Mono-jet searches for Dark Matter in the LHC (ATLAS)

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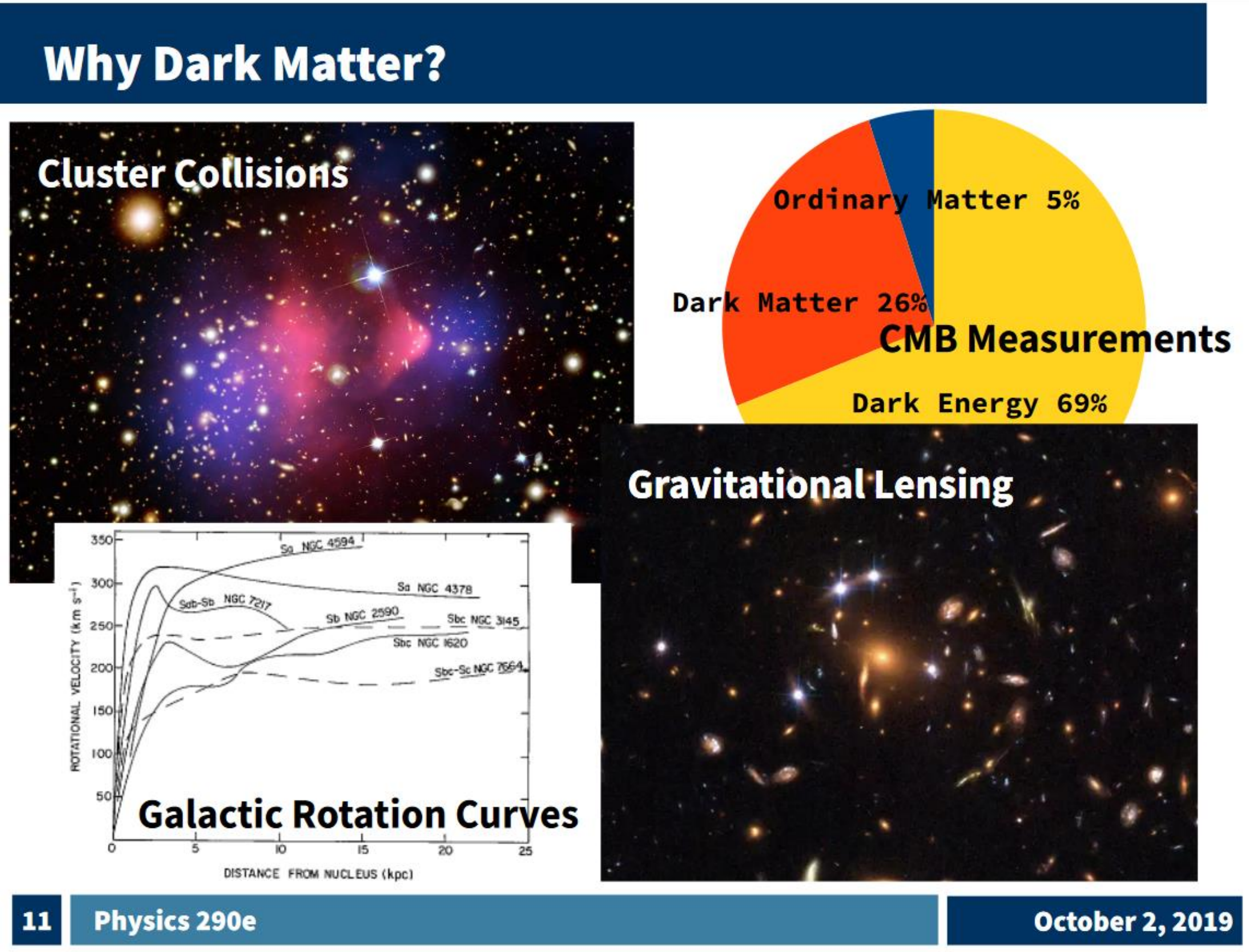
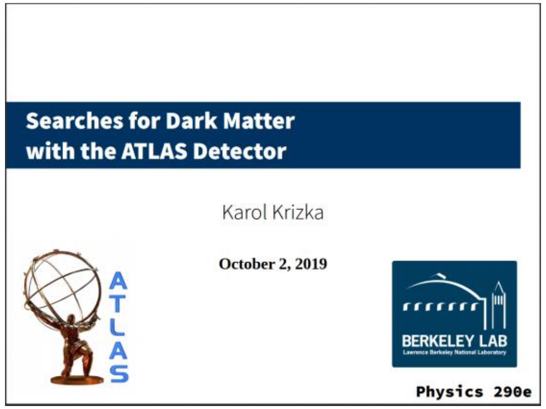
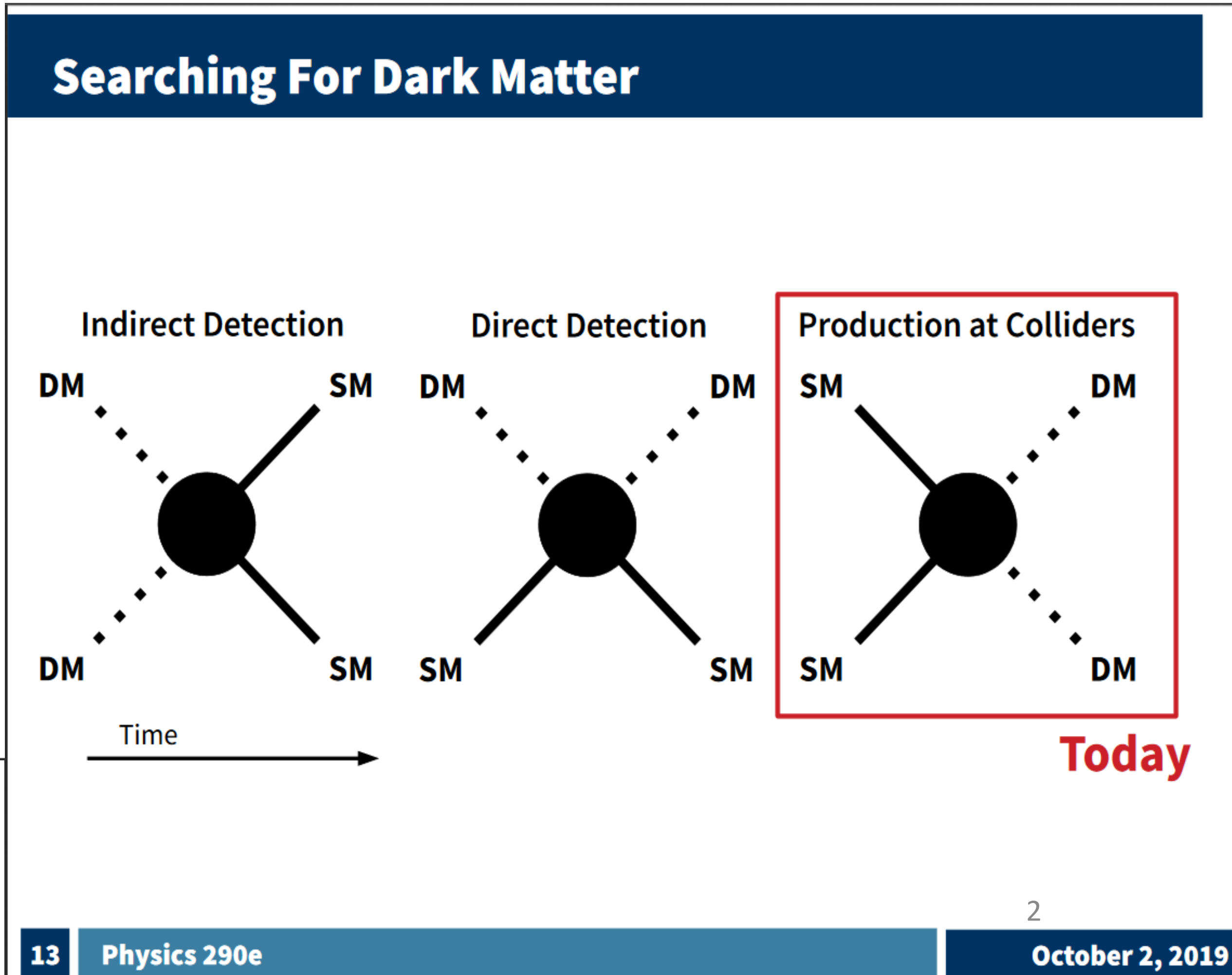
11/20/19

Context

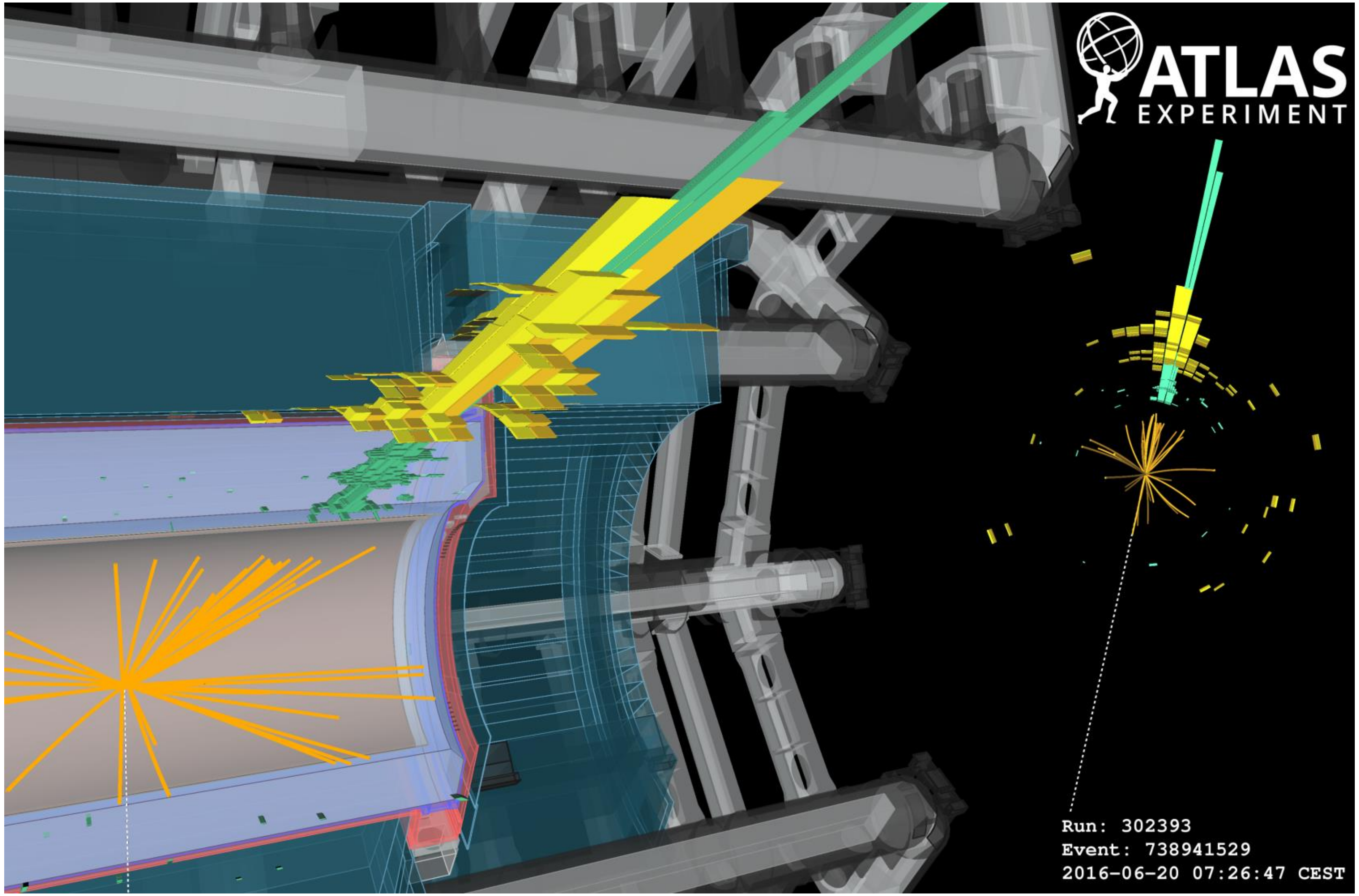






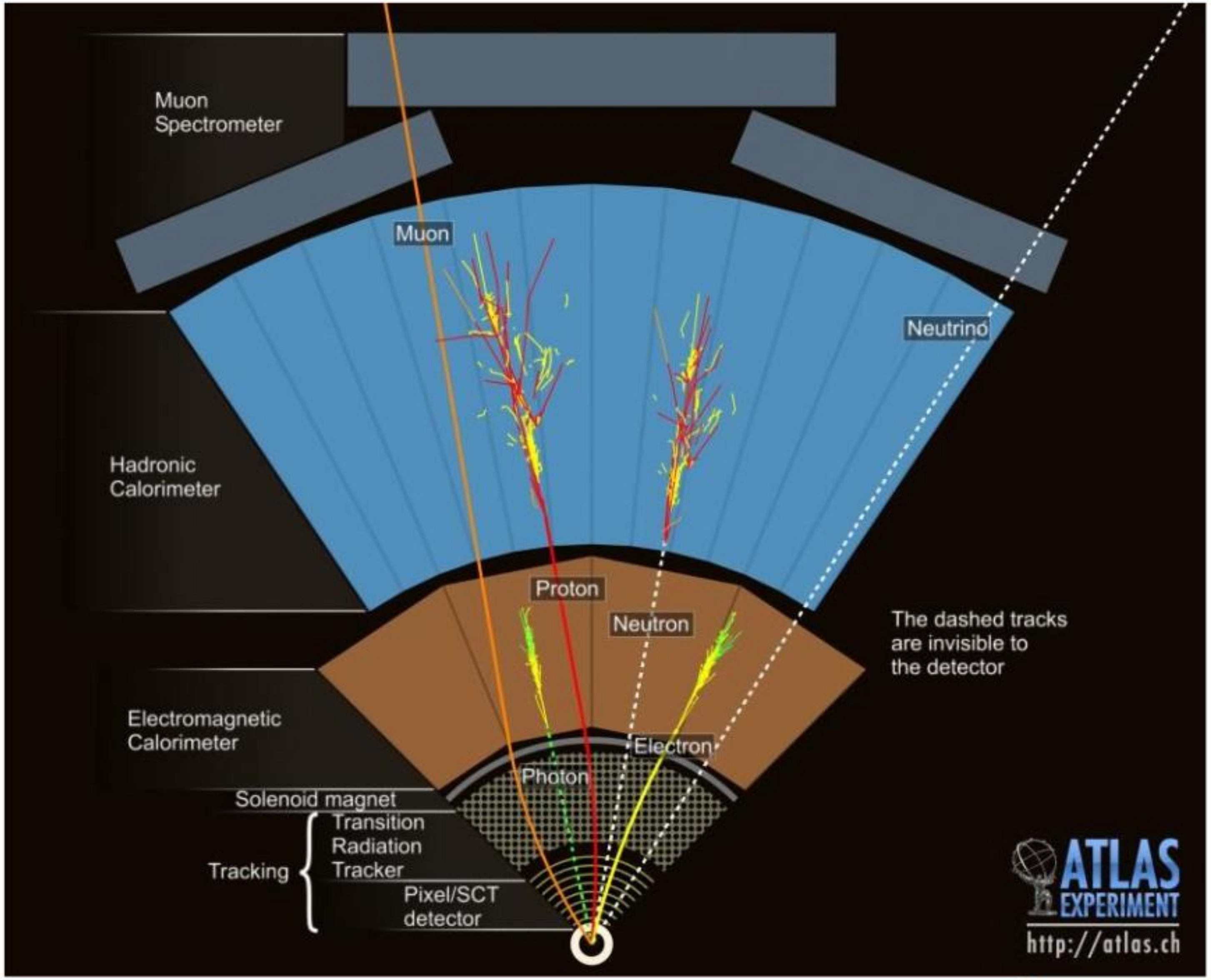
See Karol's talk!:
https://indico.physics.lbl.gov/indico/event/968/contributions/3962/attachments/2032/2610/phys290e.pdf

The Collider



- pp collider with $\sqrt{s} = 13\ TeV$
- Total Data collected for this particular talk $36.1\ fb^{-1}$
- Seen are multiple orange tracks measured in the inner tracker
- Also seen, yellow, green and orange blocks showing deposit in the calorimeter
- Notice asymmetry of final product

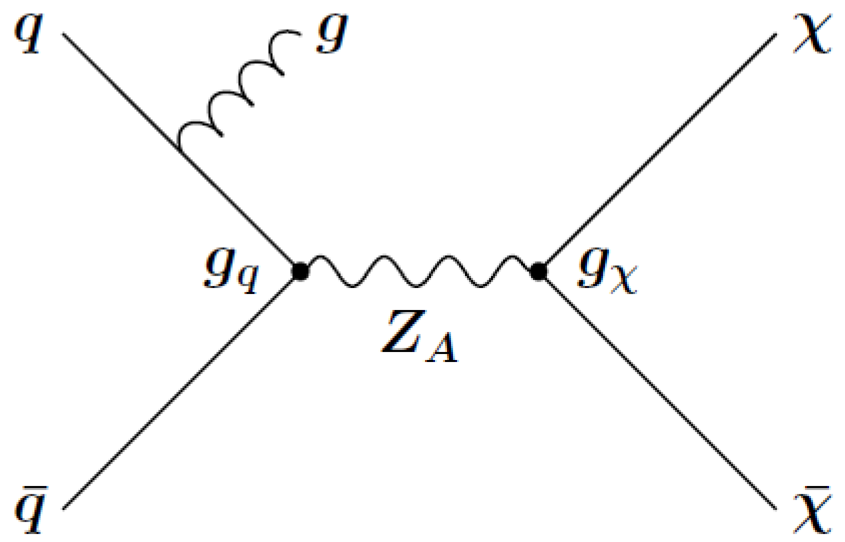
Particle Identification



Theory

$$\Gamma(m_{Z_A})_{\min} = \frac{g_\chi^2 m_{Z_A}}{12\pi}\beta_\chi^3\theta(m_{Z_A} - 2m_\chi) + \sum_q \frac{3g_q^2 m_{Z_A}}{12\pi}\beta_q^3\theta(m_{Z_A} - 2m_q)$$

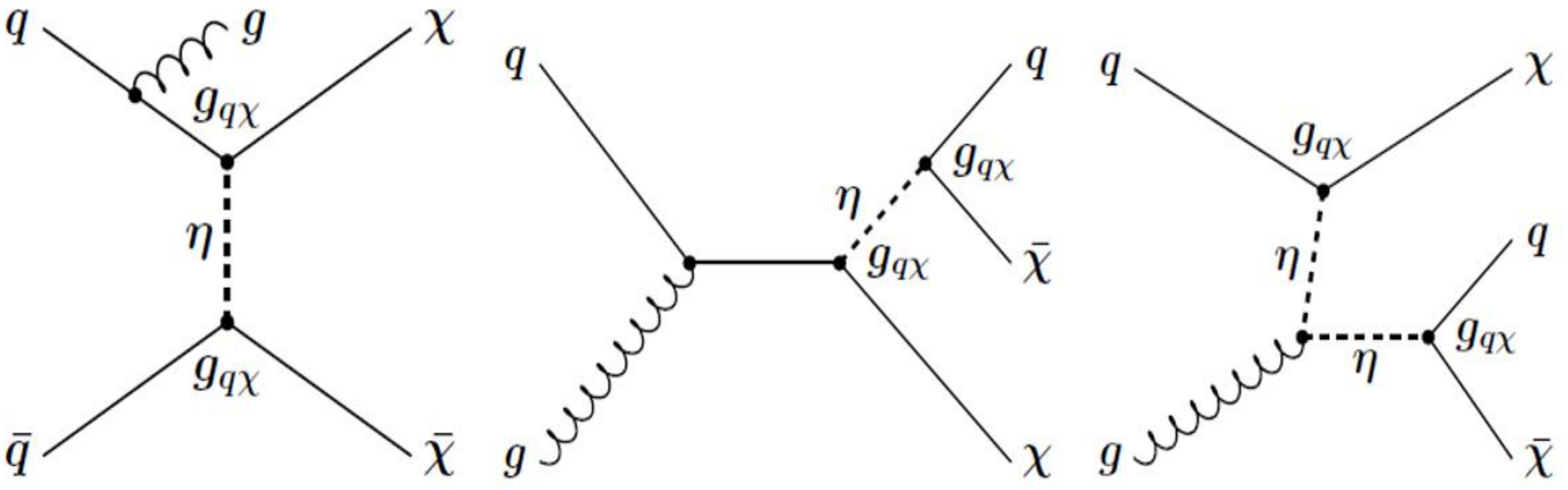
- DM model where Dirac fermion WIMPs are pair-produced by a spin-1 axial-vector mediator particle Z_A.
- Also probed are coupling to a vector mediator Z_V and a spin-0 pseudoscalar Z_P
- Coupling to other SM particles not considered (Important to note!)



Theory (cont.)

- WIMP produced via exchange of colored scalar mediator
- Couples as a color-triplet, SU(2) doublet to left-handed quarks

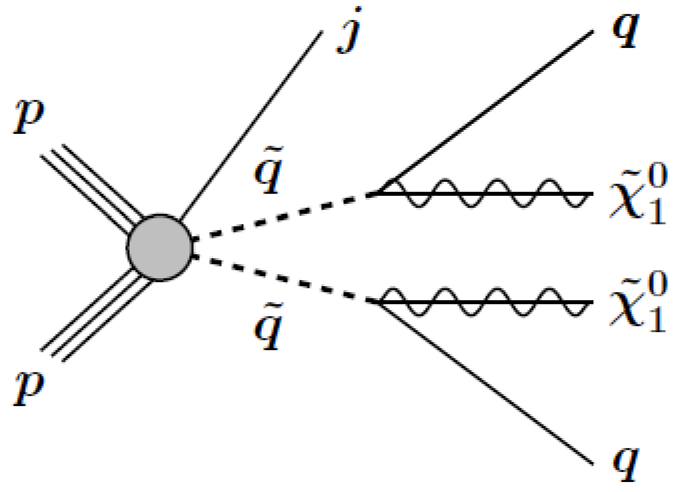
$$\Gamma(\eta)_{\min} = \frac{g^2}{16\pi m_\eta^3}\left(m_\eta^2 - m_q^2 - m_\chi^2\right)\sqrt{\left(m_\eta^2 - \left(m_q + m_\chi\right)^2\right)\left(m_\eta^2 - \left(m_q - m_\chi\right)^2\right)},$$



(b) (c) (d)

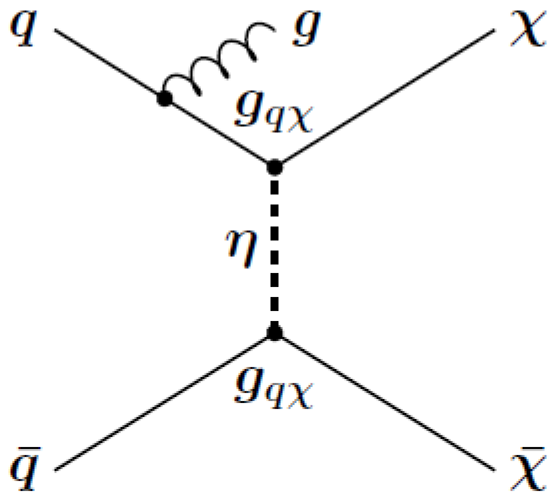
Theory (cont.)

- Also included a search for squark production under the compressed-mass scenario ($m_{\tilde{q}} - m_{\widetilde{\chi_1^0}}\ small$)
- For $\Delta m < 25\ GeV$ both transverse momenta of quark jet and E_T^{MISS} are small.
- This leads to a very difficult final state to reconstruct given the kinematic thresholds.

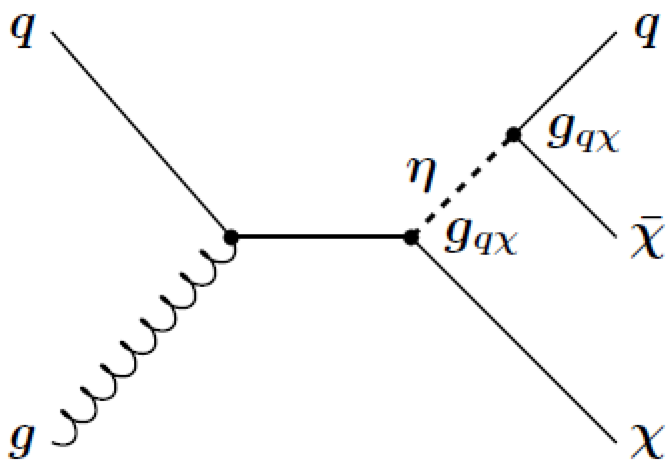


- Final model considered: Extra Spatial Dimensions
  - KK Graviton escapes into extra dimensions resulting in missing energy.

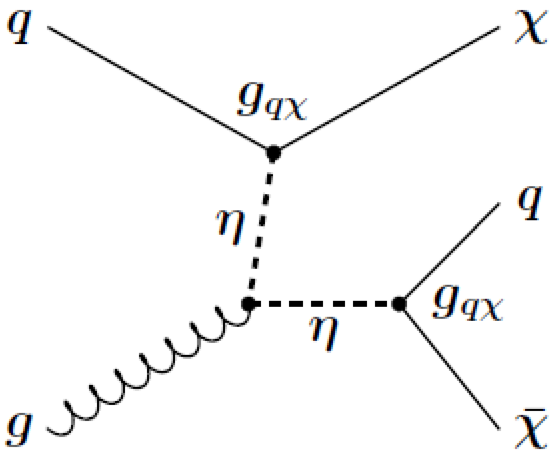
$M_{PL}^2\ \sim M_D^{2+n} R^n$ where $M_D \sim 1\ TeV$


q
g
χ
g_{qχ}
η
g_{qχ}
q̄
χ̄

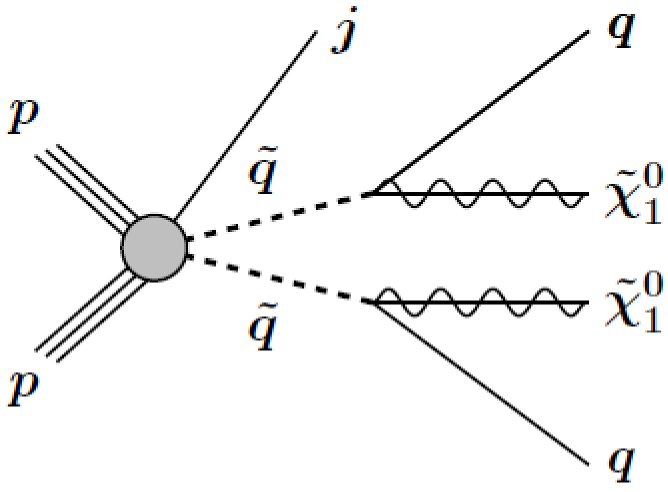
(b)


q
g
η
g_{qχ}
g_{qχ}
q
χ̄
χ

(c)


q
χ
g_{qχ}
η
q
g_{qχ}
η
g
χ̄

(d)


p
p
j
q̃
q̃
q
χ̃⁰₁
χ̃⁰₁
q

(e)

The Signal

Table 1: Inclusive (IM1–IM10) and exclusive (EM1–EM10) signal regions with increasing E_T^{miss} thresholds from 250 GeV to 1000 GeV. In the case of IM10 and EM10, both signal regions contain the same selected events in data. In the case of the IM10 signal region, the background predictions are computed considering only data and simulated events with $E_T^{miss} > 1$ TeV, whereas the EM10 background prediction is obtained from fitting the full E_T^{miss} shape in data and simulation, as described in Section 6.

Inclusive (IM)	IM1	IM2	IM3	IM4	IM5	IM6	IM7	IM8	IM9	IM10
E_T^{miss} [GeV]	>250	>300	>350	>400	>500	>600	>700	>800	>900	>1000
Exclusive (EM)	EM1	EM2	EM3	EM4	EM5	EM6	EM7	EM8	EM9	EM10
E_T^{miss} [GeV]	250–300	300–350	350–400	400–500	500–600	600–700	700–800	800–900	900–1000	>1000

- $E_T^{MISS} > 250\ GeV$
- $p_{T,j1} > 250\ GeV$
- $|\eta| < 2.8$

- $N_{jets} < 4\ , p_T > 30\ GeV\ , |\eta| < 2.8$
- $\Delta\phi\left(jet, \vec{p}_T^{miss}\right) > 0.4$

Background

- **Irreducible and/or Dominant**
- $Z(\rightarrow \nu\nu) + jets$
- $W(\rightarrow \tau\nu) + jets$

- **The Rest**
- $Z\backslash\gamma^{*}(\rightarrow l^{+}l^{-}) + jets$
- Multijet
- $t\bar{t}$
- Single-top
- Diboson

Fitting The Background

- Data Driven Background Estimation
  - Simultaneous Fit of Control Regions
  - Binned in MET
- Modeling of Z->vv Background
  - Taken from MC
    - Ratio between Z->vv vs Z->mumu vs W->lv
    - General shape of MC distribution
  - Taken from Data
    - Overall normalization of W/Z processes
    - Constraints on systematics

Final Result

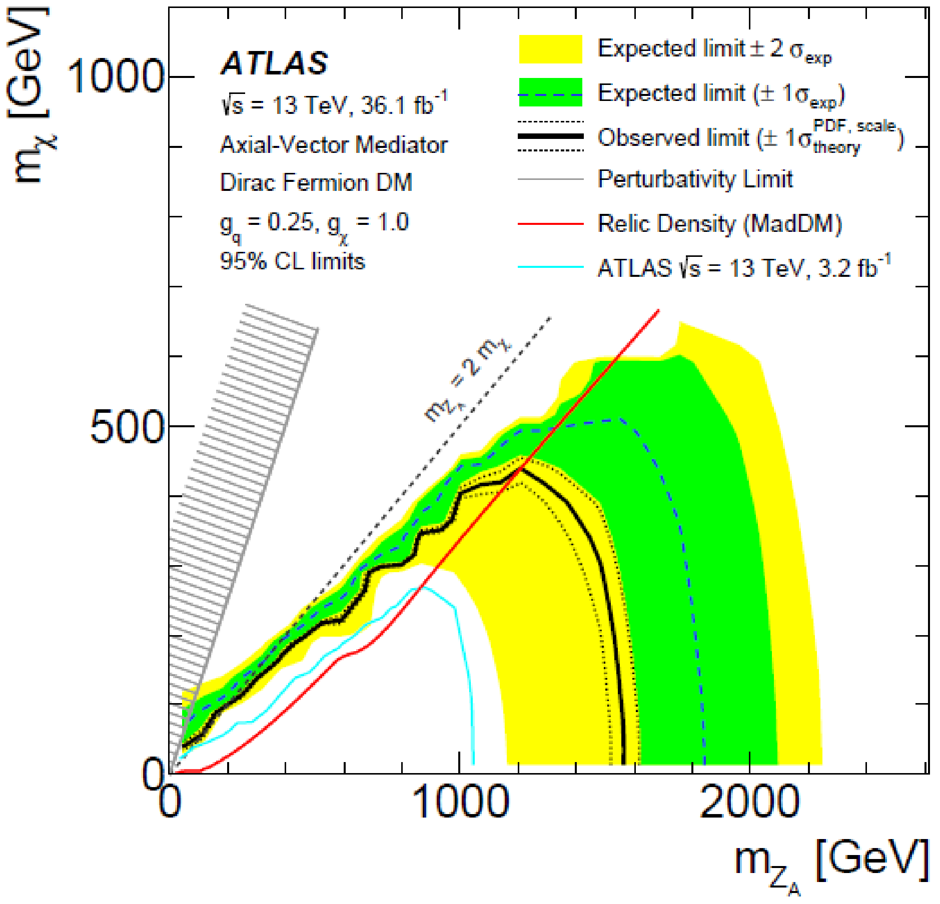
	Inclusive Signal Region			Exclusive Signal Region	
Region	Predicted	Observed	Region	Predicted	Observed
IM1	245900 ± 5800	255486	EM1	111100 ± 2300	111203
IM2	138000 ± 3400	144283	EM2	67100 ± 1400	67475
IM3	73000 ± 1900	76808	EM3	33820 ± 940	35285
IM4	39900 ± 1000	41523	EM4	27640 ± 610	27843
IM5	12720 ± 340	13680	EM5	8360 ± 190	8583
IM6	4680 ± 160	5097	EM6	2825 ± 78	2975
IM7	2017 ± 90	2122	EM7	1094 ± 33	1142
IM8	908 ± 55	980	EM8	463 ± 19	512
IM9	464 ± 34	468	EM9	213 ± 9	223
IM10	238 ± 23	245	EM10	226 ± 16	245

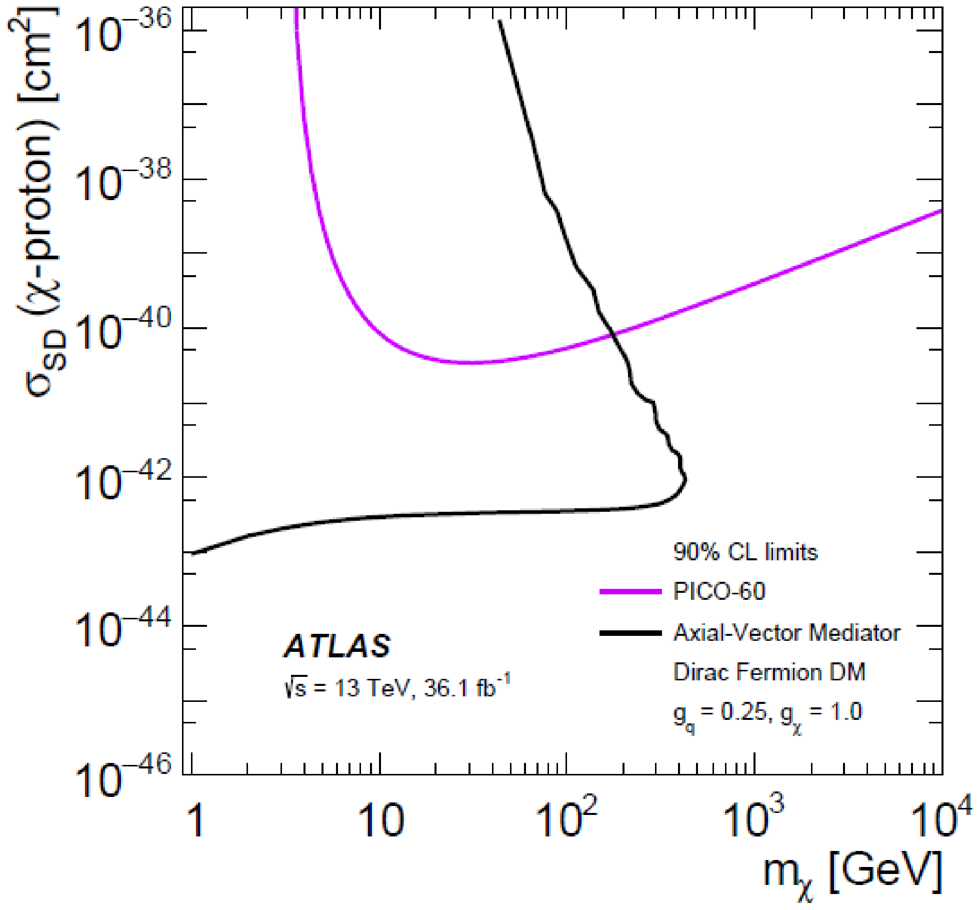
Limits

Table 6: Observed and expected 95% CL upper limits on the number of signal events, S^{95}_{obs} and S^{95}_{exp}, and on the visible cross section, defined as the product of cross section, acceptance and efficiency, $\langle\sigma\rangle^{95}_{obs}$, for the IM1–IM10 selections.

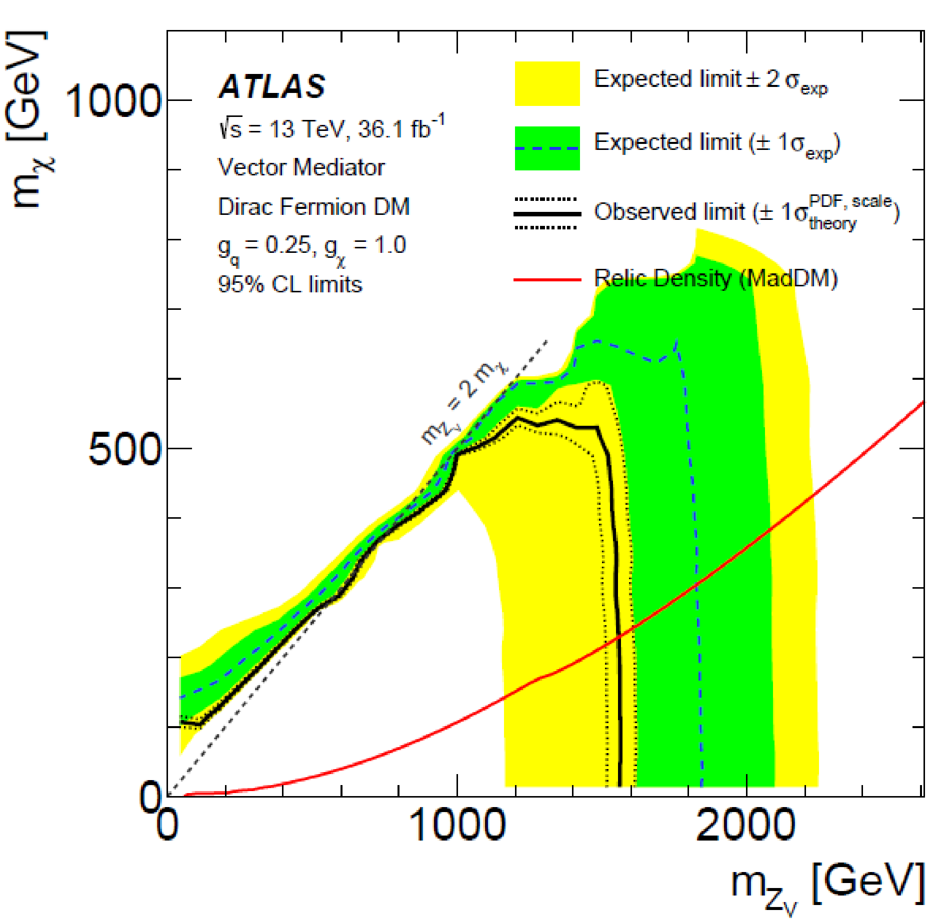
Selection	$\langle\sigma\rangle^{95}_{obs}$ [fb]	S^{95}_{obs}	S^{95}_{exp}
IM1	531	19135	11700^{+4400}_{-3300}
IM2	330	11903	7000^{+2600}_{-2600}
IM3	188	6771	4000^{+1400}_{-1100}
IM4	93	3344	2100^{+770}_{-590}
IM5	43	1546	770^{+280}_{-220}
IM6	19	696	360^{+130}_{-100}
IM7	7.7	276	204^{+74}_{-57}
IM8	4.9	178	126^{+47}_{-35}
IM9	2.2	79	76^{+29}_{-21}
IM10	1.6	59	56^{+21}_{-16}

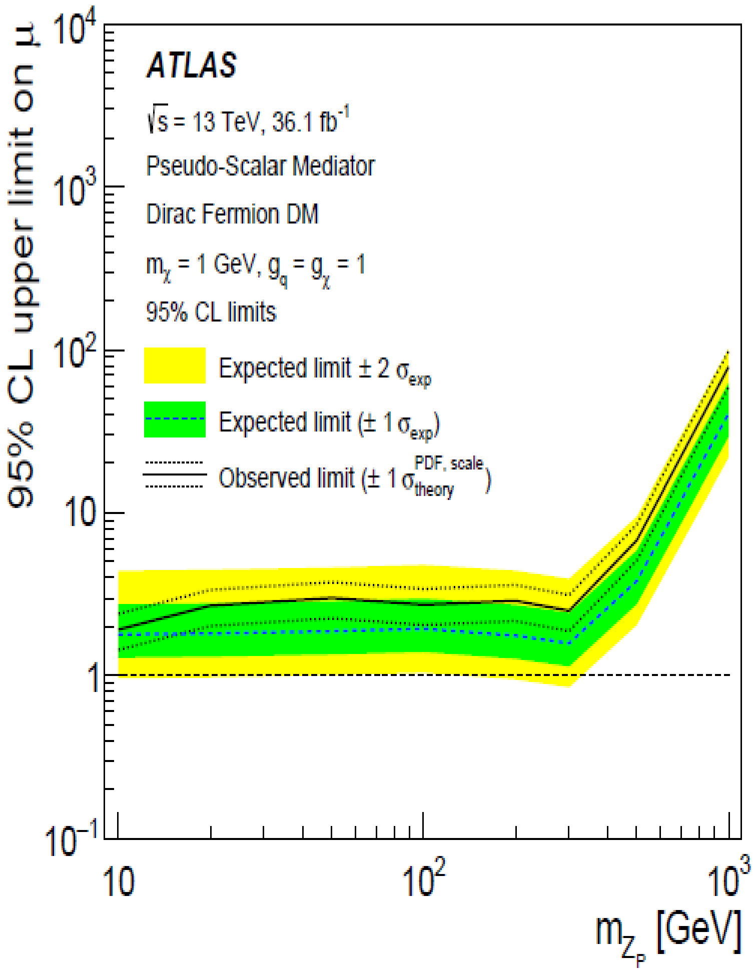
Limits (cont.)

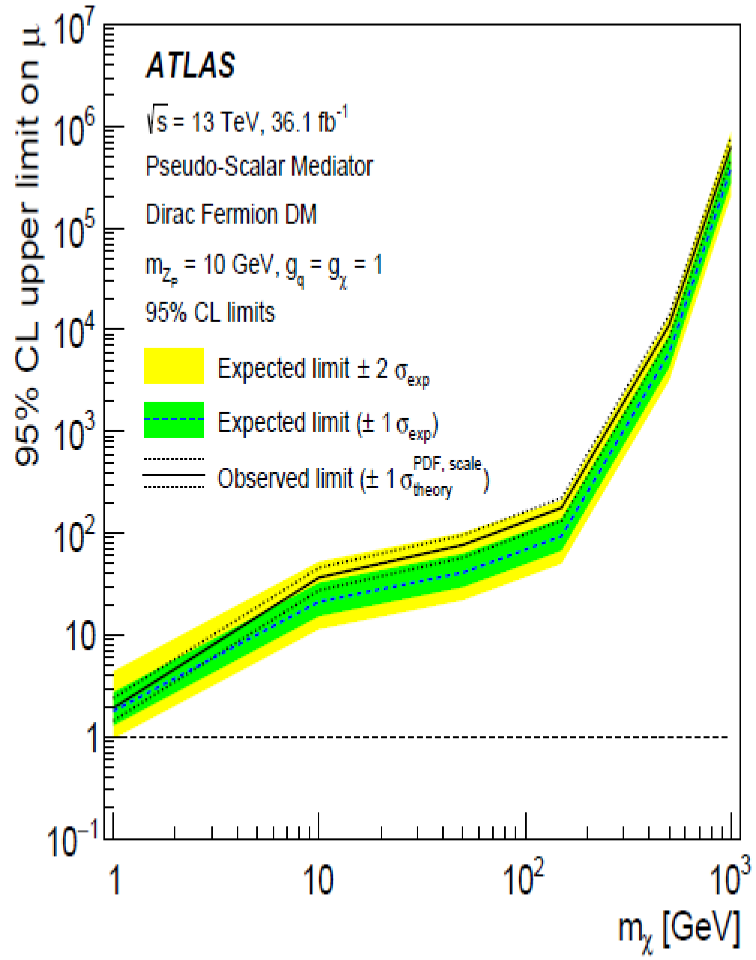

ATLAS
√s = 13 TeV, 36.1 fb-1
Axial-Vector Mediator
Dirac Fermion DM
gq = 0.25, gχ = 1.0
95% CL limits
Expected limit ± 2 σexp
Expected limit (± 1σexp)
Observed limit (± 1σ PDF, scale theory)
Perturbativity Limit
Relic Density (MadDM)
ATLAS √s = 13 TeV, 3.2 fb-1
mZA = 2 mχ
mχ [GeV]
mZA [GeV]
0
500
1000
2000


σSD (χ-proton) [cm2]
10−36
10−38
10−40
10−42
10−44
10−46
90% CL limits
PICO-60
Axial-Vector Mediator
Dirac Fermion DM
gq = 0.25, gχ = 1.0
ATLAS
√s = 13 TeV, 36.1 fb-1
1
10
102
103
104
mχ [GeV]

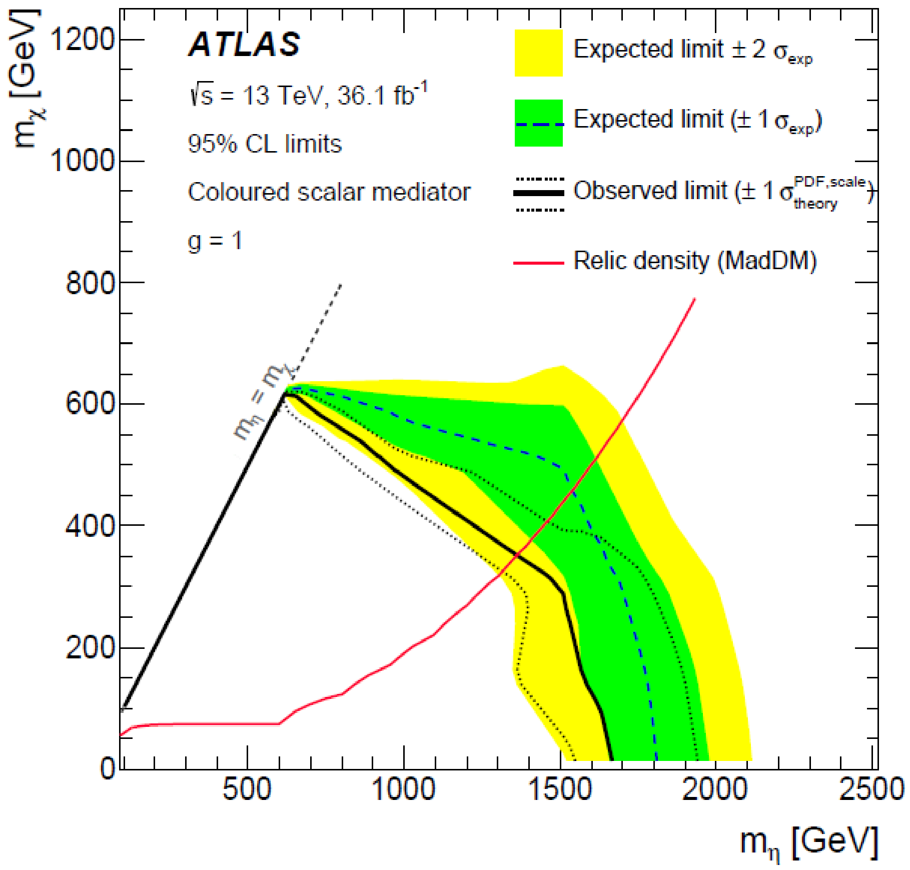
Limits (cont.)


ATLAS
√s = 13 TeV, 36.1 fb-1
Vector Mediator
Dirac Fermion DM
gq = 0.25, gχ = 1.0
95% CL limits
Expected limit ± 2 σexp
Expected limit (± 1σexp)
Observed limit (± 1σ PDF, scale theory)
Relic Density (MadDM)
mZV = 2 mχ
mχ [GeV]
mZV [GeV]

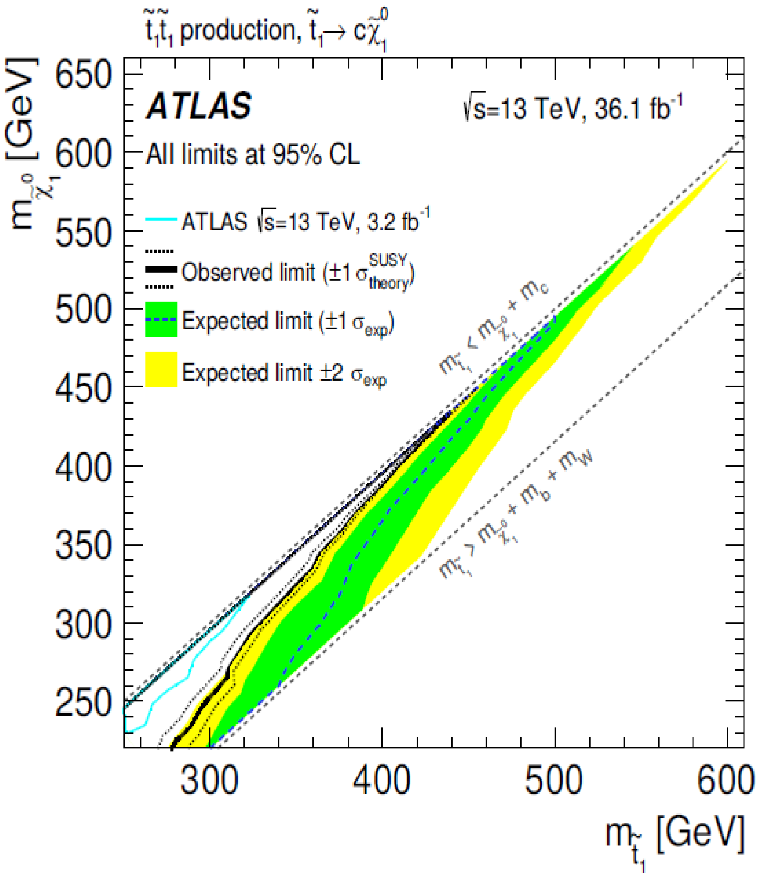

ATLAS
√s = 13 TeV, 36.1 fb-1
Pseudo-Scalar Mediator
Dirac Fermion DM
mχ = 1 GeV, gq = gχ = 1
95% CL limits
Expected limit ± 2 σexp
Expected limit (± 1 σexp)
Observed limit (± 1 σ PDF, scale theory)
95% CL upper limit on μ
mZP [GeV]


ATLAS
√s = 13 TeV, 36.1 fb-1
Pseudo-Scalar Mediator
Dirac Fermion DM
mZP = 10 GeV, gq = gχ = 1
95% CL limits
Expected limit ± 2 σexp
Expected limit (± 1 σexp)
Observed limit (± 1 σ PDF, scale theory)
95% CL upper limit on μ
mχ [GeV]

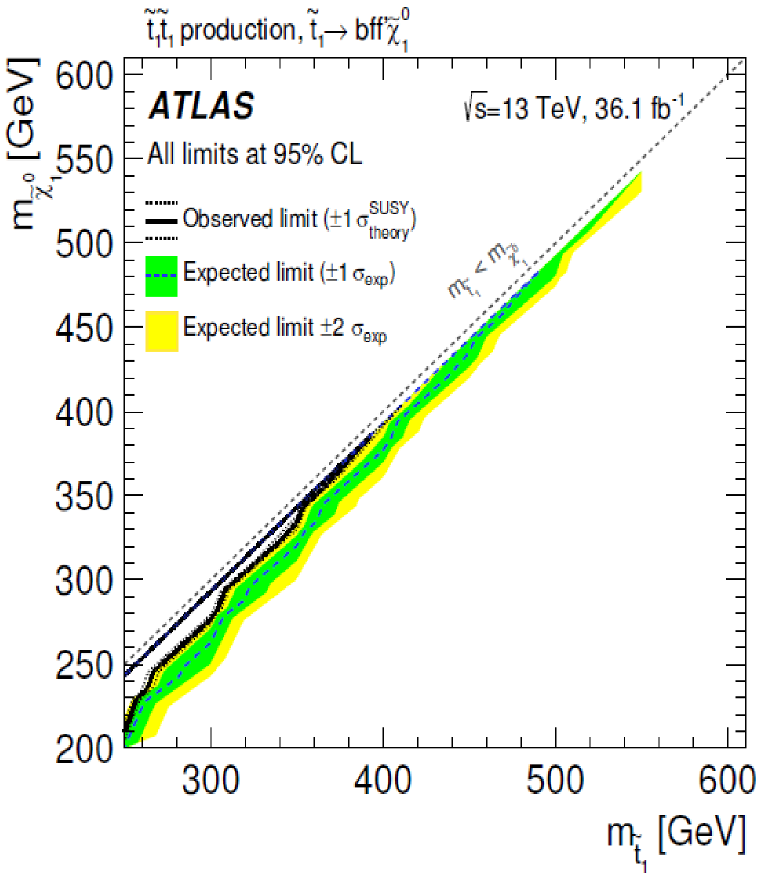
Limits (cont.)



ATLAS
√s = 13 TeV, 36.1 fb-1
95% CL limits
Coloured scalar mediator
g = 1
Expected limit ± 2 σexp
Expected limit (± 1 σexp)
Observed limit (± 1 σtheory PDF,scale)
Relic density (MadDM)
mη = mχ
mχ [GeV]
mη [GeV]

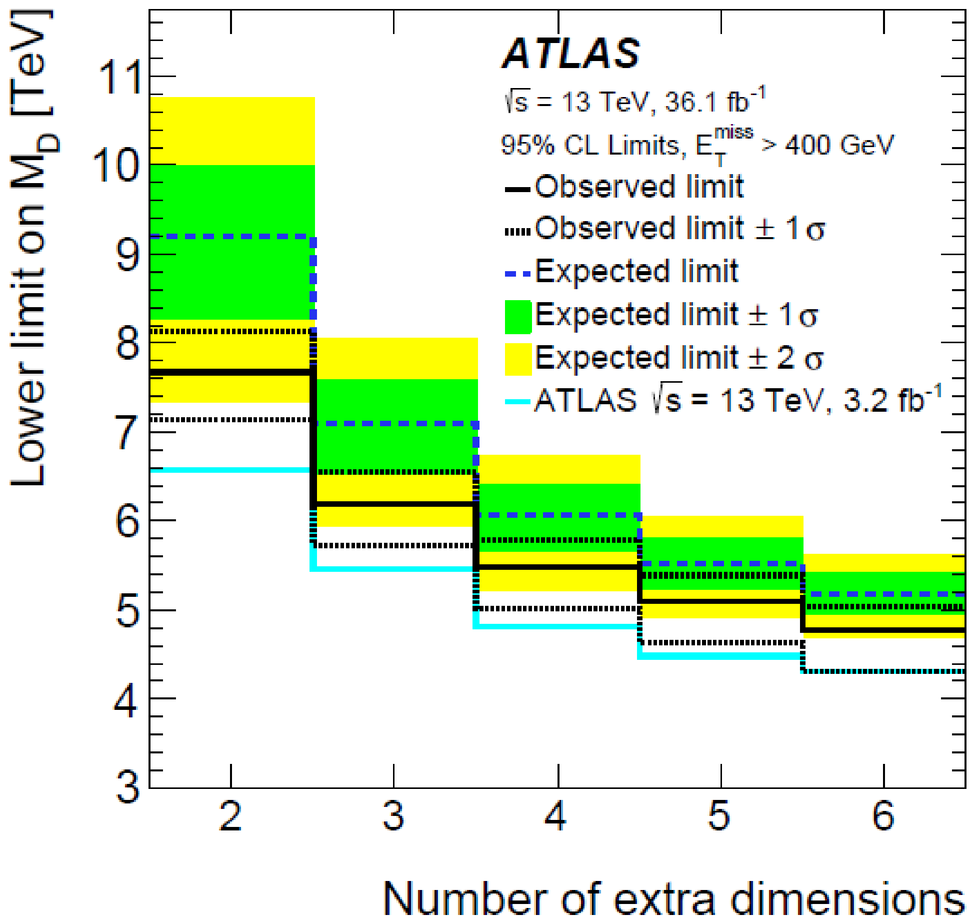


t̃1t̃1 production, t̃1→ cχ̃10
ATLAS
√s=13 TeV, 36.1 fb-1
All limits at 95% CL
ATLAS √s=13 TeV, 3.2 fb-1
Observed limit (±1 σtheory SUSY)
Expected limit (±1 σexp)
Expected limit ±2 σexp
mt̃1 < mχ̃10 + mc
mt̃1 > mχ̃10 + mb + mW
mχ̃10 [GeV]
mt̃1 [GeV]



t̃1t̃1 production, t̃1→ bff'χ̃10
ATLAS
√s=13 TeV, 36.1 fb-1
All limits at 95% CL
Observed limit (±1 σtheory SUSY)
Expected limit (±1 σexp)
Expected limit ±2 σexp
mt̃1 < mχ̃10
mχ̃10 [GeV]
mt̃1 [GeV]

ADD Model Limits on M_D (95% CL)			
	Expected [TeV]	Observed [TeV]	Observed (damped) [TeV]
$n = 2$	$9.2^{+0.8}_{-1.0}$	$7.7^{+0.4}_{-0.5}$	7.7
$n = 3$	$7.1^{+0.5}_{-0.6}$	$6.2^{+0.4}_{-0.5}$	6.2
$n = 4$	$6.1^{+0.3}_{-0.4}$	$5.5^{+0.3}_{-0.5}$	5.5
$n = 5$	$5.5^{+0.3}_{-0.3}$	$5.1^{+0.3}_{-0.5}$	5.1
$n = 6$	$5.2^{+0.2}_{-0.3}$	$4.8^{+0.3}_{-0.5}$	4.8



Limits (cont.)

Conclusion

- Early Run 2 (36.1 fb-1) results show no excesses in any model probed but limits set for model free cross-sections.
- Full Run 2 result (not out yet, stay tuned) will probably (almost definitely) give tighter limits on models probed.
- It’s clear to see that D.M. discovery will be a combination of Direct Production, Indirect Detection and Direct Detection experiments.
- Much hope for the future and the new generation of DM detection experiments.

References

- ATLAS Collaboration, “Search for dark matter and other new phenomena in events with an energetic jet and large missing transverse momentum using the ATLAS detector”, arXiv:1711.03301v2
- Karol Krizka’s 290e talk:
  - https://indico.physics.lbl.gov/indico/event/968/contributions/3962/attachments/2032/2610/phys290e.pdf
- N. Trevisani, “Collider Searches for Dark Matter (ATLAS + CMS)”, Universe 2018, 4, 131; doi:10.3390/universe4110131
- S. Belwal and M. Drees, “Analysis on the Bounds of Dark Matter Models from Monojet Searches at the LHC”, arXiv:1709.08545v1