Overview of dark matter searches with ATLAS

Mario Martínez

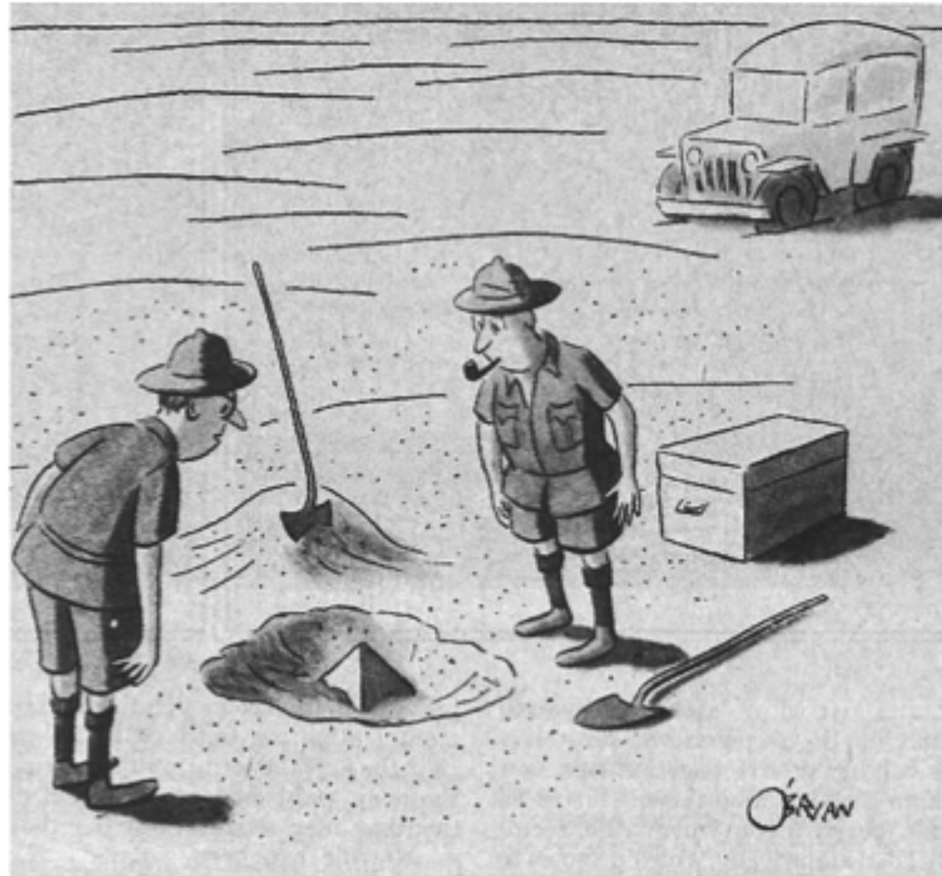
(on behalf of the ATLAS Collaboration)

2nd World Summit on Exploring the Dark Side of the Universe
25th – 29th June 2018

Outline

- Theory Framework
- LHC and ATLAS
- Mono-jet & Dijet
- Mono-X
- Susy-Inspired
- DM+HF results
- Higgs postal

- Final notes



"This could be the discovery of the century. Depending, of course, on how far down it goes."

This talk is focused on dedicated DM searches inspired by simplified models with light mediators

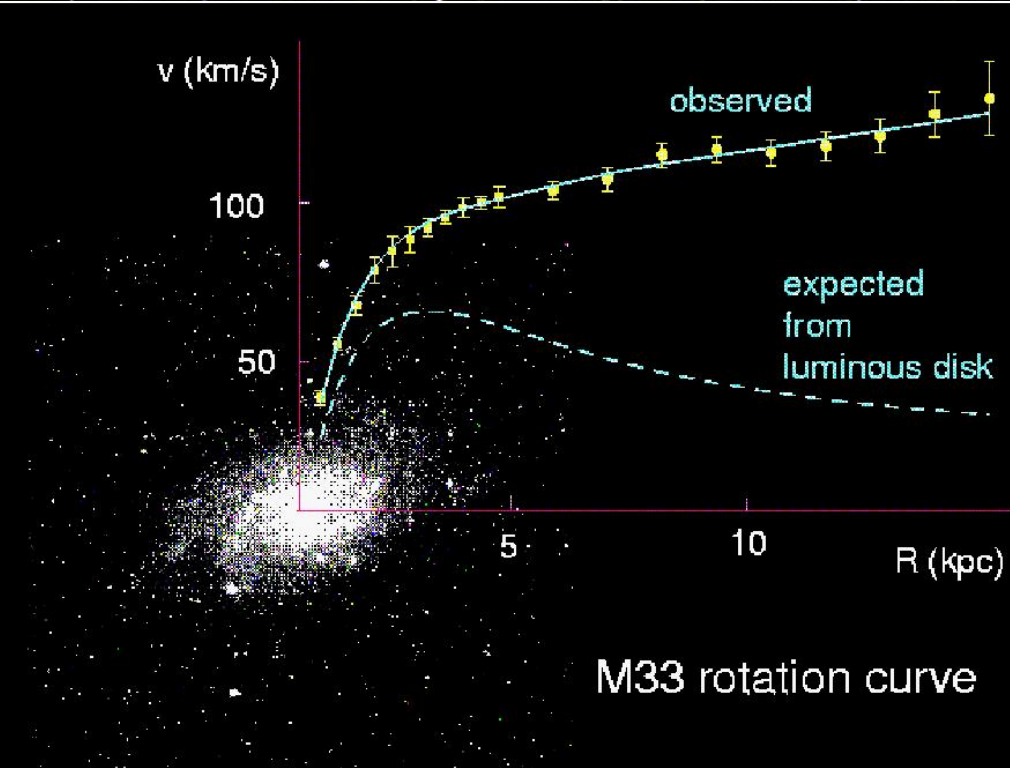
Focused mainly on 13 TeV data

See also section on Young Scientist talks

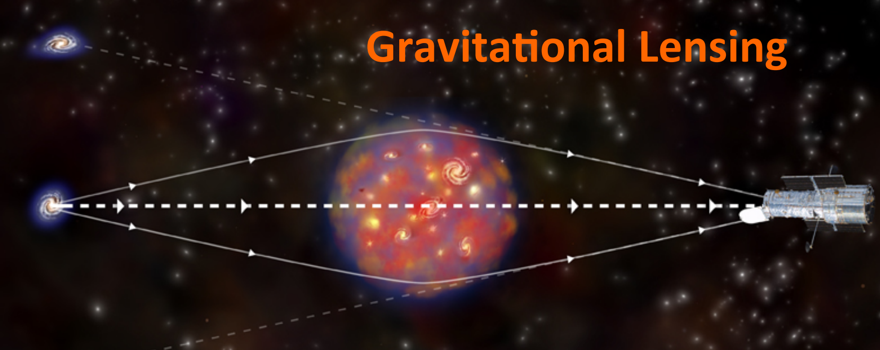
Evidence for Dark Matter

The rotation of the stars around the center of the galaxies is not consistent with the amount of mass observed $(L/M\ ratio)_{SUN}$

Spherical dark matter halo



Gravitational Lensing



Large distortion of the images of distant galaxies due to gravitation lensing

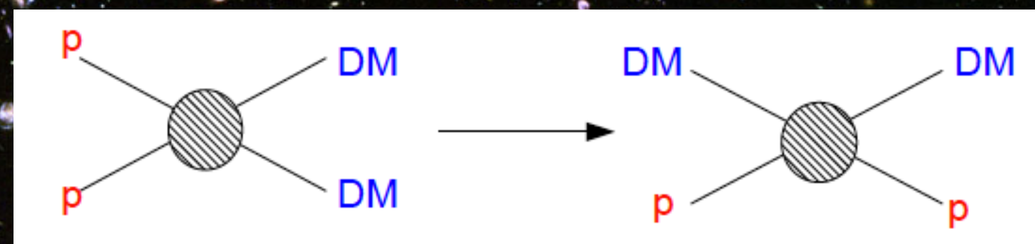
→ indication of DM in galaxy clusters

Collisions of clusters of galaxies

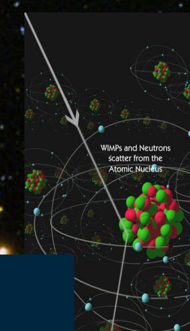
Considered the ultimate demonstration of the presence of Dark Matter since this does not involve Newton's Law

Introductory notes

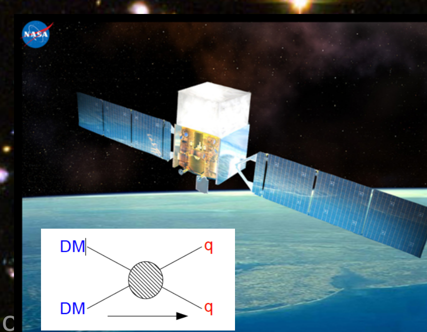
If Dark Matter turns to be WIMP like (weakly interacting) there is a chance to produce it directly at colliders (Golden channel → Mono-jet final state)

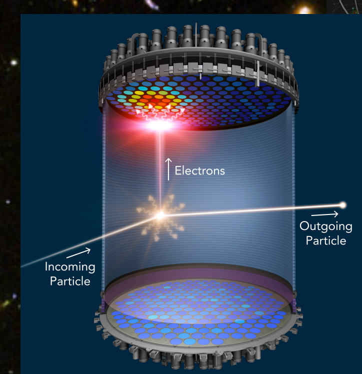


This makes the LHC complementary to direct-detection dedicated experiments underground



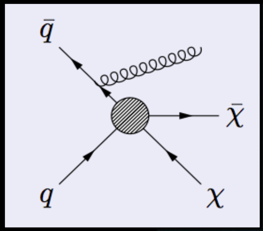
Some of the models explored at the LHC are also inspired by the Higgs boson and /or indirect searches at satellites → heavy flavors involved

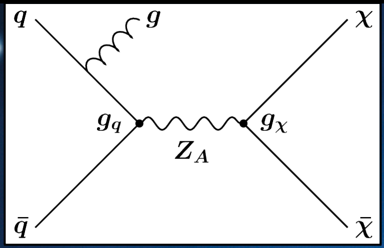




Benchmark Models

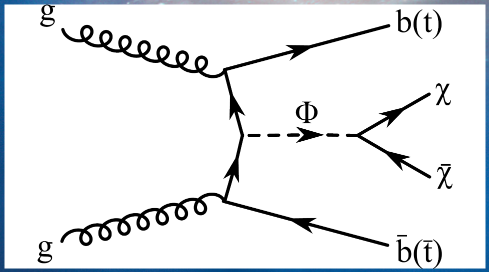
In Run II the ATLAS and CMS experiments moved away from the use of EFT inspired models with questionable validity at high-Q^2

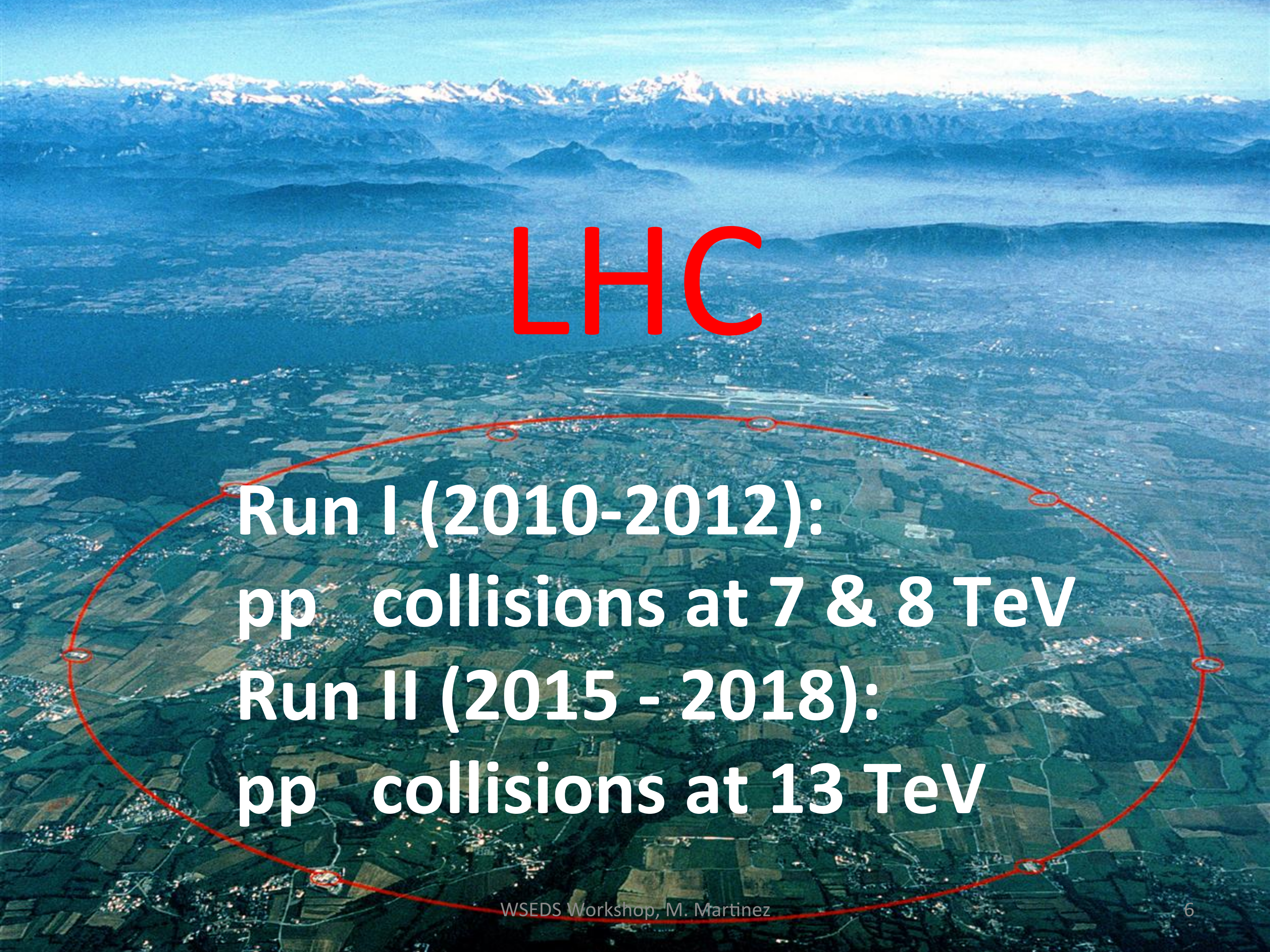




A set of well-defined simplified diagrams with heavy mediators is now considered motivated by a number of different considerations (DM Forum: arXiv:1507.00966)

- Simple extensions of SM symmetries
- Minimal Flavor Violation
- Assuming Yukawa couplings
  → favor 3rd generation
- Some models inspired by satellite "hints"



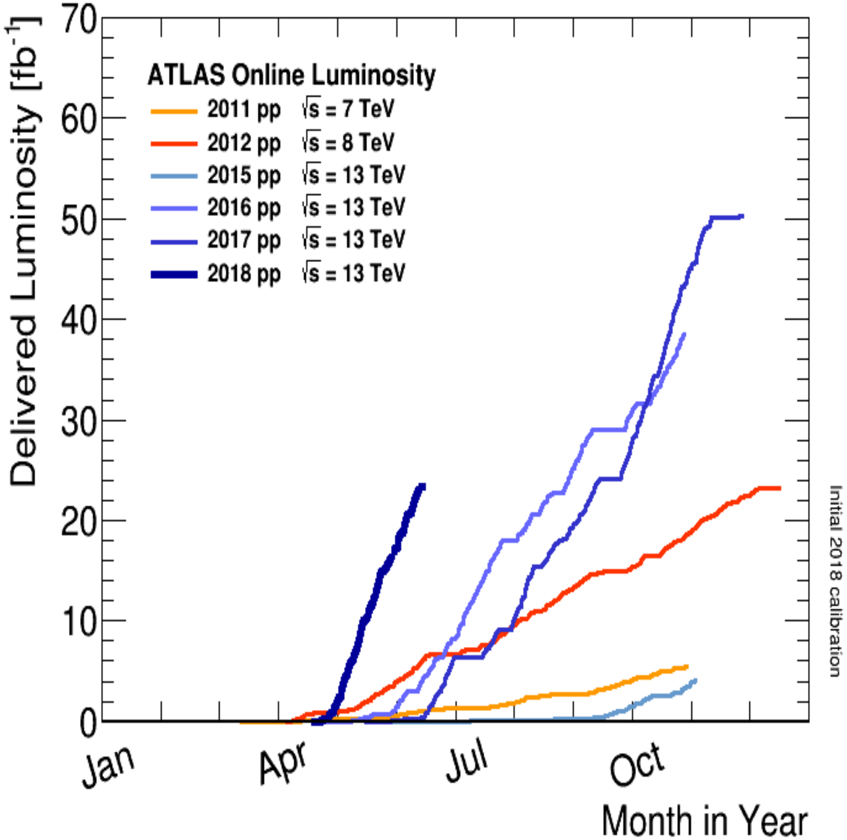


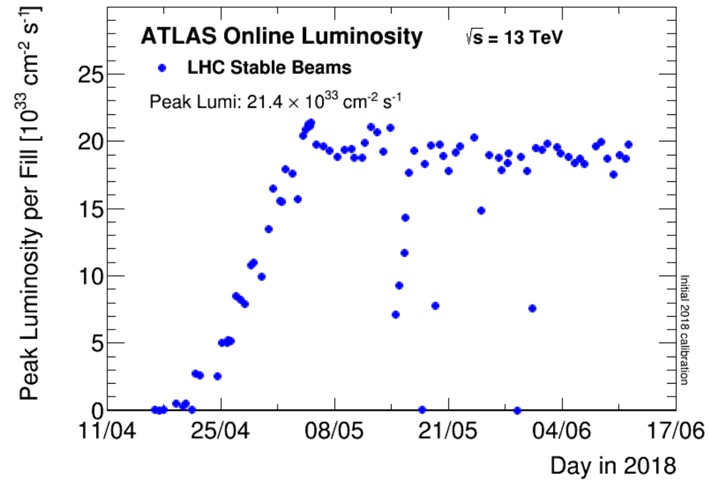
LHC

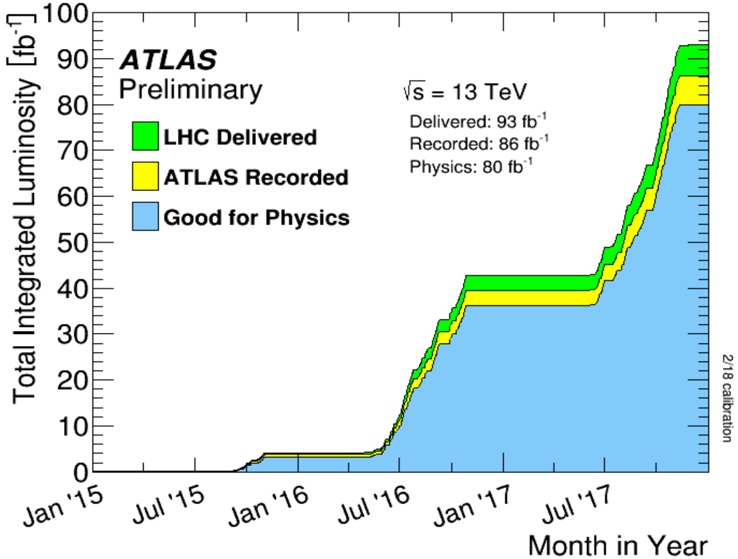
Run I (2010-2012):
pp collisions at 7 & 8 TeV
Run II (2015 - 2018):
pp collisions at 13 TeV

LHC Performance (2011-2018)

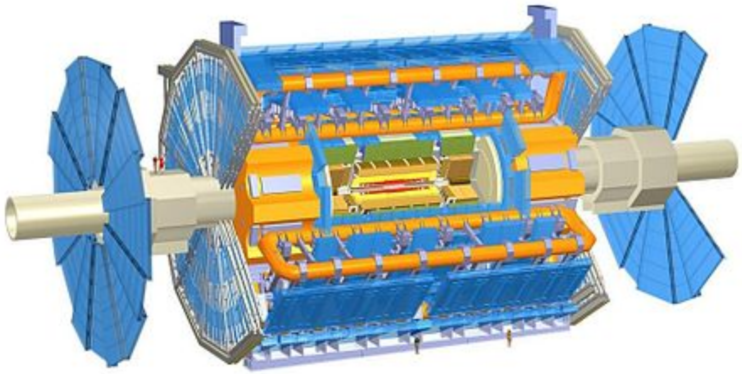
Spectacular LHC performance (rapid increase of data samples)





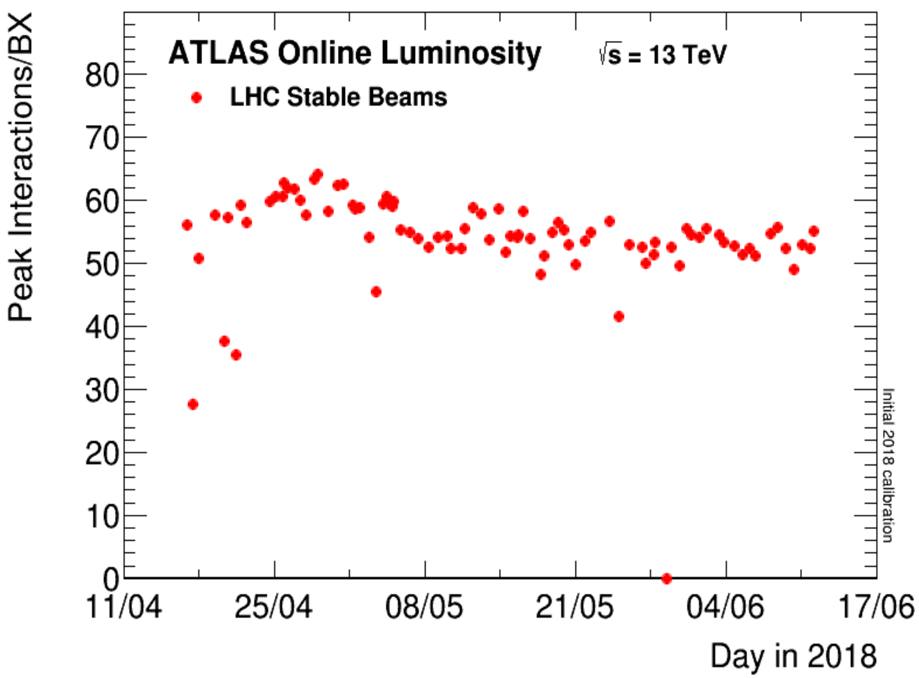


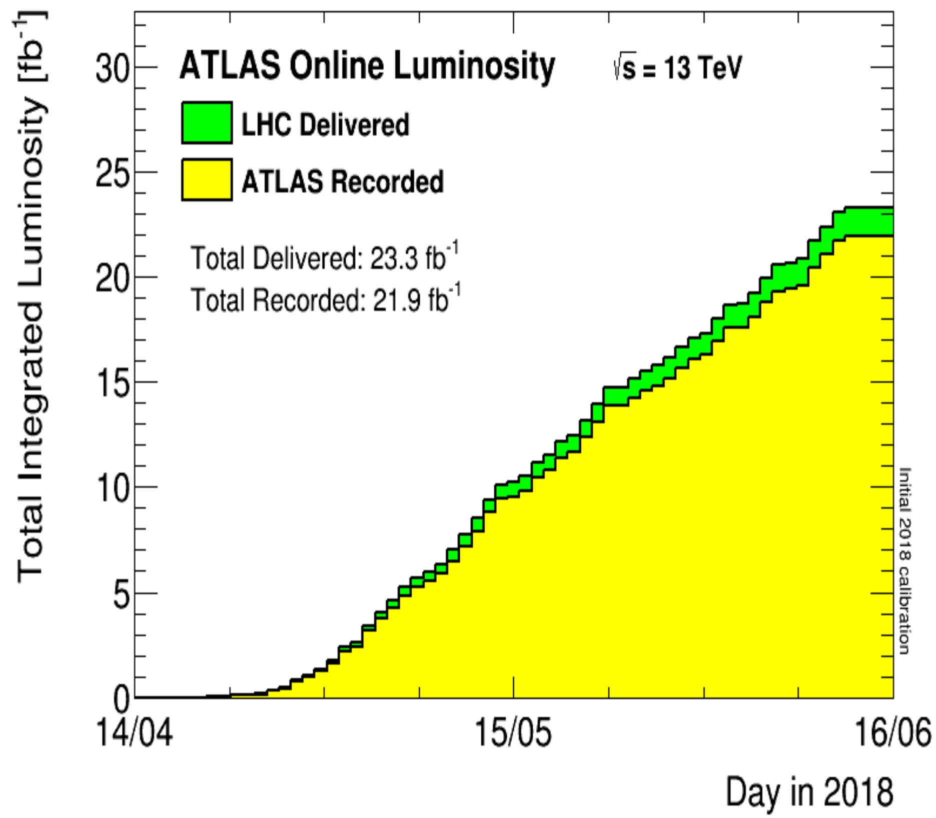
By now a total integrated luminosity for physics of 80 fb^{-1} at 13 TeV



ATLAS

94.0% efficiency

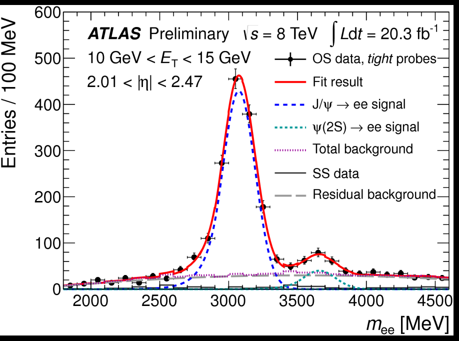


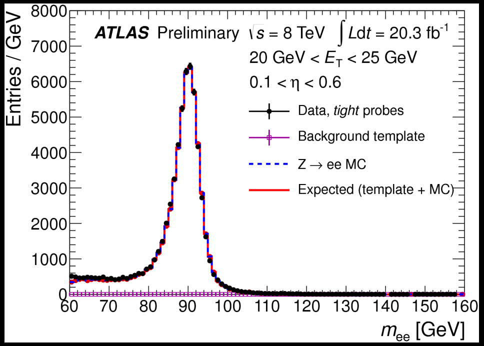


Challenging pile up conditions for the physics analysis
(In 2018 data taking with up to 60-65 interactions/crossing)

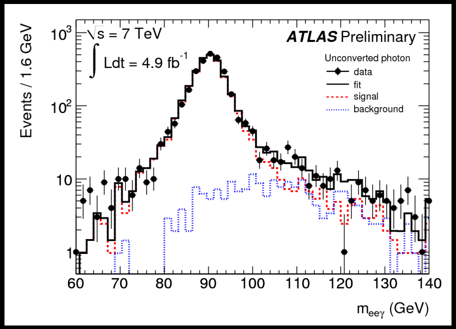
Building Blocks

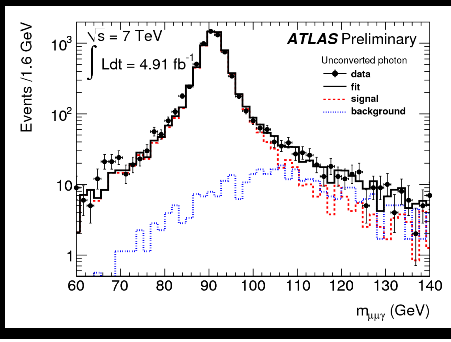
Z → ee , J/Psi → ee .....

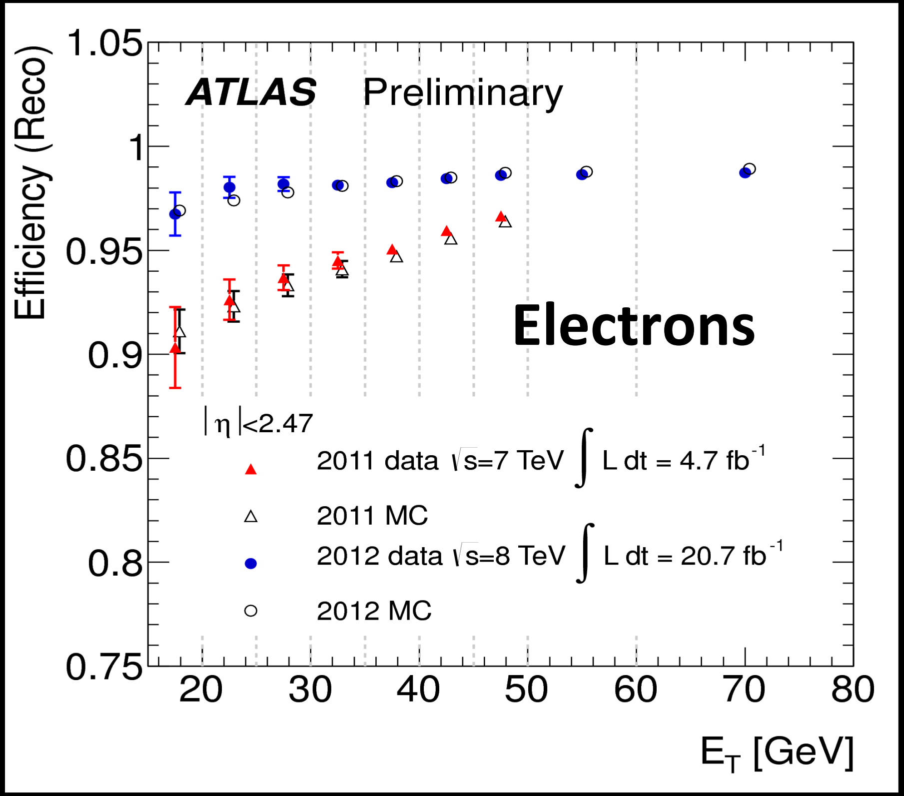


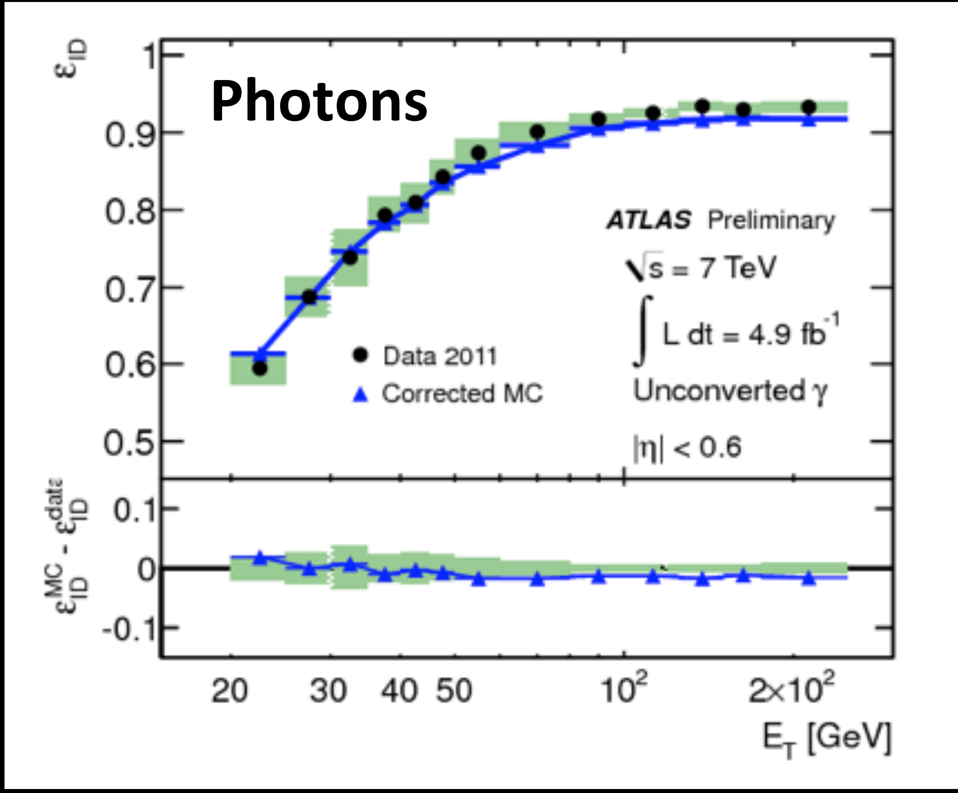


eeγ and μμγ





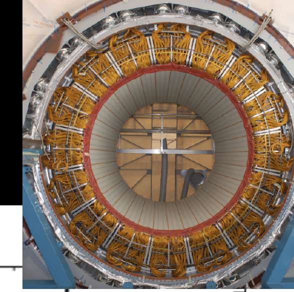


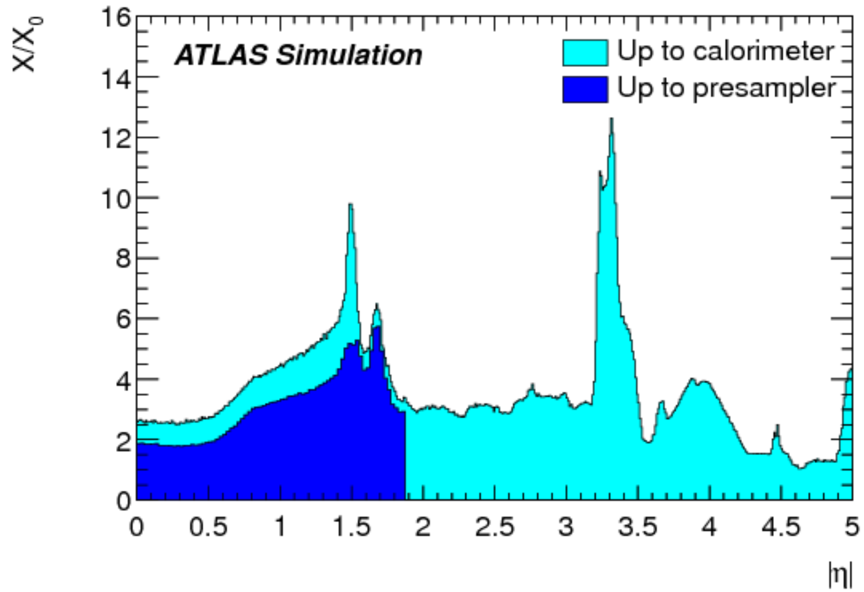


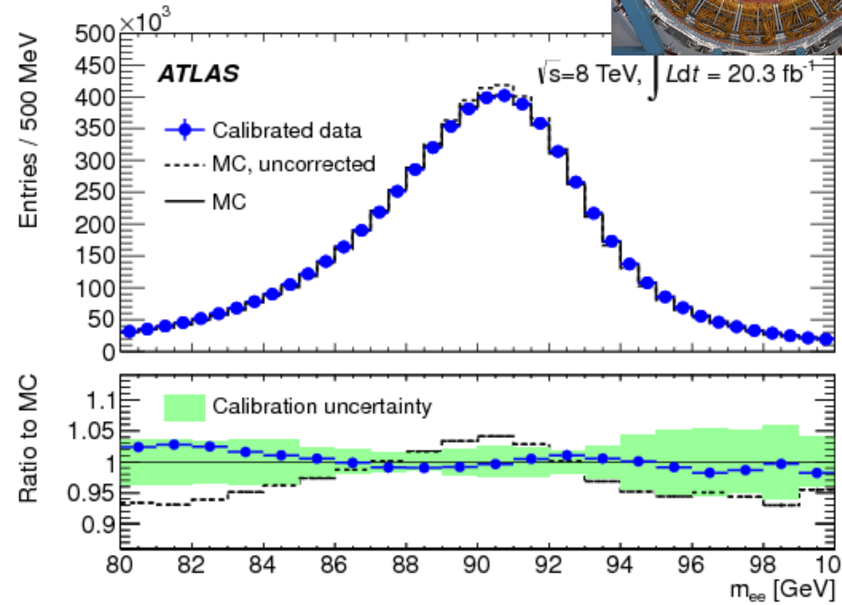
Building Blocks

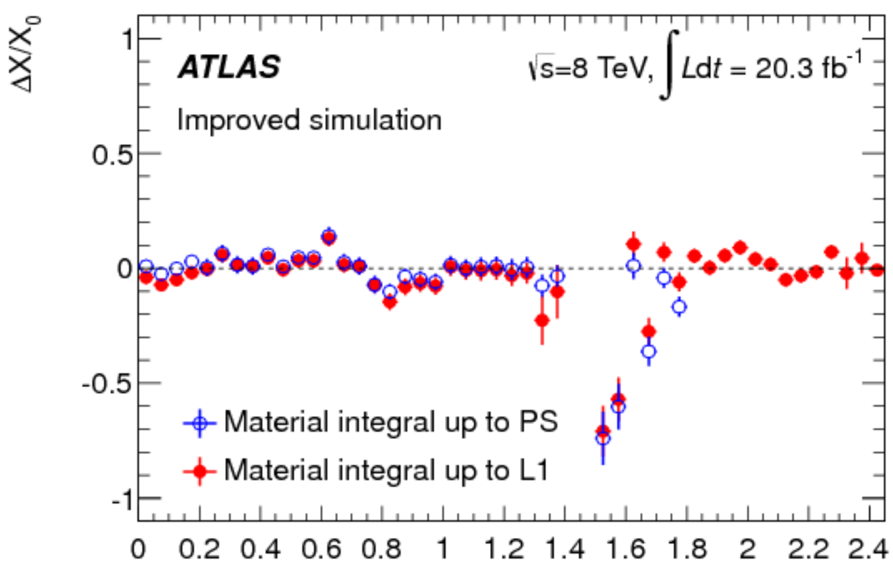
Detector Material

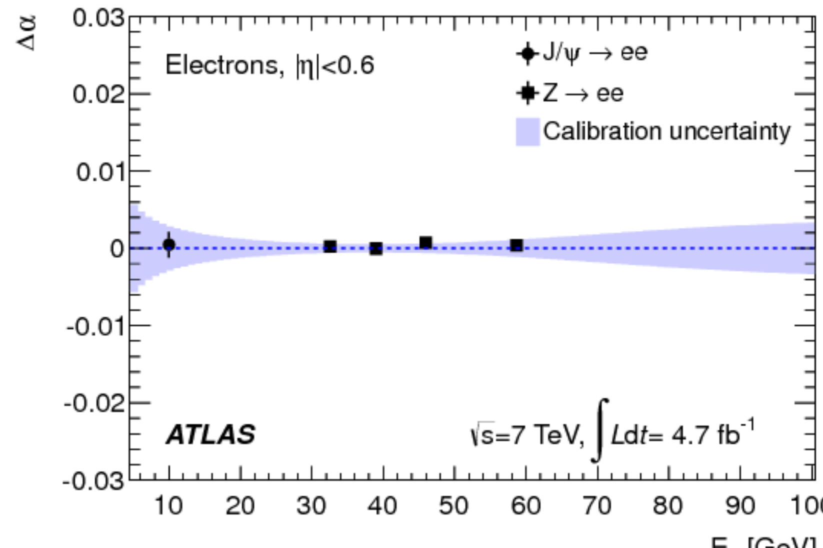
EM absolute scale



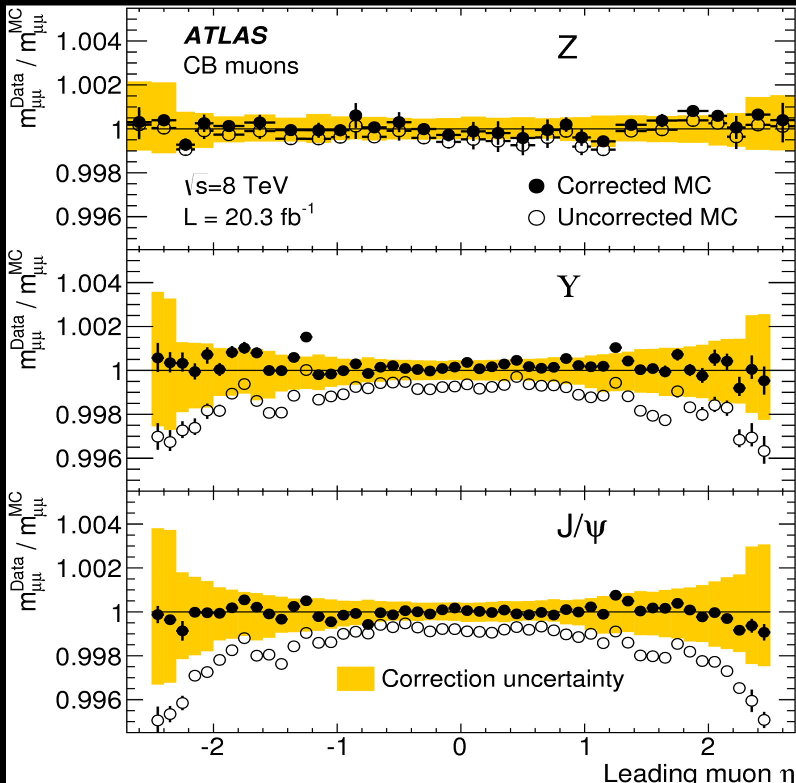




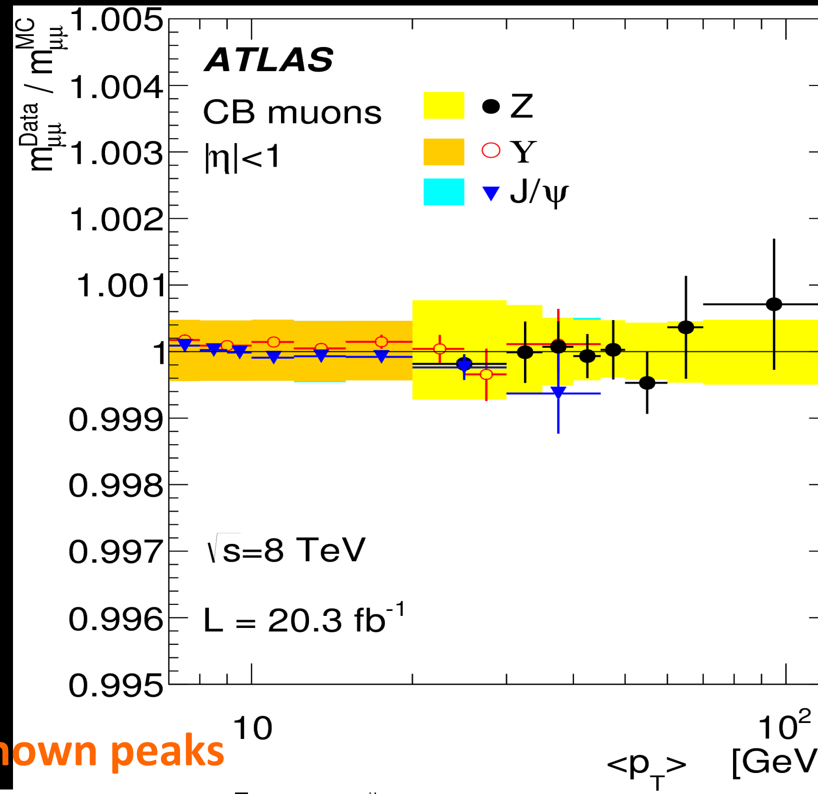




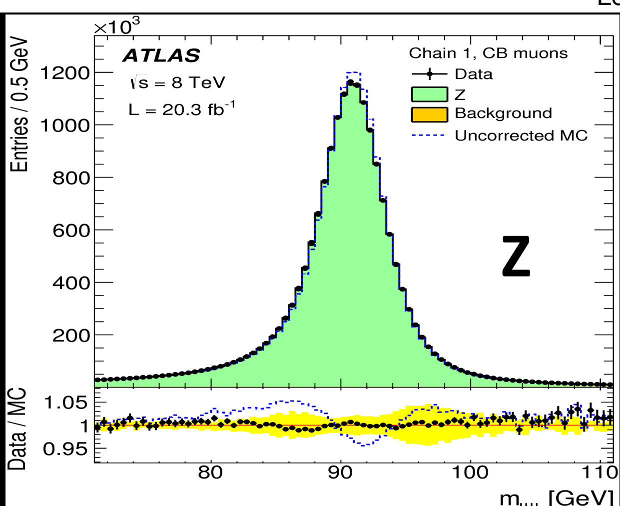
Building Blocks

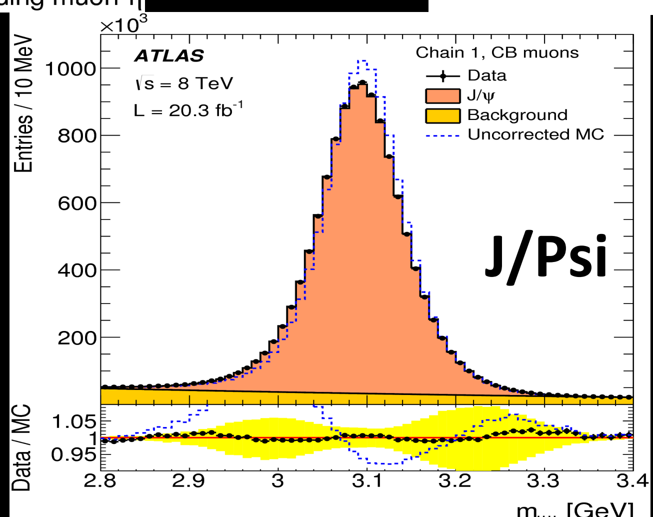


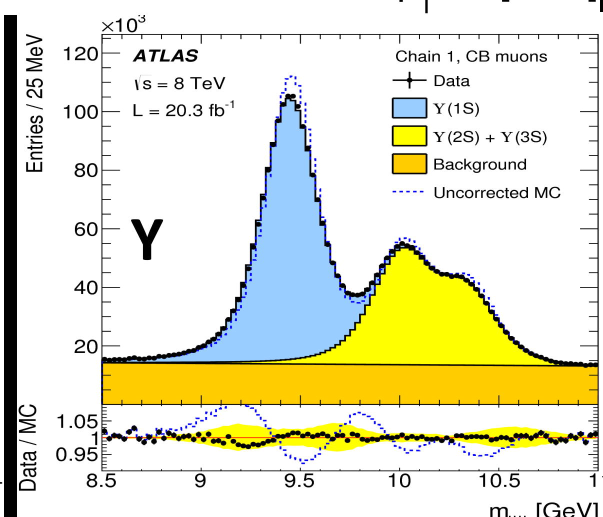
Alignment of trackers and muon chambers



Using well-known peaks

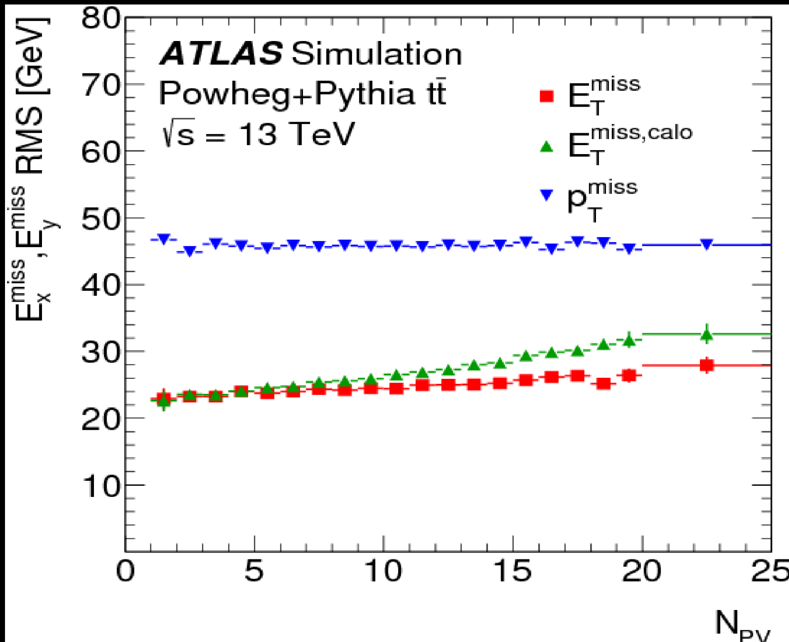




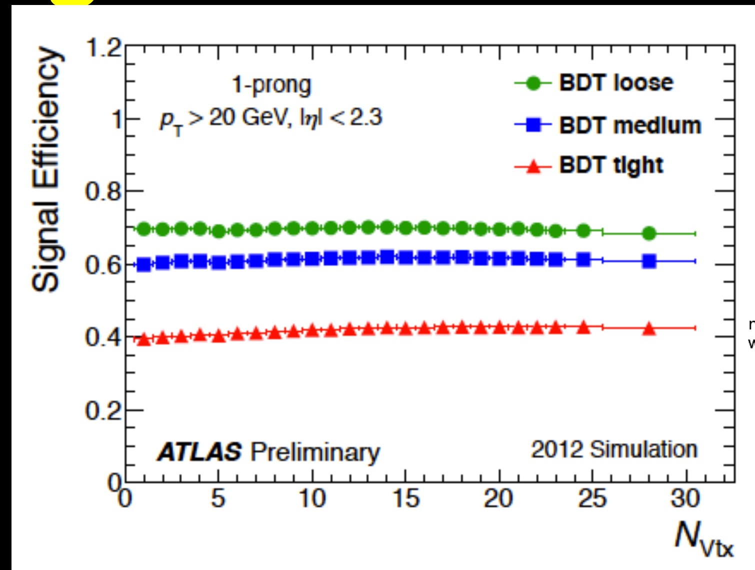


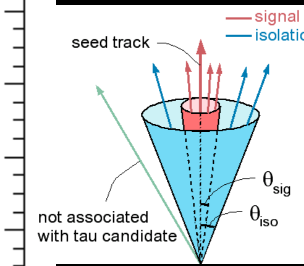
Building Blocks

Missing E_T vs PILEUP

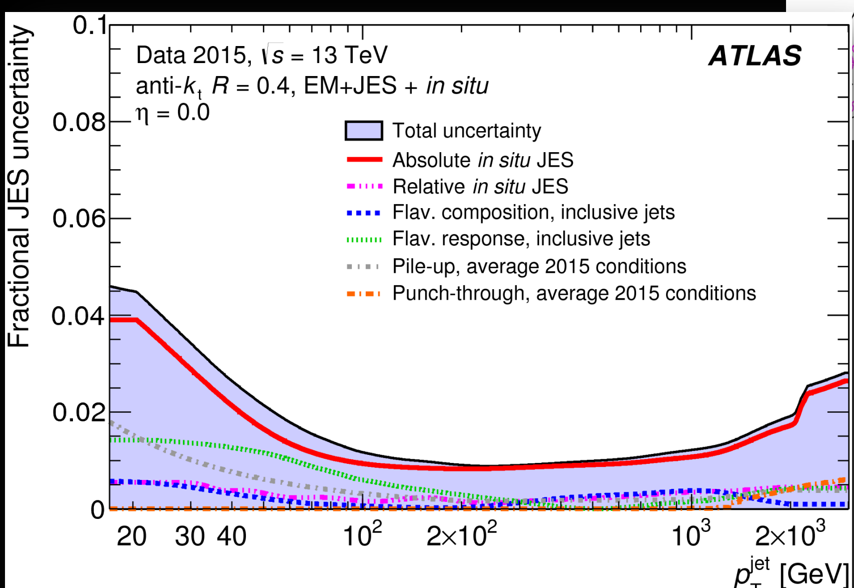


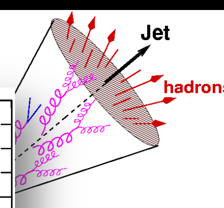
TAU ID vs PILEUP



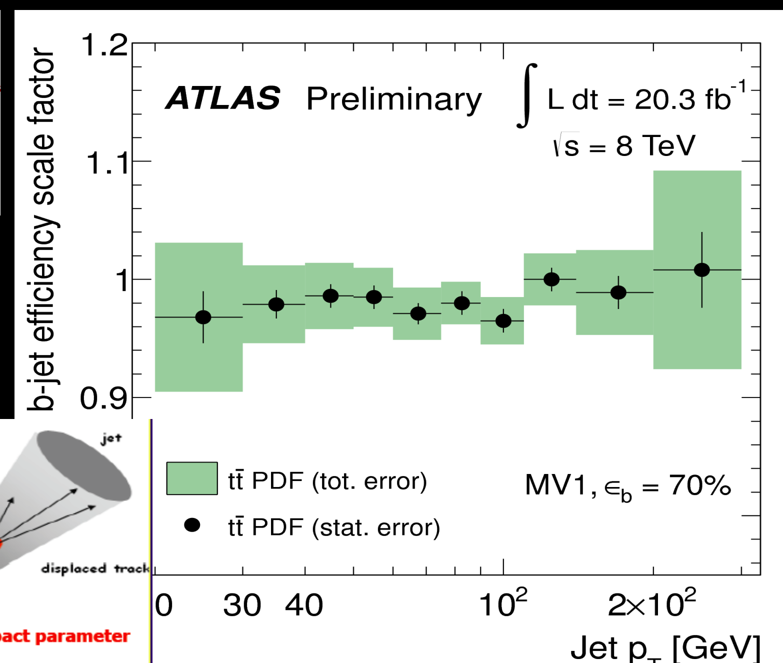


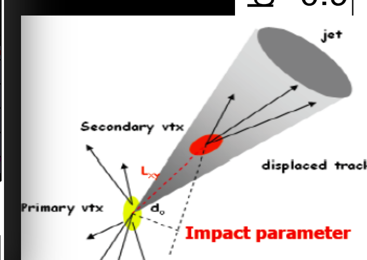
JET ENERGY SCALE UNCERTAINTY





B-JET TAGGING EFFICIENCY

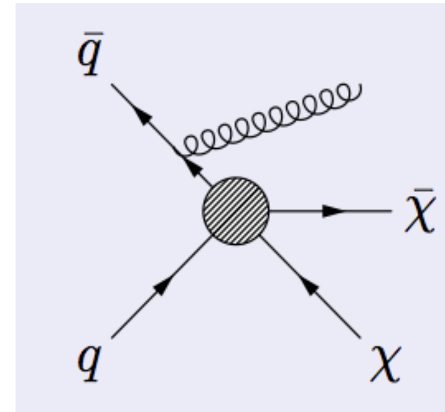




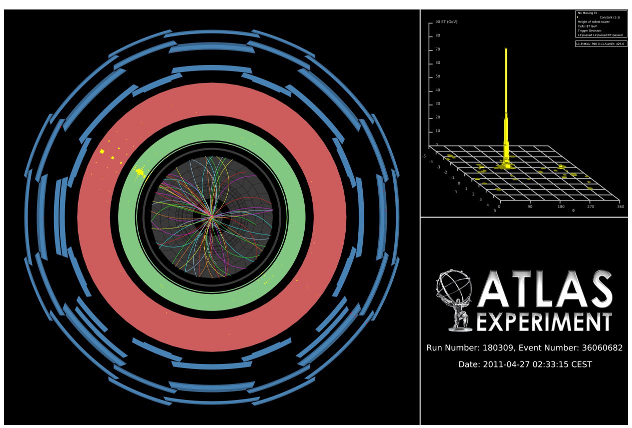
WIMP Pair Production at Hadron Colliders

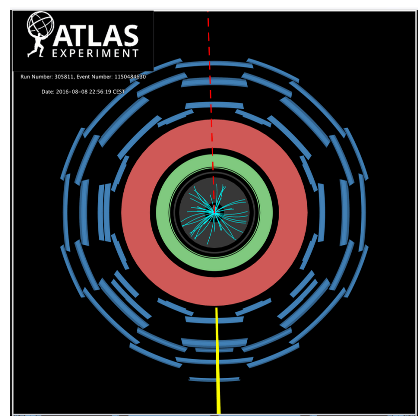
At colliders (LHC) WIMPs are produced in pairs
leading to "nothing to detect" in the final state

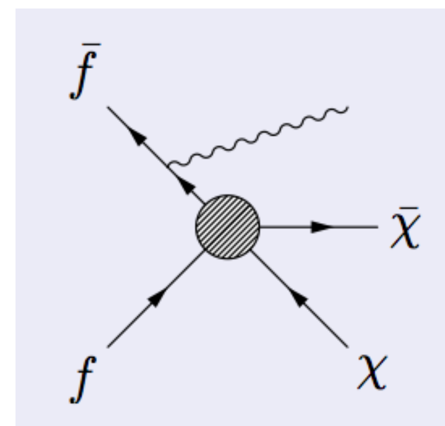
Such events are tagged via the presence of
an energetic jet or a photon (or a W/Z) from initial state radiation



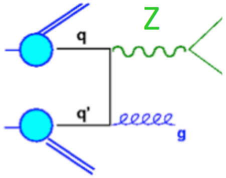
→Mono-jet, Mono-photon, Mono-W/Z

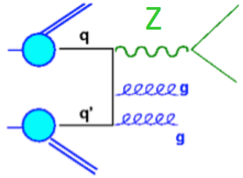






Rather spectacular and distinctive signature to search for new physics

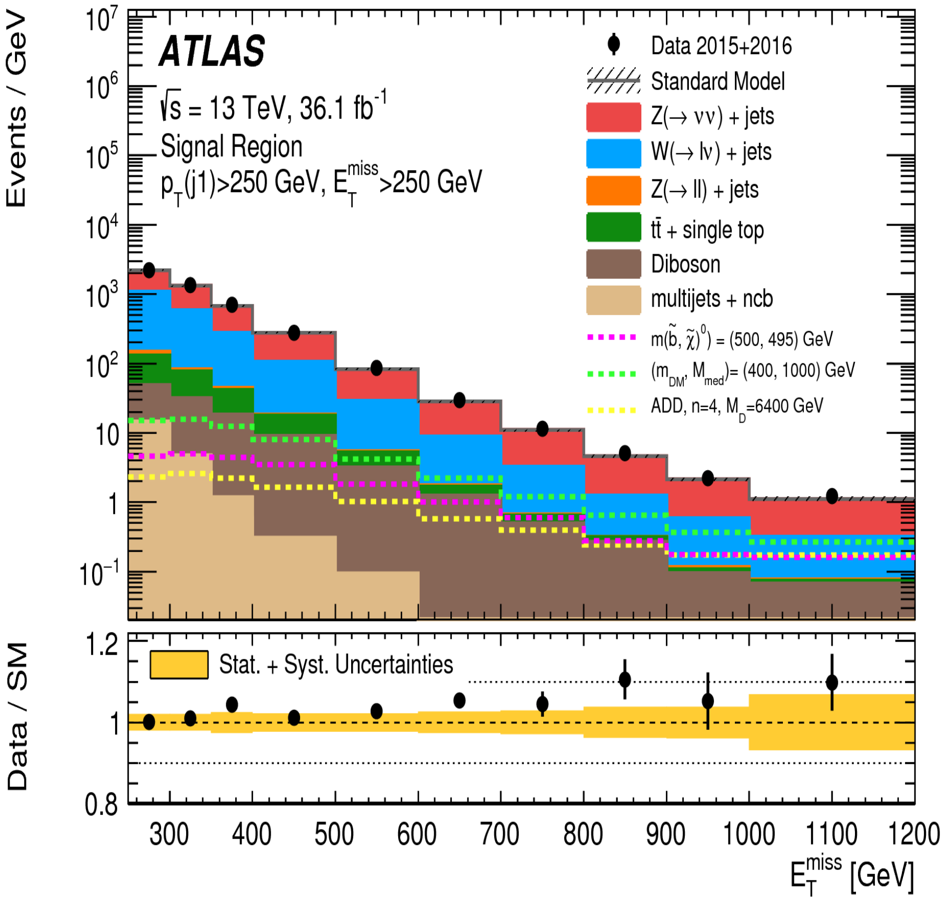




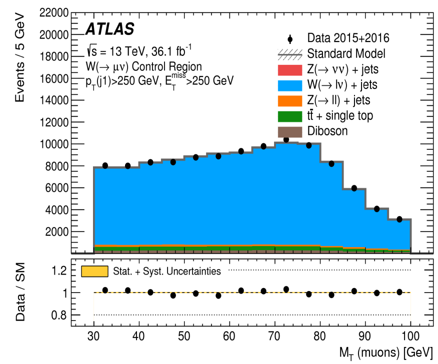
Jet+X

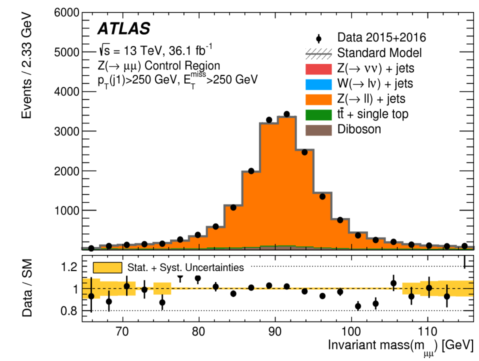
JHEP 01 (2018) 126

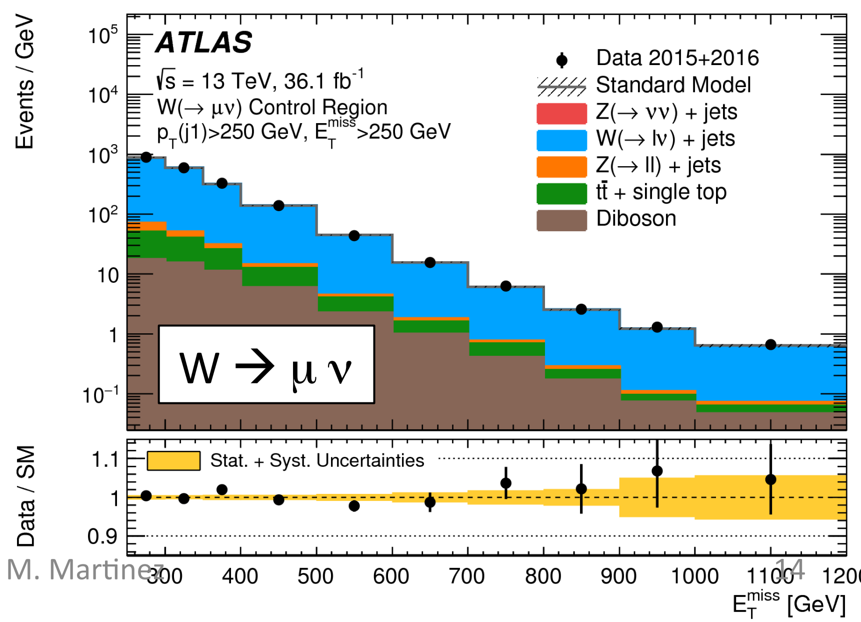
36.2 fb^{-1}



Data driven estimation of the dominant Z+jets and W+jets background using control regions in order to constrain MC predictions as determined @ NLO (QCD+EWK) accuracy







E_T^{miss} > , 250, 300 GeV, …, 1 TeV

$p_T(j_1)$ > 250 GeV

$N_{jet}(p_T > 30$ GeV) < 4

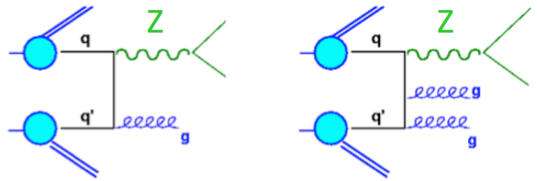
$\Delta\phi$ (E_T^{miss}, jets) > 0.4

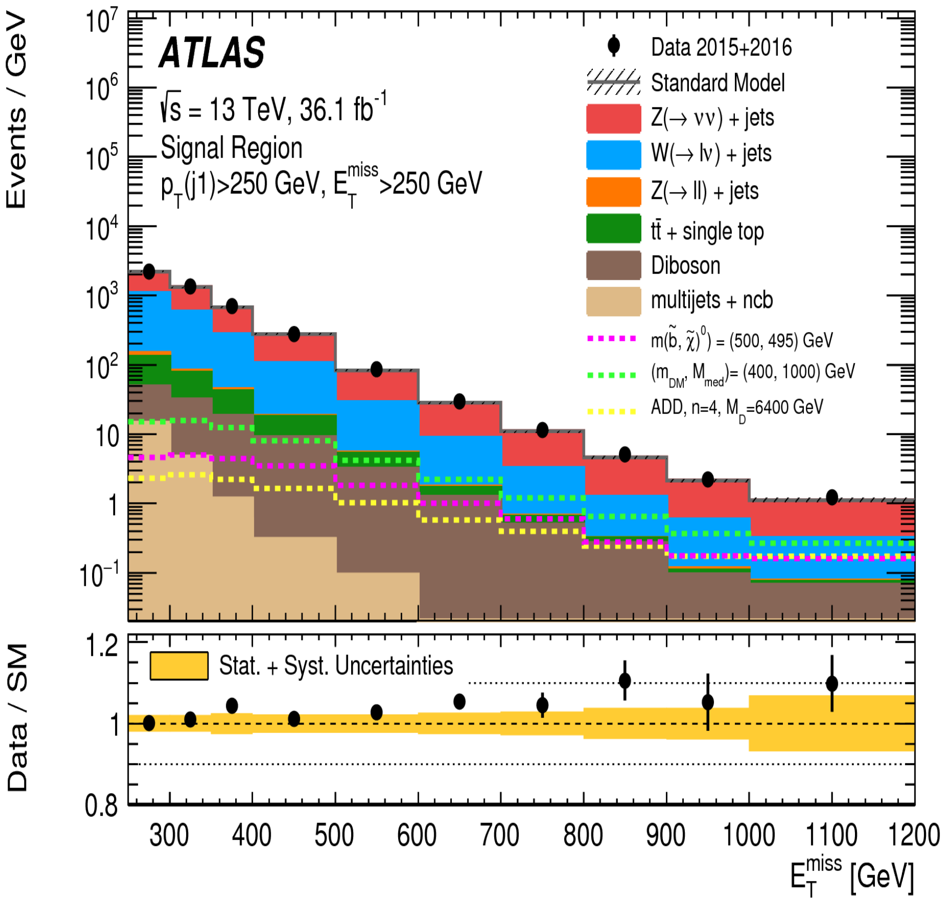
Lepton vetoes

Jet+X

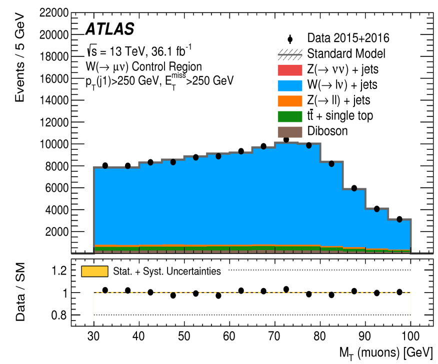
JHEP 01 (2018) 126

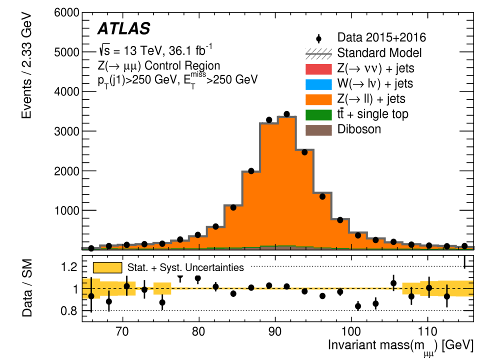
36.2 fb^{-1}

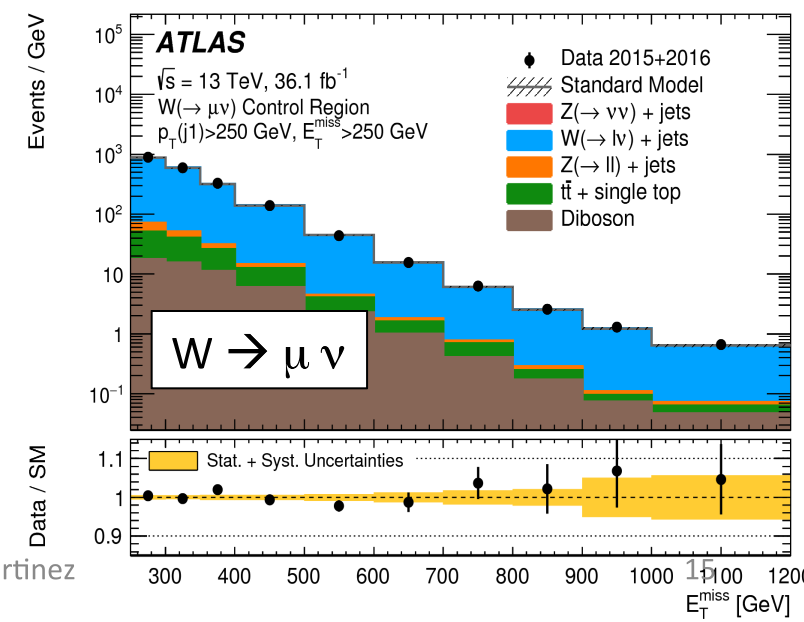




Data driven estimation of the dominant Z+jets and W+jets background using control regions in order to constrain MC predictions as determined @ NLO (QCD+EWK) accuracy



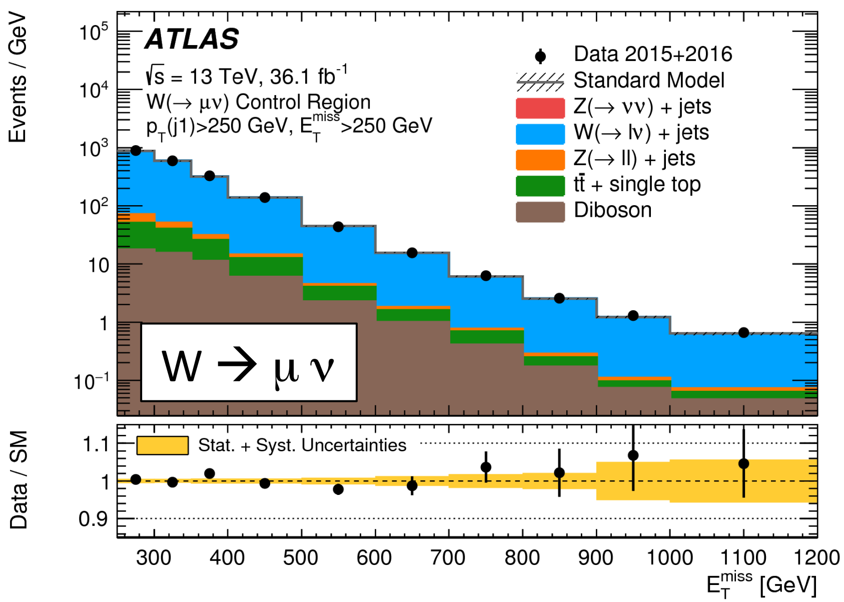


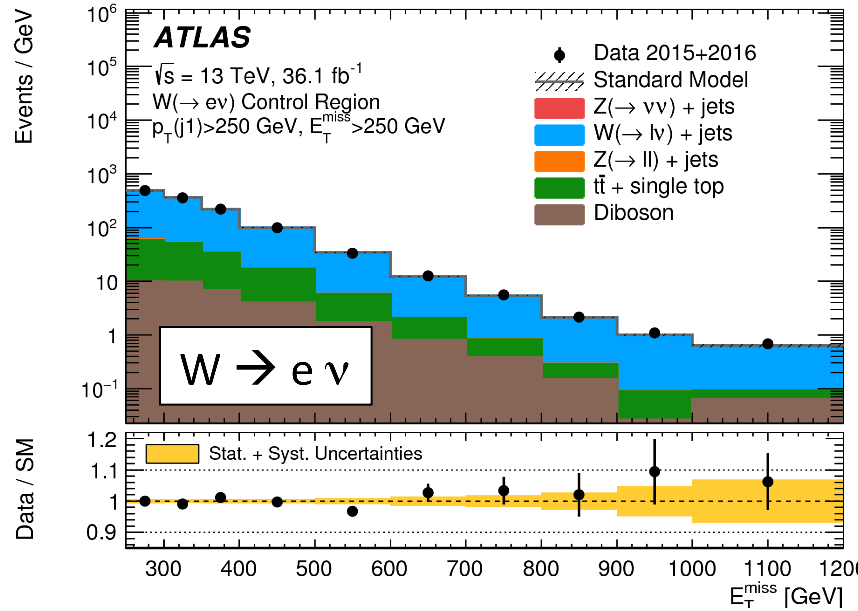


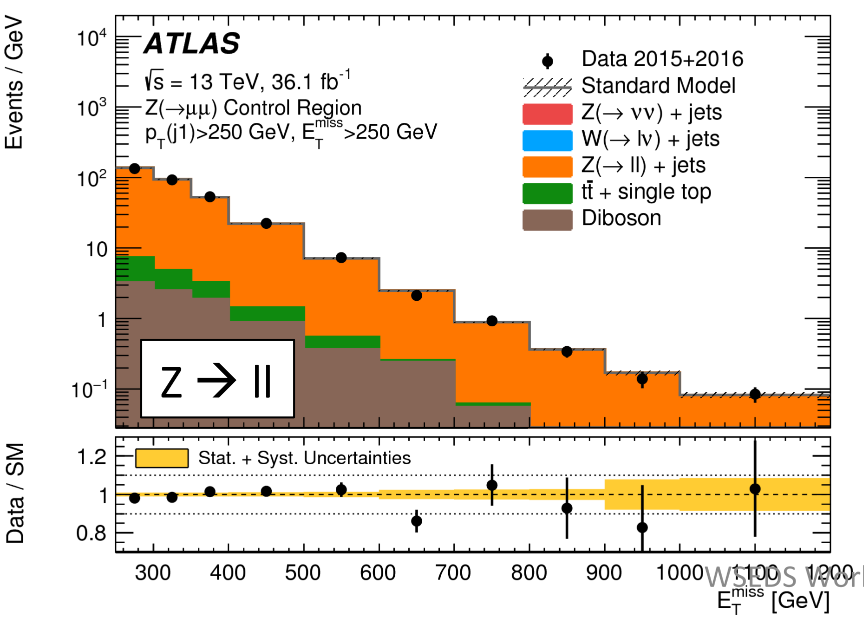
Simultaneous binned- likelihood fit in CRs constrains the normalization of the background in the SRs

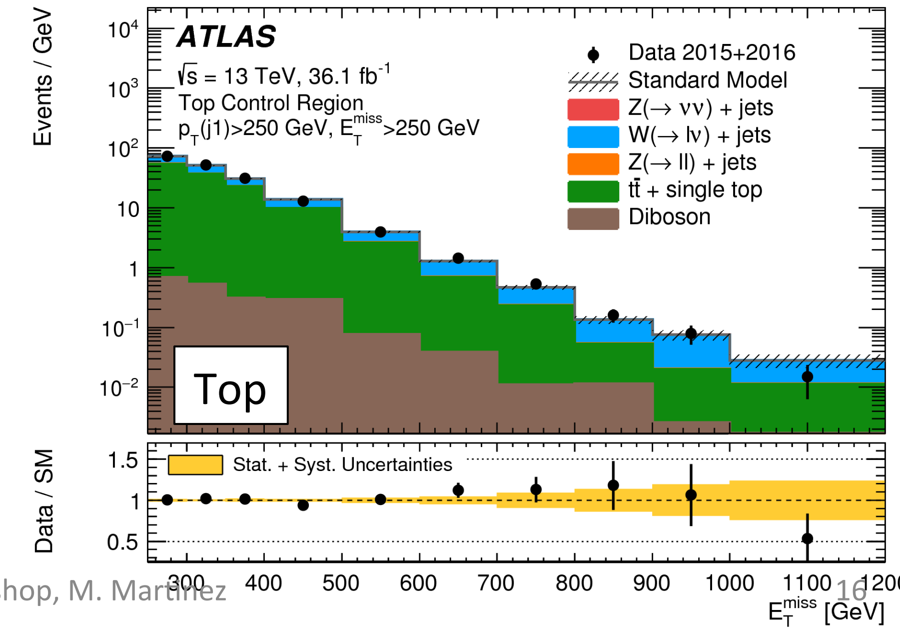
- **→ With correlations and syst. uncertainties**
- **→ A single k-factor for W/Z+jets processes**
- **→ A single k-factor for top-related processes**

Jet+X (control regions)

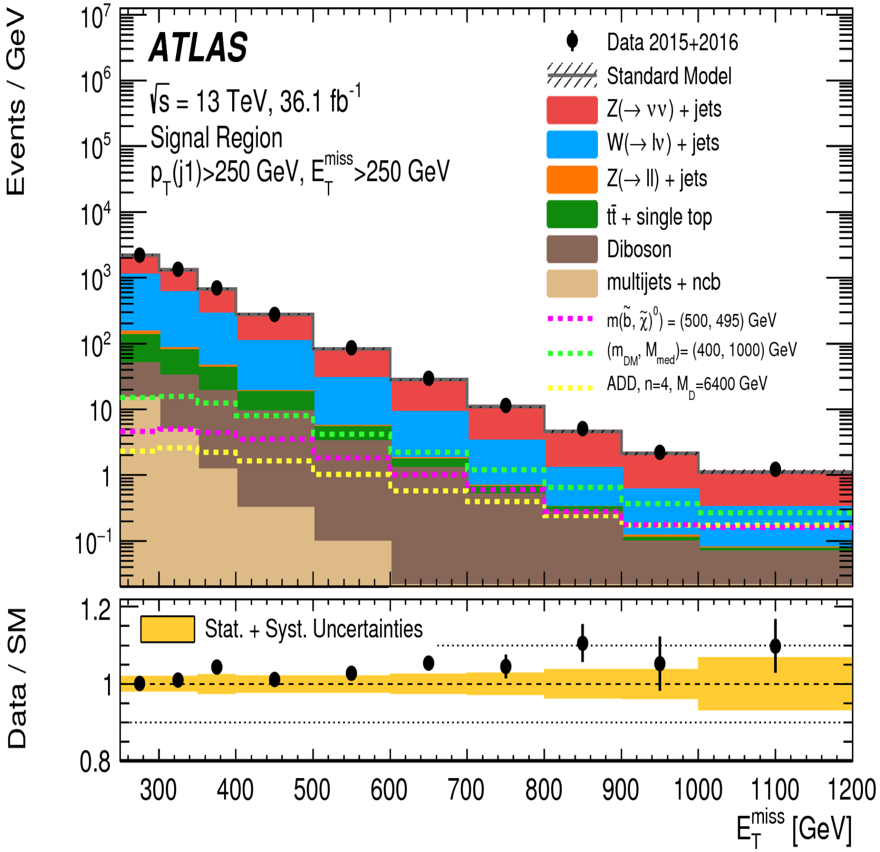








Jet+X (results)



This analysis becoming a precise test of SM predictions (total uncertainty 2%-7%)

→ Lepton ID: 1% -- 5%

→ Jet / E_T^{miss} : 1% -- 6%

→ V+jets theory : 1% -- 7%

Room for improvement at high pT

Exclusive Signal Region

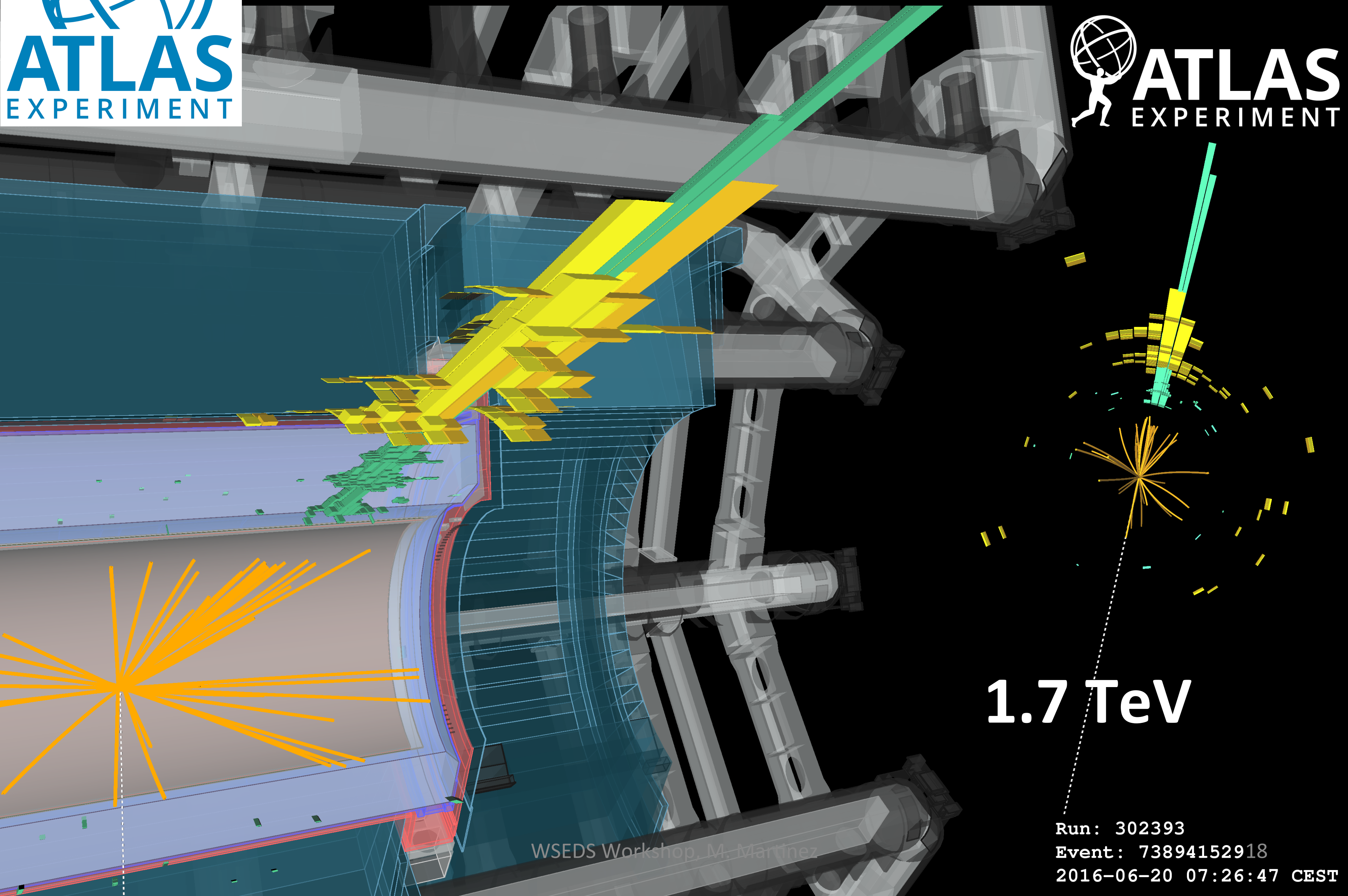
Region	Predicted		Observed
EM1	111100 ± 2300	2%	111203
EM2	67100 ± 1400		67475
EM3	33820 ± 940		35285
EM4	27640 ± 610		27843
EM5	8360 ± 190		8583
EM6	2825 ± 78		2975
EM7	1094 ± 33		1142
EM8	463 ± 19		512
EM9	213 ± 9		223
EM10	226 ± 16	7%	245

95% CL limits on visible cross sections in the range of 531 fb at low pT and about 1.6 fb at very high pT

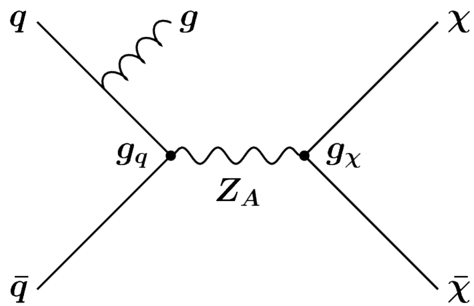
→ **Sensitivity to O(1fb) at the tail !**

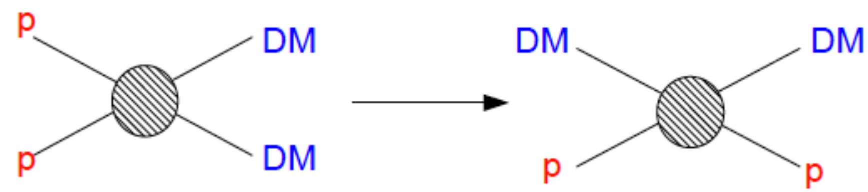
Agreement with SM predictions

p-values ranges : 0.01-0.04 (< 2.1σ)

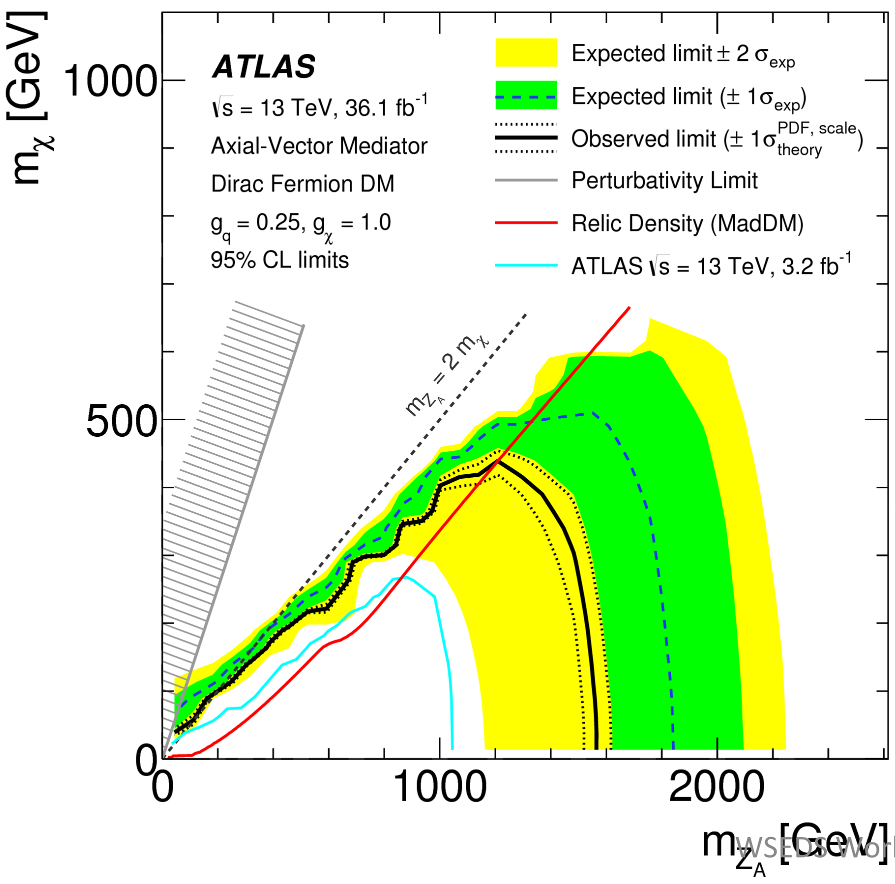

ATLAS
EXPERIMENT
1.7 TeV
Run: 302393
Event: 738941529
2016-06-20 07:26:47 CEST

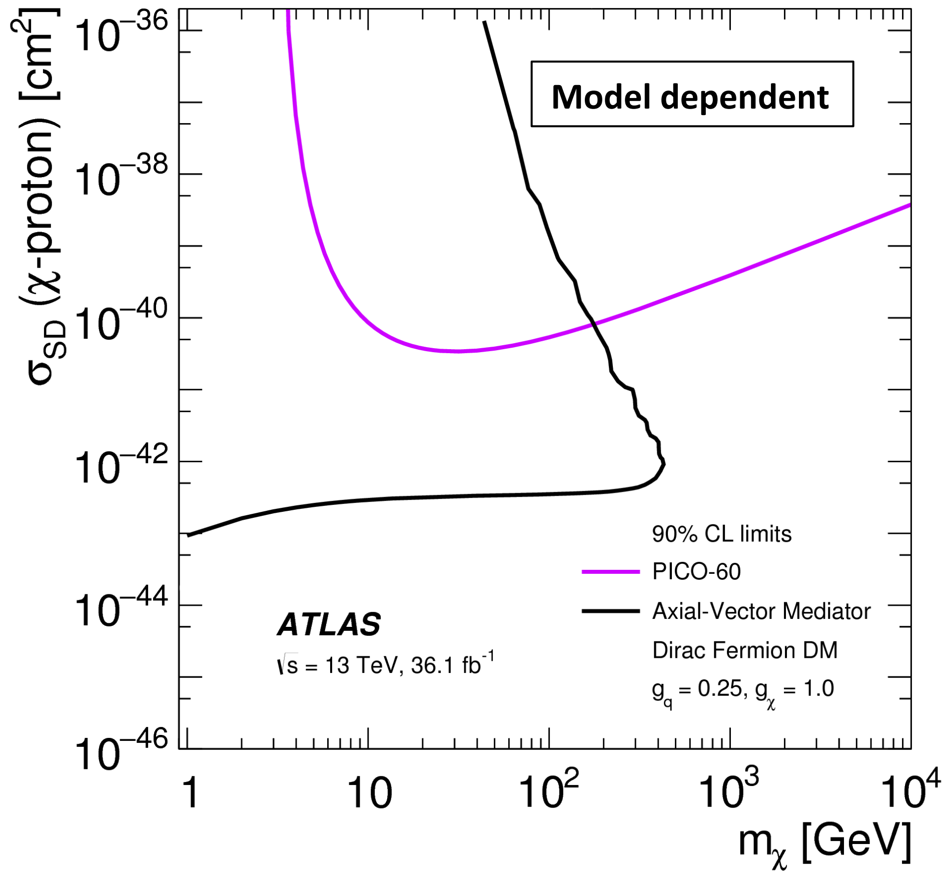
Jet+X





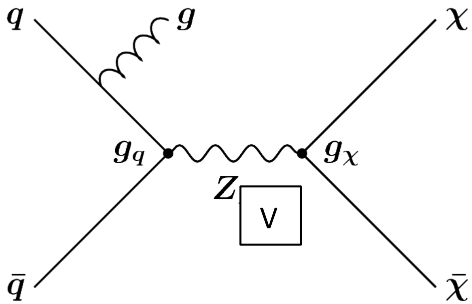
95% CL limits on axial-vector mediator model with couplings fixed to g_q = ¼ and g_{DM}= 1

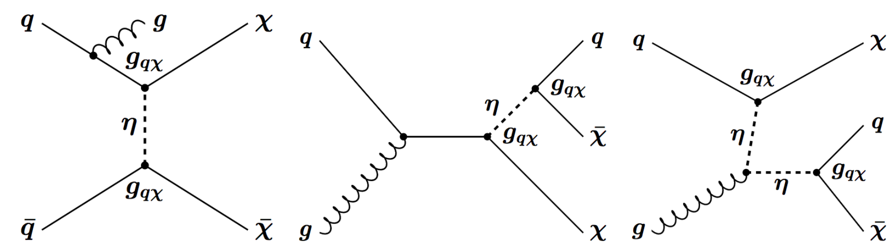




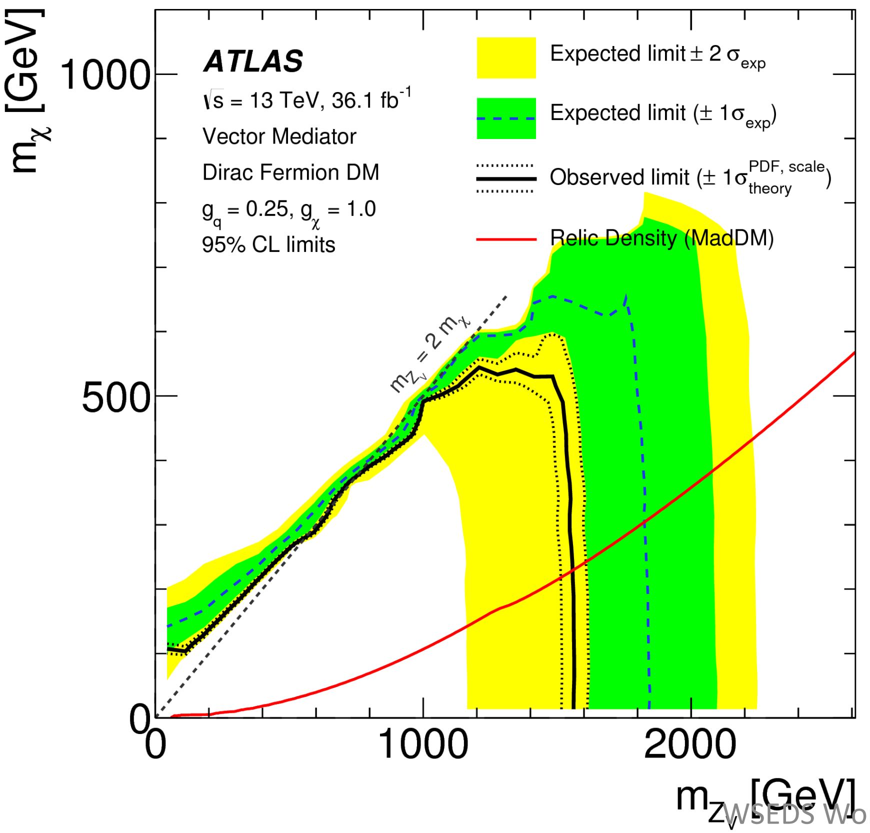
LHC results complement Direct DM experiments at low DM mass.

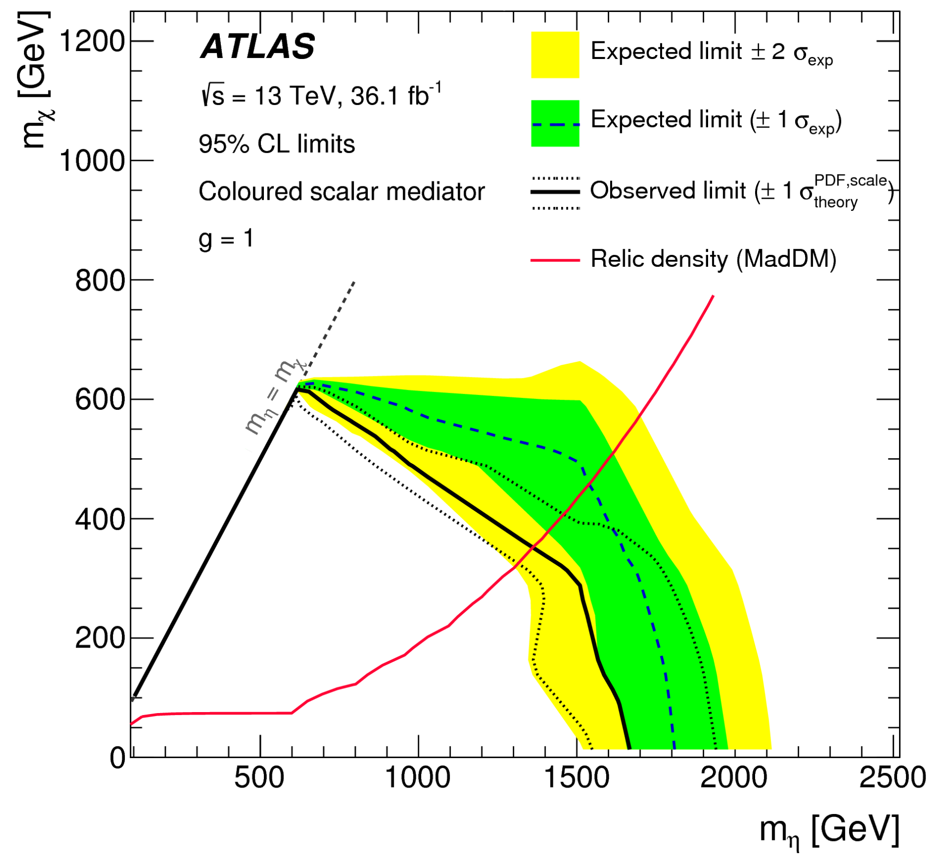
Jet+X





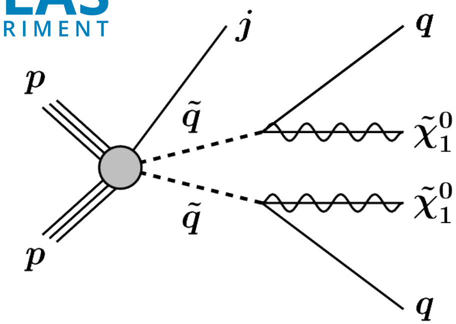
95% CL limits on vector-like mediator models



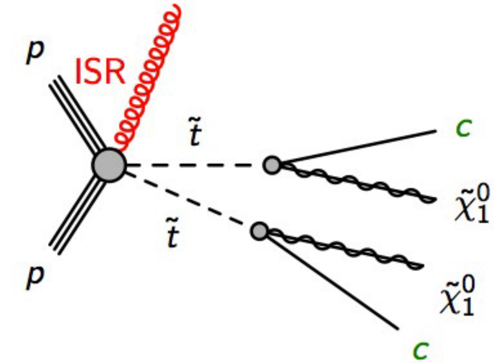


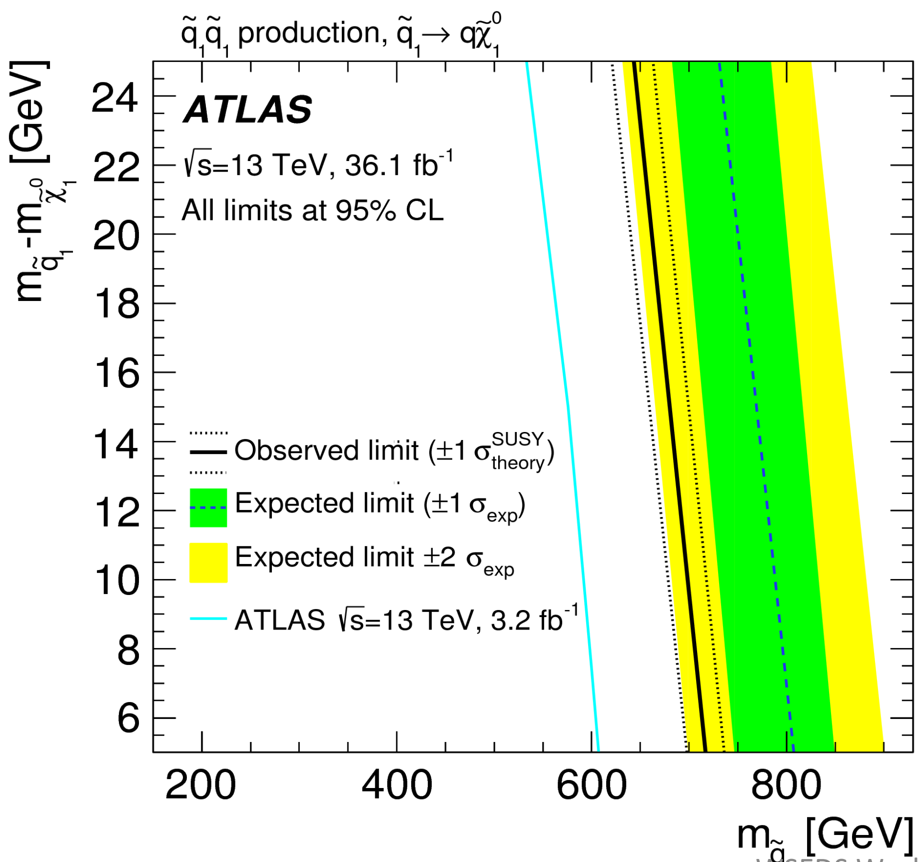
95% CL limits on models with colored scalar mediators (→ also t-channel diagrams involved)

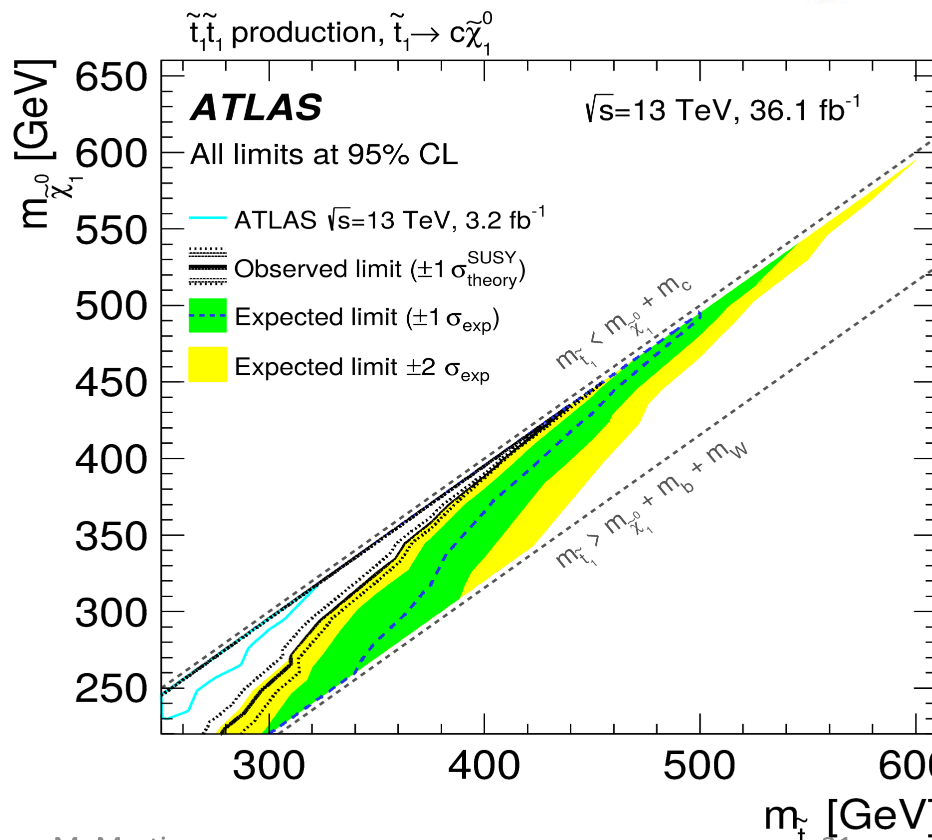
SUSY Compressed



Mono-Jet final state opens access to compressed spectra and neutralinos in the range 450 GeV – 800 GeV



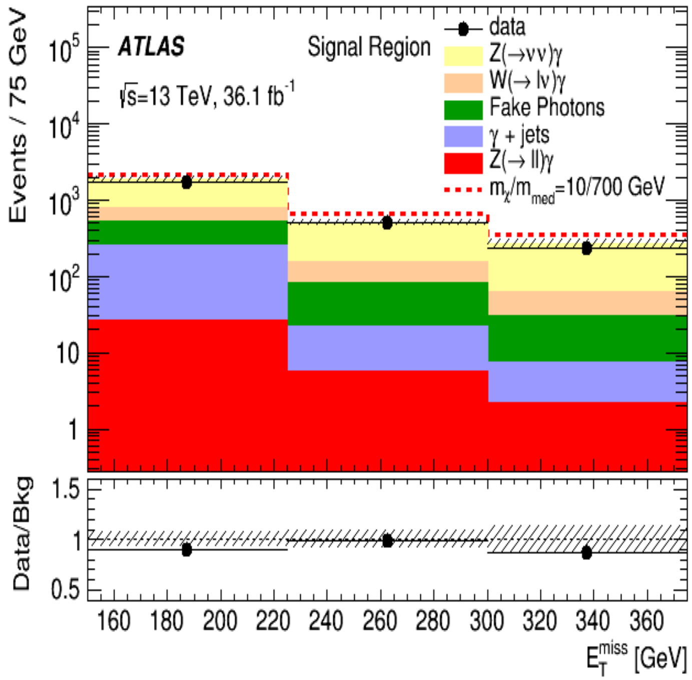




γ+X

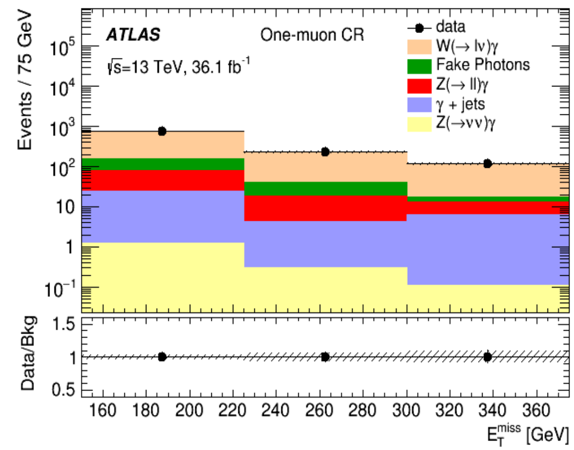
Eur. Phys. J. C 77 (2017) 393

36.1 fb^{-1}



Background dominated by Z/W+γ followed by contributions with jets faking photons plus other small contributions (γ+jets) **(γ+ μ + E_t^{miss} CR)**

- **Z/W+γ from MC normalized in CRs**
- **γ+jets CR at low E_T^{miss}**
- **Jet and electron fakes also fully data driven**



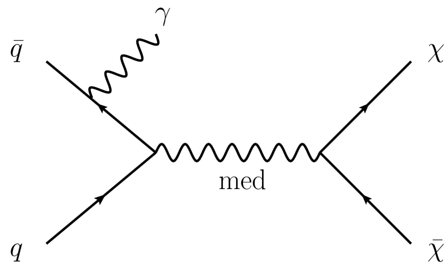
P_T^{γ} >150 GeV, $|\eta^{\gamma}|$ < 2.37, isolated
E_T^{miss} > 150, 225, 300 GeV
E_T^{miss} / SQRT(H_T) > 8.5 GeV$^{1/2}$

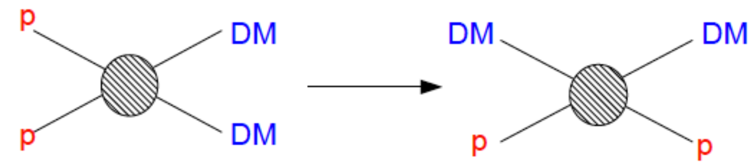
N^{jet} < 2 (p_T > 30 GeV)
$\Delta\phi$ (γ, E_T^{miss}) >0.4, $\Delta\phi$ (jet, E_T^{miss}) >0.4
Veto on leptons

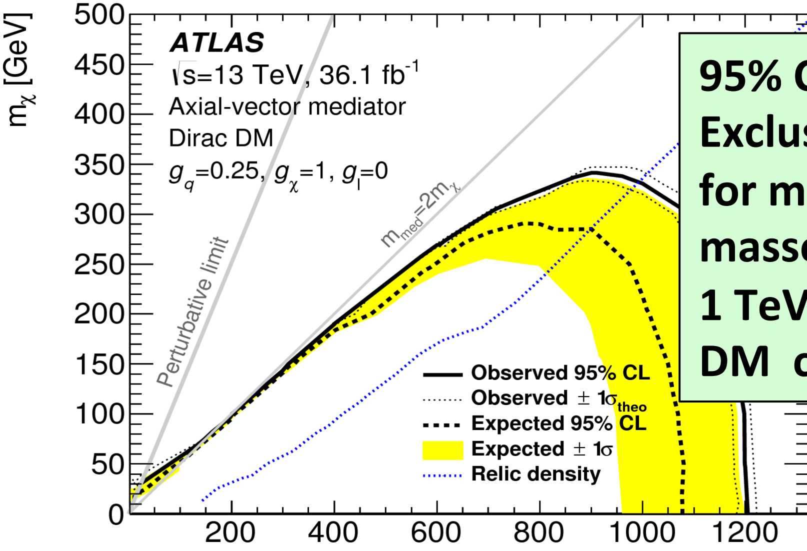
σxA < 7 – 2 fb @ 95% CL	SRI1	SRI2	SRI3
Observed events	2400	729	236
Fitted Background	2600±160	765±59	273±37
$Z(\to \nu\nu)\gamma$	1600±110	543±54	210±35
$W(\to \ell\nu)\gamma$	390±24	109±9	33±4
$Z(\to \ell\ell)\gamma$	35±3	7.8±0.8	2.2±0.4
γ + jets	248±80	22±7	5.2±1.0
Fake photons from electrons	199±40	47±11	13±3
Fake photons from jets	152±22	37±15	$9.7^{+10}_{-9.7}$

Good agreement with SM

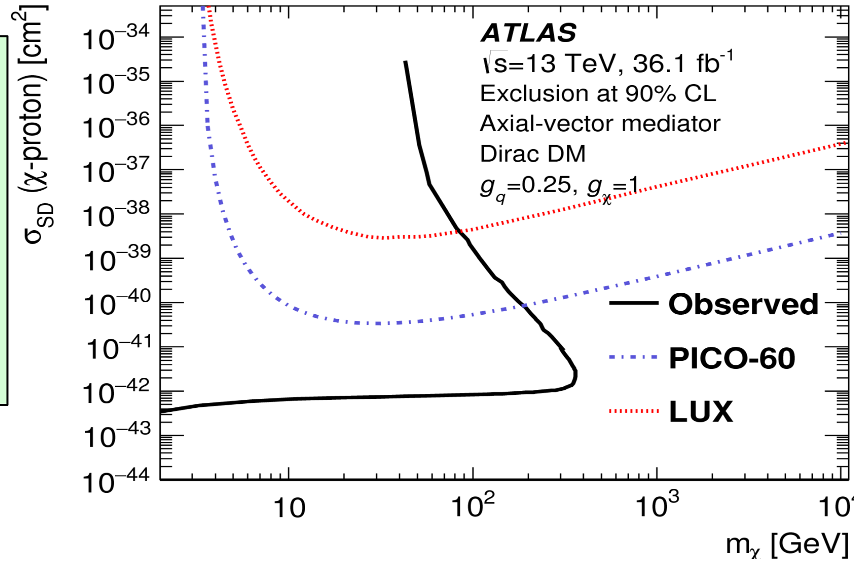
γ+X

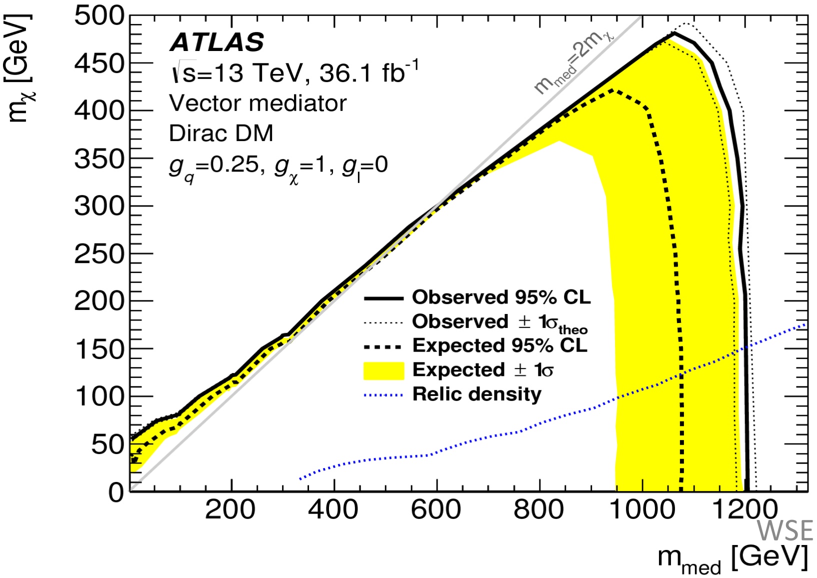


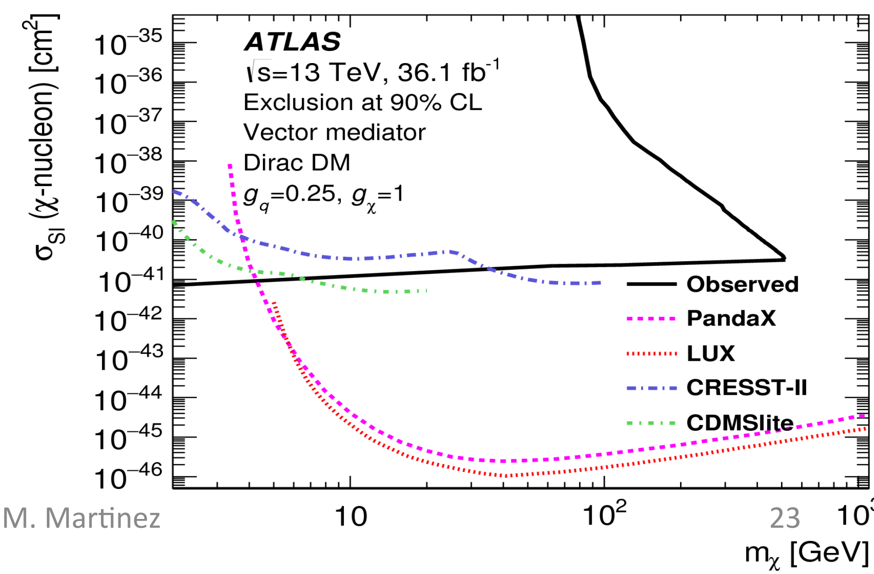




95% CL Exclusions for mediator masses below 1 TeV and light DM candidates



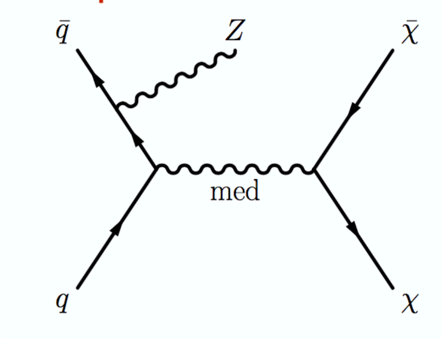


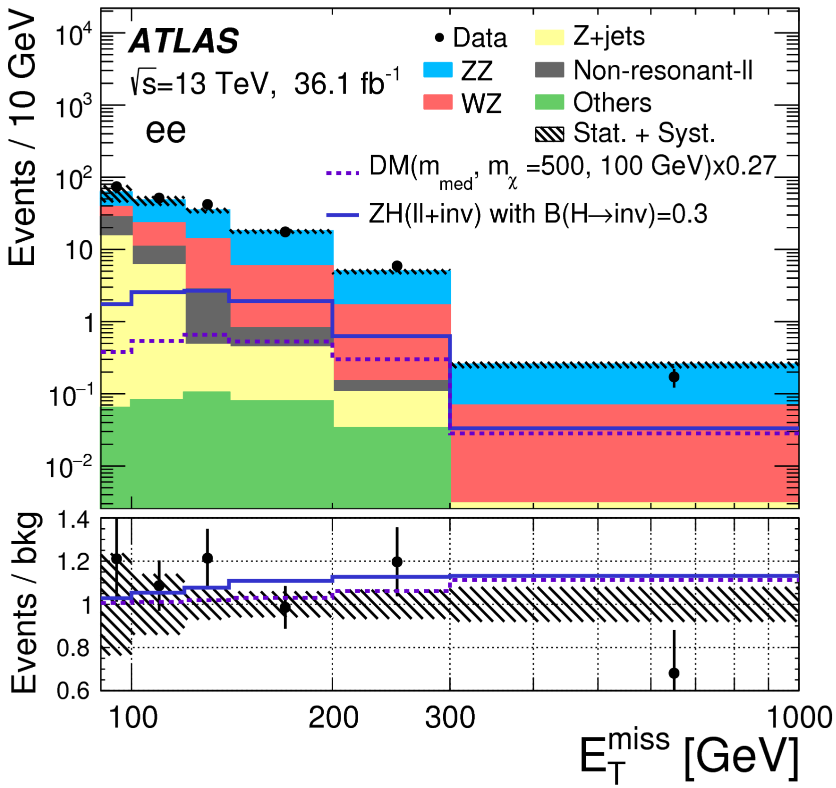


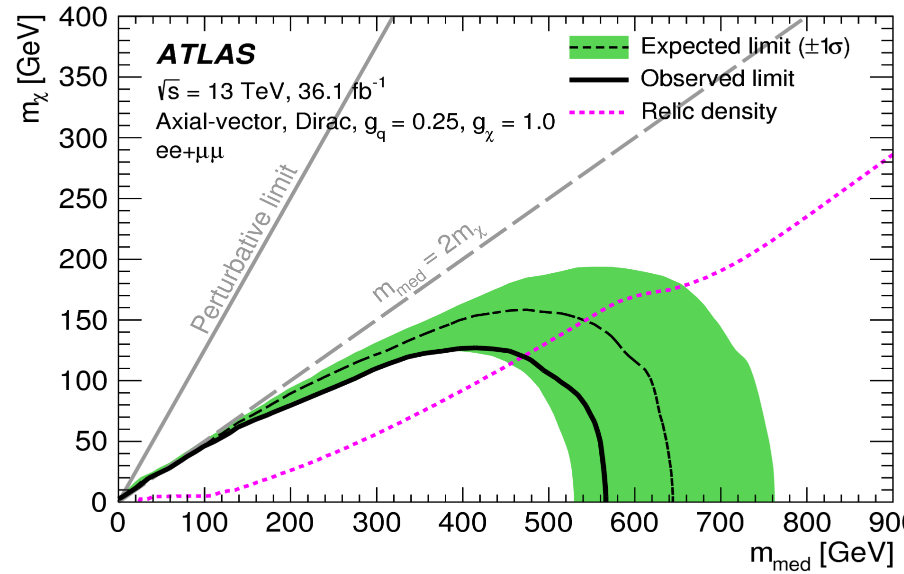
Mono-Z(→ll)

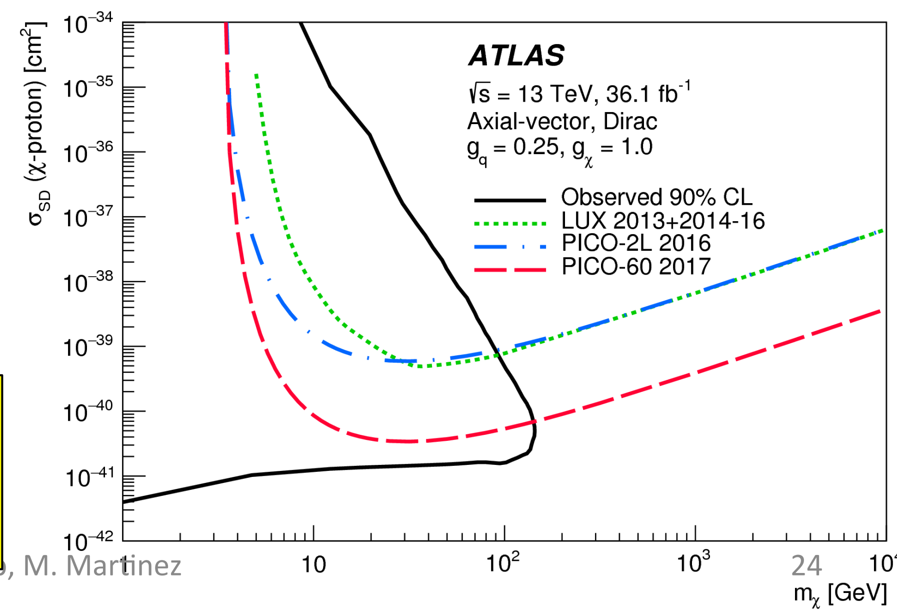
PLB 776 (2017) 318

36.1 fb^{-1}





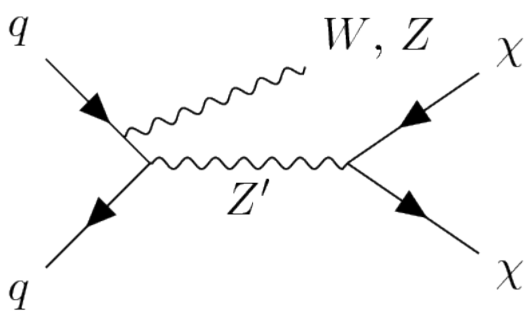




See talk by Vincent Kitali: "ATLAS search for an invisibly decaying Higgs boson produced via vector boson fusion"

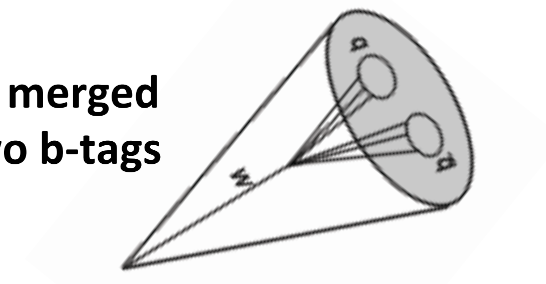
Mono-W/Z

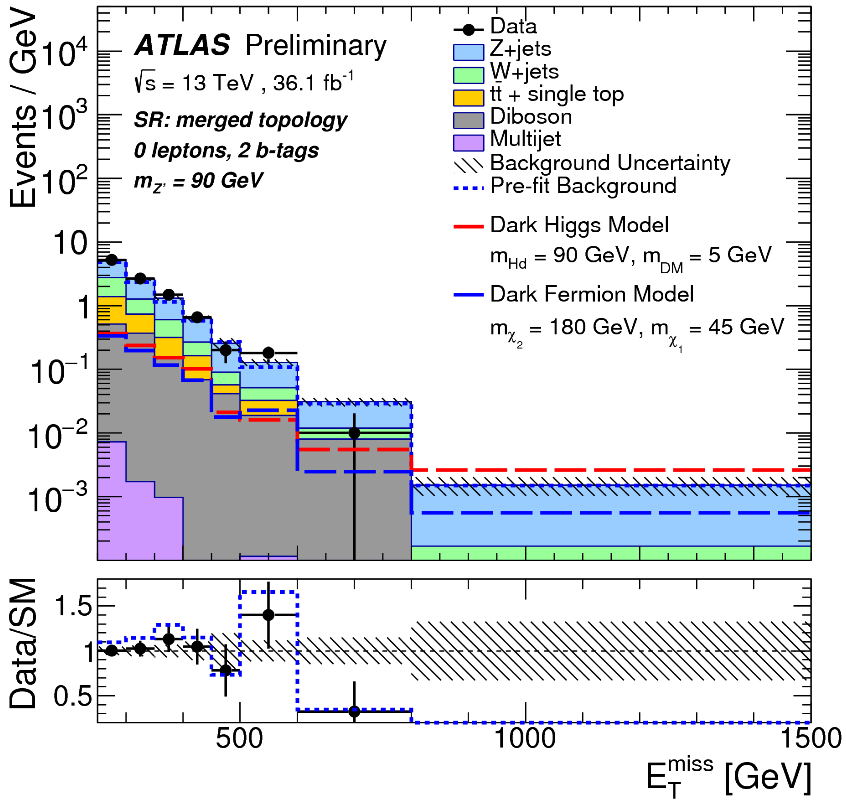
ATLAS-CONF-2018-005

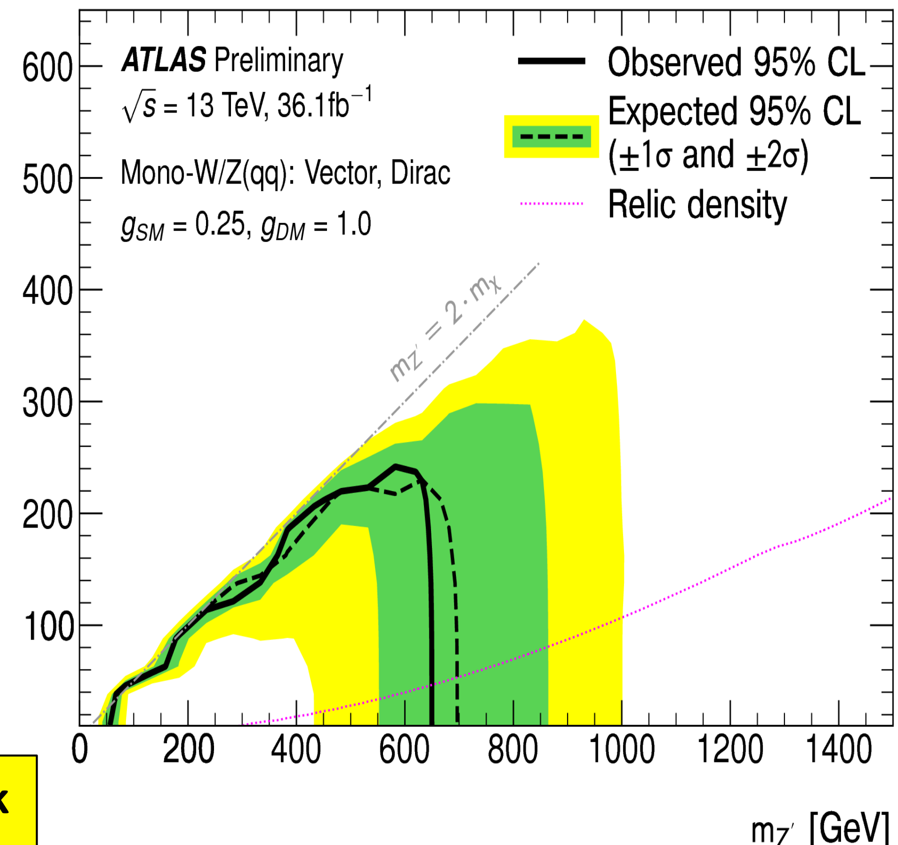


(hadronic channel)

Including resolved and merged configuration and w/wo b-tags







See talk by Wei Wang: "ATLAS search for dark matter produced in association with a hadronically decaying vector boson"

Dijets

37 fb⁻¹

$$\chi = e^{2|y^*|} \sim \frac{1+\cos\theta^*}{1-\cos\theta^*}$$

Phys. Rev. D 96 (2017) 052004

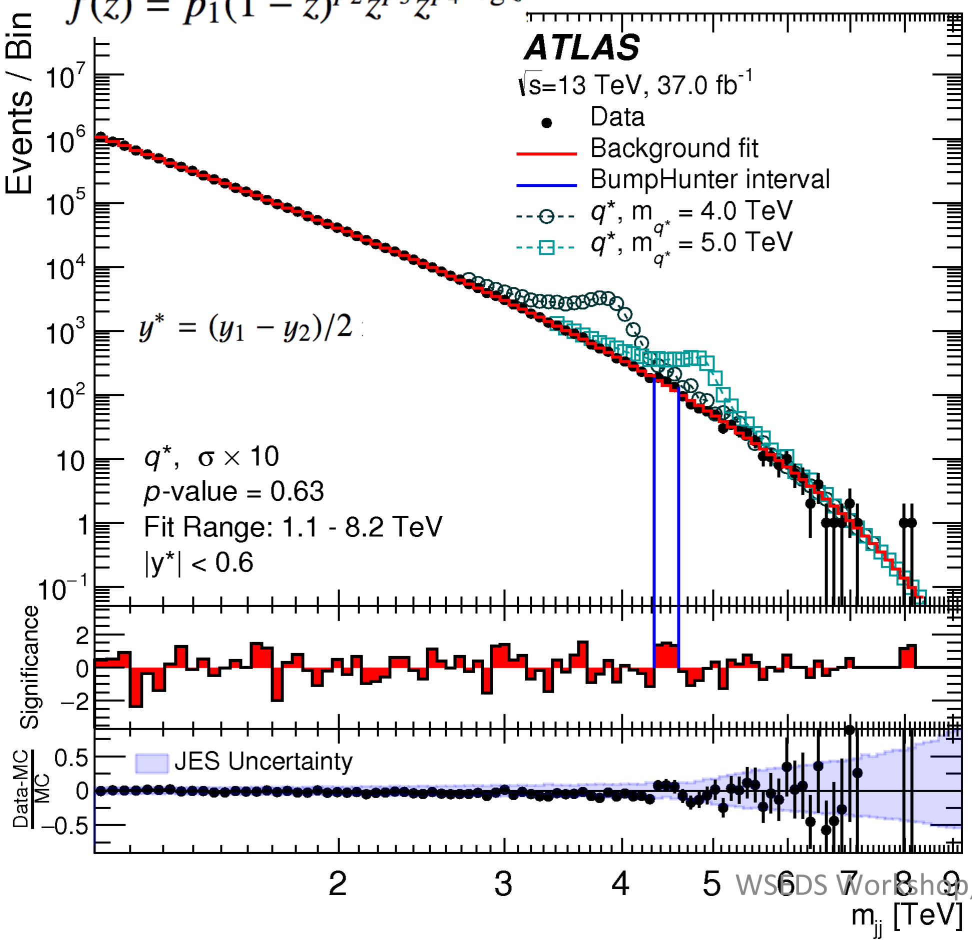
Search for resonances in dijets

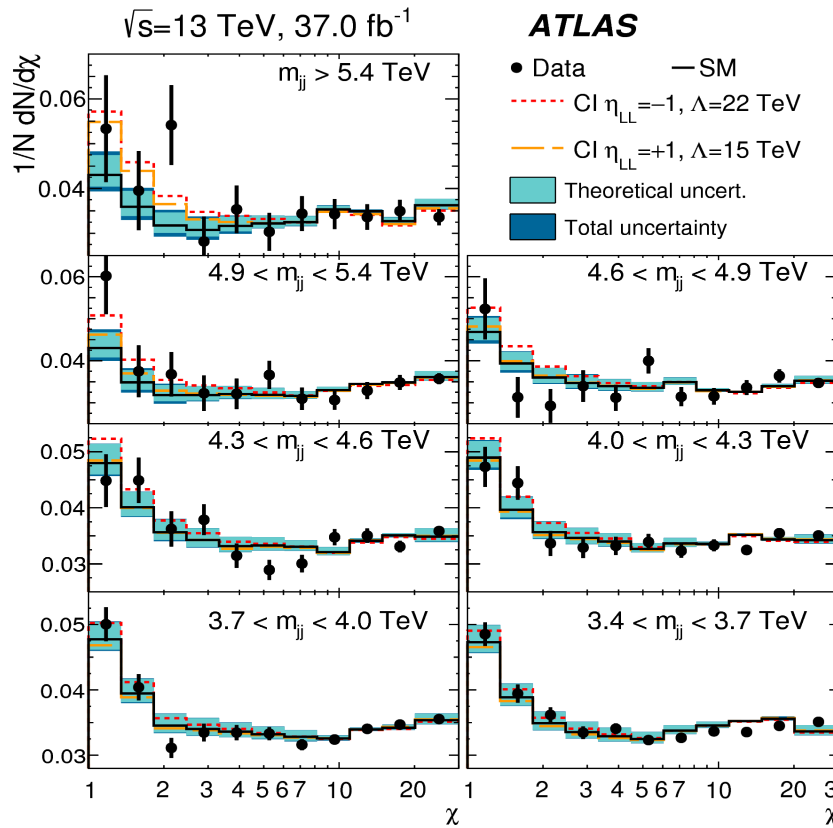
→ New physics should be central

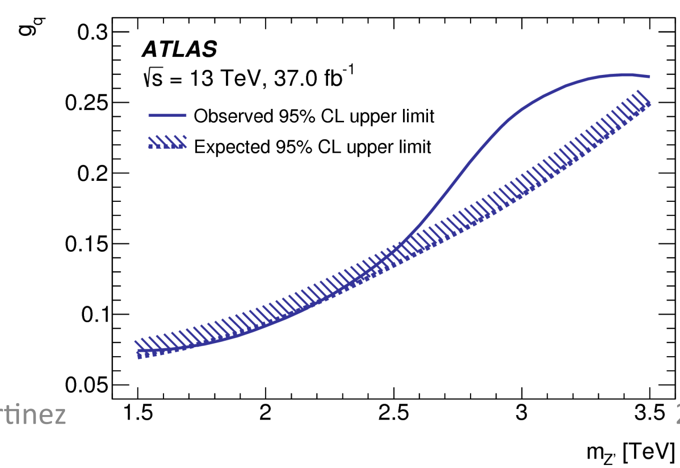
→ 95% CL on Z' → qq model (linked with DM)

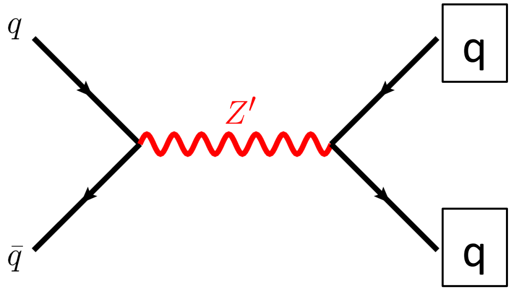
$$f(z) = p_1(1-z)^{p_2} z^{p_3} z^{p_4 \log z}$$

$$y^* = (y_1 - y_2)/2$$







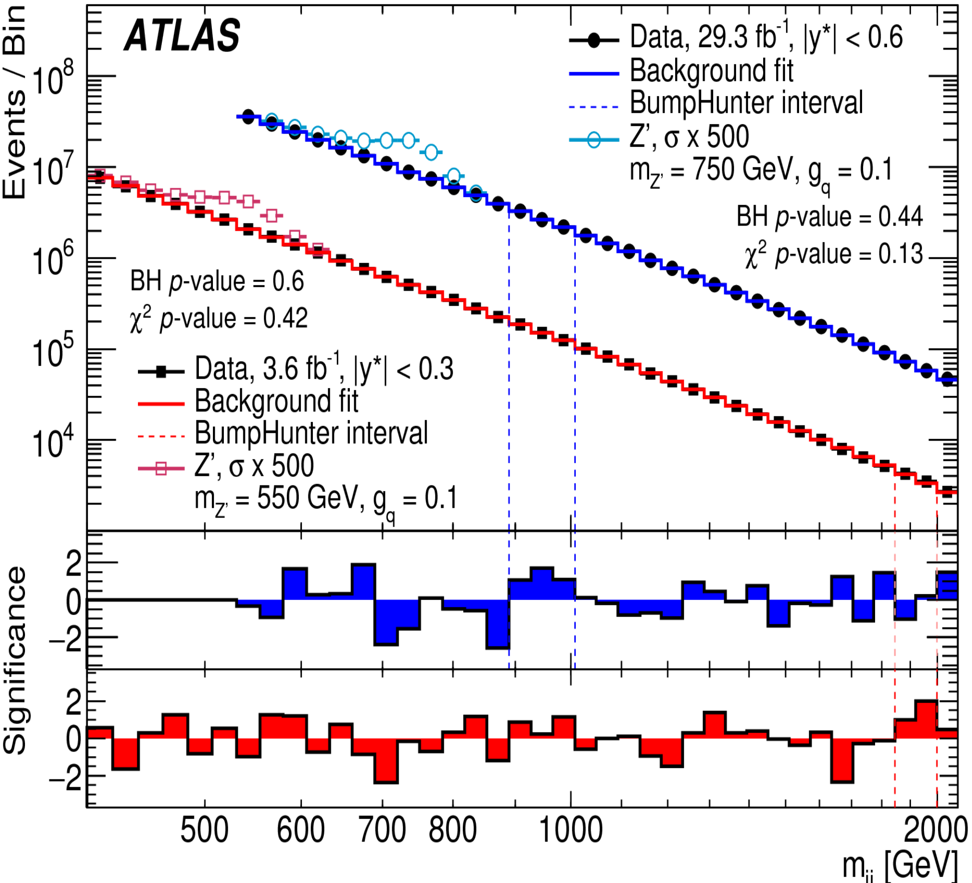


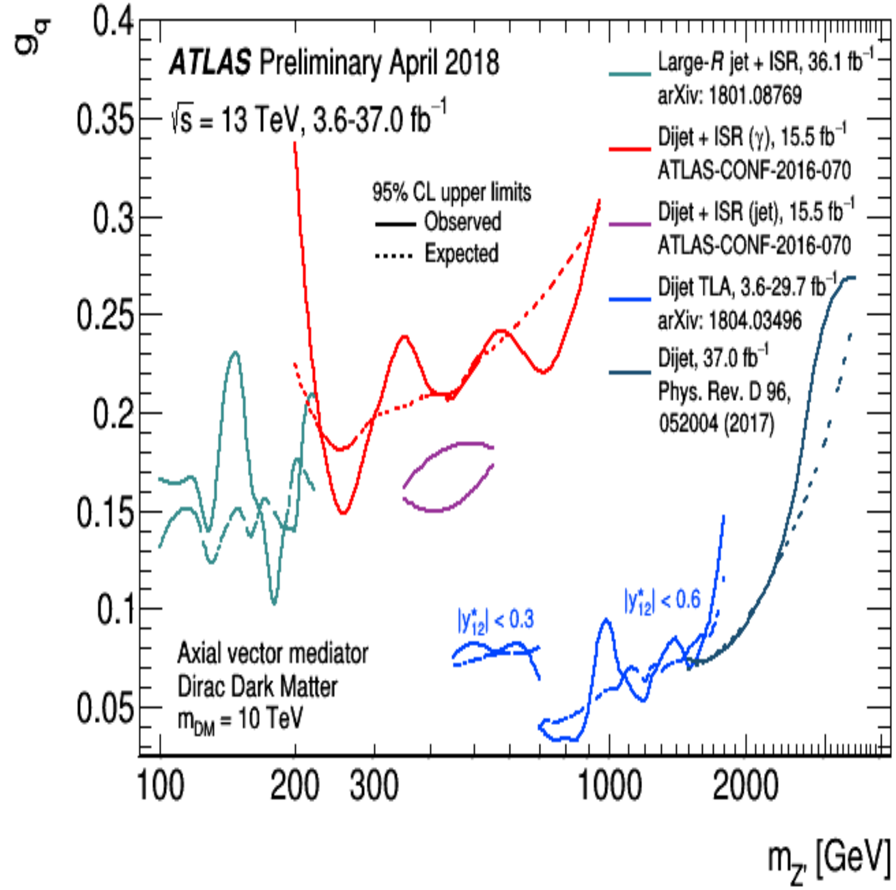
Dijet low mass

29.3 fb^{-1}

ATLAS EXPERIMENT

ATLAS: arXiv:1804.03496





New ways at the trigger level to re-explore low mass dijets without paying bandwidth price

This opened the way to explore Z' low mass (0.5 – 1 TeV) at the LHC with coupling to quarks

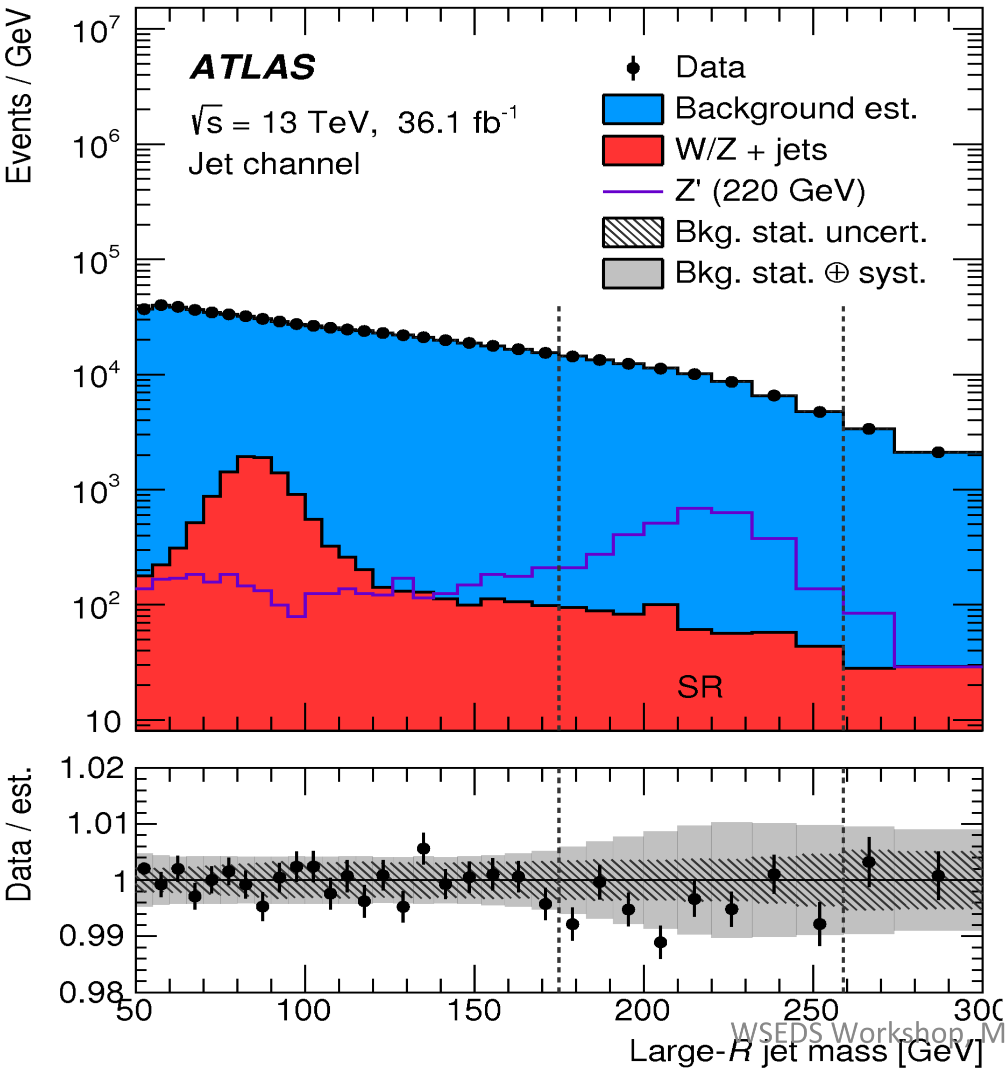
→ **and can be reinterpreted in terms of the Z' mediator in DM models**

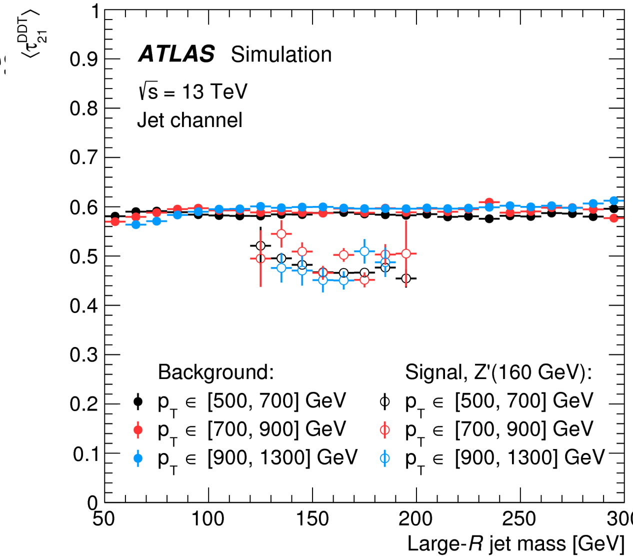
36.1 fb^{-1}

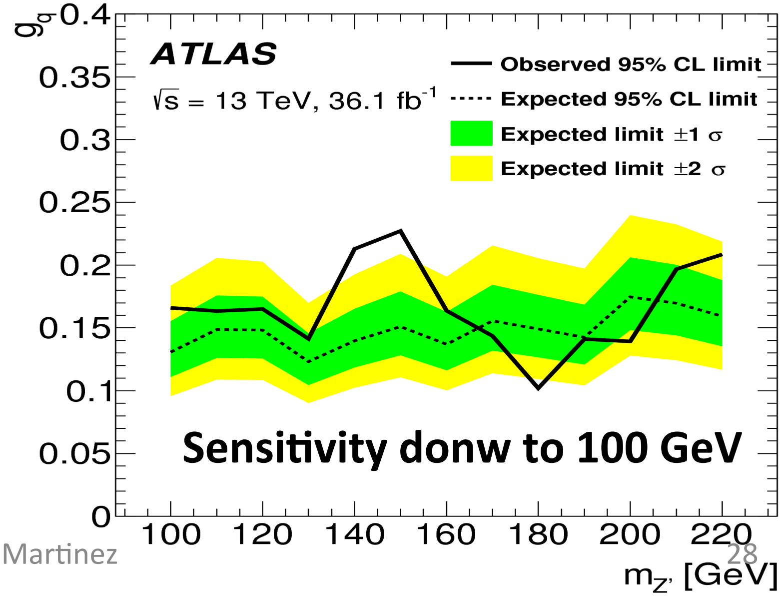
dijets + ISR

ATLAS: arXiv:1801.08769
Jesse Thaler, Ken Van Tilburg, JHEP 1103:015,2011

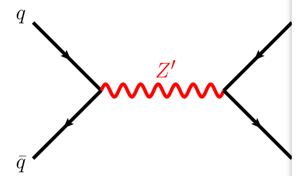
Search for low mass Z' (→ qq) + jet reconstructing the qq system (boosted) with refined subjet variables

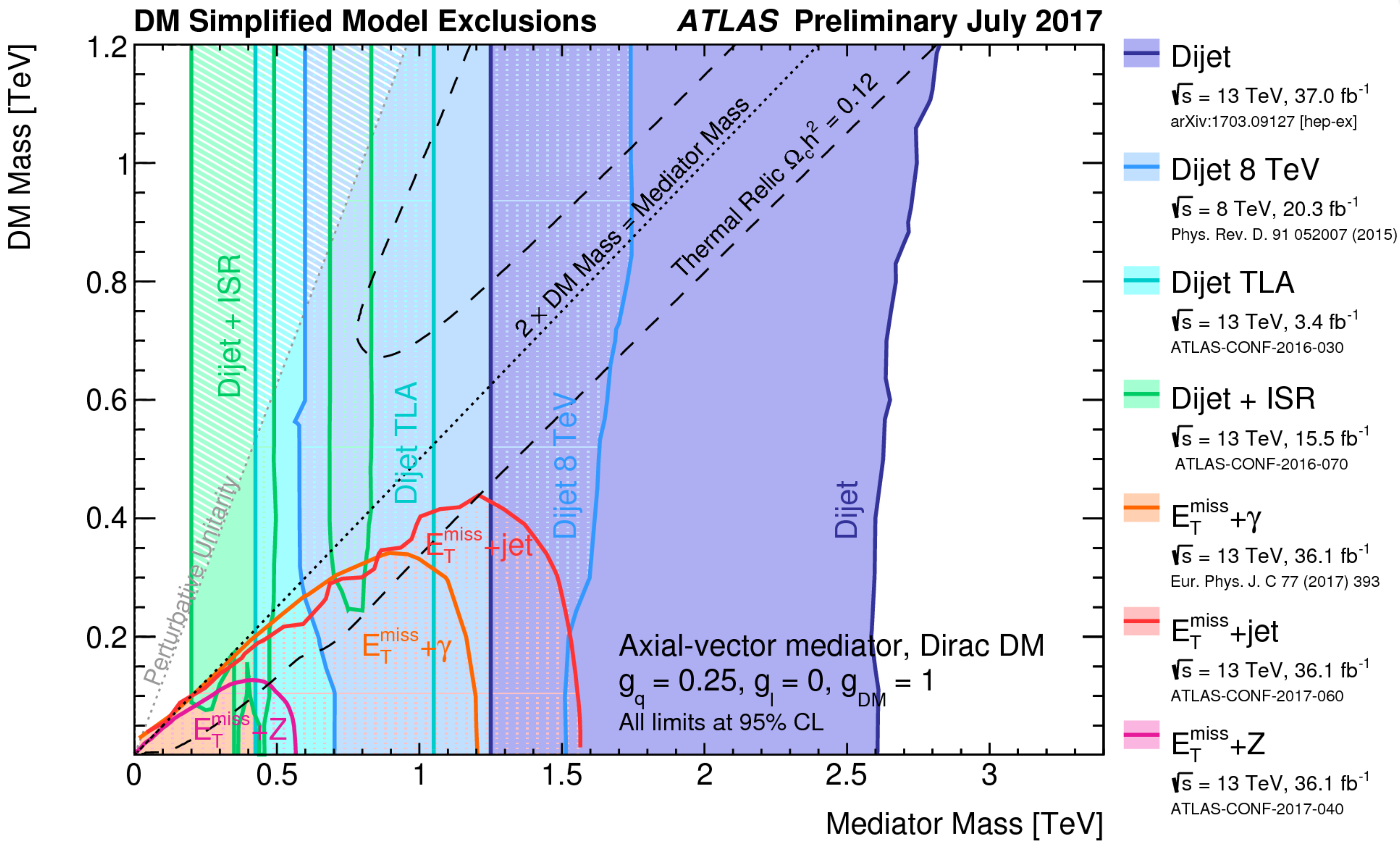






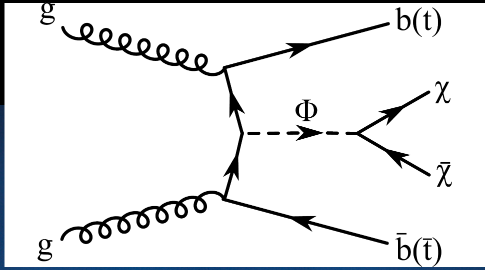
Summary Mono-X + Dijets





Benchmark Models

A set of well-defined simplified diagrams with heavy mediators is now considered motivated by a number of different considerations (DM Forum: arXiv:1507.00966)



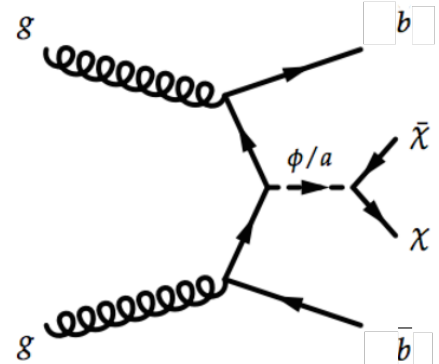
- **Simple extensions of SM symmetries**
- **Minimal Flavor Violation**
- **Assuming Yukawa couplings → favor 3rd generation**
- **Some models inspired by satellite "hints"**

In some cases a clear overlap with SUSY-inspired simplified models for direct production of 3rd generation squarks

This part focused on DM+HF

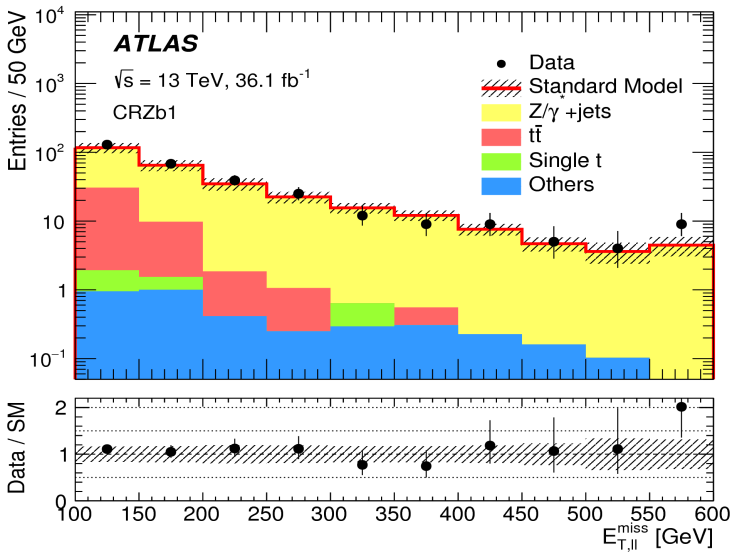
Eur. Phys. J. C 78 (2018) 18

DM+bb



Parameters:
Mediator and DM masses
(minimal mediator width)
couplings: g_q,g_{DM} = g=1

√s=13 TeV, 36.1 fb^{-1}



The analysis is optimized for a spin-0 mediator
Final state characterized by

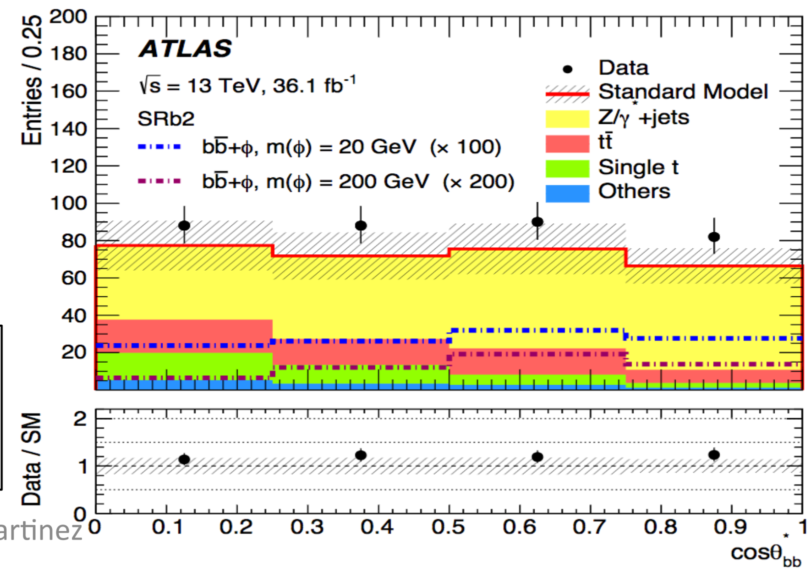
- Two b-jets, no more than 3-jets,
- Large missing transverse energy
- No leptons
- Azimuthal E_T^{miss}-Jet separation against QCD

As expected SM backgrounds driven by
Z(→νν)+bb, W(→lν)+bb and top quark production

Observable	SRb1	SRb2
Trigger	E_T^{miss}	
$\mathcal{N}_j$	≥ 2	2 or 3
$\mathcal{N}_b^T$	≥ 1	≥ 2
$\mathcal{N}_\ell^B$	0	
E_T^{miss} [GeV]	> 650	> 180
$p_T(bj_1)$ [GeV]	> 160	> 150
$p_T(j_1)$ [GeV]	> 160	> 150
$p_T(j_2)$ [GeV]	> 160	> 20
$p_T(j_3)$ [GeV]	-	< 60
H_{T3} [GeV]	< 100	-
H_T^{ratio}	-	> 0.75
δ^- [rad]	-	< 0
δ^+ [rad]	-	< 0.5
Multi-jet rejection specific		
$\Delta\phi(j, \vec{p}_T^{miss})$ [rad]	> 0.6	> 0.4

$$\delta^- = \Delta\phi(j, \vec{p}_T^{miss}) - \Delta\phi_{bb},$$
$$\delta^+ = |\Delta\phi(j, \vec{p}_T^{miss}) + \Delta\phi_{bb} - \pi|.$$

$$\cos\theta^*_{bb} = \left|\tanh\left(\frac{\Delta\eta_{bb}}{2}\right)\right|$$

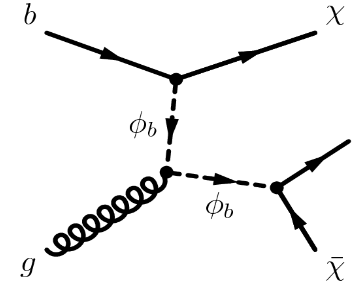


DM+b

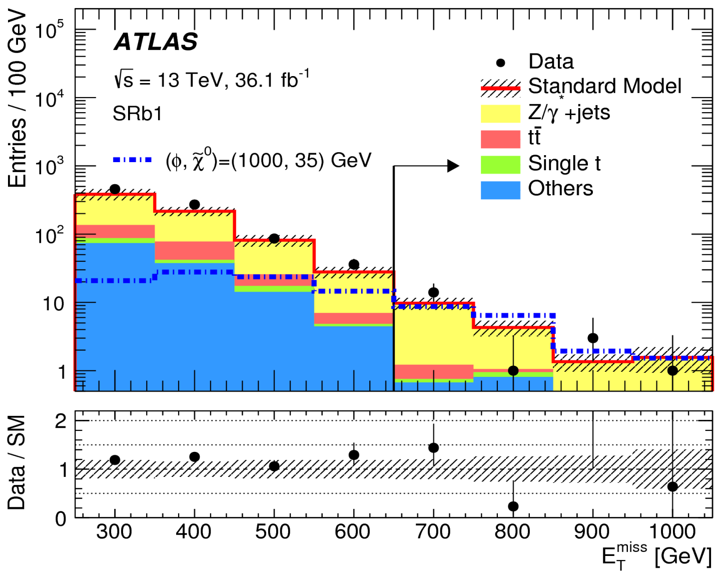
Eur. Phys. J. C 78 (2018) 18

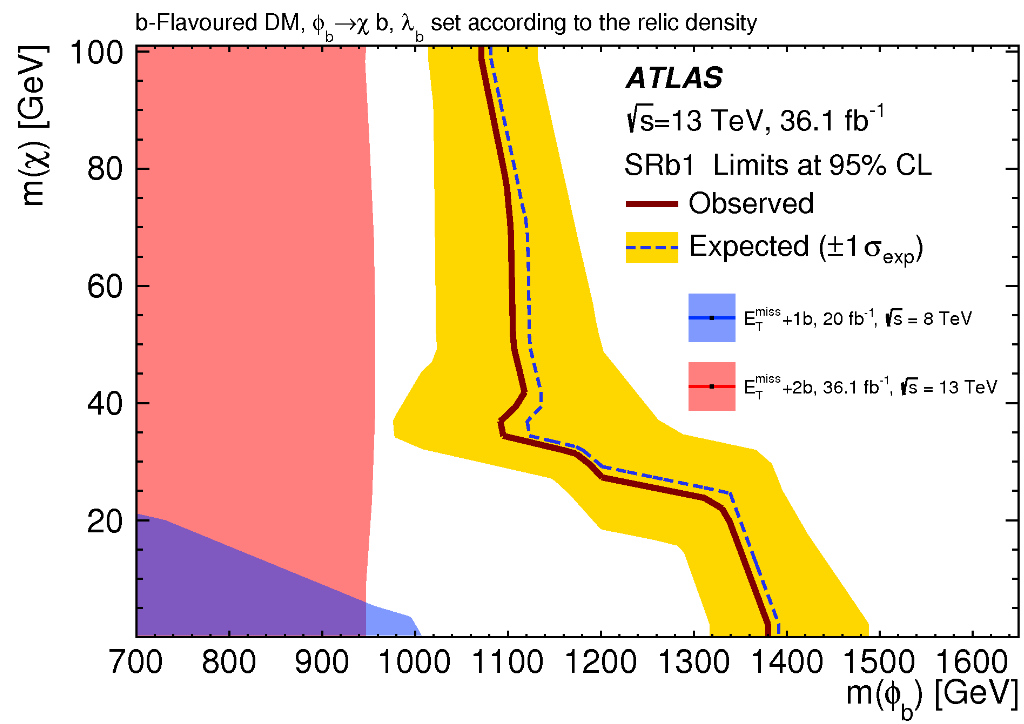
ATLAS EXPERIMENT

$\sqrt{s}$=13 TeV, 36.1 fb^{-1}

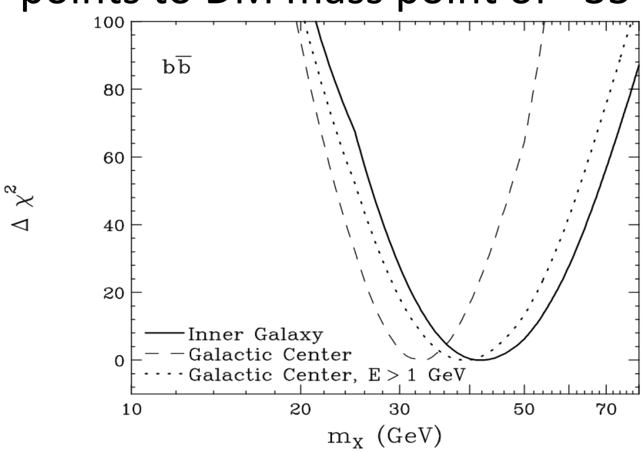


Bottom Flavored DM model
(motivated to accommodate Fermi-LAT hints)
P. Agrawal et al., Phys. Rev. D 90, 063512 (2014)





Analysis of Fermi-LAT data
points to DM mass point of ~35 GeV



Taken from: T. Daylan et al.,
Physics of the Dark Universe Volume 12, P1, 2016

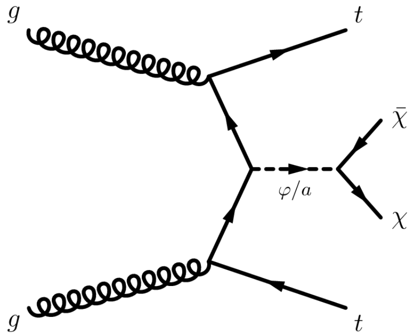
For a DM mass of 35 GeV, mediator masses in the range of 1.1 TeV are excluded at 95% CL

DM+tt

(hadronic channel)

$\sqrt{s}$=13 TeV, 36.1 fb^{-1}

Eur. Phys. J. C 78 (2018) 18



Large E_T^{miss} and E_T^{miss} significance

At least four jets, and 2 b-jets, lepton veto

Reconstruction of two large jets R=1.2

with masses above 140 and 80 GeV

Some topological requirements optimized for a

DM signal with M_{MED} = 100-300 GeV and M_{DM} = 1 GeV

$\Delta R(bb) > 1.5$, $M_T^{\ b,min} > 200$ GeV

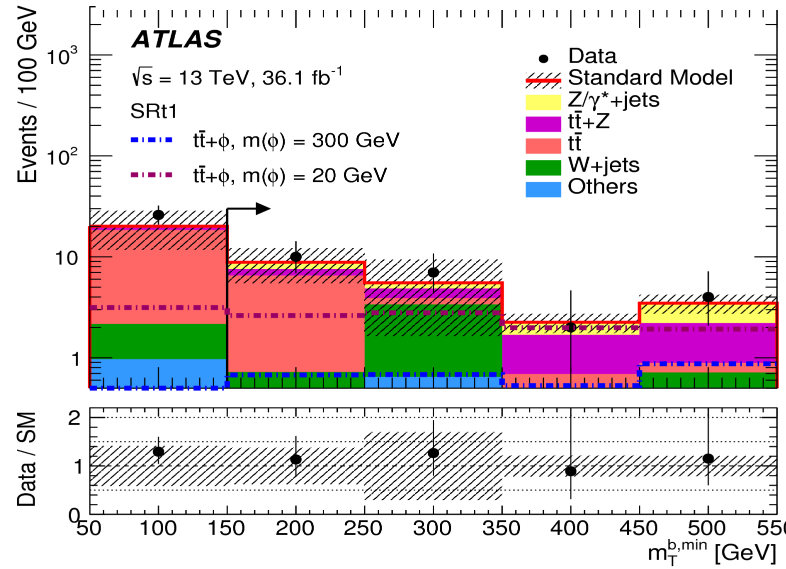
→ Dominated by top production

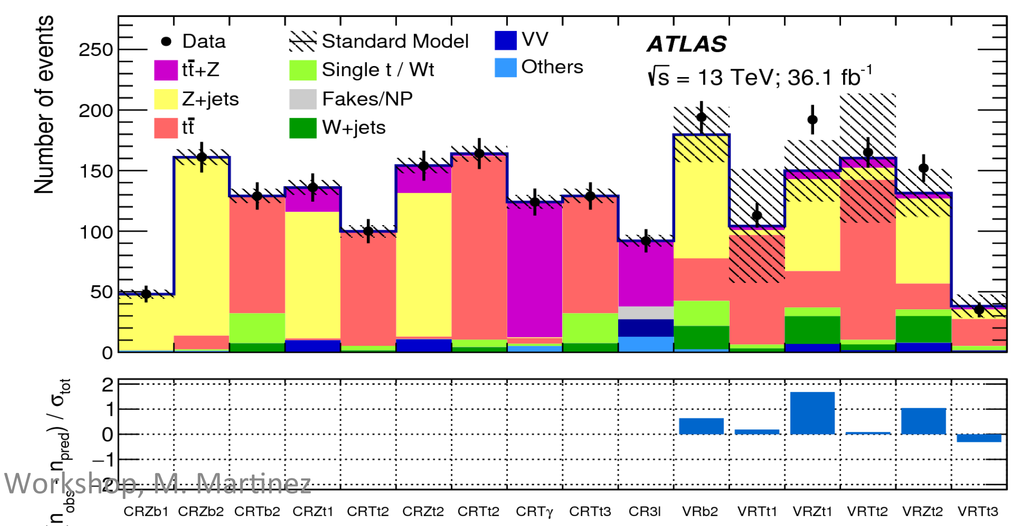
(tt & Z(→ νν)+jets)

Background normalizations constrained

in dedicated control regions.

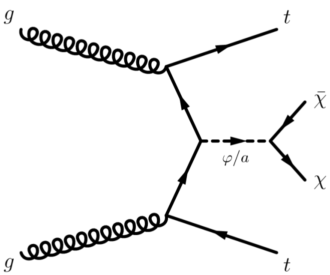
$$m_T^{b,\min} = \sqrt{2\, p_T^b\, E_T^{\rm miss}\left[1 - \cos\Delta\phi\left(\mathbf{p}_T^b, \mathbf{p}_T^{\rm miss}\right)\right]}$$

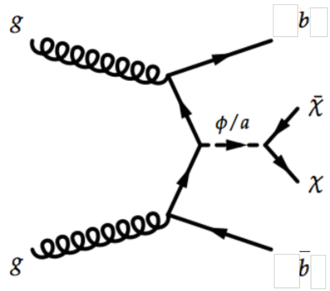




Results

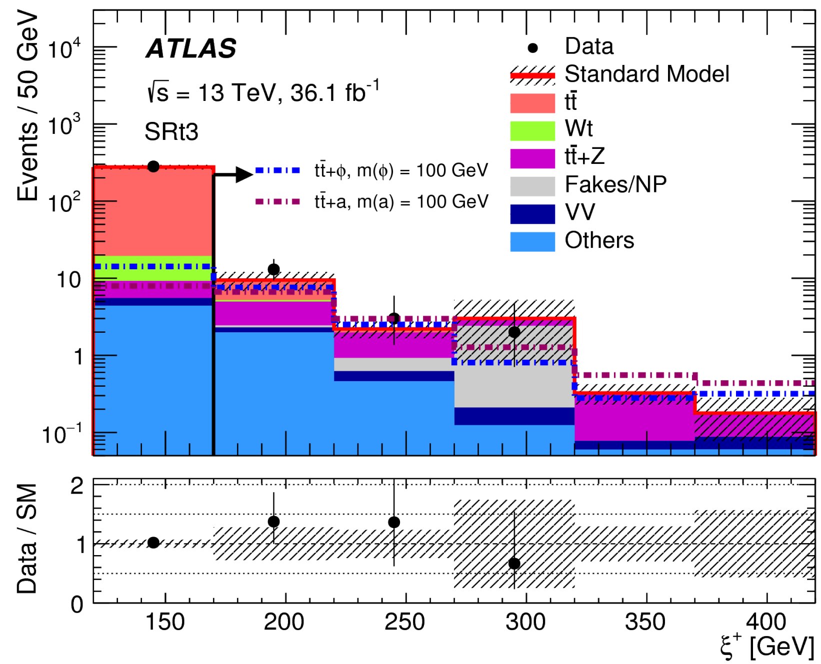
$\sqrt{s}$=13 TeV, 36.1 fb^{-1}
[Eur. Phys. J. C 78 (2018) 18]





	SRt1	SRt2	SRt3
Observed	23	24	18
Total background (fit)	20.5 ± 5.8	20.4 ± 2.9	15.2 ± 4.3
$t\bar{t}$	7.0 ± 3.9	3.1 ± 1.3	4.5 ± 2.5
$t\bar{t}+Z$	4.3 ± 1.1	6.9 ± 1.4	4.4 ± 1.9
$W+$jets	3.3 ± 2.6	1.28 ± 0.50	incl. in Fakes/NP
Wt	incl. in Others	incl. in Others	$0.33^{+0.53}_{-0.33}$
Z/γ^*+ jets	3.7 ± 1.4	6.2 ± 1.1	incl. in Others
VV	incl. in Others	incl. in Others	0.61 ± 0.25
Fakes/NP	-	-	2.7 ± 1.3
Others	2.2 ± 1.2	3.00 ± 1.6	2.69 ± 0.93
$t\bar{t}$ (pre-fit)	6.1	2.8	4.0
$t\bar{t}+Z$ (pre-fit)	3.53	5.6	5.6
Z/γ^*+ jets (pre-fit)	3.2	5.72	-

$$\xi^+ = m_{T2}^{\ell\ell} + 0.2 \cdot E_T^{miss}$$

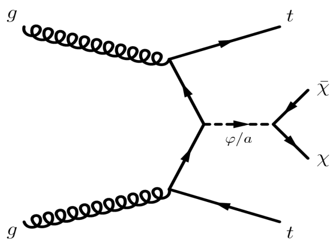


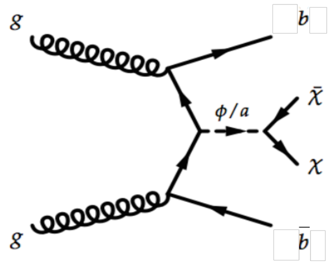
Good agreement with SM predictions in all SRs

Analyses with a sensitivity to Exclude new physics processes at the 1 fb level

$$\cos\theta^*_{bb} = \left|\tanh\left(\frac{\Delta\eta_{bb}}{2}\right)\right|$$

Signal channel	$\langle\epsilon\mathcal{A}\sigma\rangle_{95}^{obs}$[fb]	S_{95}^{obs}	S_{95}^{exp}	$p(s=0)$ (Z)
SRb1	0.37	13.4	12^{+5}_{-1}	0.33 (0.43)
SRb2 bin-1	1.10	39.6	33^{+12}_{-8}	0.22 (0.76)
SRb2 bin-2	1.17	42.1	31^{+10}_{-8}	0.11 (1.21)
SRb2 bin-3	1.21	43.7	33^{+11}_{-8}	0.16 (1.00)
SRb2 bin-4	1.10	39.8	26^{+11}_{-7}	0.10 (1.26)
SRt1	0.51	18.4	16^{+5}_{-4}	0.33 (0.44)
SRt2	0.44	15.7	12^{+5}_{-3}	0.24 (0.70)
SRt3	0.44	15.9	13^{+5}_{-2}	0.33 (0.45)



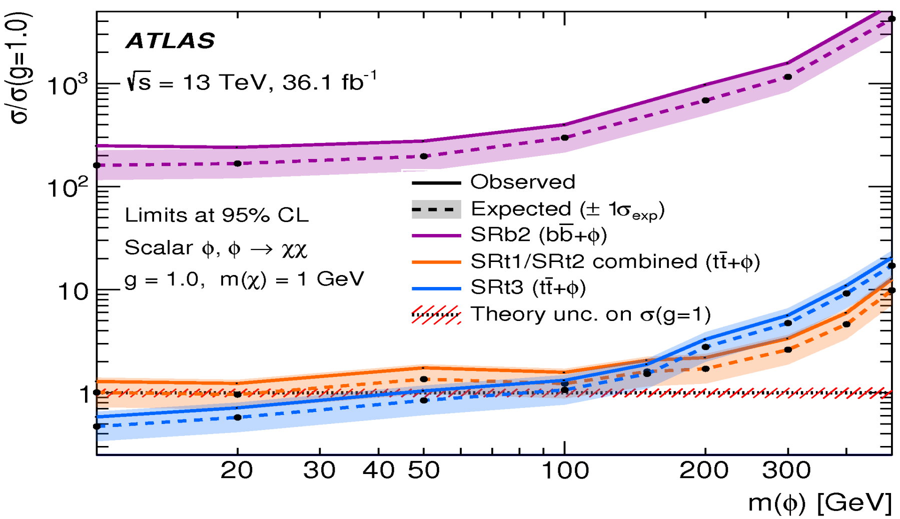


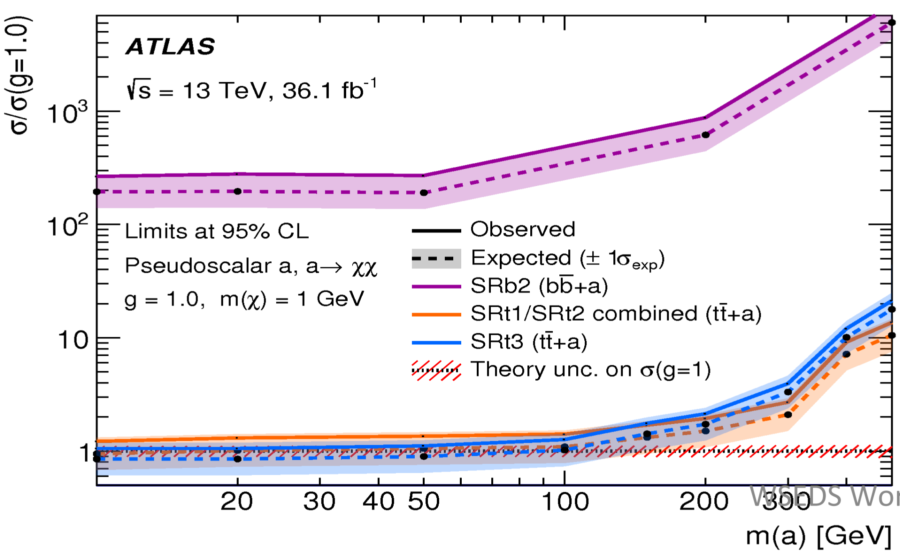
Results

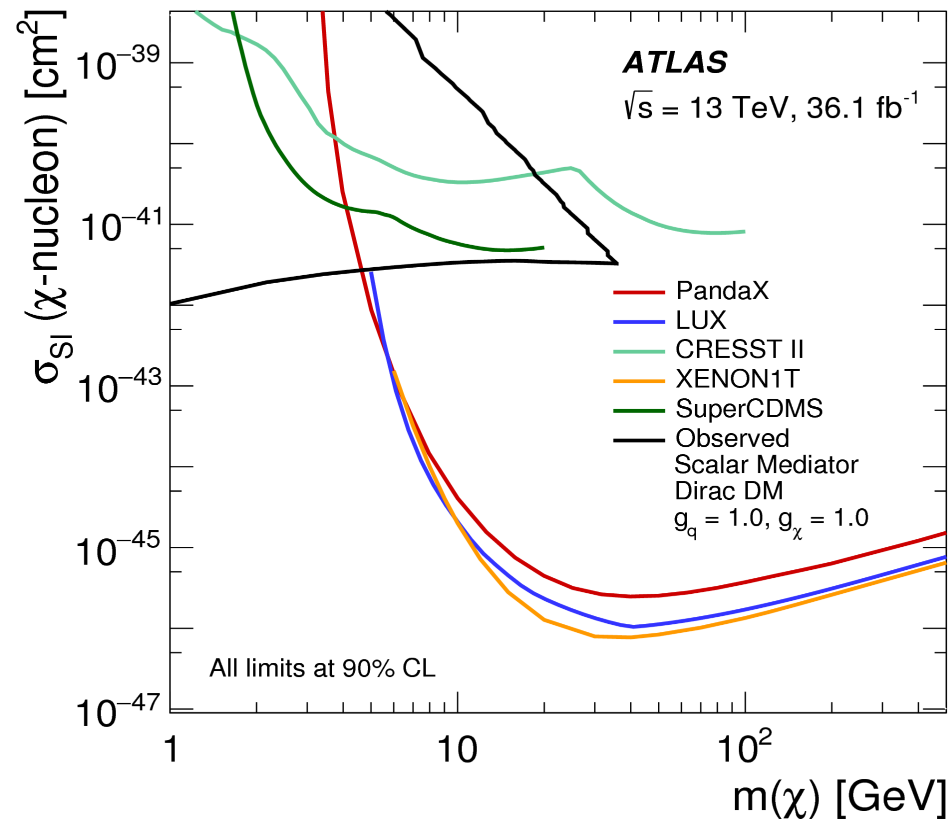
√s=13 TeV, 36.1 fb^{-1}

Eur. Phys. J. C 78 (2018) 18

95%CL upper limits w.r.t σ_{signal} @ g=1







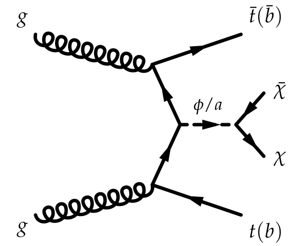
The tt+X analysis shows the sensitivity of the benchmark model with g= 1 for 1GeV DM for both scalar and pseudo-scalar mediators
→ Limits depend strongly on the DM mass.

arXiv:1711.11520

$\sqrt{s}$=13 TeV, 36 fb^{-1}

DM+tt

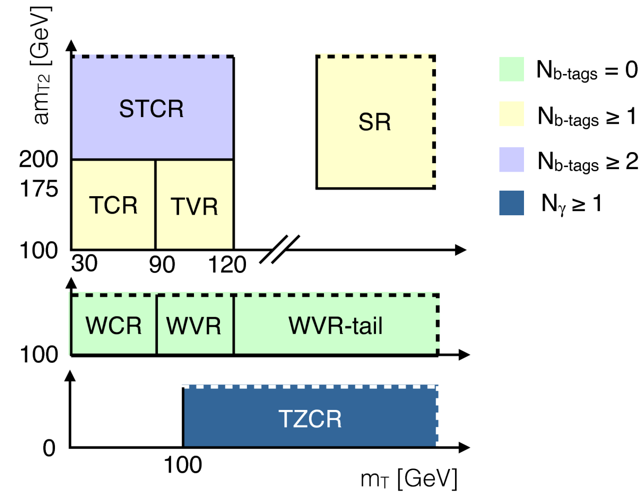
(semileptonic channel)



Large E_T^{miss} and E_T^{miss} significance
At least one lepton
At least four jets, and 1 b-jets
Azimuthal separations: jets, E_T^{miss}, lepton

Some topological requirements based on variants of m_{T2} (arXiv:hep-ph/9906349)

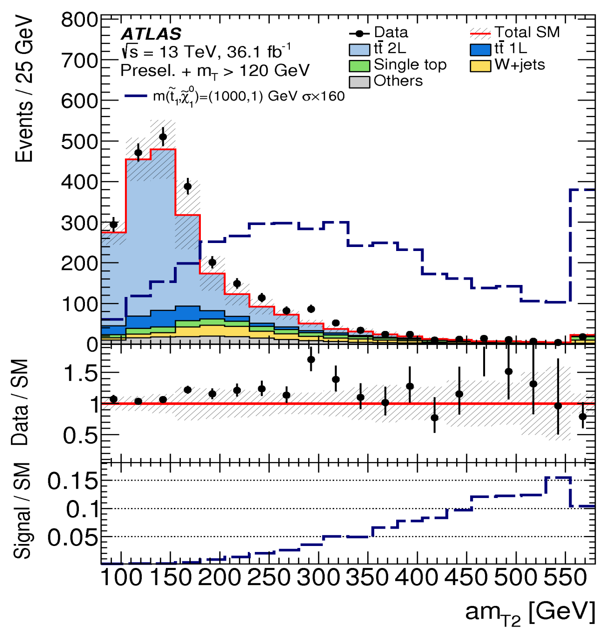
$$m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1}+\mathbf{q}_{T,2}=\mathbf{q}_T} \{\max[\ m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})\ ]\}$$

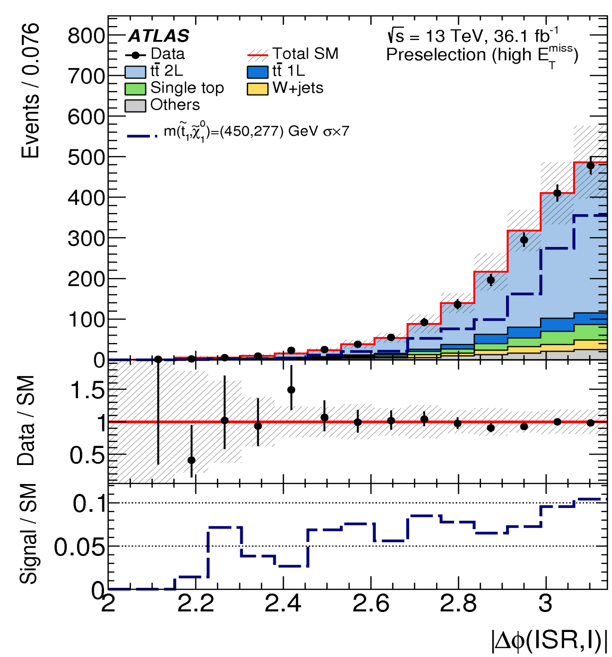


Background dominated by top processes.

Constrained in control regions via simultaneous fit

Different control regions and validation regions defined in the plane of topological variables and different N b-jets



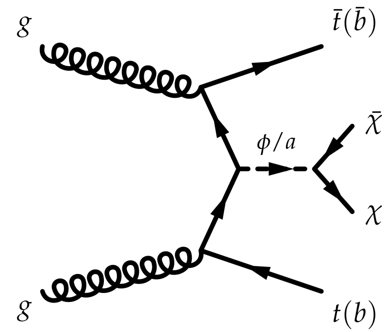


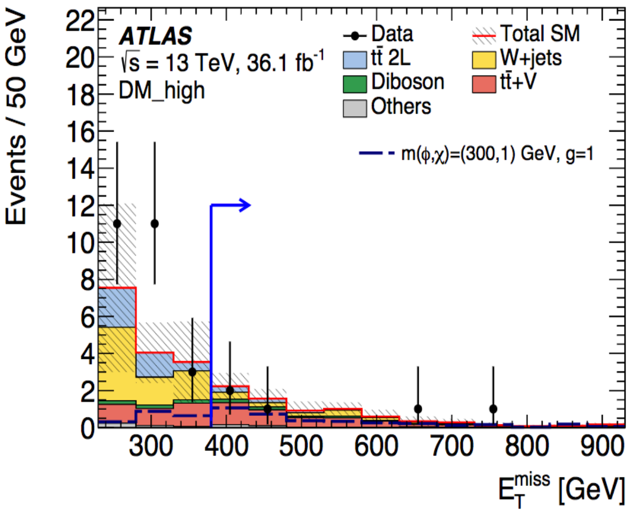
arXiv:1711.11520

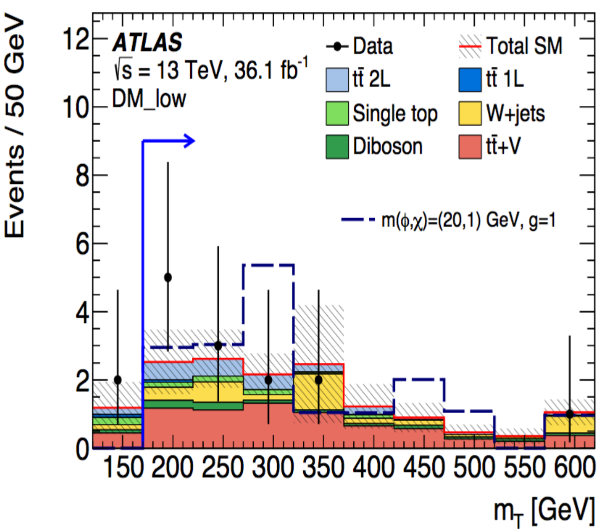
√s=13 TeV, 36 fb^{-1}

DM+tt

(semileptonic channel)

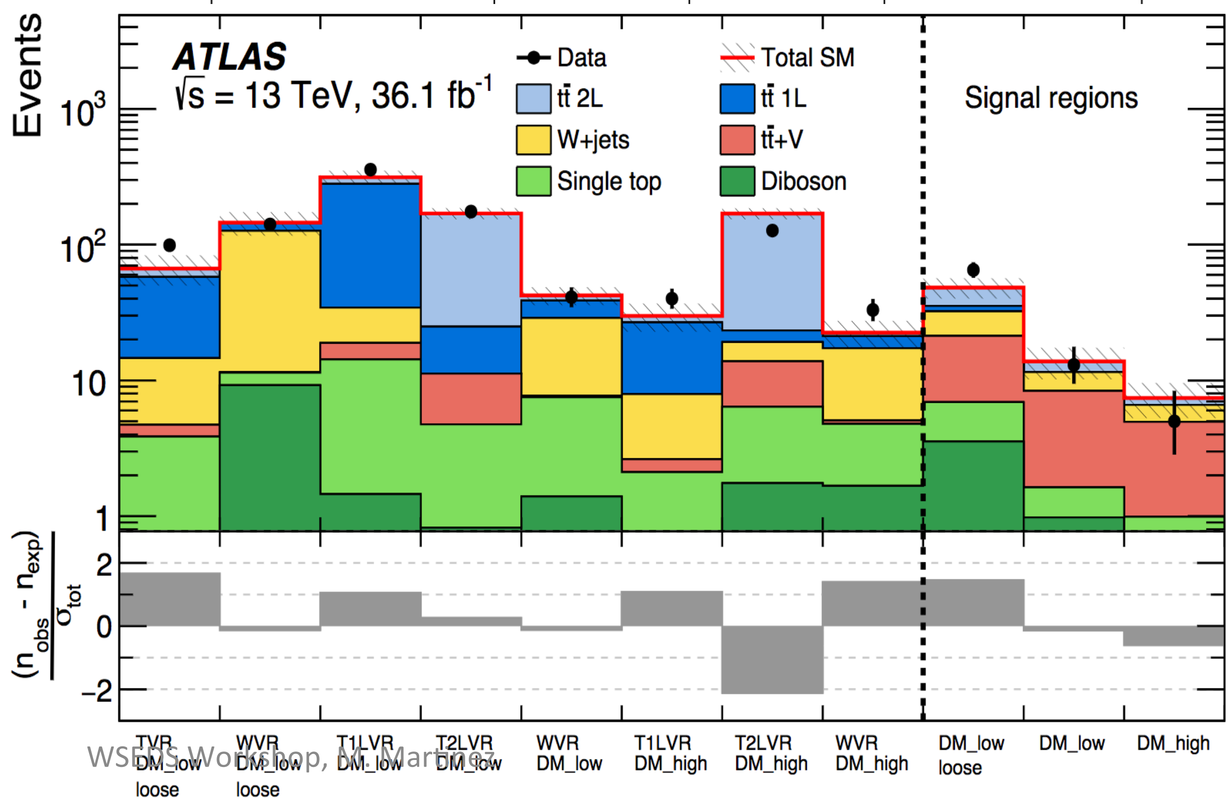






Good agreement with SM predictions

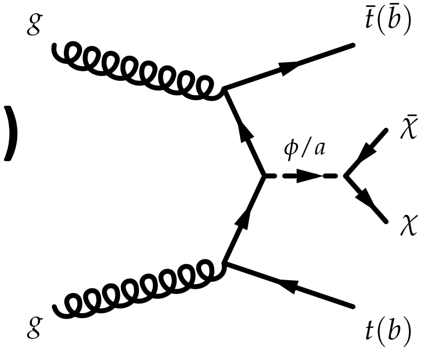
Signal region	DM_high	DM_low	DM_low_loose
Observed	5	13	65
Total background	7.4 ± 2.1	13.8 ± 3.6	48.3 ± 8.2



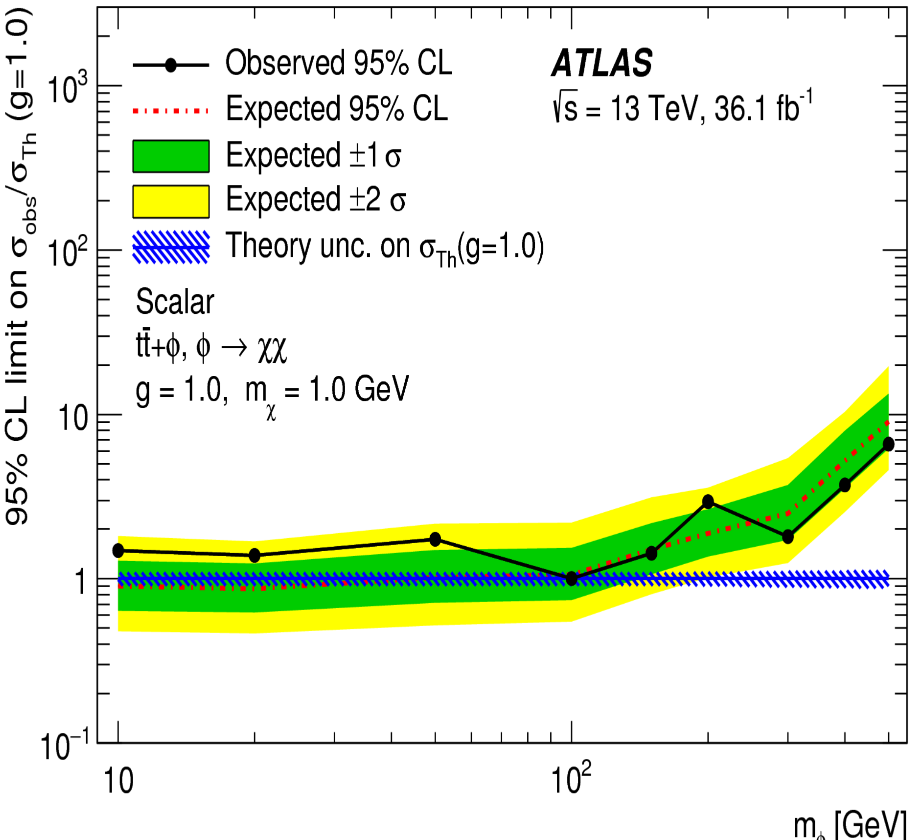
arXiv:1711.11520

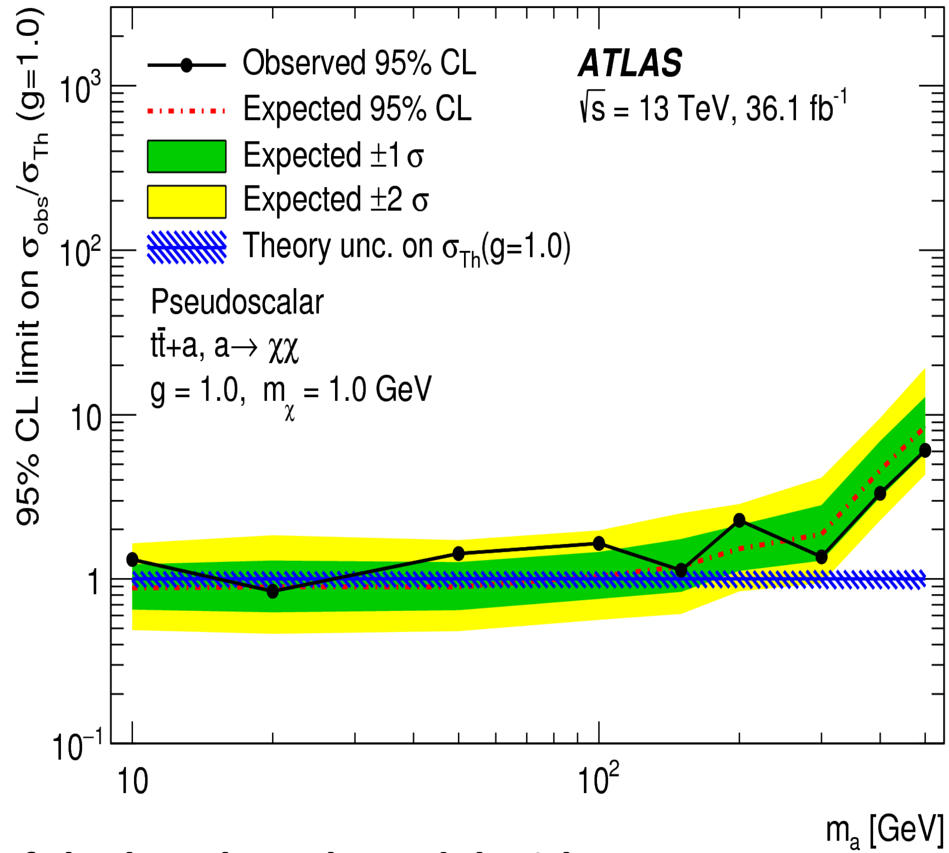
$\sqrt{s}$=13 TeV, 36 fb^{-1}

DM+tt
(semileptonic chanel)



95%CL upper limits w.r.t σ_{signal} @ g=1





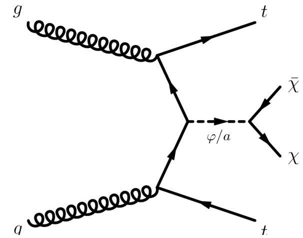
The tt+X analysis shows the sensitivity of the benchmark model with g= 1 for 1GeV DM for both scalar and pseudo-scalar mediators

→ Limits depend strongly on the DM mass.

ATLAS-CONF-2016-076

$\sqrt{s}$=13 TeV, 13.3 fb^{-1}

DM+tt
(dilepton channel)



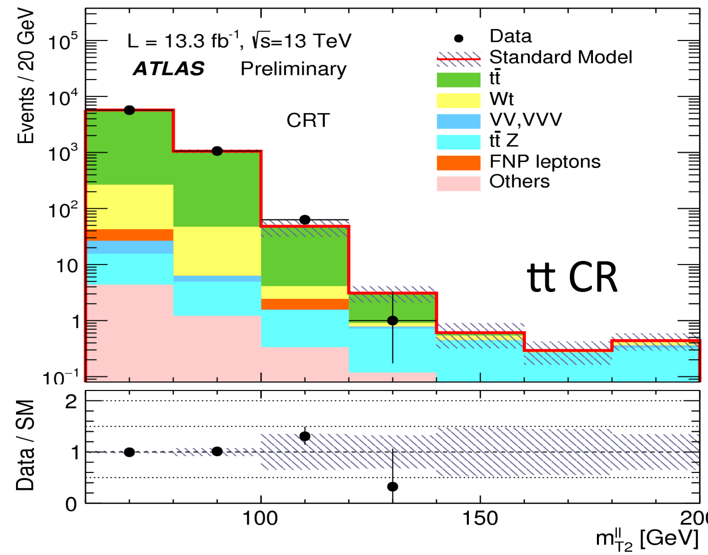
Considering dilepton channels (ee,μμ,eμ)

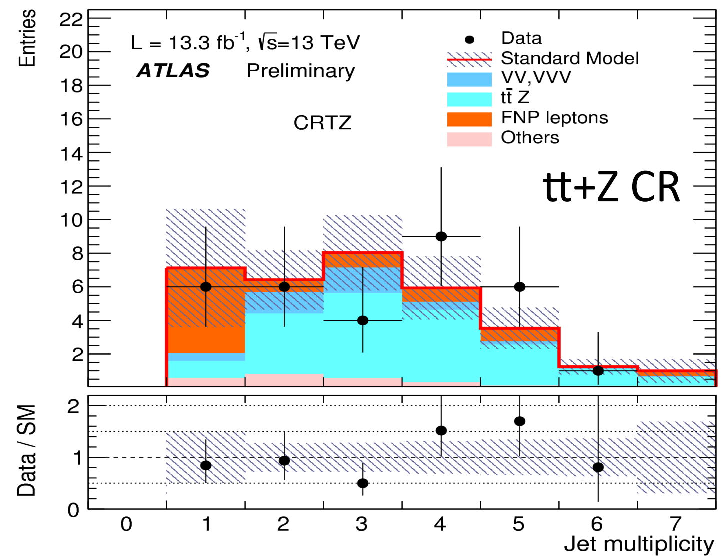
→ Moderate E_T^{miss}, at least one b-jet, multiple jets

→ Topological cuts to enhance signal

Variable	DM-SRL	DM-SRH
$\lvert m_{\ell\ell} - m_Z \rvert$ [GeV] (SF only)	>20	>20
b-jet multiplicity	> 0	> 0
$\Delta\phi_{\rm boost}$	< 1.0	< 1.0
m_{T2}^{ll} [GeV]	>120	>120
$E_T^{\rm miss}$ [GeV]	> 180	> 260

$$m_{T2}(\mathbf{p}_{T,1}, \mathbf{p}_{T,2}, \mathbf{q}_T) = \min_{\mathbf{q}_{T,1}+\mathbf{q}_{T,2}=\mathbf{q}_T} \{\max[\ m_T(\mathbf{p}_{T,1}, \mathbf{q}_{T,1}), m_T(\mathbf{p}_{T,2}, \mathbf{q}_{T,2})\ ]\}$$



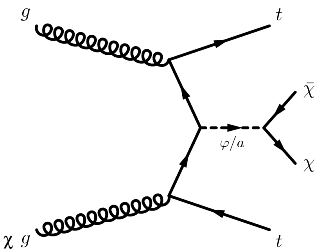


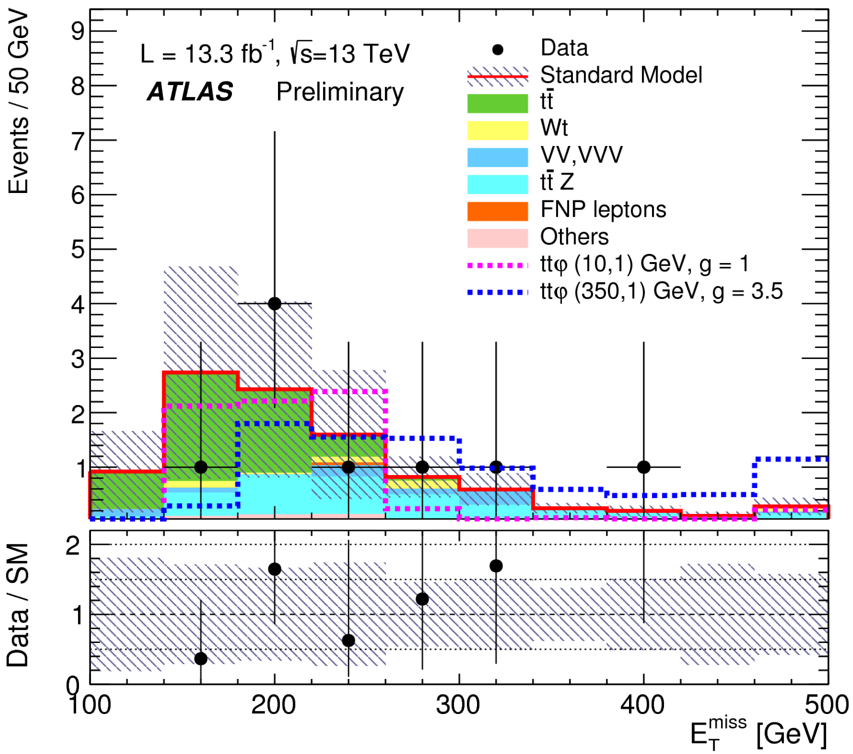
→ Dominated by top production (tt & tt+Z)

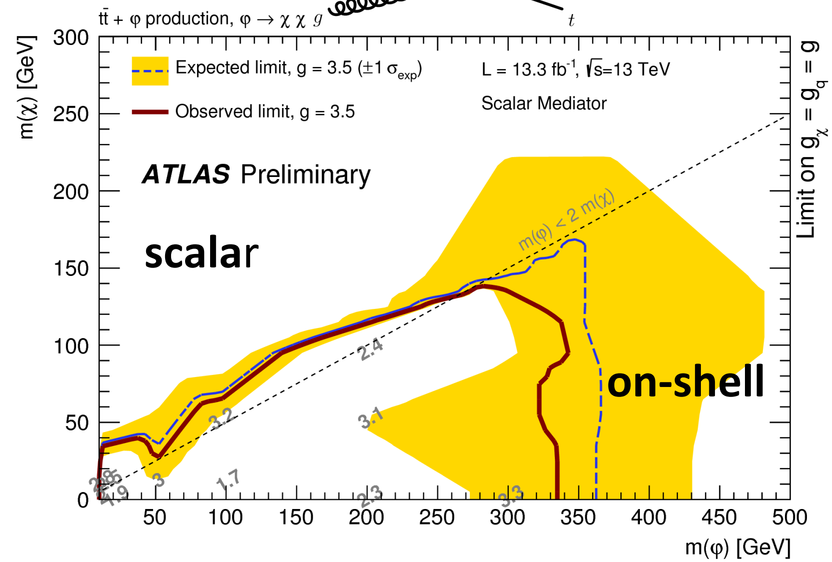
Background normalizations constrained in dedicated control regions.

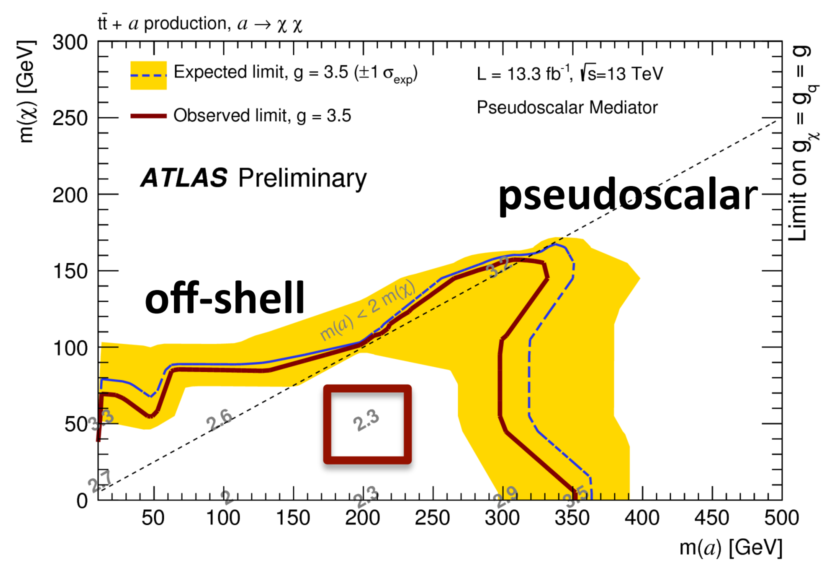
ATLAS-CONF-2016-076

DM+tt
(dilepton channel)









Good agreement with SM predictions

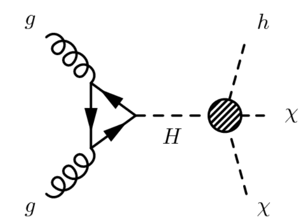
95% CL limits on visible cross section in the range **0.65 fb – 0.43 fb**

Limits on DM models assuming g= 3.5
(95% limits on g in the Figures)

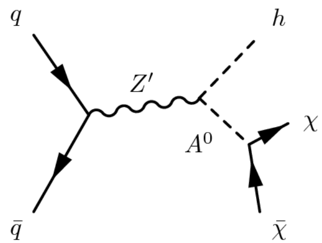
Higgs (→ γγ) + X

Phys. Rev. D 96 (2017) 112004

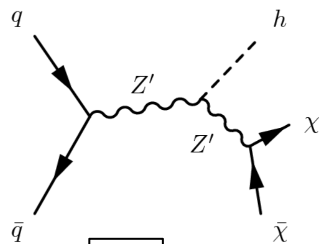
√s=13 TeV, 36.1 fb^{-1}



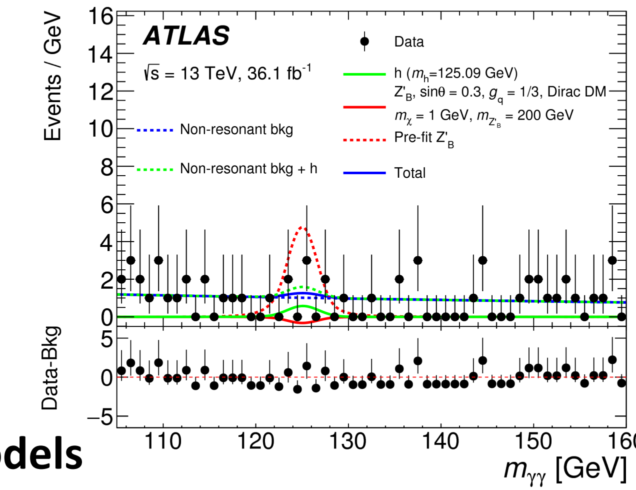
Heavy Scalar



Z'-2HDM

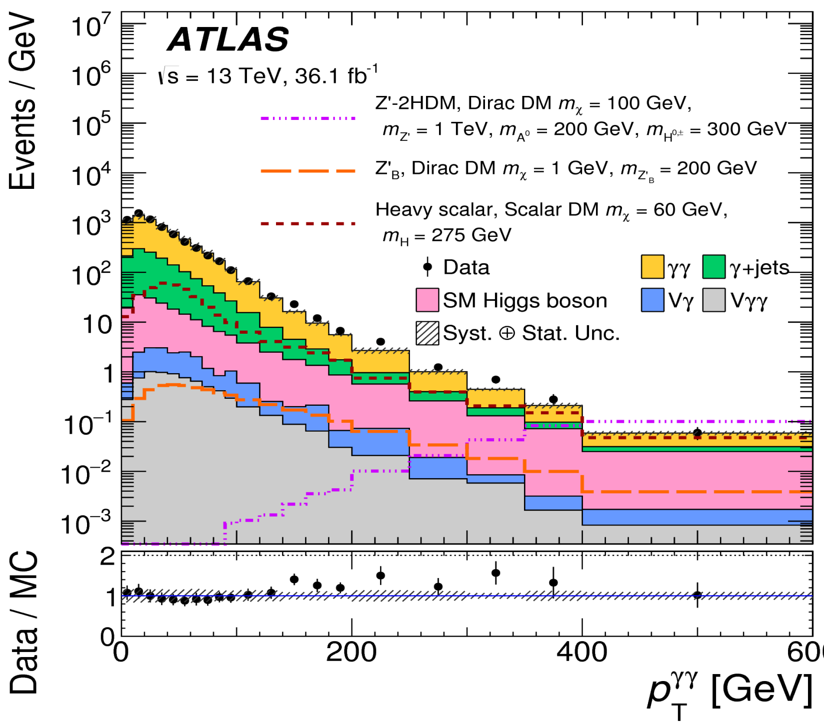


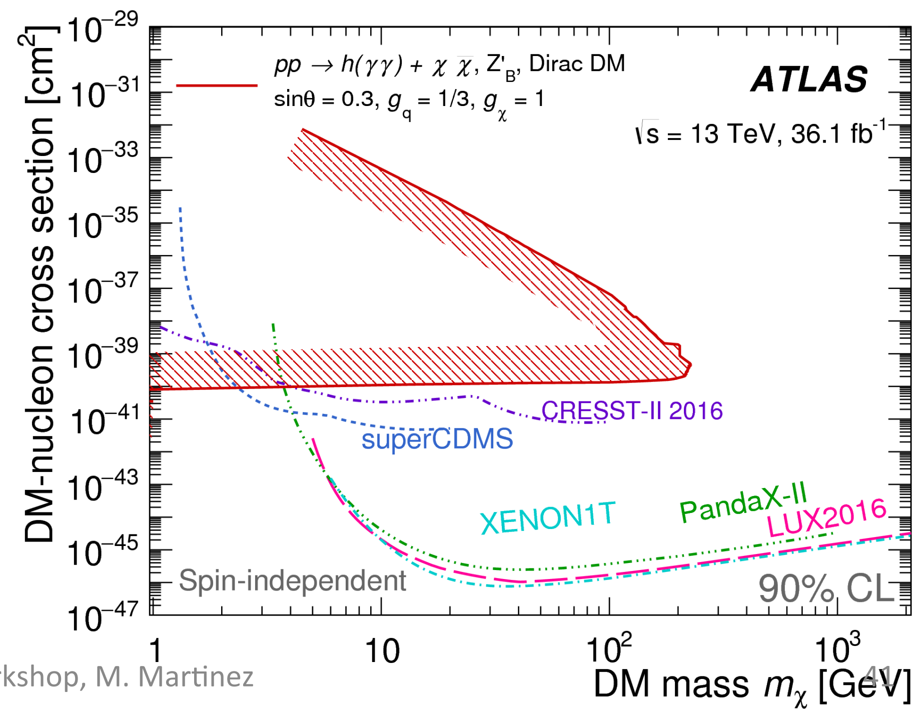
Z'



Different selections in terms of $p_T^{\gamma\gamma}$ and E_T^{miss} significance

→ Agreement with SM translated in to limits on different models

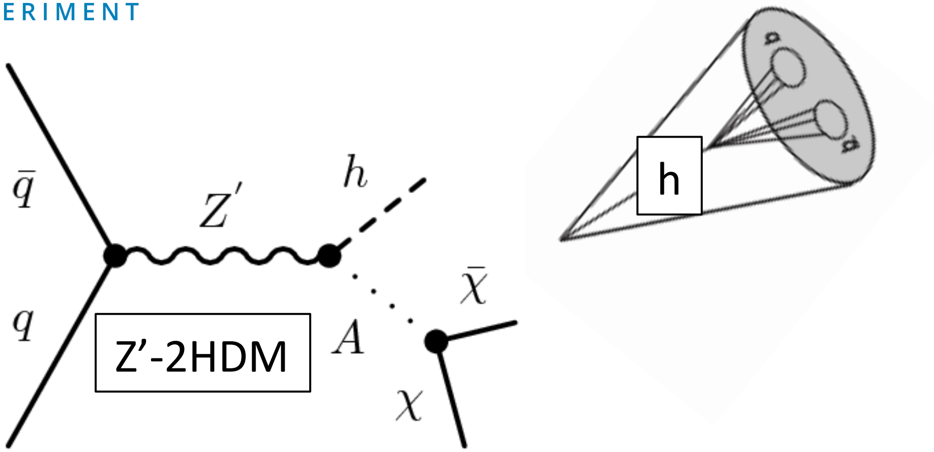


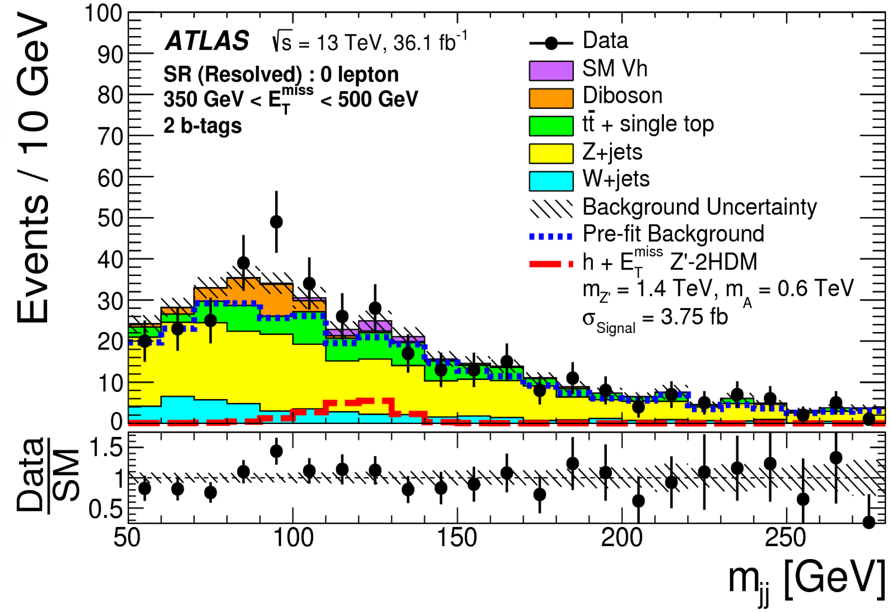


Higgs (→ bb) + X

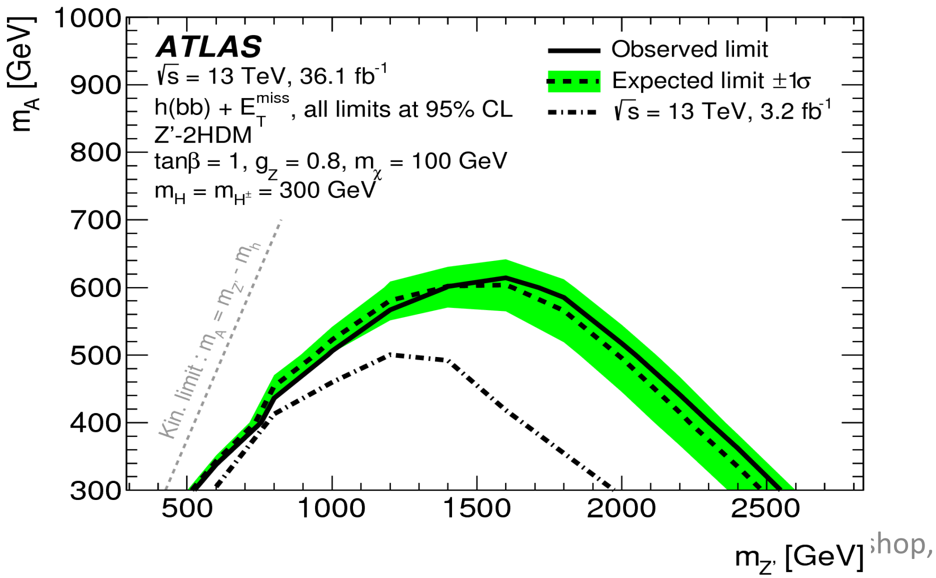
Phys. Rev. Lett. 119 (2017) 181804

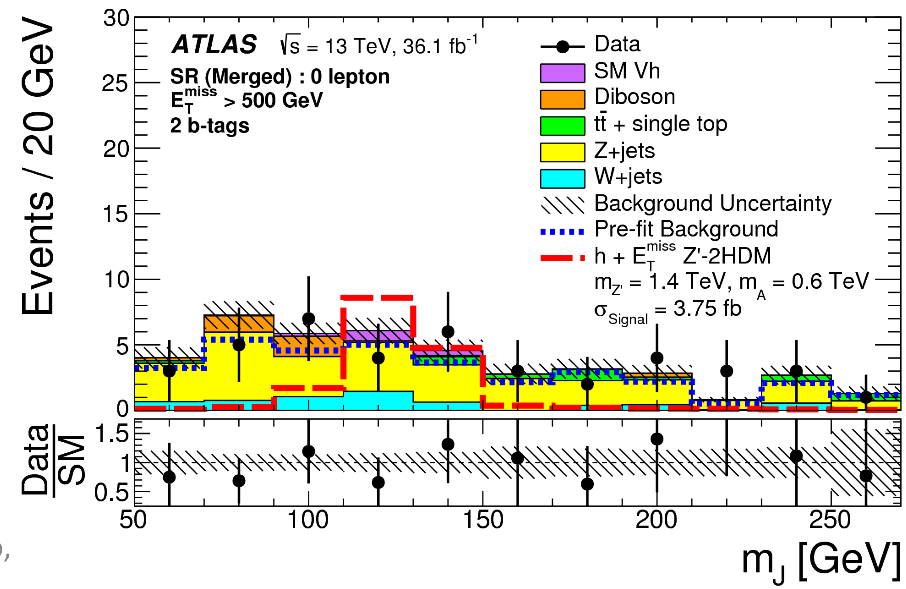
$\sqrt{s}$=13 TeV, 36.1 fb^{-1}





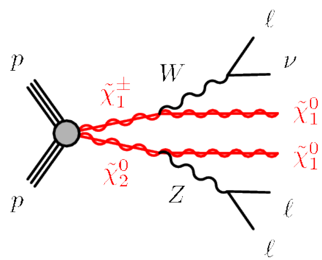
Both resolved and merged configurations with large missing transverse energy and b-tags



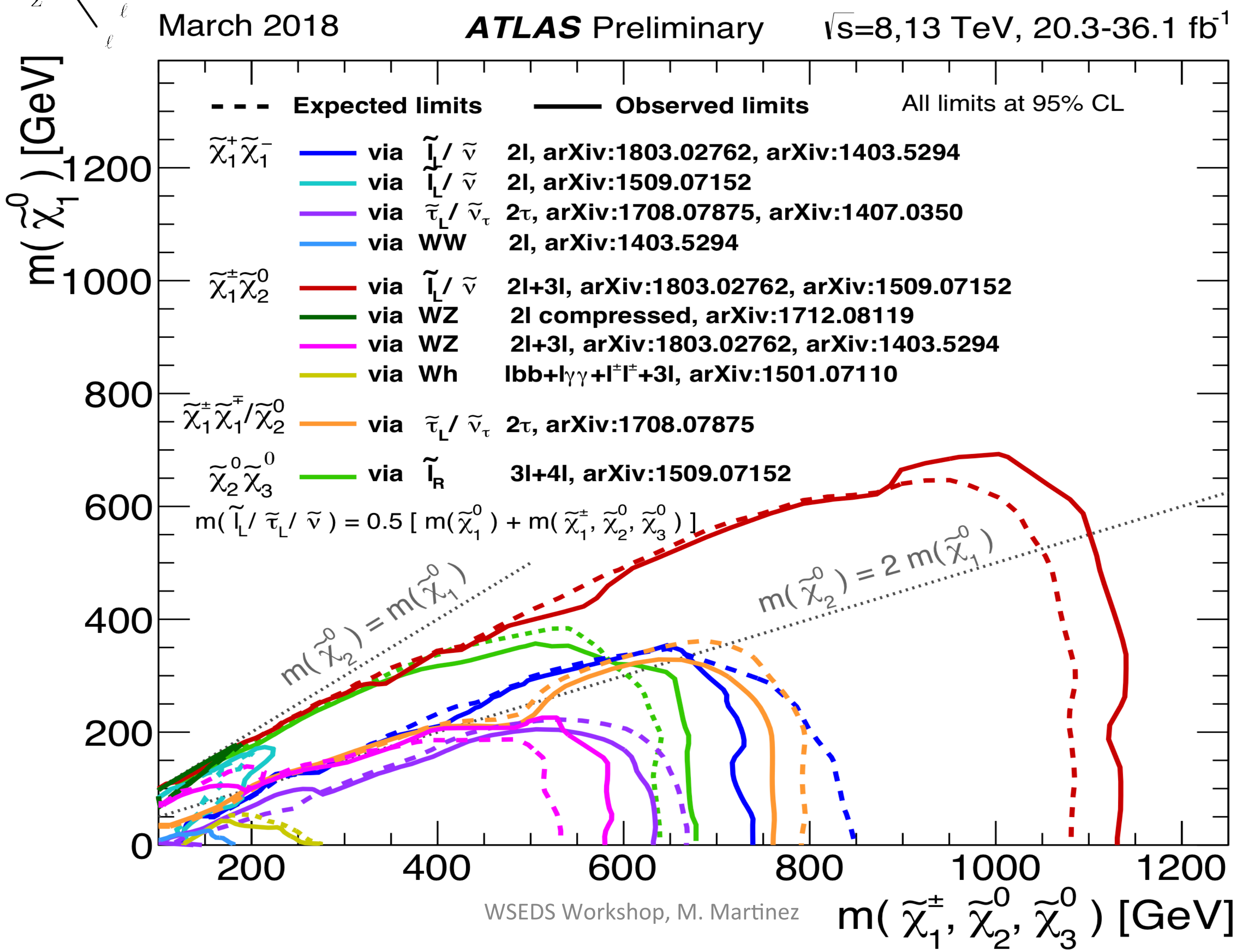


Final notes

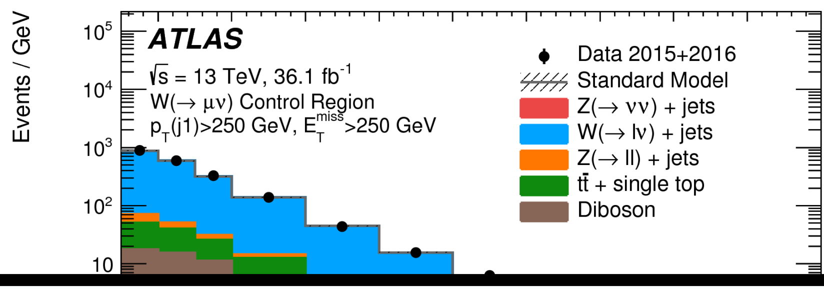
- The nature of the Dark Matter remains one of the biggest questions on particle physics and its potential discovery is a pillar of the ATLAS physics program
- Mono-X and Dijet translated into stringent limits on simplified models based on light mediators
- The search for Dark Matter in association with heavy flavors at the LHC is well motivated and still statistically limited
- Exclusion limits on DM strongly depend on model assumptions
- Less than 1/3 of the data for Run II analyzed.. more to come
- Stay tuned!

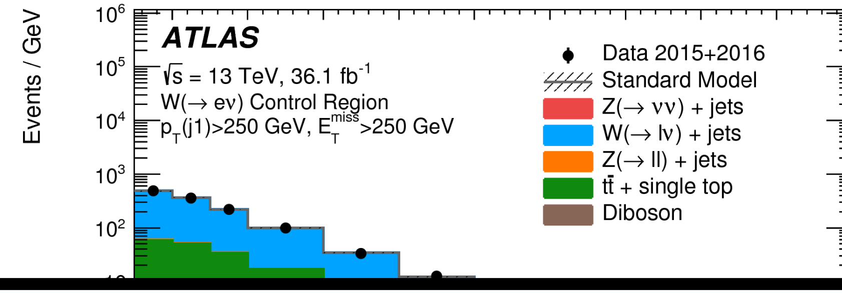


SUSY EWK production



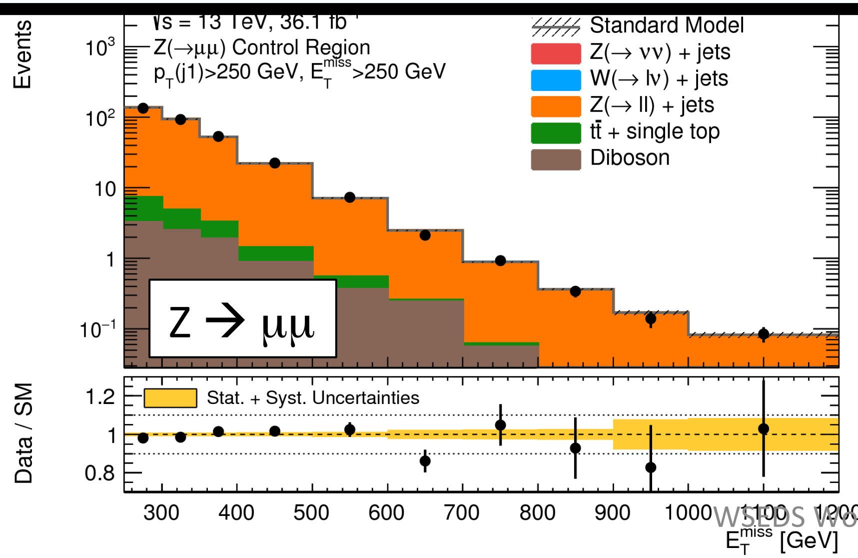
Jet+X (control regions)

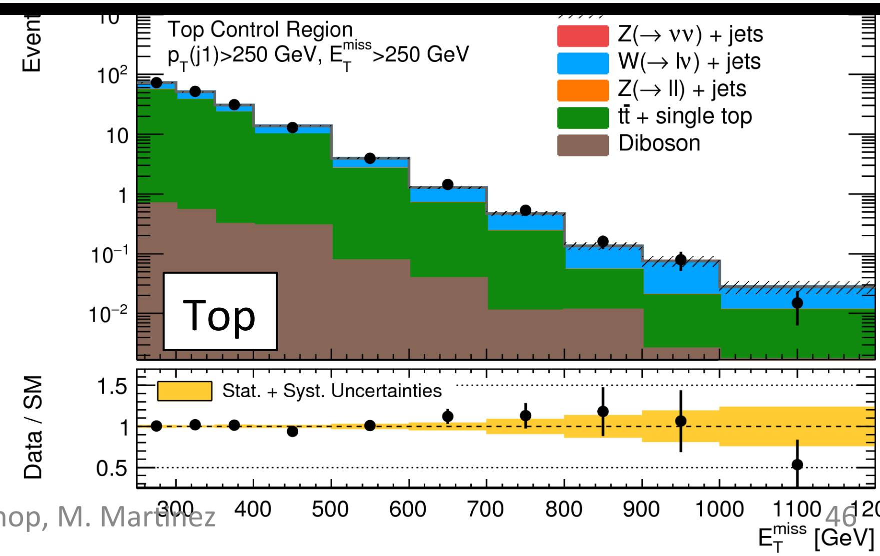




$$\mathcal{L}(\mu, \kappa, \theta) = \prod_r \prod_i \text{Poisson}\left(N_{ri}^{\text{obs}} \mid \mu N_{ri}^{\text{sig}}(\theta) + N_{ri}^{\text{bkg}}(\kappa, \theta)\right) f_{\text{constr}}(\theta)$$

$$\begin{aligned} N_{ri}^{\text{bkg}} = \kappa^{W/Z} (& N_{ri}^{Z(\nu\nu)+\text{jets}} \\ & + N_{ri}^{W(\mu\nu)+\text{jets}} + N_{ri}^{W(e\nu)+\text{jets}} + N_{ri}^{W(\tau\nu)+\text{jets}} \\ & + N_{ri}^{Z\to\tau\tau+\text{jets}} + N_{ri}^{Z\to\mu\mu+\text{jets}}) \\ & + \kappa^{t} (N_{ri}^{t\bar{t},\text{single}-t}) \\ & + N_{ri}^{Z\to ee+\text{jets}} + N_{ri}^{\text{diboson}} + N_{ri}^{\text{multi-jet}} + N_{ri}^{\text{NCB}} \end{aligned}$$

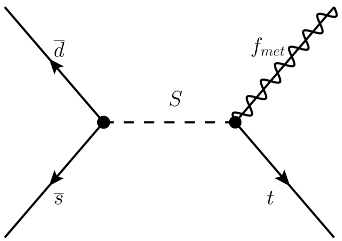




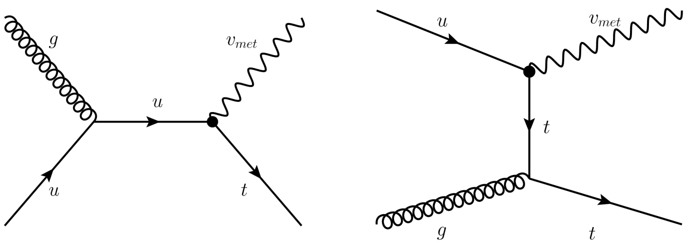
Eur. Phys. J. C75 (2015) 79

DM+t

$\sqrt{s}$=8 TeV, 20.3 fb^{-1}



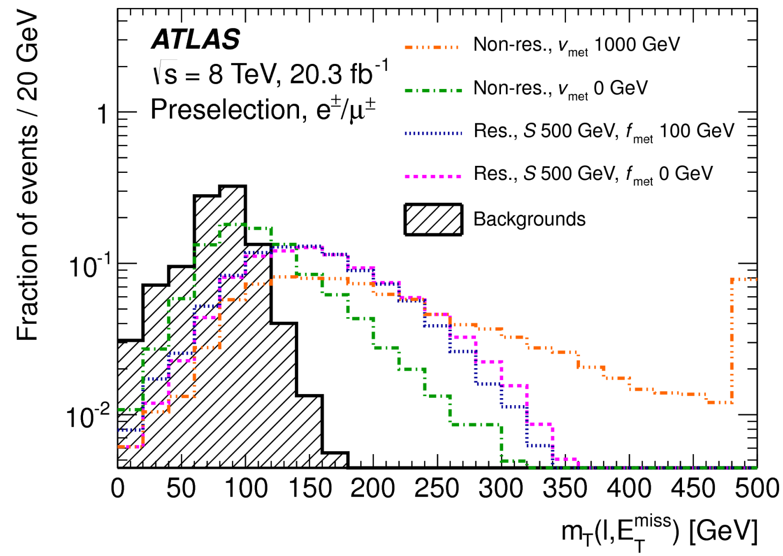
Resonant channel
Spin-0 mediator → t + (invisible) fermion

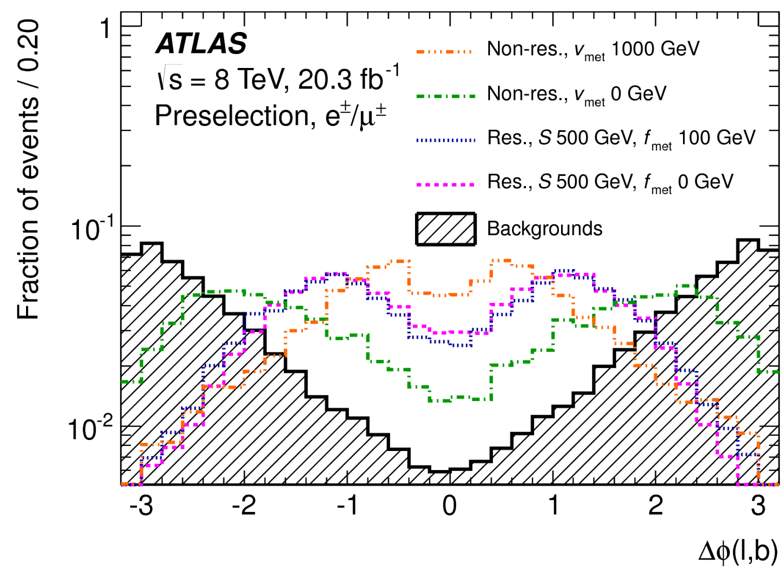


Non-resonant channel
Production of t + spin-1 (invisible) particle

No such mono-top process is available
in the SM at tree level
(t+Z (Z → νν) is GIM suppressed)
→ **Sizable event rate would indicate BSM**

Considering Top decay in lepton+jets



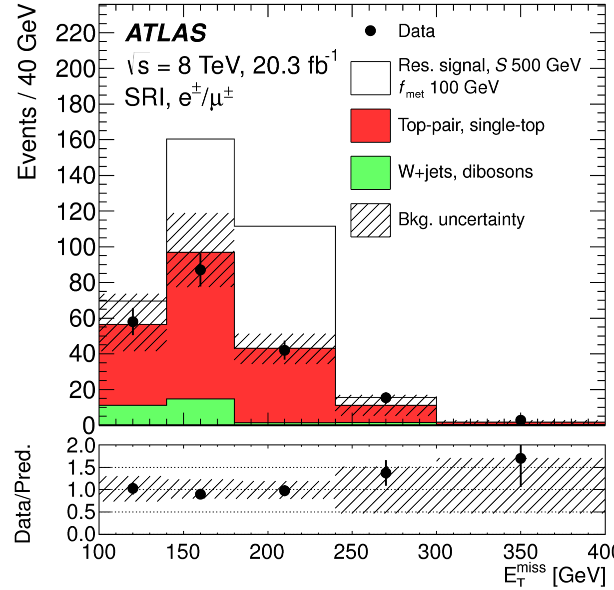


Eur. Phys. J. C75 (2015) 79

DM+t

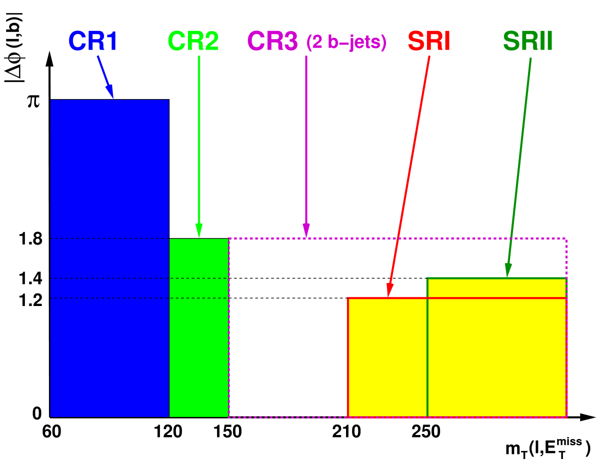
Selection based on

- Large missing transverse energy
- One lepton and exactly one b-tagged jet from the top semi-leptonic decay

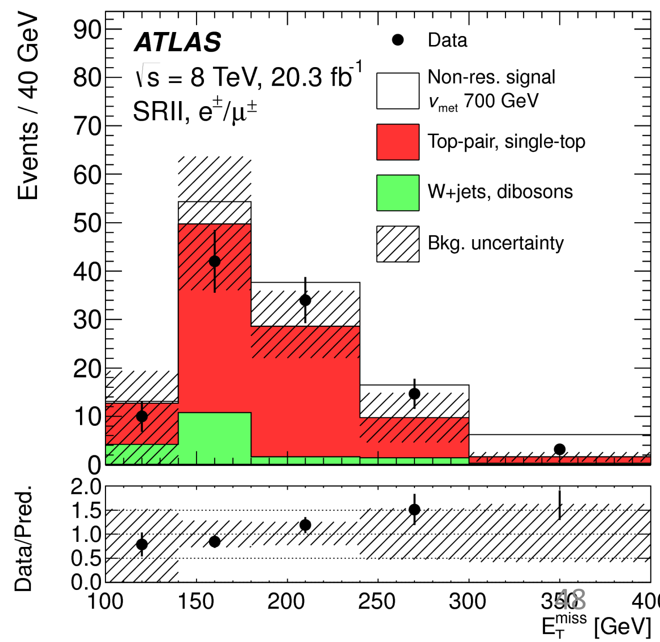


SM background dominated by tt pairs followed by W+jets processes

Background predictions are taken from simulation and validated in CRs



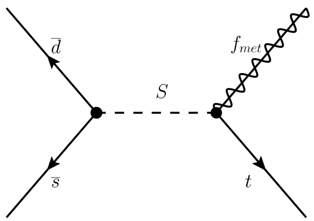
Good agreement with SM predictions



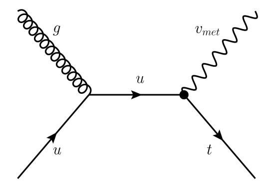
Systematic uncertainties from Jet energy scale, b-tagging efficiency and MC modeling + x-section uncertainties

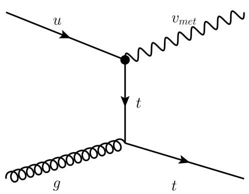
Eur. Phys. J. C75 (2015) 79

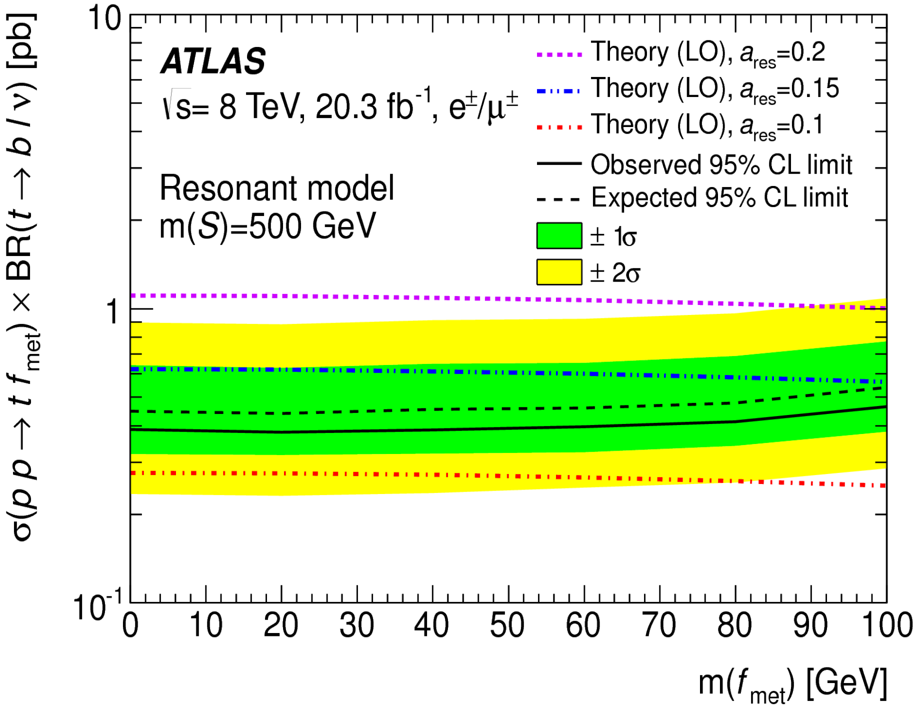
DM+t

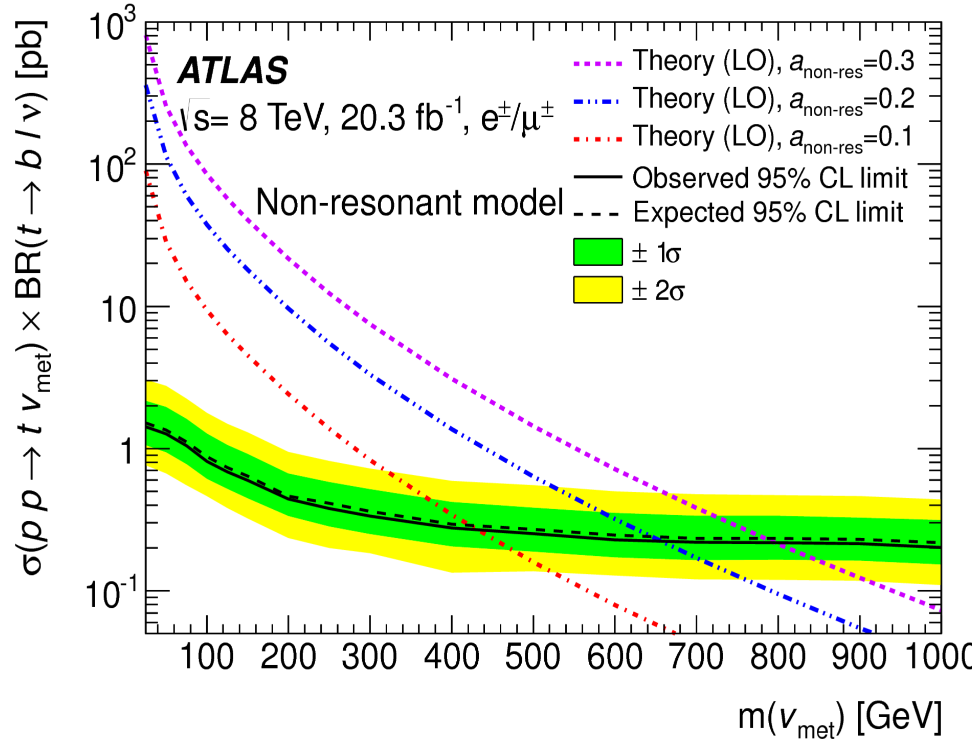


Parameters:
Mediator mass (resonant)
Mass of invisible particles
couplings









For a spin-0 mediator mass of 500 GeV Fermion masses below 100 GeV and couplings above 0.1 are excluded at 95% CL

In the non-resonant case masses below 400 – 800 GeV are excluded @ 95% CL depending on the coupling assumed