Beyond the Standard Model
ATLAS Odyssey

Hadron Structure ’11
Tatranská Štrba, Slovakia

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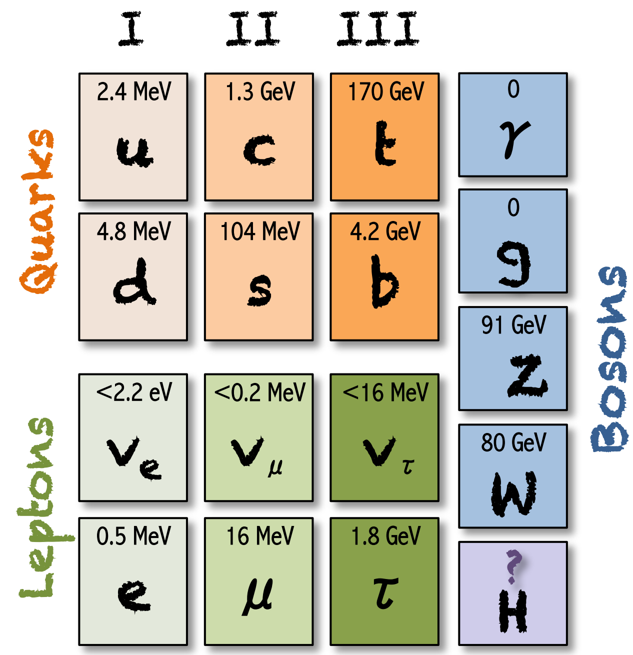
for the ATLAS Collaboration

The pending questions of the SM

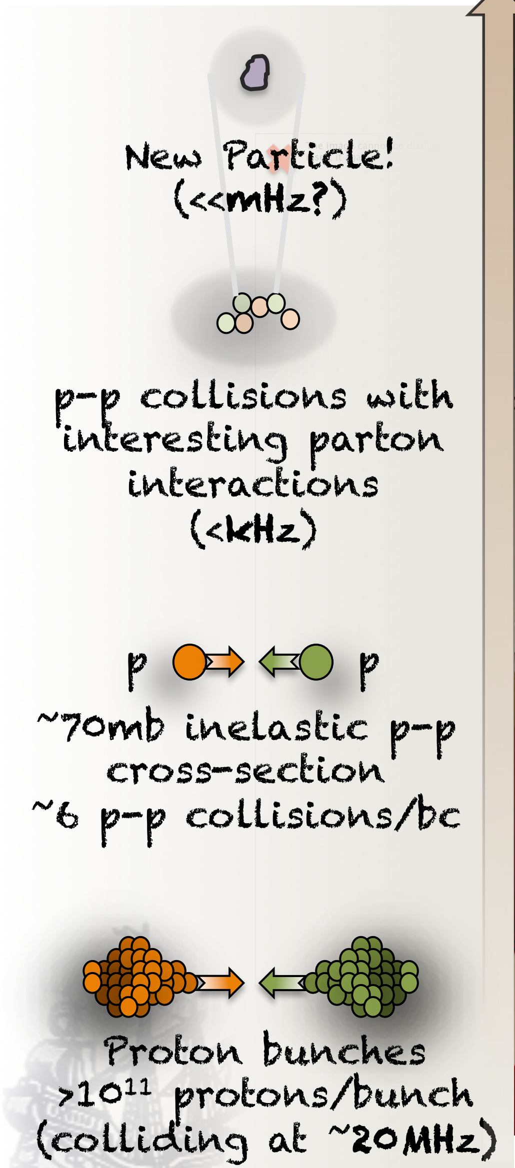
- The Standard Model (SM) is a beautiful theory that describes nature with great precision.
  - All particles and forces it predicts have been experimentally discovered, except one: the Higgs Boson.
- What the SM doesn't tell us, about what it predicts
  - Why 3 generations,
  - What determines masses and mixings,
  - What is the origin of matter-antimatter asymmetry,
  - Is there a unified description of all forces,
  - …and many other things.
- And also doesn't tell us anything at all about
  - What is Dark Matter, what is Dark Energy,
  - What exactly was the Big Bang,
  - Why is the universe so big,
  - …and many other things.



- Extensions to the SM foresee new phenomena that try to tackle the hierarchy problem.
- Most favorable extensions are accessible at the LHC. Discovering them is one of the reason the LHC was built.

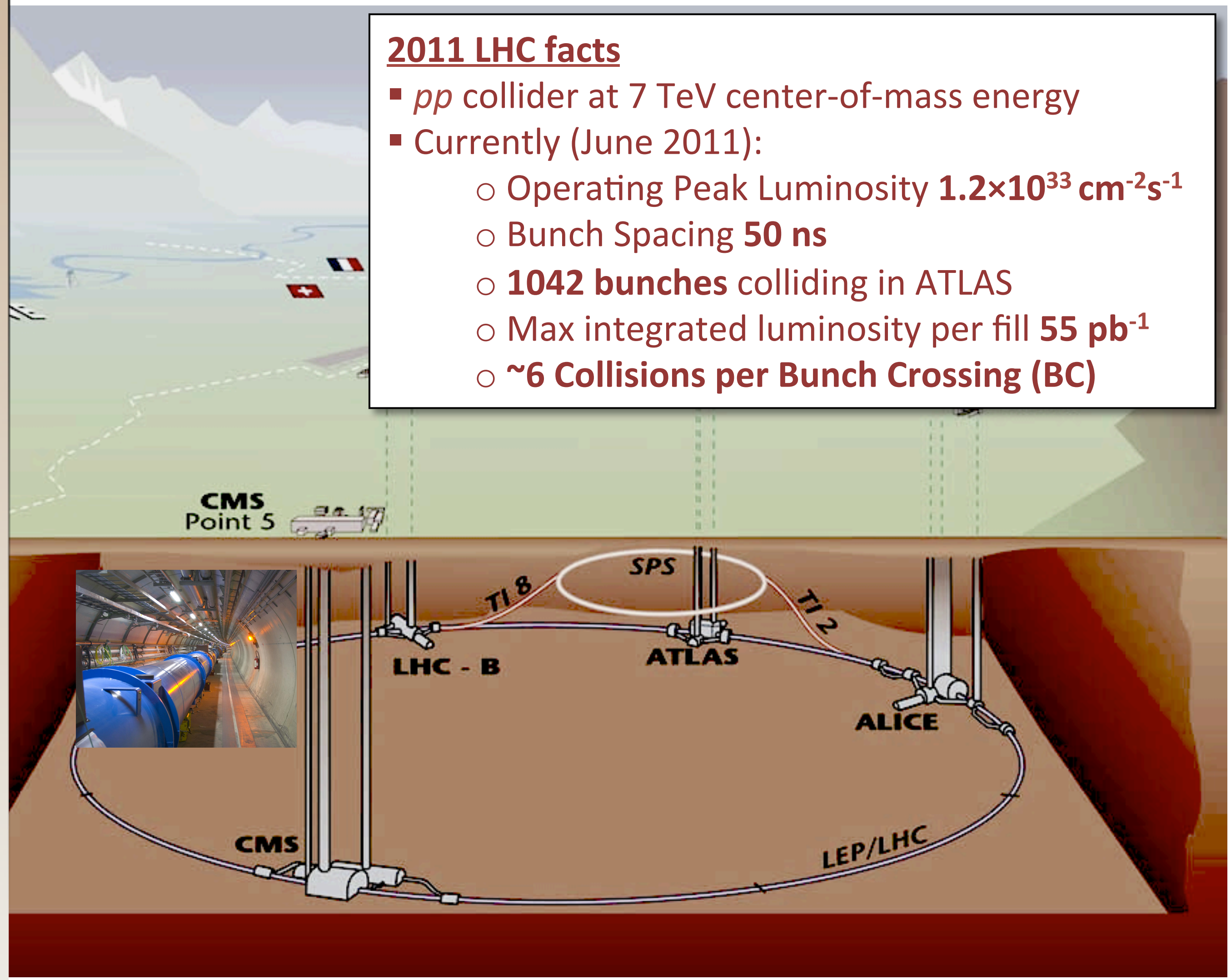
The Large Hadron Collider

in 2011



2011 LHC facts

- *pp* collider at 7 TeV center-of-mass energy
- Currently (June 2011):
  - Operating Peak Luminosity **1.2×10^{33} cm^{-2}s^{-1}**
  - Bunch Spacing **50 ns**
  - **1042 bunches** colliding in ATLAS
  - Max integrated luminosity per fill **55 pb^{-1}**
  - **~6 Collisions per Bunch Crossing (BC)**



The Large Hadron Collider

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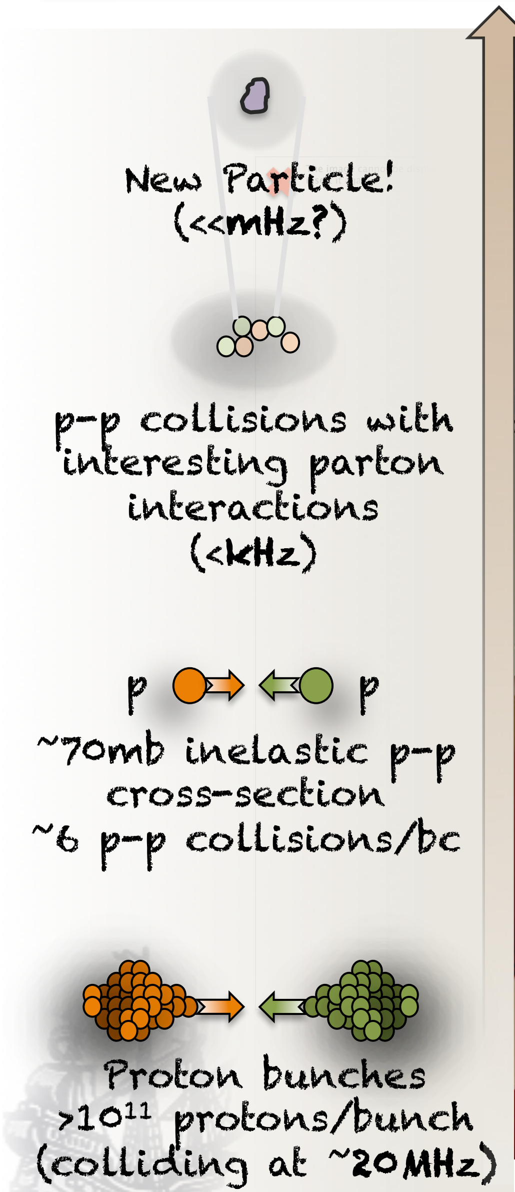

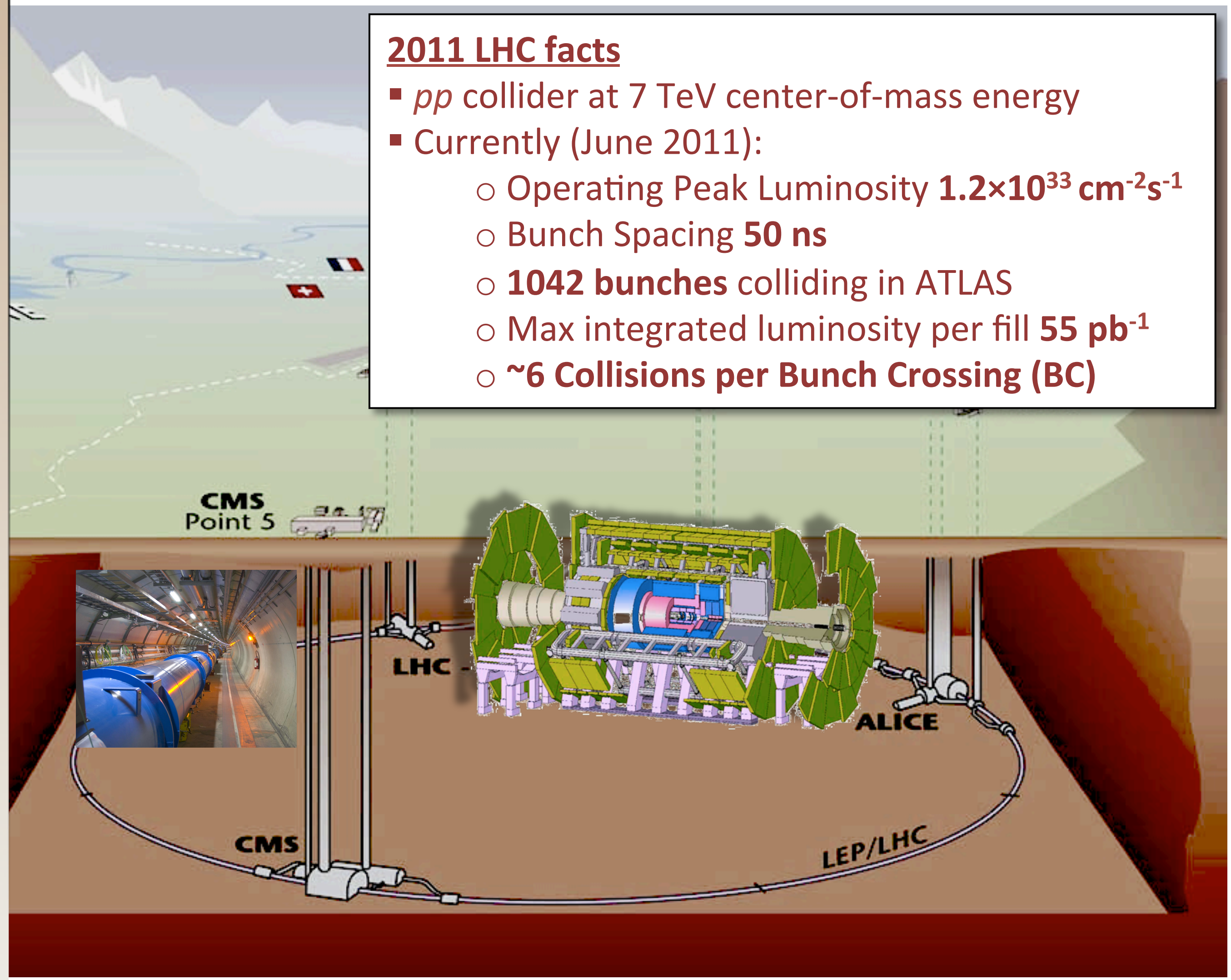

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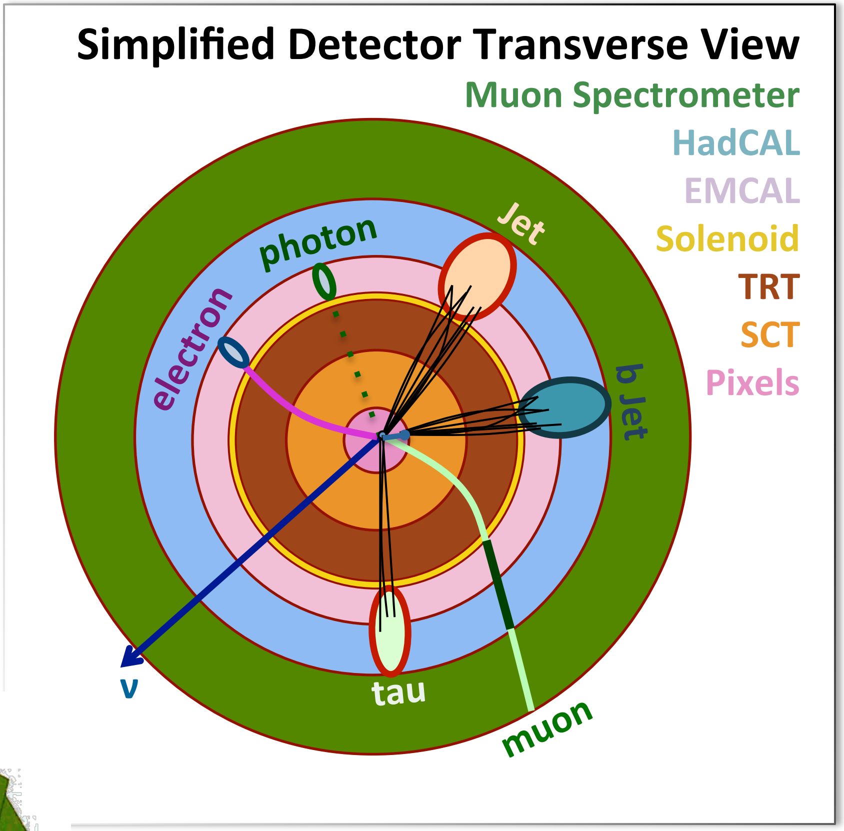
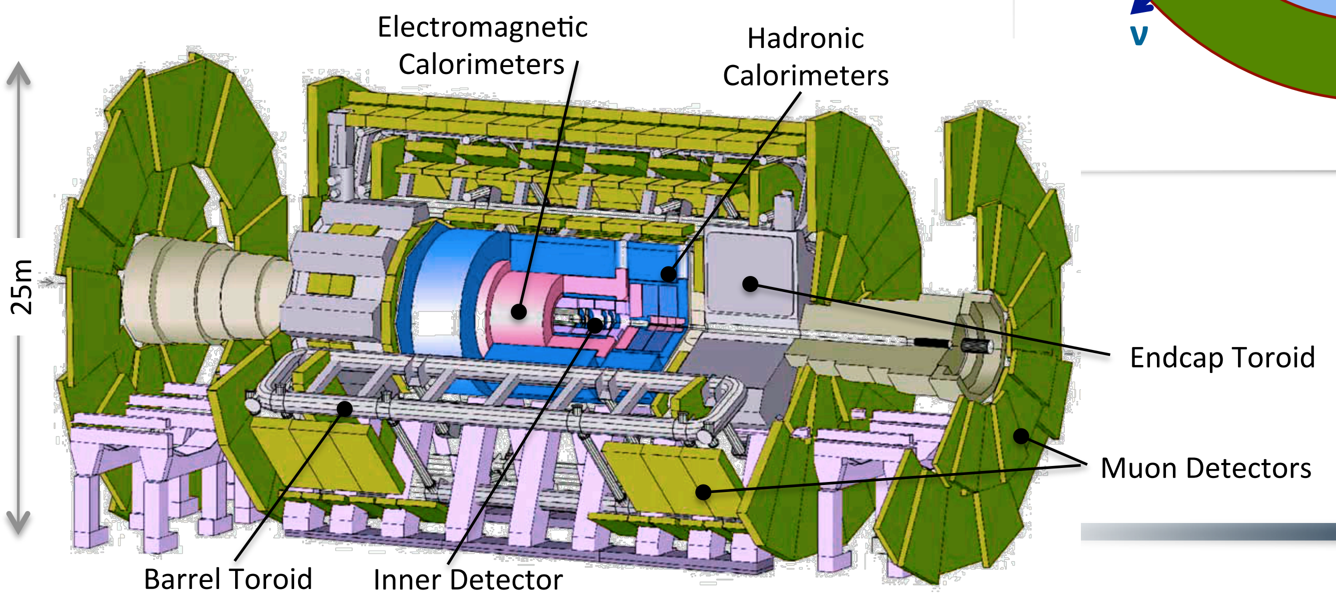
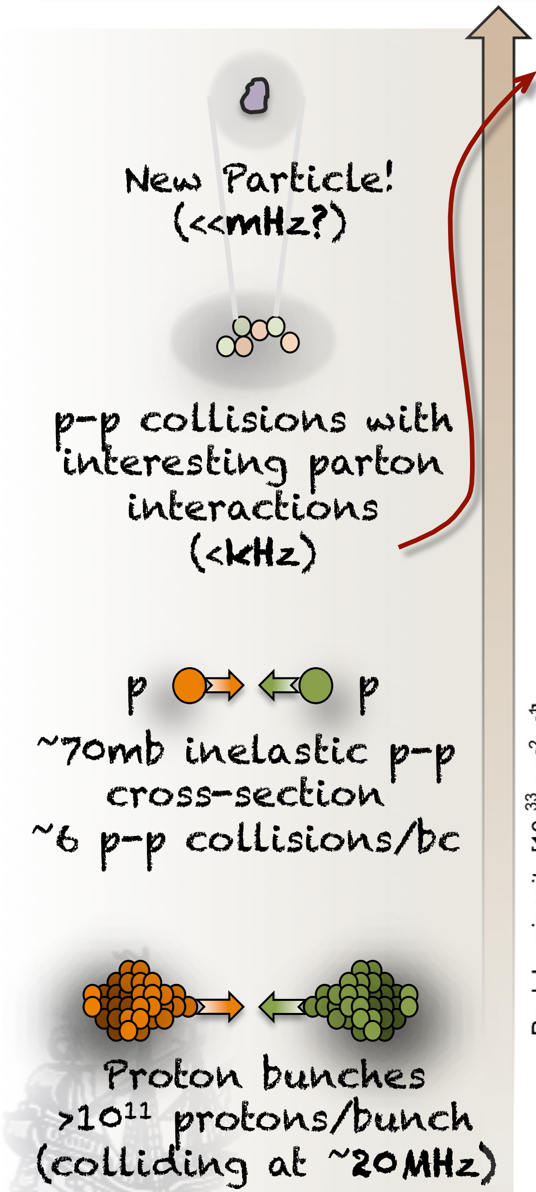
The ATLAS Detector at the LHC

- Multi-purpose multi-layered collider detector
- Design specifications
  - Fast response, fast readout
  - High granularity
  - Radiation resistance
- Performance specifications
  - Large acceptance and hermeticity
  - Excellent particle ID,
    Vertex reconstruction,
    Jet and E_t^{miss} resolution
    ➥ Crucial for precise measurements and BSM searches.



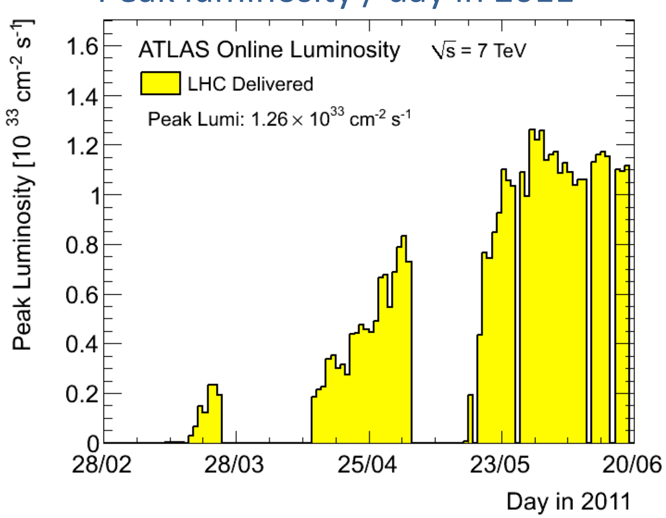


ATLAS taking data

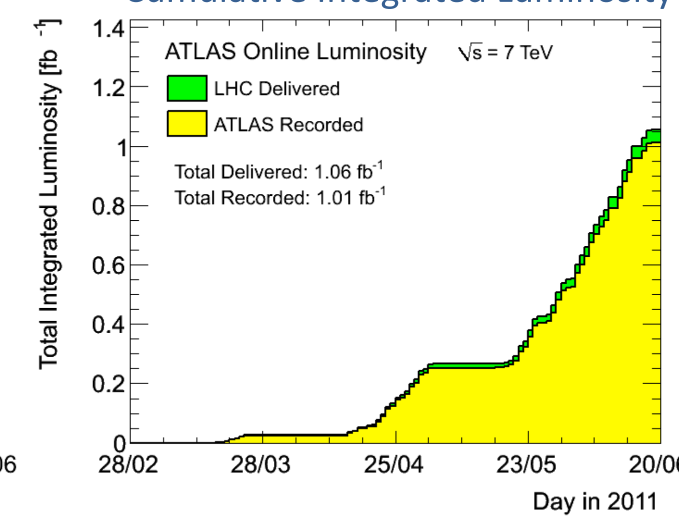


- About 300-400Hz of interesting collision events are recorded by the ATLAS Trigger System.
  - A big challenge: the trigger has to select as many interesting events as possible for the diverse ATLAS physics programs (SM precision measurements, searches for Higgs, SUSY and exotics), as well as any **unpredicted new physics**.
  - It also has to provide enough data for calibrations, efficiency measurements and background estimations.
- In 2010, ATLAS collected ~45pb^{-1} of integrated luminosity.
  - Peak LHC luminosity ~2e32 cm^{-2}s^{-1}.
- In 2011, the currently available dataset is ~1fb^{-1}!

Peak luminosity / day in 2011

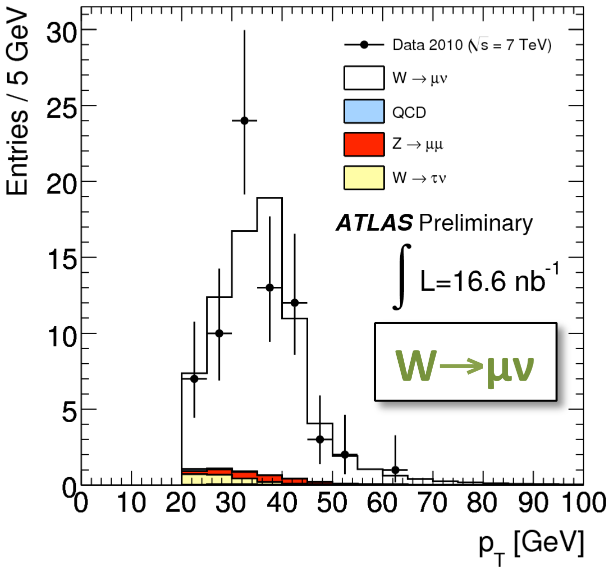


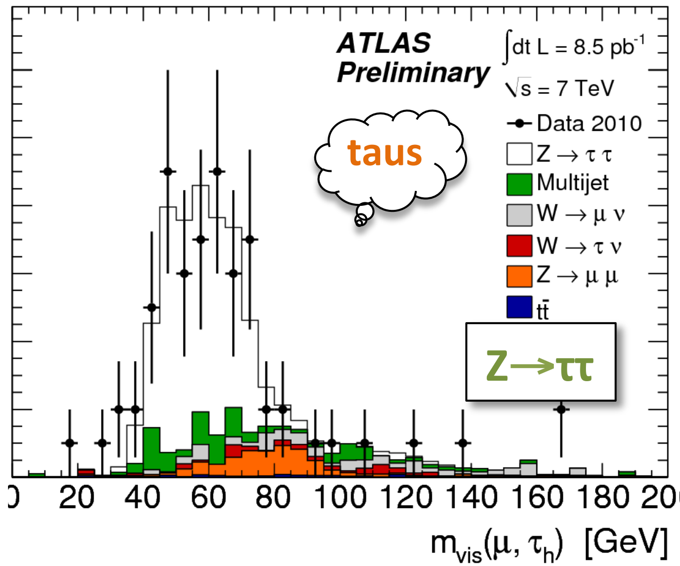
Cumulative Integrated Luminosity

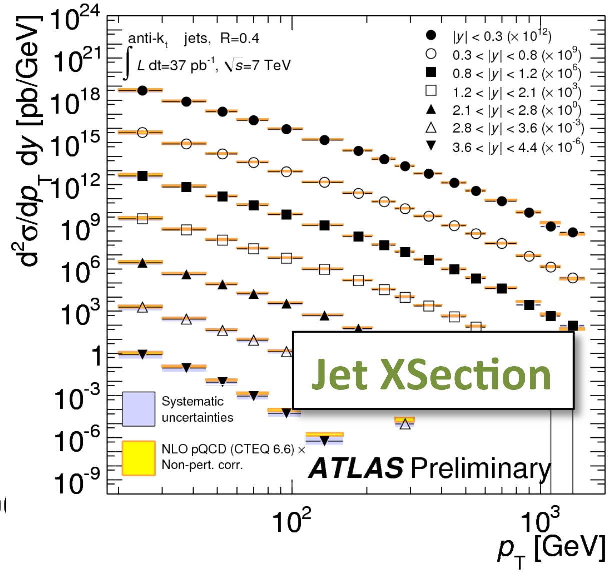


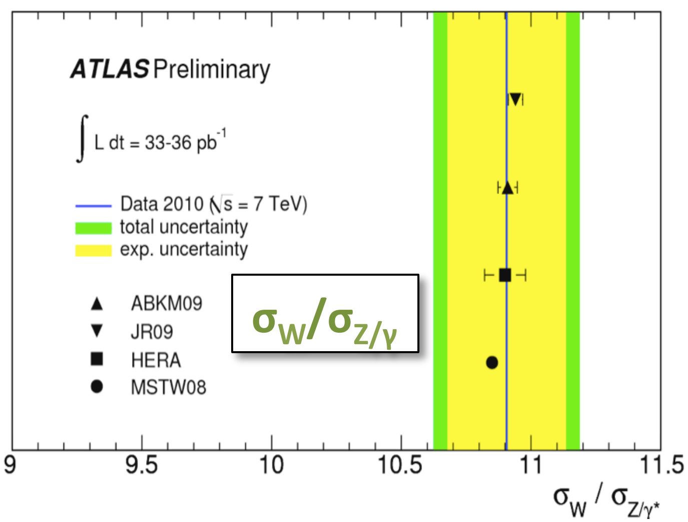
ATLAS measurements

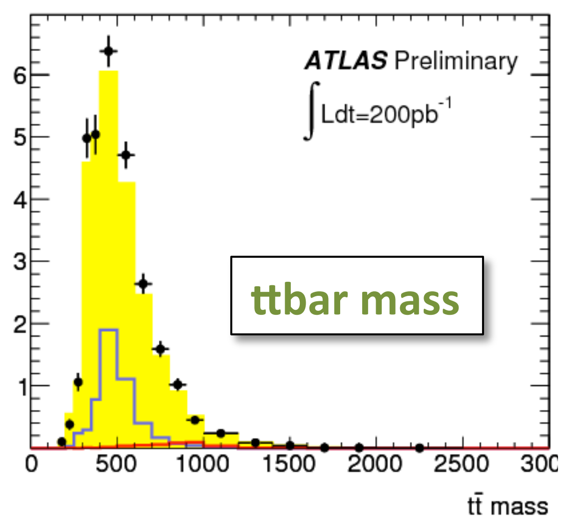
From simple signatures (and objects) to more complicated ones

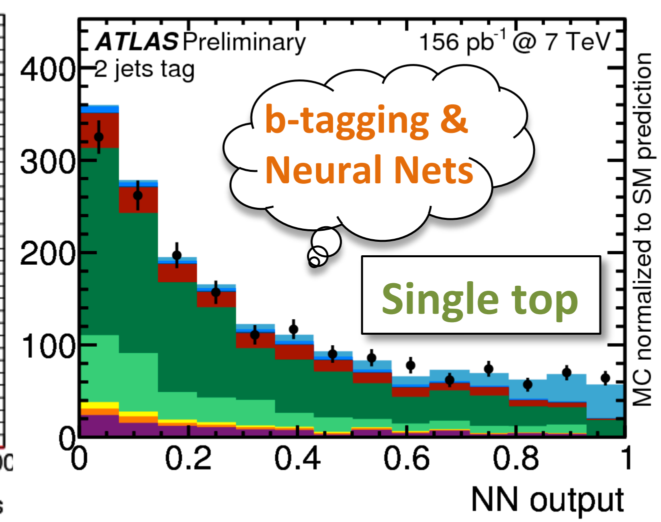










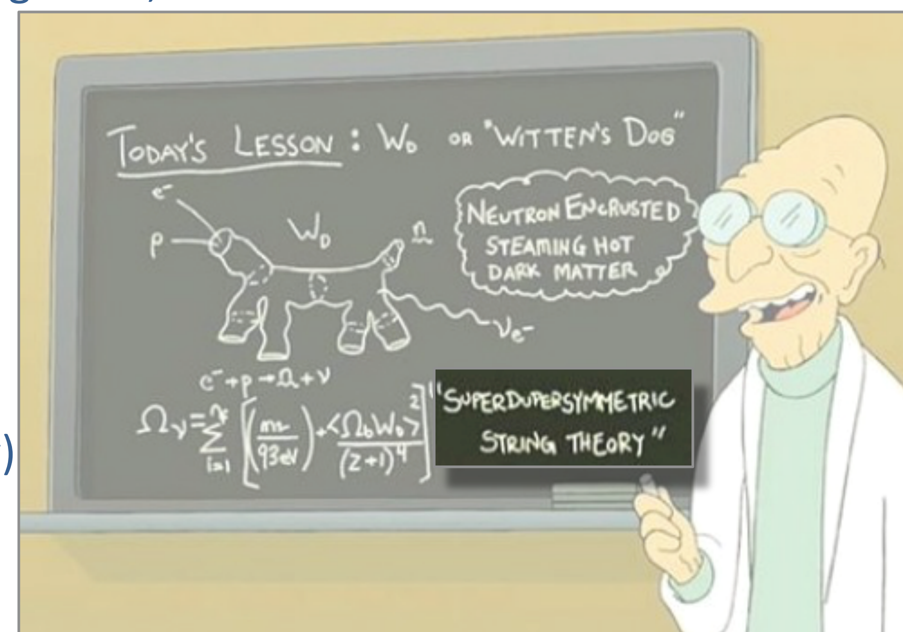


Searches – an Outline

- **Exotics**
  - Search for new heavy gauge bosons (W', Z')
  - Search in di-jet final state (excited quarks, contact interactions, …)
  - Search in multi-jet final state (black holes)
  - Search in lepton(s) + jets final state (leptoquarks, ttbar resonance, …)

- **SuperSymmetry (SUSY)**
  - MET-based searches for squarks and gluinos, in final states with:
    - jets (and lepton[s])
    - b-jets (and a lepton)

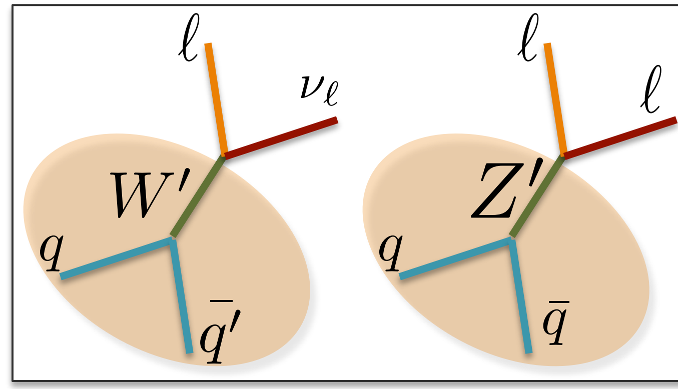
- **SUSY-Based exotics**
  - Search for di-photons (GMSB/UED)
  - Search of eμ resonance
    (RPV sneutrinos, LFV Z's)
  - Search for lepton-jets (Hidden Valley)
  - Search for Long Lived Particles



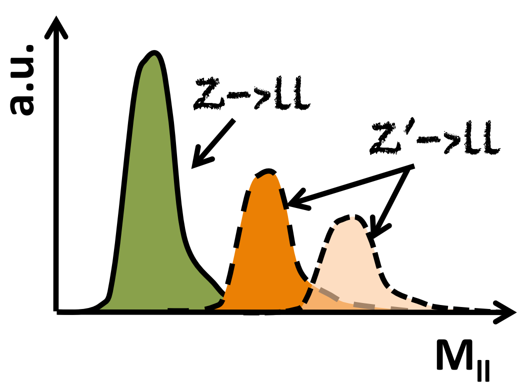
1. Search for new heavy gauge bosons

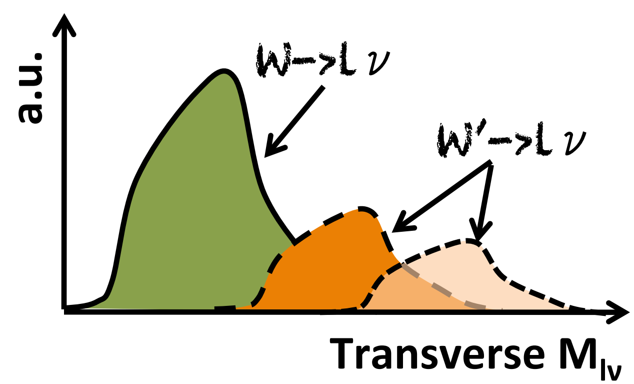
Motivation and observables

- Various SM extensions predict existence of **heavy bosons**.
  - Benchmark model is the **Sequential Standard Model (SSM):**
    - -W’ and Z’ have the same fermionic couplings as SM W and Z.
    - - Widths scale linearly with mass.
  - For Z’, there are string theory inspired models.



- Allows for early discoveries: use clean signatures with only leptons and E_T^{Miss}.

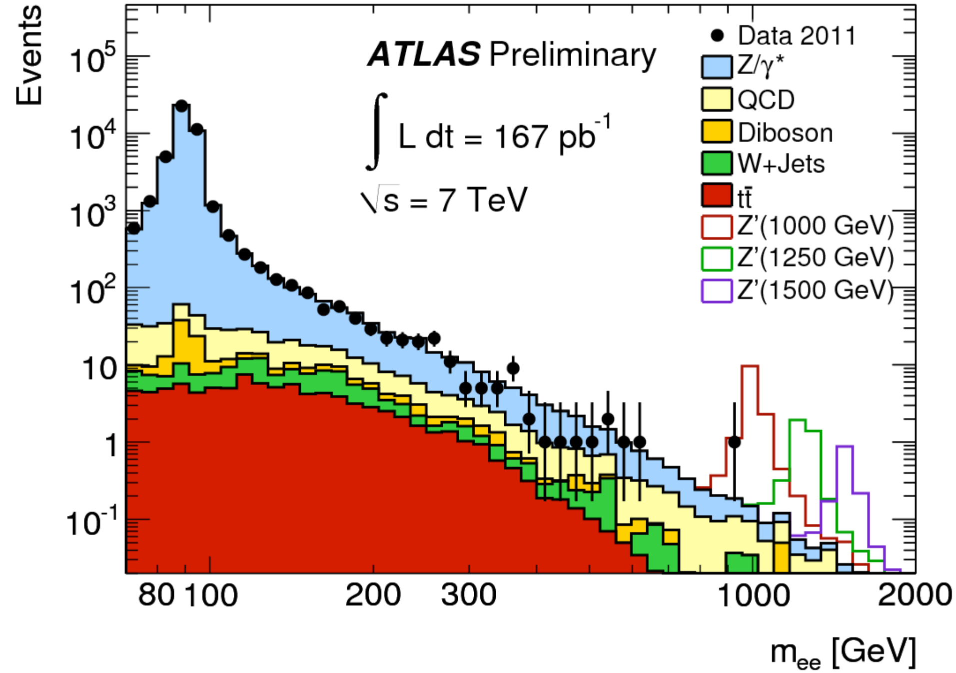


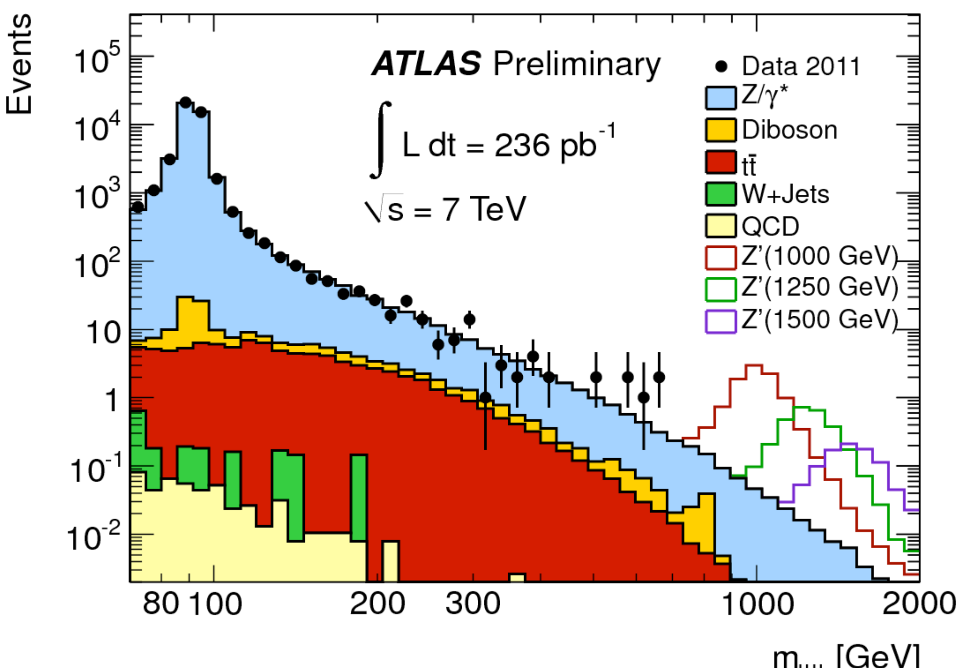


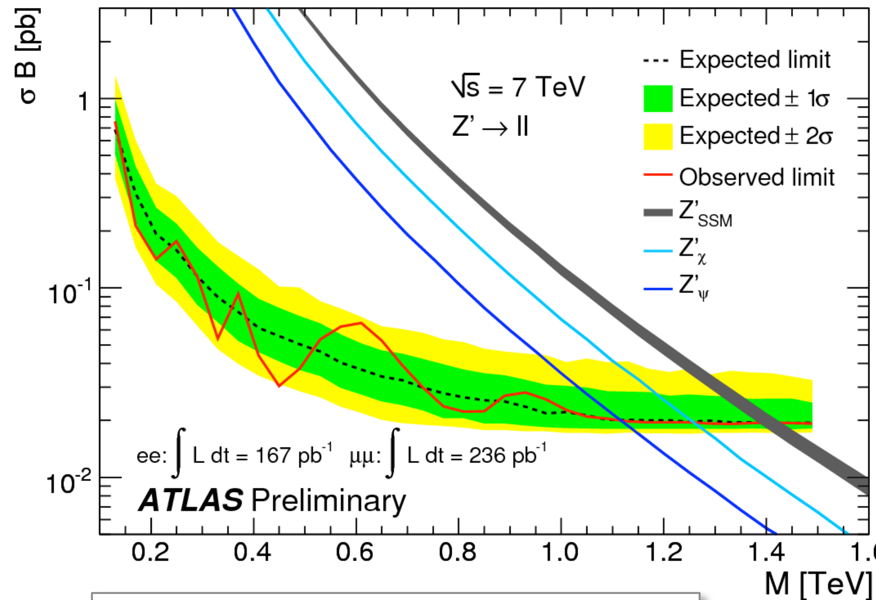
$$M_T = \sqrt{(p_T^\mu + E_T^{Miss}) - (\vec{p}_T^\mu + \vec{E}_T^{Miss})}$$
$$= \sqrt{2 \cdot p_T \cdot E_T^{Miss} \cdot (1 - cos\Delta\phi(\ell, E_T^{Miss})}$$

1a. Search for Z'

Results – 2011 Data







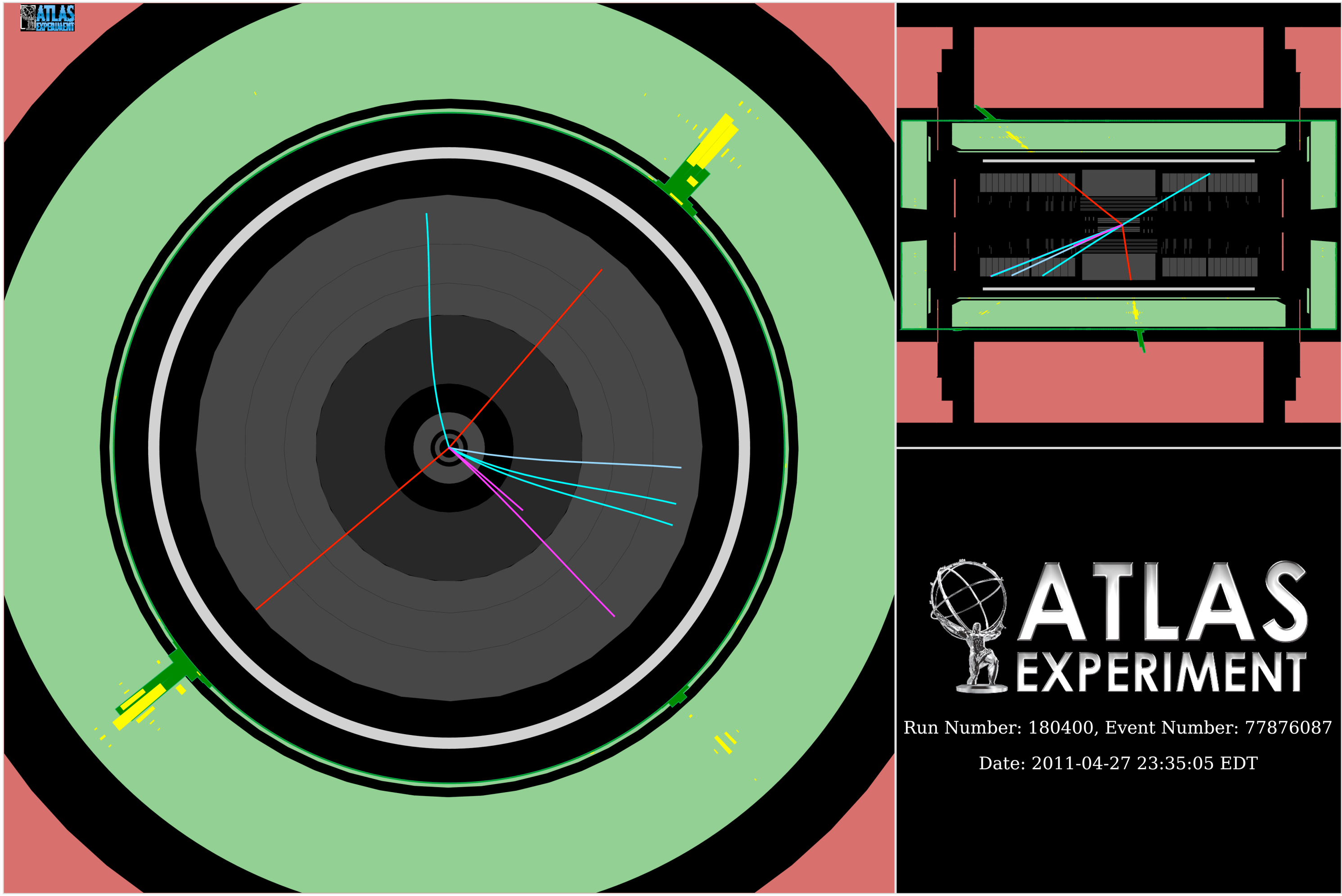
95% C.L. SSM Z' excluded
$M_{Z'}$ < 1.4 TeV

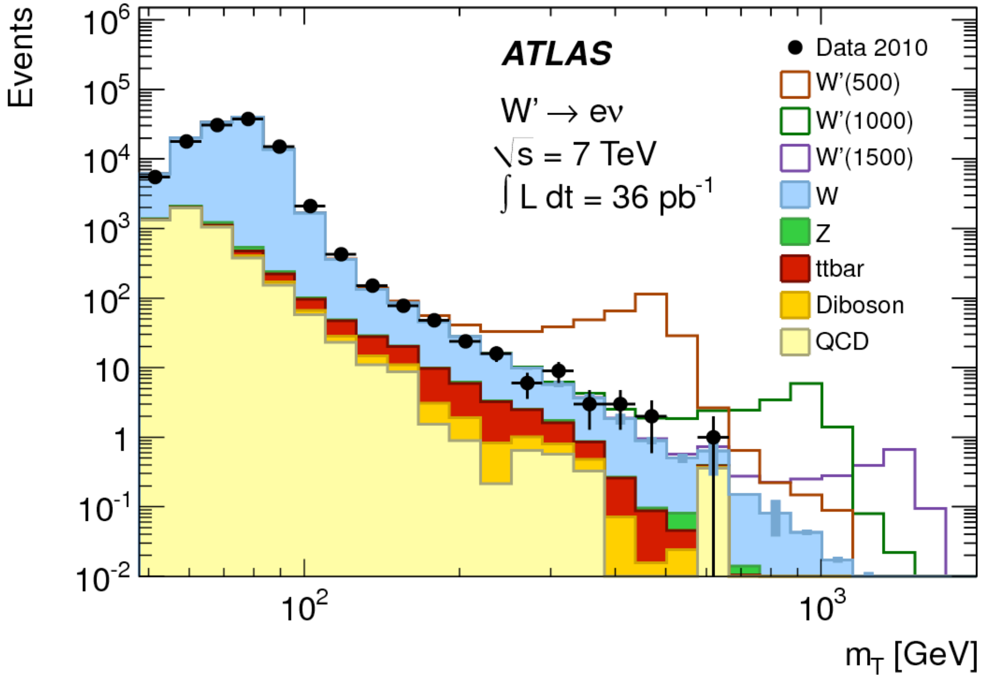
- $m_{\mu\mu}$ gives a handle to also search for μμqq contact interactions.
  - 95% C.L. limits set:
    Λ > 4.9 TeV (4.5 TeV) for constructive (destructive) interference in the L-L isoscalar compositeness model.

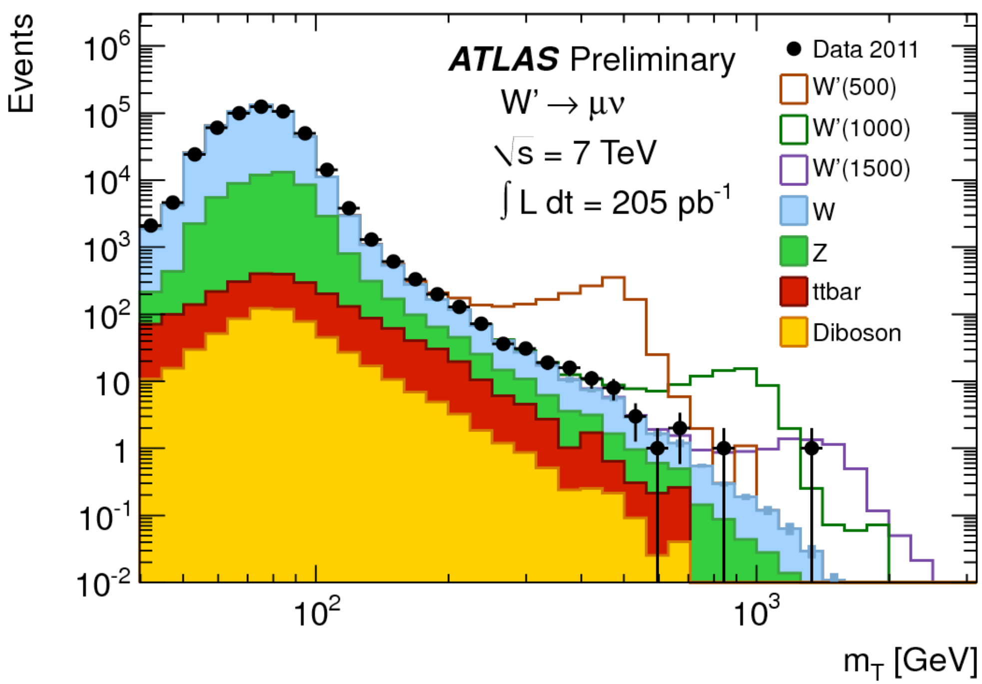
1a. Search for Z’

Highest-mass di-electron event

M_{ee} = 920GeV
$E_T(e_1)$=390GeV
$E_T(e_2)$=388GeV

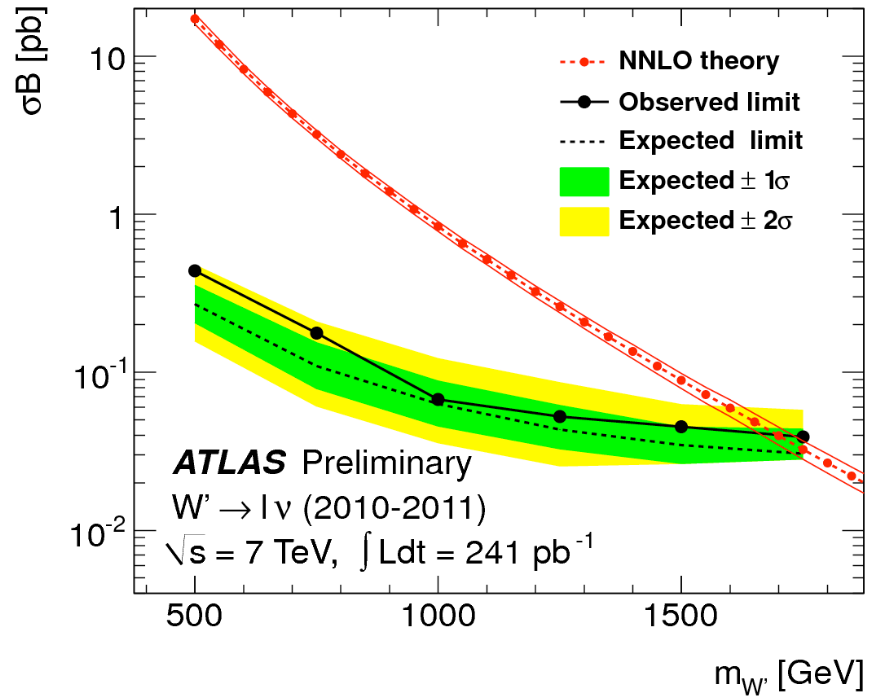






1a. Search for W'

Results – 2010, 2011 Data



95% C.L. SSM W' excluded
$M_{W'}$ < 1.7 TeV

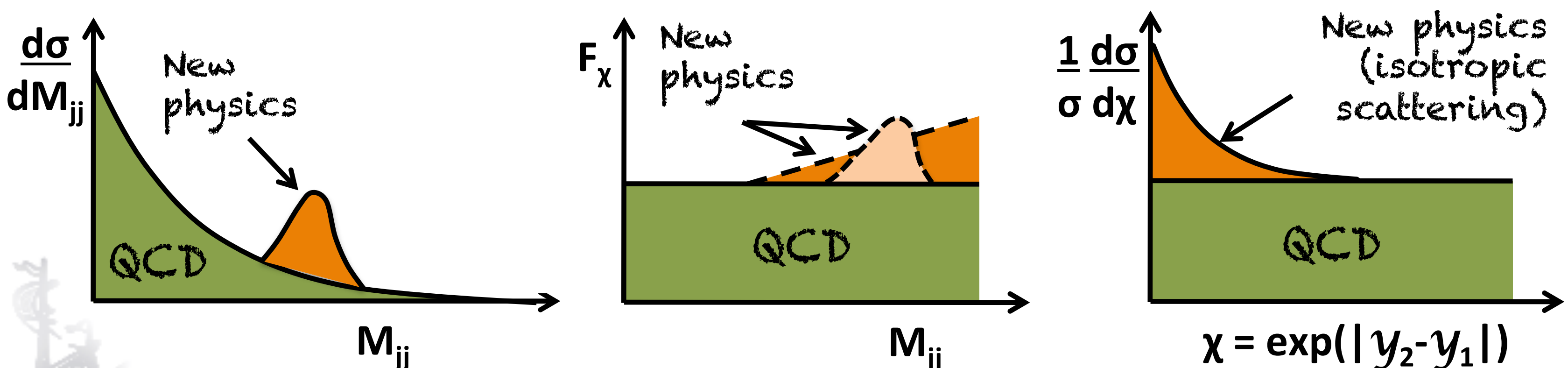
arxiv:1103.1391, ATLAS-CONF-2011-083

2. Search in di-jet final state

Motivation and Observables

- Scattering process is well described by perturbative Quantum Chromodynamics (pQCD).
- It is possible there are additional contributions from either new massive particles, or new forces. Rich variety of new physics models that could manifest in dijet spectra:
  - **Compositeness**: are quarks made from more fundamental particles?,
    e.g. $qg \to q^* \to qg$
  - **TeV-scale gravity** and **Quantum Black Holes**,
  - **Axigluons** and **Randall-Sundrum (RS) gravitons**, …

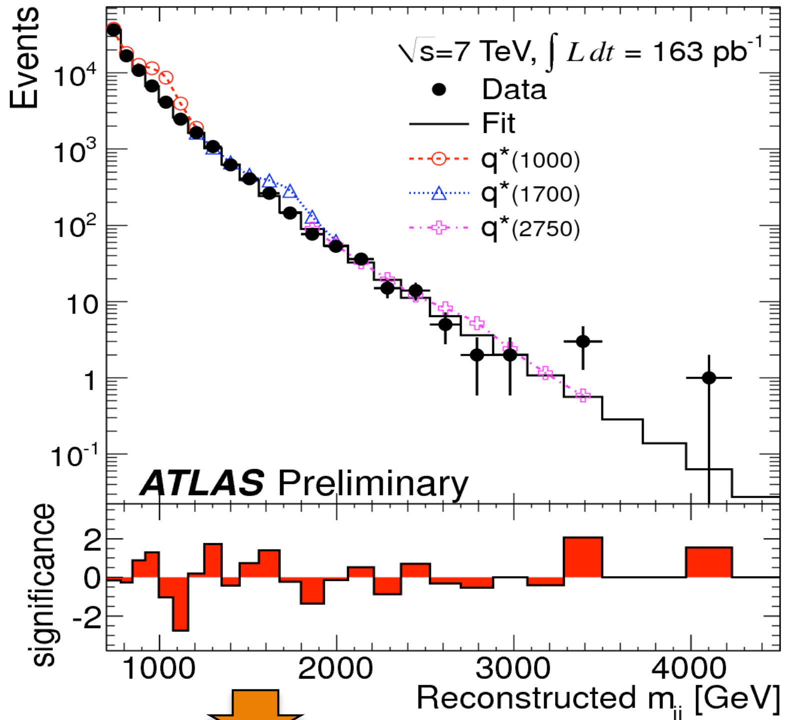
- New physics can be measured in the dijet mass spectrum, or angular distributions.

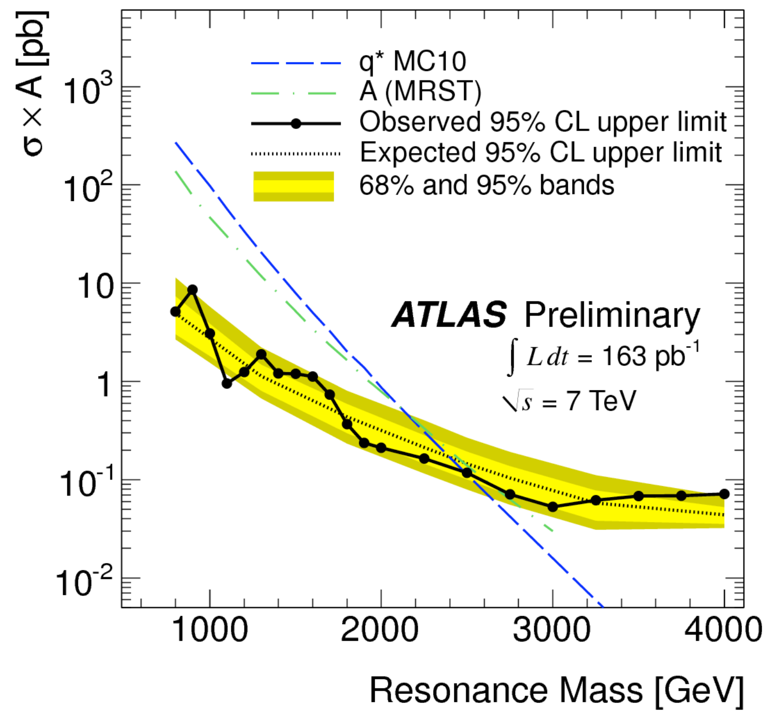


$$F_\chi = \frac{N_{events}(|y_1 - y_2| < 1.2)}{N_{events}(|y_1 - y_2| < 3.4)}$$

2. Search in di-jet final state

Resonance Search – 2011 Data





- Data-driven background fit uses smooth function:

$$f(x) = p_1(1-x)^{p_2} x^{p_3+p_4 lnx}$$

where $x = M_{jj}/\sqrt{s}$

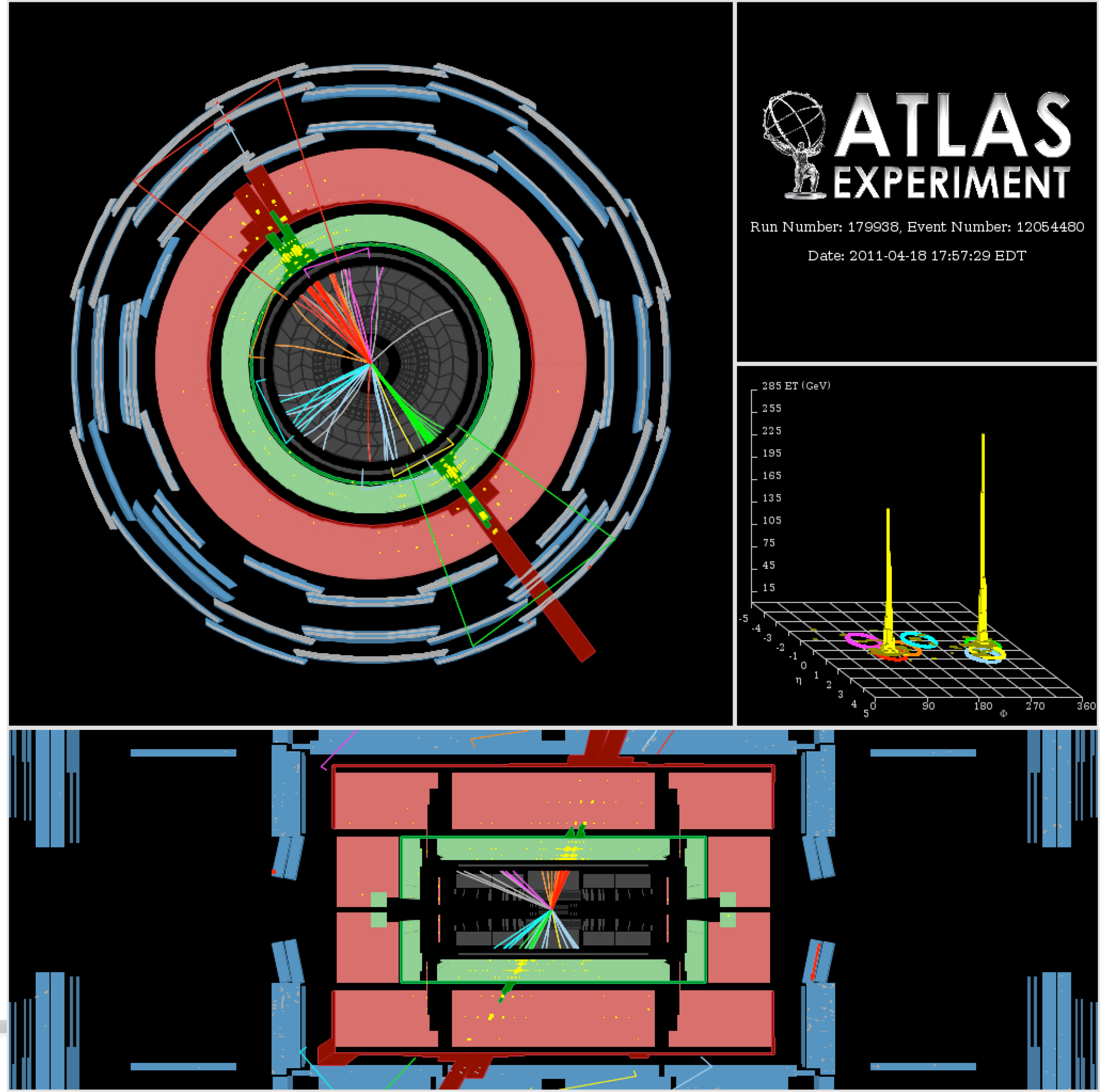
- 'Bump-Hunter' identifies the most significant discrepancy, including 'trials factor' for significance of finding.
- No evidence for a resonance signal…

Highest mass event

M_{jj} = 4.04TeV

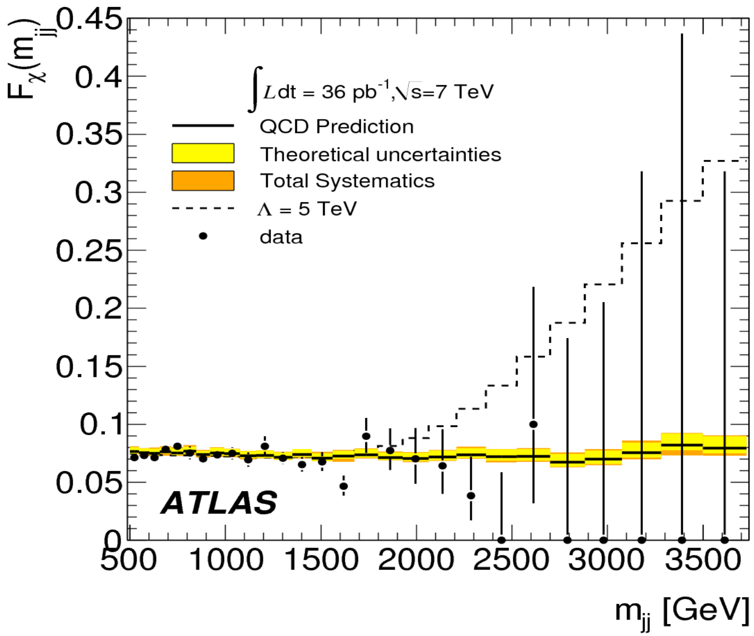
$p_T(j_1)$=1.85TeV

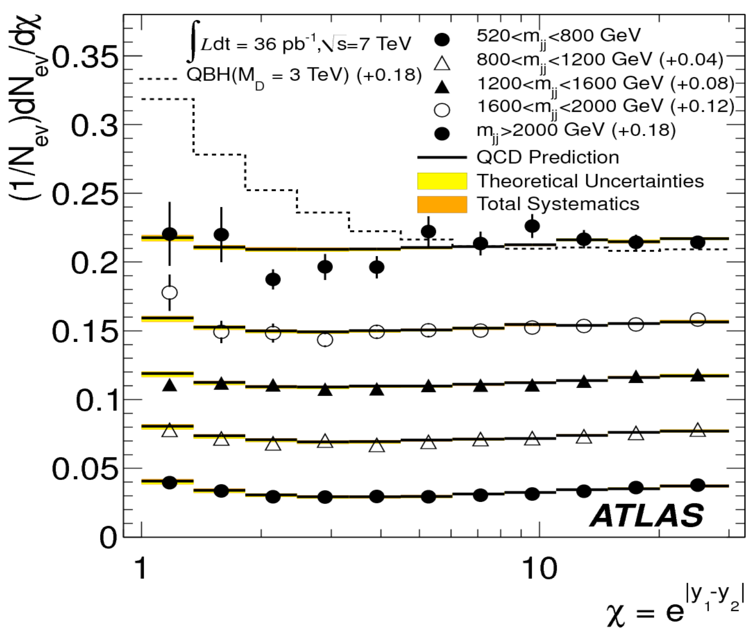
$p_T(j_2)$=1.84TeV



2. Search in di-jet final state

Angular analysis – 2010 Data



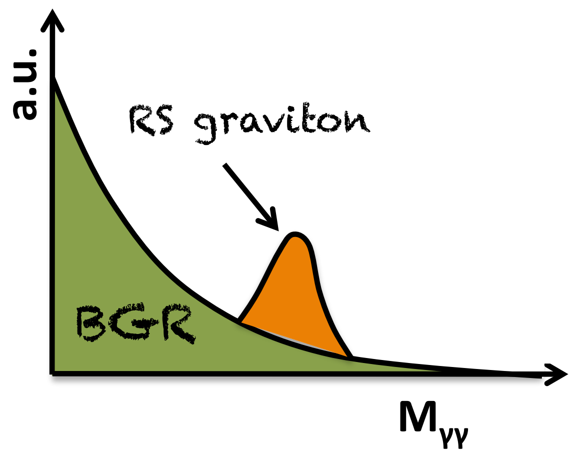


Limits set by the di-jet final state search		
Analysis Strategy	95% C.L. Limits (TeV)	
	Expected	Observed
Excited Quark q* Mass		
M_{jj} resonance (2011)	2.40	2.49
F_χ (2010)	2.12	2.64
Randall-Meade Quantum Black Hole M_D(d=6)		
M_{jj} resonance (2010)	3.64	3.67
F_χ (2010)	3.49	3.78
Axigluon Mass		
M_{jj} resonance (2011)	2.48	2.67
Contact Interaction Λ		
F_χ (2010)	6.7	5.7

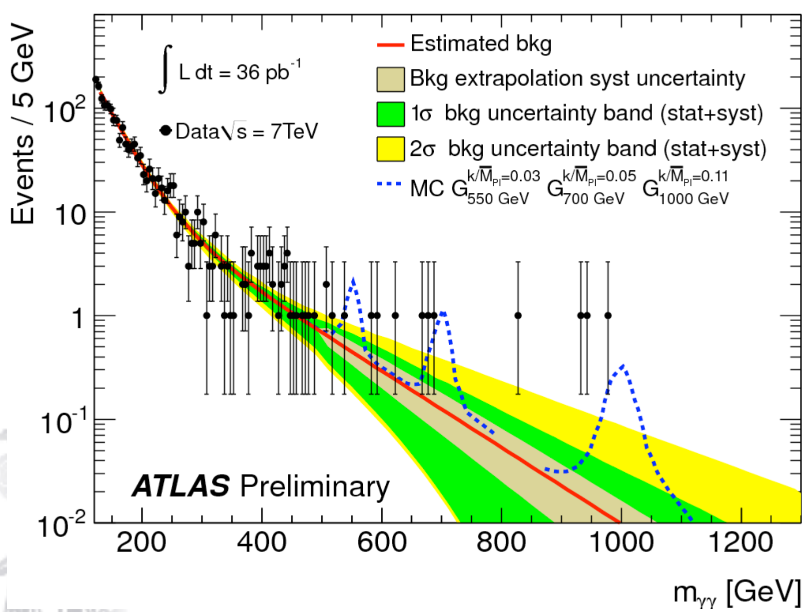
arxiv:1103.3864, ATLAS-CONF-2011-081

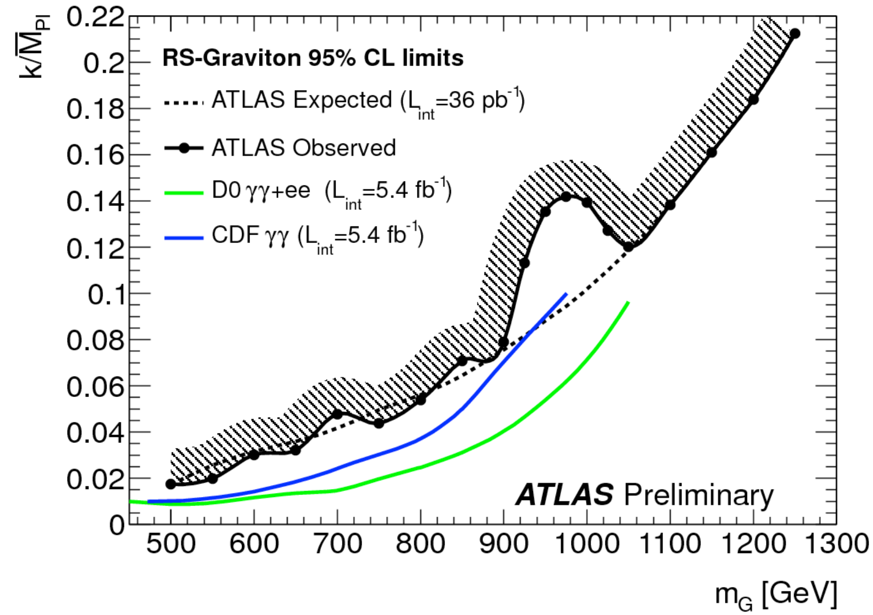
3. Search in di-photon final state

Motivation, Observables and Results – 2010 data



- **Extra dimensions**; In the minimal Randall-Sundrum model, gravitos are the only particles that can propagate in the bulk, generating a series of massive graviton excitations.
  - RS KK gravitons have a universal dimensionless coupling to the SM fields, $k/\bar{M}_{Pl}$, and are searched from their decays to photons, $G \to \gamma\gamma$.
- Sensitive to other BSM models, e.g. Z'





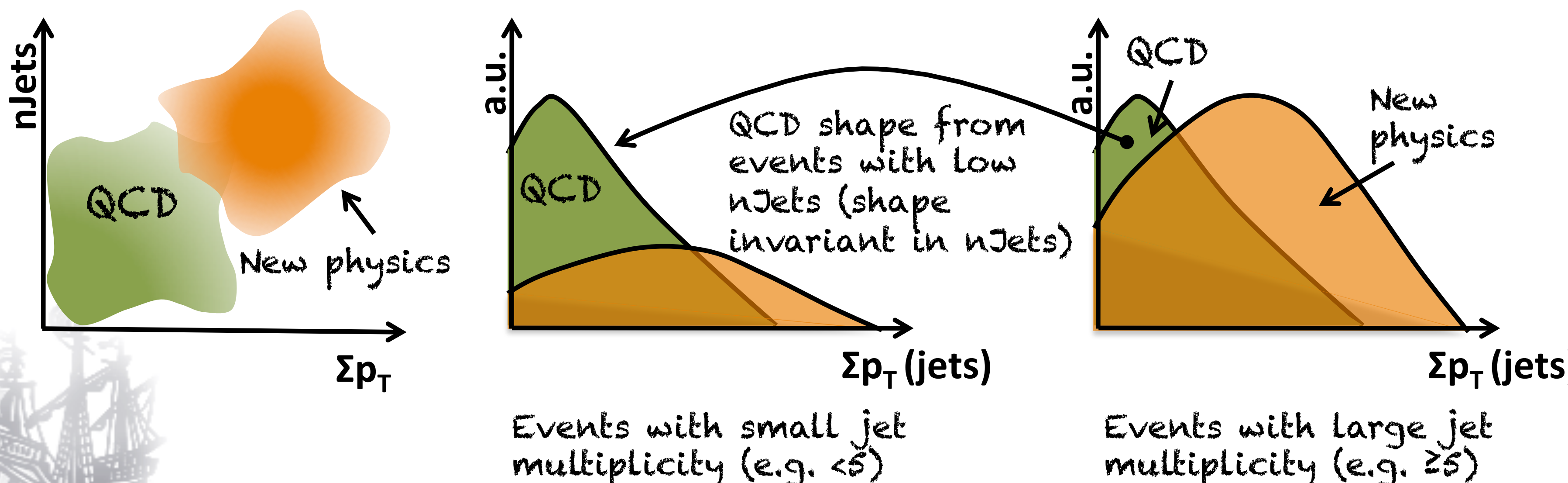
Exclude at 95% C.L. graviton masses < 545 (920) GeV for RS coupling $k/\bar{M}_{Pl}$ =0.02 (0.1)

4. Search in multi-jet final state

Motivation and Observables

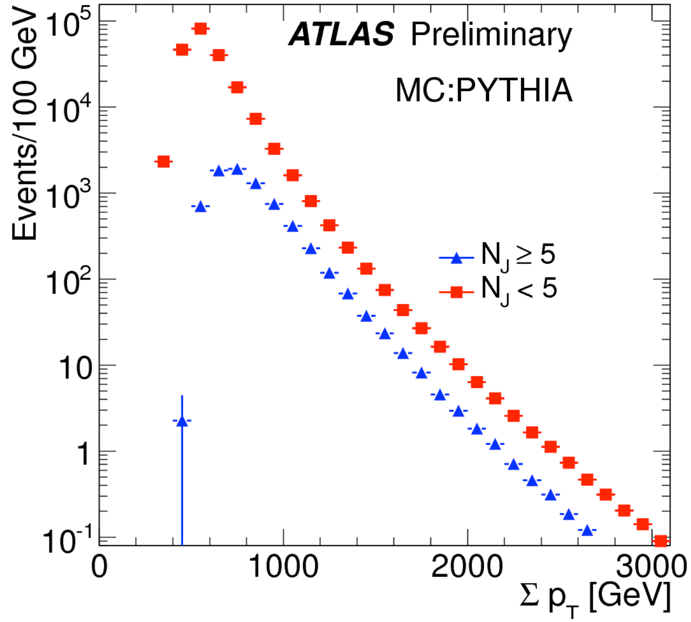
- **Black Holes**: **the** signature for low-scale quantum gravity.
  - They form when two colliding partons have distance smaller than R_S, the Schwarzschild radius corresponding to their invariant mass.
  - Cross section: $\sigma=\pi R_S^2$ – can be as high as 100pb!
  - They decay instantaneously (Hawking evaporation) emitting a large number of quarks, gluons, leptons, etc. Can be discovered in multi-jet events.
    - ⇒ Caveat: over most of the viable parameter space, this is probably not a very realistic expectation (arXiv:0708.3017v1)

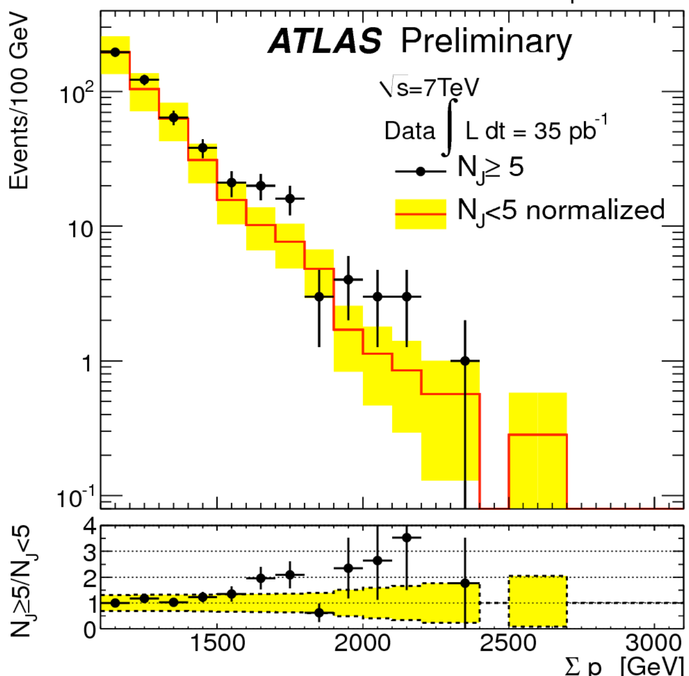
- Look for excess in Σp_T of jets, in events with large jet multiplicity.



4. Search in multi-jet final state

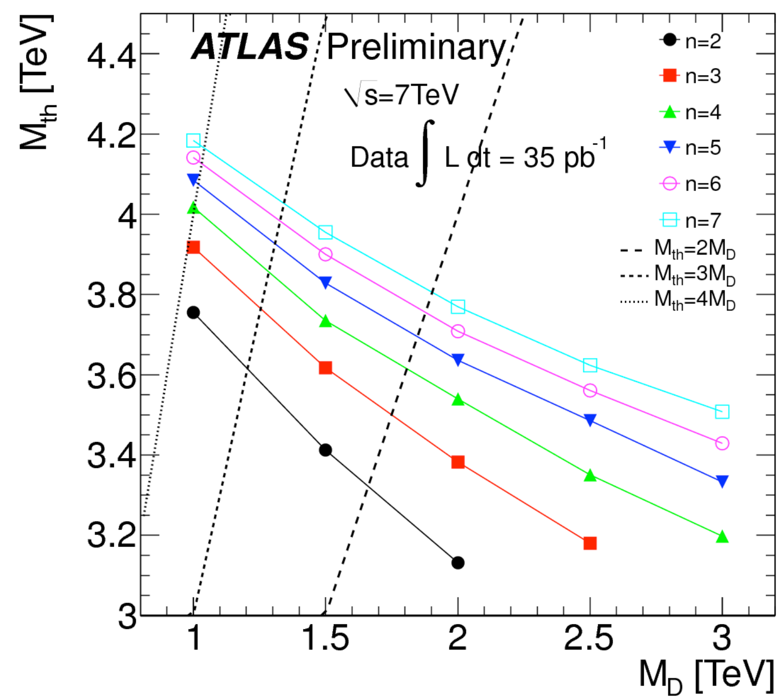
Results – 2010 data





Datasets normalized to number of events in $1.1TeV<\Sigma p_T<1.2TeV$.

CTEQ6.6 PDFs

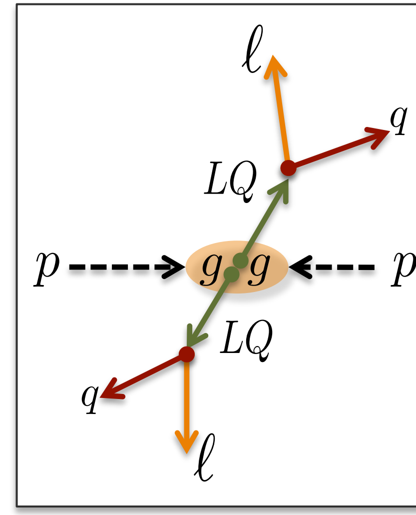


Exclusion regions as a function of the Planck scale (M_D), the number of extra dimensions and the minimum production mass.
For events with nJets >=5 and Σp_T>2TeV, a 95% C.L. lower limit on the cross-section×acceptance of 0.29pb is obtained.

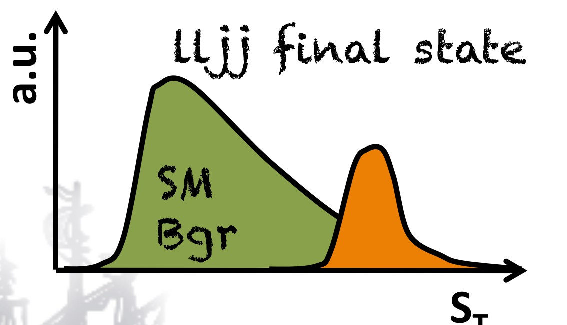
5. Search in lepton(s) & jets final state

Motivation and observables

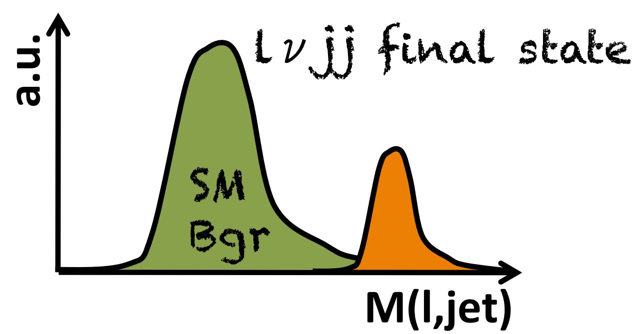
- **Leptoquarks**: particles that carry both lepton and baryon numbers (both 'leptons' and 'quarks'). They also carry color – thus have large cross-section and could be observed early.
  - GUT-inspired, with proton decay acting as one of the main motivations.
  - Decay into charged lepton plus quark or neutrino plus quark.
  - A leptoquark per generation. Searches carried out for each generation separately. Easier ones are for the first two generations (e/μ): LQ1 and LQ2.



- Pair produced final state (gluon fusion): look for a lepton-jet resonance. ATLAS is looking for final states with 2 massive leptons (e/μ) plus jets, or a lepton plus jets plus E_T^{Miss}.



$S_T = p_T^{\ell_1} + p_T^{\ell_2} + p_T^{j_1} + p_T^{j_2}$

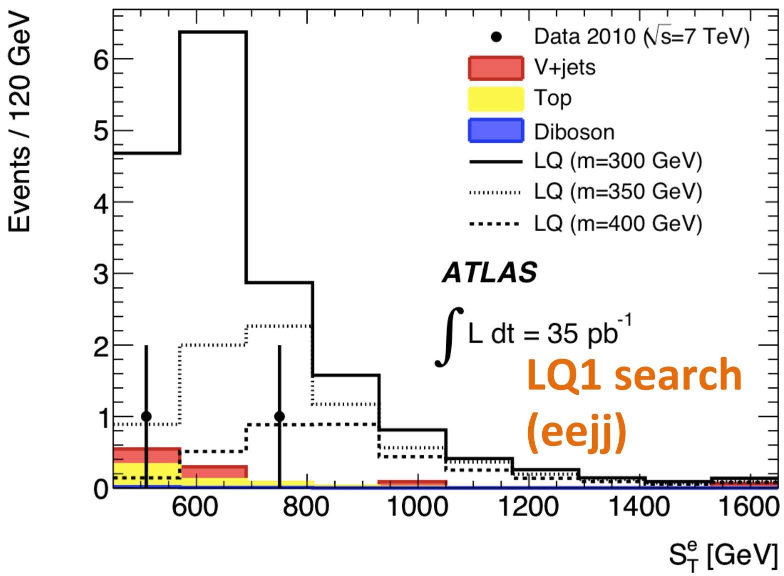


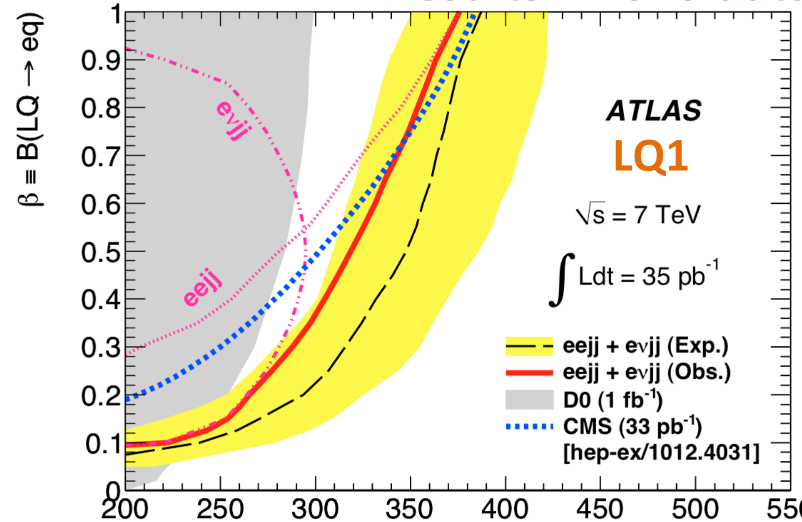
M(l,jet) = average of the masses from the 2 lepton-jet combinations

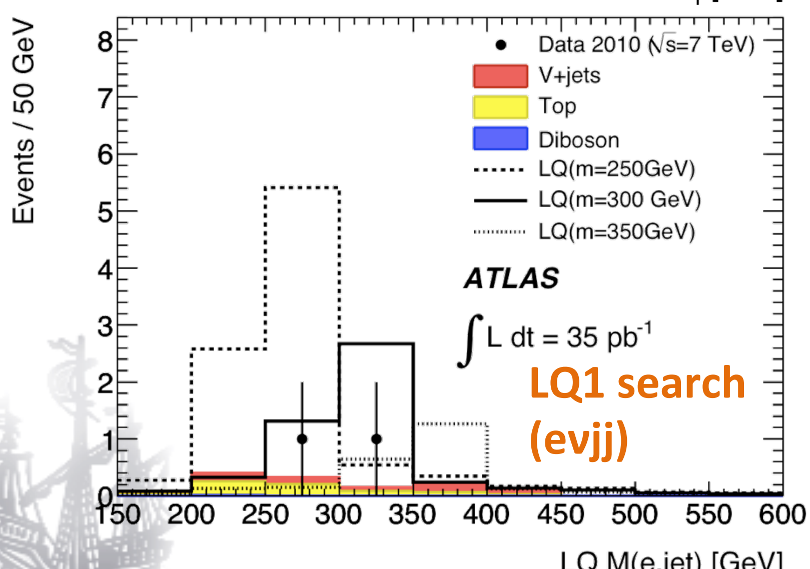
In both cases:
- QCD Bgr data driven.
- V+jets, ttbar from MC but normalized to control regions.

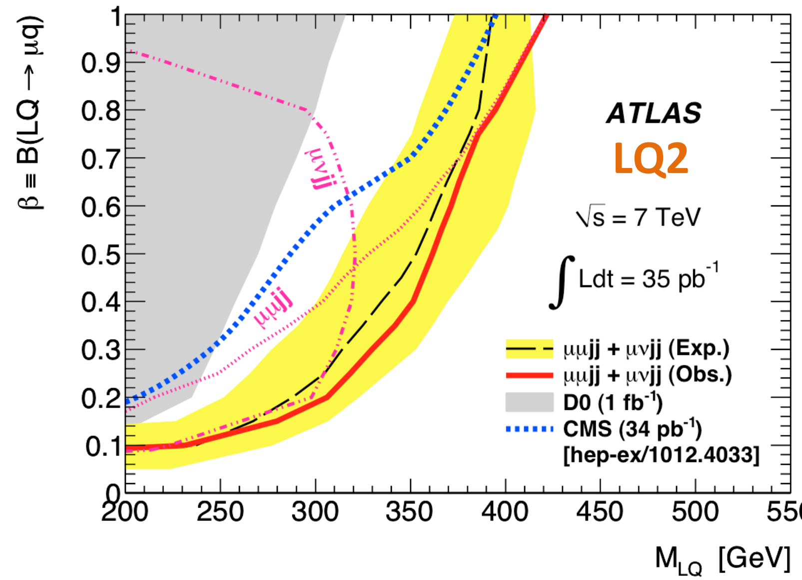
5. Search in lepton(s) & jets final state

Results – 2010 data









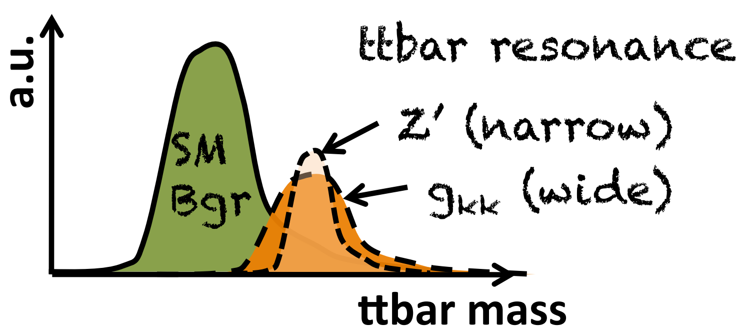
arxiv:1104.4481

6. Search in 1 lepton & jets final state

Motivation and observables

- **Searching for a ttbar resonance.**
  - The top quark is the heaviest of the known fermions: heavy resonances in ttbar production are predicted in various SM extensions:
    - EWSB through top quark condensation (topcolor-assisted technicolor): a color-singlet vector particle (Z') couples primarily to the 3rd quark generation (**leptophobic Z'**). Would manifest as a narrow resonance.
    - Randall-Sundrum scenario with single warped extra-dimension, where the SM matter and gauge fields propagate in the bulk (arXiv:hep-ph/0701166v1); resonant production of the Kaluza-Klein excitations of the gauge bosons. **KK-gluons (g_{KK})** have the largest production rate and decay primarily to ttbar. Would manifest as a wide resonance.

- Look for a second peak (narrow resonance) or an excess (wide resonance) in the ttbar mass spectrum.

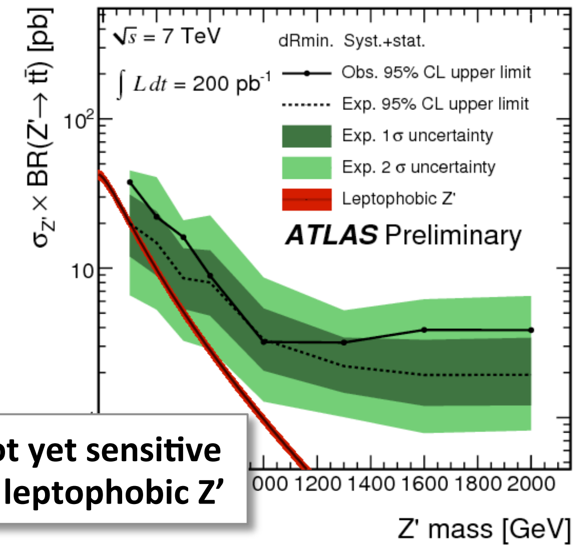


- ttbar mass reconstructed from semileptonic decays.
- ν ambiguity resolved using the W mass

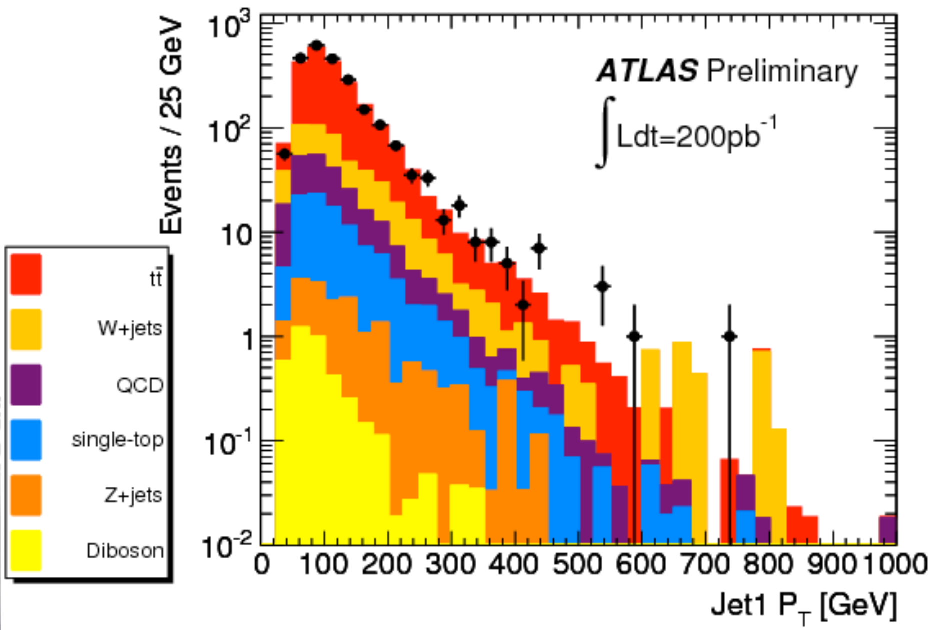
6. Search in 1 lepton & jets final state

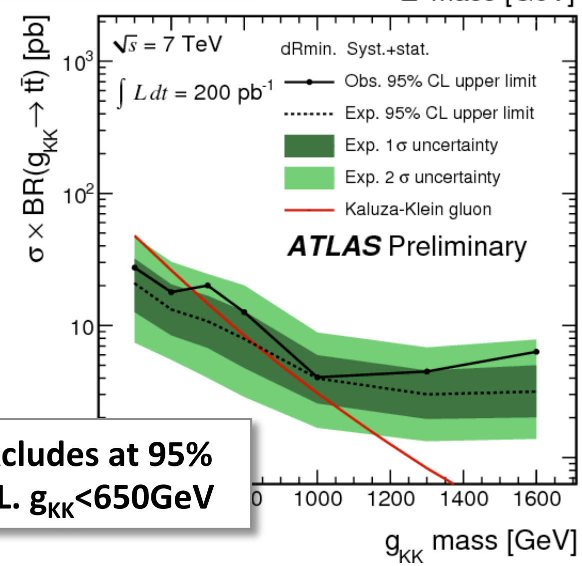
- Event selection:
  - One isolated lepton (electron or muon)
  - E_T^{Miss}
  - at least 4 jets, out of at least one b-tagged
- The ttbar mass is reconstructed from the 4jets, lepton and E_T^{Miss}; the E_T^{Miss} ambiguity is resolved using the W mass information. ISR/FSR jets are removed.
  - dRmin method: remove jets that are “far” from the rest of the activity in the event.

Analysis & Results – 2011 data



Not yet sensitive to leptophobic Z’

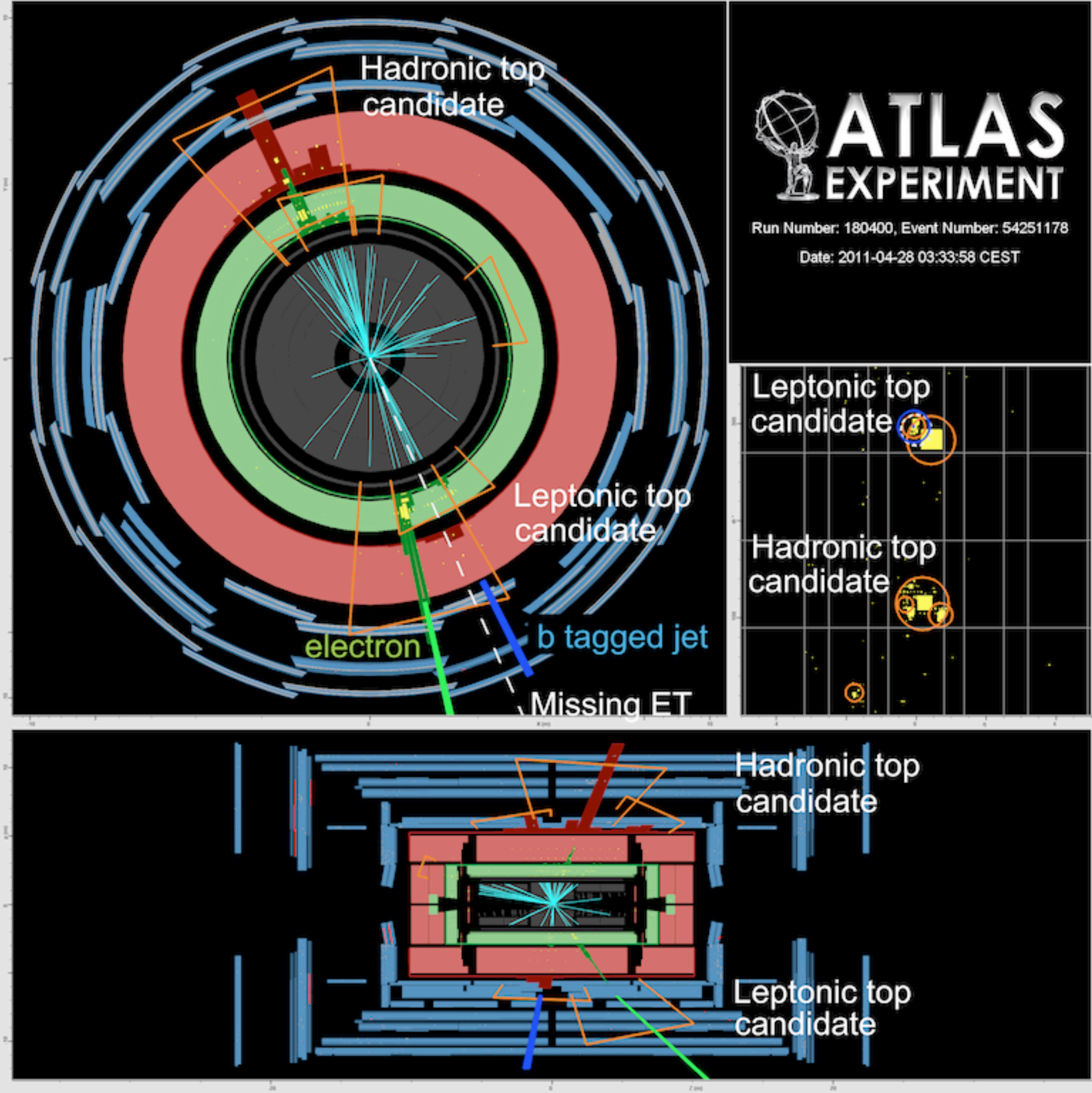




Excludes at 95% C.L. g_{KK}<650GeV

A high mass event

M_{ttbar} = 1.6TeV



- **One of the most popular extensions of the SM**
  - Maps boson degrees of freedom to fermion degrees of freedom.
  - Boson and fermion superpartners have same interactions (mass, charges).
  - If R-parity $R=(-1)^{2j+3B+L}$ is conserved, SUSY particles are pair produced and the lightest one is stable.

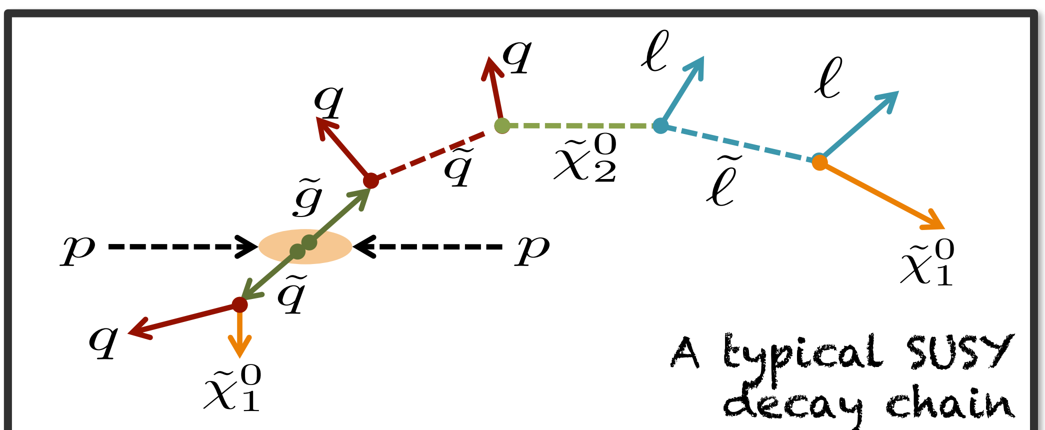
- Why popular? It answers many open questions in once:
  - Provides unification of gauge couplings,
  - Solves the mass hierarchy problem; the fermion and boson contributions to the Higgs mass exactly cancel,
  - Provides a dark matter candidate, …

- The SUSY 'problem'
  - SUSY is very predictive in terms of **spins** and **couplings**, but tells us nothing about the **masses** (after symmetry breaking).
  - Result: **huge** number of theoretical models.
    - E.g. consider all possible mass hierarchies between SUSY particles:

      $\Rightarrow$ 9! models

$\tilde{u}_L, \tilde{d}_L$	$\tilde{u}_R$	$\tilde{d}_R$	$\tilde{e}_L, \tilde{\nu}_L$	$\tilde{e}_R$	$\tilde{h}^{\pm}, \tilde{h}^0_u, \tilde{h}^0_d$	$\tilde{b}^0$	$\tilde{w}^{\pm}, \tilde{w}^0$	$\tilde{g}$
Q	U	D	L	E	H	B	W	G
M_Q	M_U	M_D	M_L	M_E	M_H	M_B	M_W	M_G

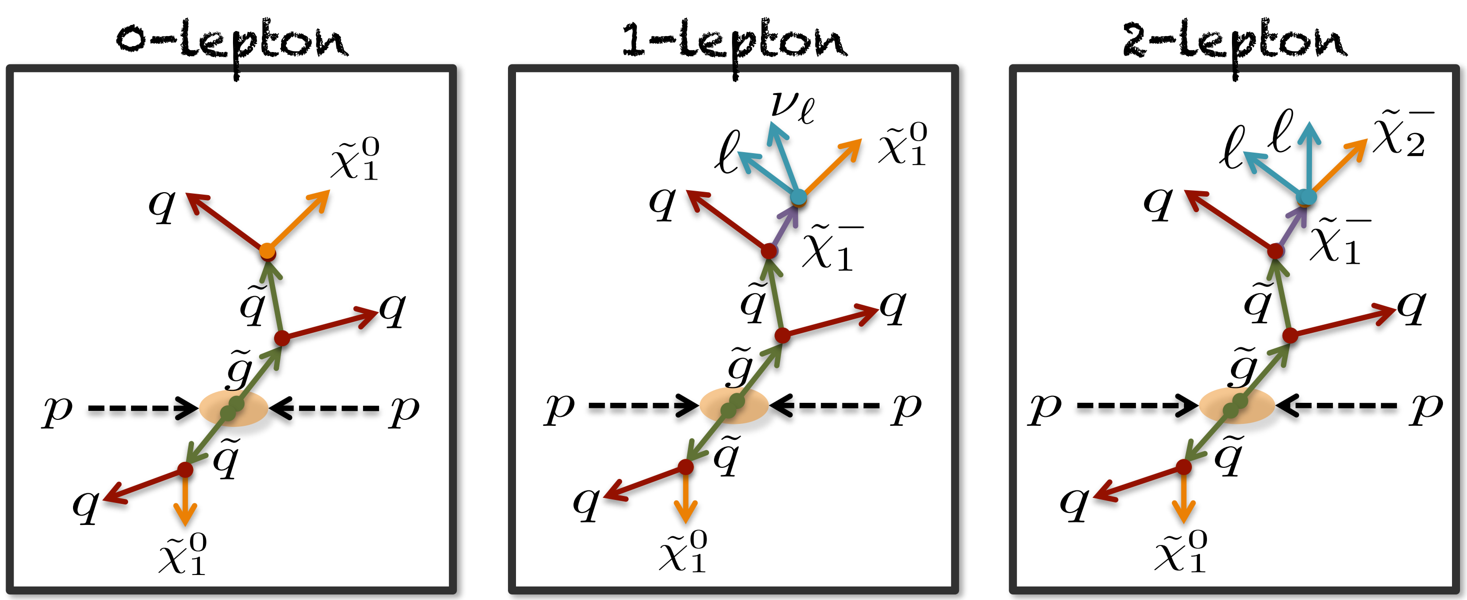
- Where to start?
  - A minimal model, **Constraint Minimal SUSY (CMSSM)** (mSugra, i.e. gravity-mediated, based) only has 5 free parameters:
    - Scalar mass parameter, $\mathbf{m_0}$
    - Gaugino mass parameter, $\mathbf{m_{1/2}}$
    - Trilinear Higgs-sfermion-sfermion coupling, $\mathbf{A_0}$
    - Ratio of Higgs vaccum expectation values, **tanβ**
    - Sign of SUSY Higgs parameter, **sign(μ)**
  - Dominant SUSY production at the LHC: **gluinos and squarks produced together with high cross-sections.**
    - They produce many hard jets, large E_T^{Miss} and leptons: spectacular events!
    - Not seen so far…



SUSY seaches

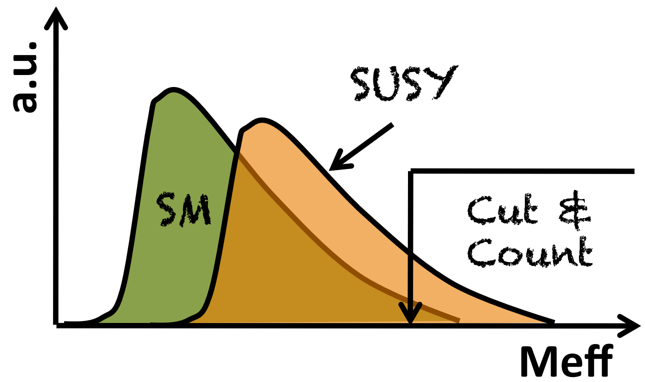
Active ATLAS SUSY analyses (excluding SUSY-based exotics)
E_T^{Miss} + Jets + 0 lepton
E_T^{Miss} + Jets + 1 lepton
E_T^{Miss} + Jets + 2 lepton
E_T^{Miss} + Jets + ≥3 lepton
E_T^{Miss} + b Jets + 0/1 lepton

Example diagrams of what we are looking for



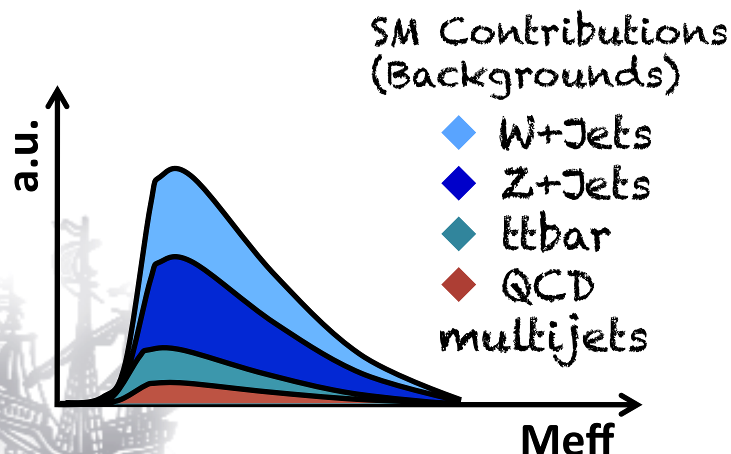
1. 0-lepton search

Observables and Backgrounds



$$\text{Meff} = \sum_{i=1}^{NJets} p_T^{jet_i} + E_T^{Miss}$$

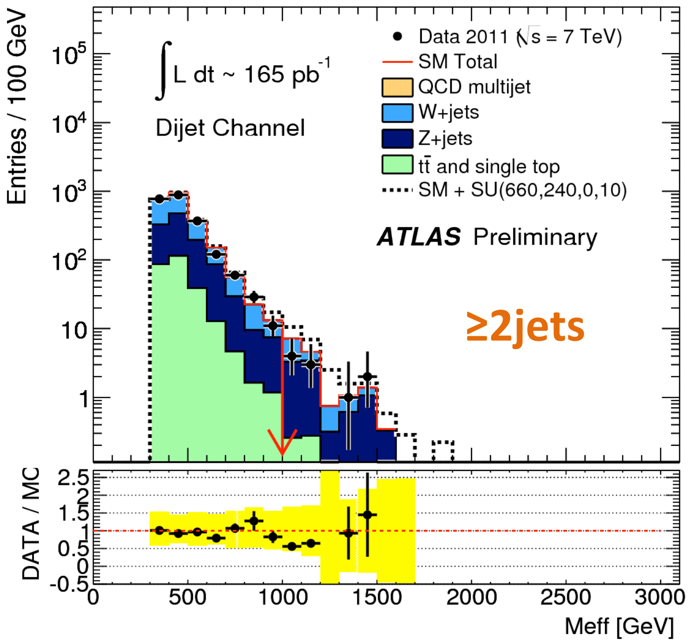
Signal Region	≥2Jets	≥3Jets	≥4Jets
E_T^{Miss} (GeV)	> 130		
Leading Jet p_T (GeV)	> 130		
N Subleading Jet p_T (N=2,3,4) (GeV)	> 40		
$\Delta\phi(\text{Jet}_i, E_T^{Miss})_{min}$, i=1,2,3	**> 0.4**		
E_T^{Miss}/Meff	**> 0.3**	**> 0.25**	
Meff (GeV)	**> 1000**		

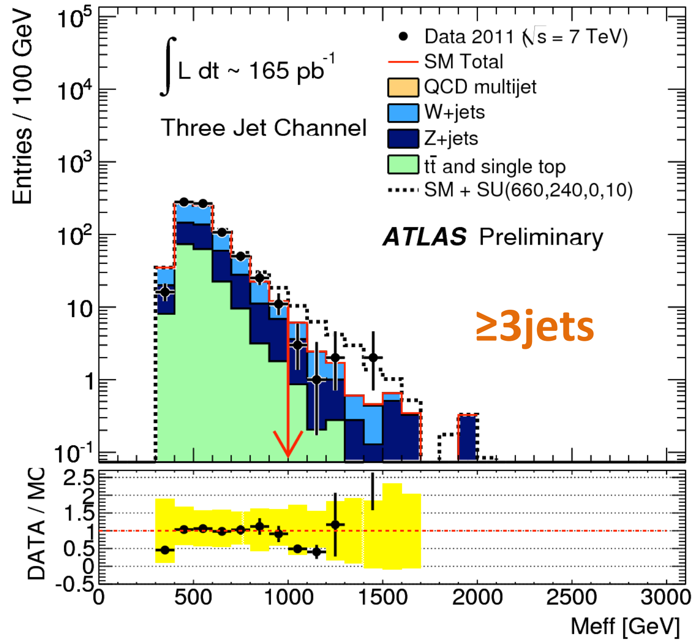


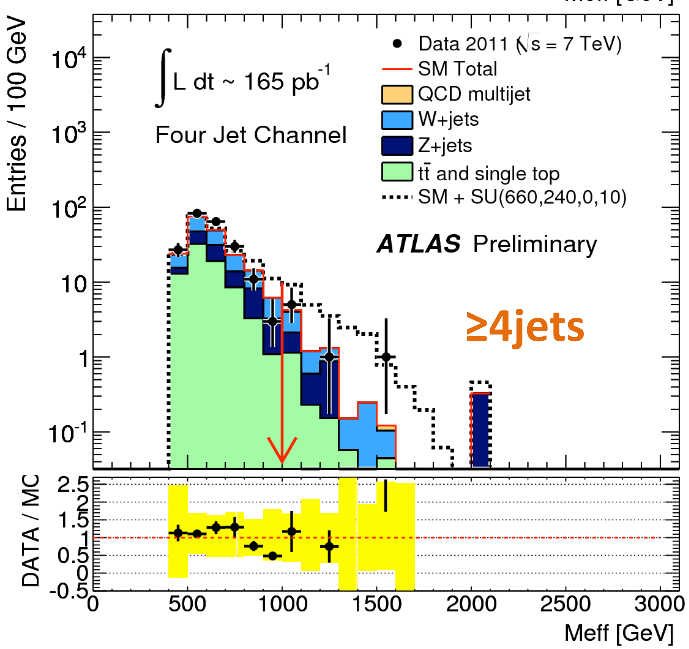
Background Sources	
W+jets	Leptons measured as a jet
Z+jets	Irreducible Z→νν+jets
ttbar	Hadronic τ from ttbar
QCD multijets	Mismeasured jets or emission of neutrinos in heavy flavor decay
All background estimations are data-driven!	

1. 0-lepton search

Results – 2011 data







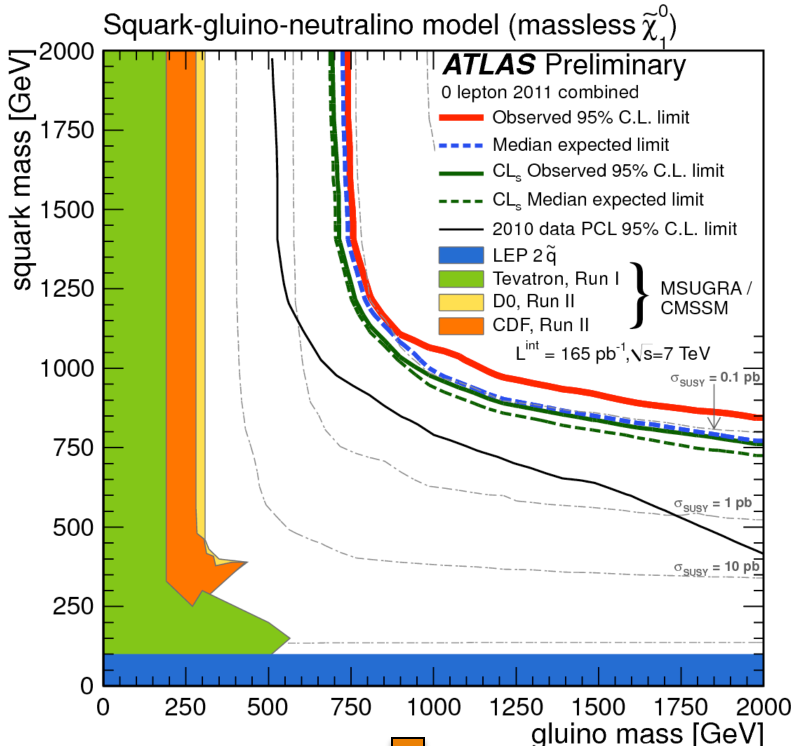
Signal Region	≥2jets	≥3jets	≥4jets
Total Expected	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed	10	8	7

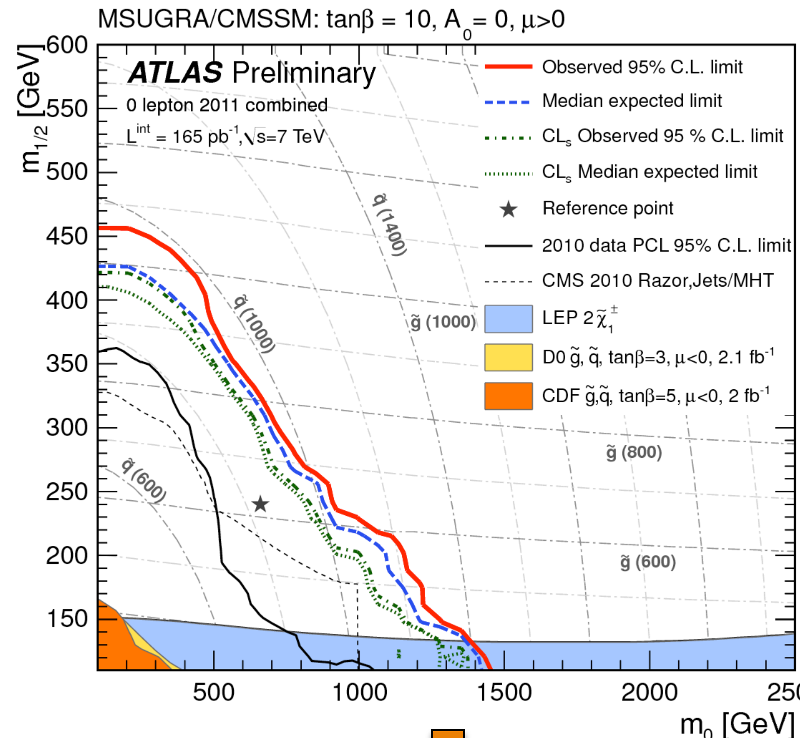
- Uncertainties (~25%) dominated by Jet Energy Scale, Jet Resolution and Z+jets background estimate.

1. 0-lepton search

Results – 2011 data

- Best expected signal region per model point is chosen





Exclude at 95% C.L.
- gluino masses < 725 GeV.
- If m(gluino)=m(squark), masses<1025 GeV.

Exclude at 95% C.L.
- If m(gluino)=m(squark), masses<950GeV.

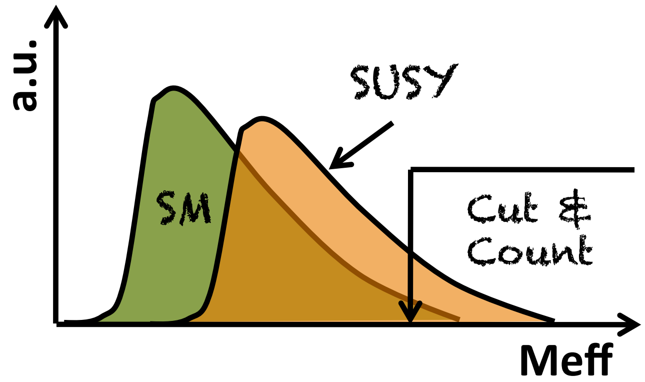
Exclude at 95% C.L. non-SM xsection × acceptance × efficiency

≥2jets	≥3jets	≥4jets
35 fb	30 fb	35 fb

ATLAS-CONF-2011-086

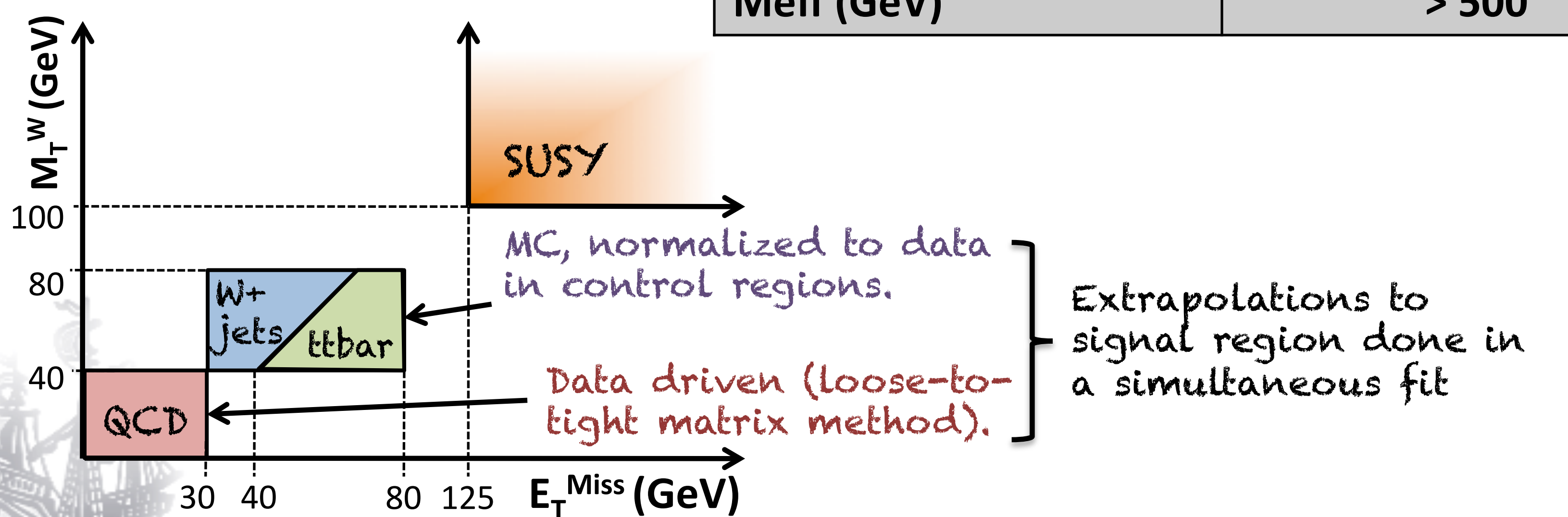
2. 1-lepton search

Observables and Backgrounds



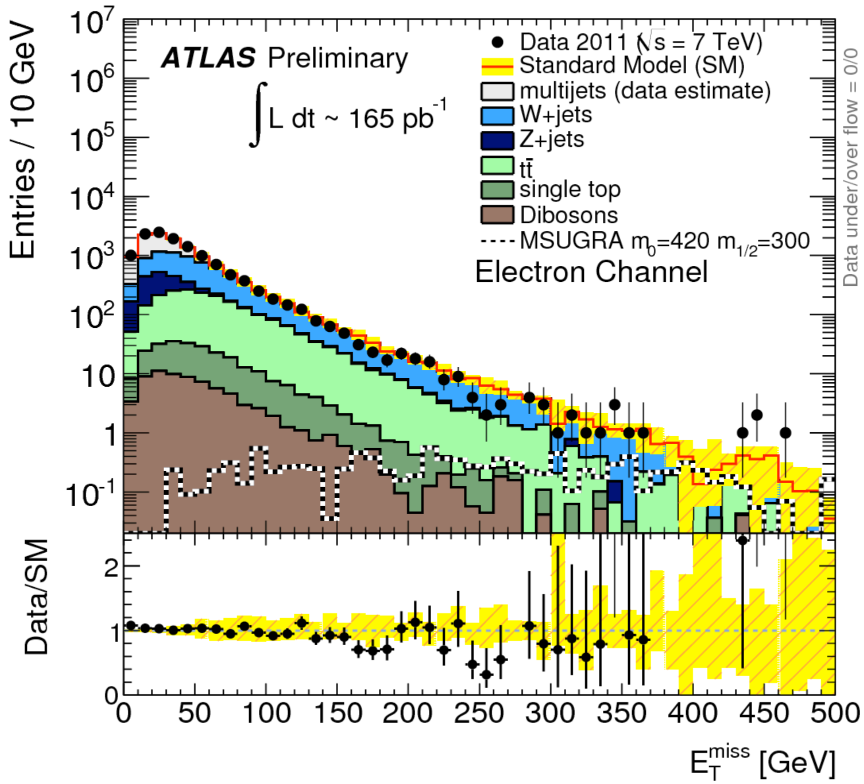
$$\text{Meff} = \sum_{i=1}^{NJets=3} p_T^{jet_i} + p_T^{\ell} + E_T^{Miss}$$

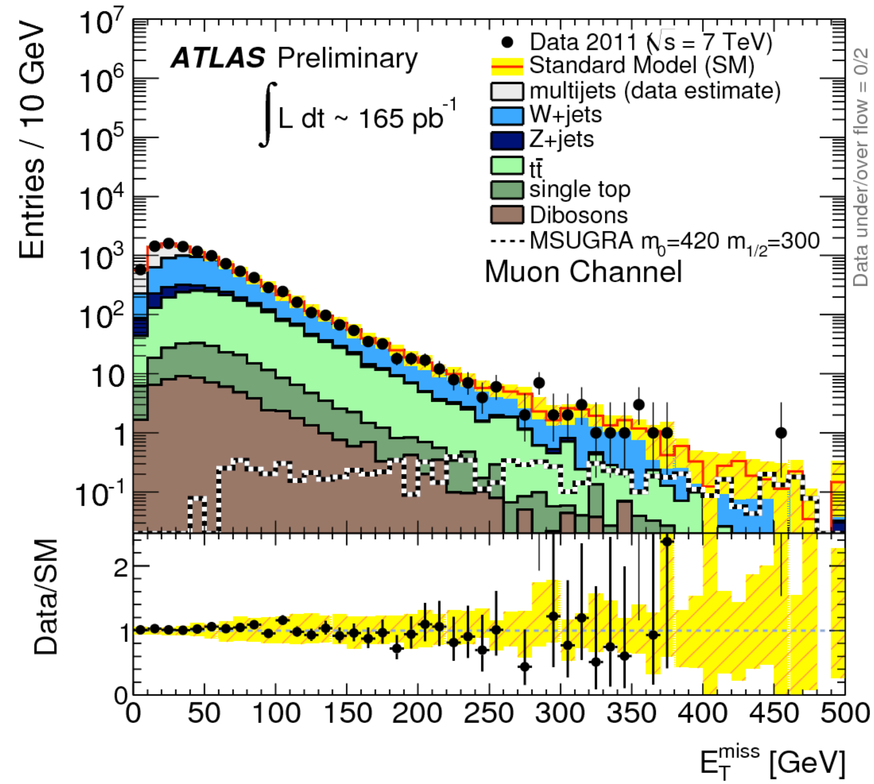
Signal Region	e-channel	μ-channel
Lepton p_T (GeV)	> 25	> 20
3 leading Jet p_T (GeV)	> 60, > 25, > 25	
$\Delta\phi(\text{Jet}_i, E_T^{Miss})_{min}$, i=1,2,3	**> 0.2**	
M_T (GeV)	**> 100**	
E_T^{Miss} (GeV)	**> 125**	
E_T^{Miss}/Meff	**> 0.25**	
Meff (GeV)	**> 500**	



2. 1-lepton search

Results – 2011 data



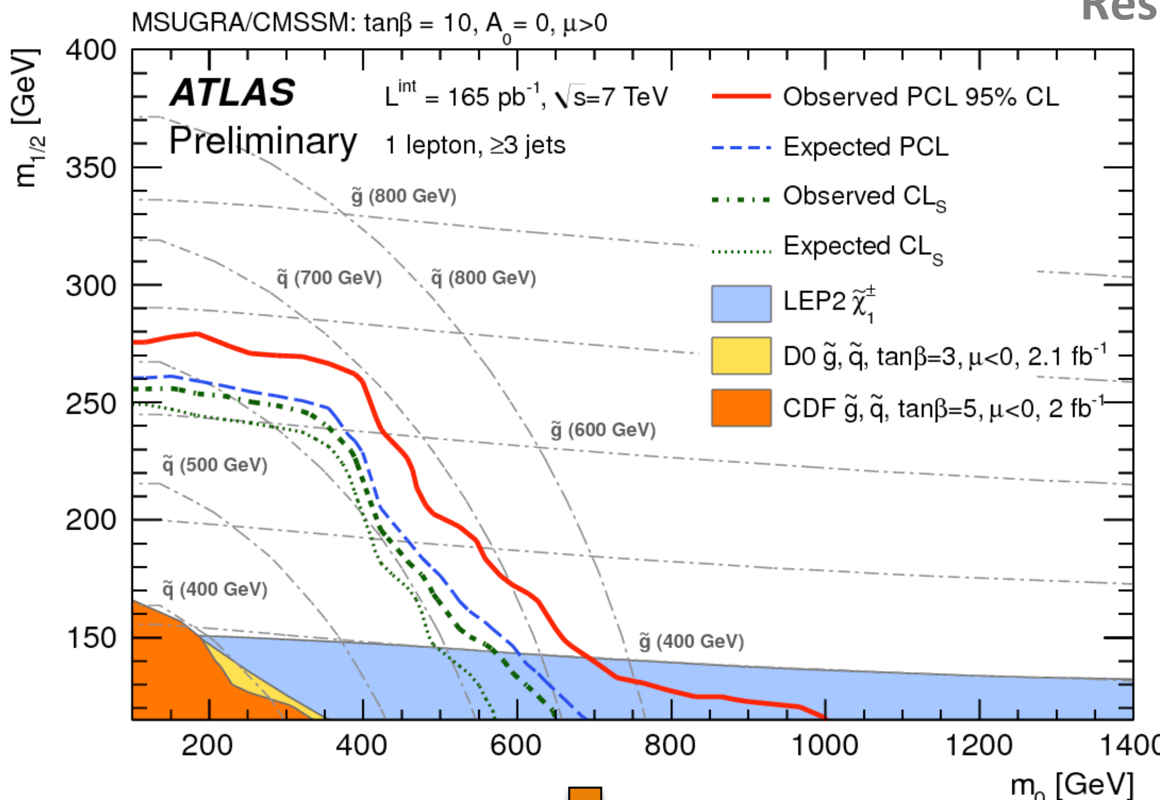


Total Expected Number of Events	**14.5 ± 5.2**
Observed	10

- Uncertainties dominated by Jet Energy Scale, Jet Resolution, limited MC statistics and theory uncertainty on background extrapolation.

2. 1-lepton search

Results – 2011 data



Exclude at 95% C.L.

- If m(gluino)=m(squark), masses<750GeV.

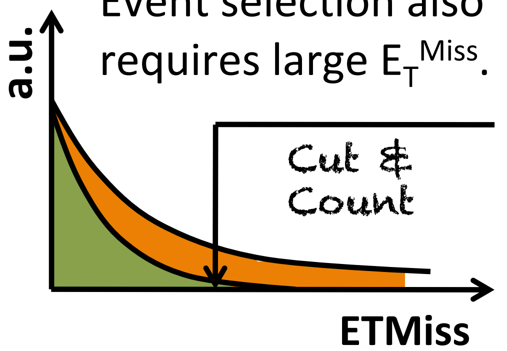
Exclude at 95% C.L. non-SM xsection × acceptance × efficiency

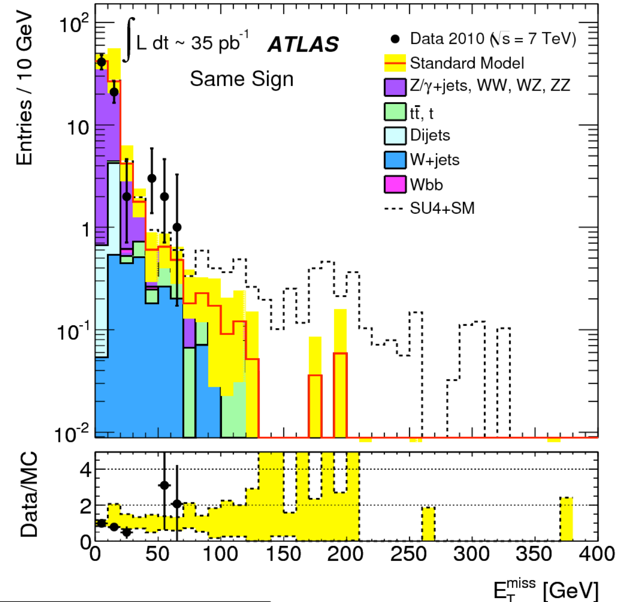
e-channel	μ-channel
41 fb	53 fb

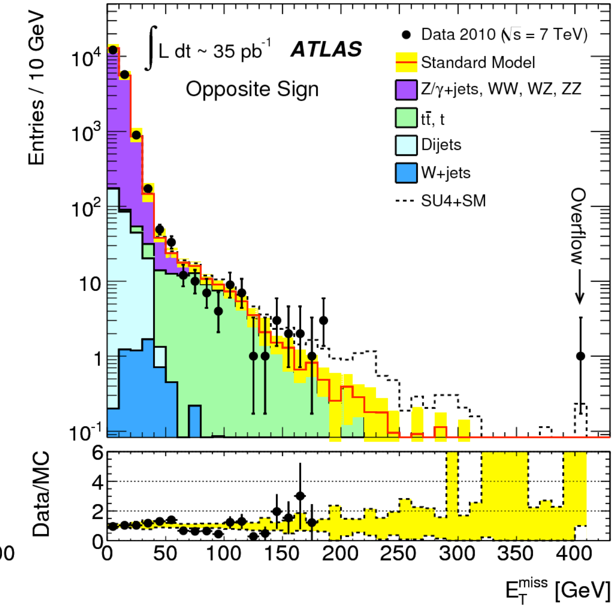
3. 2-lepton search

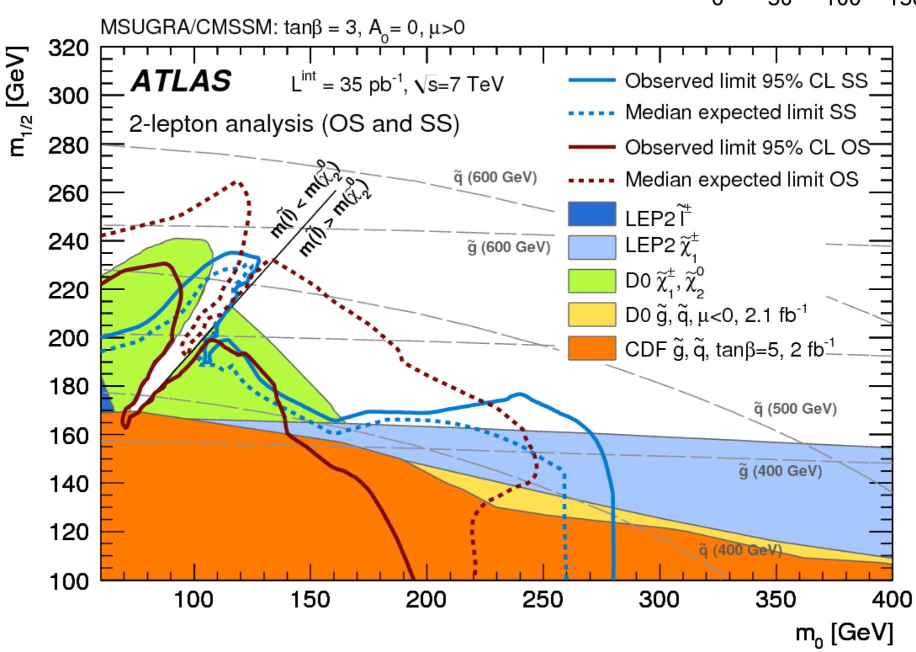
Observables and Results – 2010 data

- Search with same and opposite charge leptons, exactly two. Event selection also requires large E_T^{Miss}.







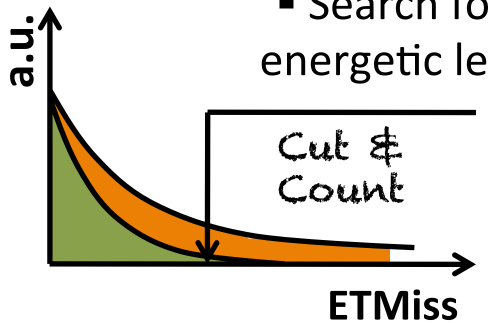


- Another analysis uses different flavor combination as control sample.
- Limits depend on SUSY mass hierarchy, but are in the range: **m(squark) > 450-690GeV**

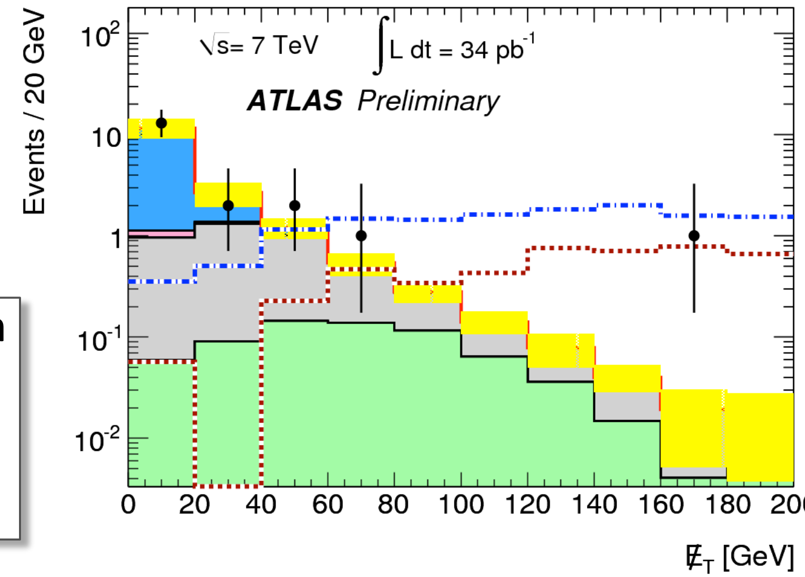
ArXiV:1103.6214, ArXiV:1103.6208

4. Multi-lepton search

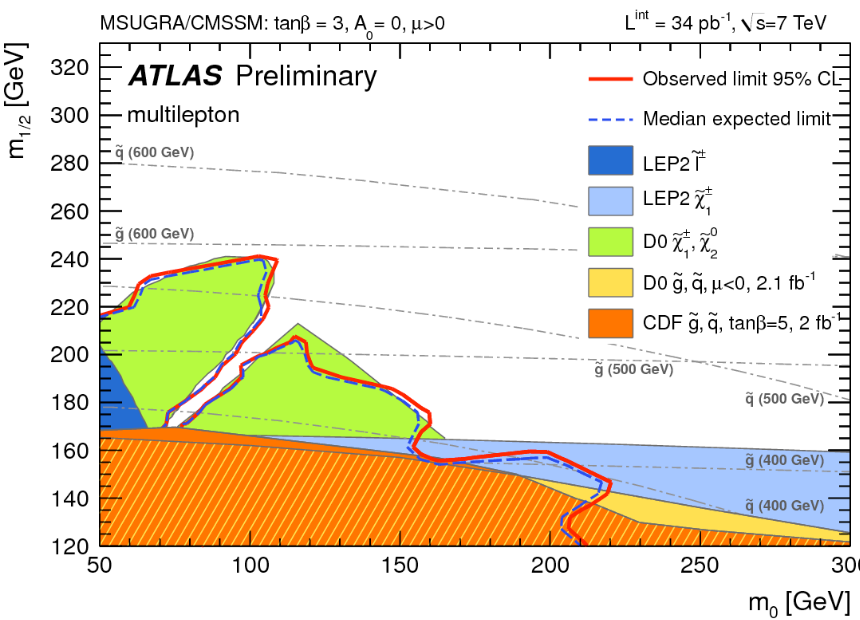
Observables and Results – 2010 data

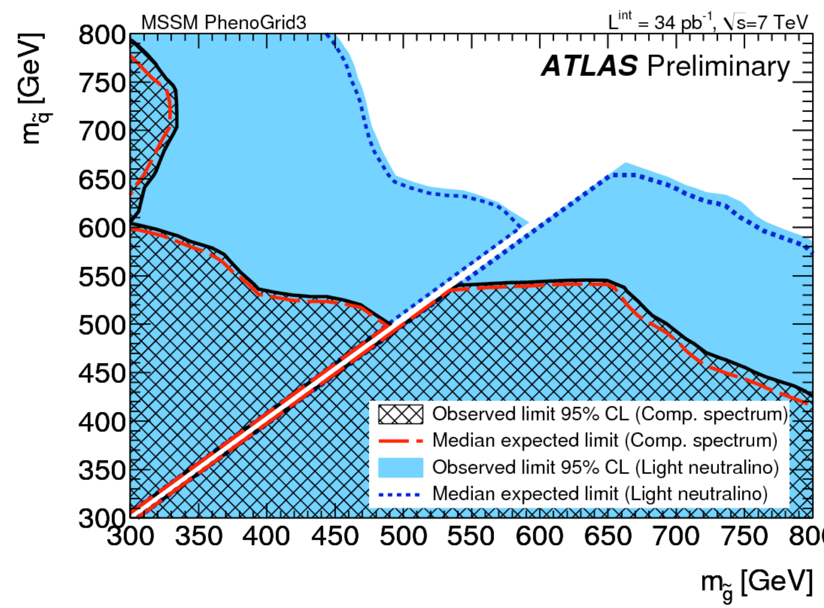


- Search for events with at least 3 energetic leptons, 2 jets and E_T^{Miss}.
- After a 4-lepton cut: 0.11 evts expected, 0 evts observed



- mSugra interpretation: limits similar to Tevatron
- MSSM Grid: assuming $m_{gluino} = m_{squark}+10$:
  - m_{squark}>540GeV (“compressed spectrum”)
  - m_{squark}>670GeV (“light neutralino”)



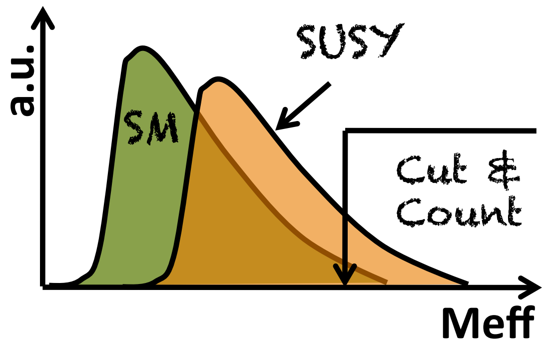


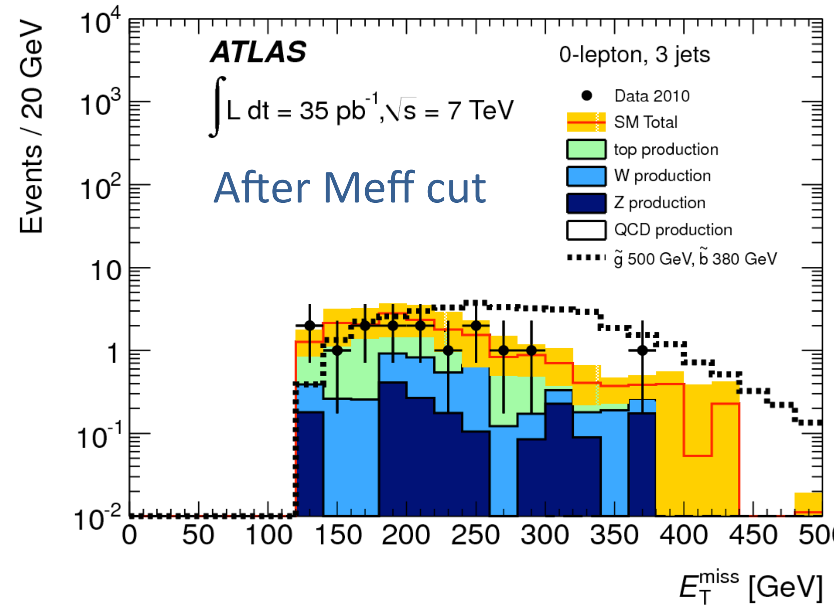
5. b-jet(s) (+ lepton) search

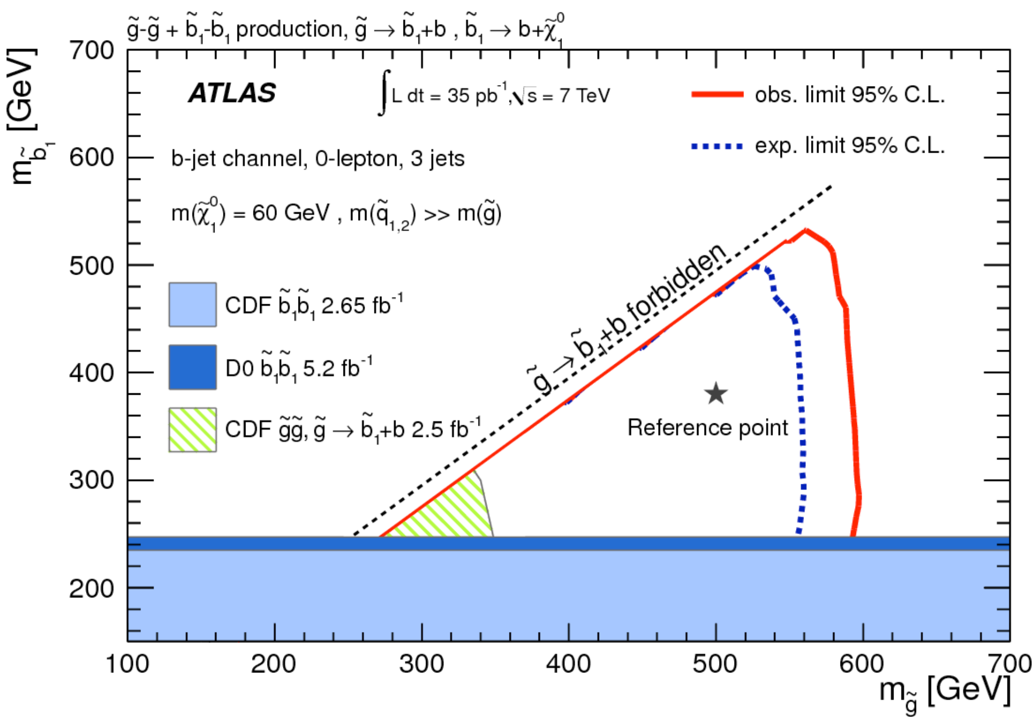
Observables and Results – 2010 data

- Two channels: 0- and 1-lepton
- Selections similar to 0- and 1-lepton inclusive analyses, add the requirement of at least 1 b-jet.

- Mixing effects would make the 3rd generation squarks much lighter than all other squarks.







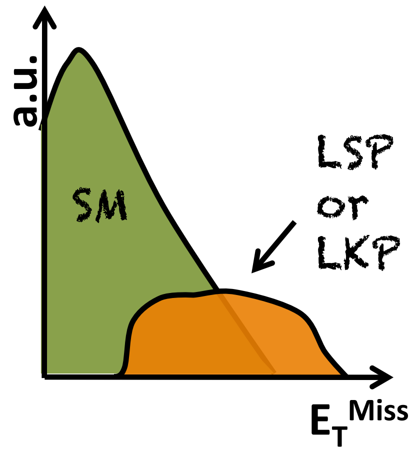
Channel	0-lepton	1-lepton
Total Expected	19.6 ± 6.9	14.7 ± 3.7
Observed	15	9

- Assuming BR($\tilde{g} \to b\bar{b}$) = 100%
  - m_{gluino}>590GeV

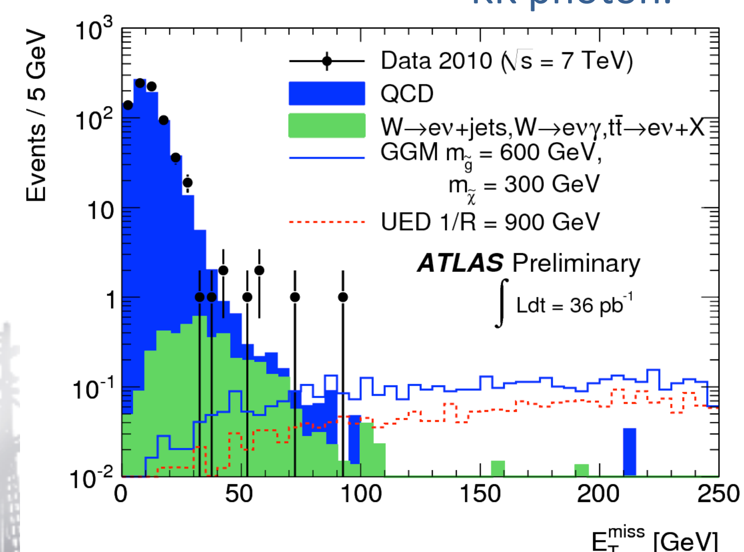
ArXiV:1102.5290

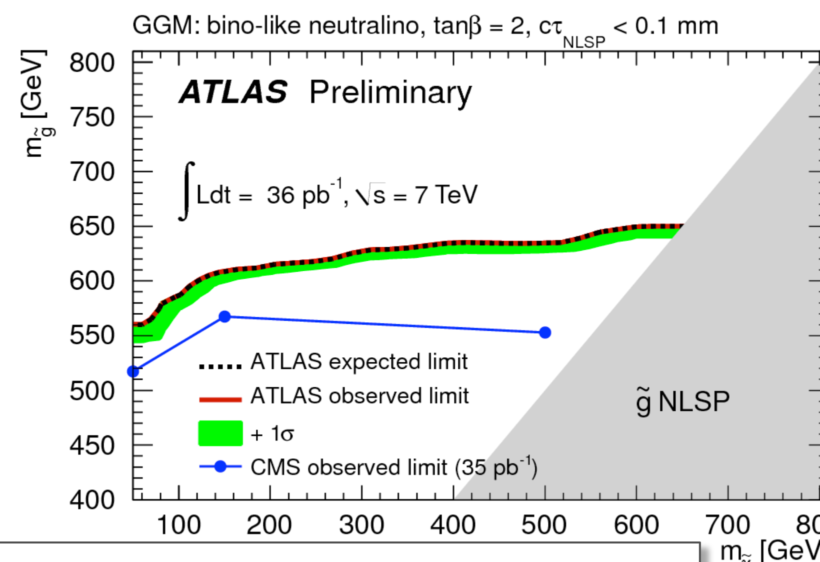
1. Di-photon & E_T^{Miss} search

Motivation, Observables and Results – 2010 data



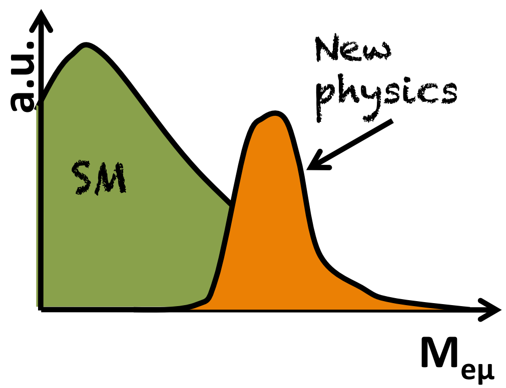
- In GMSB SUSY (SUSY breaking is Gauge-Mediated), the LSP is the gravitino, $\tilde{G}$.
  - Final decay in the cascade is dominated by $\tilde{\chi}_1^0 \to \gamma \tilde{G}$, with two cascades per event.
  - Leads in events with 2 photons and large E_T^{Miss}.
- Similar topologies are generated in Universal Extra Dimension (UED) models.
  - They predict excitations of SM particles (Kaluza-Klein particles).
  - In specific single UED models, the lightest KK particle (LKP) is a KK photon.





GGM gluino mass > 560 GeV at 95% C.L

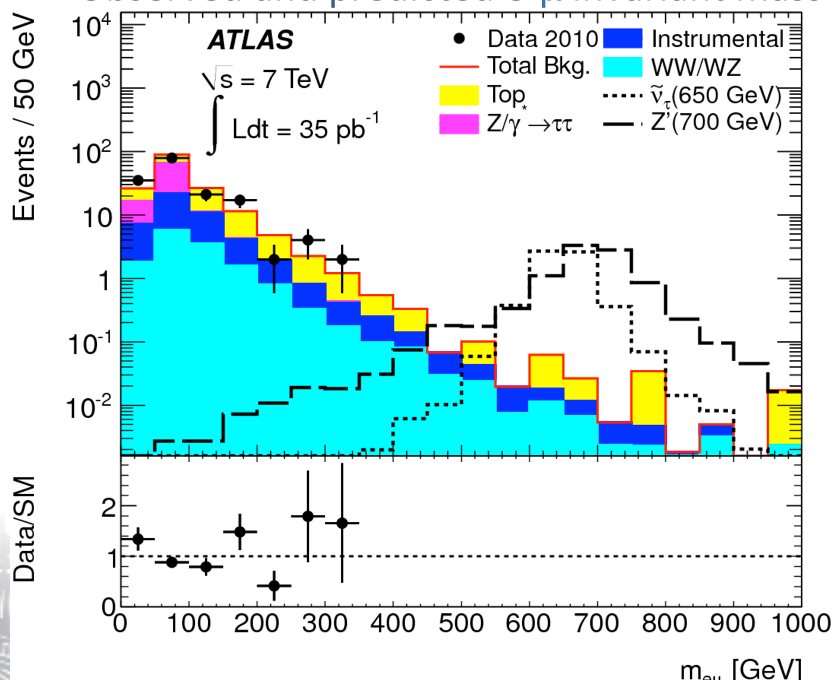
2. e+μ resonance search



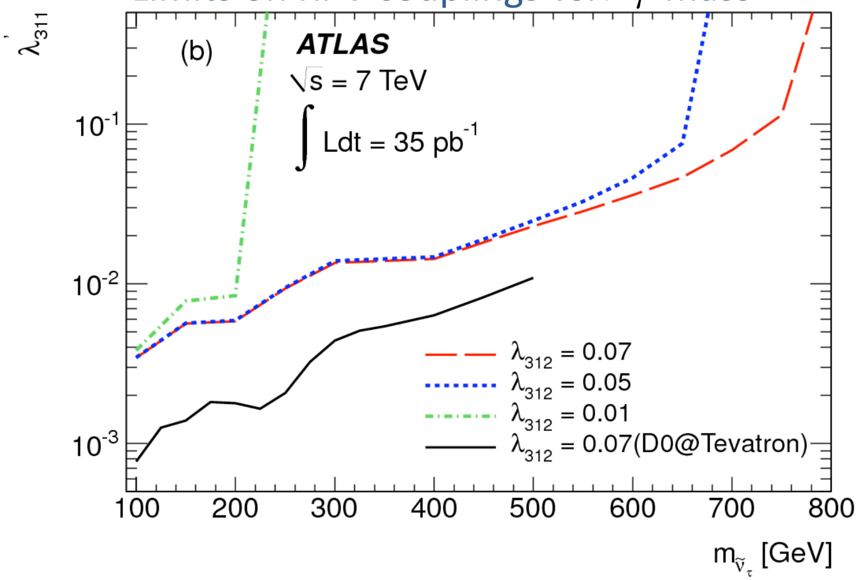
Motivation, Observables and Results – 2010 data

- Looking for **R-Parity Violating SUSY**: Single particles, Lepton Flavor Violation (LFV), no E_T^{Miss}.
  - $d\bar{d} \to \tilde{\nu}_\tau \to e\mu$
- Also sensitive to models with LFV decays of an extra gauge boson **Z'**.

Observed and predicted e-μ invariant mass



Limits on RPV couplings vs. $\tilde{\nu}_\tau$ mass

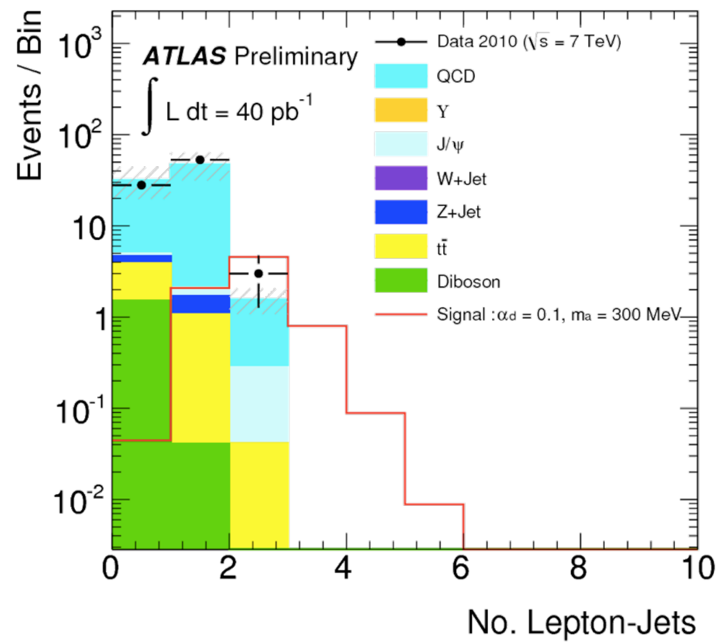


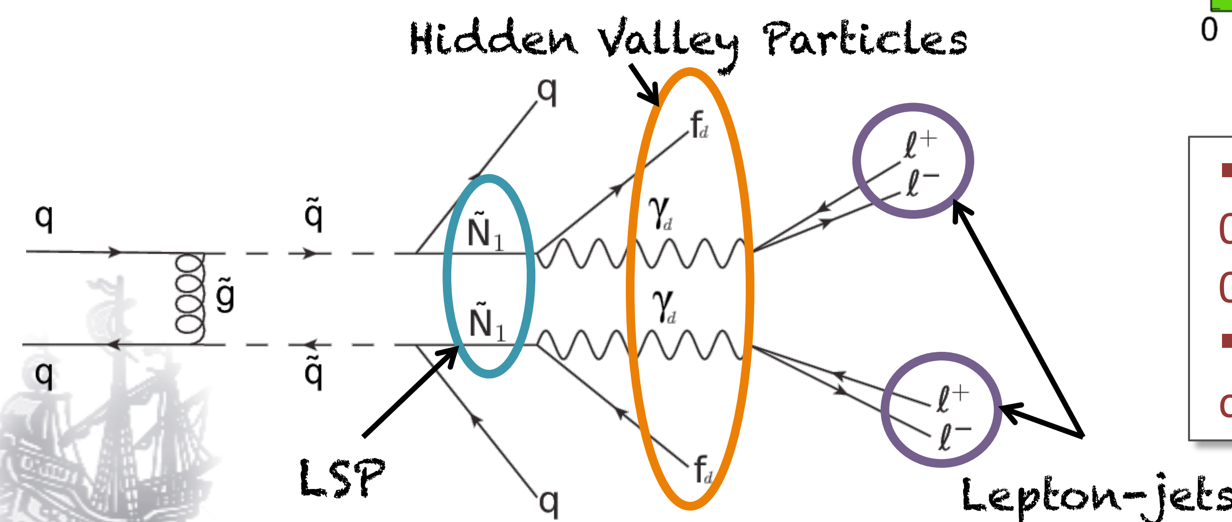
- For λ'_{311}=0.11 and λ_{321}=0.07, 95% C.L.:
  - m($\tilde{\nu}_\tau$) > 750 GeV

3. Lepton-jets search

Motivation, Observables and Results – 2010 data

- A light boson in a hidden sector, weakly coupled to the SM, could explain anomalies in dark matter detection experiments.
  - The proposed new boson, the dark photon, decays into SM fermion pairs, and promptly.
  - Collimated lepton-pairs (lepton-jets).
- In this search, selection requires two isolated lepton-jets, each of which contains at least two muons.





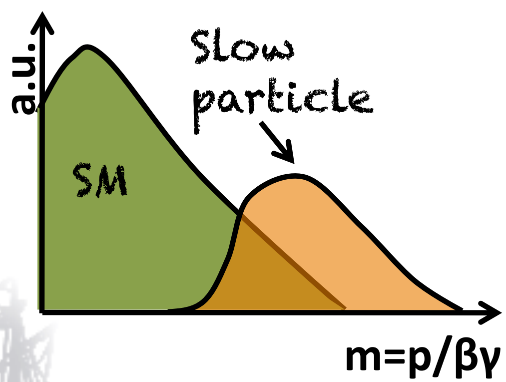
- After all selection cuts: 0.2±0.2 events expected
  0 observed
- Model-dependent limits on cross section of $O(0.2\text{pb})$

4. Search for slow-particles

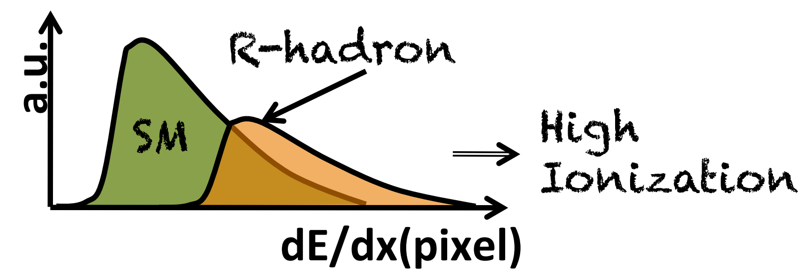
Motivation and Observables

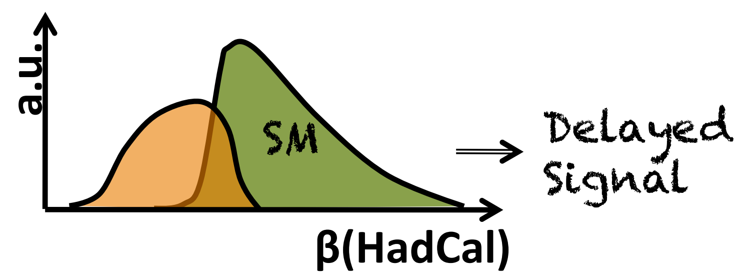
- Slow, heavy Long-Lived Particles (LLP), are predicted in a range of BSM theories, including SUSY.
- They travel significantly lower than **c**. Their mass can be measured from their velocity **β** and their momentum **p**: **m = p/βγ**.
- There are two ATLAS analyses looking for slow particles:

1. Search for R-hadrons, or long-lived sleptons. Relies on the particles reaching the Muon Spectrometer (MS). The search for sleptons uses ID & MS, the search for R-hadrons only uses MS.



2. Dedicated to R-hadrons (gluinos and squarks that hadronize). Uses tracking and calorimeter information only.



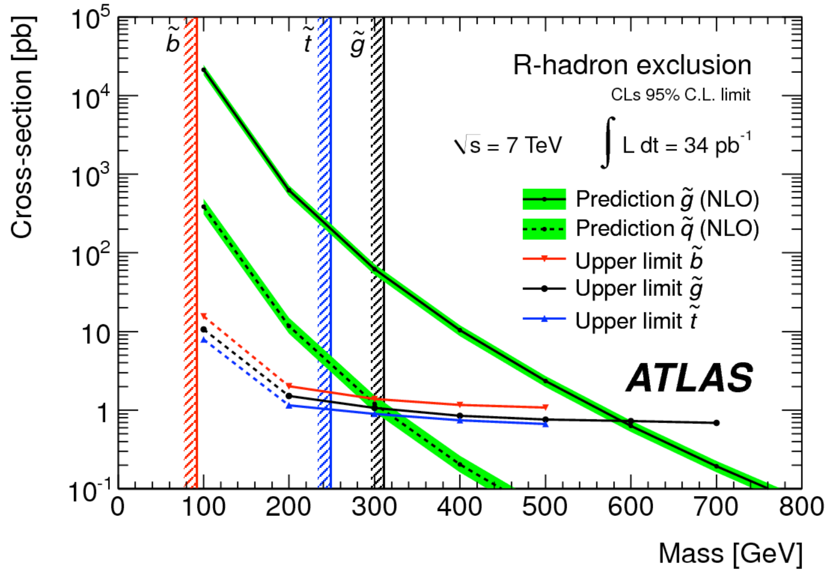


ArXiV:1106.4495

4. Search for slow-particles

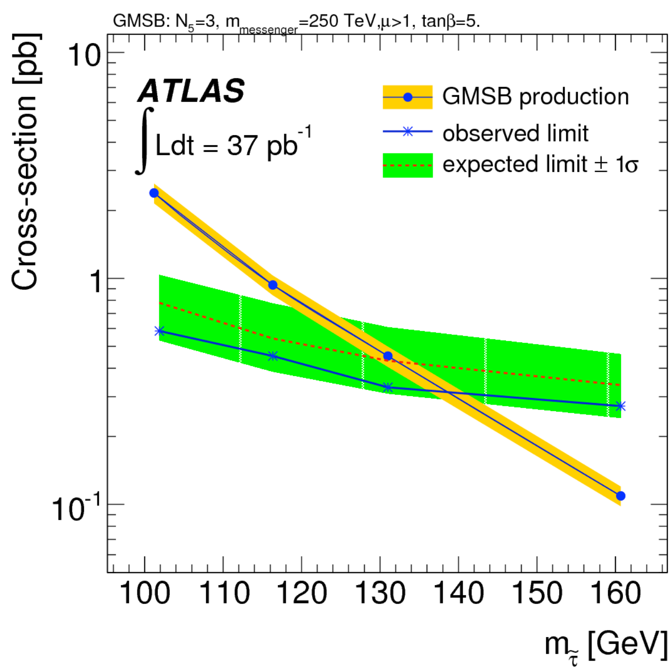
Results – 2010 data

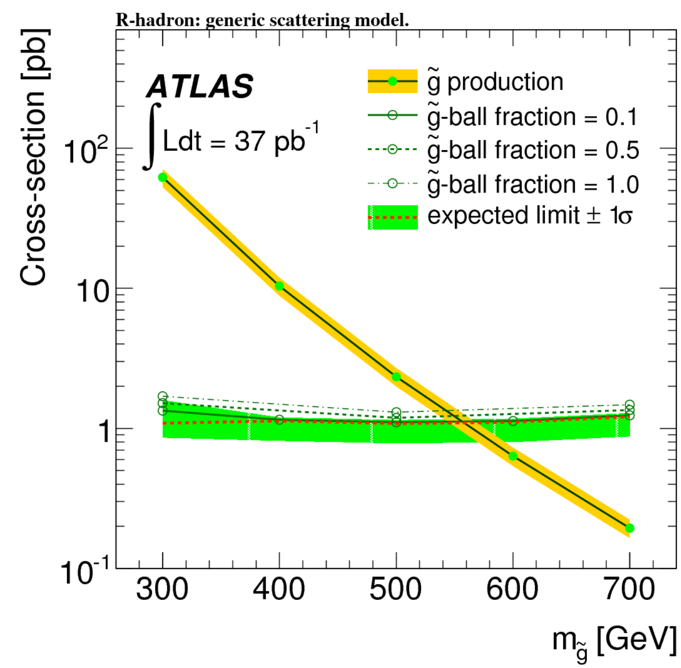
Results of MS-agnostic LLP analysis



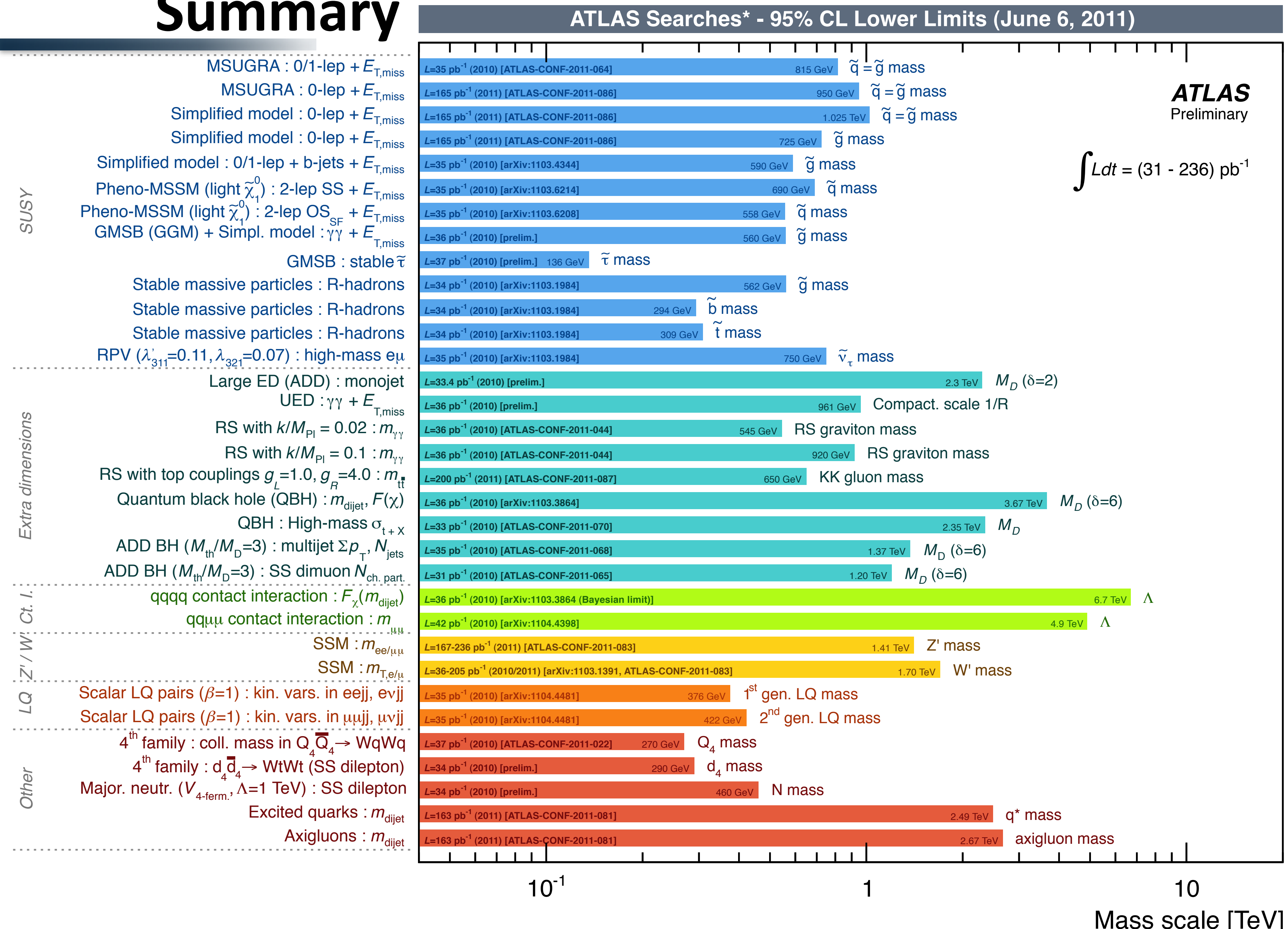
95% C.L. Exclusion from R-hadron MS-agnostic analysis:
sbottom < 294 GeV
stop < 309 GeV
gluino < 562–586 GeV

Results of MS-based LLP analysis





Summary



*Only a selection of the available results shown

What to expect from the future…

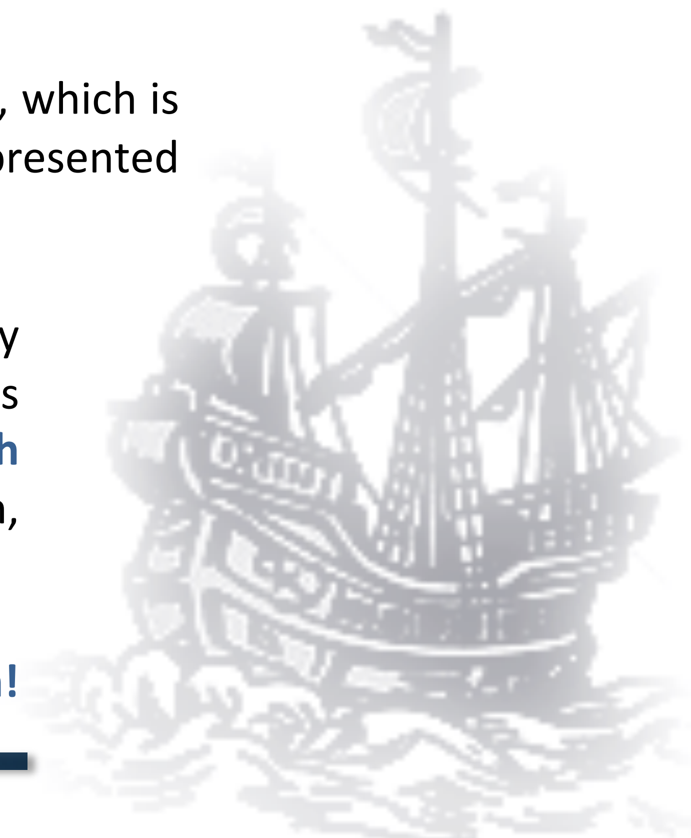
- On the road to discoveries, ATLAS already achieved a **well understood detector** and **well developed background estimation techniques**, tested in many important **Standard Model measurements**.

- Beyond the Standard Model searches have already provided results that **far exceed the Tevatron reach**. Many others keep on **expanding** the kinematic and parameter phase space reach.

- We already have available > 1fb^{-1} of data to analyze, which is more than 5-20 times the data used in the analyses presented in this talk.

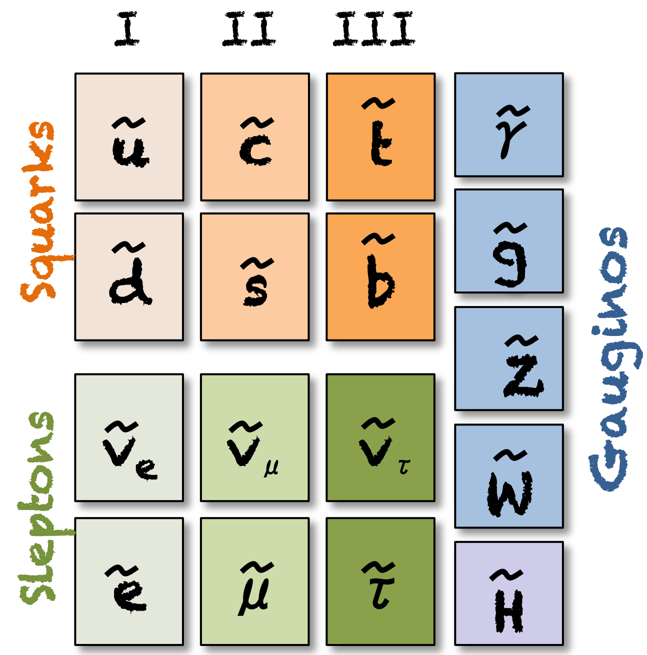
- On the road to discoveries, we won't necessarily address all the questions the Standard Model leaves open for us. However, the LHC gives us a **huge reach** and a **great potential** to answer many of them, **discovering the unexpected**.

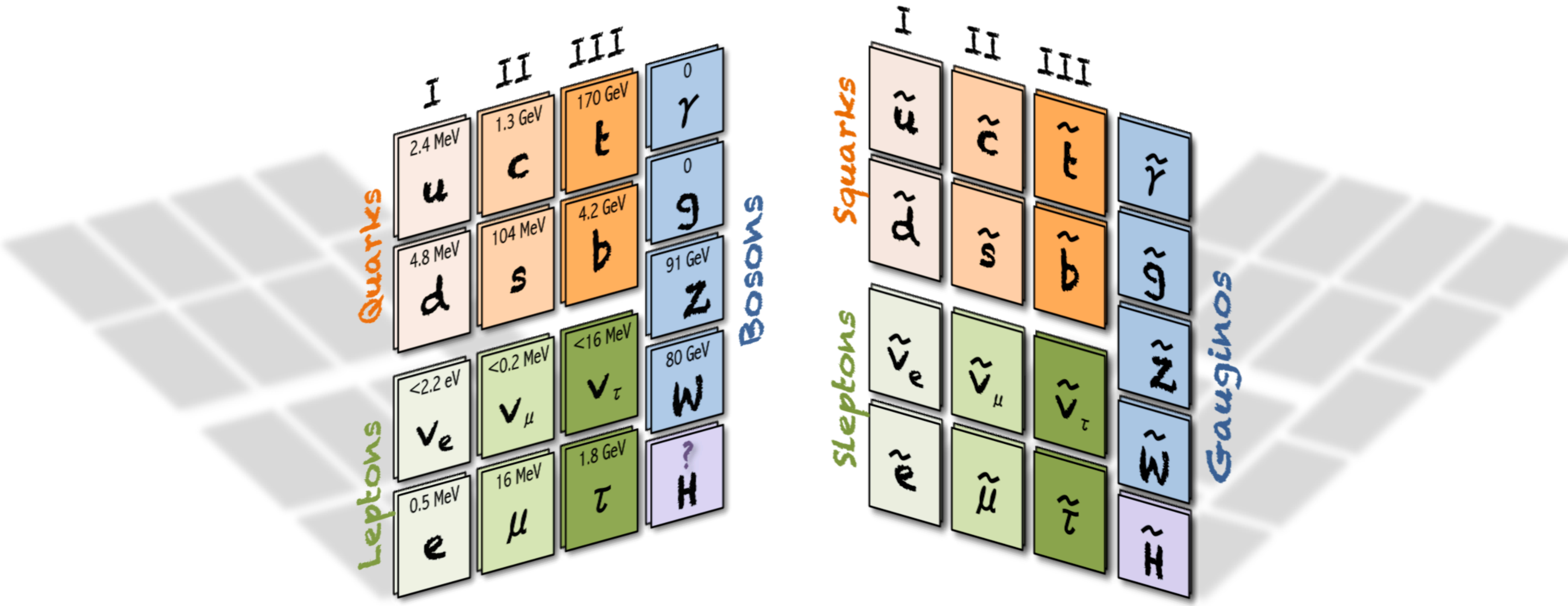
Our journey has just begun!



Some General References

- **ATLAS Public Results**: https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - **Exotics**: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
  - **SUSY**: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
- "**Outlook: the Next Twenty Years**", H. Murayama, LP03 proceedings.
- "**Supersymmetry Without Prejudice at the LHC**", J. Conley et al., ArXiV:1009.2539.
- "**How to Look for Supersymmetry Under the Lamppost at the LHC**", P. Konar et al., ArXiV:1008.2483.
- "**LHC 2010: Summary of the Odyssey So Far and Near-Term Prospects**", CERN Academic Training Lectures, P. Sphicas.
- "**Beyond the Standard Model**", J.D. Lykken, ArXiV:1005.1676v2.


I
II
III
Squarks
Sleptons
Gauginos
$\tilde{u}$ $\tilde{c}$ $\tilde{t}$
$\tilde{d}$ $\tilde{s}$ $\tilde{b}$
$\tilde{\nu}_e$ $\tilde{\nu}_\mu$ $\tilde{\nu}_\tau$
$\tilde{e}$ $\tilde{\mu}$ $\tilde{\tau}$
$\tilde{\gamma}$
$\tilde{g}$
$\tilde{Z}$
$\tilde{W}$
$\tilde{H}$


I
II
III
Quarks
Leptons
Bosons
2.4 MeV
u
1.3 GeV
c
170 GeV
t
0
γ
4.8 MeV
d
104 MeV
s
4.2 GeV
b
0
g
91 GeV
Z
<2.2 eV
νe
<0.2 MeV
νμ
<16 MeV
ντ
80 GeV
W
0.5 MeV
e
16 MeV
μ
1.8 GeV
τ
?
H
Squarks
Sleptons
Gauginos
ũ
c̃
t̃
γ̃
d̃
s̃
b̃
g̃
Z̃
ν̃e
ν̃μ
ν̃τ
W̃
ẽ
μ̃
τ̃
H̃