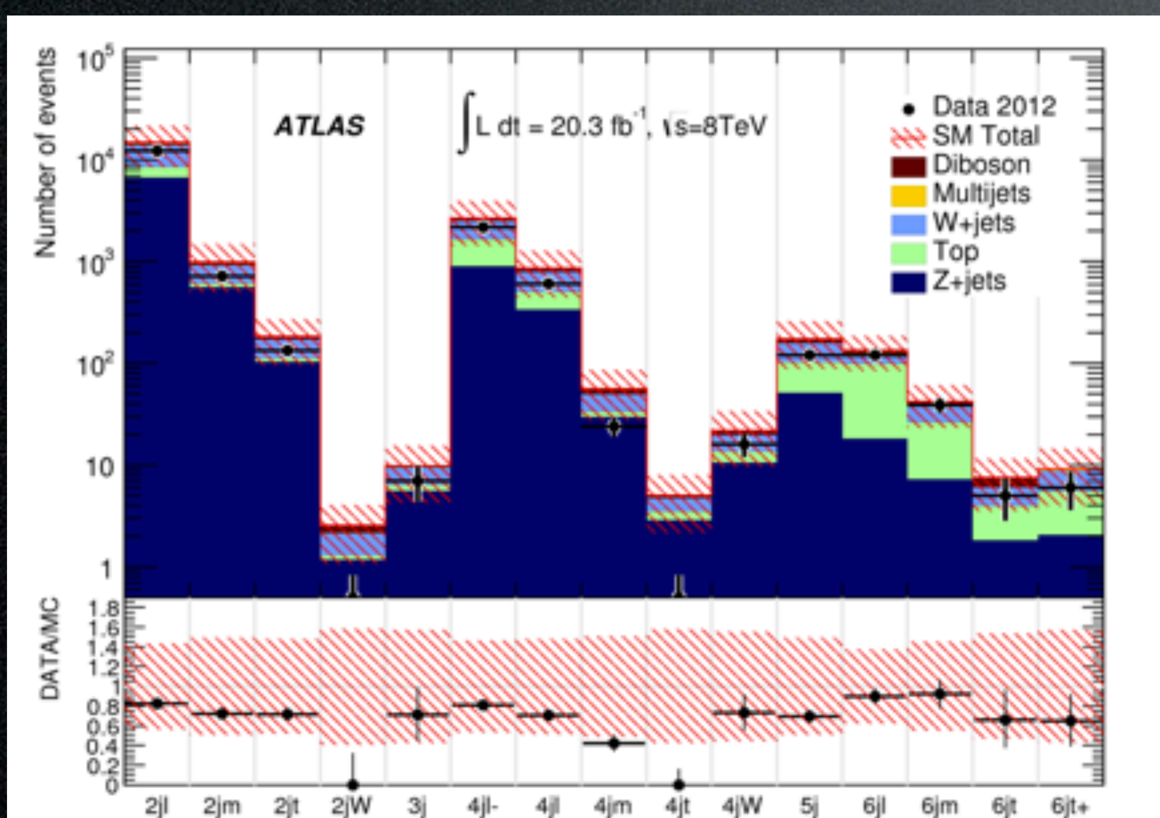
Lightest SUSY particle (LSP) is stable: the decay of the SUSY particle will cascade until it gets to LSP.

Search for Squarks & Gluinos

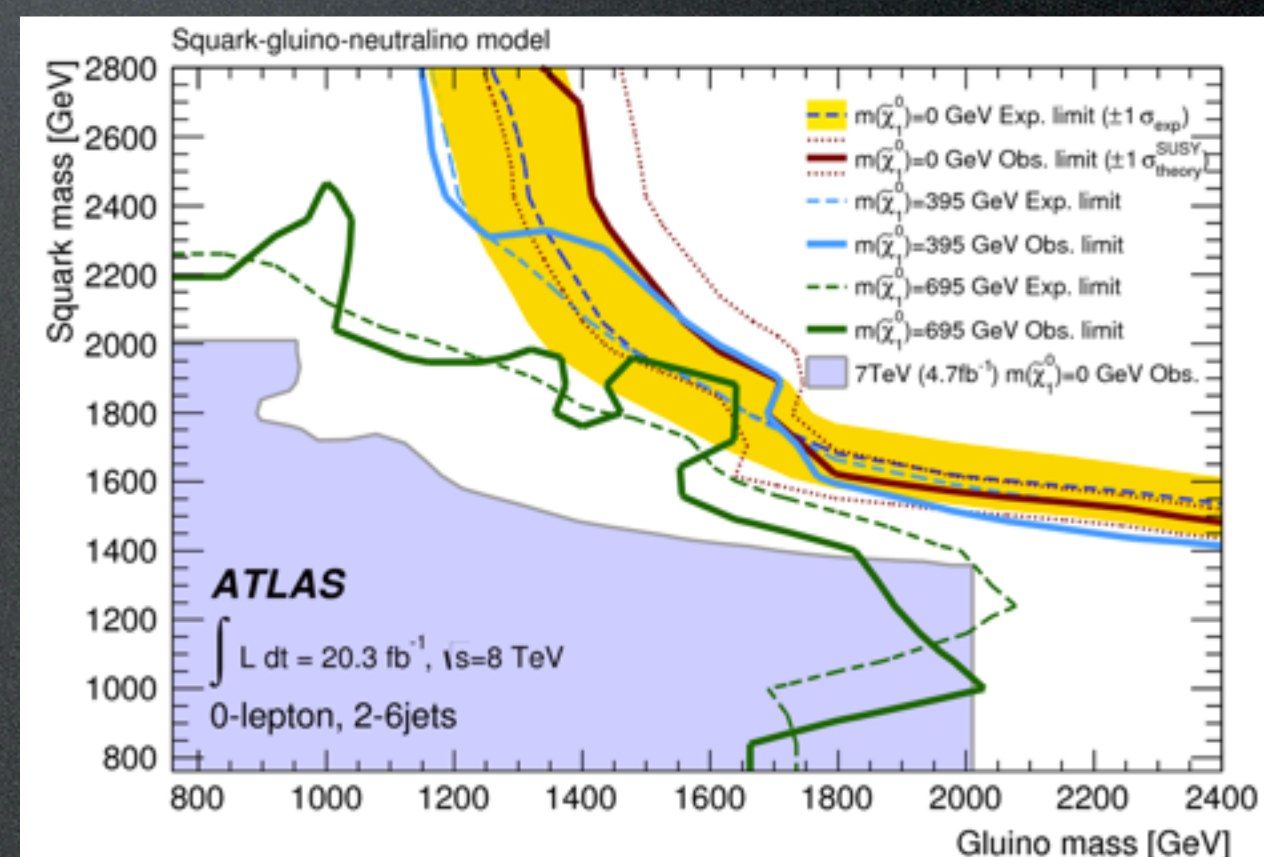


Select events with large missing transverse energy and high-pT jets

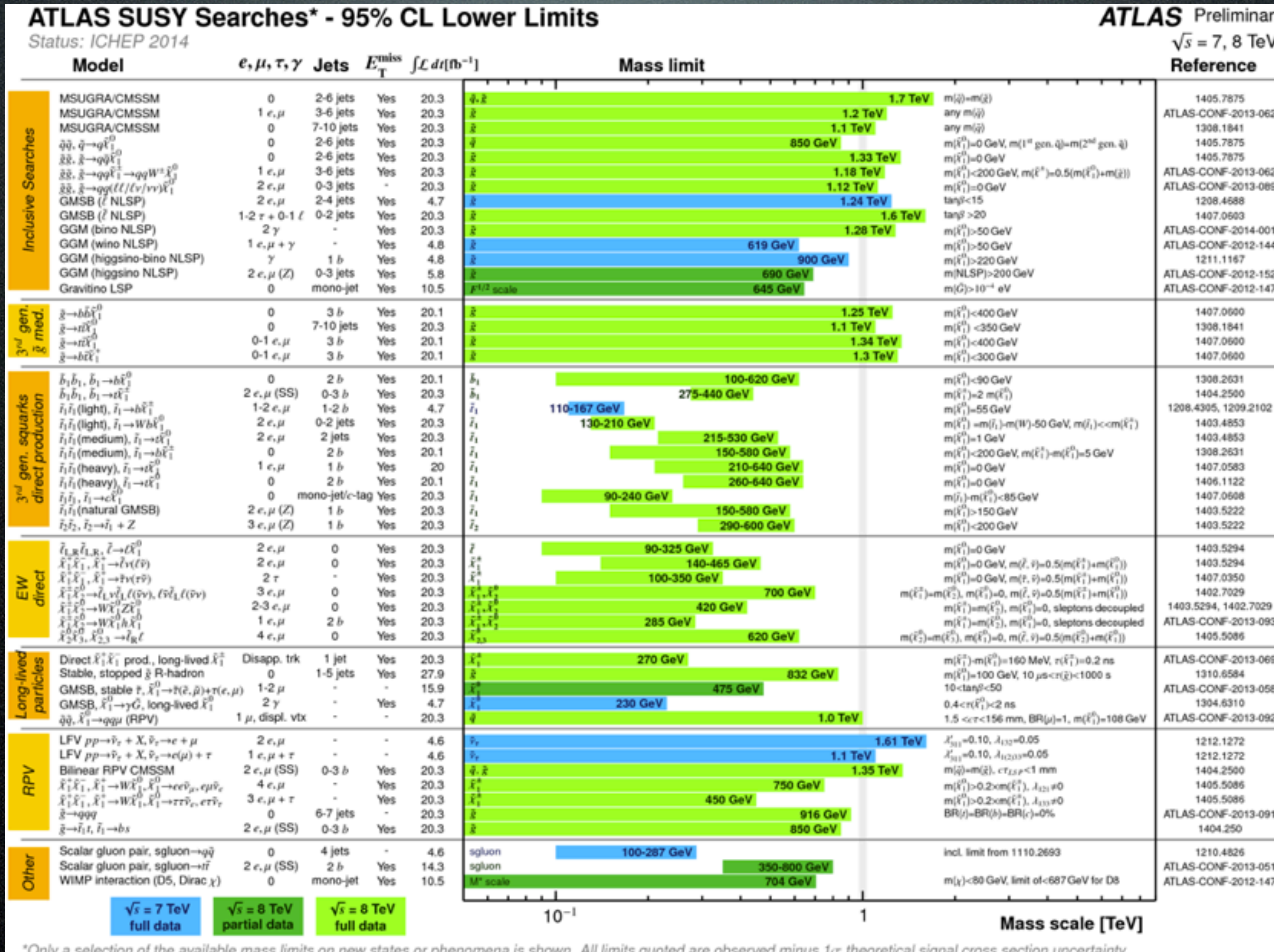
Define 15 signal regions with different jet multiplicity, MET and jet p_T requirements



arXiv:1405.7875



SUSY Searches Summary



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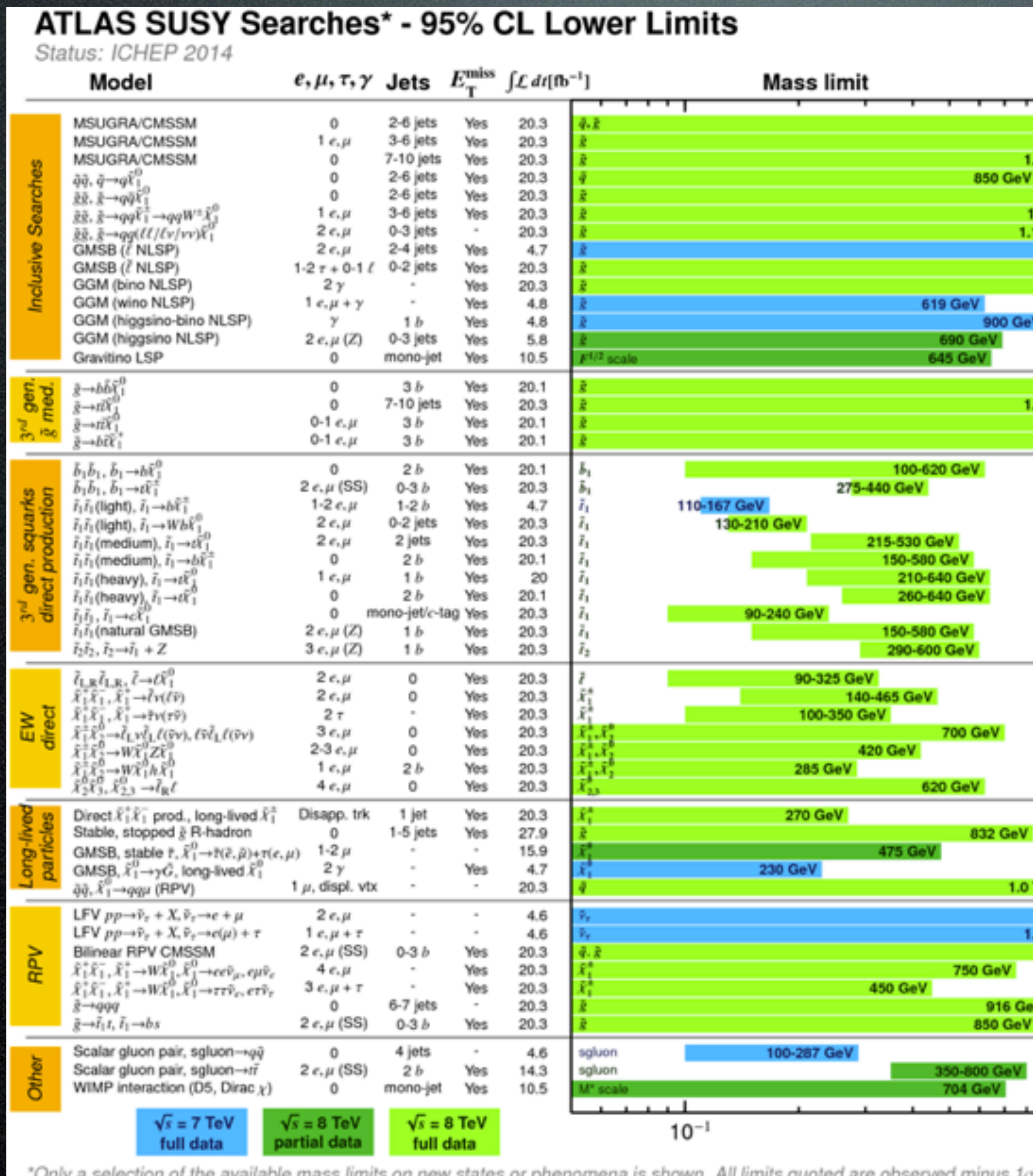
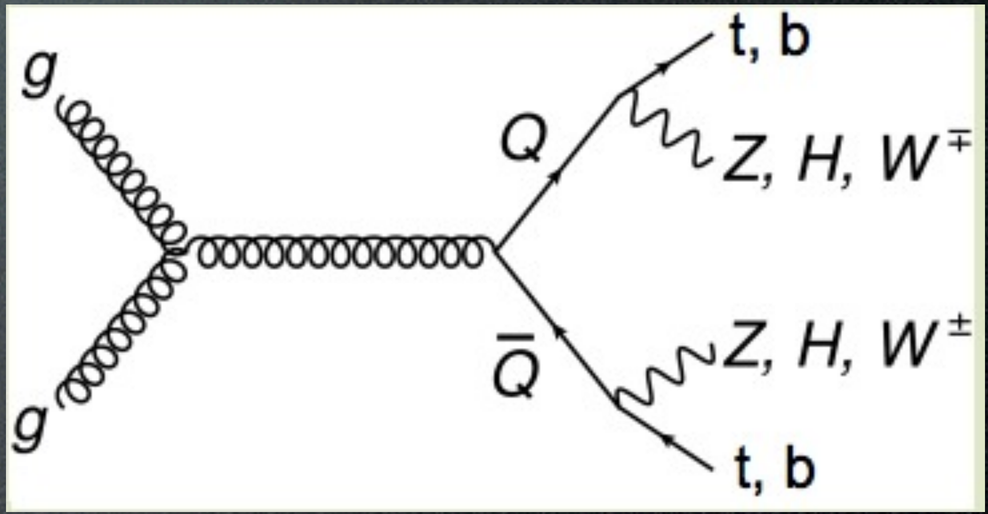


Exotics

Again, many models...

- Heavy bosons
- 4th Generation/Vector Like Quarks/Top partner
- Charged Higgs
- Dark matter candidates
- Microscopic black holes ...



VLQ pair production

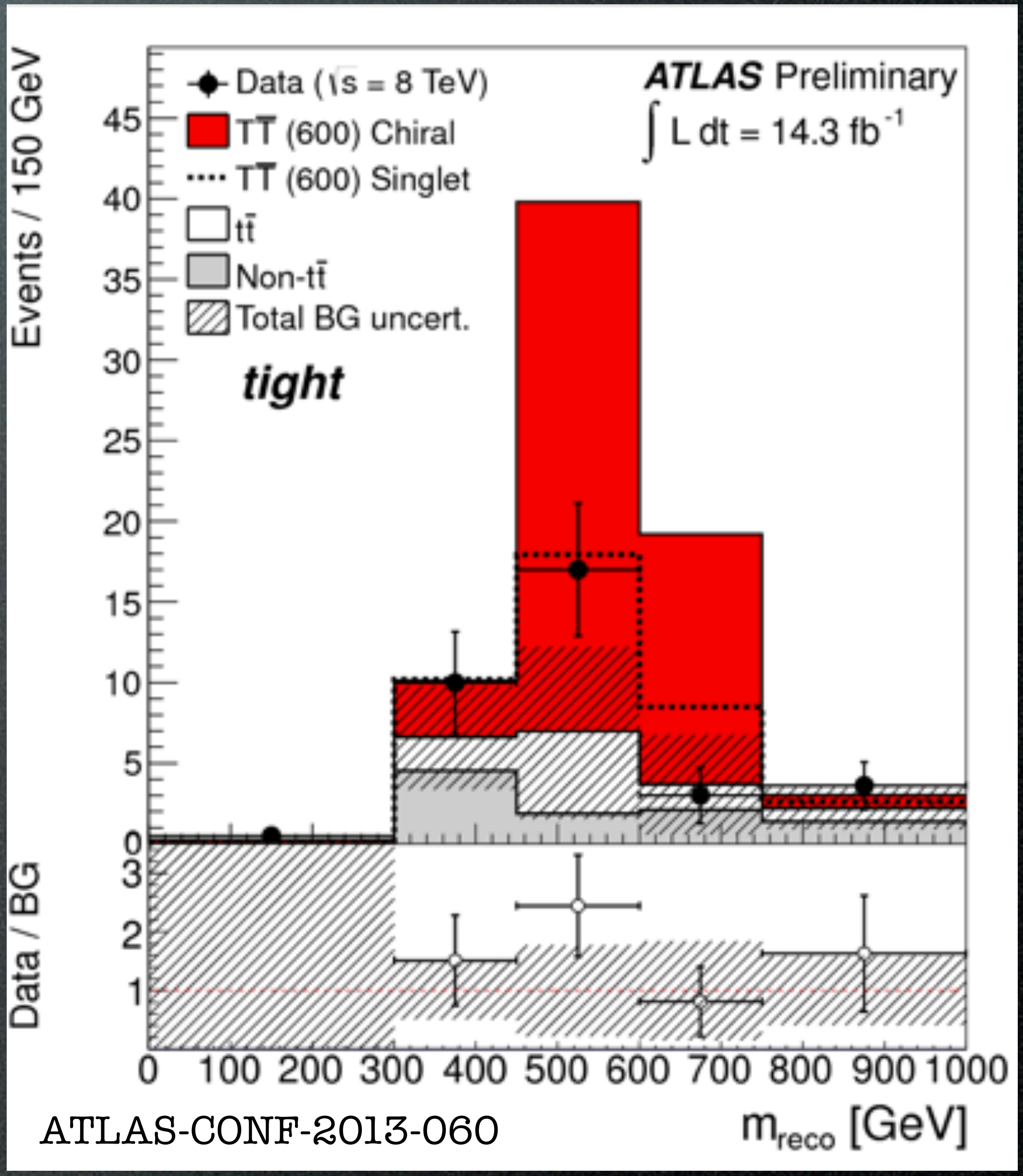
VLQs are excluded up to ~800 GeV
Z'.W' excluded > 2-3 TeV
Diboson Resonances excluded almost to 2 TeV

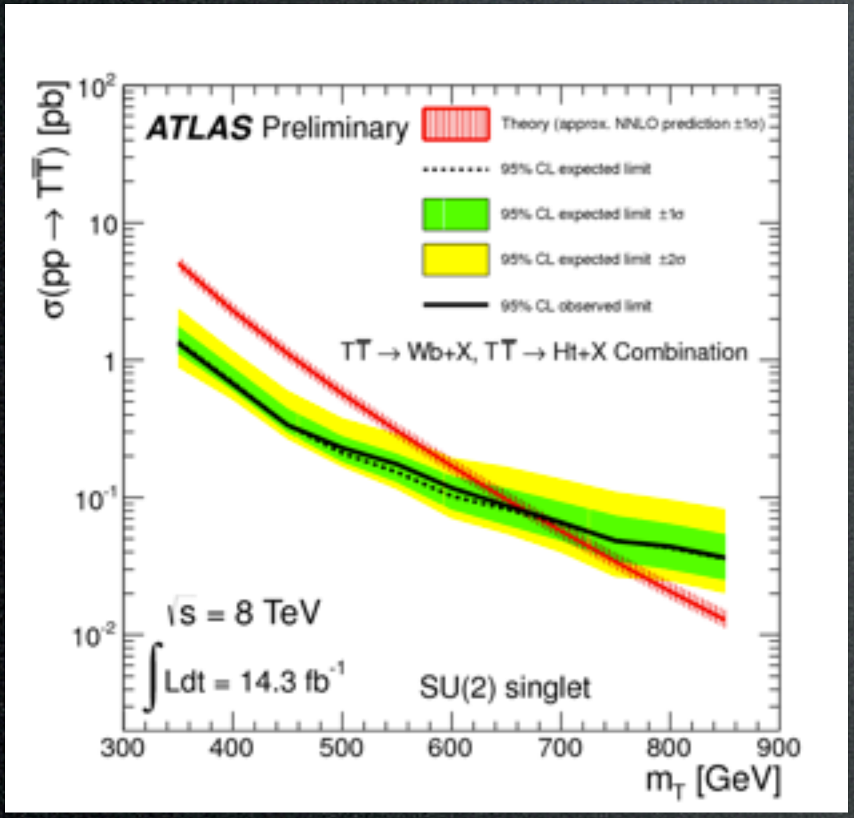
Top-like Quark Pair Search

Decay in semi-leptonic W and b-quark assumed.

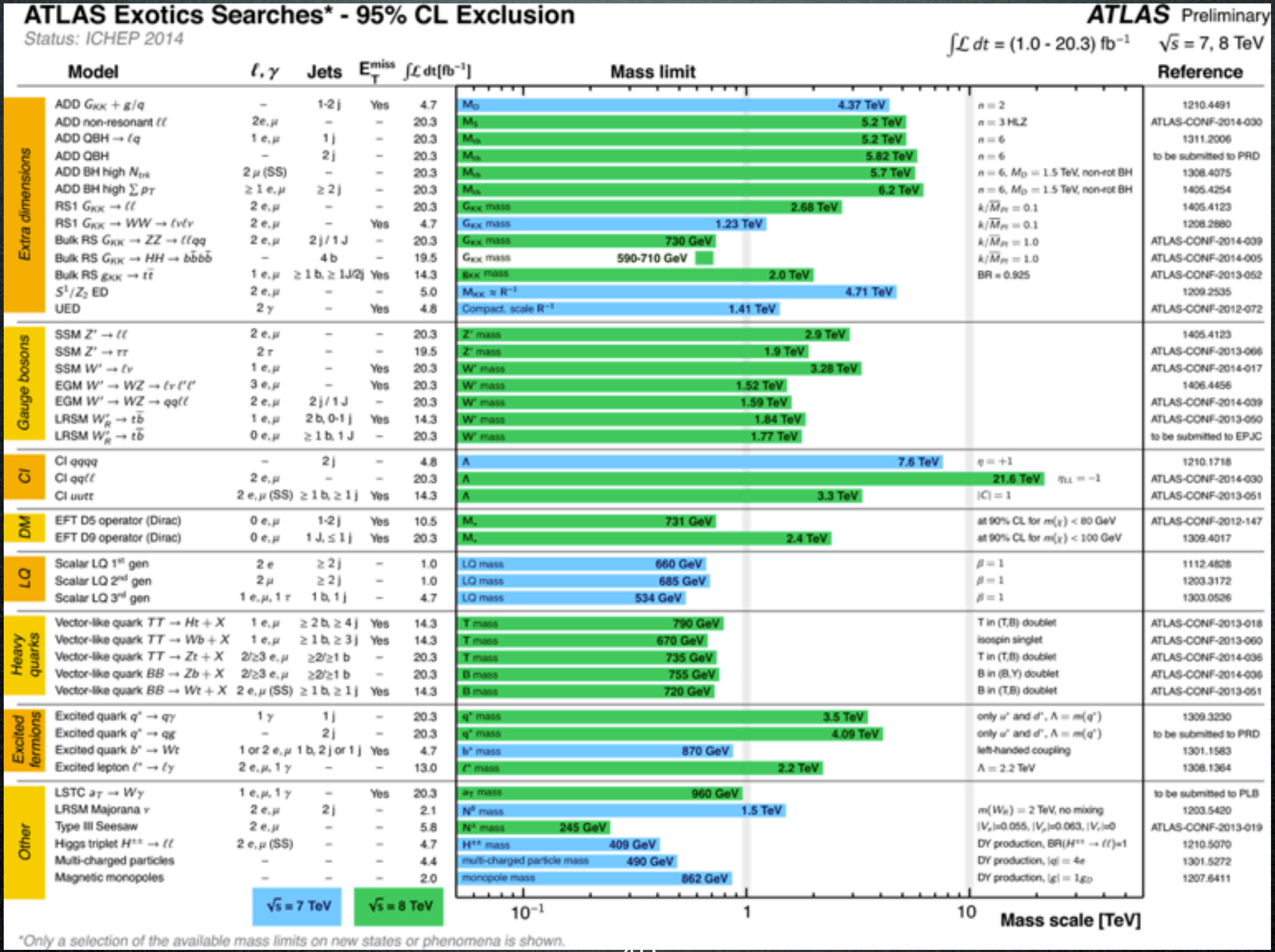
For chiral 4th gen: < 740 GeV Excluded.

For vector-like: exclusion limits derived.





Summary of Exotics Searches



Outlook

- Although no obvious signs of BSM physics yet, many exciting and useful results.
- Run 2 is imminent, with higher energies and larger datasets.
- Everything we learned from Run 1 will be useful designing Run 2 search strategies.
- We need smart, motivated students to sustain the progress in the field!

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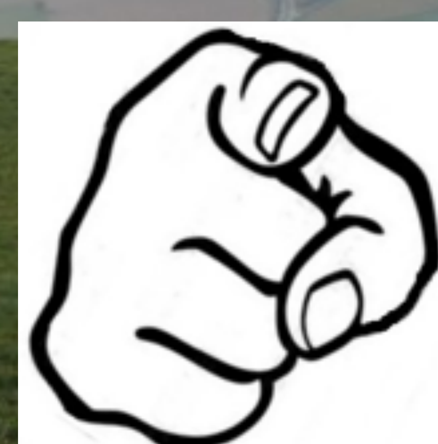
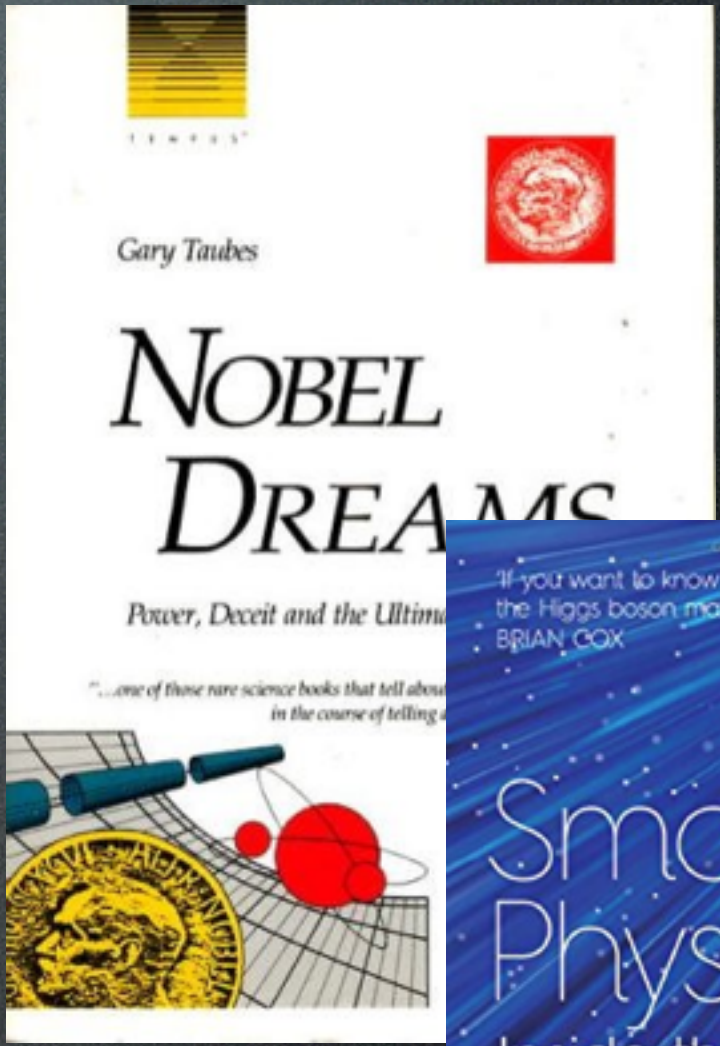
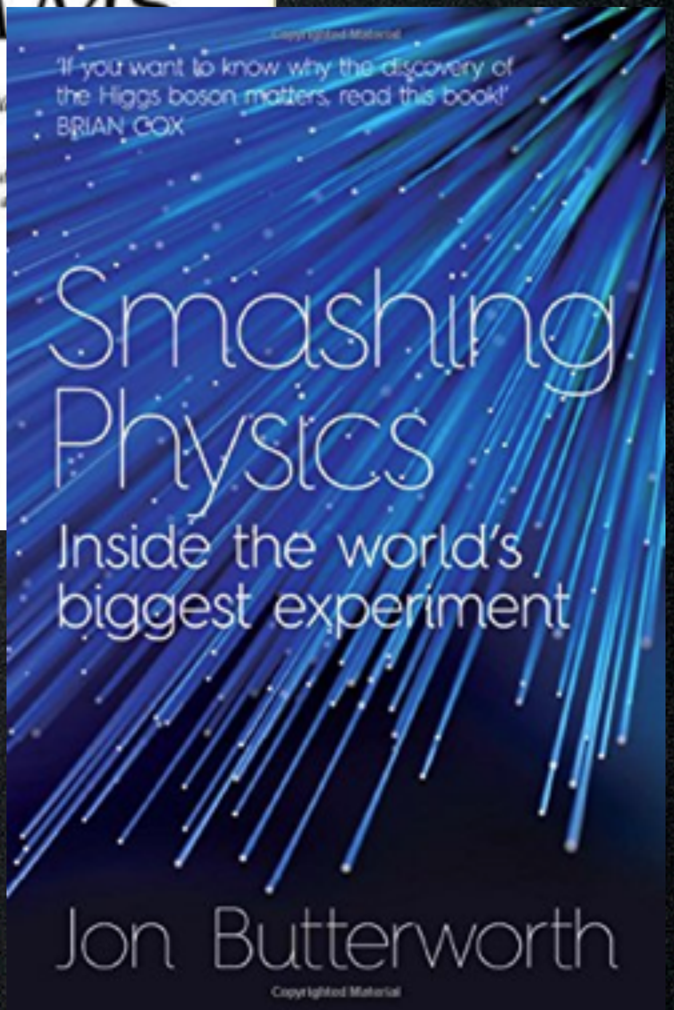


Supporting Material

How to make a discovery in particle physics?

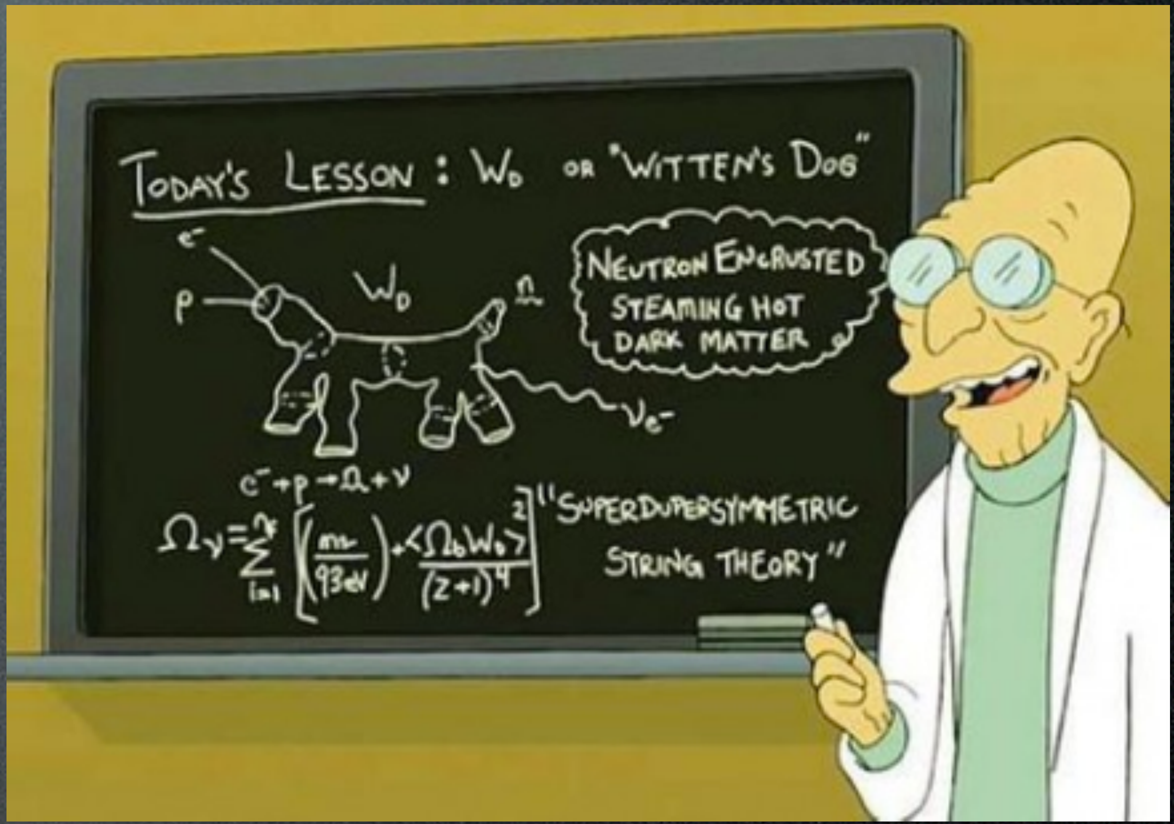
- W/Z boson in UA1/UA2
- Top quark in CDF/DØ
- Higgs boson in ATLAS/CMS
- What next?





Event Generators

- We want realistic simulation of the collision events. Why? Devise analysis strategy, background model, study/ remove detector effect, etc.
- The hard scattering part can be calculated theoretically (in some order) .
- The soft part is not calculable, so we use phenomenological models implemented in Monte Carlo event generators.

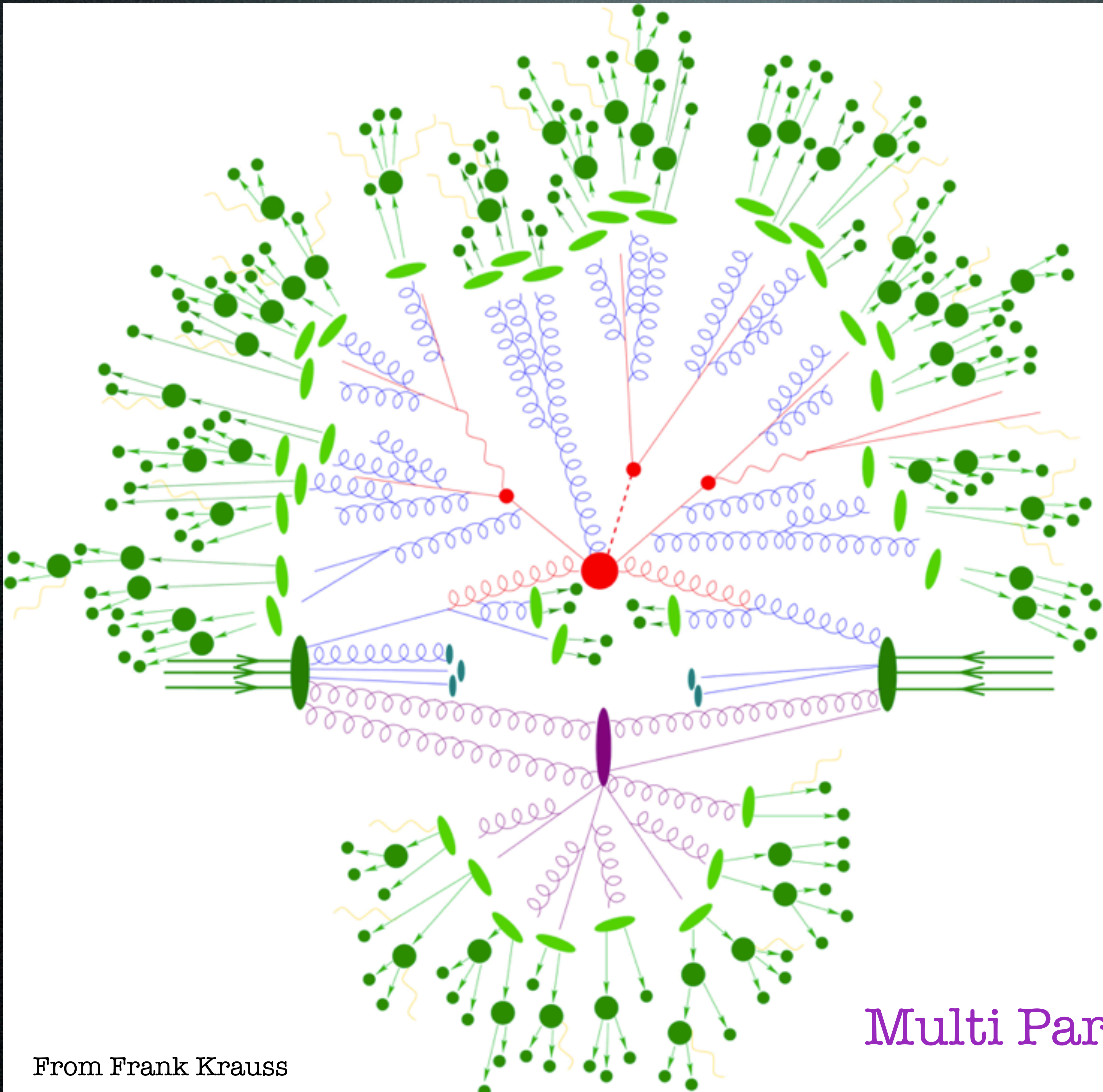


Actually two step process, but not going to discuss detector simulation!

Monte Carlo Models

"The predictions of the model are reasonable enough physically that we expect it may be close enough to reality to be useful in designing future experiments and to serve as a reasonable approximation to compare to data. We do not think of the model as a sound physical theory . . . "

– Richard Feynman and Rick Field, 1978



Hard Process

Parton Shower

Hadronization

Decays

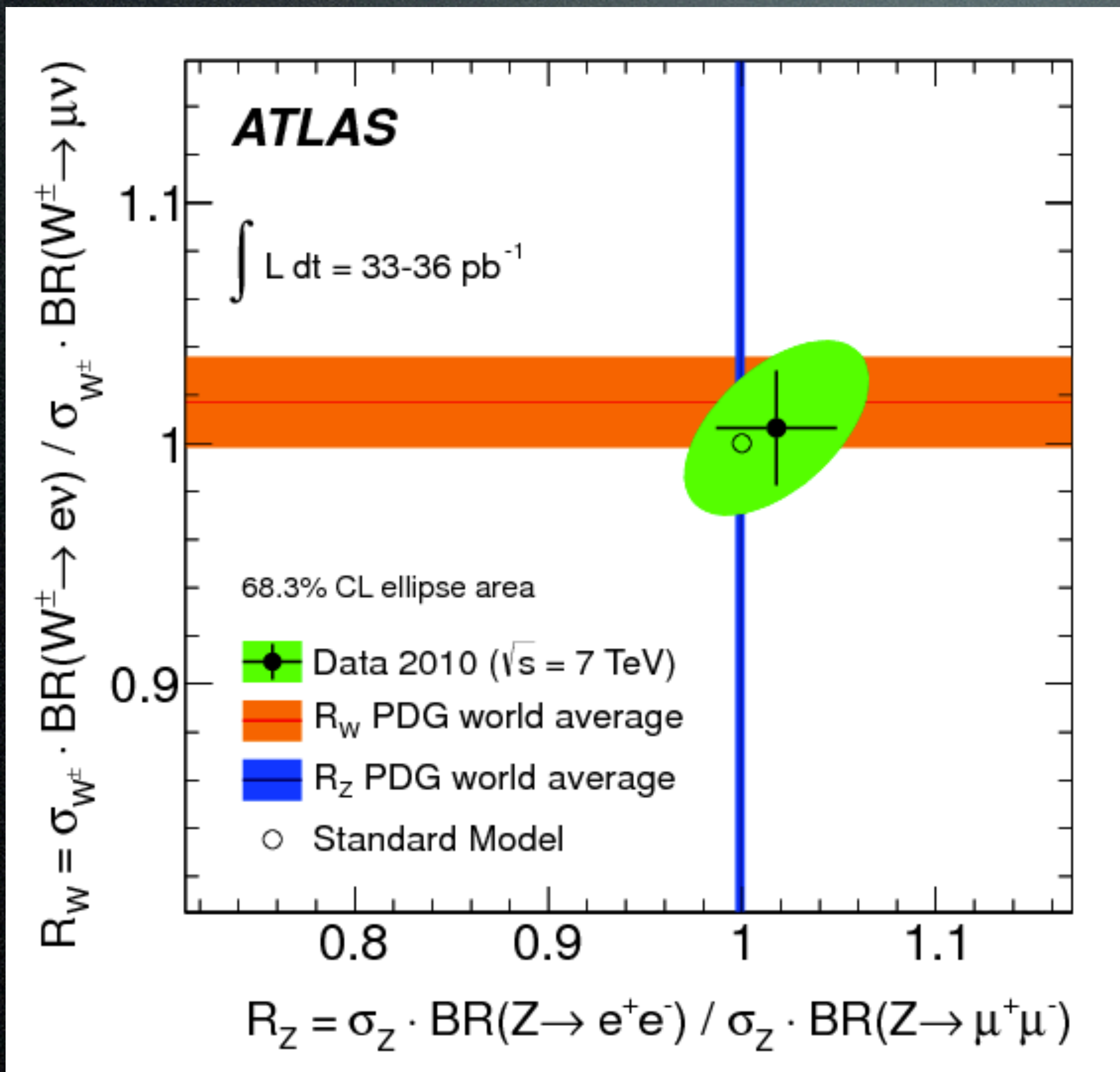
Multi Parton Interaction

From Frank Krauss

Detour: Unfolding

- We measure at detector level.
- But each detector is different!
- Unfold the detector effect to arrive at generator level.
- Mathematically: $m_i = \sum_j \alpha_{ij} t_j$, which is an ill-posed problem!
- Bin-by-bin or (iterative) Bayesian method.

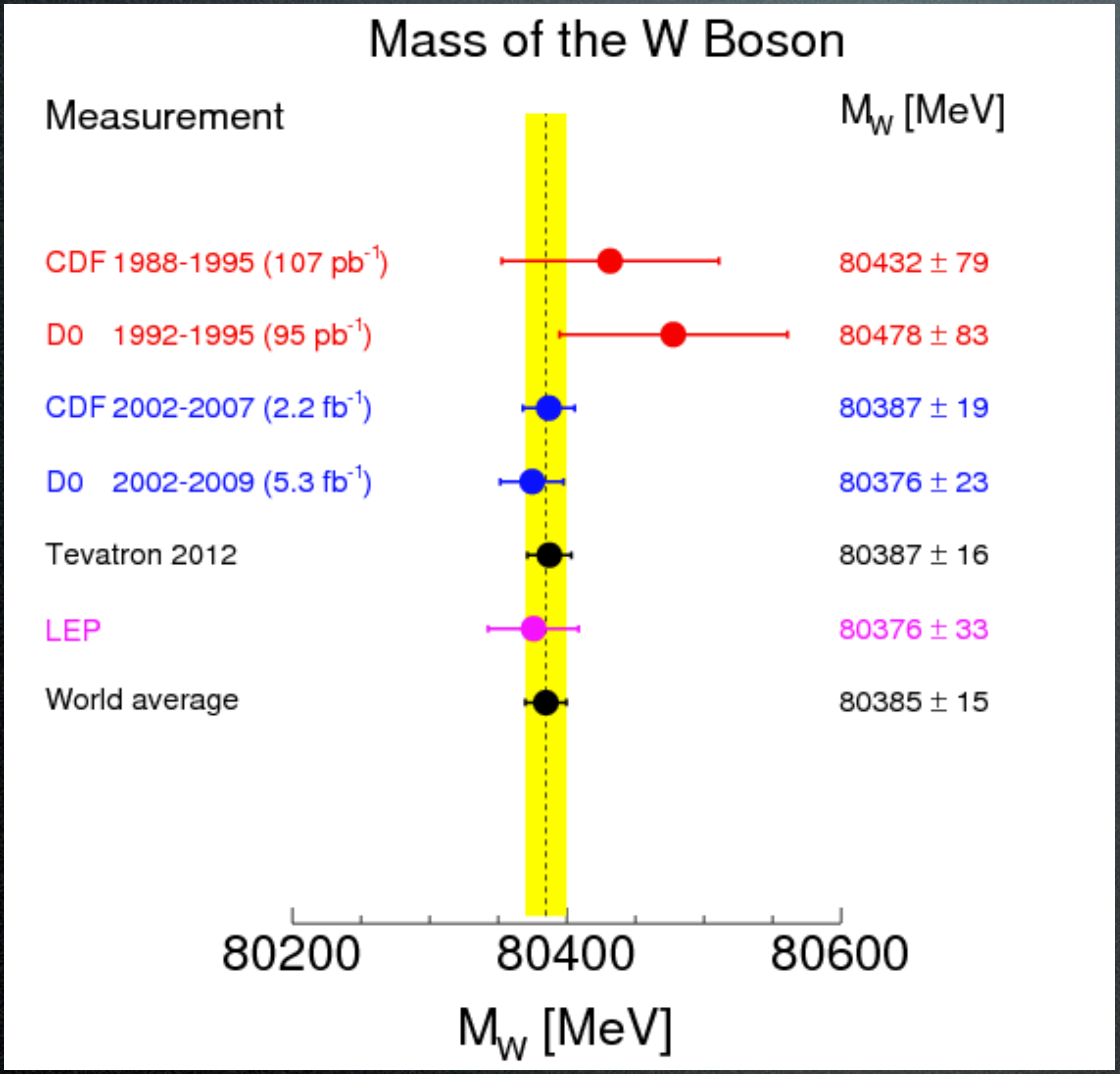
Lepton Universality



Coupling of leptons
to W and Z bosons should be independent

Cross sections measured in electron
and muon channel compared

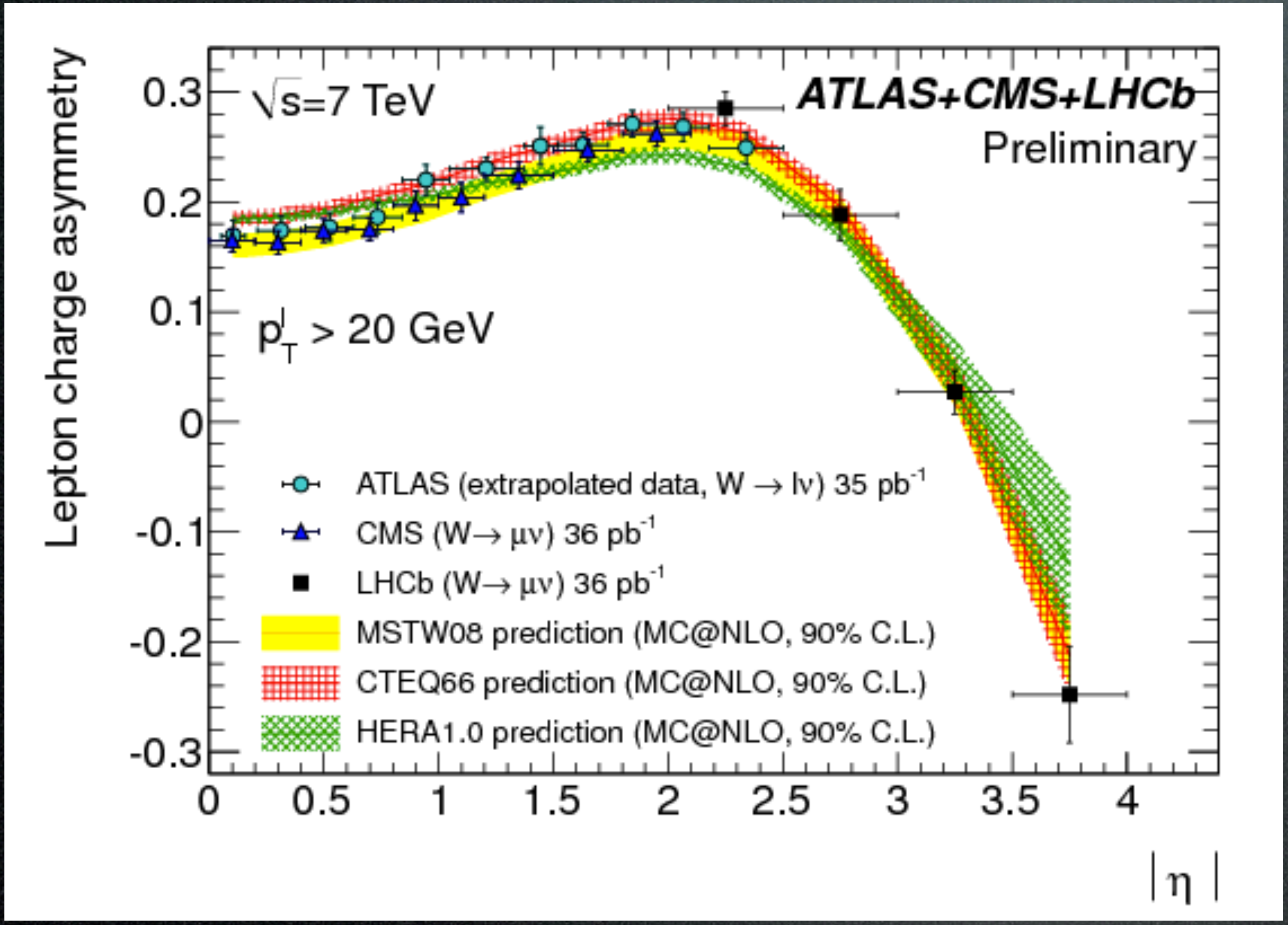
W Mass



No result from LHC yet

Necessary for precision measurement for other EW processes

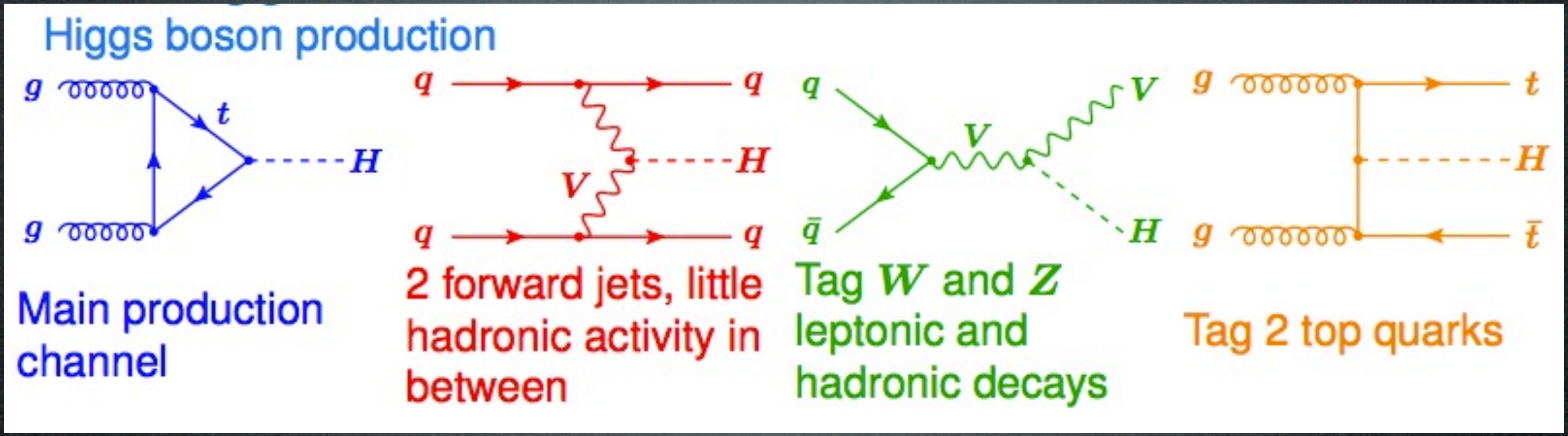
W Lepton Charge Asymmetry

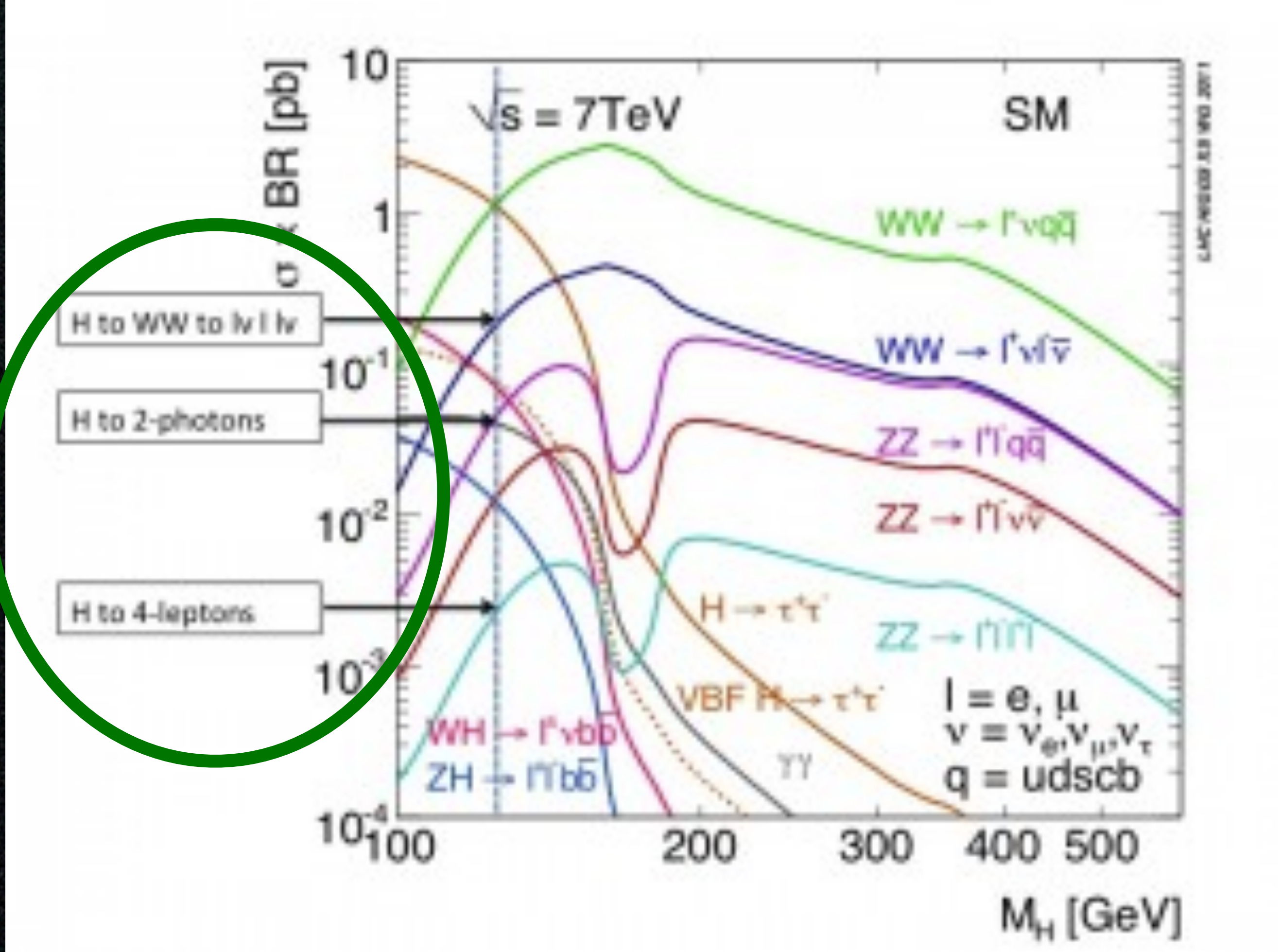


$$A_W = \frac{\sigma_{W^+} - \sigma_{W^-}}{\sigma_{W^+} + \sigma_{W^-}}$$

Sensitive to quark distributions inside the proton

Higgs at the LHC





Final states with leptons or photons are easier to distinguish, measure.

Decays to jets are more difficult to separate from multijet background.

Top Models!

- 4th gen chiral quarks: a $SU(2)_L$ doublet $(t' ,b')_L$ with the corresponding right-handed singlets t'_R , b'_R. Disfavoured by 125 GeV Higgs.
- Quarks for which both chiralities have the same transformation properties under the electroweak group SU(2)×U(1). Often introduced as a top partner to cancel the quadratic divergence of the top loop in the Higgs propagator.

Milestones and Prospects

Run 1	Commissioning the tools
Run 2: 100 fb^{-1}	and... Improve precision of top/W/Higgs mass measurements. Exclude/severely constraint many of the new physics models with the higher energy reach
Run 3: 300 fb^{-1}	and... Directly test the coupling of the Higgs boson to fermions
HL-LHC: 3000 fb^{-1}	and... Measure Higgs self coupling Measure vector boson scattering Observe rare Higgs decays