Exotics searches with ATLAS

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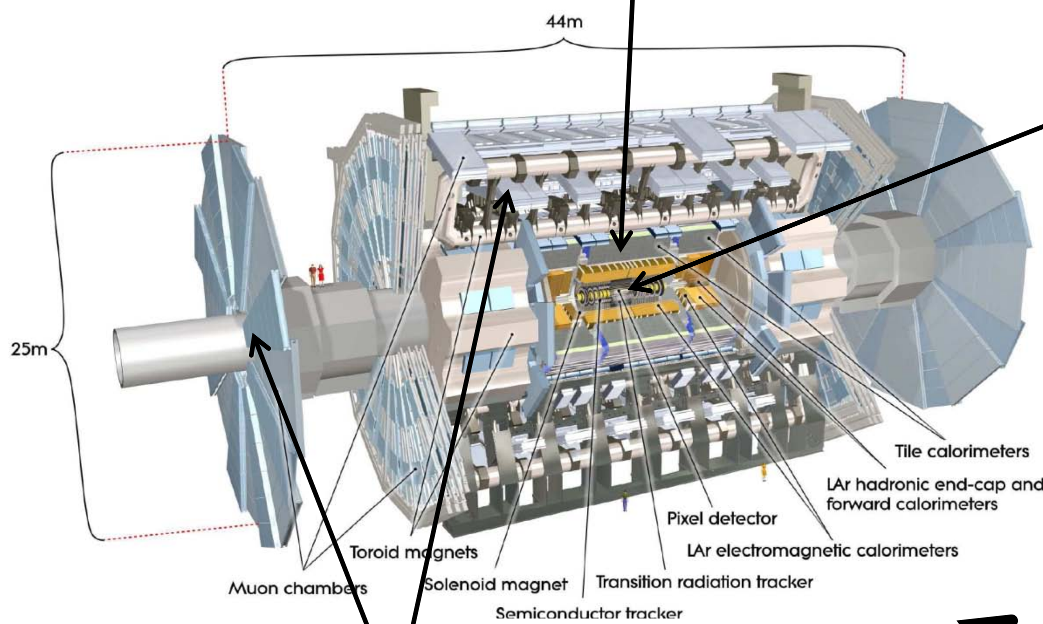
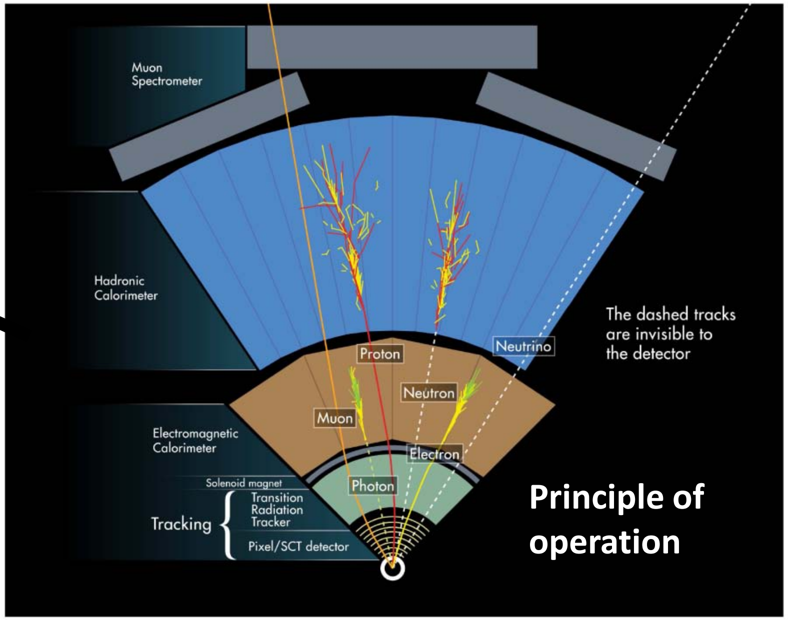
The ATLAS detector

Electromagnetic and hadronic calorimeters

Inner tracker:
- Silicon detectors
- Transition radiation detector



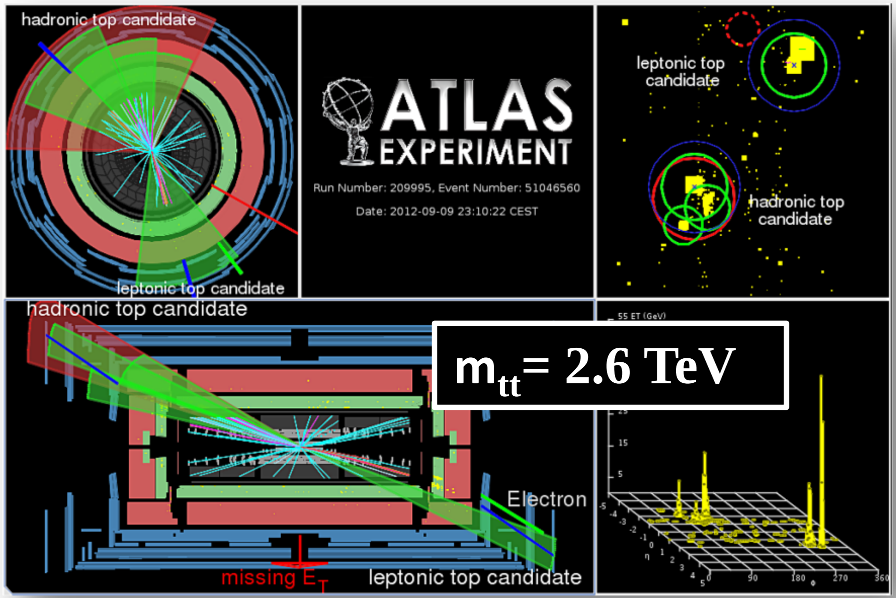
Muon spectrometer

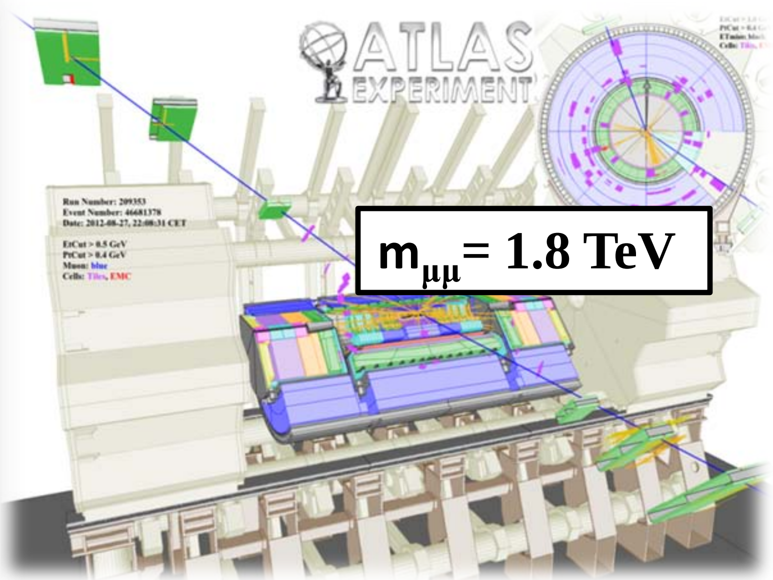


Outline

A wealth of exotics analyses at ATLAS – impossible to cover everything in a 15 min talk! – selection of results is presented:

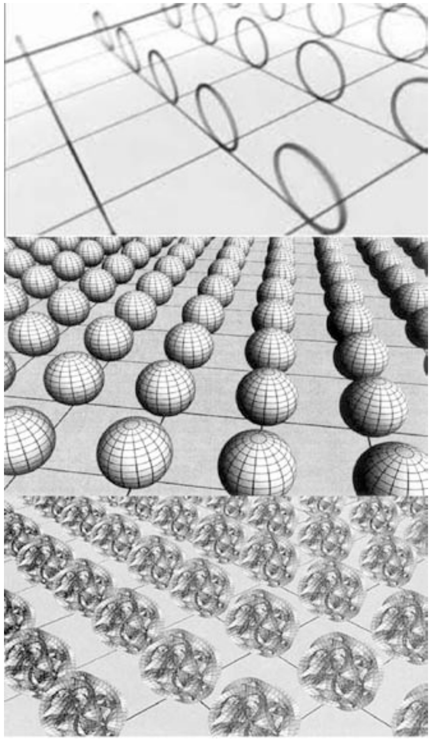
- **Extra dimensions** – solution to hierarchy problem
- **Dark matter** – WIMPs, gravitionos, hidden sectors?
- **Origin of neutrino masses** – seesaw mechanism?
- **Vector-like quarks** – a non-SUSY solution to naturallness problem





Extra dimensions

Models of extra dimensions:



- **4 +1** – one warped extra dimension – RS model:
  ttbar resonances (via Kaluza-Klein excitations of gluon); dilepton or diphoton resonances.

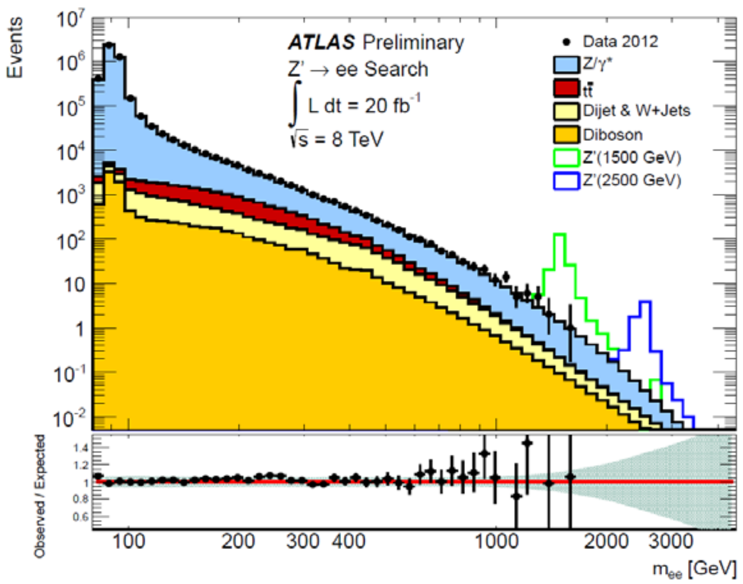
- **4 + n** – n large flat extra dimensions – ADD models:
  Microscopic black holes;
  Heavy KK excited states of graviton (escape the detector, giving raise to significant missing transverse momentum)

- Extra dimensions are compactified at some scale, leading the weakness of gravity in 4 space-time dimensions → apparent Planck scale is 19 orders of magnitude higher than electroweak scale.

- The ``truth'' Planck scale in 4+n dimensions is postulated to be of the order of electroweak scale.

Extra dimensions

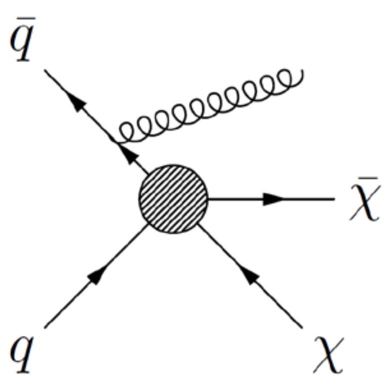
- **Search for heavy resonances**
  - Dielectron and dimuom
  - Di-tau
  - Di-photon
  - ttbar
  - jet-jet
  - Jet-photon
  - photon-photon
  - ZZ-resonances

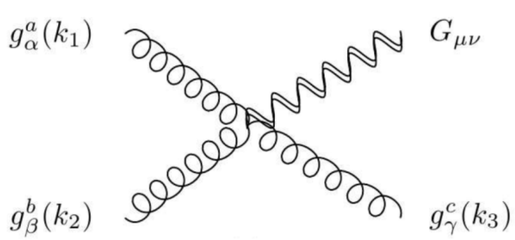


Also sensitive to GUT models, technicolor, extended Higgs sectors, etc.

- **Multi-track (e.g. micoroscopic black holes)**
- **Mono-object with high missing transverse momentum**
  - Mono-jet
  - Mono-photon
  - Mono-W(Z)

Also sensitive to WIMP dark Matter and SUSY gravitinos





Extra dimensions

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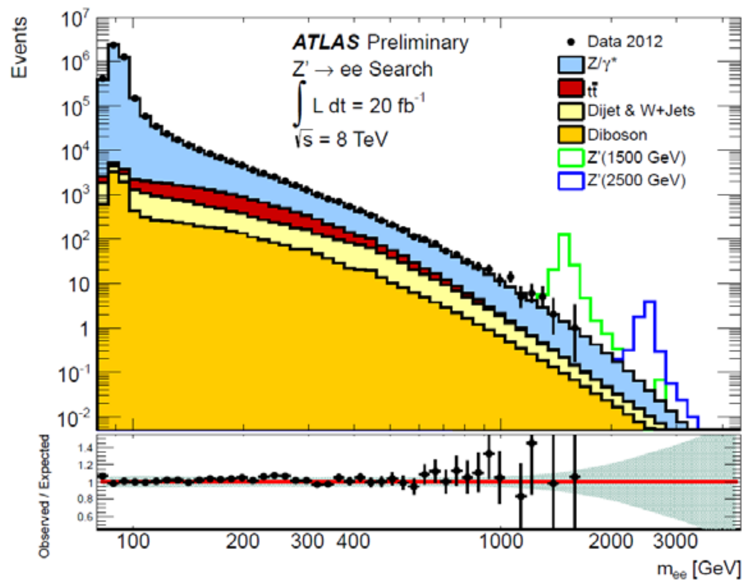
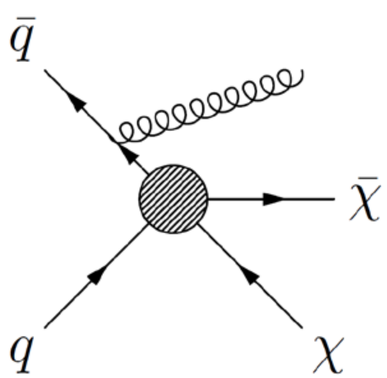
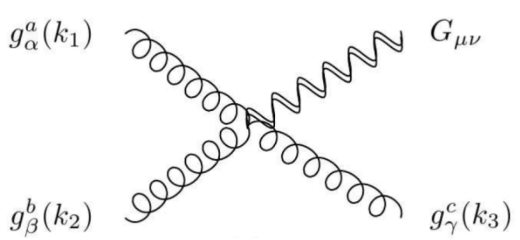


Also sensitive to GUT models, technicolor, extended Higgs sectors, etc.

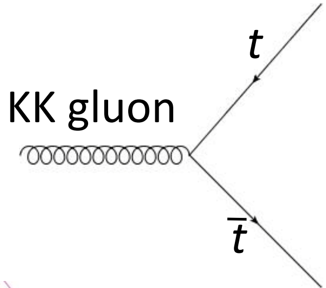
- **Multi-track (e.g. micoroscopic black holes)** ***New!***
- **Mono-object with high missing transverse momentum**
  - Mono-jet
  - Mono-photon
  - Mono-W(Z)

Also sensitive to WIMP dark Matter and SUSY gravitinos

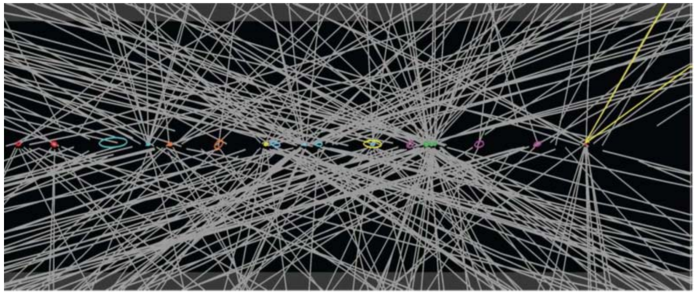


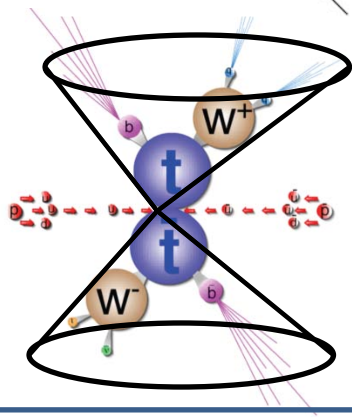


Extra dimensions: ttbar



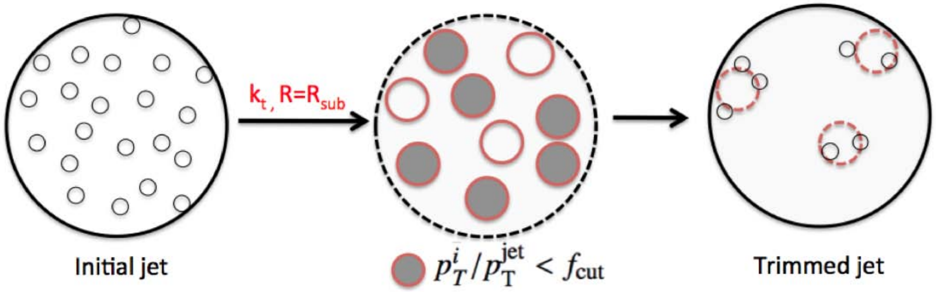
The extremely high pile-up of about 20 *pp* collisions per bunch crossing in 2012!



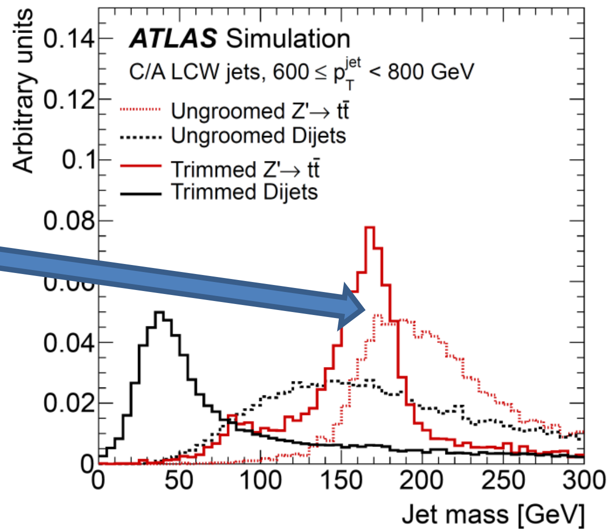


Pile-up represents a challenge for top-quark reconstruction

Advanced jet "grooming" is applied



- Subjets are formed with R=0.3; soft subjets with less than a certain fraction of the original jet pT are removed;
- **JVF > 0.5.** ***mitigates the effect of pileup***
  JVF is the summed transverse-momentum p_T of all tracks matched to the jet from the primary vertex divided by the summed p_T of all matched tracks from all vertices.



Background	2400 ± 500	3300 ± 700	5600 ± 1200
Data	2177	2945	5122

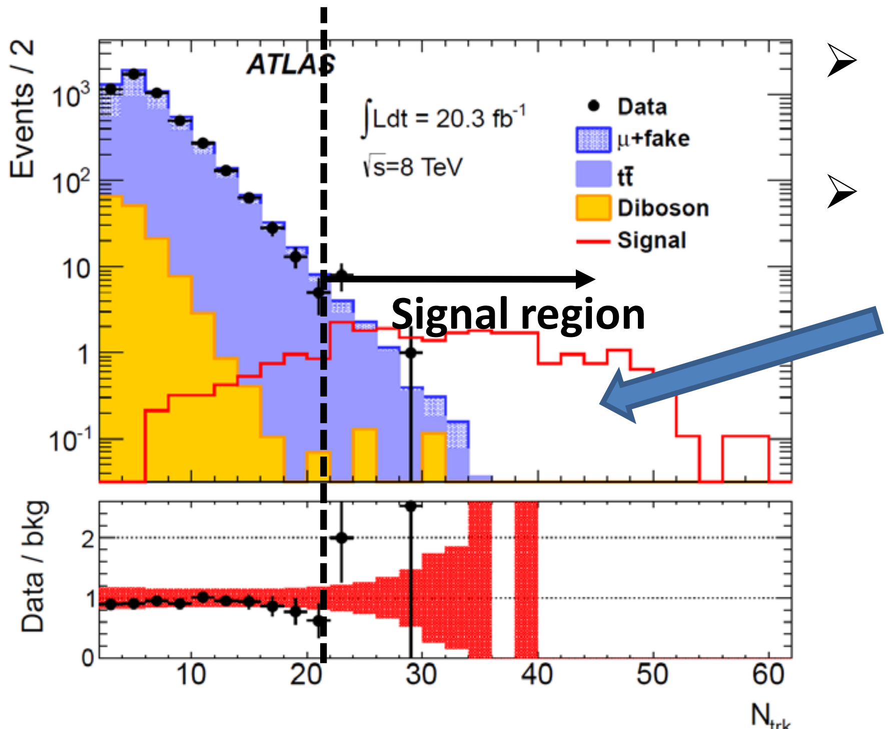
ATLAS-CONF-2013-052, arxiv:1306.4945

Extra dimensions: multi-track

- If one assumes the fundamental Planck M_D scale in n+4 dimensions order of 1 TeV, **microscopic black holes with TeV-scale mass could exist and be produced at LHC!**

  Black Hole (BH)production has a continuous mass distribution ranging from M_D to pp mass; ***BH are produced when the impact parameter of the two colliding protons is smaller than the higher-dimensional event horizon of a black hole with mass equal to pp mass.***

Black holes



- BH evaporate by emitting Hawking radiation
- **BH events are expected to have a high multiplicity of high-momentum particles!**

arxiv:1308.4075

Source	Signal Region
μ+fake	$0.21 \pm 0.09 \pm 0.09$
$t\bar{t}$	$0.22 \pm 0.08 \pm 0.04$
Diboson	$0.12 \pm 0.08 \pm 0.03$
Total	$0.55 \pm 0.15 \pm 0.10$
Data	0
Signal	$14.2 \pm 1.3 \pm 2.7$

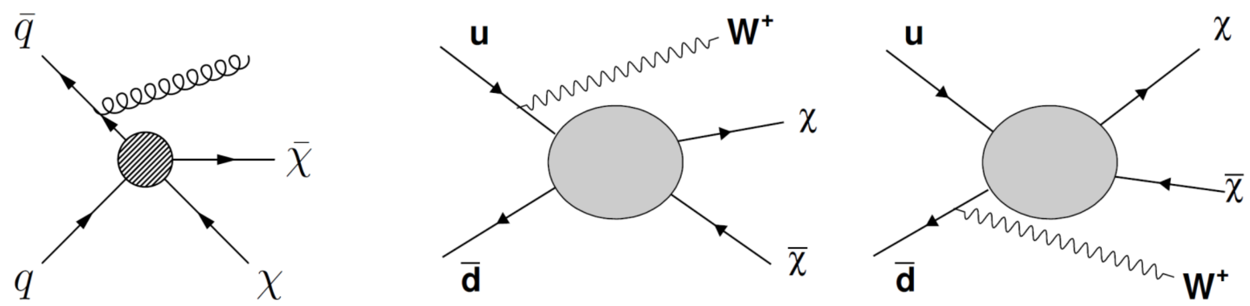
N_{muons} >= 2 (100 GeV)
N_{trk} >= 30 (10 GeV)

No deviation from SM prediction → BH mass below 5 TeV are excluded at 95% CL

Dark matter

WIMP dark matter

ATLAS-CONF-2012-147, ATLAS-CONF-2013-073, arXiv:1209.4625



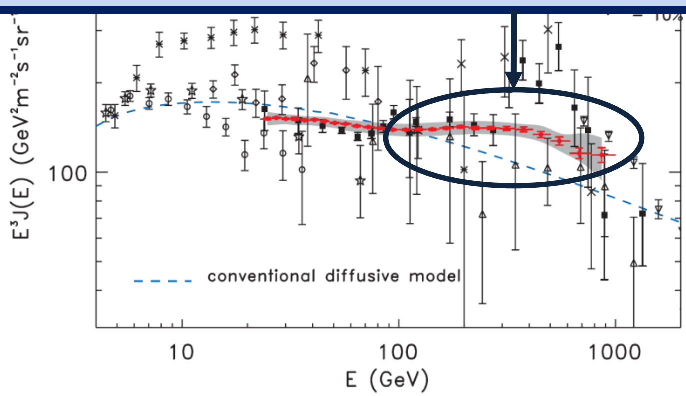
- pp→$\chi\chi$ + g / γ / W / Z – pair of WIMPs (with mass below few TeV) are produced in association either with **single gluon or photon or W(Z) gauge boson**
- **WIMPs escape detection giving rise to significant missing transverse momentum**

These analyses are also sensitive to gravitino DM production

Non-standard WIMP scenarios: *hidden-sectors*

Assumption of Arkani-Hamed *et.al.*:
WIMP-like Dark Matter is charged under the hidden-sector gauge group, which is broken at a GeV scale

Provides an elegant explanation of Fermi / Pamela/AMS electron (positron) anomaly



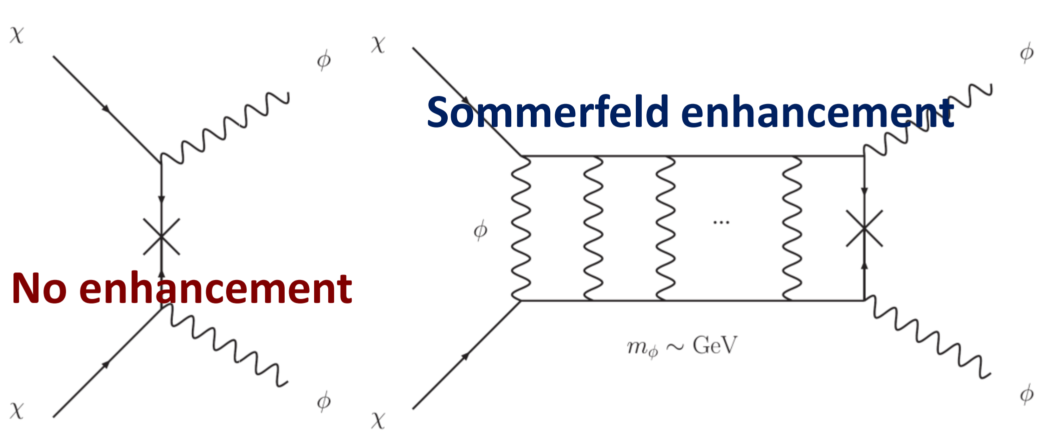
Dark matter: lepton-jets

The conventional WIMP models can't address the PAMELA anomaly for two main reasons:

1. Annihilation rate of dark matter should be a few orders of magnitude larger than the annihilation rate that produces the correct DM relic abundance;
2. Dark Matter should annihilate predominantly into leptons and not hadrons.

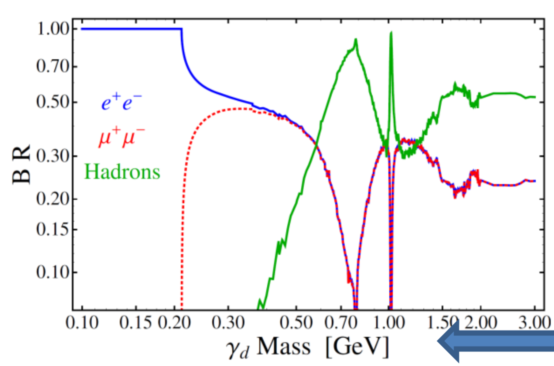
*Hidden sectors models feature massive gauge U(1) boson – **dark photon** with mass < 2 GeV:*

1. Annihilation cross-section is enhanced via Sommerfeld mechanism:



2. Decays to protons are kinematically forbidden

*Manifest itself at hadron colliders through the **lepton jets** – collimated sets of electrons/muons/pions*

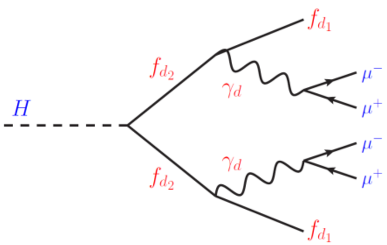


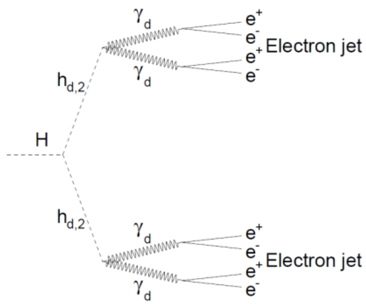
Depending on the strength of mixing between dark photon and SM photon, lepton jets can be either prompt (originating from interaction point) or displaced

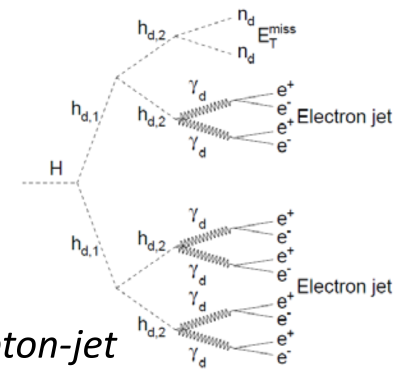
Branching fraction of dark photon w.r.t. its mass

Dark matter: lepton-jets

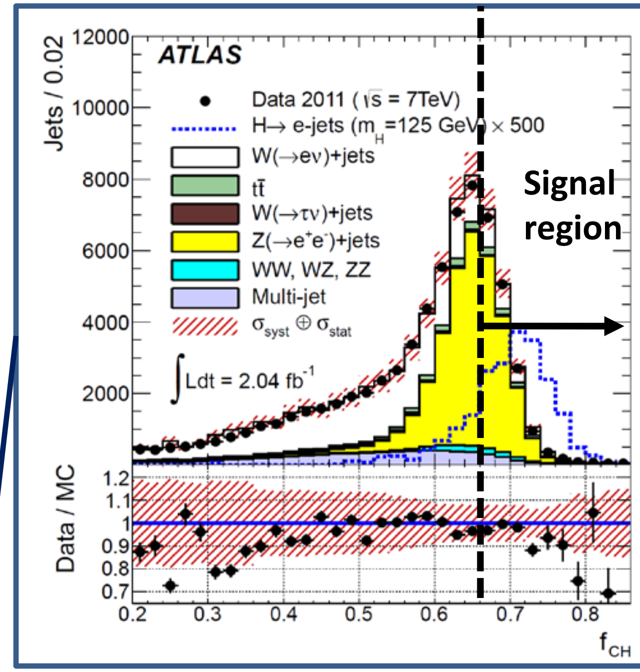
Lepton jets can be produced in the decays of Higgs boson:







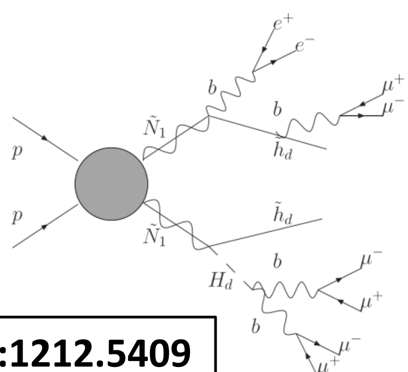
possibly from 2 to about ten leptons per lepton-jet



Advanced signal/background discriminating parameters are used: f_{CH} *–fraction of jet energy deposited in the calorimeter cells within a cone of R = 0.2 around each of the tracks associated with the jet*

arxiv:1302.4403, 1210.0435

… or directly in the SUSY cascade (f. ex. through squark or neutrlino channels):



arxiv:1212.5409

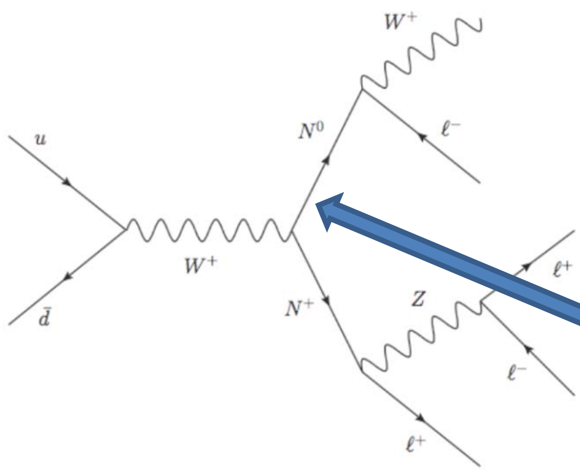
Backgrounds:

- multi-jet
- photon + jet

Background yield is determined from data using ABCD-likelihood method

	2 e-jets	1 μ-jet	2 μ-jets
Data	15	7	3
All backgrounds	15.2±2.7	3.0±1.0	0.5± 0.3

Origin of neutrino masses: multilepton



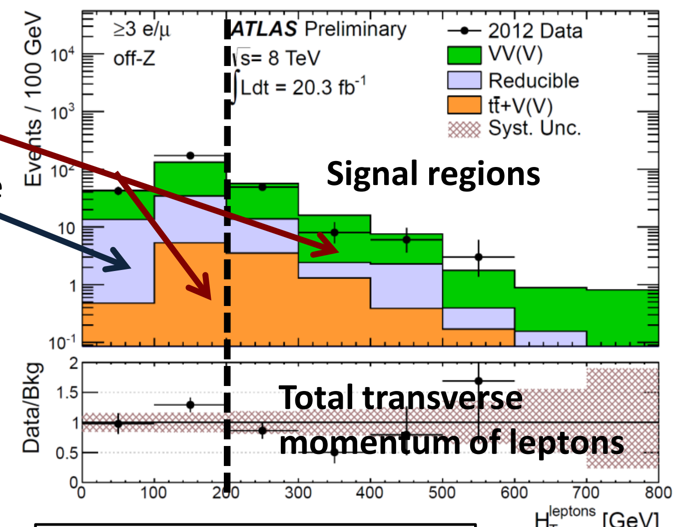
Seesaw mechanism → light neutrino masses are generated by adding new massive particles to the model

... these are f.ex. New heavy fermions N^0, N^+, N^-, in type-III seesaw models

Decays of new heavy particles result in events with more than two energetic, prompt and isolated charged leptons

Irreducible SM backgrounds: WZ, ZZ where both bosons decay leptonically, tt+W(Z), Drell-Yan

Reducible SM backgrounds: semi-leptonic decays of *b*- or *c*-hadrons, jets penetrating muon spectrometer, etc. – determined from the data using the fake factor method – **up to 50% systematic uncertainty**

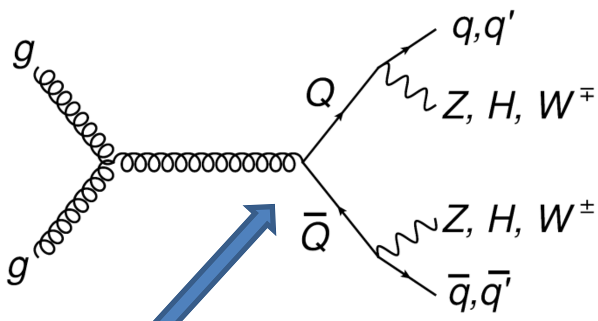


ATLAS-CONF-2013-070

4 signal regions:

Flavor Chan.	Z Chan.	Expected			Observed
$\geq 3e/\mu$	off-Z	260 ±	10 ±	40	280
$2e/\mu + \geq 1\tau_{had}$	off-Z	1200 ±	10 ±	290	1193
$\geq 3e/\mu$	on-Z	3100 ±	40 ±	500	3199
$2e/\mu + \geq 1\tau_{had}$	on-Z	17000 ±	40 ±	4000	14733

Vector-like quarks

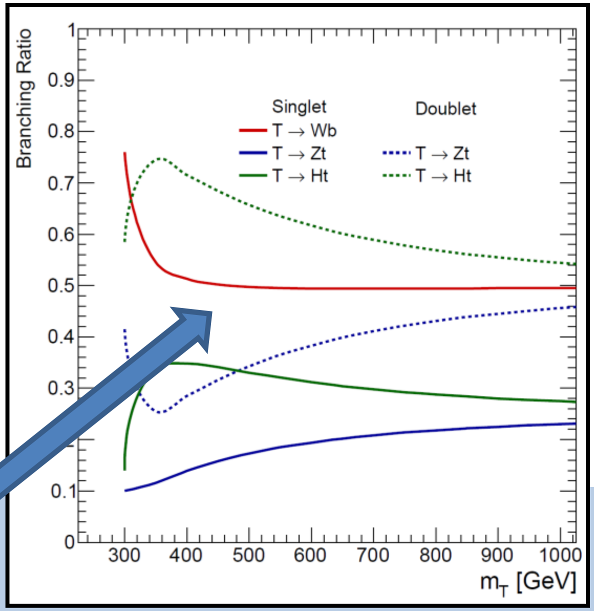


Vector-like quarks : *both chiralities have the same transformation properties under SM SU(2) x U(1)*

Vector-like quarks emerge as a characteristic feature of many non-SUSY natural models

Vector-like top-partner quark T plays a key role in cancelling the quadratic divergences in the Higgs boson mass (induced by t-quark)

T quark mixes preferentially with the 3rd generation quarks → signal events feature high multiplicity of jets plus isolated prompt leptons

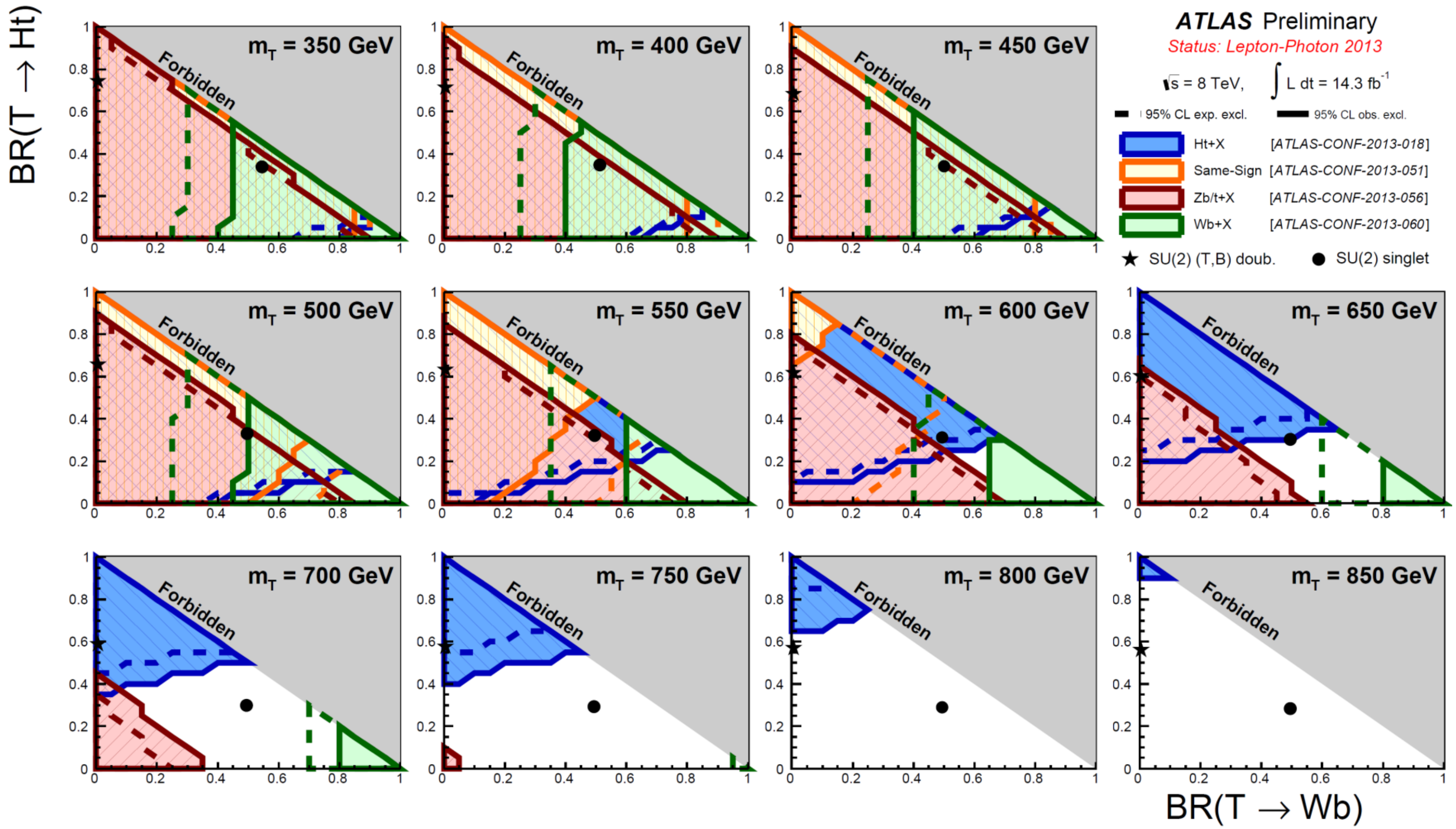


Decays of T-quark involve W,Z or Higgs boson → many complementary analyses are performed:

Analysis	leptons	jets	b-jets	E_T^{miss}	Preprint
Ht + X		≥ 6	≥ 2		ATLAS-CONF-2013-018
Same-sign dilepton	$e^{\pm}e^{\pm}$ / $\mu^{\pm}\mu^{\pm}$	≥ 2	≥ 1	40 GeV	ATLAS-CONF-2013-051
Zb/t + X	$Z \rightarrow ee(\mu\mu)$		≥ 2		ATLAS-CONF-2013-056
Wb + X	e/μ	≥ 4	≥ 2	20 GeV	ATLAS-CONF-2013-060

Vector-like quarks

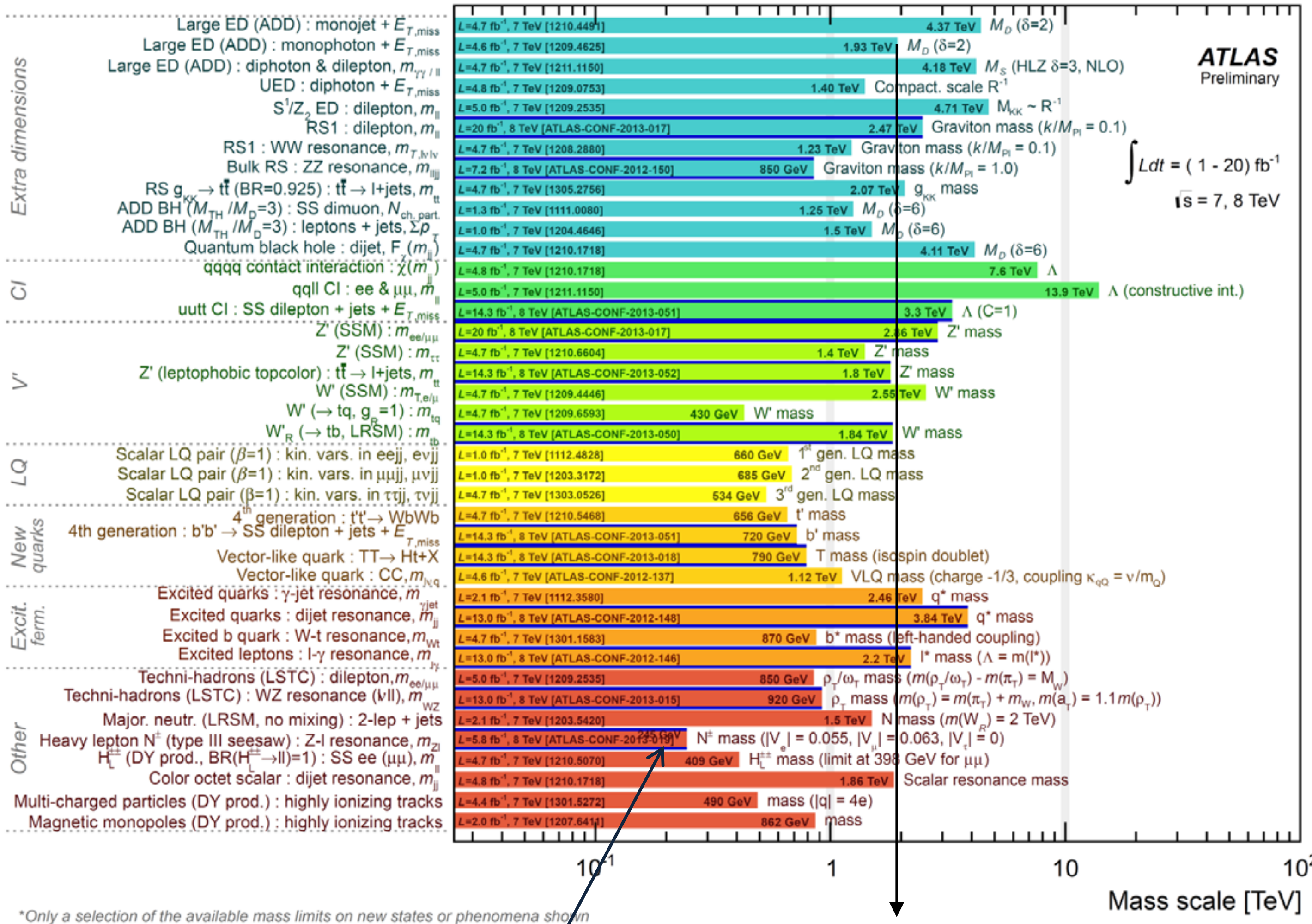
95% confidence level exclusion contours with respect to branching fractions and for different masses of vector-like T quark:



Vector-like T quarks with masses in the range 350–550 GeV are completely excluded

Summary of Exotics searches

Mass reach for various ATLAS exotics analyses:



Dark blue lines indicate 8 TeV results

Fundamental Planck scale in Large extra dimensions (ADD models) below 1.9 TeV is excluded

Conclusions

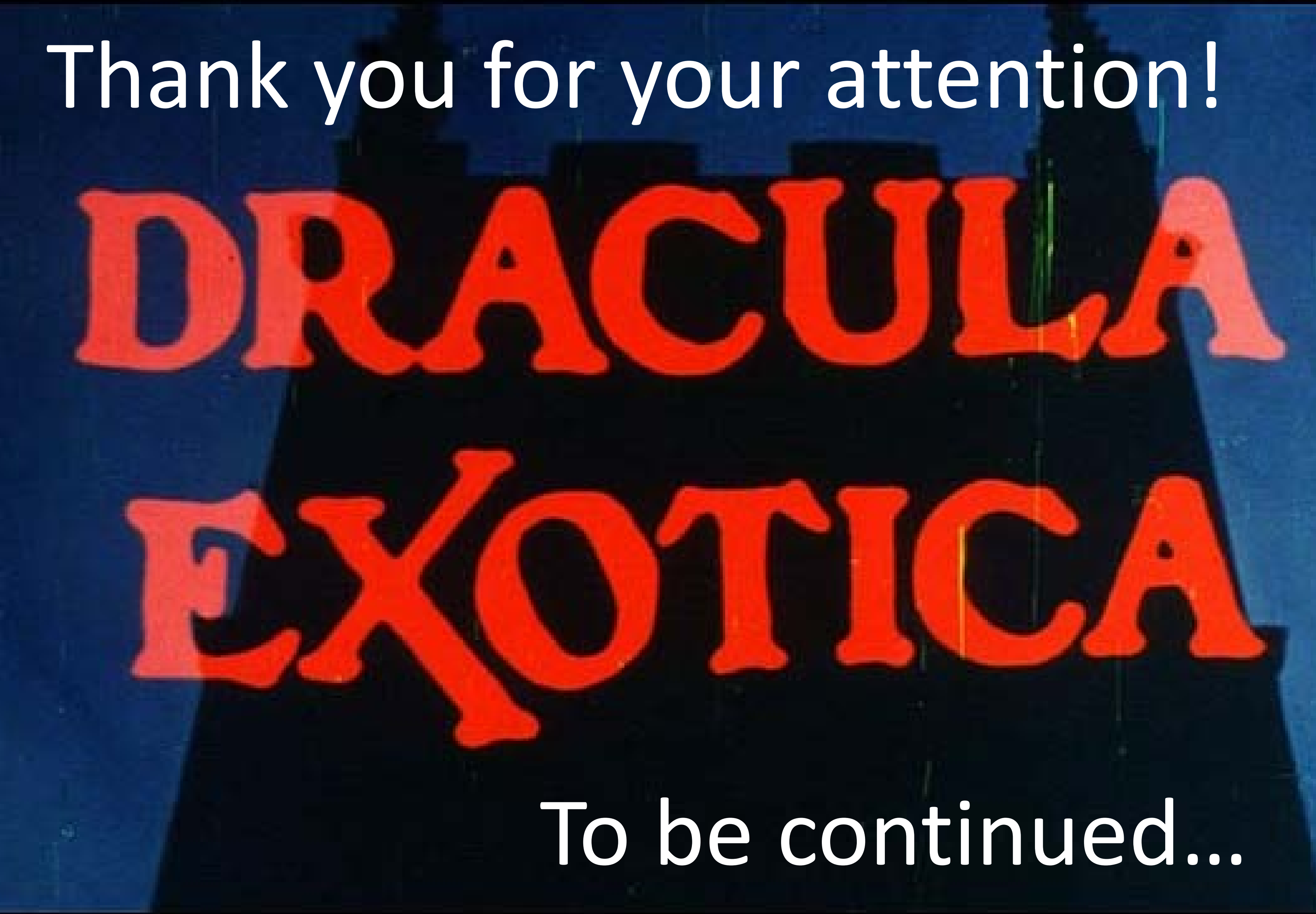
- **A plethora of Exotics analysis is underway at ATLAS:**
  - 20 conference notes with 2012 data
  - 53 papers published with 2011 data

- **New physics was not around the corner…**

  … however, not all analyses unblinded their 2012 data→ surprises with 8 TeV data are still possible!

- **Preparing for the 14 TeV run → a non-exhaustive list of challenges:**
  - Reconstruction of TeV leptons
  - Boosted objects (W, top-quarks)
  - Investigate less obvious signatures, f.ex. lepton jets and displaced decays

Thank you for your attention!



To be continued…