# ATLAS Results Overview

#### Deepak Kar Glasgow/Witwatersrand

High Energy Particle Physics Workshop Johannesburg 11-13th February, 2015

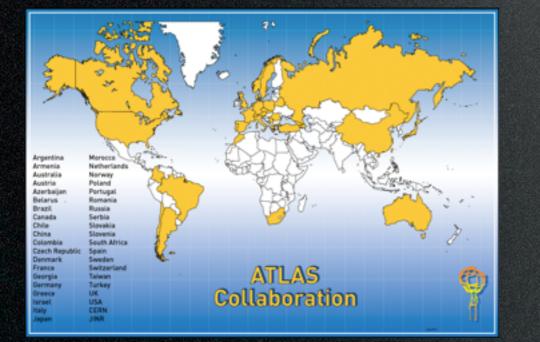
#### An amazing adventure...

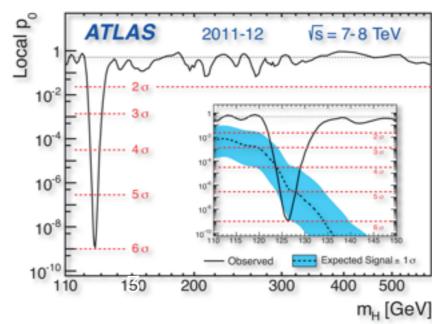


#### Overview

- 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.





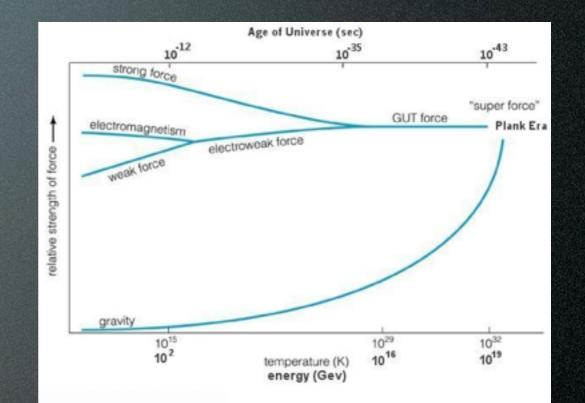


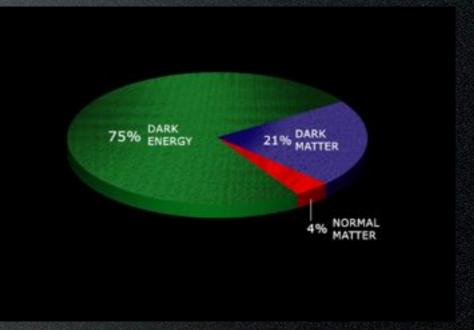


## So, what is left to discover?

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

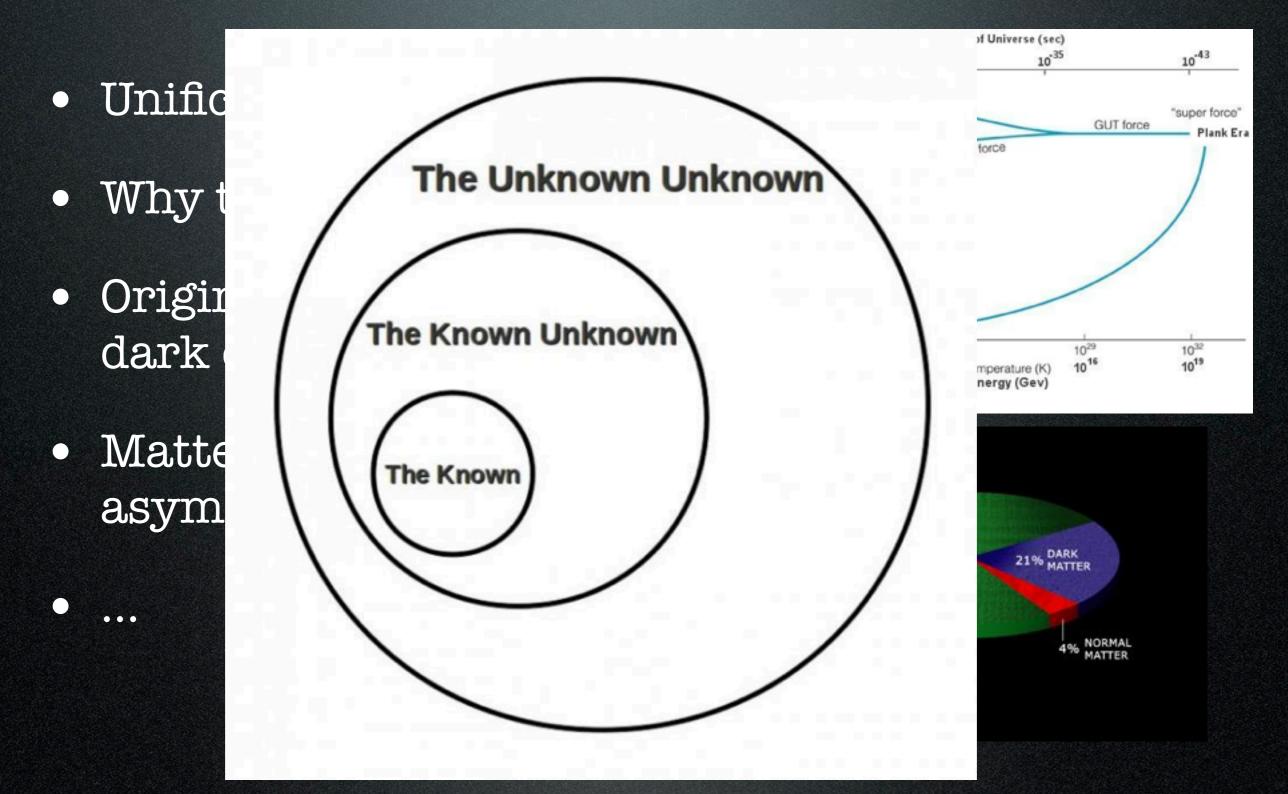
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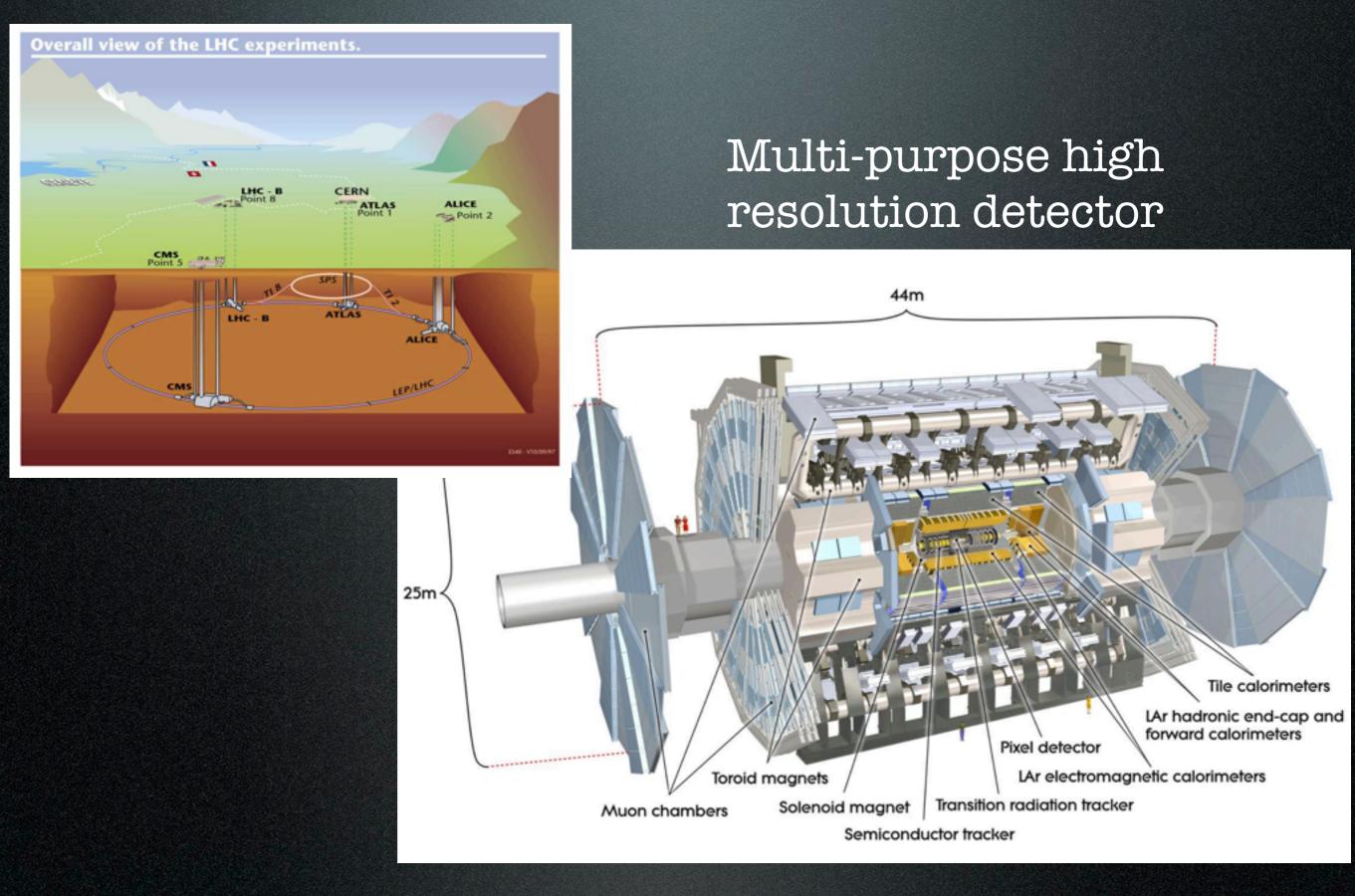
LHC 13/14 TeV runs will help us to probe a new energy domain.

## So, what is left to discover?



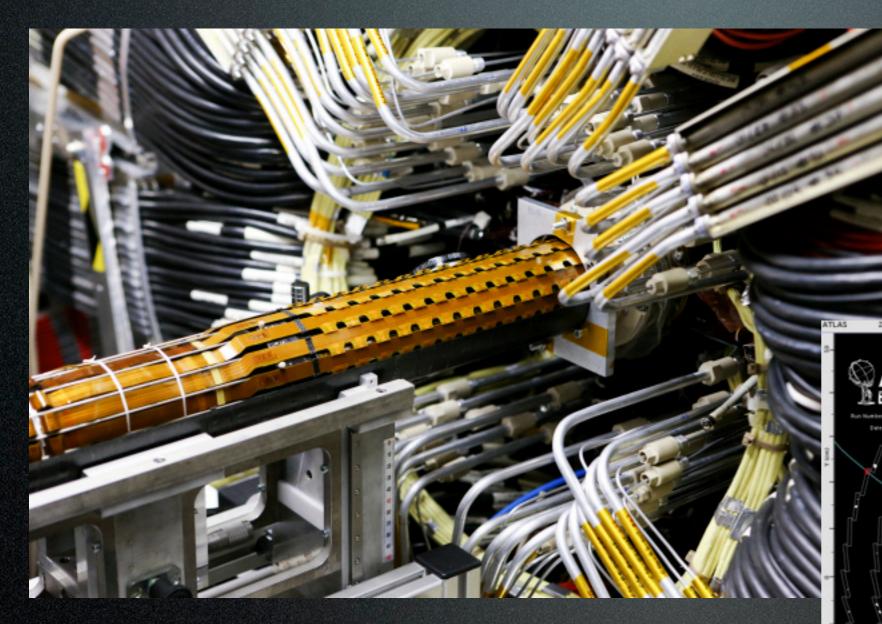
LHC 13/14 TeV runs will help us to probe a new energy domain.

#### LHC and ATLAS



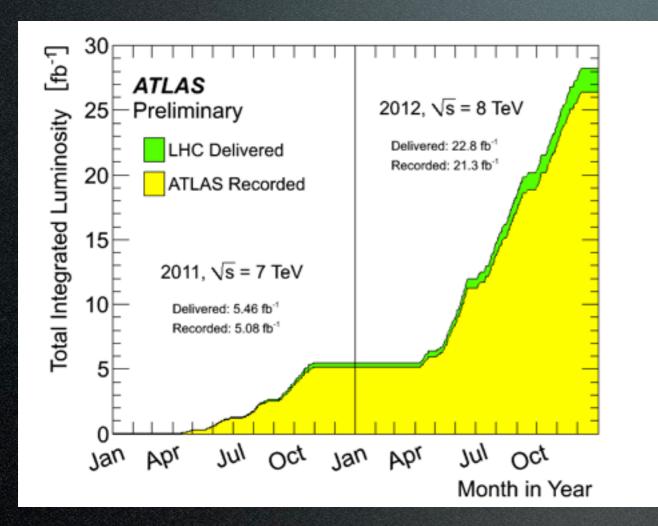
#### What's new: IBL

7



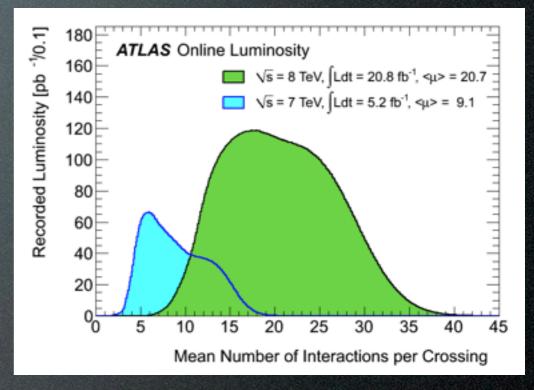
Improved track reconstruction and b-tagging Additional layer of radiation-damage resistant pixels

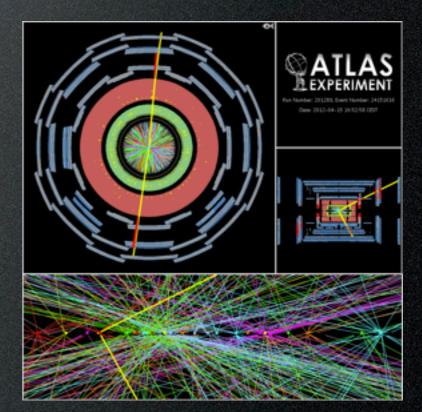
## A lot of data!



excellent data collection efficiency with <2% luminosity uncertainty.

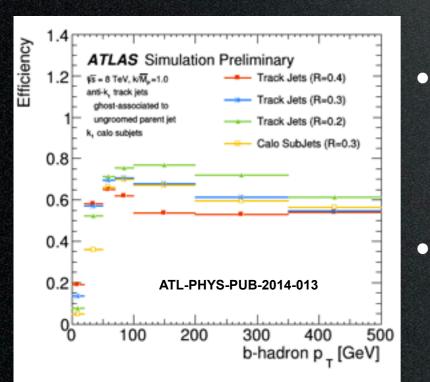
Price of high luminosity: pileup



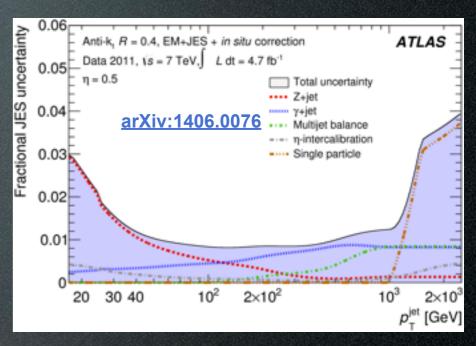


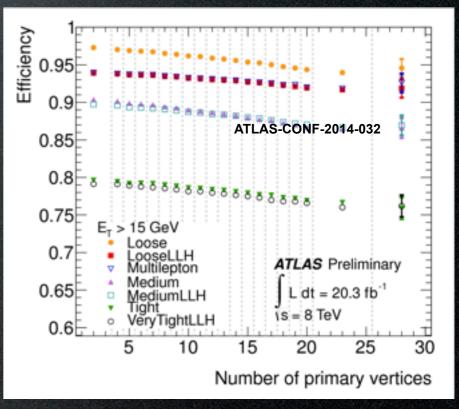
#### Physics Object Reconstruction

- 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)

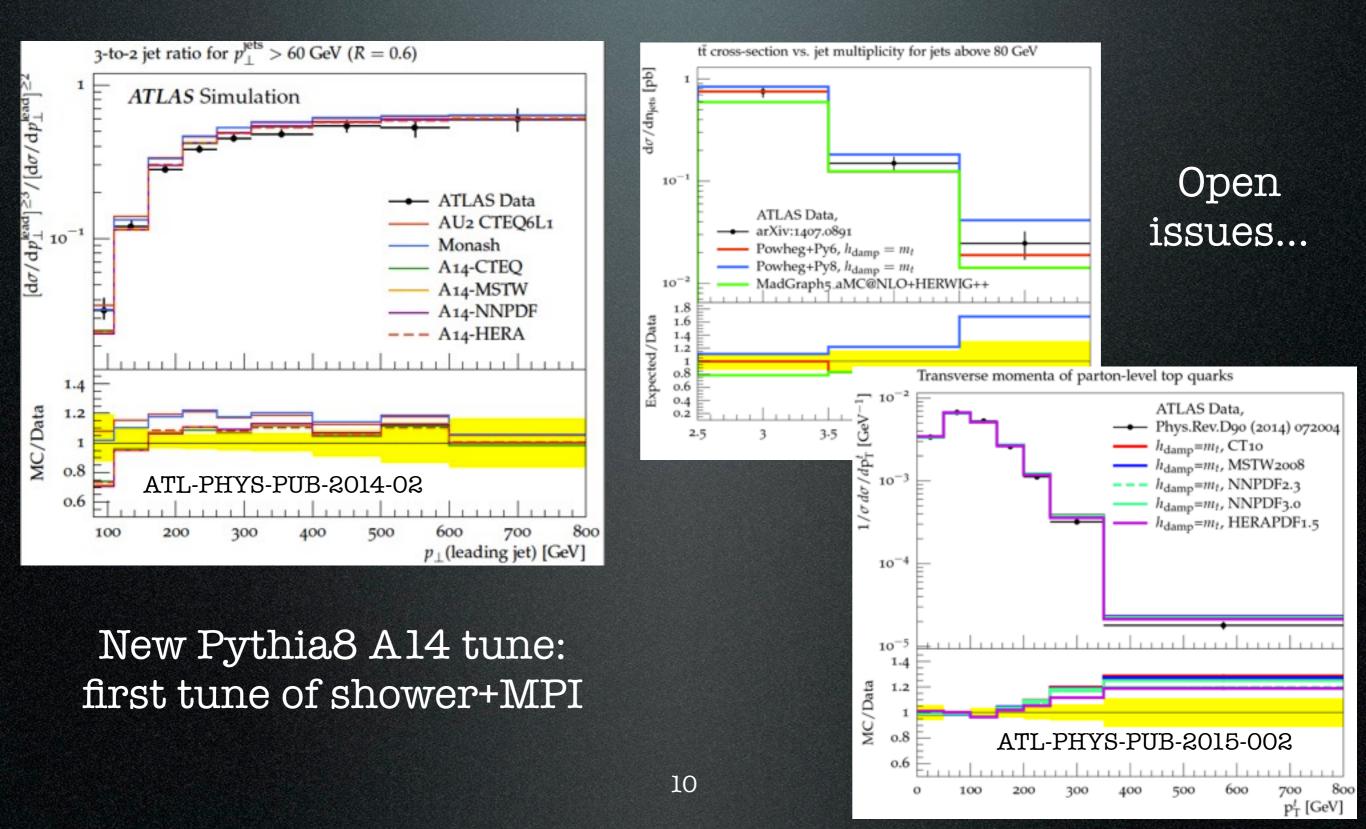


- Multivariate flavour taggers with high performance and small uncertainty.
- Exploring new ideas for btaggng, i.e using trackjets for small radius jets.





## MC tuning/top modelling





#### **HIGGS BOSON**

\*\*\*\*\*\*\*\*\*\*\*\*

**≹PARTICLEZ00** 

HEAVY

**Z BOSON** 

LIGHT

#### H

The HIGGS BOSON is

the particle of the Higgs

mechanism, believed by

physicists to reveal how all matter in the

CMS and Atlas

collaborations at

CERN announced a

been detected with

a mass of around 125 GeV.

\$10.49 ALL DAMAGE

Wool felt, fleece with gravel fill

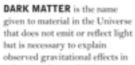
for maximum mass,

5-sigma level of certainty that the Higgs boson had

universe gets its mass. On July 4, 2012, the

#### ?





dark exactly it is.



observed gravitational effects in galaxies and stars. Dark matter, along with dark energy, totals \$6% of the Universe, yet it remains a mystery as to what

Acrylic felt, wool felt, and fleece with gravel fill for maximum mass. Packaged in a black opaque bag designed for concealing contents.

..........

#### \$10.49 PLUS SHIPPING





DARK MATTER







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.

Z

\*\*\*\*\*\*\*\*\*\*\* HEAVY

**≹PARTICLEZ00** 

YON ELECT

\$10.49 PLUS SHIPPING

**TOP QUARK** 



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<sup>-24</sup> 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

\$10.49

TOP OILAR!

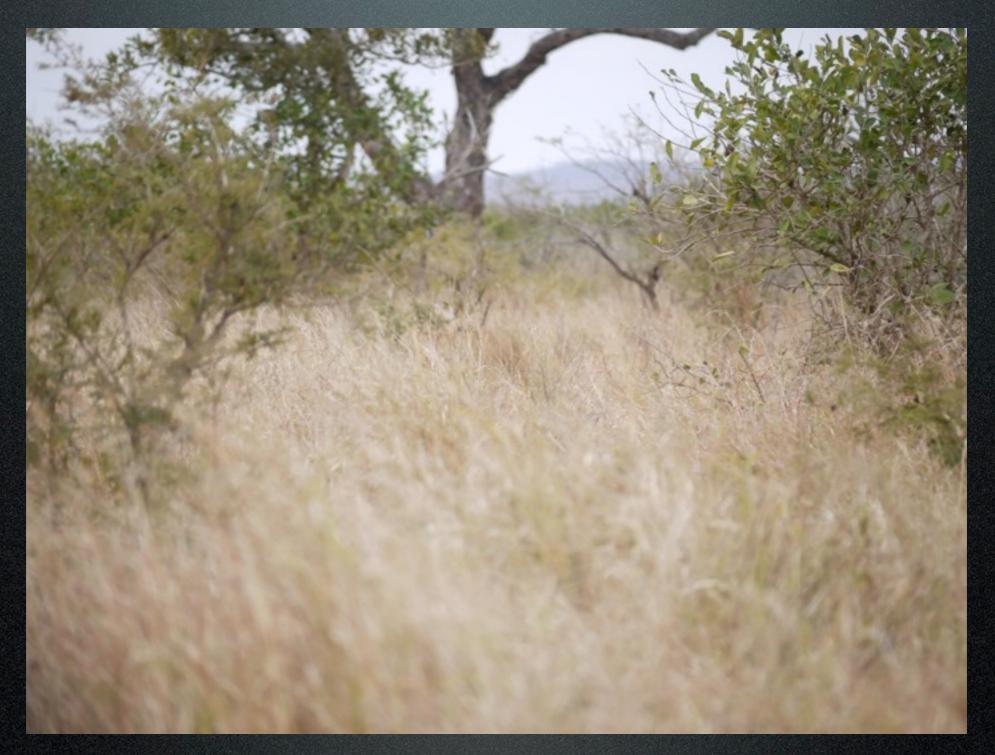


Big 5

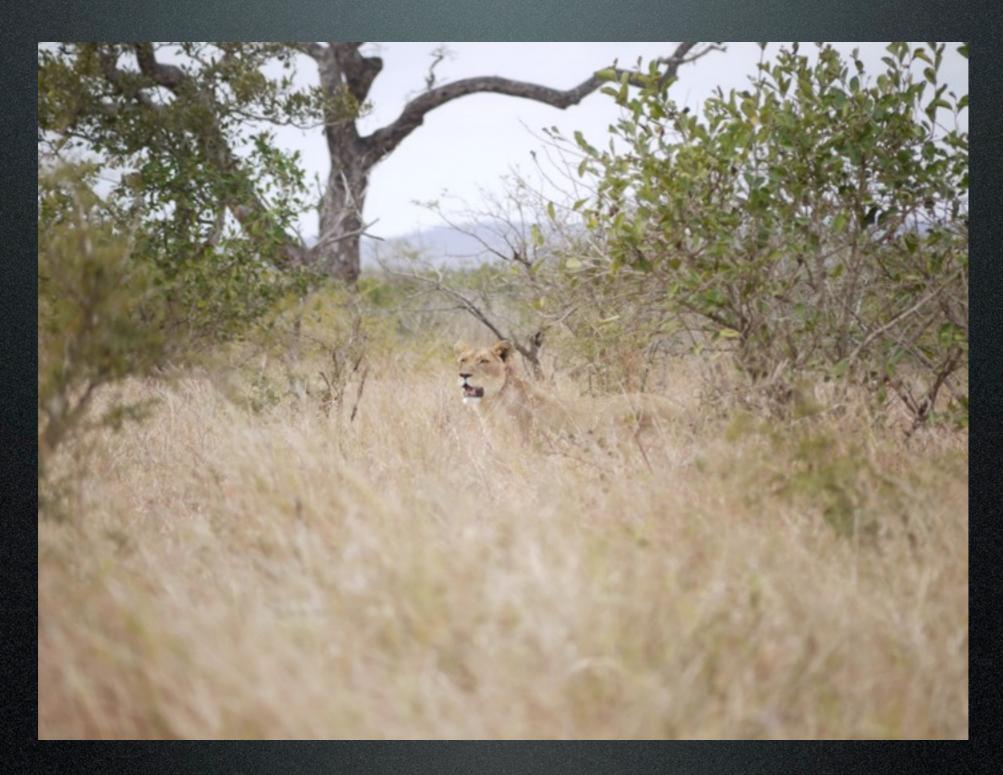
t

gravel fill for maximum mass.









#### $H \rightarrow \gamma \gamma (5.2\sigma)$

H->ZZ->41 (8.2 $\sigma$ )

Data

Background ZZ'

Background Z+jets, tł

Systematic uncertainty

Signal (m, = 125 GeV µ = 1.51)

m<sub>4/</sub> [GeV]

GeV

S

N

Events

35

30

25

20

15

10

5

80

🗕 ATLAS

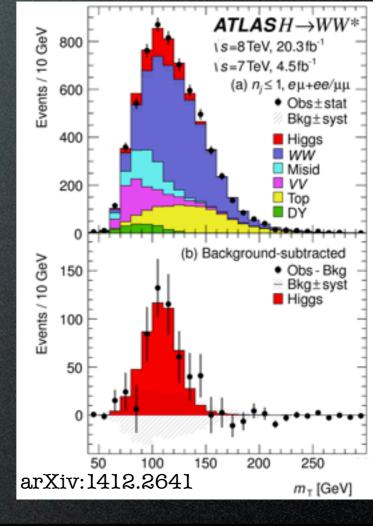
 $H \rightarrow ZZ^* \rightarrow 4l$ 

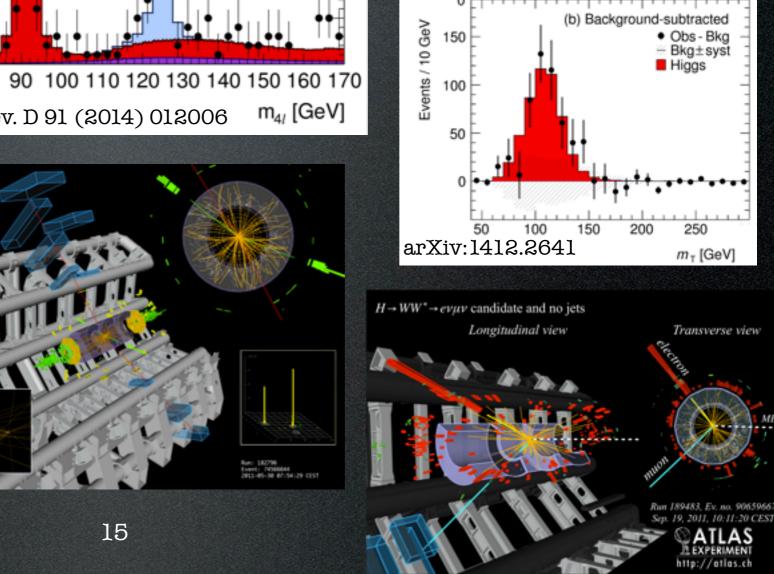
Vs = 7 TeV Ldt = 4.5 fb<sup>-1</sup>

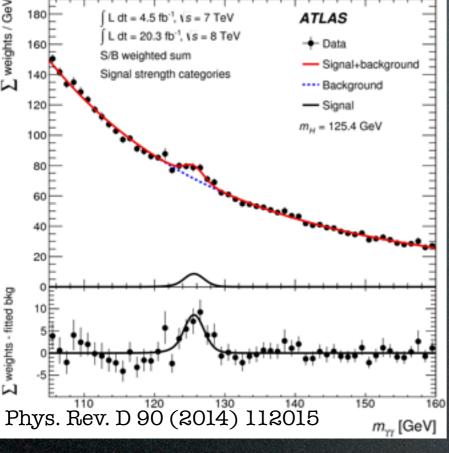
Vs = 8 TeV Ldt = 20.3 fb<sup>-1</sup>

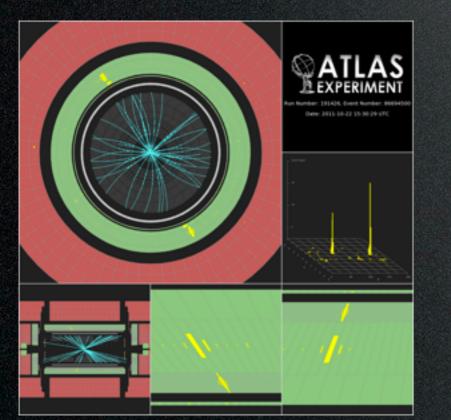
Phys. Rev. D 91 (2014) 012006

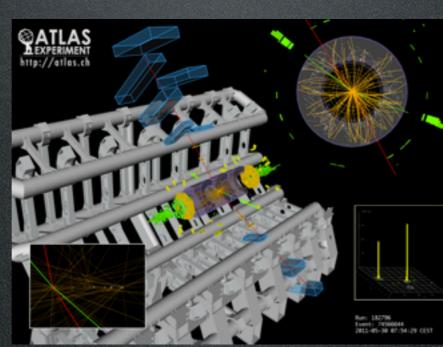
#### $H \rightarrow WW \rightarrow 212v$ $(6.1 \sigma)$











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#### 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



#### $(V)H->bb(1.4\sigma)$

#### $(tt)H \rightarrow \gamma\gamma$

Background fit

120

ATLAS

130

4 j, ≥ 4 b

5 j, ≥ 4 b

 $\geq 6$  j,  $\geq 4$  b

is = 8 TeV [Ldt = 20.3 fb<sup>-1</sup>

8 TeV leptonic category

140

 $t\bar{t}H, H \rightarrow \gamma\gamma, m_{\mu} = 125.4 \text{ GeV}$ 

150

ATLAS

Preliminary

Simulation

m, = 125 GeV \s = 8 TeV

tt̃H. H→bb

ttH. H→WW ttH. H→τ₹ ttH. H→aa

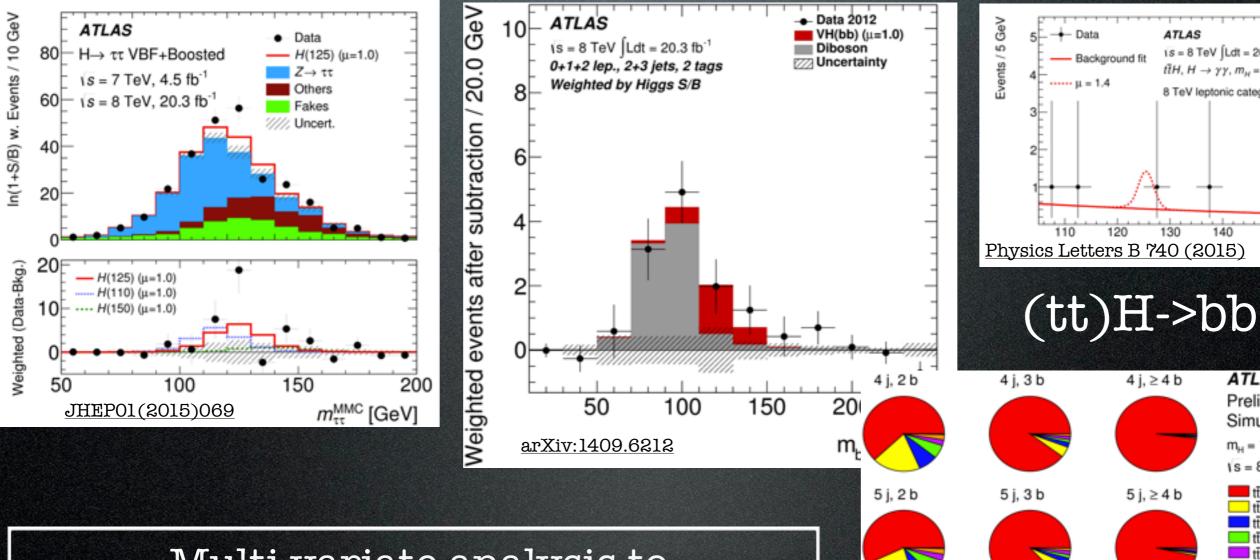
ttH, H→cc ttH, H→ZZ Itt̃H, H→ others

Single lepton

CONF-2014-011

160

m,, [GeV]

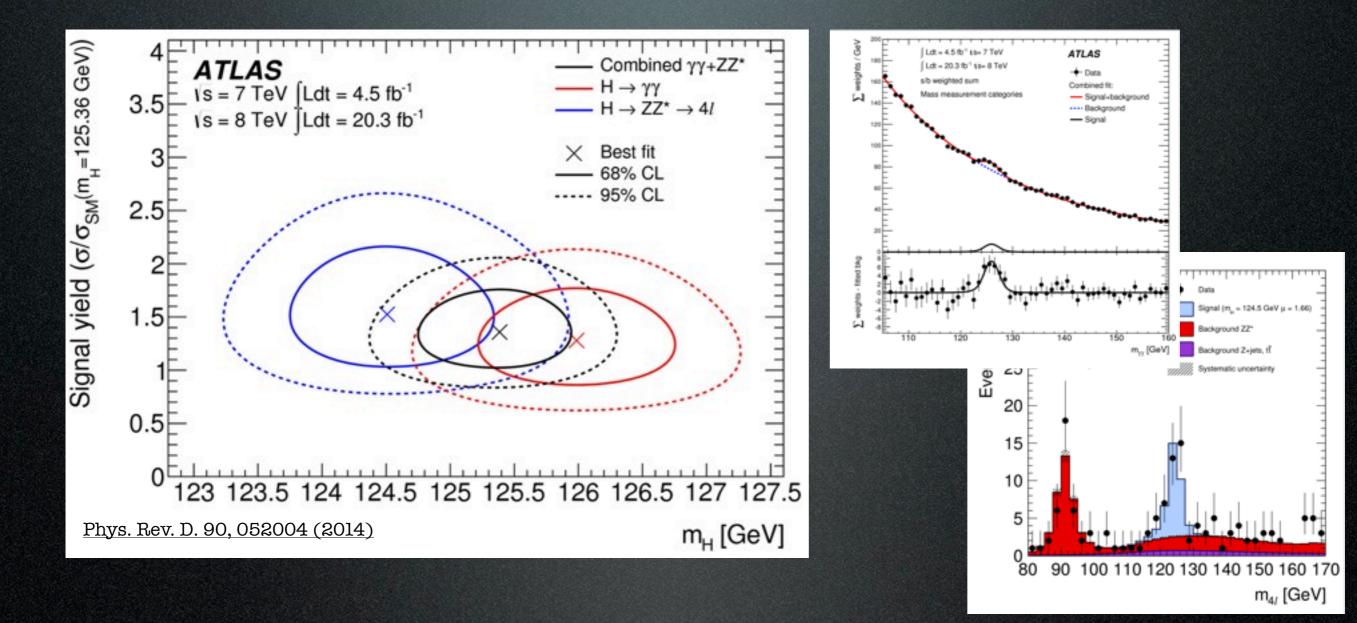


Multi variate analysis to distinguish signal from background

≥6 j, 2 b

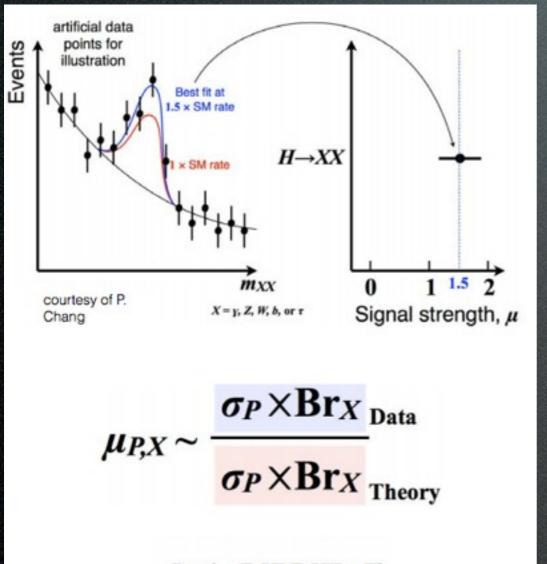
≥6 j. 3 b

#### Higgs Mass Measurements

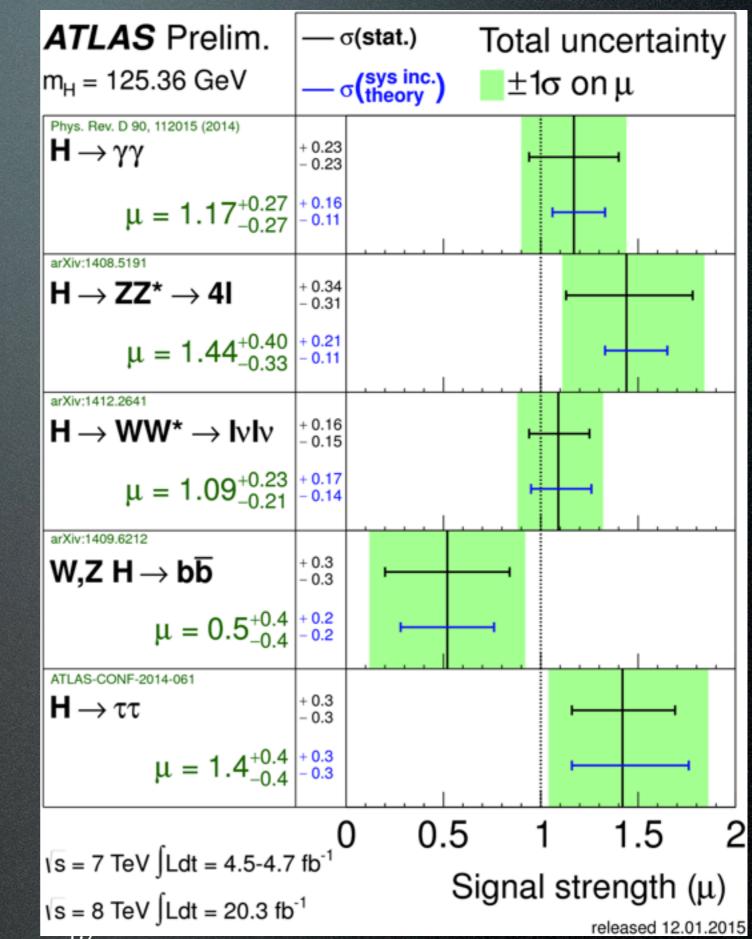


Measured in high resolution channels,  $\gamma\gamma$  and 41

# Signal Strength



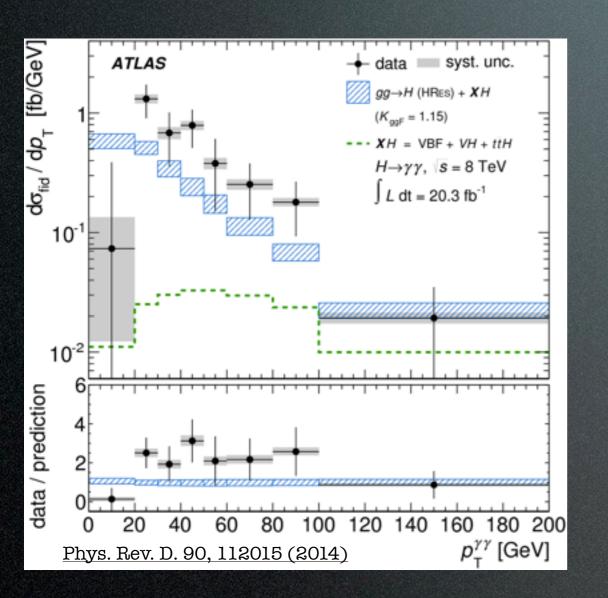
 $P \in \{ggF, VBF, VH, ttH\}$  $X \in \{yy, ZZ, WW, bb, \tau\tau\}$ 

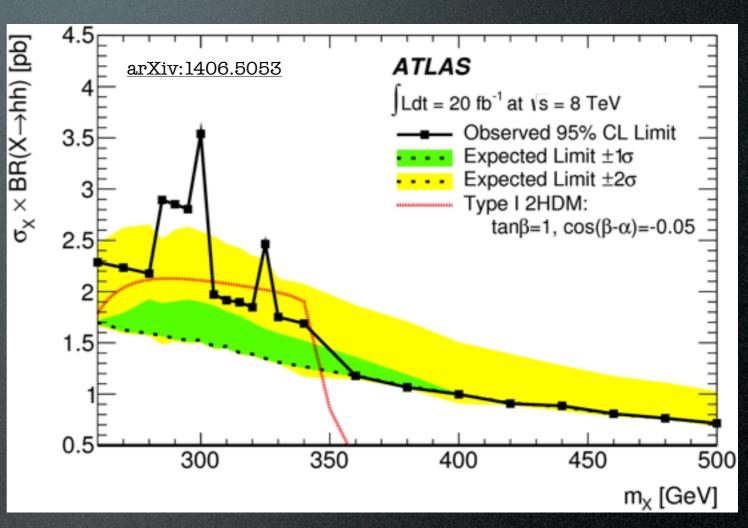


#### **Other Properties**

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

## **Open Questions?**





A narrow resonance decaying to pairs of Higgs bosons?

Mismodelling of Higgs p<sub>T</sub>?

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.

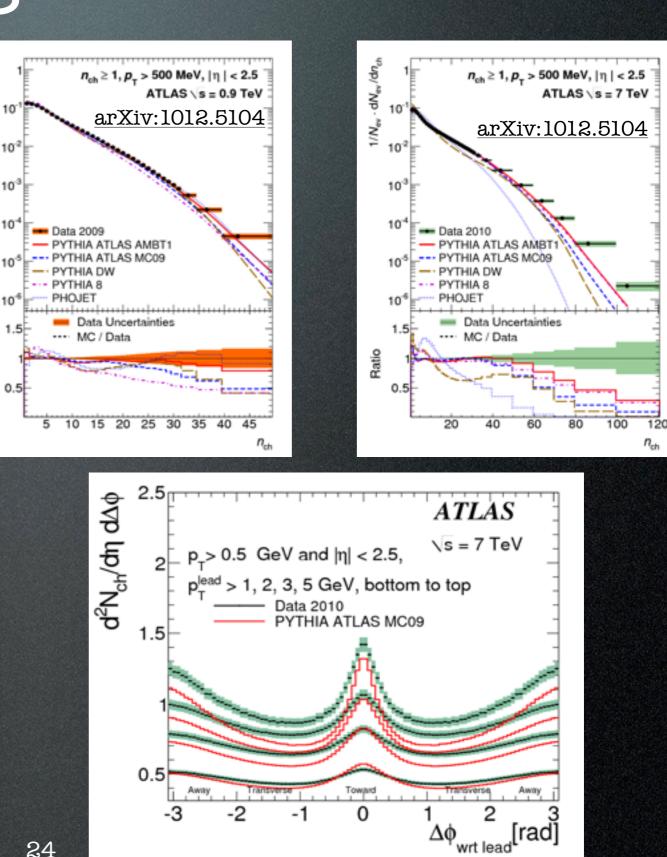
## Beginning of the LHC

I/Nev - dNev/dn

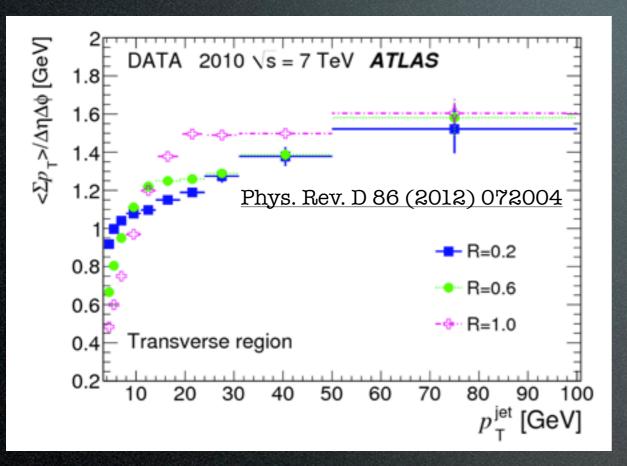
Ratio

- 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!

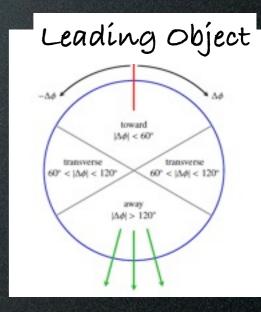


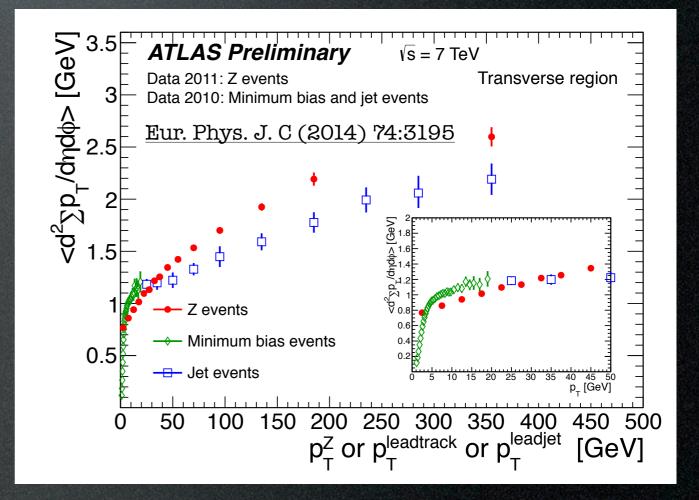
## SoftQCD: W/jet comp



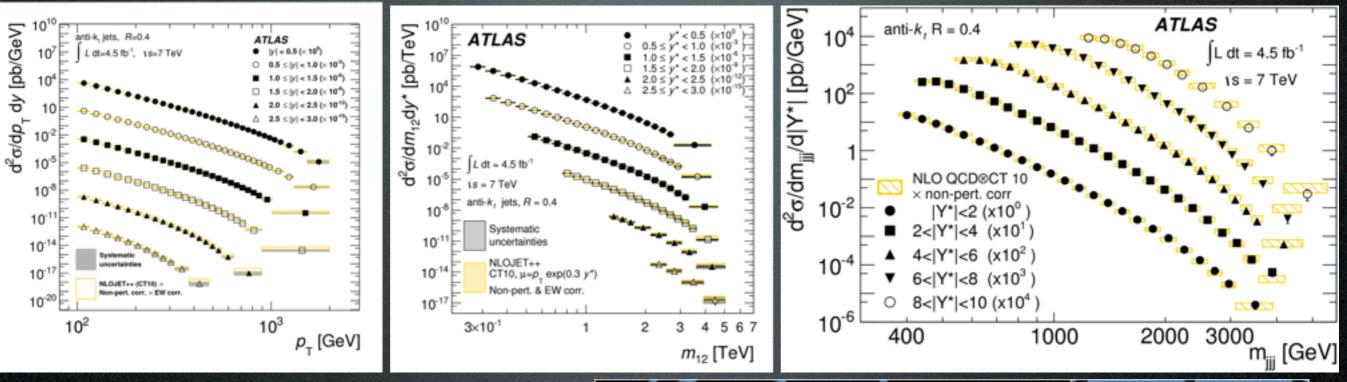
## Difference due to selection bias.

UE activity contaminated by extra jets Activity increases with jet radius



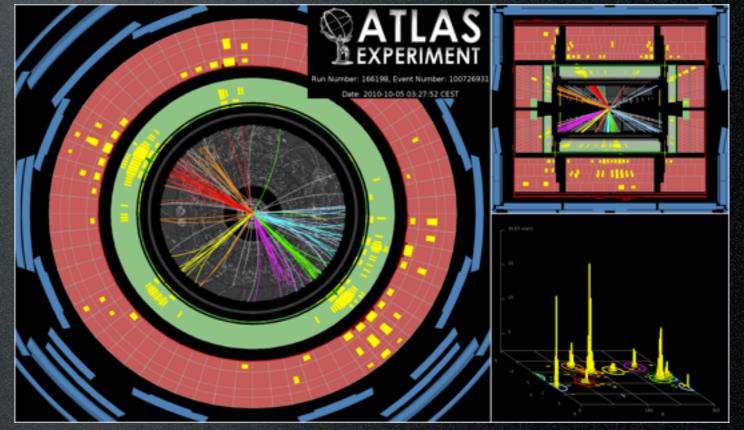


#### Jet Production

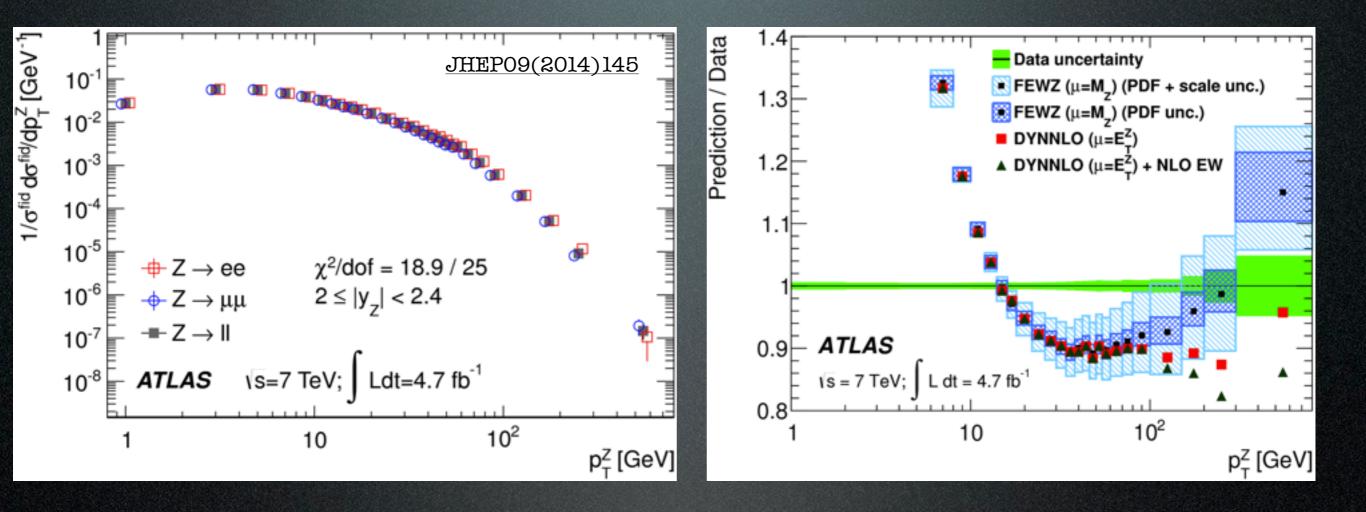


Inclusive, dijet and 3-jet differential cross-sections

Also properties of events with jets extensively studied

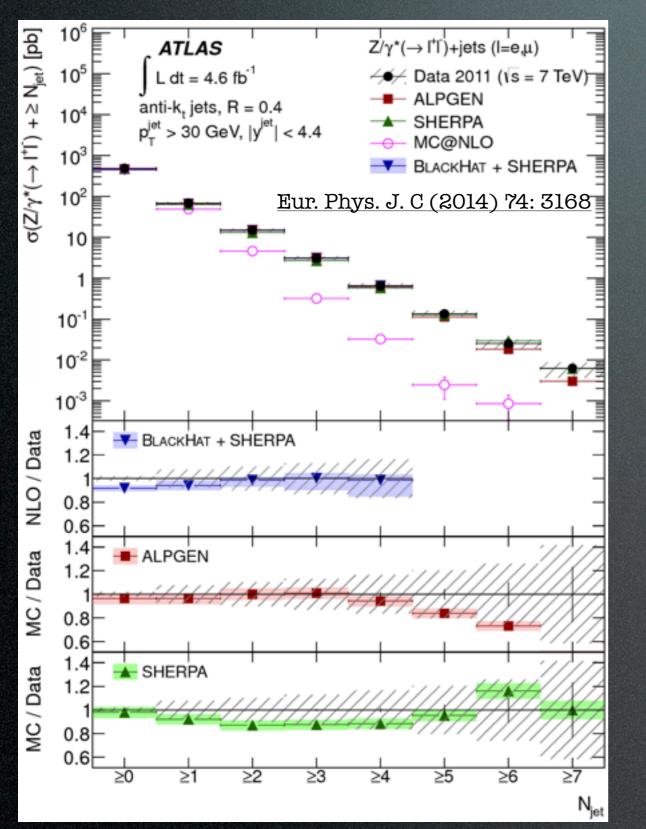


#### Z Transverse Momentum



#### Stringent test of (perturbative) QCD calculations

#### W/Z+jets Productions

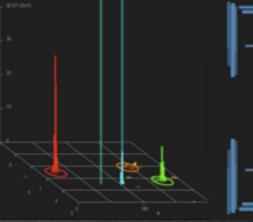


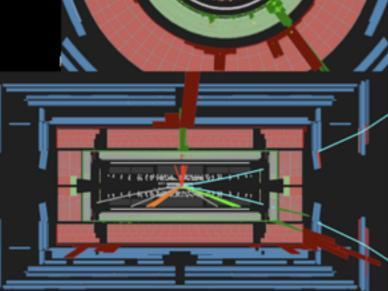
Recoil against hard jet, additional jets from radiation



 $Z \to \mu^- \mu^+ + 3$  jets

Run Number 158466, Event Number 4174272 Date: 2010-07-02 17:49:13 CEST

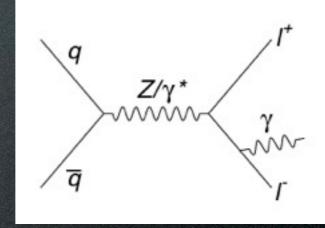


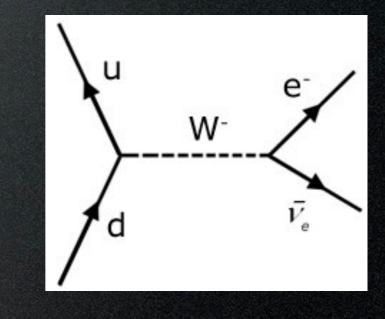


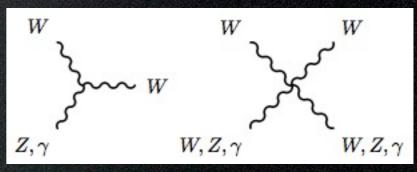
28

## (Electro-weak) Measurements

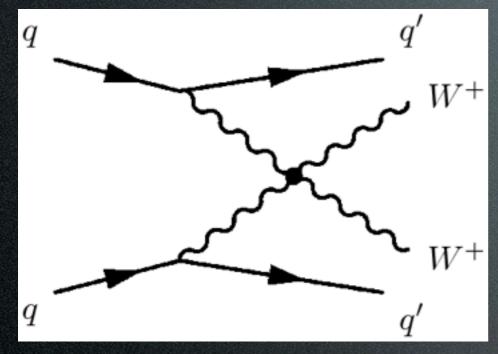
- Involves single or combination of W, Z and isolated γ, cross sections or kinematic observables.
- Reconstructed using leptons, missing energy (and jets).
- Probe triple or quartic self interactions (and set limits): they can be sensitive to new physics.





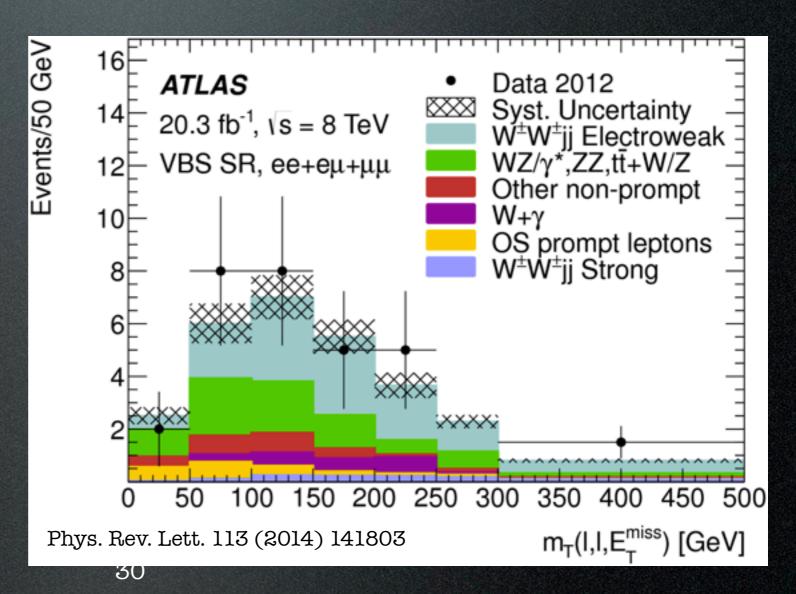


#### Observation of VBS

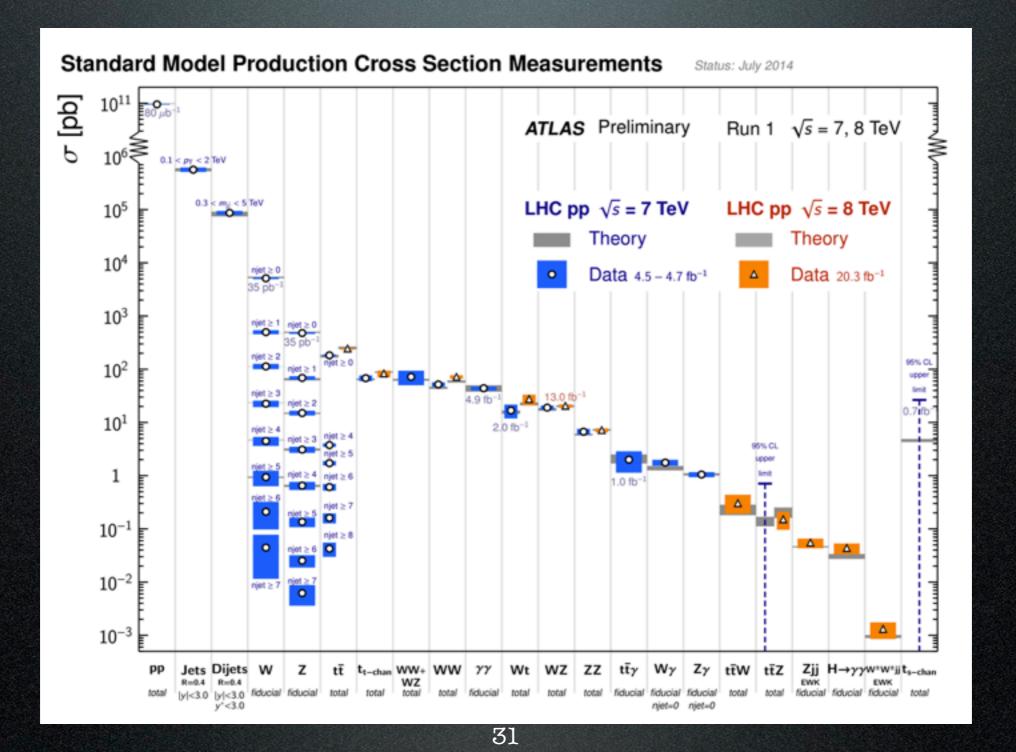


Vector Boson Scattering

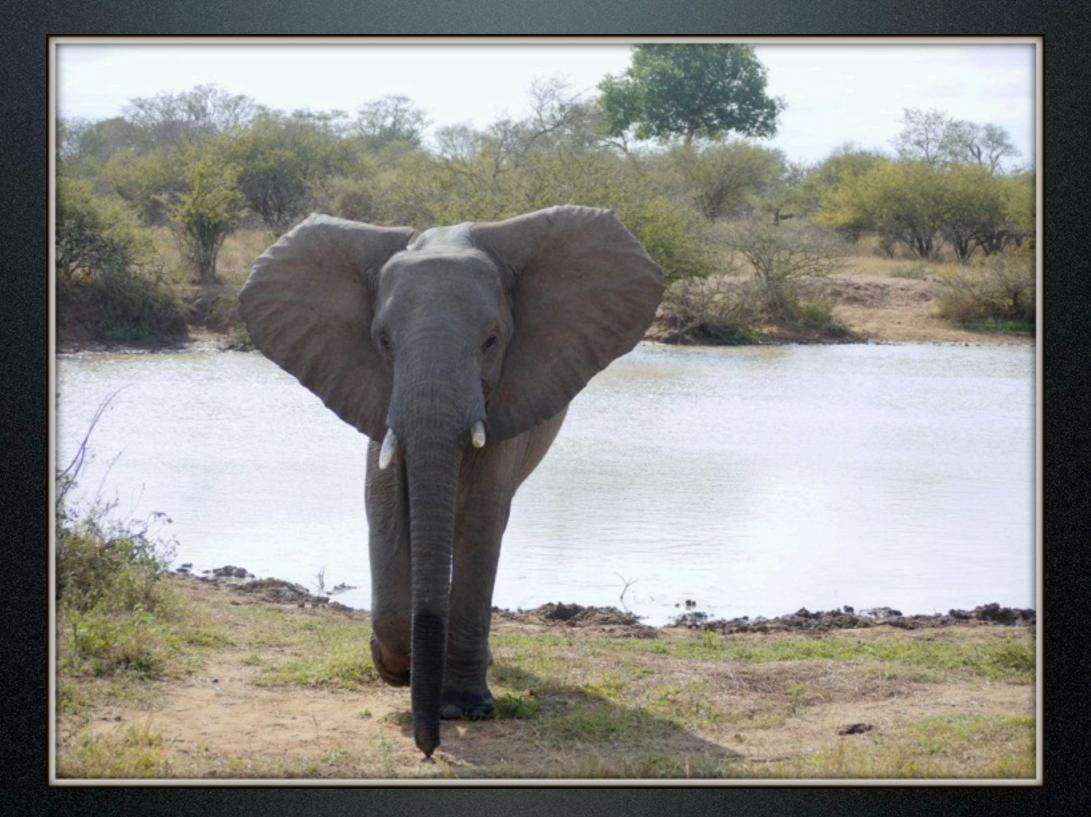
4.5σ (3.6σ) evidence for (electroweak) WWjj production Select events with same charge WW pair + two jets



#### SM Summary



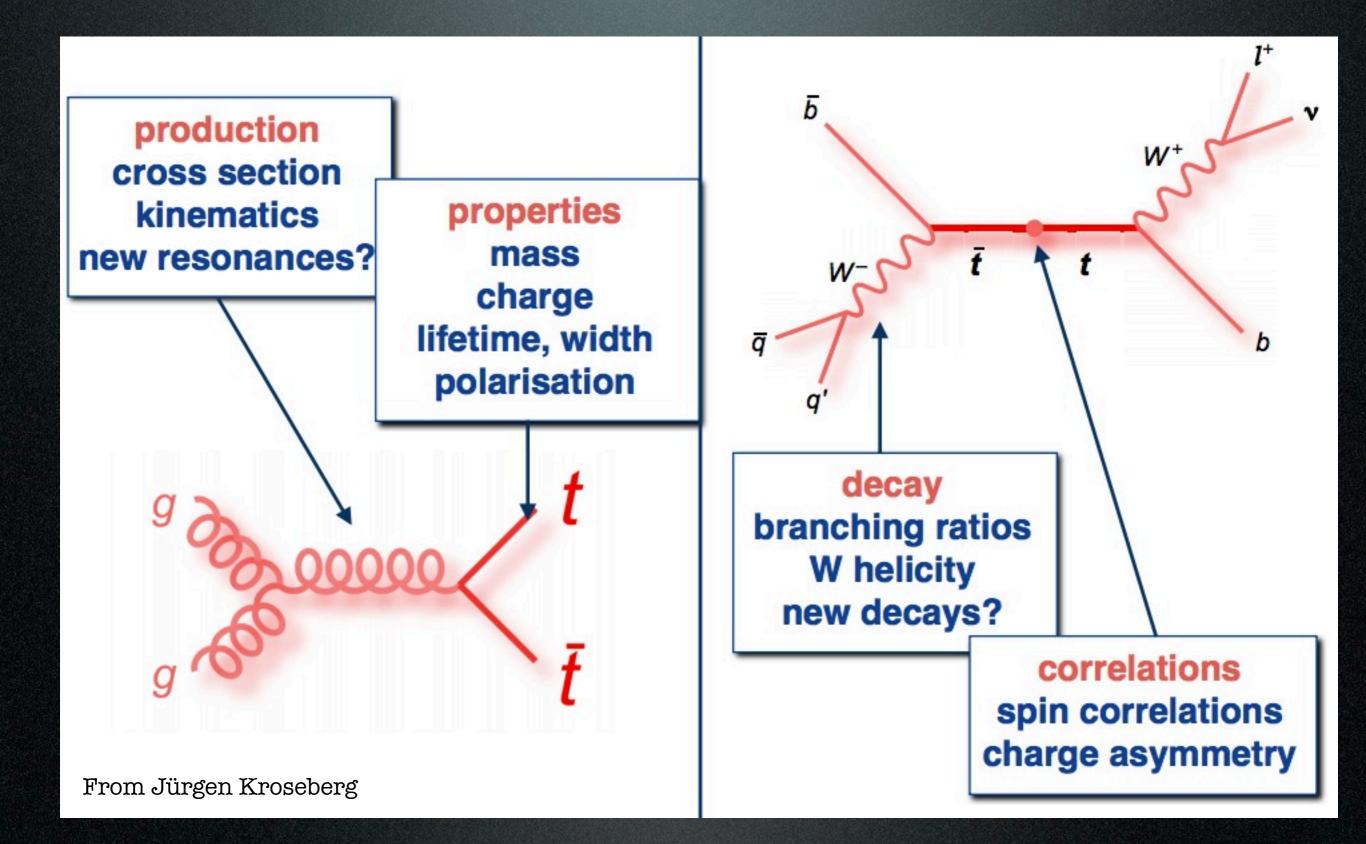
# Top



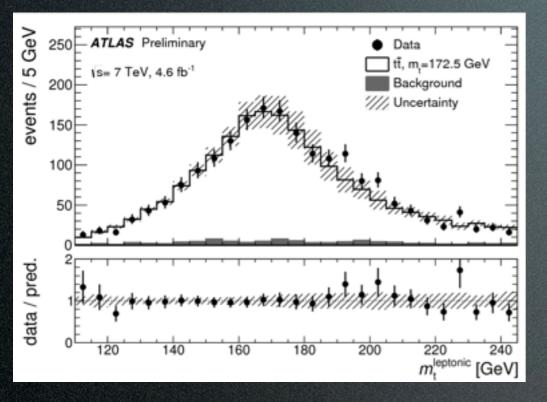
## Why Top is Special

- 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.

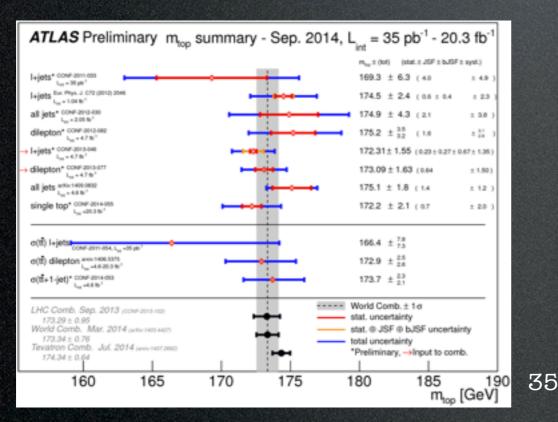
#### Top Measurements

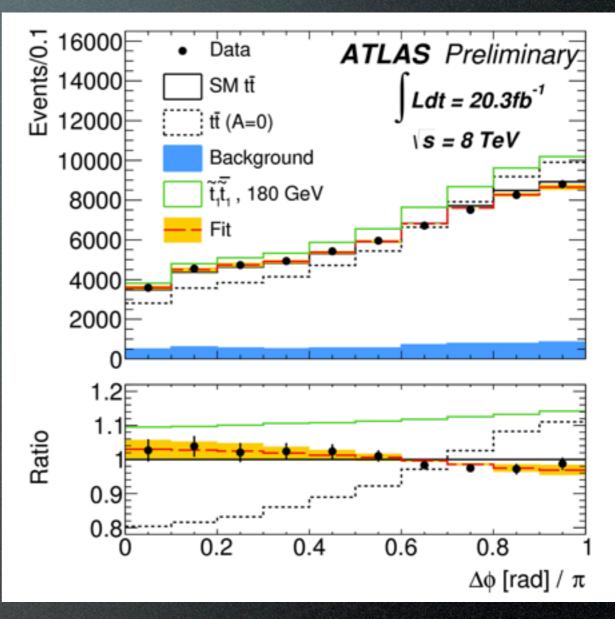


#### **Top Properties**



#### Top Mass

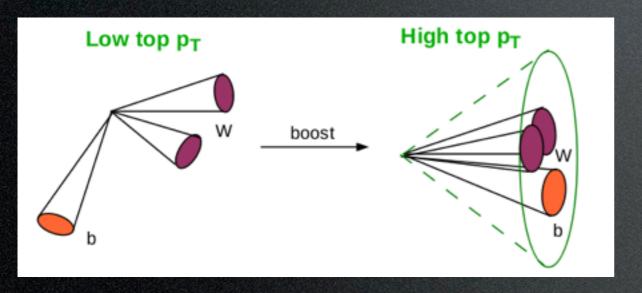




Spin of the top quark at production is transferred to its decay products and can be measured directly via their angular distributions

#### 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

## facebook

Desktop Help      Connecting	
Friends	>
Tagging	
Like	
Lists	>

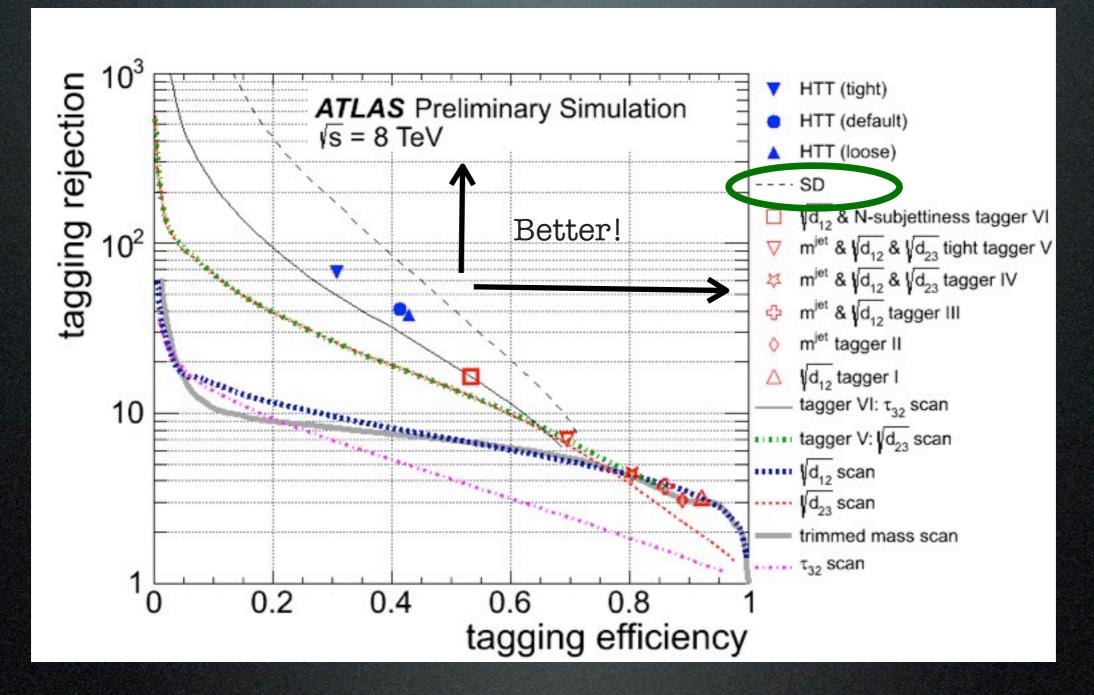
## particles

## Tag people in your posts

Add tags to anything you post, including photos and updates. Tags can point to your friends or anyone else on Facebook. Adding a tag creates a link that people can follow to learn more.

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

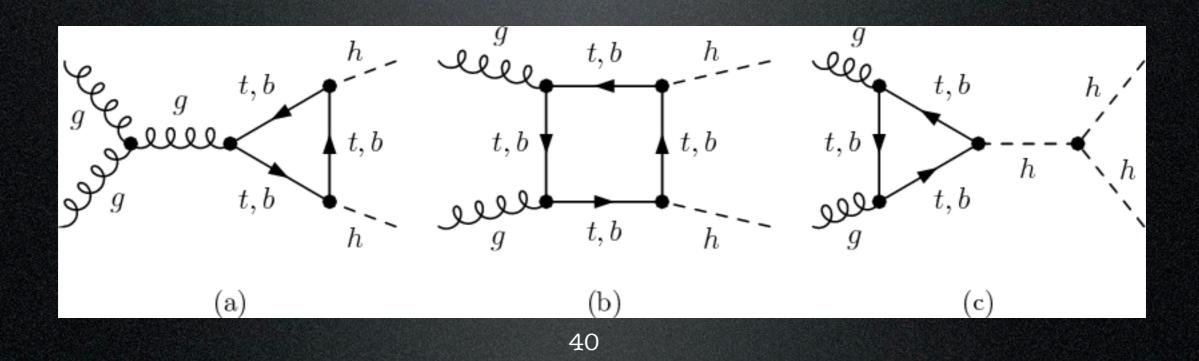
## Top-Tagging Comparison



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

## ... but also

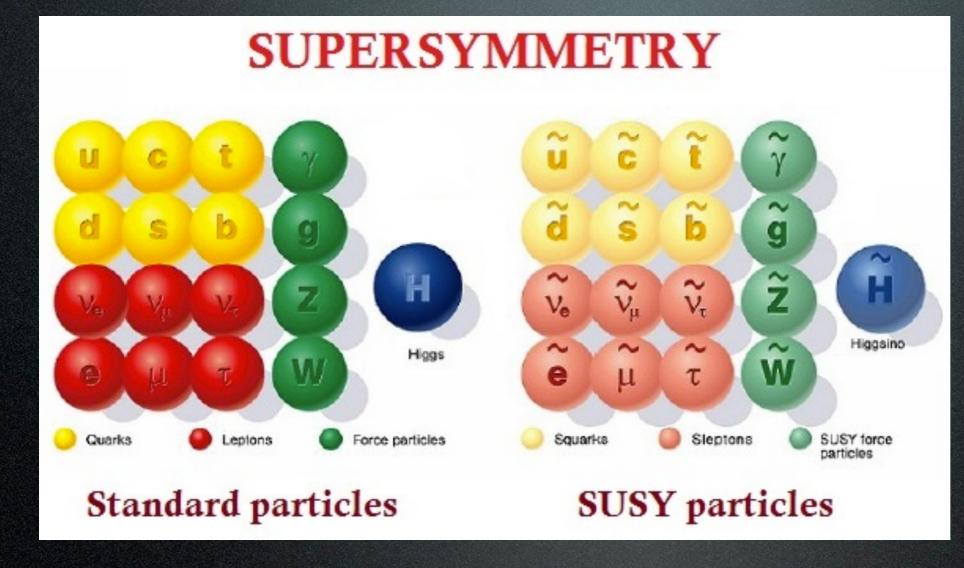
- New TeV scale particles can result in boosted W/Z bosons decaying hadronically (i.e to jets).
- Boosted di-Higgs decay and selfcoupling.



## SUSY



## SUSY



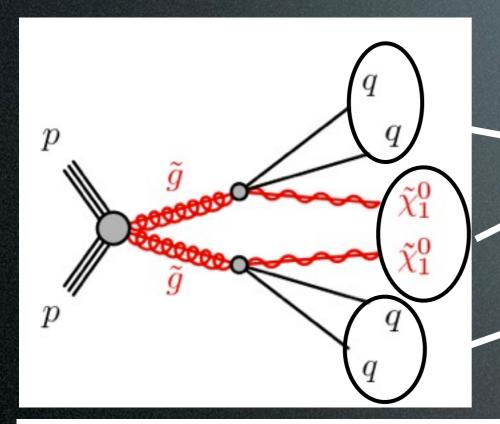
Many Models: MSSM mSUGRA CMSSM GMSB

. . .

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

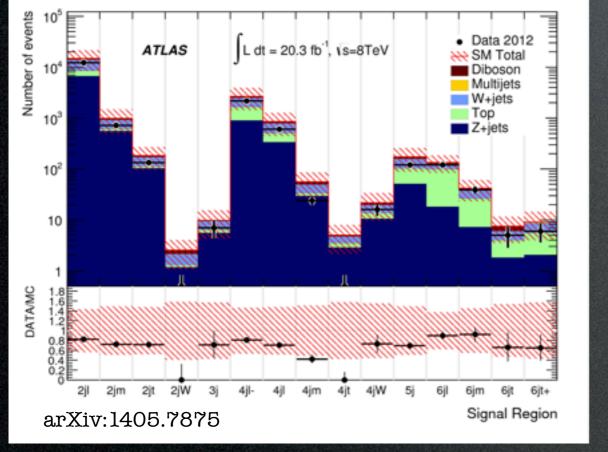
Lightest SUSY particle (LSP) is stable: the decay of the SUSY particle will cascade until it gets to LSP.

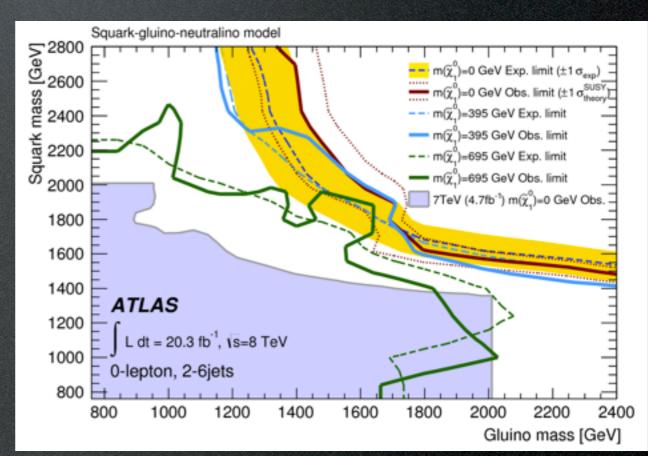
## Search for Squarks & Gluinos



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

Define 15 signal regions with different jet multiplicity, MET and jet p<sub>T</sub> requirements





## SUSY Searches Summary

### ATLAS SUSY Searches\* - 95% CL Lower Limits

#### **ATLAS** Preliminary $\sqrt{s} = 7.8 \text{ TeV}$

Status: ICHEP 2014

	Madel	$e, \mu, \tau, \gamma$	lata	<b>E</b> miss	60.440	-11	Maga limit			Pafaranaa
_	Model	e, µ, ı, 7	Jets	T	12 41(16	,	Mass limit			Reference
Inclusive Searches	ART A POPULATION FOR	$\begin{array}{c} 0 \\ 1 \ e, \mu \\ 0 \\ 0 \\ 1 \ e, \mu \\ 2 \ e, \mu \\ 2 \ e, \mu \\ 1 \ 2 \ \tau + 0 \ - 1 \ \ell \\ 2 \ \gamma \\ 1 \ e, \mu + \gamma \\ \gamma \\ 2 \ e, \mu \ (Z) \\ 0 \end{array}$	2-6 jets 3-6 jets 7-10 jets 2-6 jets 3-6 jets 0-3 jets 0-2 jets 1 b 0-3 jets mono-jet	Yes Yes · Yes Yes Yes Yes Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	\$\vec{k}\$         \$\vec{k}\$ <t< th=""><th>1.1 Te 850 GeV 1.1 1.18 1.12 Te 1.24</th><th>TeV IV 33 TeV TeV</th><th><math display="block">\begin{array}{l} m[\bar{q}] = m(\bar{z}) \\ \text{any } m[\bar{q}] \\ \text{any } m[\bar{q}] \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV, } m[1^{st} \text{ gen.} \bar{q}] = m(2^{sd} \text{ gen.} \bar{q}) \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ \tan\beta^2 &lt; 15 \\ \tan\beta^2 &gt; 20 \\ m[\tilde{\chi}_1^0] &gt; 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] &gt; 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] &gt; 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] &gt; 220 \text{ GeV} \\ m[NLSP] &gt; 200 \text{ GeV} \\ m[\tilde{G}] &gt; 10^{-4} \text{ eV} \end{array}</math></th><th>1405.7875 ATLAS-CONF-2013-062 1308.1841 1405.7875 ATLAS-CONF-2013-062 ATLAS-CONF-2013-062 ATLAS-CONF-2013-089 1208.4688 1407.0503 ATLAS-CONF-2014-001 ATLAS-CONF-2012-144 1211.1167 ATLAS-CONF-2012-152 ATLAS-CONF-2012-147</th></t<>	1.1 Te 850 GeV 1.1 1.18 1.12 Te 1.24	TeV IV 33 TeV TeV	$\begin{array}{l} m[\bar{q}] = m(\bar{z}) \\ \text{any } m[\bar{q}] \\ \text{any } m[\bar{q}] \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV, } m[1^{st} \text{ gen.} \bar{q}] = m(2^{sd} \text{ gen.} \bar{q}) \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ m[\tilde{\chi}_1^0] = 0 \text{ GeV} \\ \tan\beta^2 < 15 \\ \tan\beta^2 > 20 \\ m[\tilde{\chi}_1^0] > 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] > 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] > 50 \text{ GeV} \\ m[\tilde{\chi}_1^0] > 220 \text{ GeV} \\ m[NLSP] > 200 \text{ GeV} \\ m[\tilde{G}] > 10^{-4} \text{ eV} \end{array}$	1405.7875 ATLAS-CONF-2013-062 1308.1841 1405.7875 ATLAS-CONF-2013-062 ATLAS-CONF-2013-062 ATLAS-CONF-2013-089 1208.4688 1407.0503 ATLAS-CONF-2014-001 ATLAS-CONF-2012-144 1211.1167 ATLAS-CONF-2012-152 ATLAS-CONF-2012-147
3rd gen.	$\tilde{\tilde{g}} \rightarrow b \tilde{b} \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{\tilde{g}} \rightarrow t \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{\tilde{g}} \rightarrow t \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{\tilde{g}} \rightarrow b \tilde{t} \tilde{\tilde{\chi}}_{1}^{0}$	0 0 0-1 <i>e</i> .μ 0-1 <i>e</i> .μ	3 b 7-10 jets 3 b 3 b	Yes Yes Yes Yes	20.1 20.3 20.1 20.1	te te te	1.1 Te 1.2	5 TeV 9V 34 TeV .3 TeV	$m(\hat{x}_{1}^{0})<400 \text{ GeV}$ $m(\hat{x}_{1}^{0})<350 \text{ GeV}$ $m(\hat{x}_{1}^{0})<400 \text{ GeV}$ $m(\hat{x}_{1}^{0})<300 \text{ GeV}$	1407.0600 1308.1841 1407.0600 1407.0600
3rd gen. squarks	$ \begin{array}{c} \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow b\tilde{t}_{1}^{0} \\ \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow t\tilde{t}_{1}^{\pm} \\ \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow t\tilde{t}_{1}^{\pm} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{light}), \tilde{r}_{1} \rightarrow b\tilde{t}_{1}^{\pm} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{light}), \tilde{r}_{1} \rightarrow Wb\tilde{t}_{1}^{0} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{inedium}), \tilde{r}_{1} \rightarrow t\tilde{t}_{1}^{0} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{nedium}), \tilde{r}_{1} \rightarrow t\tilde{t}_{1}^{0} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{nedium}), \tilde{r}_{1} \rightarrow t\tilde{t}_{1}^{0} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{nedium}), \tilde{r}_{1} \rightarrow t\tilde{t}_{1}^{0} \\ \tilde{r}_{1}\tilde{r}_{1}(\text{neatural GMSB}) \\ \tilde{r}_{2}\tilde{r}_{2}, \tilde{r}_{2} \rightarrow \tilde{t}_{1} + Z \end{array} $	0 2 e, µ (SS) 1-2 e, µ 2 e, µ 2 e, µ 0 1 e, µ 0 0 m 2 e, µ (Z)	2 b 0-3 b 1-2 b 0-2 jets 2 jets 2 b 1 b 2 b tono-jet/c-1 1 b 1 b	Yes Yes Yes Yes Yes Yes Yes tag Yes Yes Yes	20.1 20.3 4.7 20.3 20.3 20.1 20.1 20.3 20.3 20.3 20.3		100-620 GeV 275-440 GeV 7 GeV 30-210 GeV 215-530 GeV 150-580 GeV 210-640 GeV 90-240 GeV 90-240 GeV 150-580 GeV 290-600 GeV		$\begin{split} & m(\tilde{k}_{1}^{0}) <\!\! 90  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) =\!\! 55  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) =\!\! 55  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) =\!\! m(\tilde{t}_{1}) \! \cdot\! m(W) \! \cdot\! 50  \text{GeV},  m(\tilde{t}_{1}) \! <\!\! <\!\! m(\tilde{k}_{1}^{0}) \\ & m(\tilde{k}_{1}^{0}) \! =\!\! 1  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) \! =\!\! 200  \text{GeV},  m(\tilde{k}_{1}^{0}) \! \cdot\!\! m(\tilde{k}_{1}^{0}) \! =\!\! 5  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) \! =\!\! 0  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) \! =\!\! 150  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) \! <\!\! 200  \text{GeV} \\ & m(\tilde{k}_{1}^{0}) \! <\!\! 200  \text{GeV} \end{split}$	1308.2631 1404.2500 1208.4305, 1209.2102 1403.4853 1403.4853 1308.2631 1407.0583 1406.1122 1407.0508 1403.5222 1403.5222
EW	$ \begin{array}{c} \tilde{\ell}_{L,R} \tilde{\ell}_{L,R}, \tilde{\ell} \rightarrow \ell \tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{*} \tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{*} \rightarrow \tilde{\ell} \nu (\ell \tilde{\nu}) \\ \tilde{\chi}_{1}^{*} \tilde{\chi}_{1}^{-}, \tilde{\chi}_{1}^{*} \rightarrow \tilde{\ell} \nu (\tilde{\nu}) \\ \tilde{\chi}_{1}^{*} \tilde{\chi}_{1}^{0} \rightarrow \tilde{\ell}_{L} \nu \tilde{\ell}_{L} \ell (\tilde{\nu}\nu), \ell \tilde{\nu} \tilde{\ell}_{L} \ell (\tilde{\nu}\nu) \\ \tilde{\chi}_{1}^{*} \tilde{\chi}_{1}^{0} \rightarrow W \tilde{\chi}_{1}^{0} Z \tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{*} \tilde{\chi}_{2}^{0} \rightarrow W \tilde{\chi}_{1}^{0} h \tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{2}^{*} \tilde{\chi}_{3}^{0}, \tilde{\chi}_{2,3}^{0} \rightarrow \tilde{\ell}_{R} \ell \end{array} $	2 e,μ 2 e,μ 2 τ 3 e,μ 2-3 e,μ 1 e,μ 4 e,μ	0 - 0 2 0 2 0	Yes Yes Yes Yes Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	<sup>δ</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup> <sup>k</sup>	90-325 GeV 140-465 GeV 100-350 GeV 700 GeV 420 GeV 285 GeV 620 GeV		$\begin{array}{l} m[\tilde{x}_{1}^{0}]{=}0 \ \text{GeV} \\ m[\tilde{x}_{1}^{0}]{=}0 \ \text{GeV}, m(\tilde{\ell}, \tilde{r}){=}0.5(m[\tilde{k}_{1}^{+}){+}m[\tilde{k}_{1}^{0}]) \\ m[\tilde{k}_{1}^{0}]{=}0 \ \text{GeV}, m(\tilde{r}, \tilde{r}){=}0.5(m[\tilde{k}_{1}^{+}){+}m[\tilde{k}_{1}^{0}]) \\ n[\tilde{k}_{2}^{0}], m[\tilde{k}_{1}^{0}]{=}0, m[\tilde{\ell}, \tilde{r}){=}0.5(m[\tilde{k}_{1}^{+}]{+}m[\tilde{k}_{1}^{0}]) \\ m[\tilde{k}_{1}^{0}]{=}m[\tilde{k}_{2}^{0}], m[\tilde{k}_{1}^{0}]{=}0, \text{ sleptons decoupled} \\ m[\tilde{k}_{1}^{0}]{=}m[\tilde{k}_{2}^{0}], m[\tilde{\ell}_{1}^{0}]{=}0, \text{ sleptons decoupled} \\ n[\tilde{k}_{2}^{0}], m[\tilde{k}_{1}^{0}]{=}0, m[\tilde{\ell}, \tilde{r}]{=}0.5(m[\tilde{k}_{2}^{0}]{+}m[\tilde{k}_{1}^{0}]) \end{array}$	1403.5294 1403.5294 1407.0350 1402.7029 1403.5294, 1402.7029 ATLAS-CONF-2013-093 1405.5086
Poug-lived	Direct $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}$ prod., long-lived $\tilde{\chi}_{1}^{\pm}$ Stable, stopped $\tilde{g}$ R-hadron GMSB, stable $\tilde{\tau}, \tilde{\chi}_{1}^{0} \rightarrow \tilde{\tau}(\tilde{e}, \tilde{\mu}) + \tau(e$ GMSB, $\tilde{\chi}_{1}^{0} \rightarrow \gamma \tilde{G}$ , long-lived $\tilde{\chi}_{1}^{0}$ $\tilde{q}\tilde{q}, \tilde{\chi}_{1}^{0} \rightarrow qg\mu$ (RPV)	Disapp. trk 0 (μ) 1-2 μ 2 γ 1 μ, displ. vtx	1 jet 1-5 jets - - -	Yes Yes Yes	20.3 27.9 15.9 4.7 20.3	X R R	270 GeV 832 GeV 475 GeV 230 GeV 1.0 TeV		$\begin{array}{l} m(\tilde{k}_{1}^{\pi})\text{-}m(\tilde{k}_{1}^{0}) {=} 160 \text{ MeV}, \ r(\tilde{k}_{1}^{\pi}) {=} 0.2 \text{ ns} \\ m(\tilde{k}_{1}^{0}) {=} 100 \text{ GeV}, \ 10 \ \mu \text{s} {<} r(\tilde{g}) {<} 1000 \text{ s} \\ 10 {<} \tan \! \beta {<} 50 \\ 0.4 {<} r(\tilde{k}_{1}^{0}) {<} 2 \text{ ns} \\ 1.5 {<} c \tau {<} 156 \text{ mm}, \ \text{BR}(\mu) {=} 1, \ m(\tilde{k}_{1}^{0}) {=} 108 \text{ GeV} \end{array}$	ATLAS-CONF-2013-069 1310.6584 ATLAS-CONF-2013-058 1304.6310 ATLAS-CONF-2013-092
RPV	$ \begin{array}{l} LFV pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e + \mu \\ LFV pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e(\mu) + \tau \\ Bilinear \ RPV \ CMSSM \\ \tilde{X}_1^+ \tilde{X}_1^-, \tilde{X}_1^+ \rightarrow W \tilde{X}_1^0, \tilde{X}_1^0 \rightarrow ee \tilde{v}_{\mu}, e\mu \tilde{v}_{e} \\ \tilde{X}_1^+ \tilde{X}_1^-, \tilde{X}_1^+ \rightarrow W \tilde{X}_1^0, \tilde{X}_1^0 \rightarrow \tau \tau \tilde{v}_{e}, e \tau \tilde{v}_{\tau} \\ \tilde{g} \rightarrow q q \\ \tilde{g} \rightarrow \tilde{t}_1 t, \tilde{t}_1 \rightarrow b s \end{array} $	$\begin{array}{c} 2 \ e, \mu \\ 1 \ e, \mu + \tau \\ 2 \ e, \mu \ (\text{SS}) \\ 4 \ e, \mu \\ 3 \ e, \mu + \tau \\ 0 \\ 2 \ e, \mu \ (\text{SS}) \end{array}$	- 0-3 b - - 6-7 jets 0-3 b	- Yes Yes - Yos	4.6 20.3 20.3 20.3 20.3 20.3 20.3	9, 9, 9, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1,	1.1 Te 1. 750 GeV 450 GeV 916 GeV 850 GeV		$\begin{split} \lambda_{S11}' = & 0.10, \lambda_{132} = & 0.05 \\ \lambda_{S11}' = & 0.10, \lambda_{1(2)3} = & 0.05 \\ m(\bar{q}) = & m(\bar{g}), c\tau_{LSP} < 1 \text{ mm} \\ m(\tilde{t}_{1}') > & 0.2 \times m(\tilde{t}_{1}''), \lambda_{121} \neq 0 \\ m(\tilde{t}_{1}'') > & 0.2 \times m(\tilde{t}_{1}''), \lambda_{133} \neq 0 \\ & BR(t) = BR(b) = BR(c) = 0\% \end{split}$	1212.1272 1212.1272 1404.2500 1405.5086 1405.5086 ATLAS-CONF-2013-091 1404.250
Other		0 2 ε,μ (SS) 0	4 jets 2 b mono-jet		4.6 14.3 10.5	sgluon sgluon M" scale	100-287 GeV 350-800 GeV 704 GeV	1	incl. limit from 1110.2693 m(χ)<80 GeV, limit of <687 GeV for D8	1210.4826 ATLAS-CONF-2013-051 ATLAS-CONF-2012-147
		$\sqrt{s} = 8 \text{ TeV}$		8 TeV data		10-1		1	Mass scale [TeV]	

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1ar theoretical signal cross section uncertainty

## SUSY Searches Summary

### ATLAS SUSY Searches\* - 95% CL Lower Limits

#### ATLAS Preliminary $\sqrt{s} = 7, 8 \text{ TeV}$

COMPANY ATTER PLICYTCHIRAPITY

	Status: ICHEP 2014						$\sqrt{s} = 7, 8 \text{ TeV}$
8	Model	$e, \mu, \tau, \gamma$	Jets	$E_{\rm T}^{\rm miss}$	∫£ dt[fb	Mass limit	Reference
	GGM (higgsino-bino NLSP) GGM (higgsino NLSP) Gravitino LSP	$\begin{array}{c} 0 \\ 1 \ e, \mu \\ 0 \\ 0 \\ 1 \ e, \mu \\ 2 \ e, \mu \\ 2 \ e, \mu \\ 1 \ 2 \ r + 0 \ - 1 \ \ell \\ 2 \ \gamma \\ 1 \ e, \mu + \gamma \\ \gamma \\ 2 \ e, \mu \ (Z) \\ 0 \end{array}$	2-6 jets 3-6 jets 7-10 jets 2-6 jets 2-6 jets 3-6 jets 0-3 jets 0-2 jets 1 b 0-3 jets mono-jet	Yes Yes Yes Yes Yes Yes Yes Yes Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	φ.ž     1.7 TeV     m(φ)=m(φ)       ĝ     1.2 TeV     any m(φ)       ĝ     1.2 TeV     any m(φ)       ĝ     1.1 TeV     any m(φ)       ĝ     850 GeV     m(φ)=m(φ)       ĝ     1.1 TeV     any m(φ)       ĝ     850 GeV     m(φ)=m(φ)       ĝ     1.1 TeV     any m(φ)       ĝ     850 GeV     m(φ)=m(φ)       ĝ     1.33 TeV     m(φ)=m(φ)       ĝ     1.12 TeV     m(φ)=0.5(m(φ)       ĝ     1.24 TeV     taφ<       ĝ     1.24 TeV     taφ<       ĝ     1.28 TeV     m(φ)=>00 GeV       ĝ     900 GeV     m(φ)=>00 GeV       ĝ     619 GeV     m(φ)=>10-4 eV	1405.7875 ATLAS-CONF-2013-062 1308.1841 1405.7875 1405.7875 ATLAS-CONF-2013-062 ATLAS-CONF-2013-069 1208.4688 1407.0603 ATLAS-CONF-2014-001 ATLAS-CONF-2012-144 1211.1167 ATLAS-CONF-2012-152 ATLAS-CONF-2012-152 ATLAS-CONF-2012-147
3 <sup>rd</sup> den.	$\tilde{z} \rightarrow b \tilde{b} \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{s} \rightarrow t \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{s} \rightarrow t \tilde{\tilde{\chi}}_{1}^{0}$ $\tilde{s} \rightarrow b \tilde{t} \tilde{\tilde{\chi}}_{1}^{0}$	0 0 0-1 e.μ 0-1 e.μ	3 b 7-10 jets 3 b 3 b	Yes Yes Yes Yes	20.1 20.3 20.1 20.1	ž         1.25 TeV         m(x̂_1)<400 GeV	1407.0600 1308.1841 1407.0600 1407.0600
3 <sup>rd</sup> den. souarks	$\begin{array}{c} \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow b\tilde{k}_{1}^{0} \\ \tilde{b}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow d\tilde{k}_{1}^{\pm} \\ \tilde{i}_{1}\tilde{b}_{1}, \tilde{b}_{1} \rightarrow d\tilde{k}_{1}^{\pm} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{light}), \tilde{i}_{1} \rightarrow b\tilde{k}_{1}^{\pm} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{light}), \tilde{i}_{1} \rightarrow Wb\tilde{k}_{1}^{0} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{medium}), \tilde{i}_{1} \rightarrow b\tilde{k}_{1}^{\pm} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{medium}), \tilde{i}_{1} \rightarrow b\tilde{k}_{1}^{\pm} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{heavy}), \tilde{i}_{1} \rightarrow t\tilde{k}_{1}^{0} \\ \tilde{i}_{1}\tilde{i}_{1}(\text{heavy}), \tilde{i}_{1} \rightarrow t\tilde{k}_{1}^{0} \\ \tilde{i}_{1}\tilde{i}_{1}(\tilde{i}_{1}, \tilde{i}_{1}) \rightarrow \tilde{k}_{1}^{0} \end{array}$	0 2 e, µ (SS) 1-2 e, µ 2 e, µ 0 1 e, µ 0 m	2 b 0-3 b 1-2 b 0-2 jets 2 jets 2 b 1 b 2 b nono-jet/c-ta	Yes Yes Yes Yes Yes Yes Yes ag Yes	20.1 20.3 4.7 20.3 20.3 20.1 20 20.1 20.3	$ \begin{array}{c c c c c c c c c c c c c c c c c c c $	1308.2631 1404.2500 1208.4305, 1209.2102 1403.4853 1403.4853 1308.2631 1407.0583
	$\tilde{t}_1 \tilde{t}_1$ (natural GMSB) $\tilde{t}_2 \tilde{t}_2, \tilde{t}_2 \rightarrow \tilde{t}_1 + Z$ $\tilde{t}_{1,R} \tilde{t}_{1,R}, \tilde{t} \rightarrow \ell \tilde{\chi}_1^0$	2 e, μ (Z) 3 e, μ (Z) 2 e, μ	1 b 1 b 0	Yes Yes Yes	20.3 20.3 20.3	Image: Time in the second se	9
EW	$\begin{array}{c} \tilde{\chi}_{1}^{*}\tilde{\chi}_{1}^{-},\tilde{\chi}_{1}^{*}\rightarrow\tilde{\ell}\nu(\tilde{\ell}\tilde{\nu}) \\ \tilde{\chi}_{1}^{*}\tilde{\chi}_{1}^{-},\tilde{\chi}_{1}^{*}\rightarrow\tilde{\ell}\nu(\tilde{\tau}\tilde{\nu}) \\ \tilde{\chi}_{1}^{*}\tilde{\chi}_{2}^{0}\rightarrow\tilde{\ell}_{L}\nu\tilde{\ell}_{L}\ell(\tilde{\nu}\nu), \ell\tilde{\nu}\tilde{\ell}_{L}\ell(\tilde{\nu}\nu) \\ \tilde{\chi}_{1}^{*}\tilde{\chi}_{2}^{0}\rightarrow W\tilde{\chi}_{1}^{0}Z\tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{1}^{*}\tilde{\chi}_{2}^{0}\rightarrow W\tilde{\chi}_{1}^{0}h\tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{2}^{*}\tilde{\chi}_{2}^{0}\rightarrow W\tilde{\chi}_{1}^{0}h\tilde{\chi}_{1}^{0} \\ \tilde{\chi}_{2}^{*}\tilde{\chi}_{2}^{0}, \tilde{\chi}_{2,3}^{0}\rightarrow\tilde{\ell}_{R}\ell \end{array}$	2 e.μ 2 τ 3 e.μ 2-3 e.μ 1 e.μ 4 e.μ	0 0 2 <i>b</i> 0	Yes Yes Yes Yes Yes	20.3 20.3 20.3 20.3 20.3 20.3	140-465 GeV       100-350 GeV <t< th=""><th></th></t<>	
Long-lived	Direct $\tilde{\chi}_{1}^{+}\tilde{\chi}_{1}^{-}$ prod., long-lived $\tilde{\chi}_{1}^{\pm}$ Stable, stopped $\tilde{g}$ R-hadron GMSB, stable $\tilde{r}, \tilde{\chi}_{1}^{0} \rightarrow \tilde{r}(\tilde{e}, \tilde{\mu}) + \tau(e, \tilde{g})$ GMSB, $\tilde{\chi}_{1}^{0} \rightarrow \gamma \tilde{G}$ , long-lived $\tilde{\chi}_{1}^{0}$ $\tilde{q}\tilde{q}, \tilde{\chi}_{1}^{0} \rightarrow qq\mu$ (RPV)	0	1 jet 1-5 jets	Yes Yes Yes	20.3 27.9 15.9 4.7 20.3	270 GeV         832 GeV           X         475 GeV           X         230 GeV           X         1.0 Te	
100	$ \begin{array}{l} LFV pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow e + \mu \\ LFV pp \rightarrow \tilde{v}_{\tau} + X, \tilde{v}_{\tau} \rightarrow c(\mu) + \tau \\ Bilinear RPV CMSSM \\ \tilde{X}_{1}^{+} \tilde{X}_{1}^{-}, \tilde{X}_{1}^{+} \rightarrow W \tilde{X}_{1}^{0} \tilde{X}_{1}^{0} \rightarrow ce \tilde{v}_{\mu}, e\mu \tilde{v}_{e} \\ \tilde{X}_{1}^{+} \tilde{X}_{1}^{-}, \tilde{X}_{1}^{+} \rightarrow W \tilde{X}_{1}^{0} \tilde{X}_{1}^{0} \rightarrow \tau \tau \tilde{v}_{e}, e\tau \tilde{v}_{\tau} \\ \tilde{X} \rightarrow q q \\ \tilde{g} \rightarrow \tilde{l}_{1} l, \tilde{l}_{1} \rightarrow b s \end{array} $	$\begin{array}{c} 2  e, \mu \\ 1  e, \mu + \tau \\ 2  e, \mu  (\text{SS}) \\ 4  e, \mu \\ 3  e, \mu + \tau \\ 0 \\ 2  e, \mu  (\text{SS}) \end{array}$	0-3 b 	- Yes Yes - Yes	4.6 4.6 20.3 20.3 20.3 20.3 20.3	Final         1.1           Q. R.         750 GeV           R.         750 GeV           R.         450 GeV           Q. R.         916 GeV           R.         850 GeV	
	$\sqrt{s} = 7 \text{ TeV}$	$\frac{0}{2 e, \mu} (SS)$ $\frac{\sqrt{s} = 8 \text{ TeV}}{\text{vartial data}}$	4 jets 2 b mono-jet $\sqrt{s} = 4$ full of	- Yes Yes 8 TeV data	4.6 14.3 10.5	soluon 100-287 GeV soluon 350-800 GeV M <sup>*</sup> scale 704 GeV 10 <sup>-1</sup>	INOS
	*Only a selection of the available mass limits on new states or phenomena is shown. All limits guoted are observed minus 1/r						

\*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1 $\sigma$ 

## Exotics





Max S. @maxx2k4 · Dec 3 Best moment at #Kruger2014? Probably...

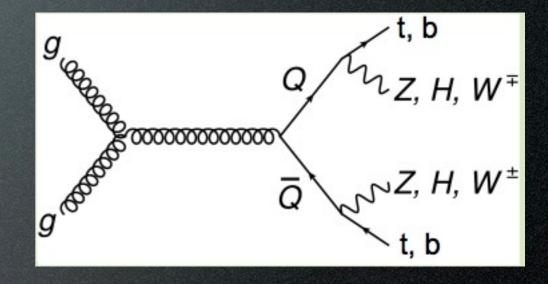
43

\* 1 \*\*\*

## Again, many models...

## Heavy bosons

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



VLQ pair production

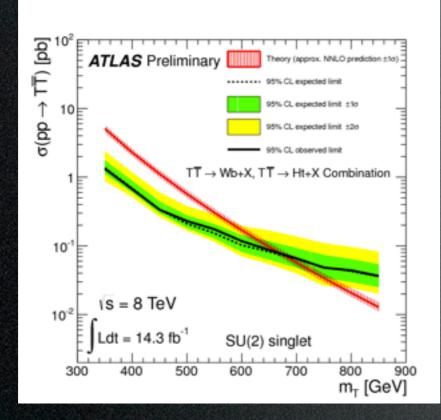
VLQs are excluded up to ~800 GeV Z'.W' excluded > 2-3 TeV Diboson Resonances excluded &lmost to 2 TeV

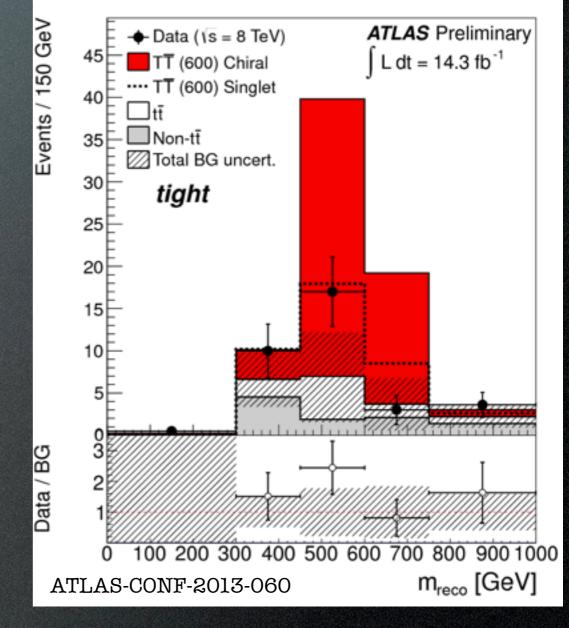
## Top-like Quark Pair Search

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

	TLAS Exotics S	earch	es* -	95%	6 CL	Exclusion	ATL	AS Preliminary
St	atus: ICHEP 2014						$\int \mathcal{L} dt = (1.0 - 20.3) \text{ fb}^{-1}$	√s = 7, 8 TeV
	Model	$\ell, \gamma$	Jets	E <sup>miss</sup> T	∫£ dt[fb			Reference
Extra dimensions	ADD $G_{KK} + g/q$ ADD non-resonant $\ell\ell$ ADD QBH $\rightarrow \ell q$ ADD QBH $\overline{\rho}_{T}$ ADD QBH high $\sum p_T$ RS1 $G_{KK} \rightarrow \ell\ell$ RS1 $G_{KK} \rightarrow WW \rightarrow \ell \nu \ell \nu$ Bulk RS $G_{KK} \rightarrow ZZ \rightarrow \ell \ell qq$ Bulk RS $g_{KK} \rightarrow HH \rightarrow b\bar{b}b\bar{b}$ Bulk RS $g_{KK} \rightarrow t\bar{t}$ $S^1/Z_2$ ED UED	- 2e, $\mu$ 1 e, $\mu$ - 2 $\mu$ (SS) ≥ 1 e, $\mu$ 2 e, $\mu$	1-2 j - 1 j 2 j - 2 j/1 J 4 b ≥ 1 b, ≥ 1 J -	Yes - - - - Yes - - - - - - - - - - - - - - - - - - -	4.7 20.3 20.3 20.3 20.3 20.3 20.3 20.3 20.3	Mo         4.37 TeV           Ms         5.2 TeV           Ma         5.2 TeV           Ma         5.2 TeV           Ma         5.82 TeV           Ma         5.82 TeV           Ma         5.82 TeV           Ma         5.82 TeV           Ma         5.7 TeV           Ma         5.7 TeV           Ma         6.2 TeV           Gxx mass         2.68 TeV           Gxx mass         730 GeV           Gxx mass         590-710 GeV           Box mass         590-710 GeV           Box mass         590-710 GeV           Compact, scale R <sup>-1</sup> 1.41 TeV	$\begin{array}{l} n=2 \\ n=3 \ \text{HLZ} \\ n=6 \\ n=6 \\ n=6, \ M_D=1.5 \ \text{TeV, non-rot BH} \\ n=6, \ M_D=1.5 \ \text{TeV, non-rot BH} \\ k/\overline{M}_{Pl}=0.1 \\ k/\overline{M}_{Pl}=0.1 \\ k/\overline{M}_{Pl}=1.0 \\ BR=0.925 \end{array}$	1210.4491 ATLAS-CONF-2014-030 1311.2006 to be submitted to PRD 1308.4075 1405.4254 1405.4123 1208.2880 ATLAS-CONF-2014-039 ATLAS-CONF-2014-035 ATLAS-CONF-2014-055 1209.2535 ATLAS-CONF-2012-072
Gauge bosons	$\begin{array}{l} \text{SSM } Z' \to \ell\ell \\ \text{SSM } Z' \to \tau\tau \\ \text{SSM } W' \to \ell\nu \\ \text{EGM } W' \to WZ \to \ell\tau \ell'\ell' \\ \text{EGM } W' \to WZ \to qq\ell\ell \\ \text{LRSM } W'_R \to t\bar{b} \\ \text{LRSM } W'_R \to t\bar{b} \end{array}$	2 e,μ 2 τ 1 e,μ 3 e,μ 2 e,μ 1 e,μ 0 e,μ	- - 2j/1J 2b,0-1j ≥1b,1J		20.3 19.5 20.3 20.3 20.3 14.3 20.3	Z' mass         2.9 TeV           Z' mass         1.9 TeV           W' mass         3.28 TeV           W' mass         1.52 TeV           W' mass         1.59 TeV           W' mass         1.84 TeV           W' mass         1.77 TeV		1405.4123 ATLAS-CONF-2013-066 ATLAS-CONF-2014-017 1406.4456 ATLAS-CONF-2014-039 ATLAS-CONF-2013-060 to be submitted to EPJC
ũ	Cl qqqq Cl qq{l Cl uutt	– 2 e,μ 2 e,μ (SS)	2j 	– – j Yes	4.8 20.3 14.3	Λ 7.6 TeV Λ Λ 3.3 TeV	$\eta = +1$ <b>21.6 TeV</b> $\eta_{LL} = -1$  C  = 1	1210.1718 ATLAS-CONF-2014-030 ATLAS-CONF-2013-051
MQ	EFT D5 operator (Dirac) EFT D9 operator (Dirac)	0 e,μ 0 e,μ	1-2j 1 J, ≤ 1 j	Yes Yes	10.5 20.3	M, 731 GeV M, 2.4 TeV	at 90% CL for $m(\chi) < 80$ GeV at 90% CL for $m(\chi) < 100$ GeV	ATLAS-CONF-2012-147 1309.4017
10	Scalar LQ 1 <sup>st</sup> gen Scalar LQ 2 <sup>nd</sup> gen Scalar LQ 3 <sup>rd</sup> gen	2 e 2 μ 1 e.μ, 1 τ	≥2j ≥2j 1b,1j	-	1.0 1.0 4.7	LQ mass         660 GeV           LQ mass         685 GeV           LQ mass         534 GeV	$\beta = 1$ $\beta = 1$ $\beta = 1$	1112.4828 1203.3172 1303.0526
Heavy quarks	Vector-like quark $TT \rightarrow Ht + X$ Vector-like quark $TT \rightarrow Wb + X$ Vector-like quark $TT \rightarrow Zt + X$ Vector-like quark $BB \rightarrow Zb + X$ Vector-like quark $BB \rightarrow Wt + X$	2/≥3 e,µ 2/≥3 e,µ	≥2/≥1 b	j Yes -	14.3 14.3 20.3 20.3 14.3	T mass 790 GeV T mass 670 GeV T mass 735 GeV B mass 755 GeV B mass 720 GeV	T in (T,B) doublet isospin singlet T in (T,B) doublet B in (B,Y) doublet B in (T,B) doublet	ATLAS-CONF-2013-018 ATLAS-CONF-2013-060 ATLAS-CONF-2014-036 ATLAS-CONF-2014-036 ATLAS-CONF-2014-036 ATLAS-CONF-2013-061
Excited fermions	Excited quark $q^* \rightarrow q\gamma$ Excited quark $q^* \rightarrow qg$ Excited quark $b^* \rightarrow Wt$ Excited lepton $\ell^* \rightarrow \ell\gamma$	1γ - 1 or 2 e, μ 2 e, μ, 1 γ	1j 2j 1b,2jor1 -	- j Yes -	20.3 20.3 4.7 13.0	q' mass     3.5 TeV       q' mass     4.09 TeV       b' mass     870 GeV       (' mass     2.2 TeV	only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ only $u^*$ and $d^*$ , $\Lambda = m(q^*)$ left-handed coupling $\Lambda = 2.2 \text{ TeV}$	1309.3230 to be submitted to PRD 1301.1583 1308.1364
Other	LSTC $a_T \rightarrow W\gamma$ LRSM Majorana $\nu$ Type III Seesaw Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$ Multi-charged particles Magnetic monopoles	$1 e, \mu, 1 \gamma$ 2 e, \mu 2 e, \mu 2 e, \mu (SS) - - - $\sqrt{s} =$	2 j -	Yes    	20.3 2.1 5.8 4.7 4.4 2.0 8 TeV	ат mass         960 GeV           N <sup>4</sup> mass         1.5 TeV           N <sup>4</sup> mass         245 GeV           H <sup>4+</sup> mass         409 GeV           multi-charged particle mass         490 GeV           monopole mass         862 GeV           10 <sup>-1</sup> 1	$m(W_{ir}) = 2 \text{ TeV, no mixing}$ $ V_e =0.055,  V_p =0.063,  V_i =0$ DY production, BR( $H^{\pi\pi} \rightarrow \ell\ell$ )=1 DY production,  q  = 4e DY production,  g  = 1g_D 10 Mass scale [TeV]	to be submitted to PLB 1203.5420 ATLAS-CONF-2013-019 1210.5070 1301.5272 1207.6411

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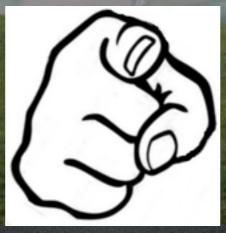
"Only a selection of the available mass limits on new states or phenomena is shown

# 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!

# Outlook

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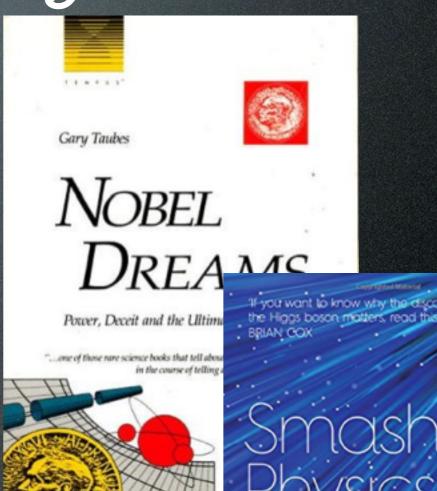


# Supporting Material



# 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?



Inside the world's / biggest experiment

terwor

## **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!

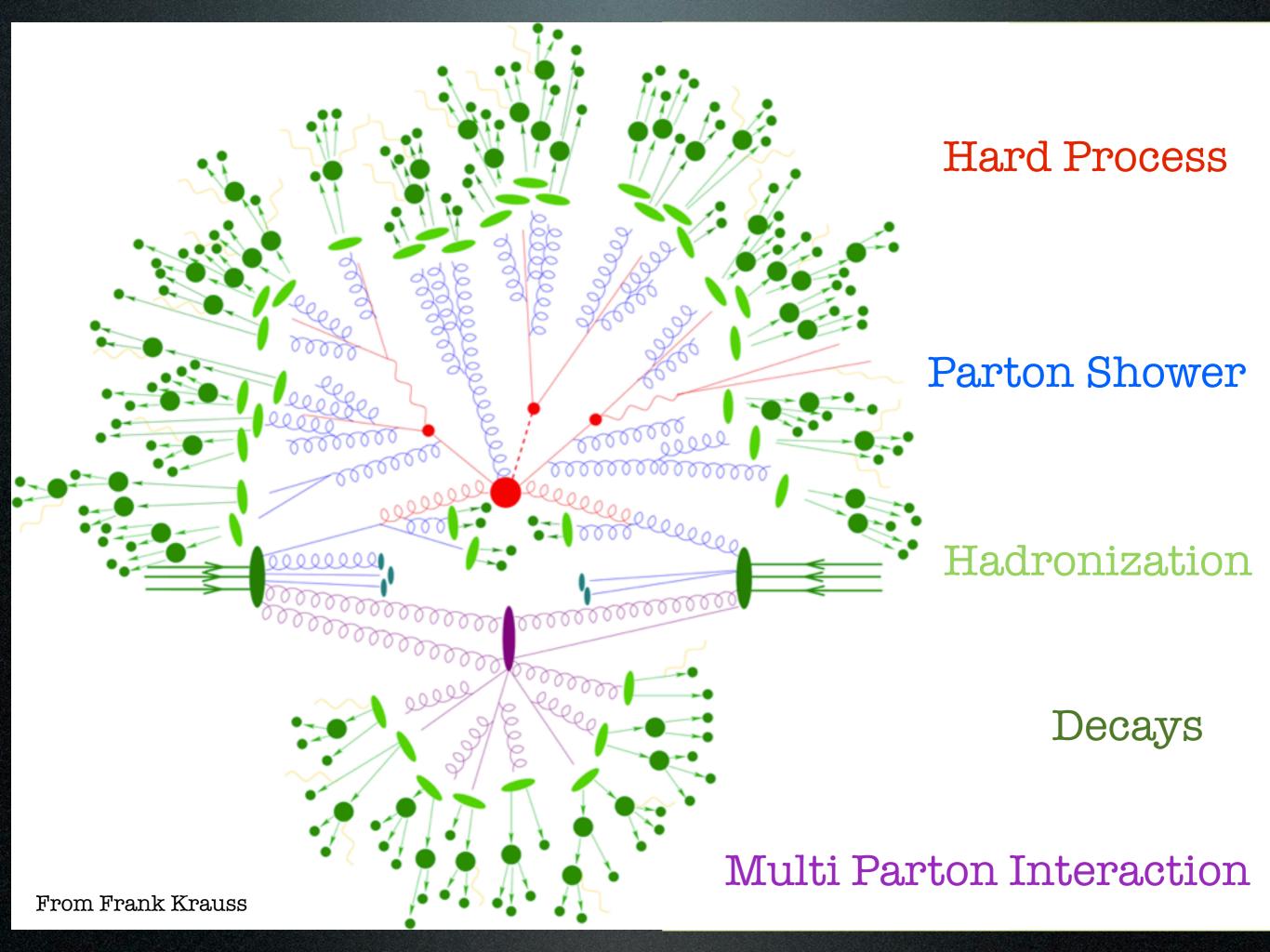
TODAY'S LESSON : WO OR "WITTEN'S DOG

## 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 ...."



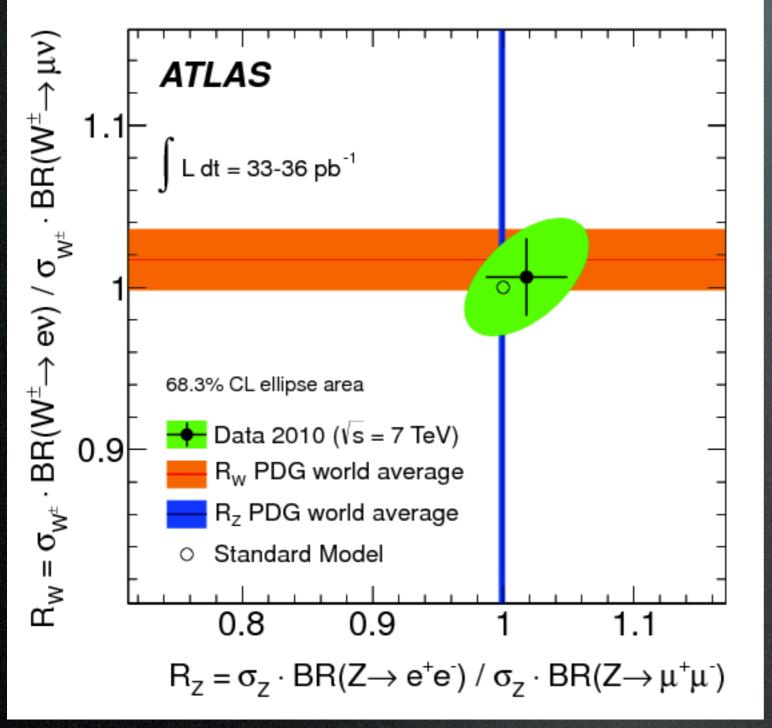
– Richard Feynman and Rick Field, 1978



## 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.

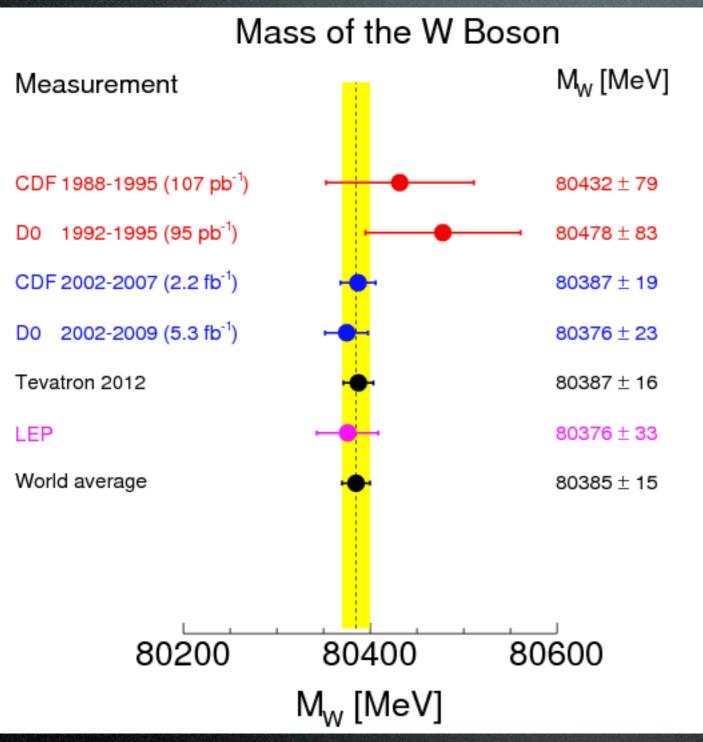
## Lepton Universality



Coupling of leptons to W and Z bosons should be independent

Cross sections measured in electron and muon channel compared

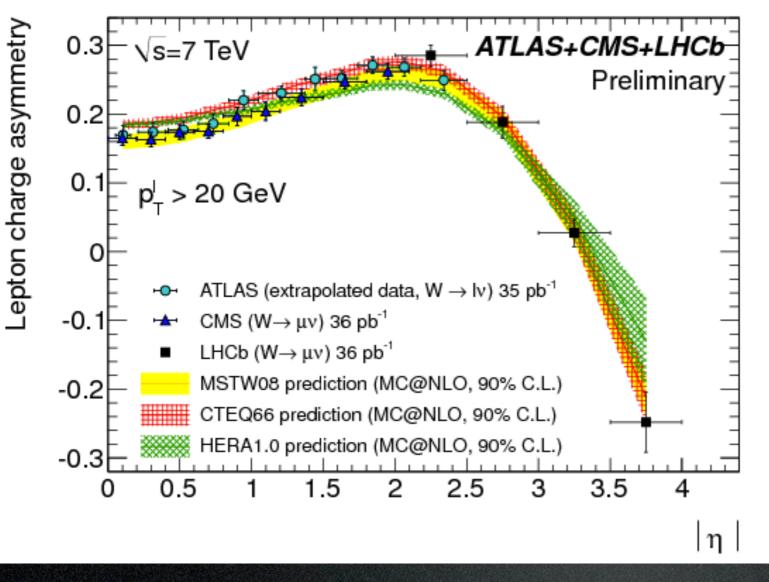
## WMass



No result from LHC yet

Necessary for precision measurement for other EW processes

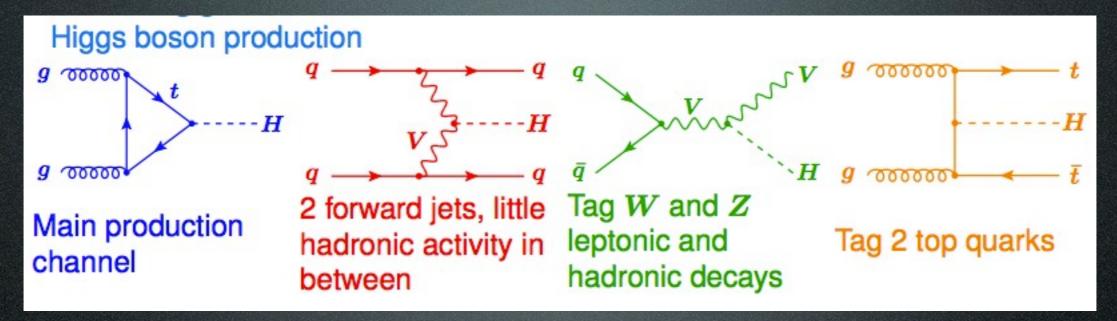
## W Lepton Charge Asymmetry

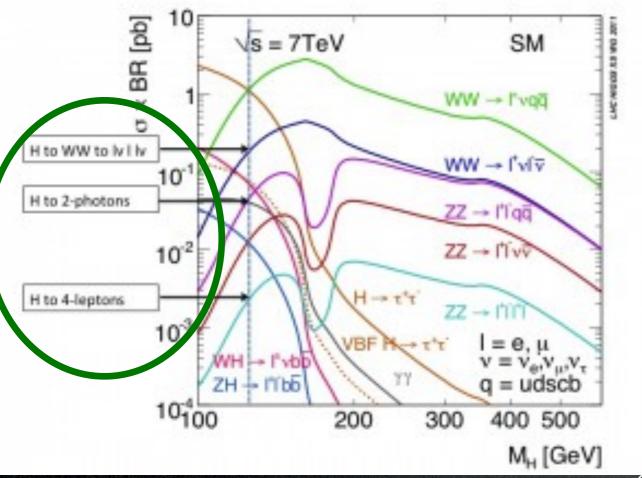


$$A_W = \frac{\sigma_{W^+} - \sigma_{W^-}}{\sigma_{W^+} + \sigma_{W^-}}$$

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')<sub>L</sub> with the corresponding right-handed singlets t'<sub>R</sub>, b'<sub>R</sub>. 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 I	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 <sup>-1</sup>	and Directly test the coupling of the Higgs boson to fermions
HL-LHC: 3000 fb <sup>-1</sup>	and Measure Higgs self coupling Measure vector boson scattering Observe rare Higgs decays