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Search for supersymmetry and exotica with ATLAS and CMS

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Joint annual HEPP and APP Conference
Institute of Physics
21-23 March 2016, University of Sussex, Brighton

LHC: searches for BSM physics

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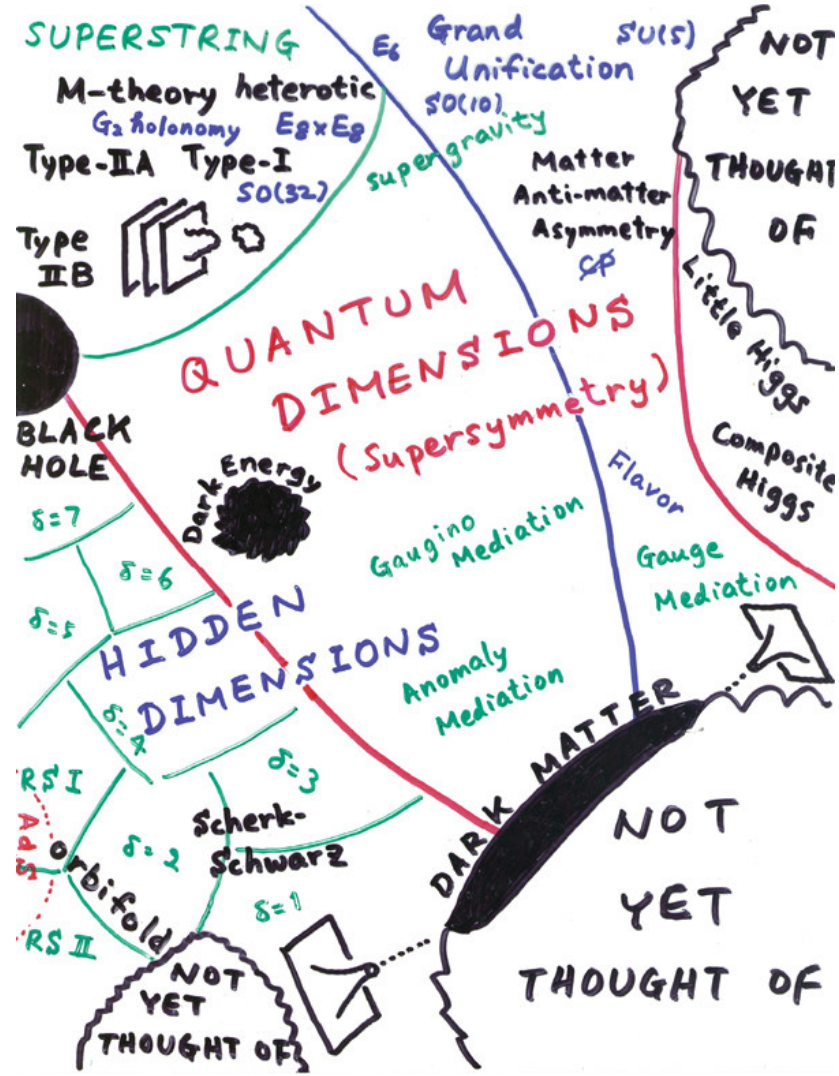
- **Theoretical considerations** (interaction unification, hierarchy,…) and **cosmological measurements** (dark matter, baryogenesis, …) call for physics phenomena **not included in SM**.
- The LHC is a tool **built to tear down the wall of the Standard Model**:
  - **Full exploration** of TeV scale and EW symmetry breaking
- Direct searches are a **vast field of research** in both collaborations:
  - **About half** of the published CMS and ATLAS papers **are searches**



Taken from www.linearcollider.org, courtesy of Hitoshi Murayama

Perform a search (in a nutshell)

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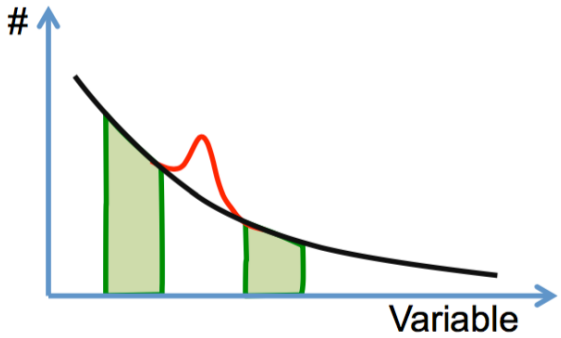

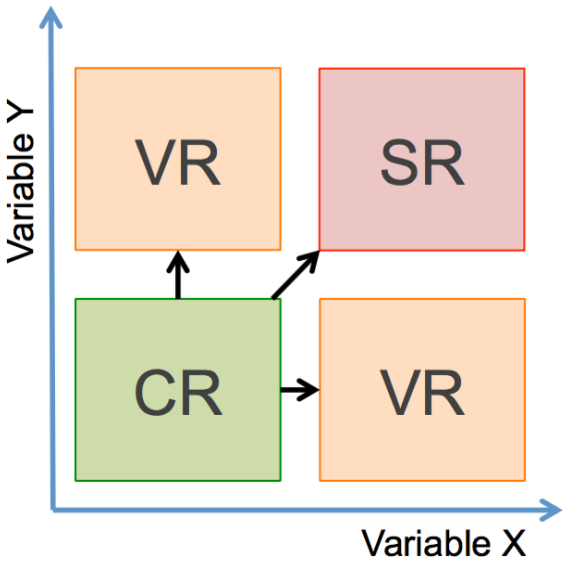

Constrained to two variables for visualization only

Courtesy of Frederich Rühr

Searching for a **localised excess** on a smooth distribution (e.g., mass resonance)

- Background determined usually **from data** (fit background with a **smooth function** or **in sidebands**)

Or for an **excess of events** for specific selections

- Background determined either **from data** or in **"control regions"** (Standard Model-dominated phase space regions)
  - MC is **key** for **extrapolating** between regions

BSM models as a guideline

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- Different searches **inspired to different physics models**
  - Often used for **optimisation** of selection and **result interpretation**
- Widely used models include (together with many others):

Supersymmetry
Solves hierarchy problem, facilitates interaction unification, could provide a dark matter candidate
Signature
Excess of events with high E_T^{miss} (assuming R-parity conservation)

Models with additional heavy vector boson

Signature
Resonance in di-fermion or diboson mass spectra

Extra-dimensions (UED, RS, ADD)
Solves hierarchy problem, facilitates interaction unification
Signature
Resonant or non-resonant graviton production giving rise to peaks or excesses in di-fermion or di-boson mass distributions; direct graviton production; black holes formation

Generic effective theories
HVT, scalar-tensor DM
Signature
mono-X (excess of events with E_T^{miss} recoiling against jets), resonances

Run 1 legacy…

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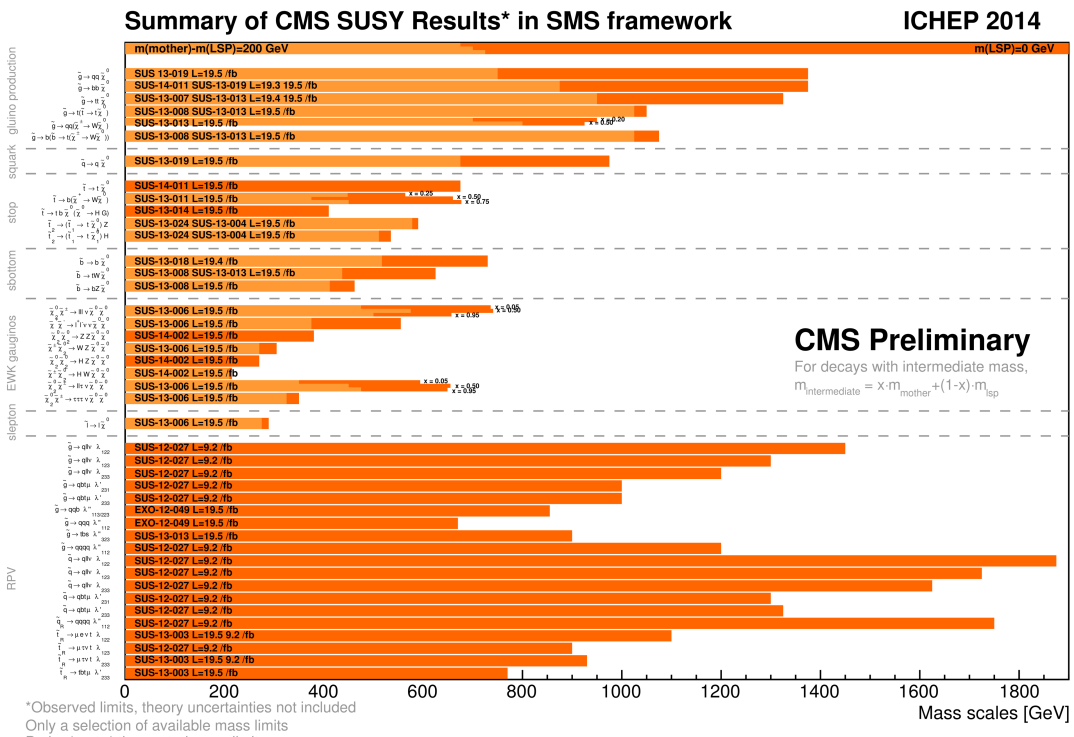
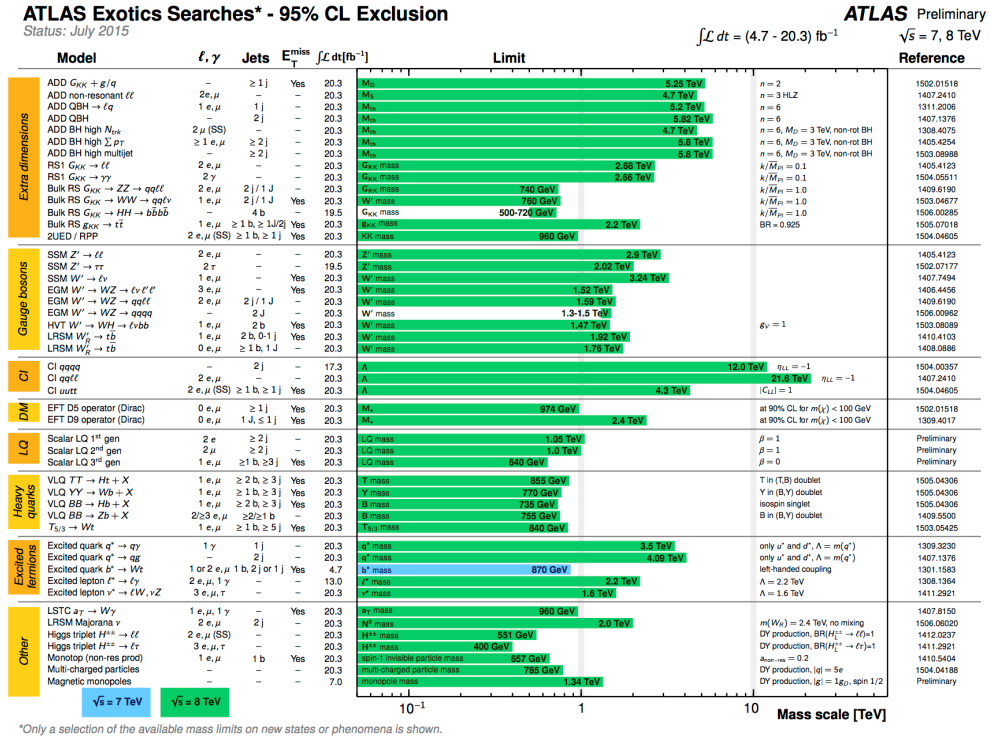
- Depending on interaction involved, run 1 sensitivity **already knocked on the multi-TeV** scale door

http://cms.web.cern.ch/org/cms-papers-and-results



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/CombinedSummaryPlots/EXOTICS/ATLAS_Exotics_Summary/ATLAS_Exotics_Summary.png



Is Run 2 better than Run 1?

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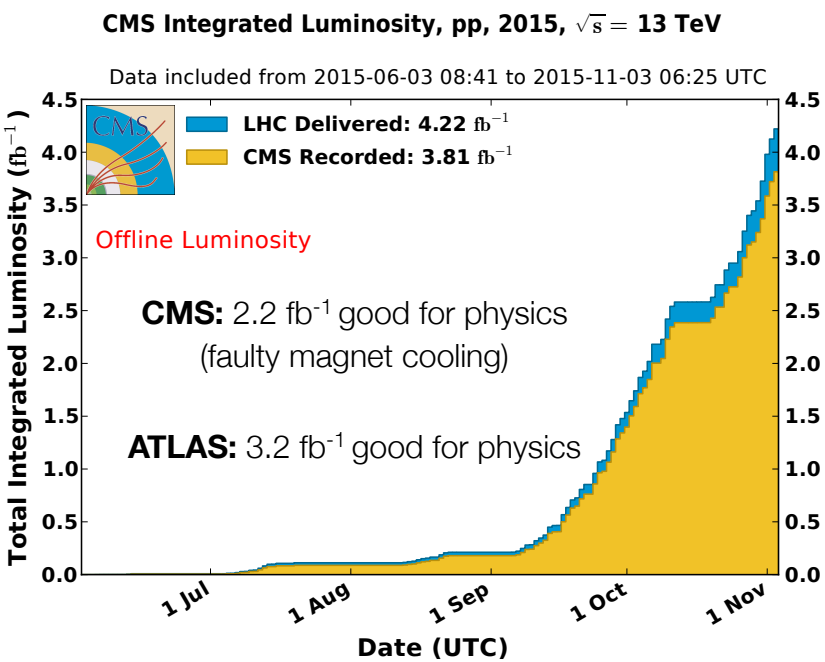
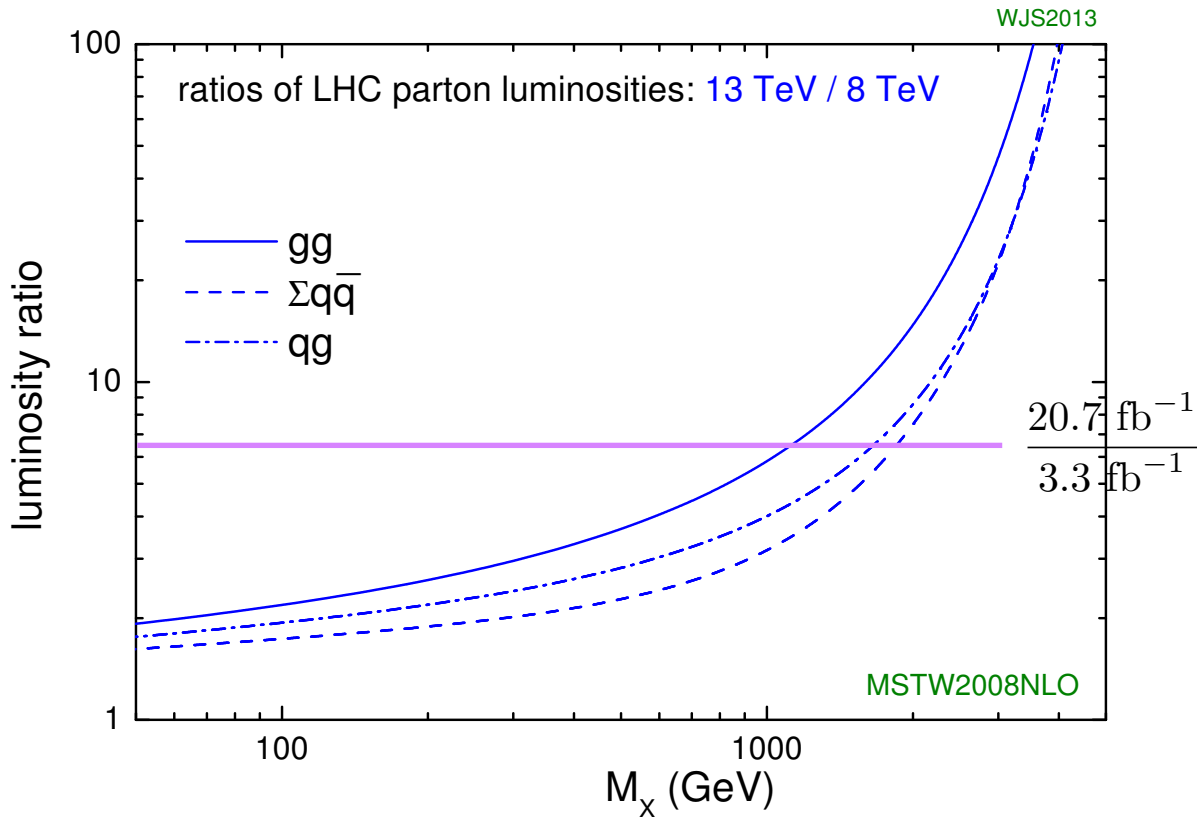
Parton luminosities at √s =13 TeV are **larger** than at √s=8 TeV

For **heavy final states** the new Run 2 dataset is **already beating Run 1**





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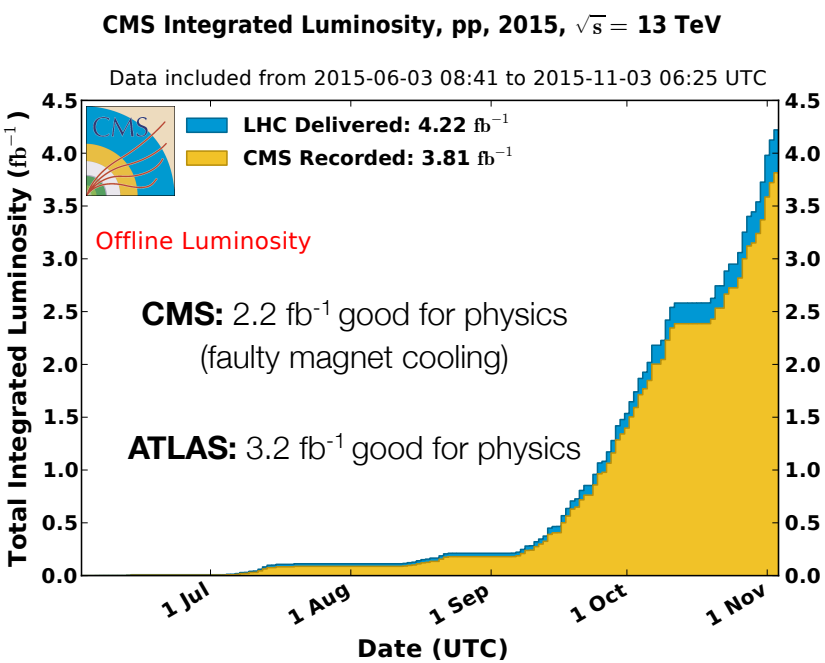

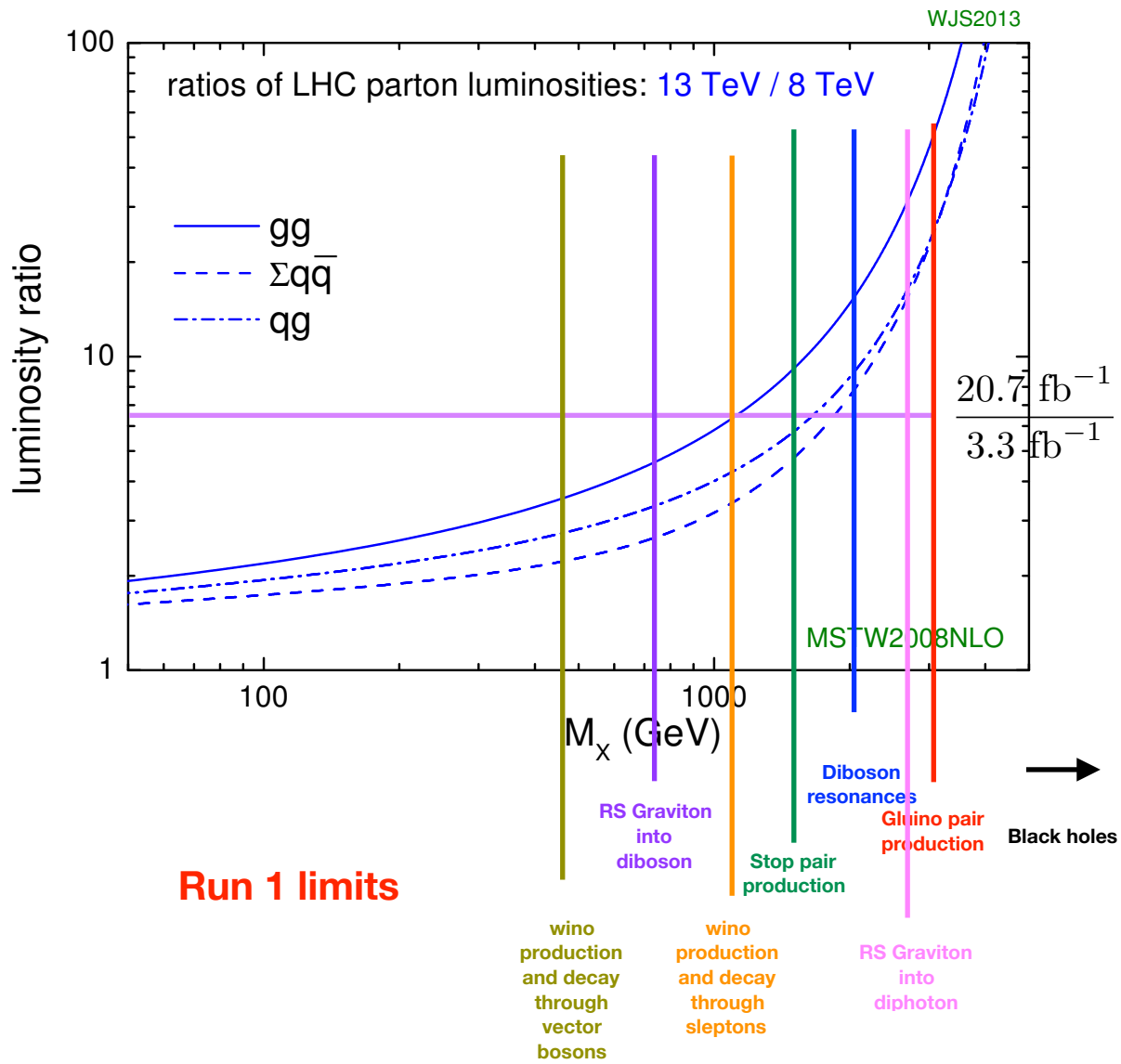

How multipurpose is a multipurpose experiment

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CMS exotica

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsB2G

Journal Publications - 2015 Run

Analysis	ArXiv Entry	Luminosity	Publication Status	Approved Plots
Search for narrow resonances decaying to dijets NEW	arXiv:1512.01224	2.4 fb^{-1}	10.1103/PhysRevLett.116.071801	EXO15001

Preliminary Results - 2015 Run

Analysis	Approved Plots	CDS Entry	Luminosity
Search for resonances decaying into pairs of boosted W and Z bosons NEW	EXO15002	PAS EXO-15-002	2.6 fb^{-1}
Search for dark matter in events with jets and missing transverse energy NEW	EXO15003	PAS EXO-15-003	2.1 fb^{-1}
Search for resonances in diphoton events NEW	EXO15004	PAS EXO-15-004	2.6 fb^{-1}
Search for Z' in dilepton events NEW	EXO15005	PAS EXO-15-005	2.6-2.8 fb^{-1}
Search for W' in lepton+MET events NEW	EXO15006	PAS EXO-15-006	2.2 fb^{-1}
Search for black holes NEW	EXO15007	PAS EXO-15-007	2.2 fb^{-1}
Search for quark contact interactions and extra spatial dimensions with dijet angular distributions NEW	EXO15009	PAS EXO-15-009	2.6 fb^{-1}
Search for heavy stable charged particles NEW	EXO15010	PAS EXO-15-010	2.4 fb^{-1}

Analysis	Approved Plots	CDS Entry	Luminosity	Comment
NEW Search for W'->tb in the semileptonic final state at sqrt(s)=13 TeV	B2G-15-004	CDS link	2.1 fb-1	13 TeV
NEW X53 in SS dilepton and lepton+jets final state%	B2G-15-006	CDS link	2.1 fb-1	13 TeV

ATLAS exotica

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults

Papers with 2015 data

Title	Journal	Papers and Plots	Int. luminosity	Date
Search for new phenomena with photon+jet events in proton-proton collisions at √s = 13 TeV with the ATLAS detector	Published in JHEP	Plots and more Info ; arxiv:1512.05910 ; JHEP 03 (2016) 041	3.2/fb	Dec 2015
Search for strong gravity in multijet final states produced in pp collisions at √s = 13 TeV using the ATLAS detector at the LHC	Published in JHEP	Plots and more Info ; arxiv:1512.02586 ; JHEP 03 (2016) 026	3.6/fb	Dec 2015
Search for new phenomena in dijet mass and angular distributions from pp collisions at √s = 13 TeV with the ATLAS detector	Published in PLB	Plots and more Info ; arxiv:1512.01530 ; PLB 754 (2016) 302-322	3.6/fb	Dec 2015

Conference Notes with 2015 data

Title	Conference Note and Plots	Int. luminosity	Date
Search for heavy resonances decaying to a Z boson and a photon in pp collisions at √s =13 TeV with the ATLAS detector	ATLAS-CONF-2016-010	3.2/fb	Mar 2016
Search for TeV-scale gravity signatures in high-mass final states with leptons and jets with the ATLAS detector at √s = 13 TeV	ATLAS-CONF-2016-006	3.2/fb	Mar 2016
Search for new resonances in events with one lepton and missing transverse momentum in pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-063	3.2/fb	Dec 2015
Search for diboson resonances in the vvqq final state in pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-068	3.2/fb	Dec 2015
Search for new phenomena in the dilepton final state using proton-proton collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-070	3.2/fb	Dec 2015
Search for diboson resonances in the llqq final state in pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-071	3.2/fb	Dec 2015
Search for beyond the Standard Model phenomena in eμ final states in pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-072	3.2/fb	Dec 2015
Search for resonances with boson-tagged jets in 3.2/fb of pp collisions at √s = 13 TeV collected with the ATLAS detector	ATLAS-CONF-2015-073	3.2/fb	Dec 2015
Search for new resonances decaying to a W or Z boson and a Higgs boson in the llbbbar, lvbbar, and vvbbbar channels in pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-074	3.2/fb	Dec 2015
Search for WW/WZ resonance production in the lvqq final state at √s = 13 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-075	3.2/fb	Dec 2015
Search for dark matter produced in association with a hadronically decaying vector boson in pp collisions at √s = 13 TeV with the ATLAS detector at the LHC	ATLAS-CONF-2015-080	3.2/fb	Dec 2015
Search for resonances decaying to photon pairs in 3.2/fb of pp collisions at √s = 13 TeV with the ATLAS detector	ATLAS-CONF-2015-081	3.2/fb	Dec 2015
Search for TeV-scale gravity signatures in high-mass final states with leptons and jets with the ATLAS detector at √s = 13 TeV	ATLAS-CONF-2015-046	80/pb	Sept 2015
Search for New Phenomena in Dijet Mass and Angular Distributions with the ATLAS Detector at √s = 13 TeV	ATLAS-CONF-2015-042	80/pb	Aug 2015
Search for evidence for strong gravity in jet final states produced in pp collisions at √s = 13 TeV using the ATLAS detector at the LHC	ATLAS-CONF-2015-043	80/pb	Aug 2015

CMS SUSY

https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

CMS-SUS-15-002	**Search for supersymmetry in the multijet and missing transverse momentum channel in pp collisions at 13 TeV**	Submitted to PLB
CMS-PAS-SUS-15-003	**Search for new physics in the all-hadronic final state with the M_{T2} variable**	
CMS-PAS-SUS-15-005	**Search for new physics in final states with jets and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the α_T variable**	
CMS-PAS-SUS-15-004	**Inclusive search for supersymmetry using the razor variables at $\sqrt{s} = 13$ TeV**	
CMS-PAS-SUS-15-007	**Search for supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV in the single-lepton final state using the sum of masses of large radius jets**	
CMS-PAS-SUS-15-008	**Search for SUSY in same-sign dilepton events at $\sqrt{s} = 13$ TeV**	
CMS-PAS-SUS-15-011	**Search for new physics in final states with two opposite-sign same-flavor leptons, jets and E_T^{miss} in pp collisions at $\sqrt{s} = 13$ TeV**	

ATLAS SUSY

https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

papers

Short Title of Paper	Date	√s (TeV)	L (fb^{-1})	Document	Plots+Aux. Material	Journal
2 same sign or 3 leptons NEW	02/2016	13	3.2	1602.09058	Link	Submitted to EPJ C
0L 7-10 jets NEW	02/2016	13	3.2	1602.06194	Link	Submitted to Phys. Lett. B

conference notes

Short Title of preliminary conference note	Date	√s (TeV)	L (fb^{-1})	Document	Plots
1L stop NEW	3/2016	13	3.2	ATLAS-CONF-2016-007	Link
2L stop NEW	3/2016	13	3.2	ATLAS-CONF-2016-009	Link
0L 2-6 jets	12/2015	13	3.2	ATLAS-CONF-2015-062	Link
1L + jets	12/2015	13	3.2	ATLAS-CONF-2015-076	Link
2L Z+MET	12/2015	13	3.2	ATLAS-CONF-2015-082	Link
multi b-jets	12/2015	13	3.2	ATLAS-CONF-2015-067	Link
2b + MET	12/2015	13	3.2	ATLAS-CONF-2015-066	Link

Screenshots taken on Wednesday, March 17

How multipurpose is a multipurpose experiment

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- More than **50 Run 2 public results** (not counting searches involving Higgs bosons) produced by **ATLAS and CMS**

A (admittedly biased) selection of the result

Supersymmetry
Dark Matter/strong gravity
Di-jet/di-lepton resonance searches
Diboson resonance searches
Diphoton resonance searches

Not covered
Other resonances (Di-top quark, photon/Z, etc.)
Vector like quarks
Leptoquarks
Non-conventional signatures (long lived particles, etc.)

Supersymmetry

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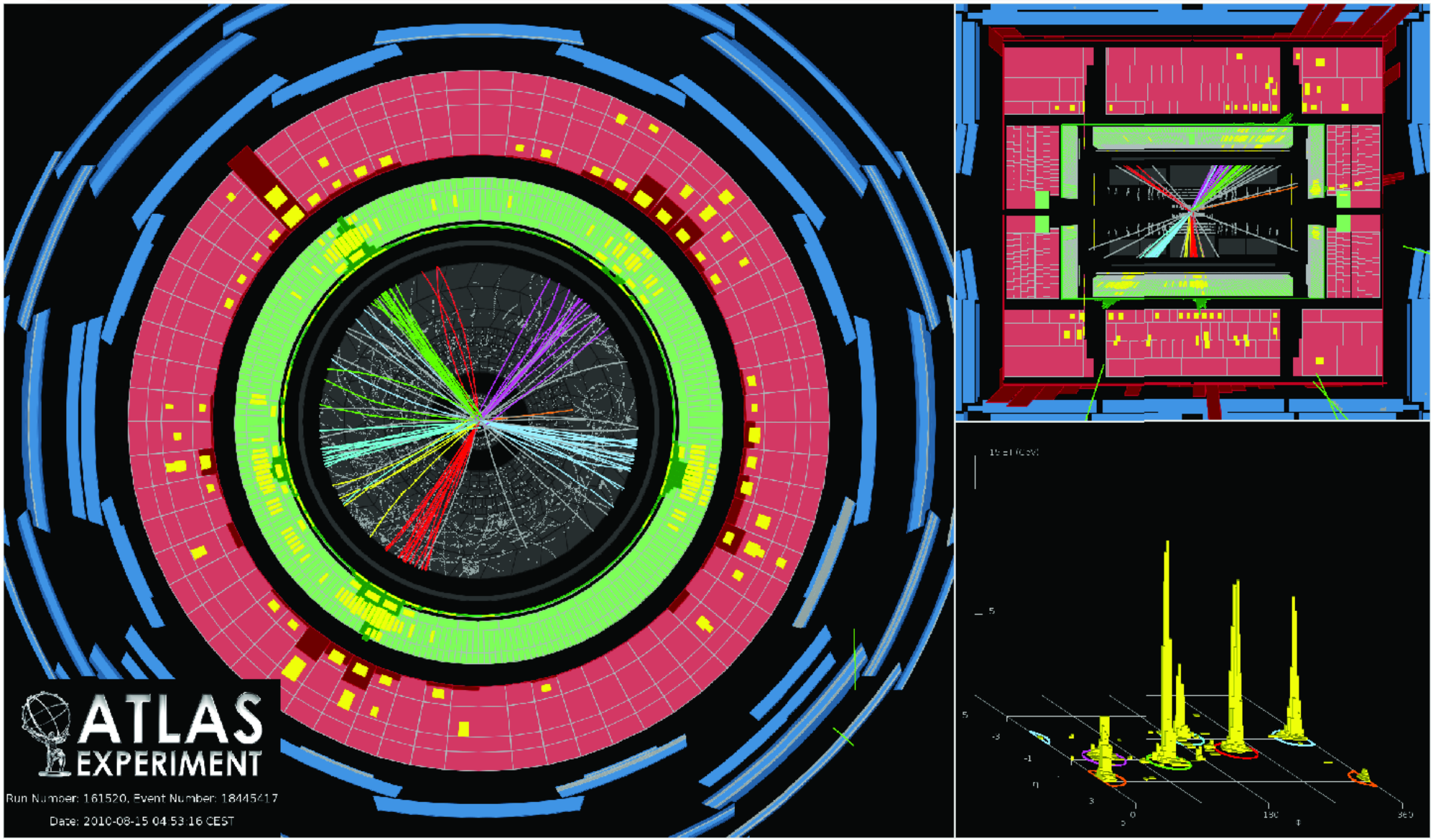

R-parity conserving (RPC) SUSY

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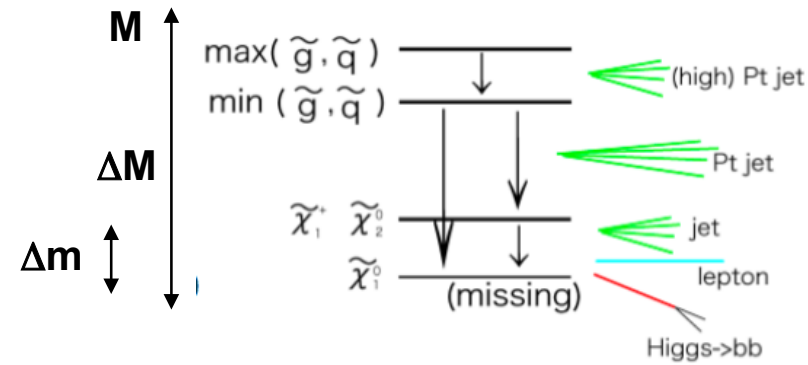
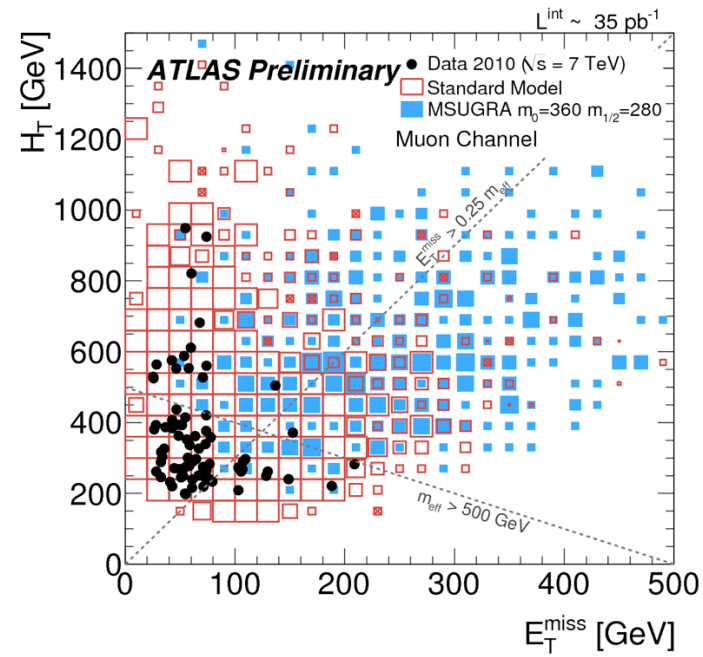
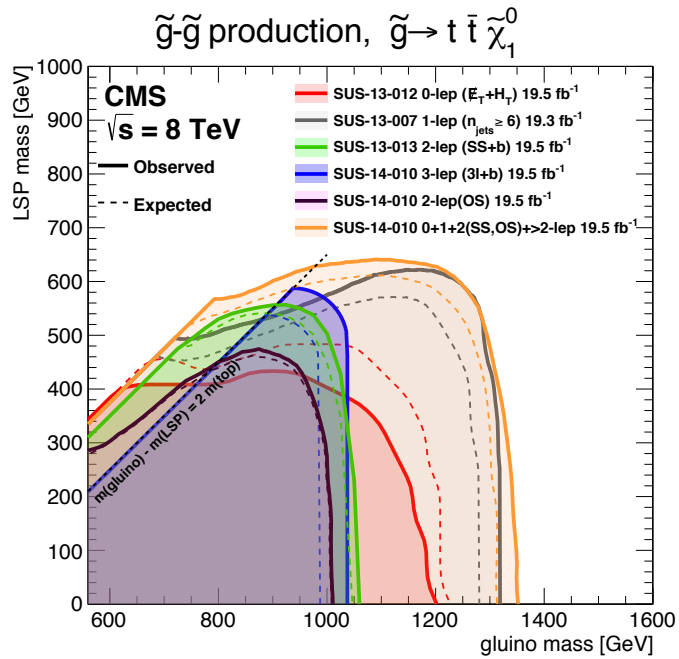
- **Heavy sparticles produced** in the primary collision
- They **decay into lighter objects**, emitting (high) p_T jets and possibly other objects (leptons, photons) and E_T^{miss} (LSP)
- A "typical" RPC SUSY event will have **large MET and large H_T**

$$H_T = \sum_{jets} p_T^{jets} (+ \sum_{l} p_T^{l} + ...)$$





The run 1 legacy

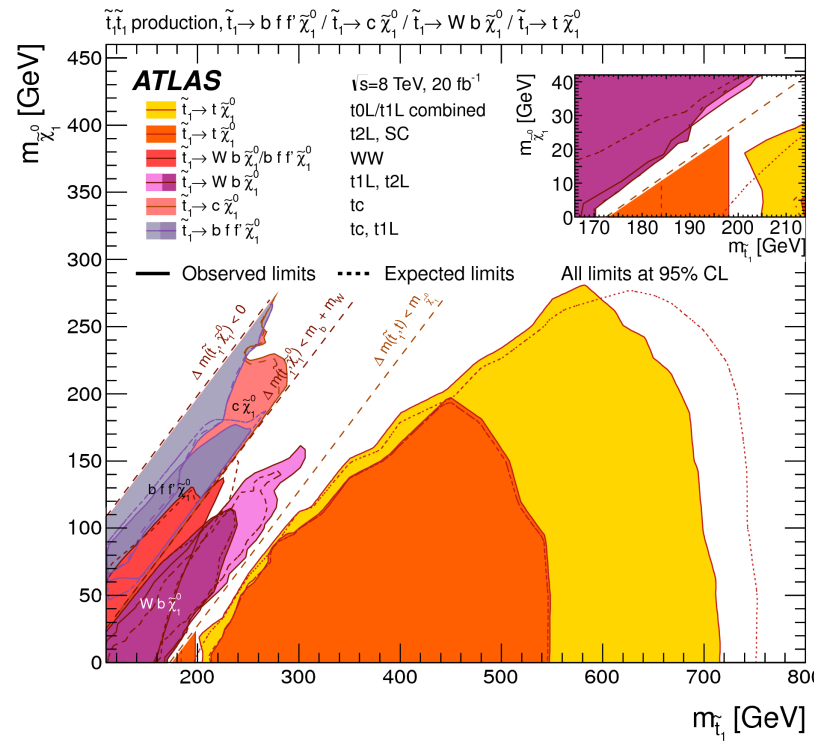


Gluinos excluded **almost independently of any hypothesis** below ~ 800 GeV

stops excluded (under certain hypotheses) **up to ~ 700 GeV**

electroweakinos **less constrained** (but excluded up to 200-300 GeV under common assumptions)

- Run 1 told us:
  - that **simple "vanilla" SUSY does not exist**
  - favourite pre-LHC models (e.g. mSUGRA/CMSSM) disfavoured



2015: the year of strong production

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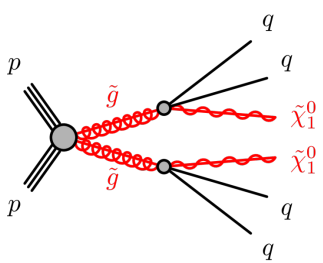
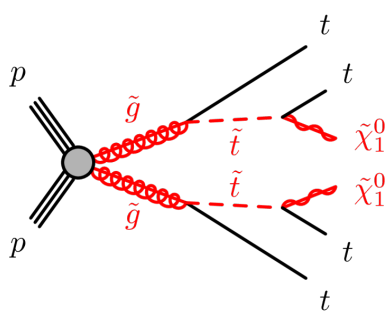
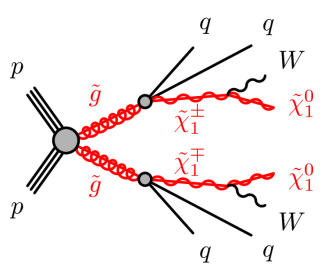
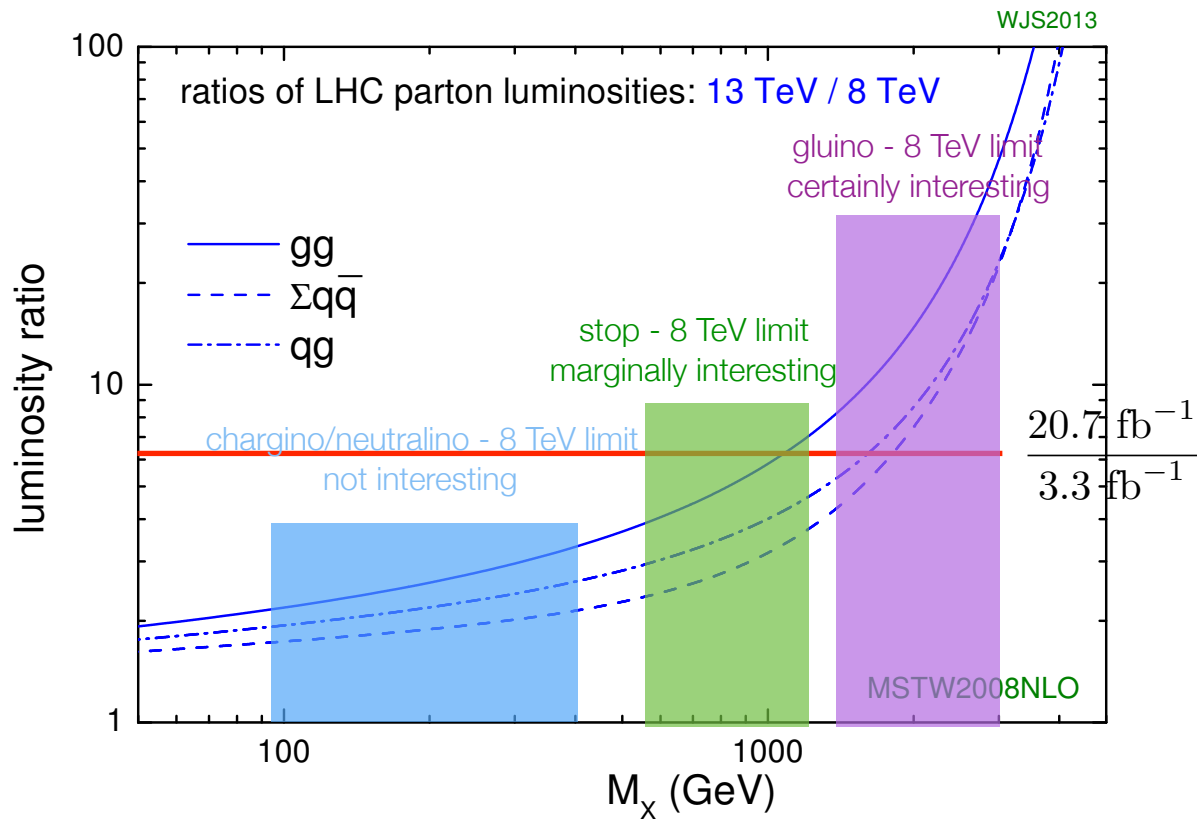
Gluino pair production: sensitivity already beating by far the run 1









(2 M_X for pair-produced particles)

Example: gluino decay in top quarks

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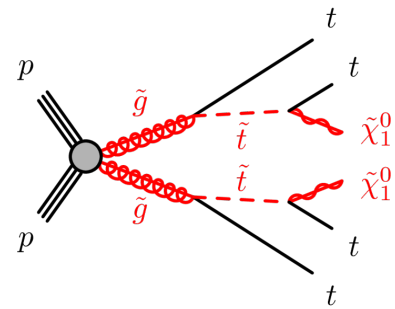
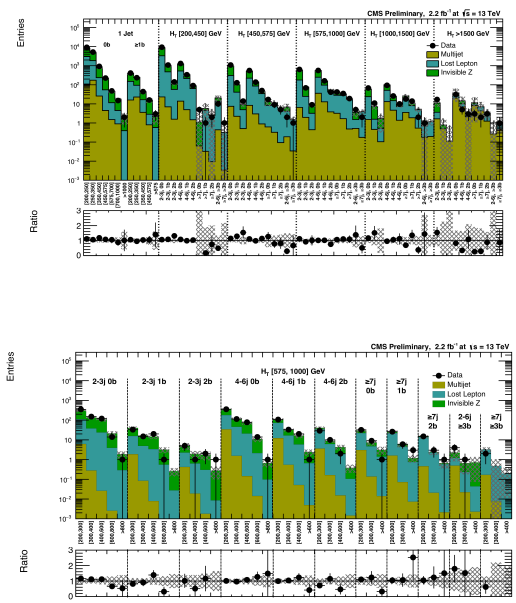
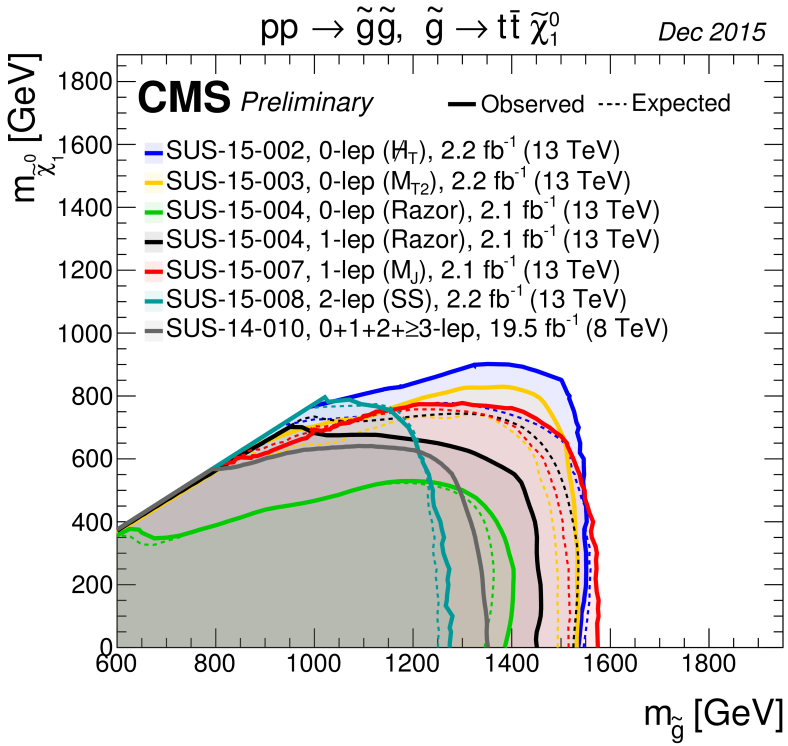
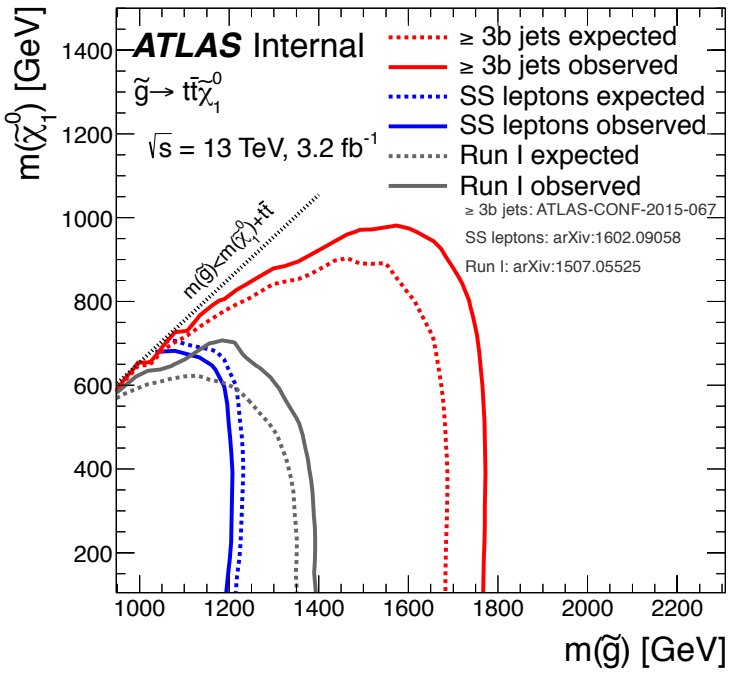
- Up to **4 b-jets**, **12 jets**, **4 leptons**, **SS leptons**, **boosted top quarks**
- Several different approaches to this final state









Third generation pair production highlights

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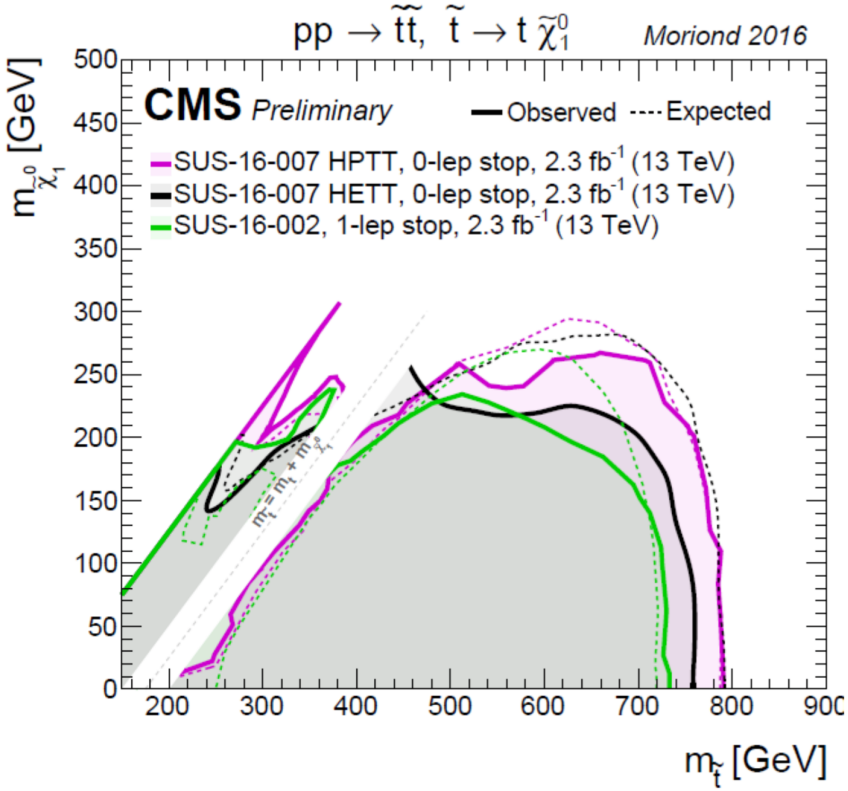
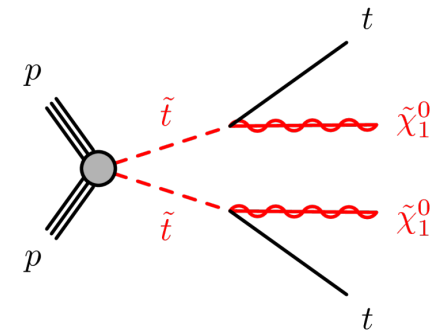
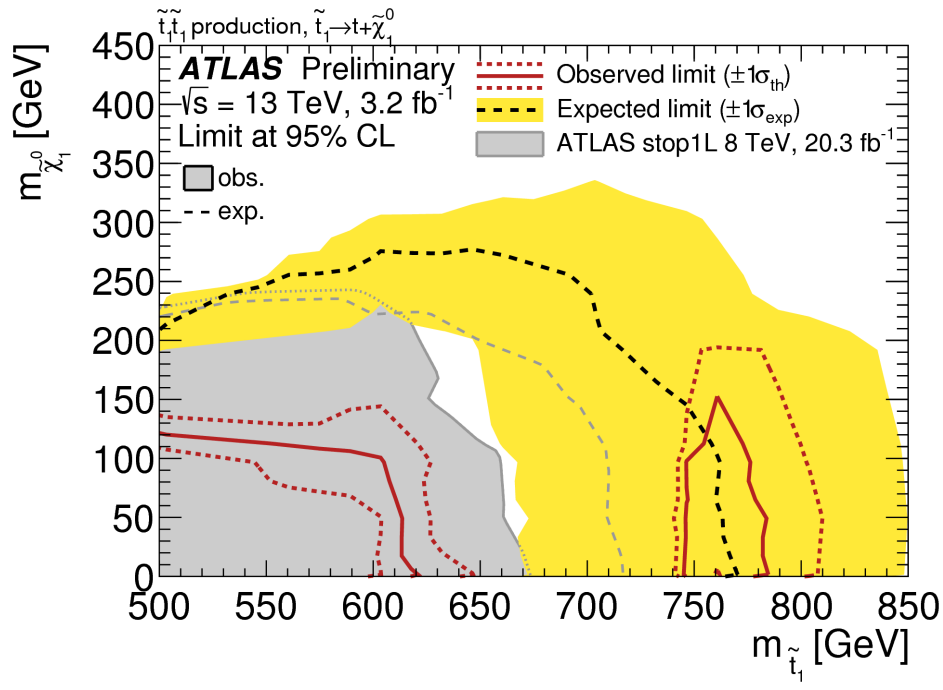
- Stops (and sbottoms) **expected light** because of **naturalness arguments.**
- Run 2 sensitivity **already larger than Run 1**

Hp: BR 100%







Something to keep an eye on

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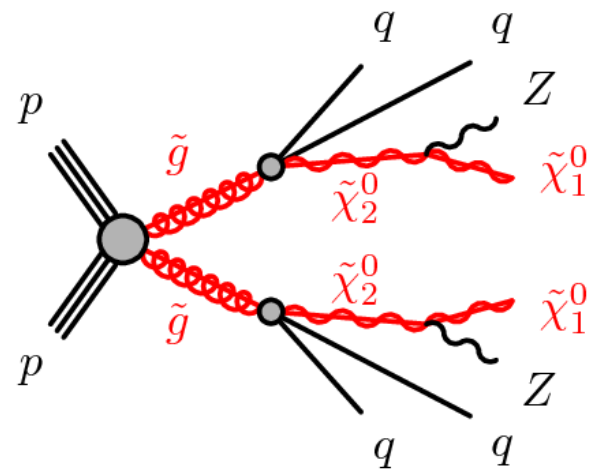
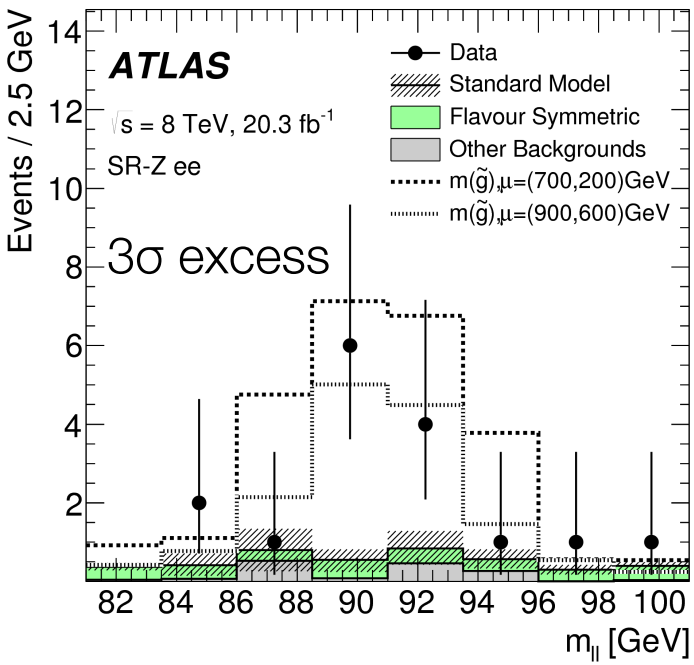
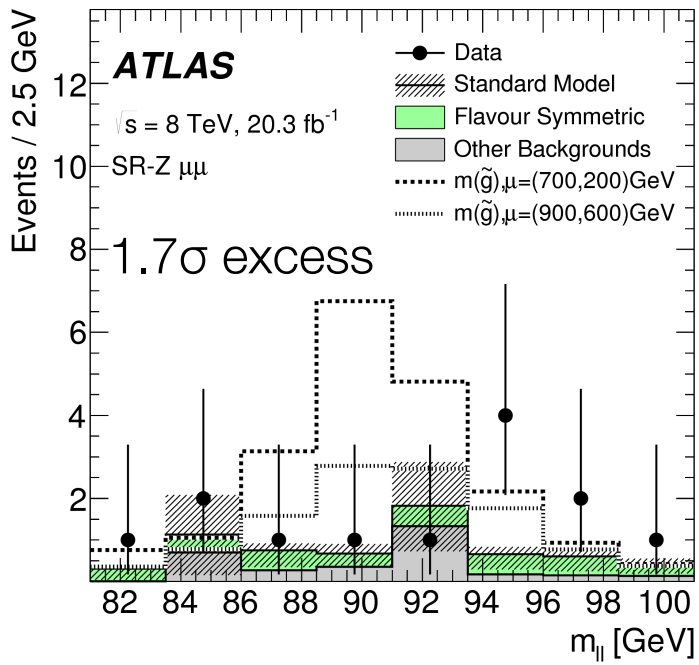
- **Basic idea:** Z boson + E_T^{miss} is a final state with **very limited SM background** (essentially WZ and ZZ production)
- Selection: 2 jets, E_T^{miss} > 225 GeV, H_T > 600 GeV



arXiv:1503.03290





Excess in run 1

non-resonant background dominated by flavour symmetric processes (mainly ttbar)

Something to keep an eye on

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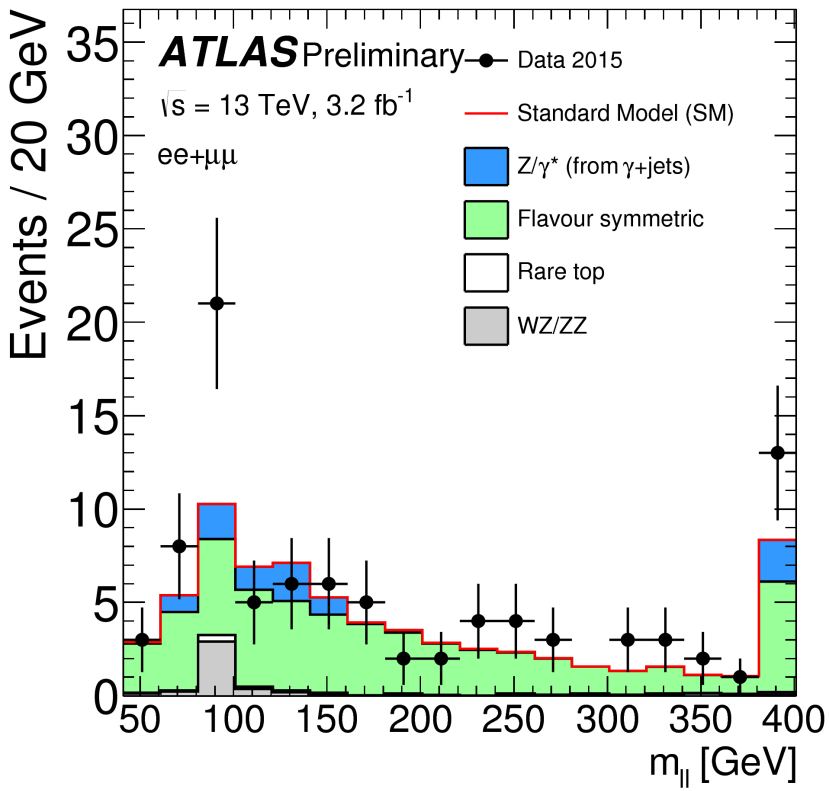
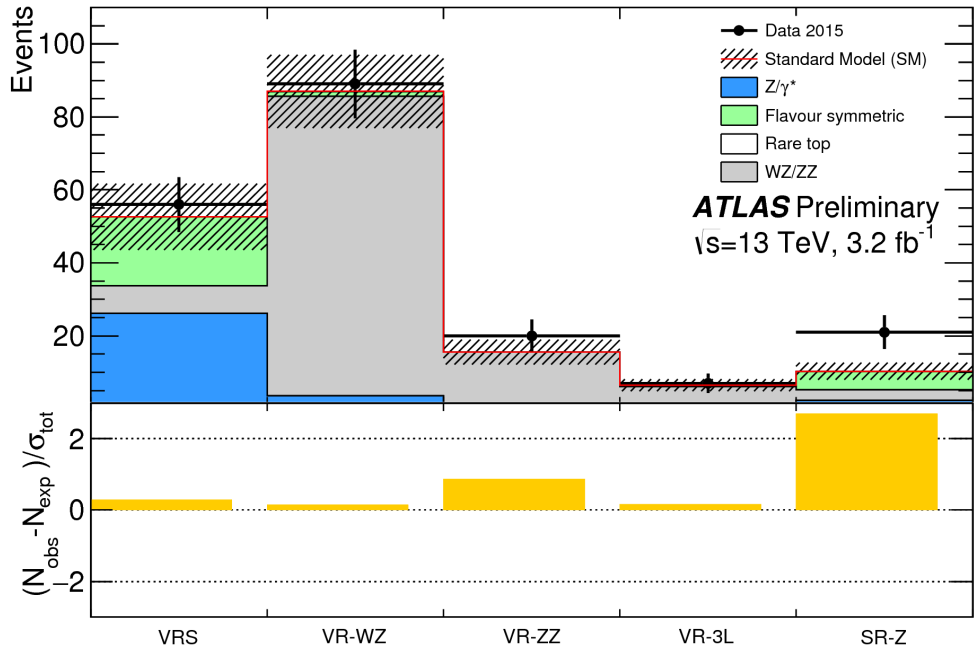
Excess still there in run 2!





Expected events: **10.3 ±2.3**
Observed: **21 (2.2σ)**
10 in ee, 11 in μμ
CMS expects and observes **12 events** in a similar region

Dark Matter

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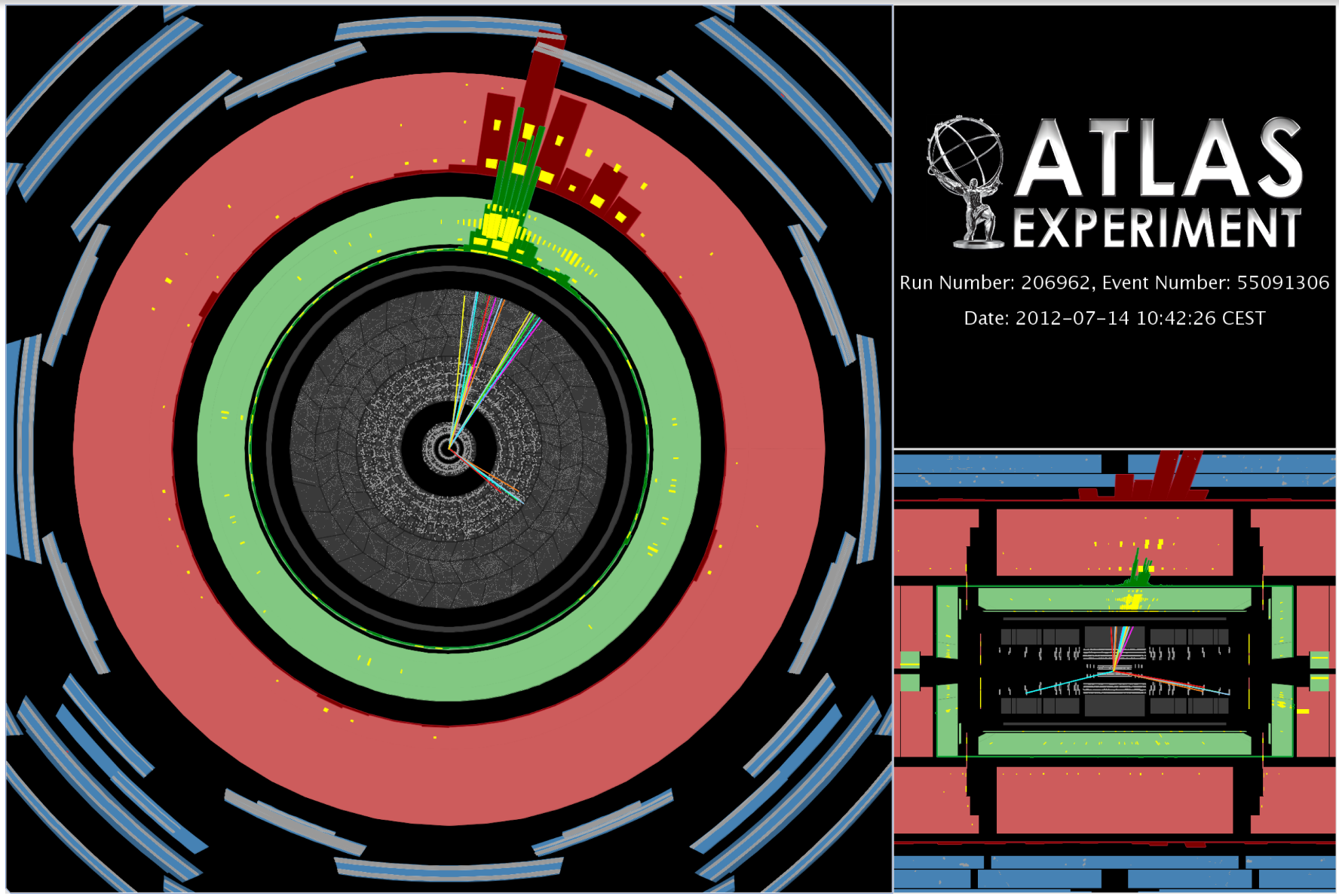

Dark matter (at the LHC)

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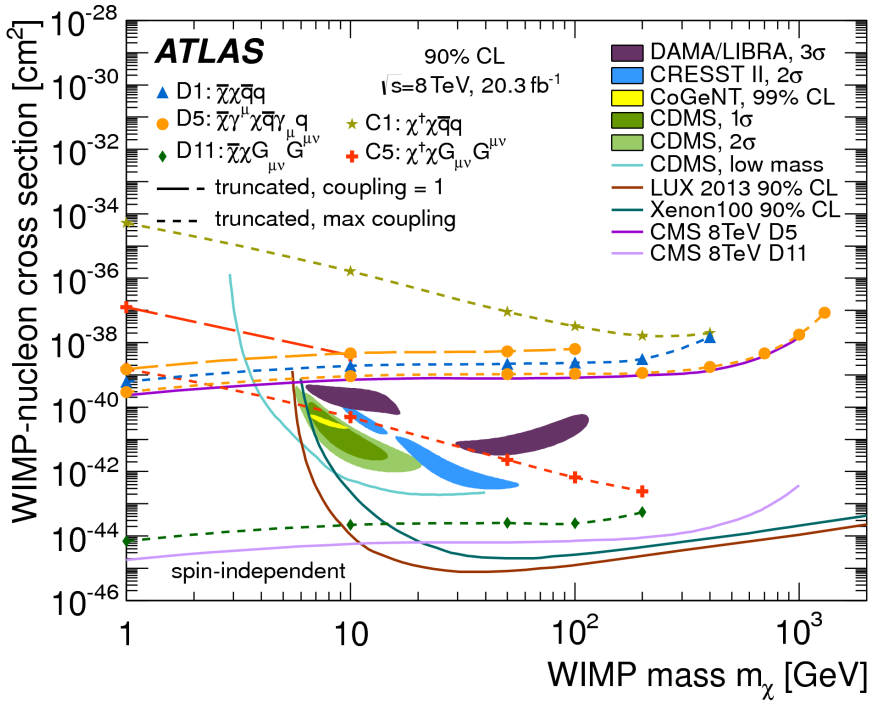
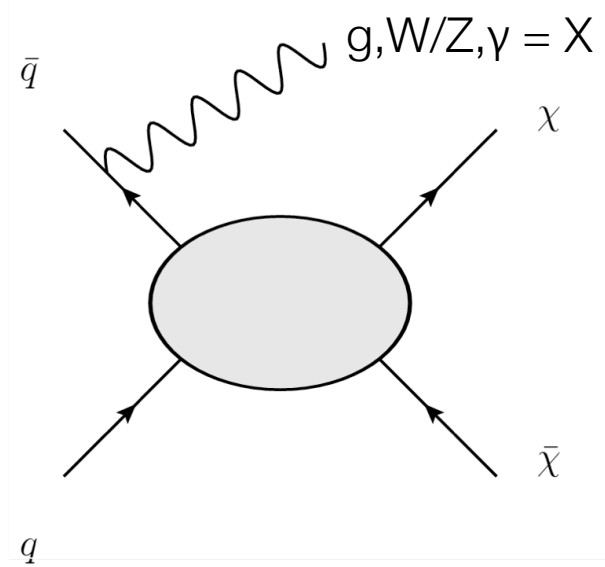
CMS-PAS-EXO-15-003





- LHC **can complement** direct searches limits
- **Signal:** production of DM particles recoiling against X (X=g,W/Z,γ)
  - **Effective theory approach** (EFT) mostly used in Run 1 (mass of the mediator large)
  - Similar signatures for direct graviton production in, e.g., ADD models

Dark matter signatures

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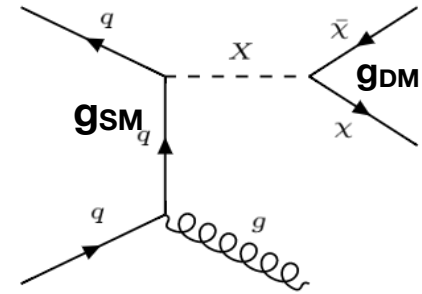
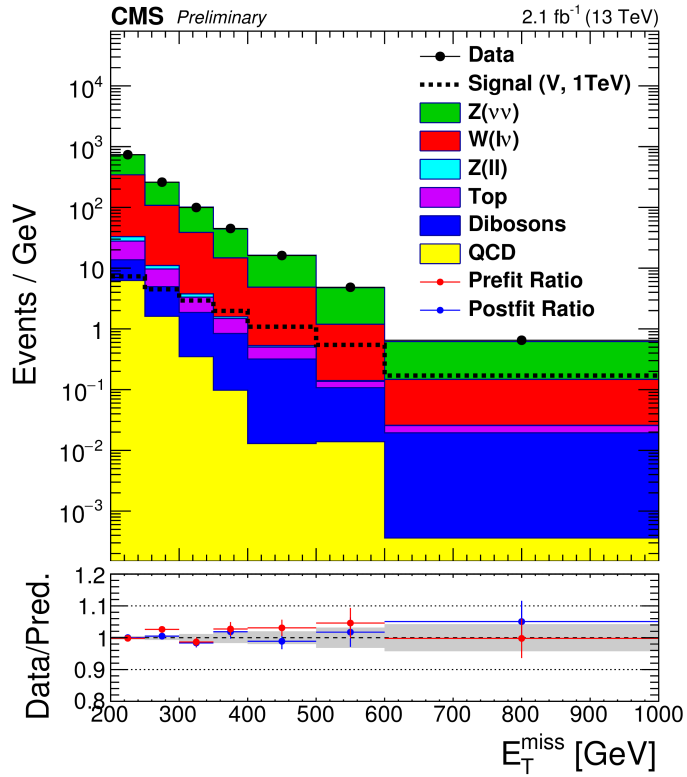
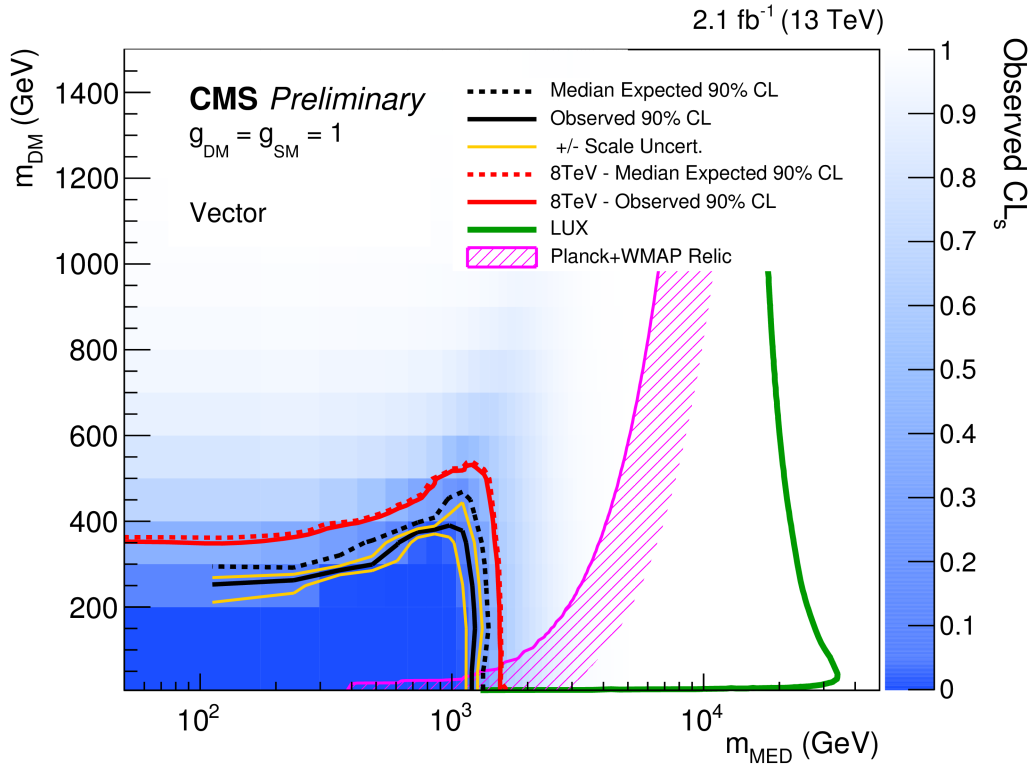
- A **huge amount of work** went into the definition of **benchmark simplified models** (see arXiv: 1506.03116, arXiv:1507.00966, arXiv:1407.8257)
- Relevant also for, e.g., compressed SUSY scenarios







High-mass resonances

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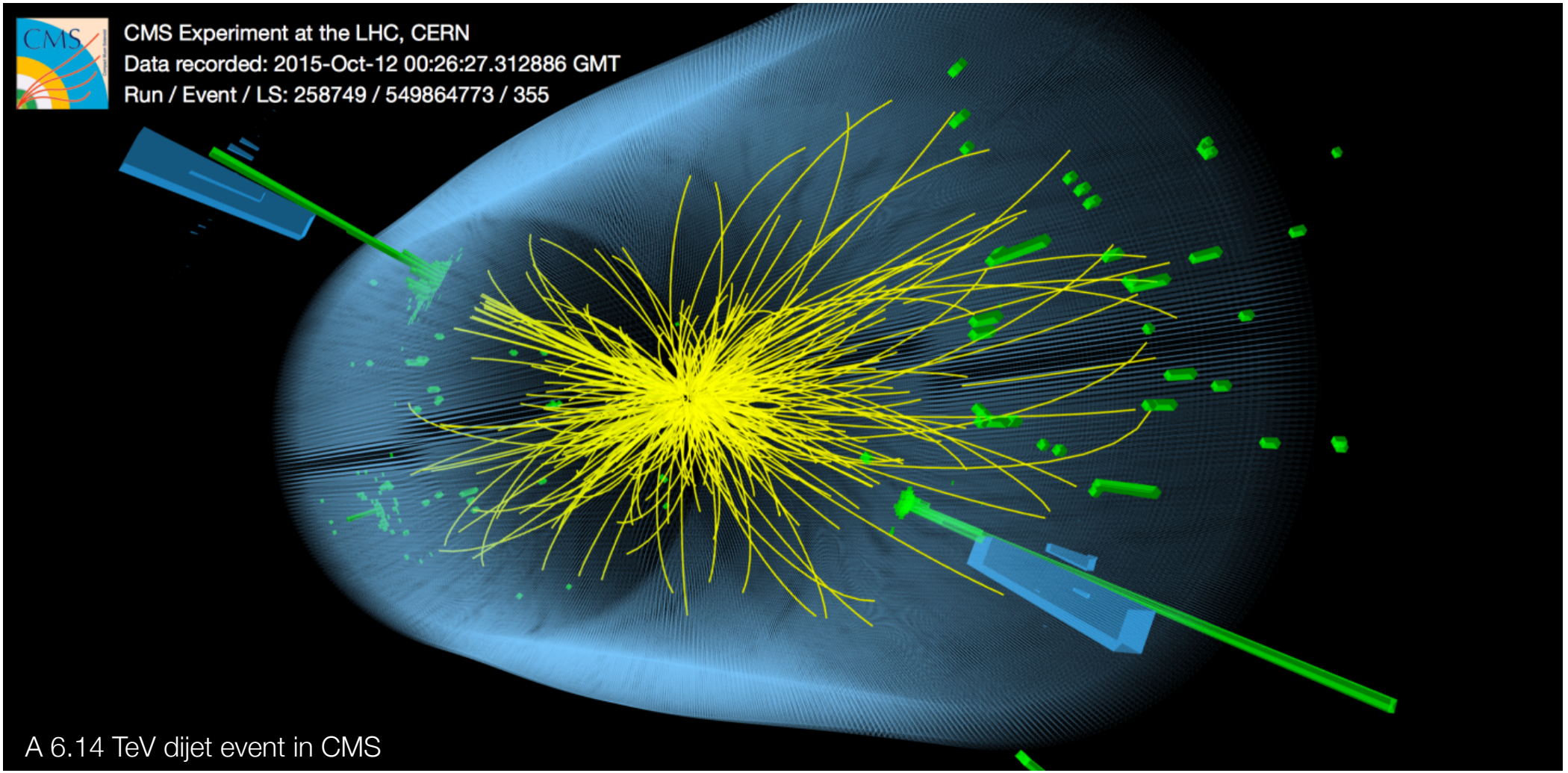

A 6.14 TeV dijet event in CMS

High-mass di-jet resonances

$$\frac{d\sigma}{dm_{jj}} = \frac{P_0(1-x)^{P_1}}{x^{P_2+P_3\ln(x)}}$$

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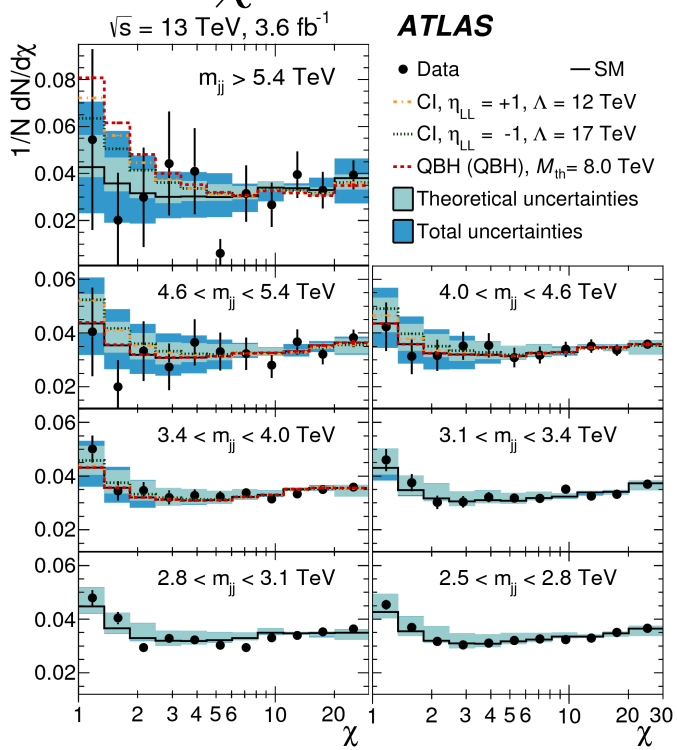
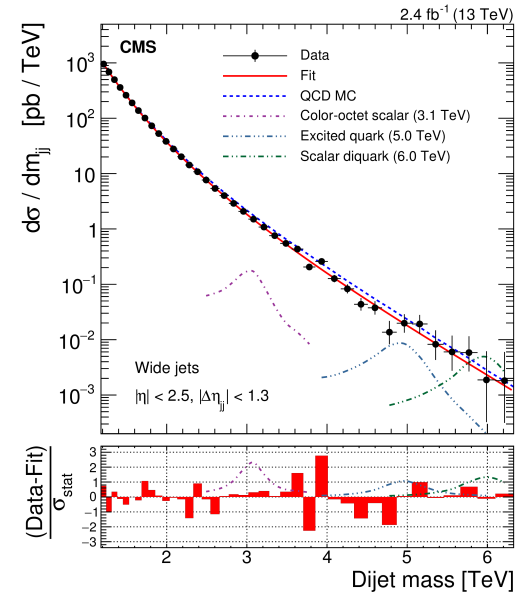
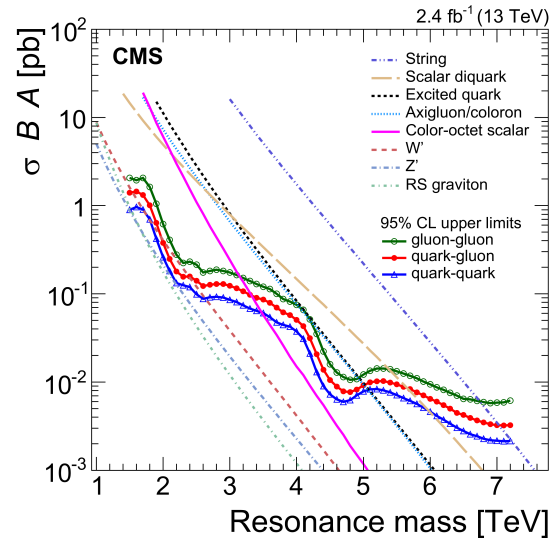
- **Di-jet resonances** are predicted in **many BSM models**
- Run 1 limits already in the **multi-TeV range** —> **large cross section gain** in Run 2
- **Di-jet angular distributions** sensitive to contact interactions, extra-dimensions, etc

$$\chi = e^{|y_1 - y_2|}$$

Limits on **contact interactions at 17 TeV** (constructive interference), **QBH (ADD) at 8 TeV**







CMS PAS EXO-15-009
Phys. Rev. Lett. 116, 071801
PLB 754 (2016) 302-322

High-mass resonances

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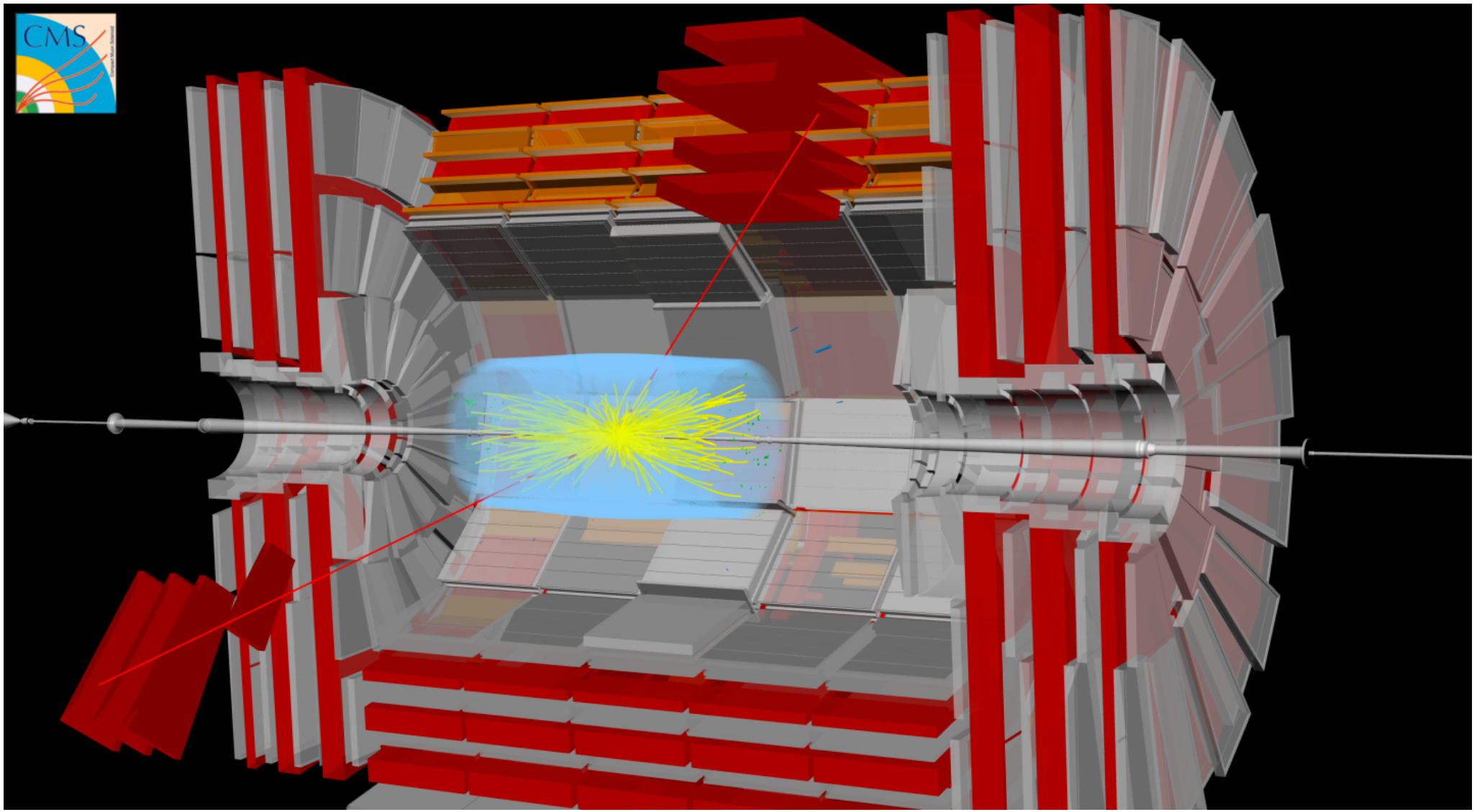

High-mass resonances

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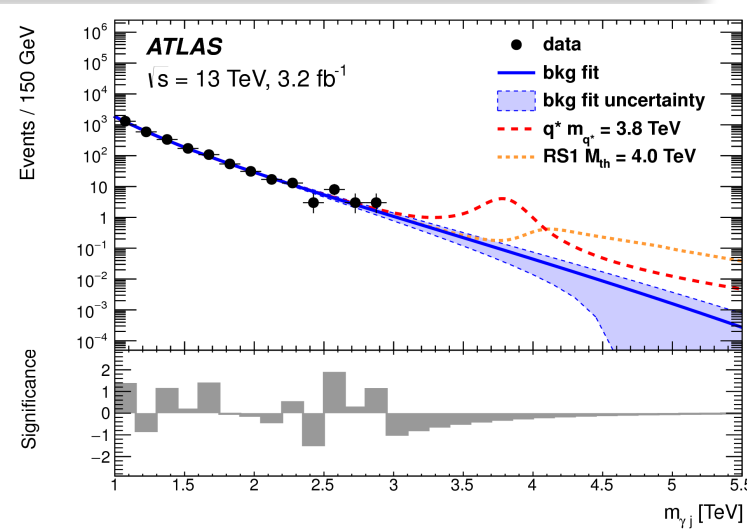
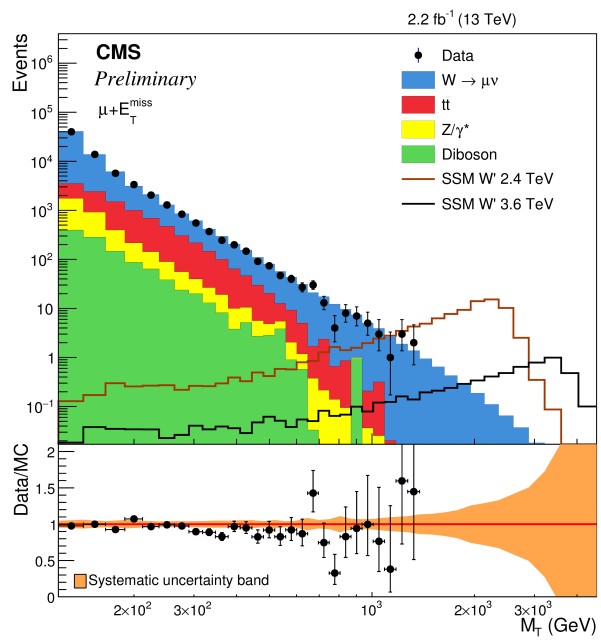
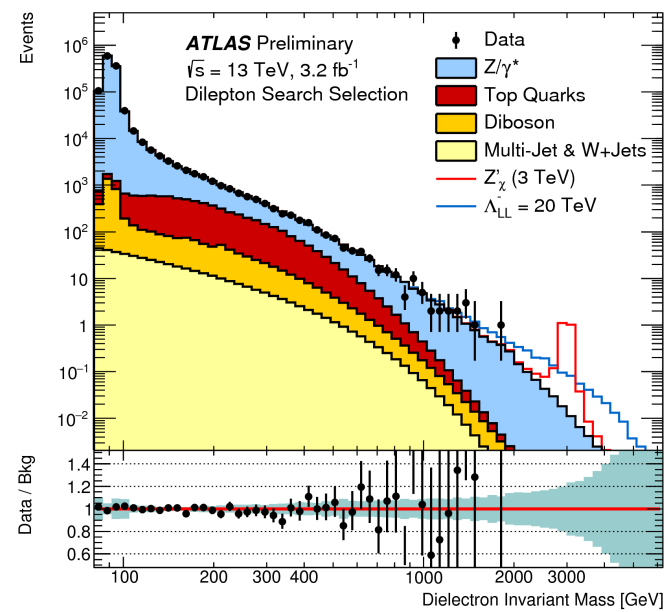
- Di-lepton (Z'), photon+jet (excited quarks, QBH), lepton+E_T^{miss} (W'):
  - look at the **m_{ll}, $m_{\gamma j}$, or at the m_T** if invisible decay products involved
  - Also sensitive to **non-resonant production** (extra-dimensions, etc.)



ATLAS
arXiv:1512.05910
ATLAS-CONF-2015-063
ATLAS-CONF-2015-070
CMS
CMS-PAS-EXO-15-005
CMS-PAS-EXO-15-006

$$m_T = \sqrt{2p_T^{\ell} E_T^{\mathrm{miss}} (1 - \cos\Delta\phi)}$$





High-mass resonances

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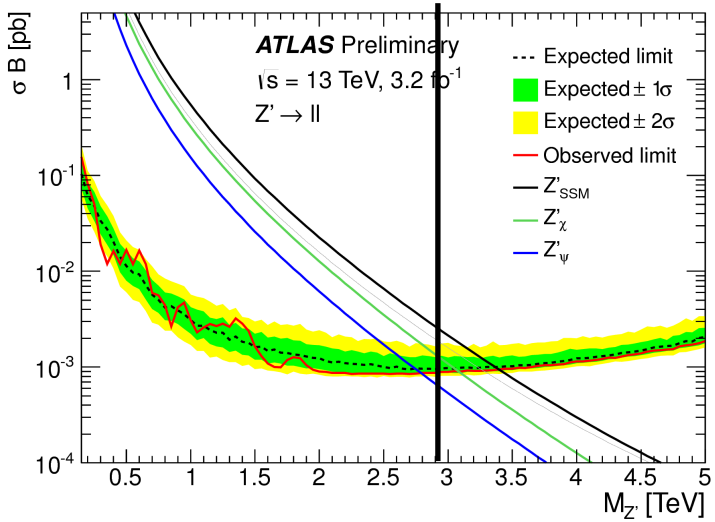
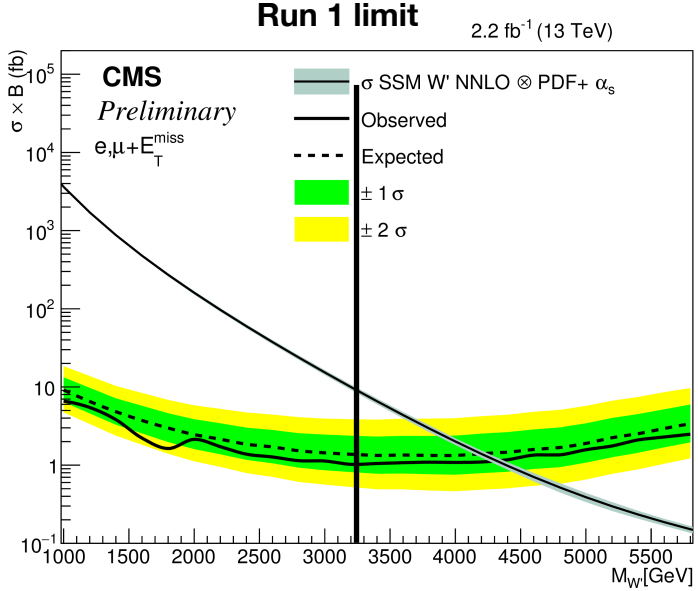
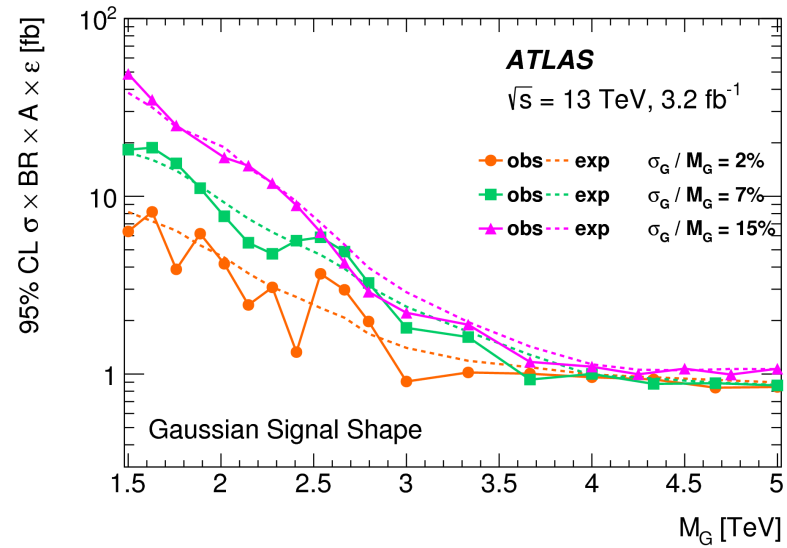
Run 1 limit on Z'$_{SSM}$



Run 1 limit



Limits from photon-jet resonance for different widths



No significant excess observed

Sensitivity significantly extended with respect to Run 1

Di-boson resonances

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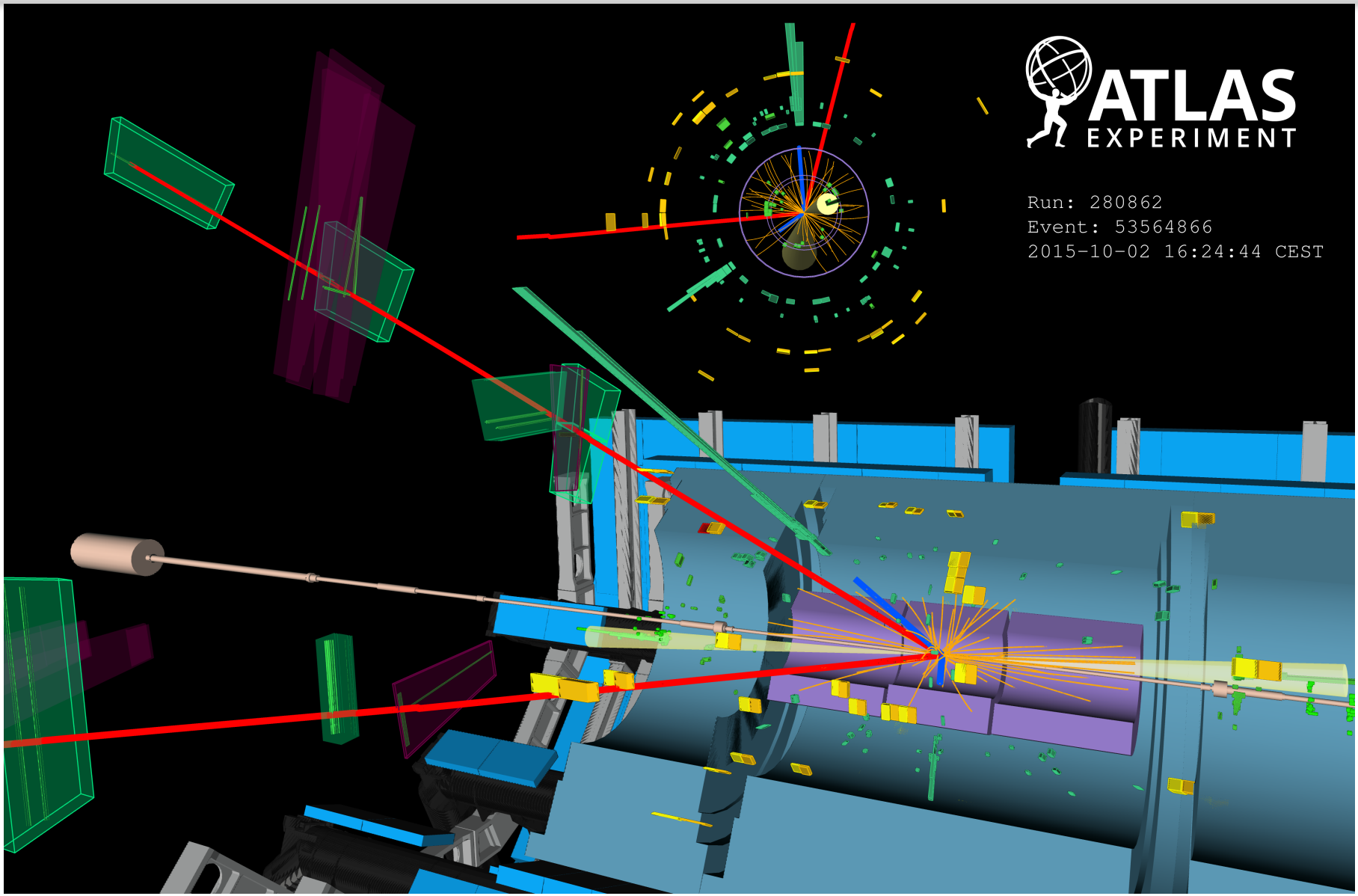

Di-boson resonances

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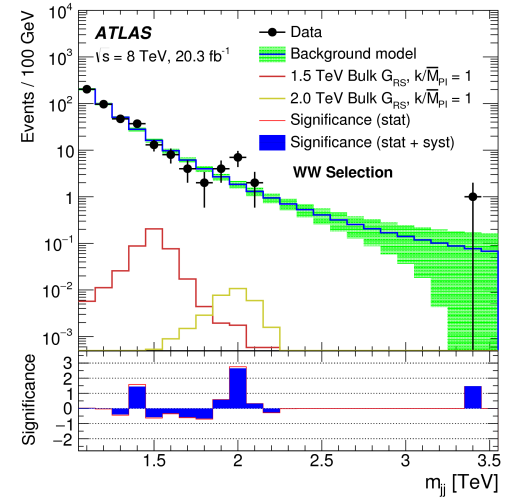
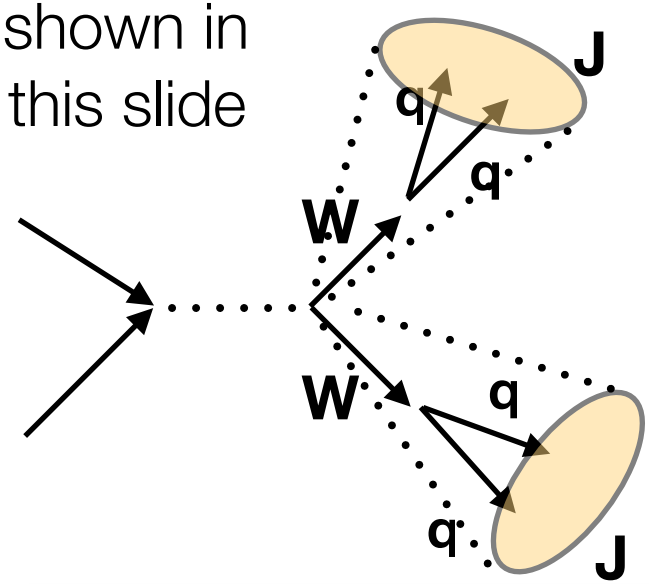
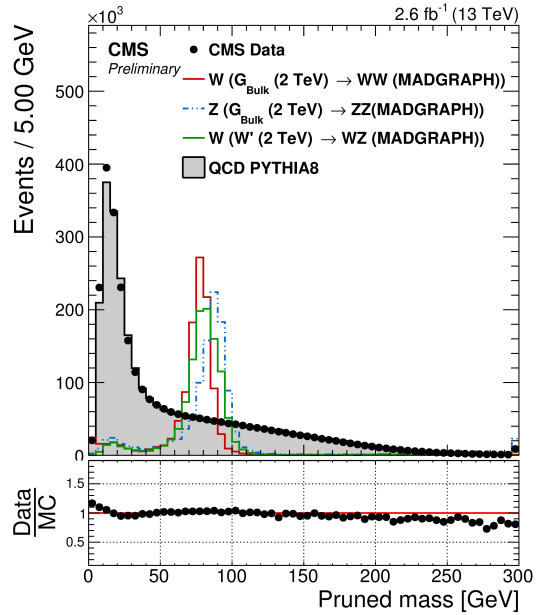
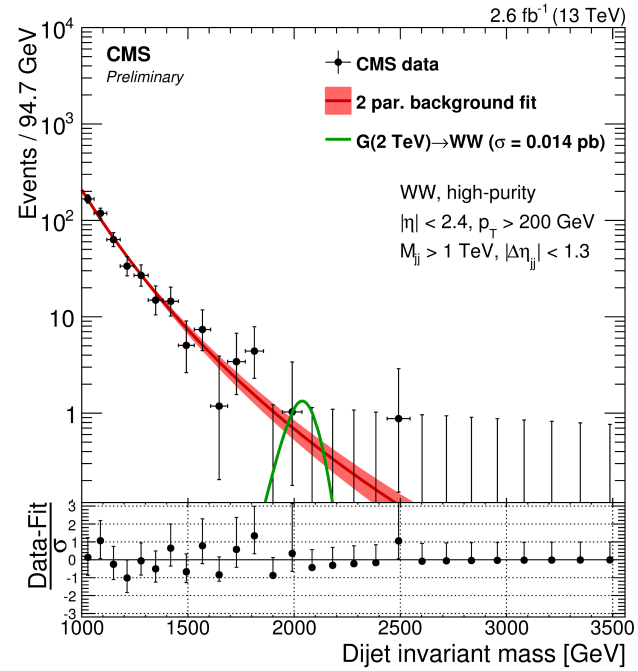
- Looking for the decay of a **heavy resonance in vector boson pairs**
- Several possible **final states** investigated
- Run 1: a **mild excess**, mostly in the di-jet channel
  - Other **minor excesses** in other channels, not **conclusively consistent with each other**



shown in this slide







Di-boson resonances

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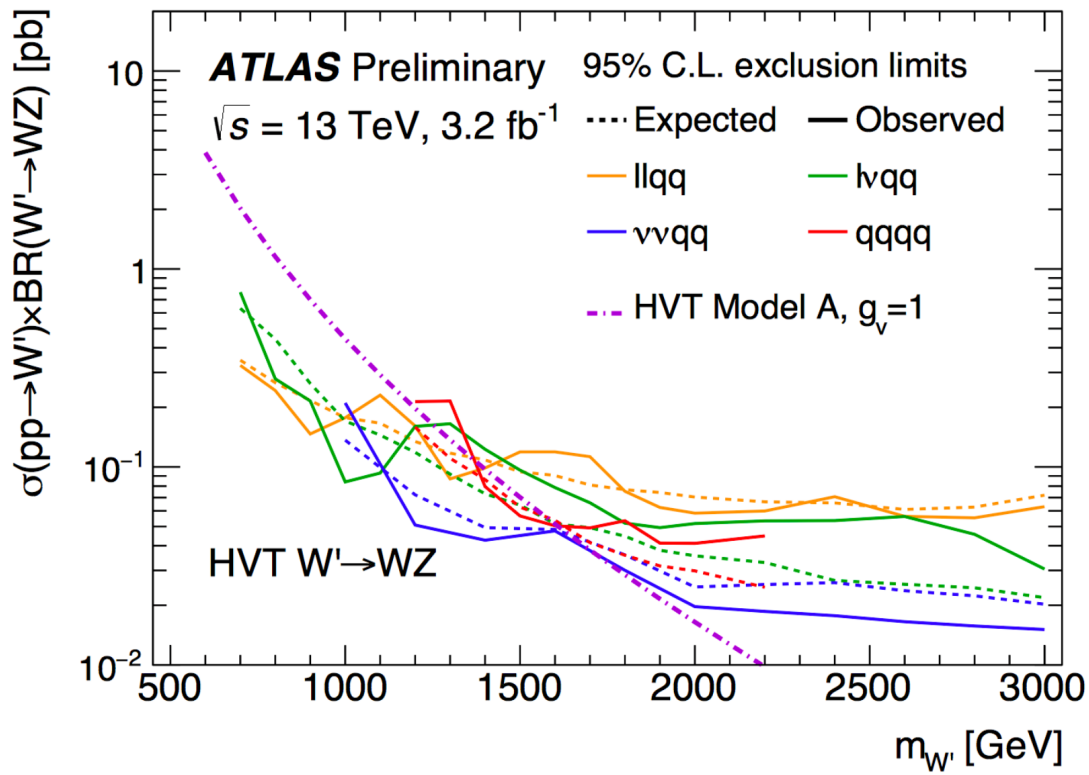
- Run 2 searches **well underway**
- Most of the **possible final states** already **under investigation**
- **No excess** above standard model…
- …but **sensitivity not yet at the level of run 1** for the individual channels
- **HVT: Heavy Vector Triplet** model (http://arxiv.org/pdf/1402.4431v2.pdf) - spin 1 particles
- But also interpreted in terms of **RS graviton (spin 2)** and a **spin 0** Higgs boson



ATLAS-CONF-2015-073 VV→qqqq
ATLAS-CONF-2015-075 WV→lνqq
ATLAS-CONF-2015-071 ZV→llqq
ATLAS-CONF-2015-068 ZV→ννqq
ATLAS-CONF-2015-074 VH
CMS-PAS-EXO-15-002 VV→qqqq,lνqq

Di-photon resonances

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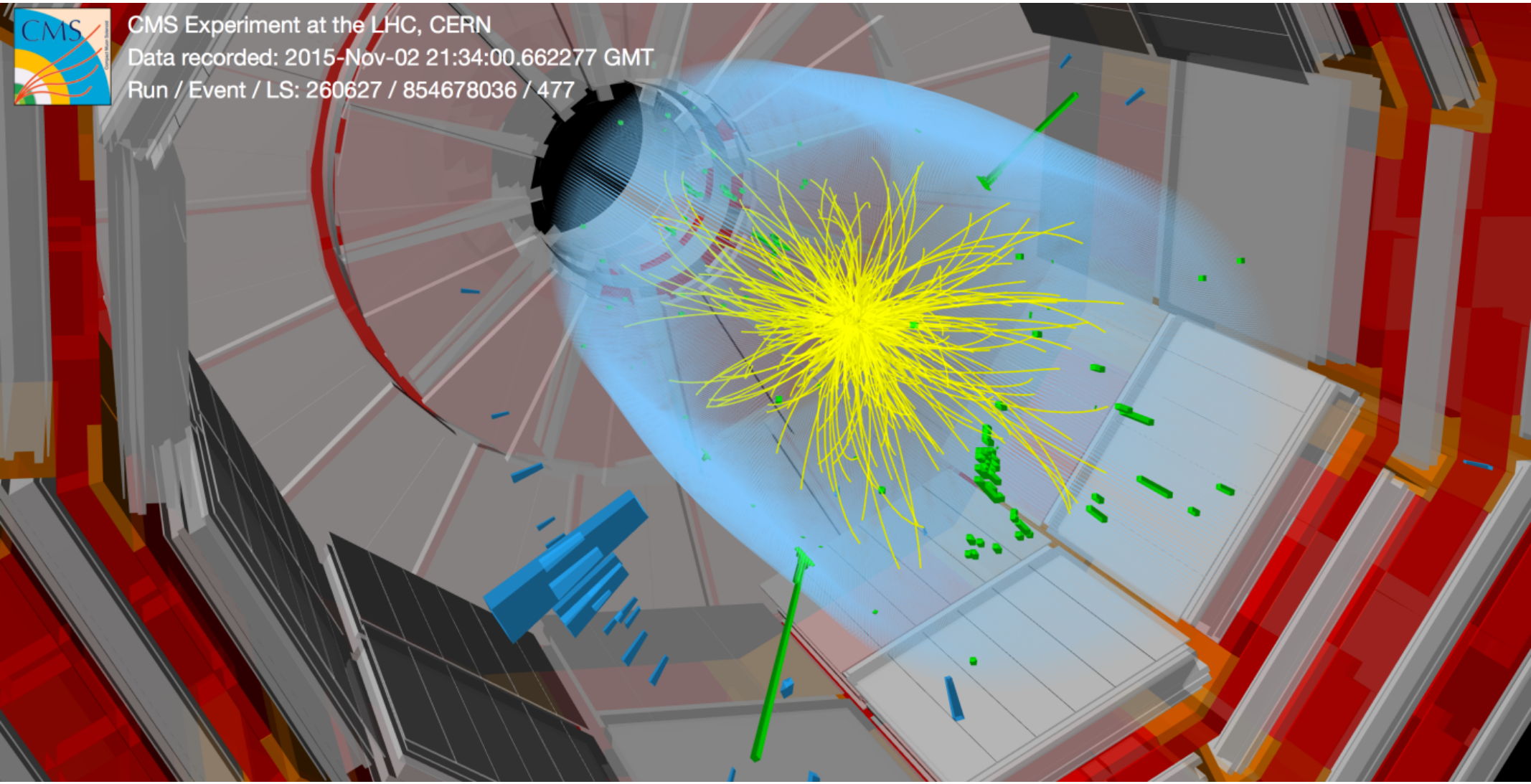

Diphoton resonances

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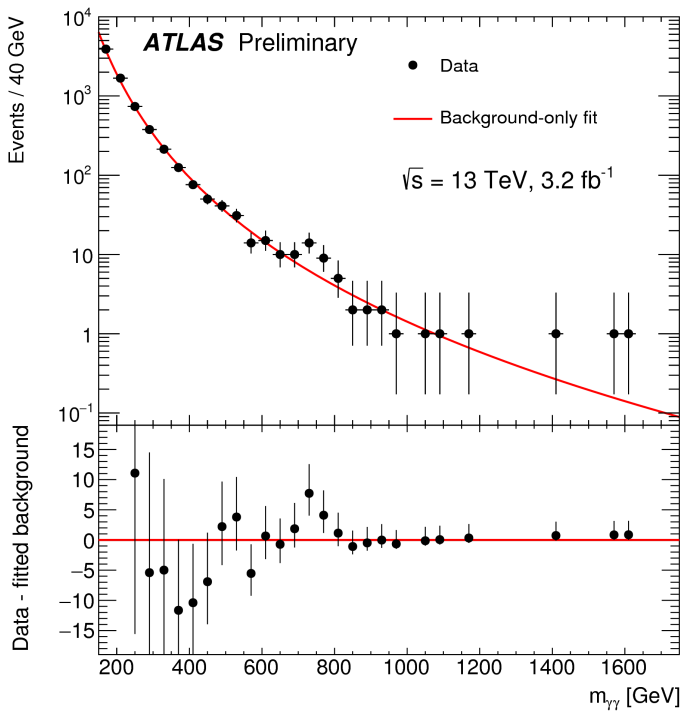
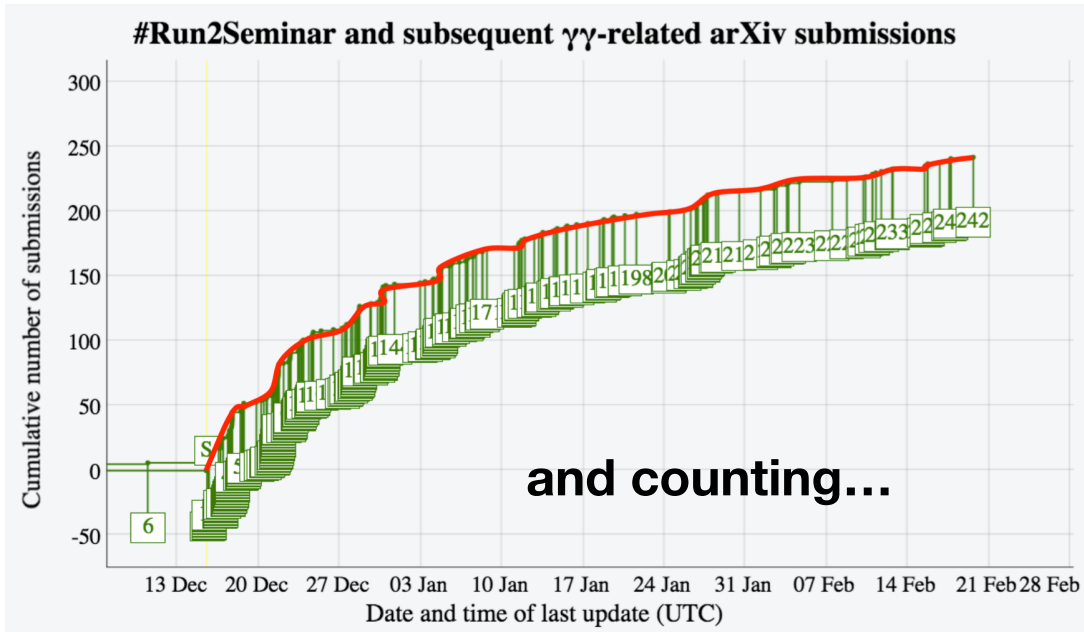
- **Great excitement** caused in the community by an excess of events around 750 GeV seen by **both experiments**
- A flood of possible interpretations by the theory community





New results from last week

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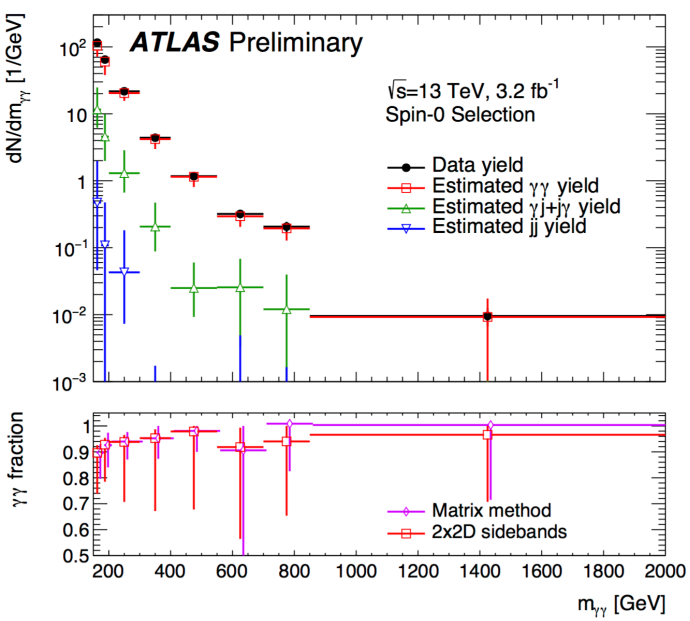
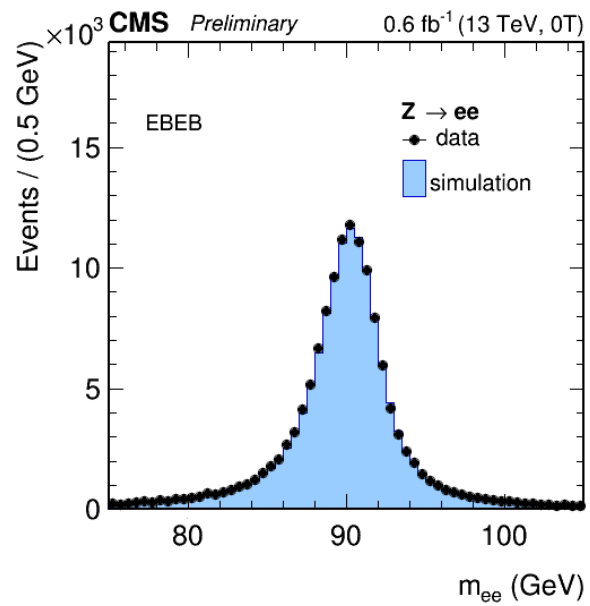
- Both ATLAS and CMS have presented:
  - A **spin 0** and a **spin 2** analysis
  - Results at 13 TeV and 8 TeV (combined, in the CMS case)
  - CMS has analysed **0.6 fb^{-1}** recorded **with no magnetic field**

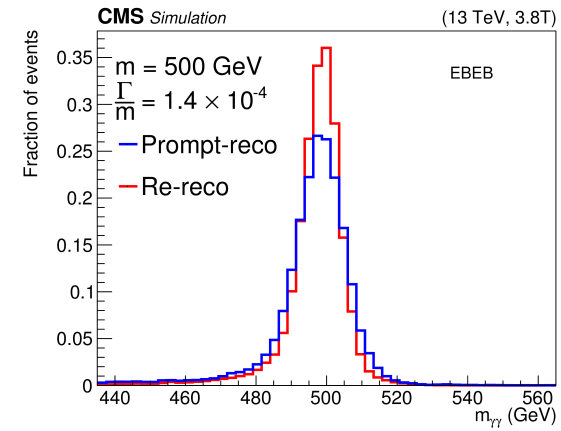
$$P_{\gamma\gamma} = 93\ ^{+3}_{-8}\ \%$$



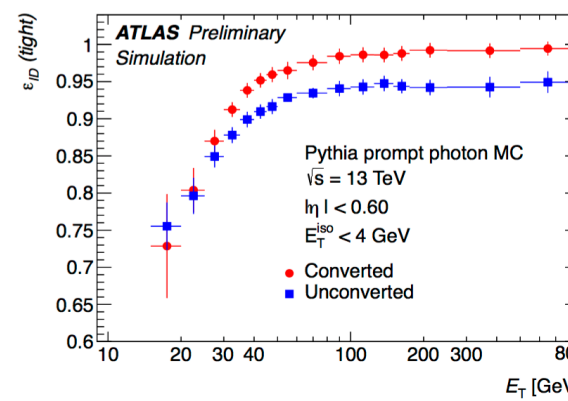
di-photon purity - ATLAS



egamma calibration with no magnetic field, CMS



improved calibration



good efficiency for converted and unconverted photons

Significance of the excess

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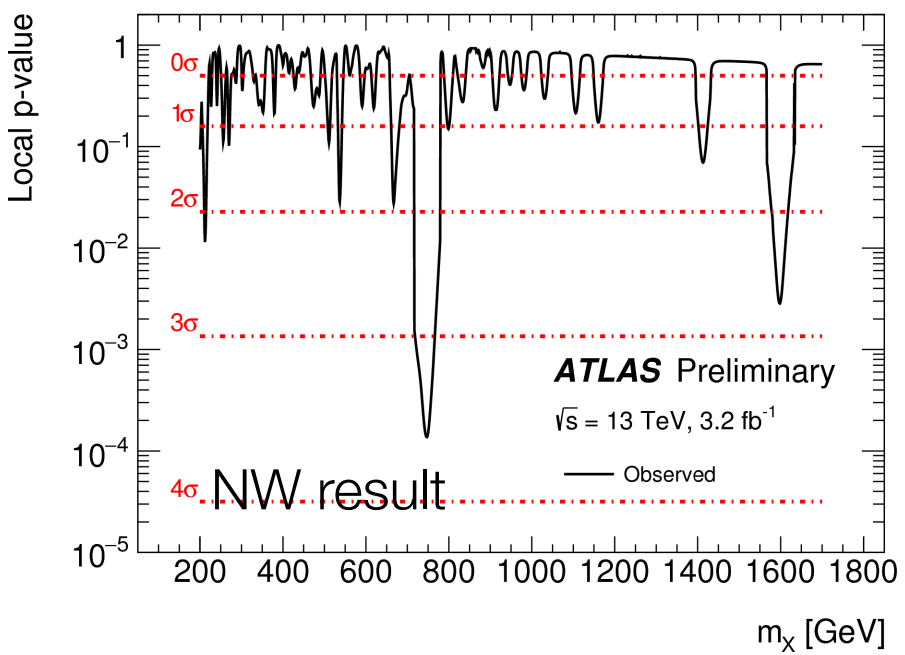
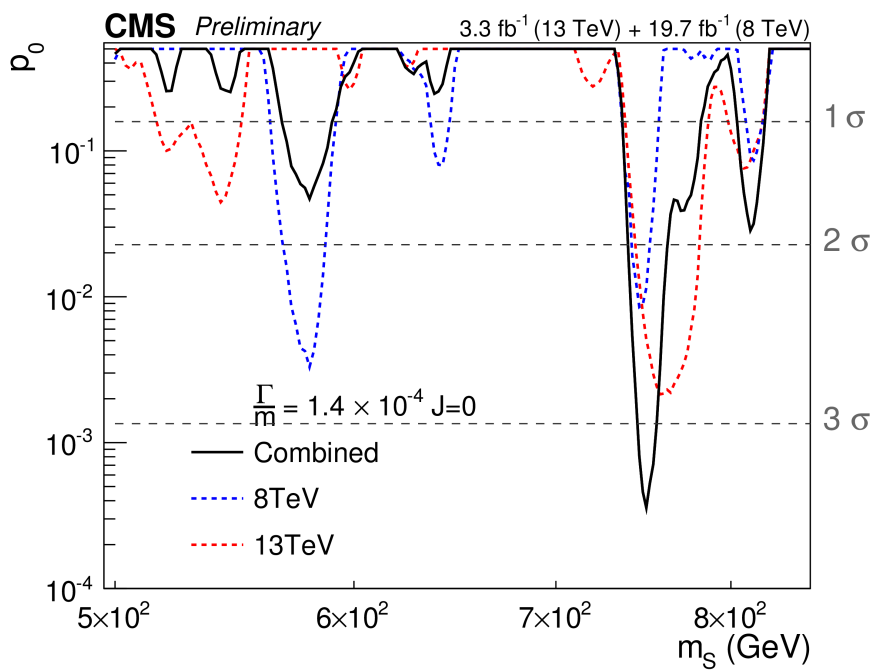
- ATLAS quotes:
  - Spin 2: **3.6σ local** (1.8σ global) for **m_G = 750 GeV, Γ_G = 7% m_G**
  - Spin 0: **3.9σ local** (2.3σ global) for variable width (largest deviation for **Γ = 45 GeV**)
  - Run 1 results (spin 0) compatible with the excess at **1.2σ for gg**.
- CMS quotes **3.4σ local** (1.6σ global) combined with run 1 (2.9 local in run 2 alone). Best fit for **narrow width and m = 750 GeV.**

ATLAS-CONF-2015-081
CMS-PAS-EXO-2015-004
CMS-PAS-EXO-2016-018
plus material from Moriond Conferences





Summary

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- The LHC opened up a **new energy frontier** (twice!)
- Direct searches (together with Higgs measurements and precision measurements) **do have severe impact** on constraining BSM physics.

- Few interesting excesses spotted (above all the **diphoton bump** at 750 GeV)
  - We need **more data**…
  - … but **they are coming real soon**!

Summary

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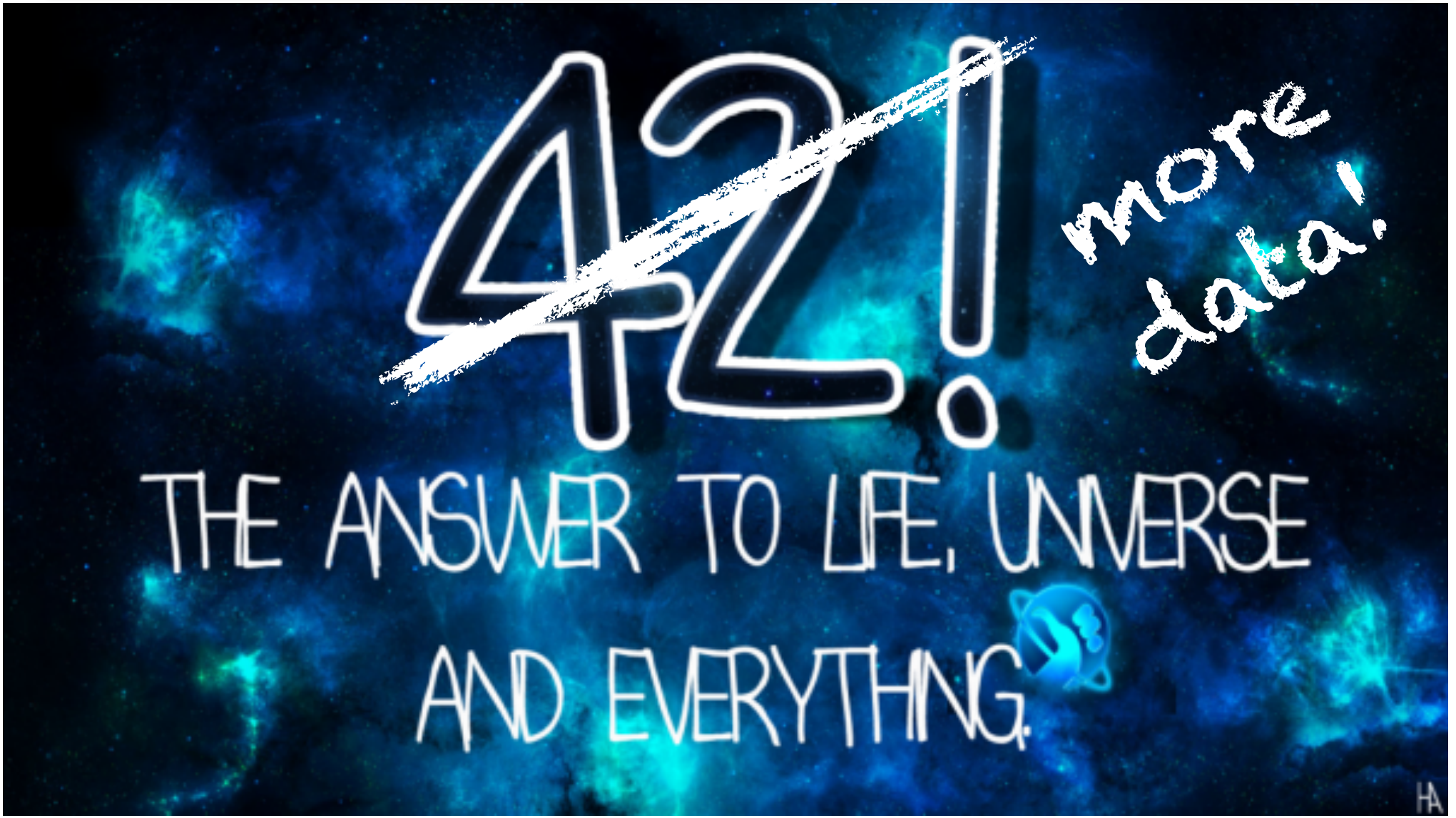

Backup

What does CMS say?

CMS-PAS-SUS-15-011

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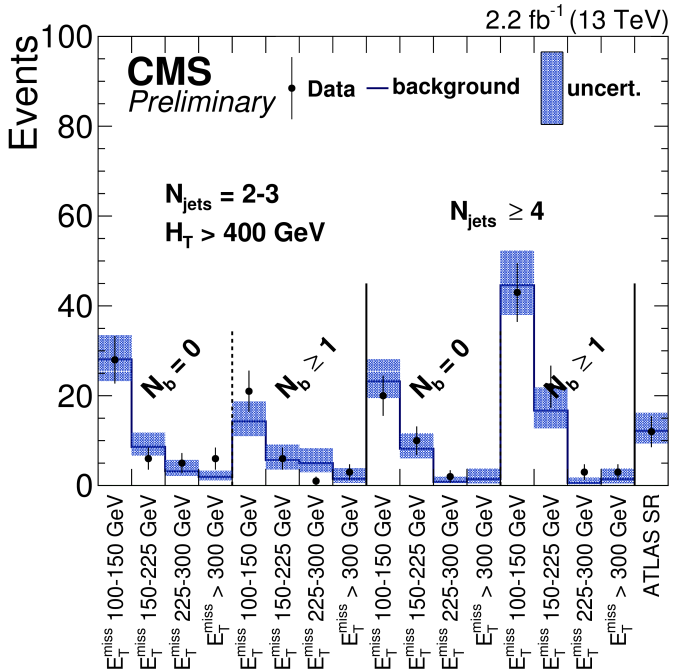
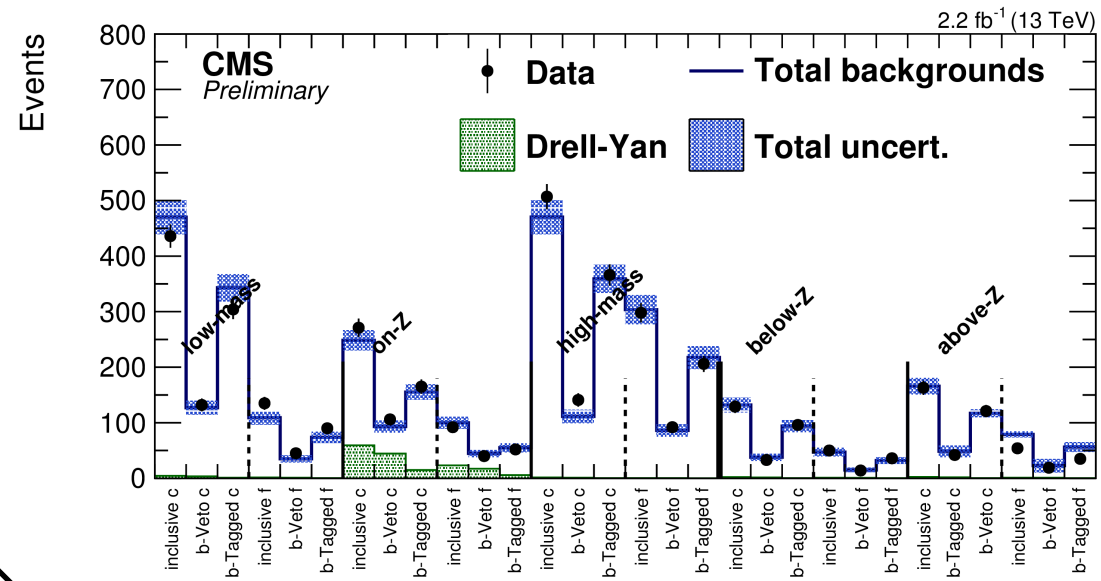
- **47 signal regions**, looking on- and off-Z (CMS had 2.6 σ below the Z peak)
  - Defined with different **jet and b-jet multiplicity, E_T^{miss}, H_T, m_{ll}**
  - Background estimation **similar to the ATLAS case.**





This is identical to the ATLAS selection

ATLAS Z+E_T^{miss}

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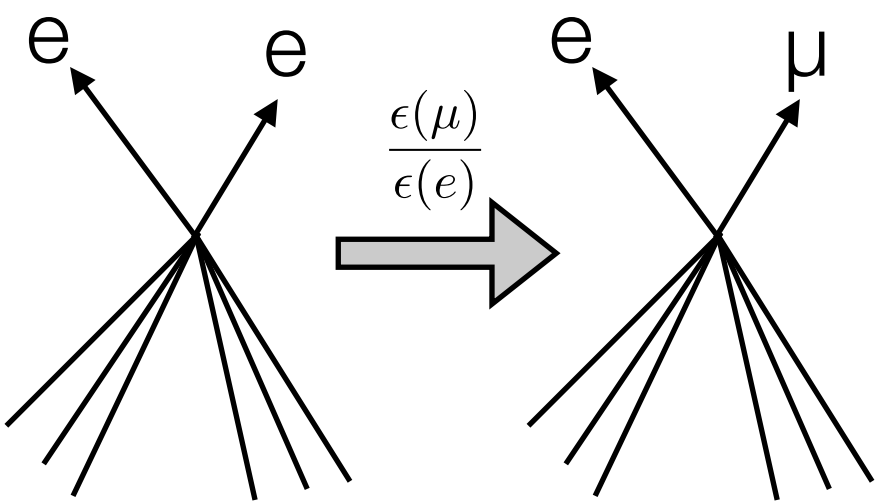
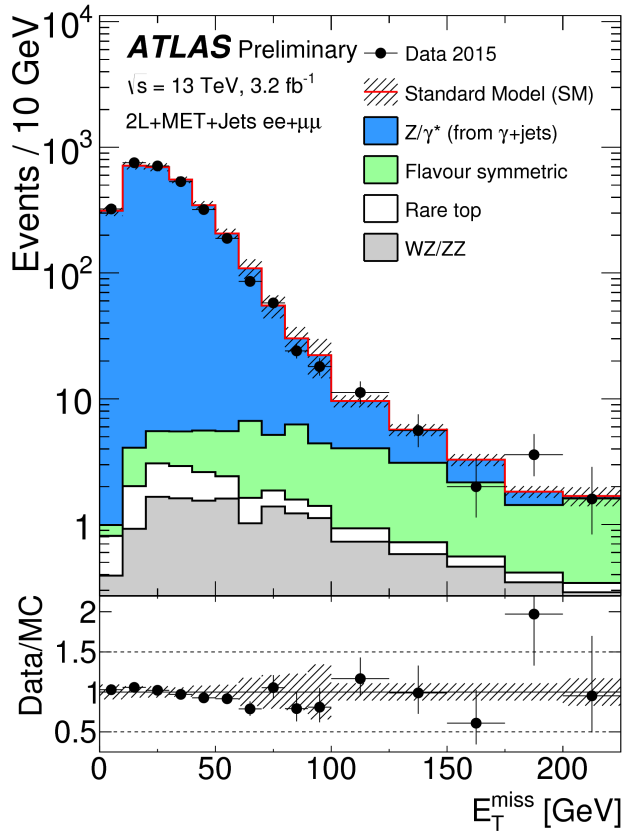
- **Flavour symmetric** background (top pair production, WW, etc.): ee:μμ:eμ events are in ratio 1:1:2
- Validated with a sideband fit to m_{ll}



- **$Z+E_T^{miss}$ background** tricky (it mainly comes from detector effects)
- Estimated from γ+jets events

- idea: γ+jets and Z +jets events are the same (beside Z mass and lepton/ photon resolution
- measure E_T^{miss} shape in γ+jets and use it to predict signal region yields



Additional info ATLAS

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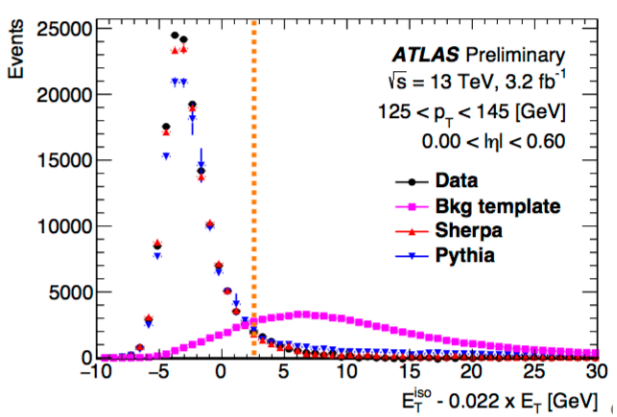
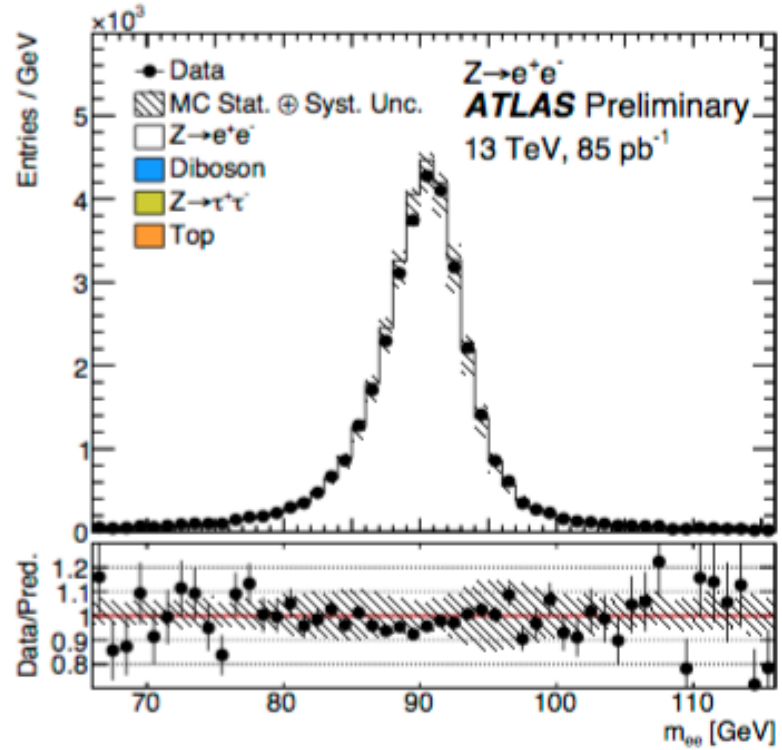
- **At E_T^γ > 100-200 GeV, resolution dominated by constant term...**
  - ✓ c = 0.6% - 1.5%

$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus \frac{b}{E} \oplus c$$

- **Uncertainties**
  - ✓ Energy scale: ±(0.4%-2%)
  - ✓ Energy resolution (E_T^γ=300 GeV): ±(80%-100%)





From Marco Del Mastro's talk at Moriond EW

Additional info ATLAS

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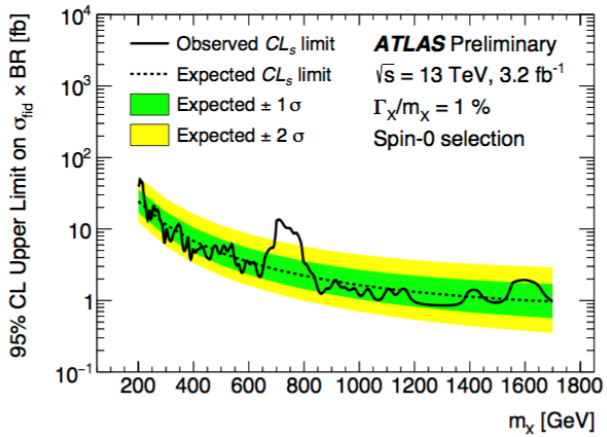
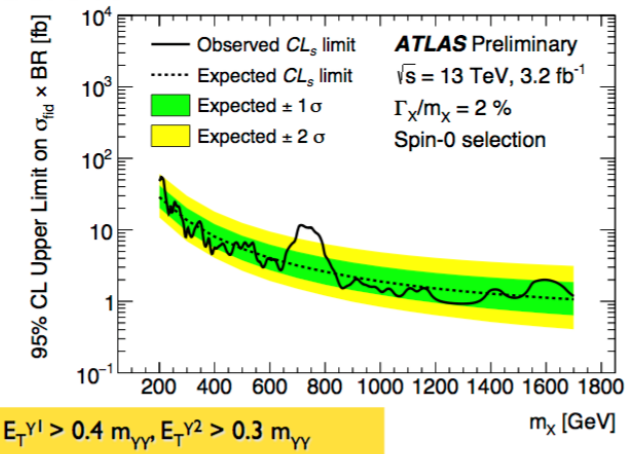
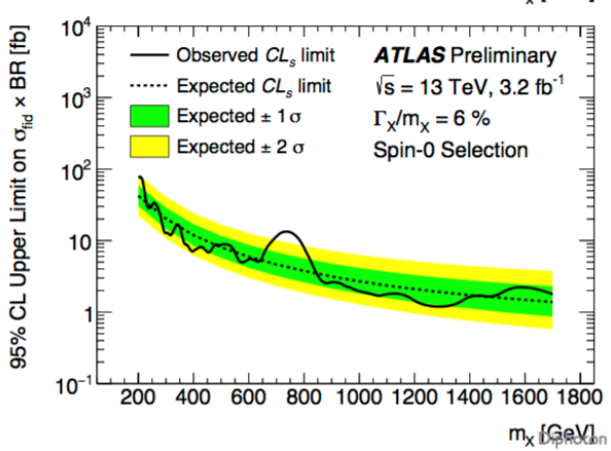
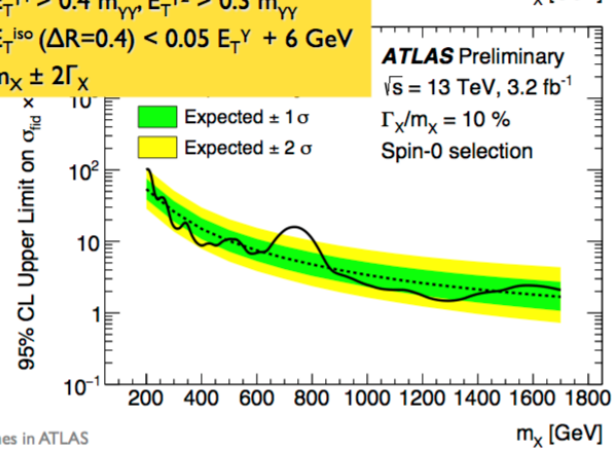
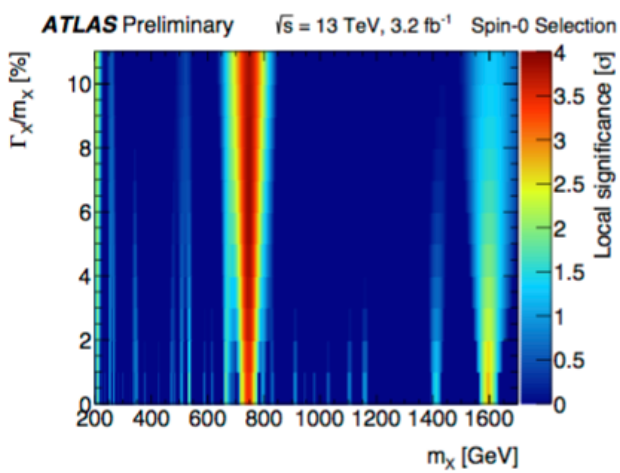






$E_T^{\gamma 1} > 0.4\ m_{\gamma\gamma}$, $E_T^{\gamma 2} > 0.3\ m_{\gamma\gamma}$
E_T^{iso} (ΔR=0.4) < 0.05 E_T^{γ} + 6 GeV
$m_X \pm 2\Gamma_X$





From Marco Del Mastro's talk at Moriond EW

Additional info CMS

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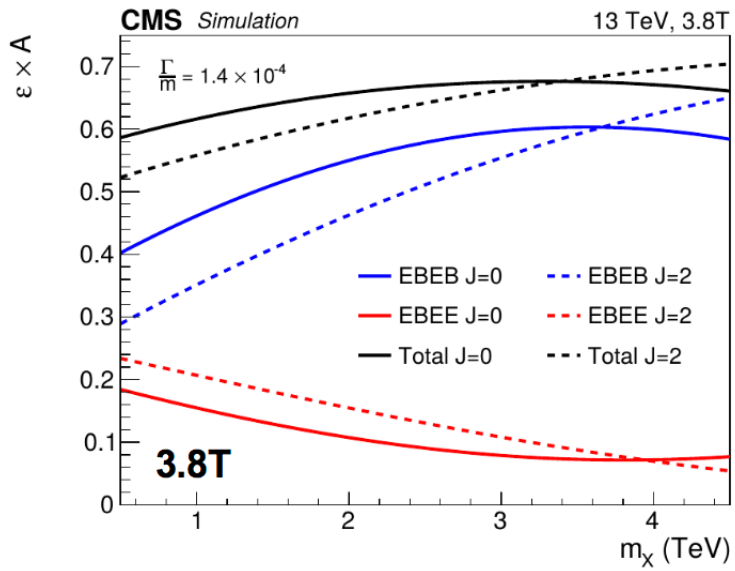

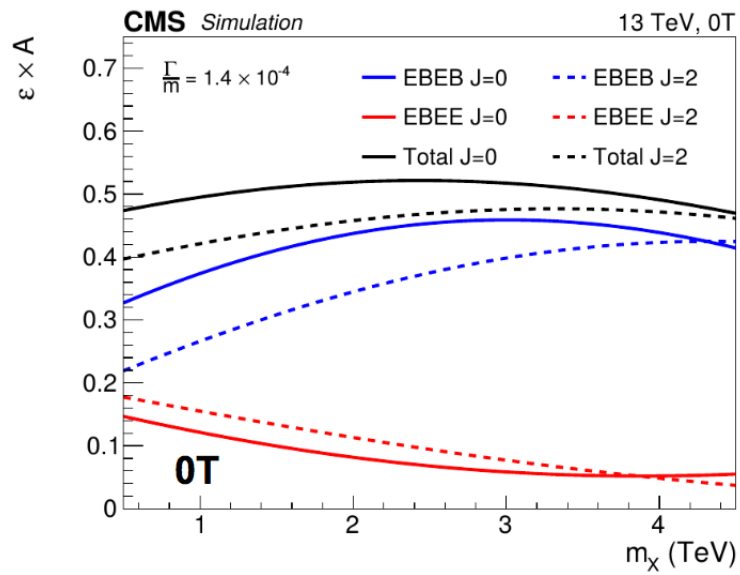

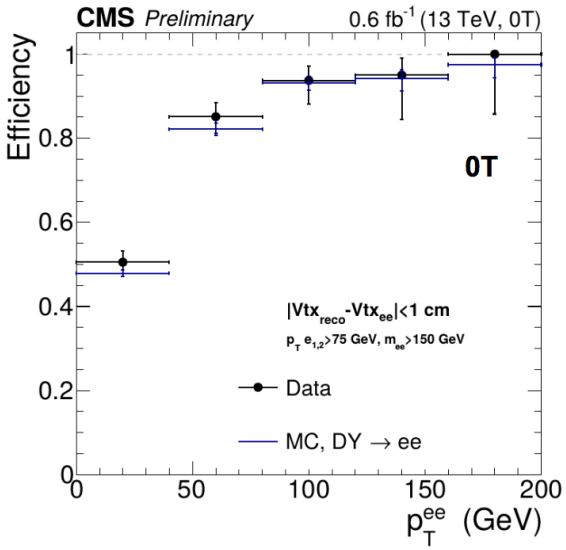

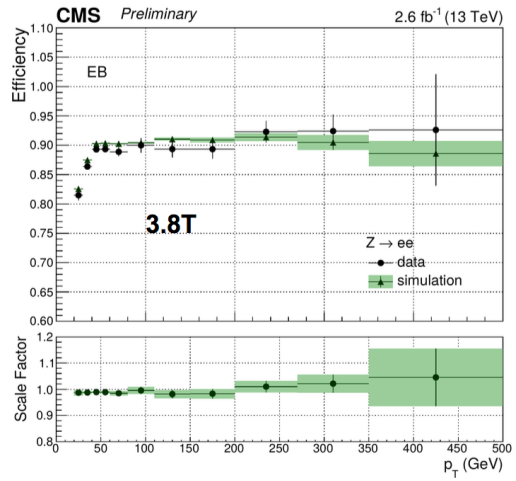

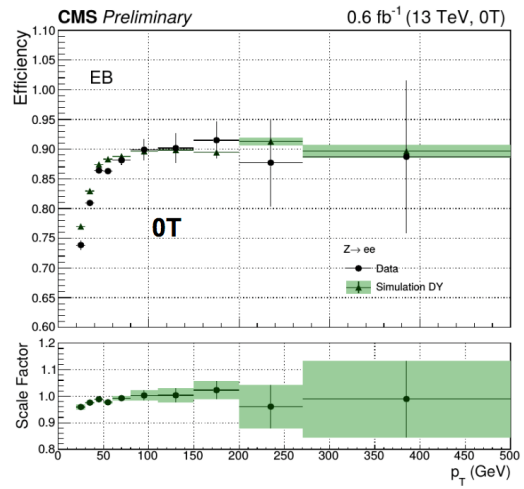

Additional info CMS

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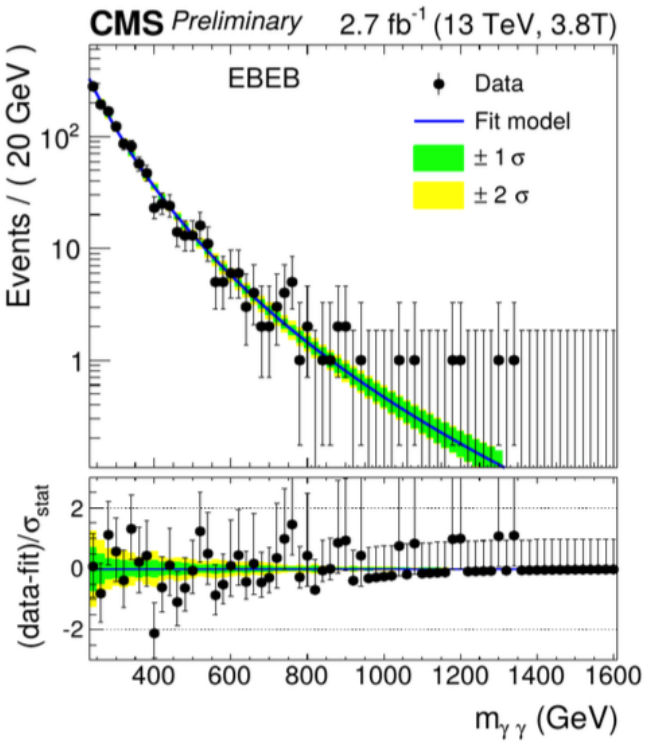
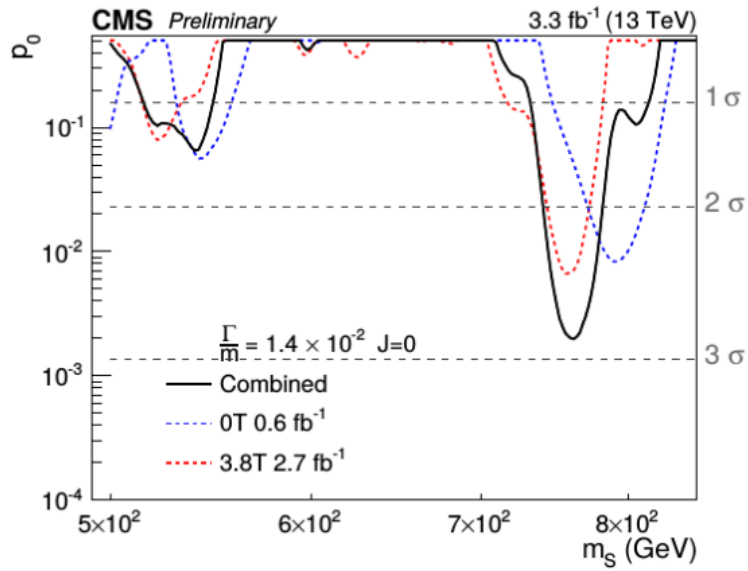
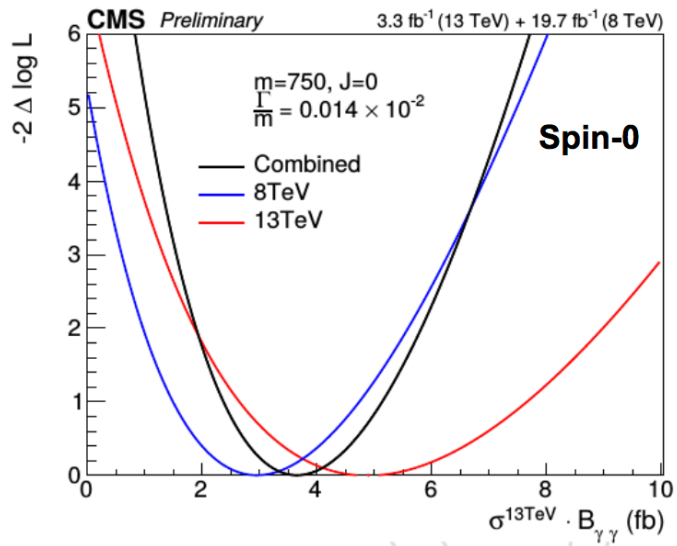
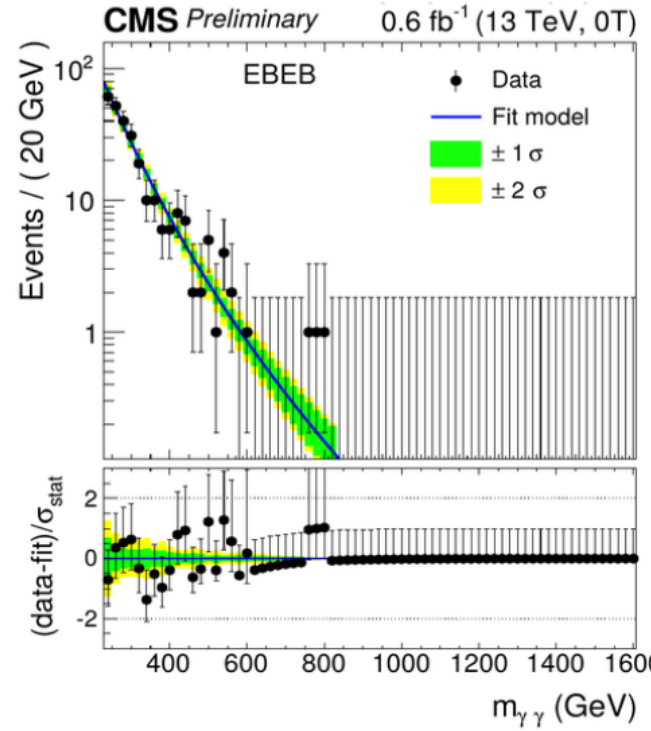
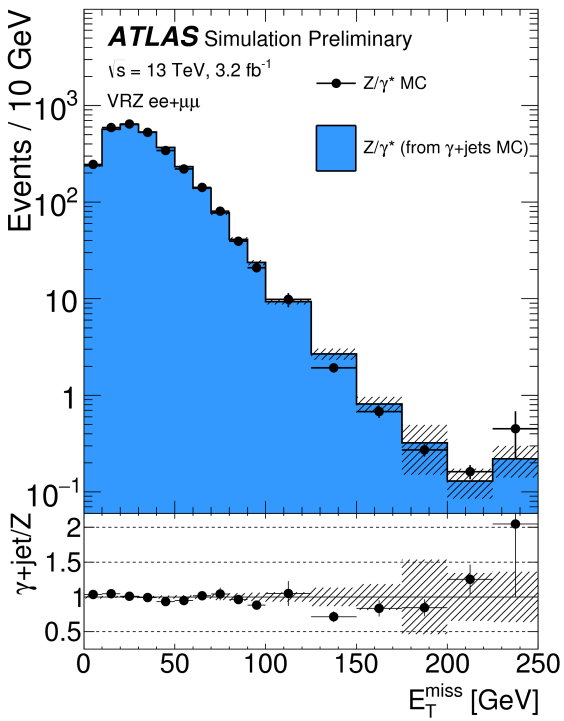


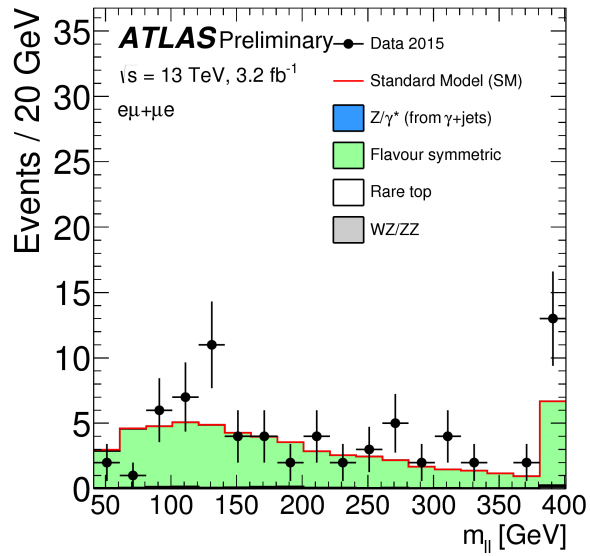


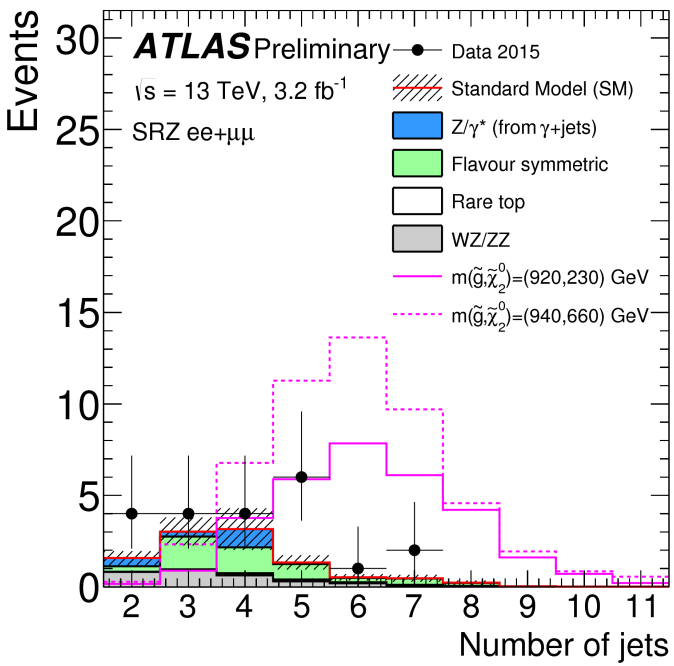


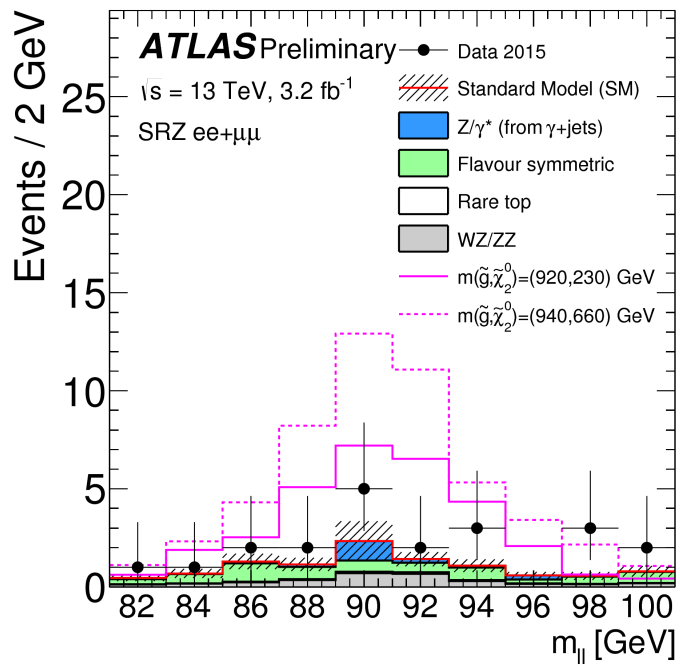


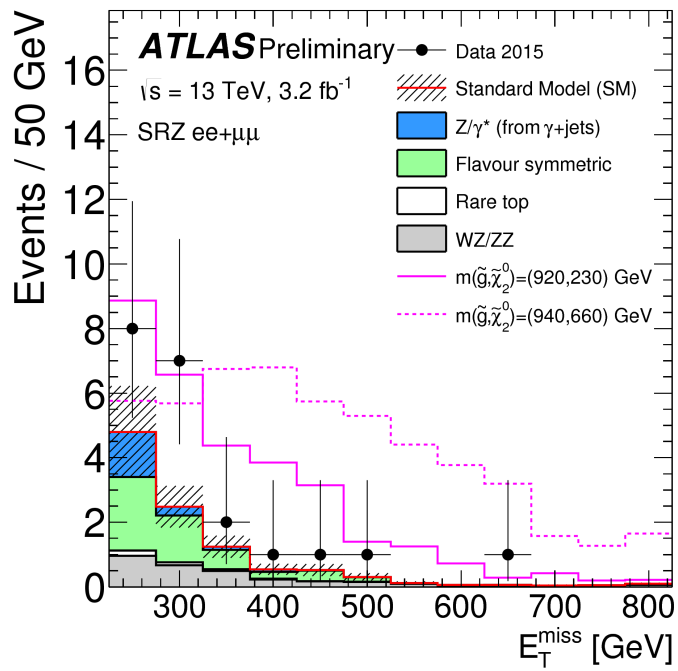
Z+jets excess

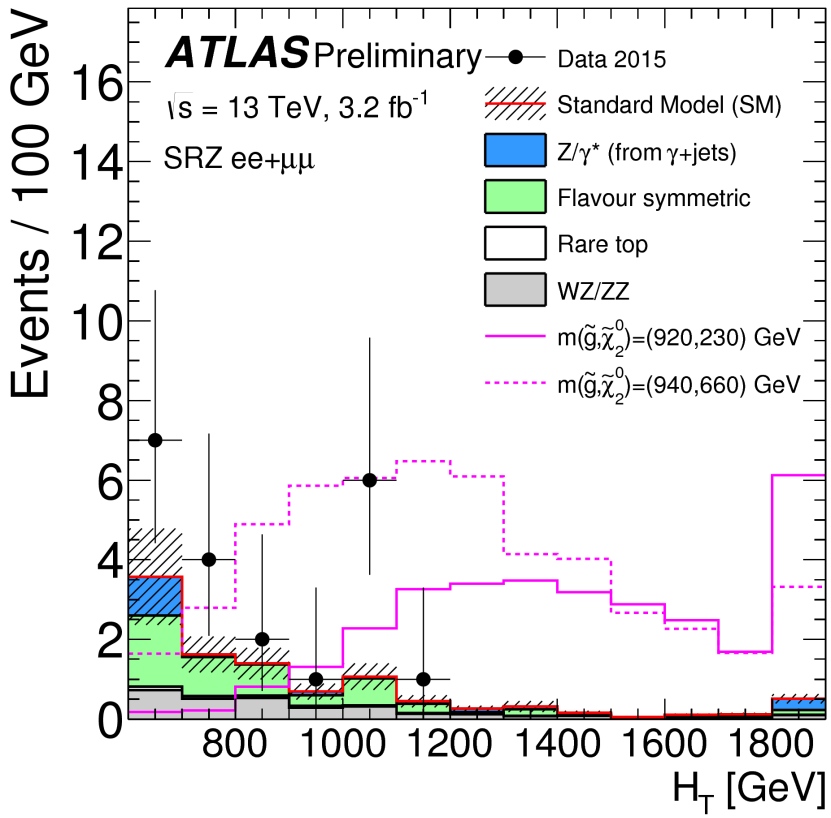


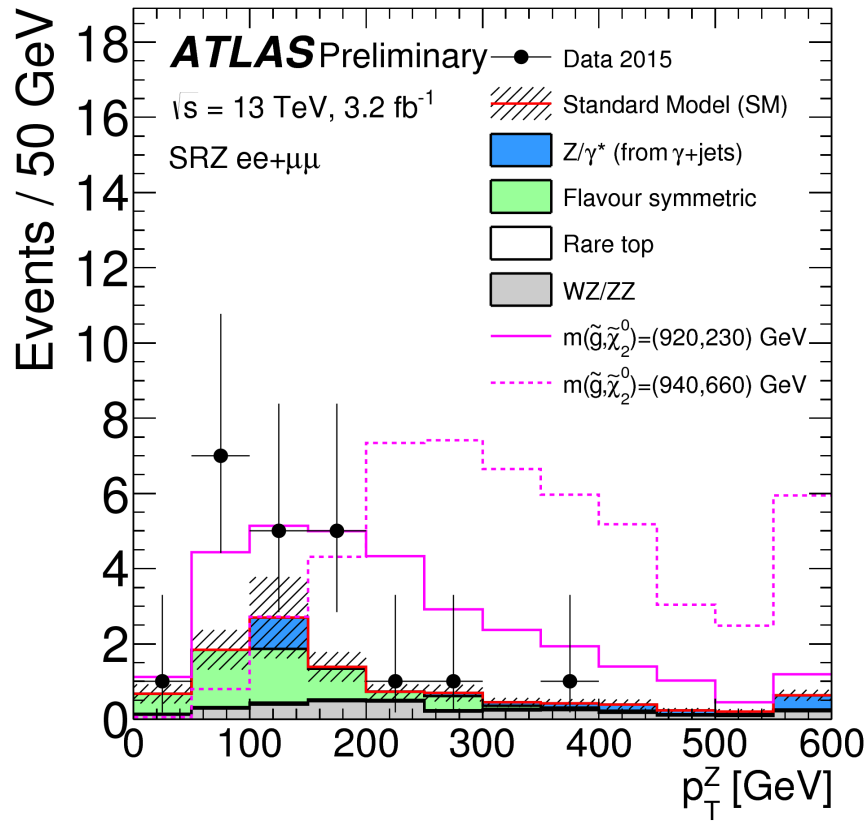



ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
SRZ ee+μμ
Data 2015
Standard Model (SM)
Z/γ* (from γ+jets)
Flavour symmetric
Rare top
WZ/ZZ
m(g̃,χ̃20)=(920,230) GeV
m(g̃,χ̃20)=(940,660) GeV
Events
Number of jets


ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
SRZ ee+μμ
Data 2015
Standard Model (SM)
Z/γ* (from γ+jets)
Flavour symmetric
Rare top
WZ/ZZ
m(g̃,χ̃20)=(920,230) GeV
m(g̃,χ̃20)=(940,660) GeV
Events / 2 GeV
mll [GeV]


ATLAS Preliminary
√s = 13 TeV, 3.2 fb-1
SRZ ee+μμ
Data 2015
Standard Model (SM)
Z/γ* (from γ+jets)
Flavour symmetric
Rare top
WZ/ZZ
m(g̃,χ̃20)=(920,230) GeV
m(g̃,χ̃20)=(940,660) GeV
Events / 50 GeV
EmissT [GeV]


ATLAS Preliminary
Data 2015
√s = 13 TeV, 3.2 fb-1
Standard Model (SM)
SRZ ee+μμ
Z/γ* (from γ+jets)
Flavour symmetric
Rare top
WZ/ZZ
m(g̃,χ̃20)=(920,230) GeV
m(g̃,χ̃20)=(940,660) GeV
Events / 100 GeV
HT [GeV]


ATLAS Preliminary
Data 2015
√s = 13 TeV, 3.2 fb-1
Standard Model (SM)
SRZ ee+μμ
Z/γ* (from γ+jets)
Flavour symmetric
Rare top
WZ/ZZ
m(g̃,χ̃20)=(920,230) GeV
m(g̃,χ̃20)=(940,660) GeV
Events / 50 GeV
pTZ [GeV]

Region	$E_{\mathrm{T}}^{\mathrm{miss}}$ **[GeV]**	H_{T} **[GeV]**	$n_{\mathbf{jets}}$	$m_{\ell\ell}$ **[GeV]**	**SF/DF**	$\Delta\phi(\mathbf{jet}_{12}, \boldsymbol{p}_{\mathrm{T}}^{\mathrm{miss}})$	$m_{\mathrm{T}}(\ell_3, E_{\mathrm{T}}^{\mathrm{miss}})$ [GeV]	$n_{\text{b-jets}}$
Signal regions								
SRZ	> 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
Control regions								
Z normalisation	< 60	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
CR-FS	> 225	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
CRT	> 225	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
Validation regions								
VRZ	< 225	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VRT	100–200	> 600	≥ 2	$m_{\ell\ell} \notin [81, 101]$	SF	> 0.4	-	-
VRS	100–200	> 600	≥ 2	$81 < m_{\ell\ell} < 101$	SF	> 0.4	-	-
VR-FS	100–200	> 600	≥ 2	$61 < m_{\ell\ell} < 121$	DF	> 0.4	-	-
VR-WZ	100–200	-	-	-	3ℓ	-	< 100	0
VR-ZZ	< 100	-	-	-	4ℓ	-	-	0
VR-3L	60–100	> 200	≥ 2	$81 < m_{\ell\ell} < 101$	3ℓ	> 0.4	-	-

	VRS	VR-WZ	VR-ZZ	VR-3L
Observed events	56	89	20	7
Total expected background events	52.6 ± 9.1	87 ± 10	15.5 ± 3.4	6.5 ± 1.6
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	18.9 ± 4.8	1.3 ± 0.4	0	0.3 ± 0.2
WZ/ZZ events	7.5 ± 1.7	82 ± 10	15.5 ± 3.4	4.9 ± 1.6
Z/γ^* + jets events	24.8 ± 7.6	2.7 ± 2.8	0	0.2 ± 0.2
Rare top events	1.4 ± 0.2	0.9 ± 0.4	0.04 ± 0.02	1.0 ± 0.1

Region	Flavour-symmetry	Sideband fit
SRZ	5.1 ± 2.0	6.1 ± 1.7
VRS	18.9 ± 4.8	20.5 ± 5.6

	SRZ
Observed events	21
Total expected background events	10.3 ± 2.3
Flavour symmetric ($t\bar{t}$, Wt, WW and $Z \to \tau\tau$) events	5.1 ± 2.0
WZ/ZZ events	2.9 ± 0.8
Z/γ^* + jets events	1.9 ± 0.8
Rare top events	0.4 ± 0.1
p-value	0.013
Significance	2.2
Observed (Expected) S^{95}	20.0 ($10.2^{+4.4}_{-3.0}$)

Source	Relative systematic uncertainty [%]
	SRZ
Total systematic uncertainty	22
Flavour symmetry (statistical)	14
Flavour symmetry (systematic)	12
Z/γ^* + jets (systematic)	7.8
WZ generator uncertainty	7.6
Z/γ^* + jets (statistical)	2.2

But…

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- The Higgs boson mass is a bit on the "high" side for the MSSM