Detecting hidden activity: from dark matter to the onset of strokes.

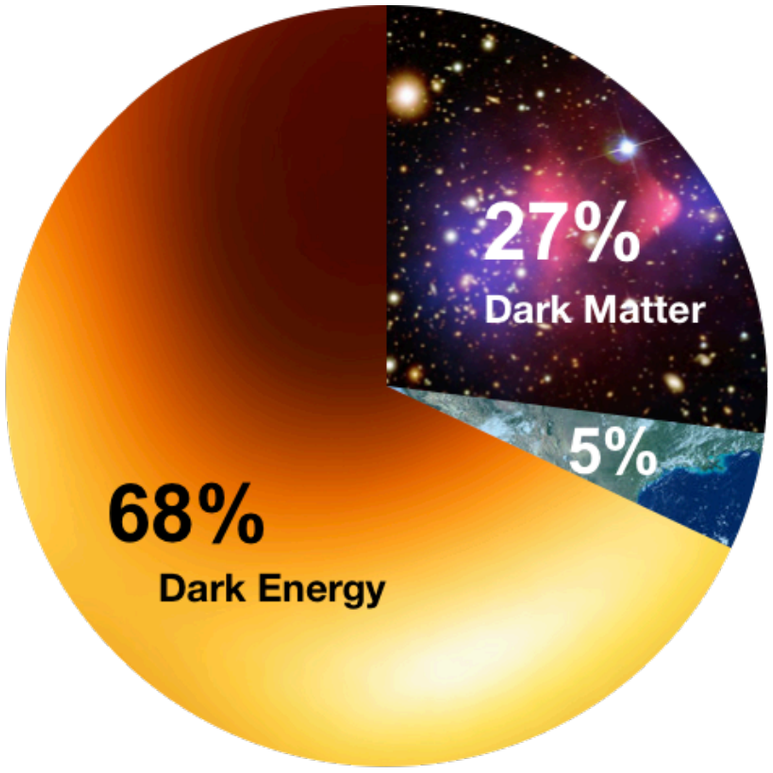
Priscilla Pani
(DESY)

DESY.

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

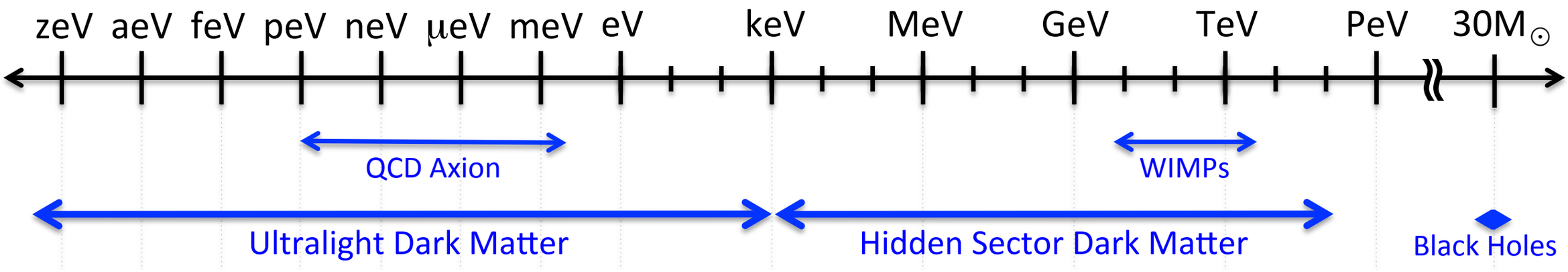
Part 1: Detecting Dark Matter with ATLAS.

The Dark Matter mystery



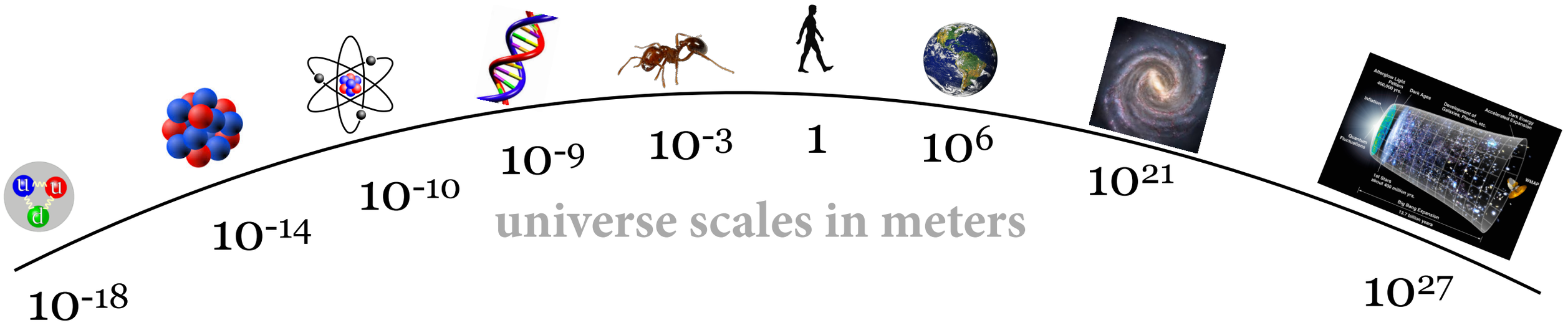
- Electrically neutral
- Observed via gravity, massive
-
-

The Dark Matter mystery

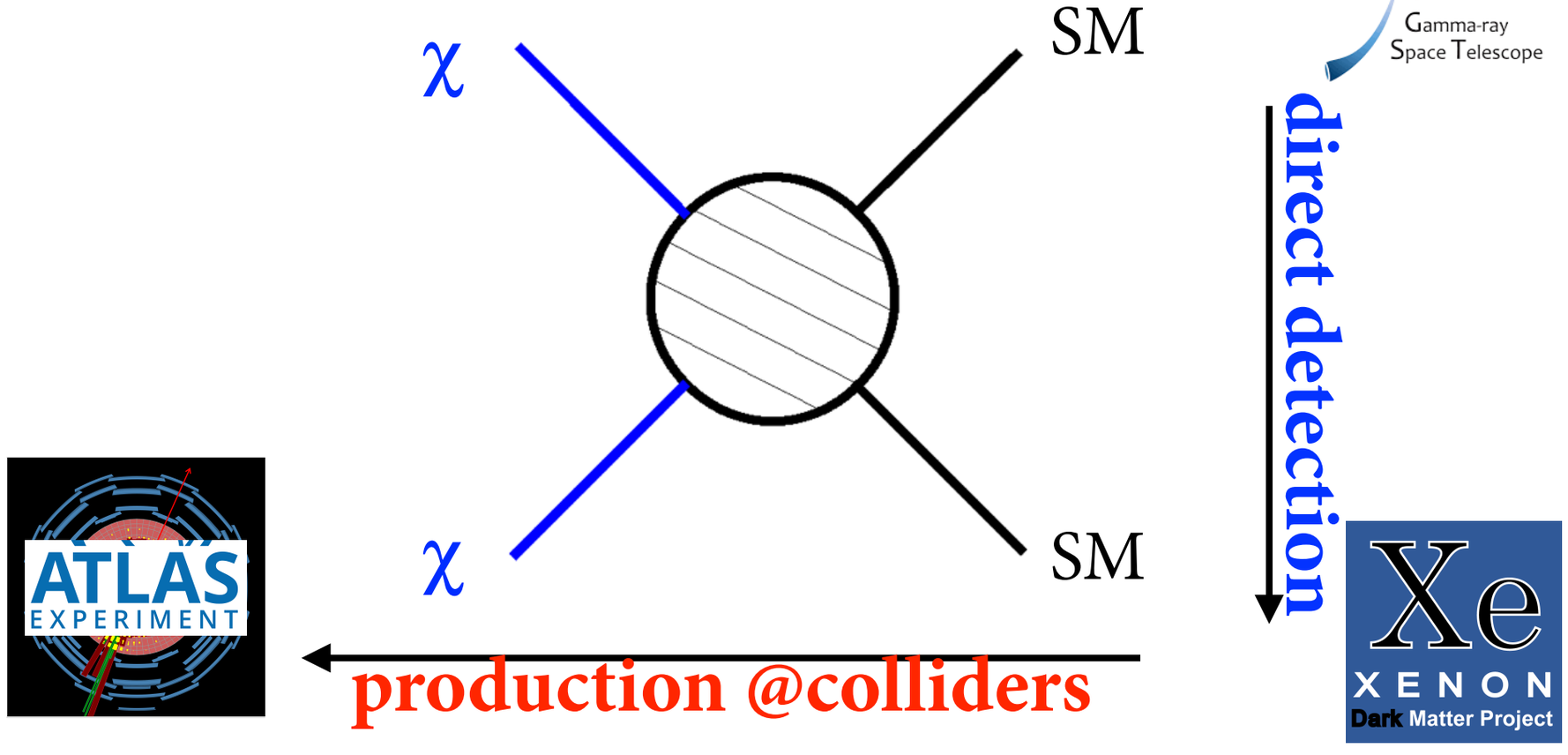


- Electrically neutral
- Observed via gravity, massive
- Weakly interacting
- Elementary particles created in the early universe

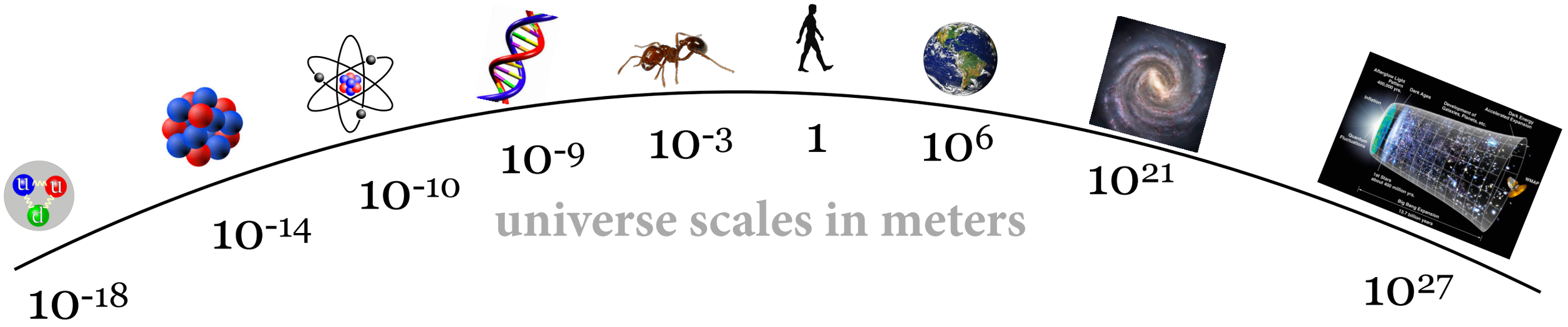
The Dark Matter quest



indirect detection



The Dark Matter quest



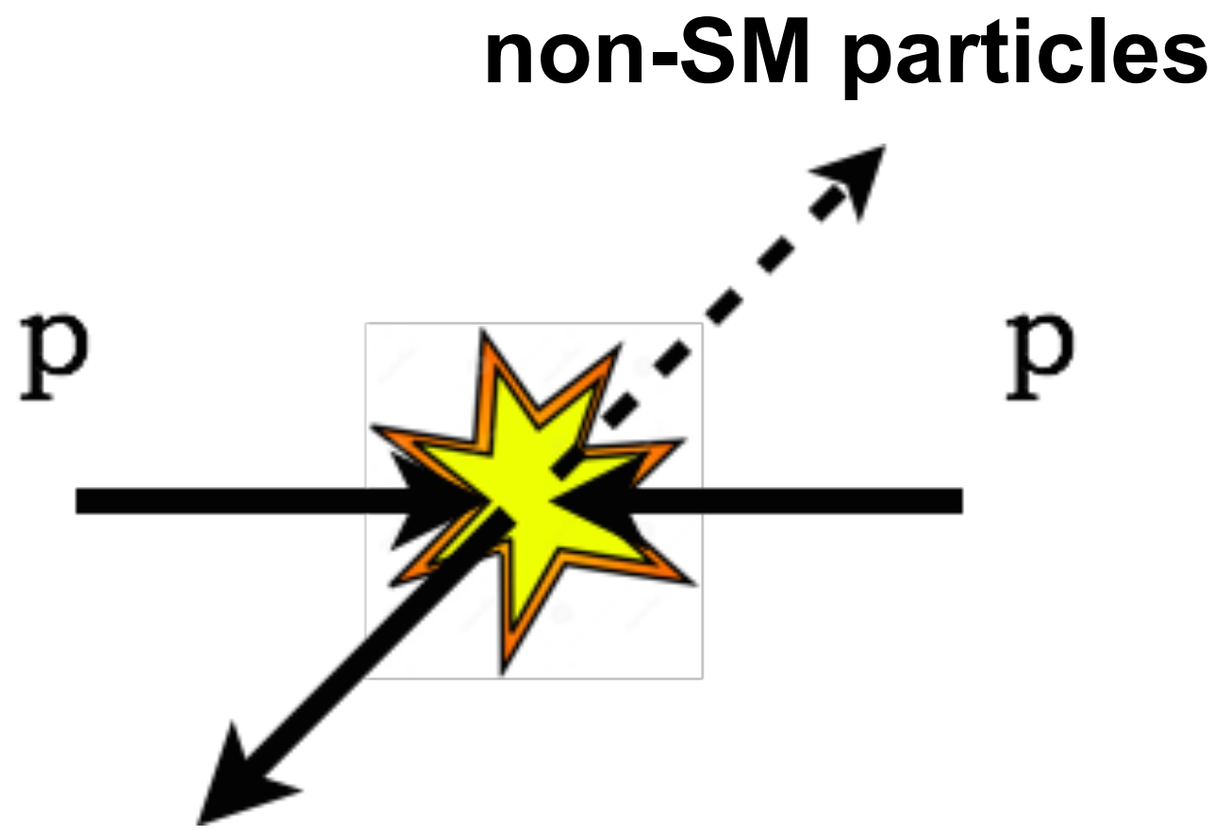
indirect detection

Very different assumptions!

direct detection

production @colliders

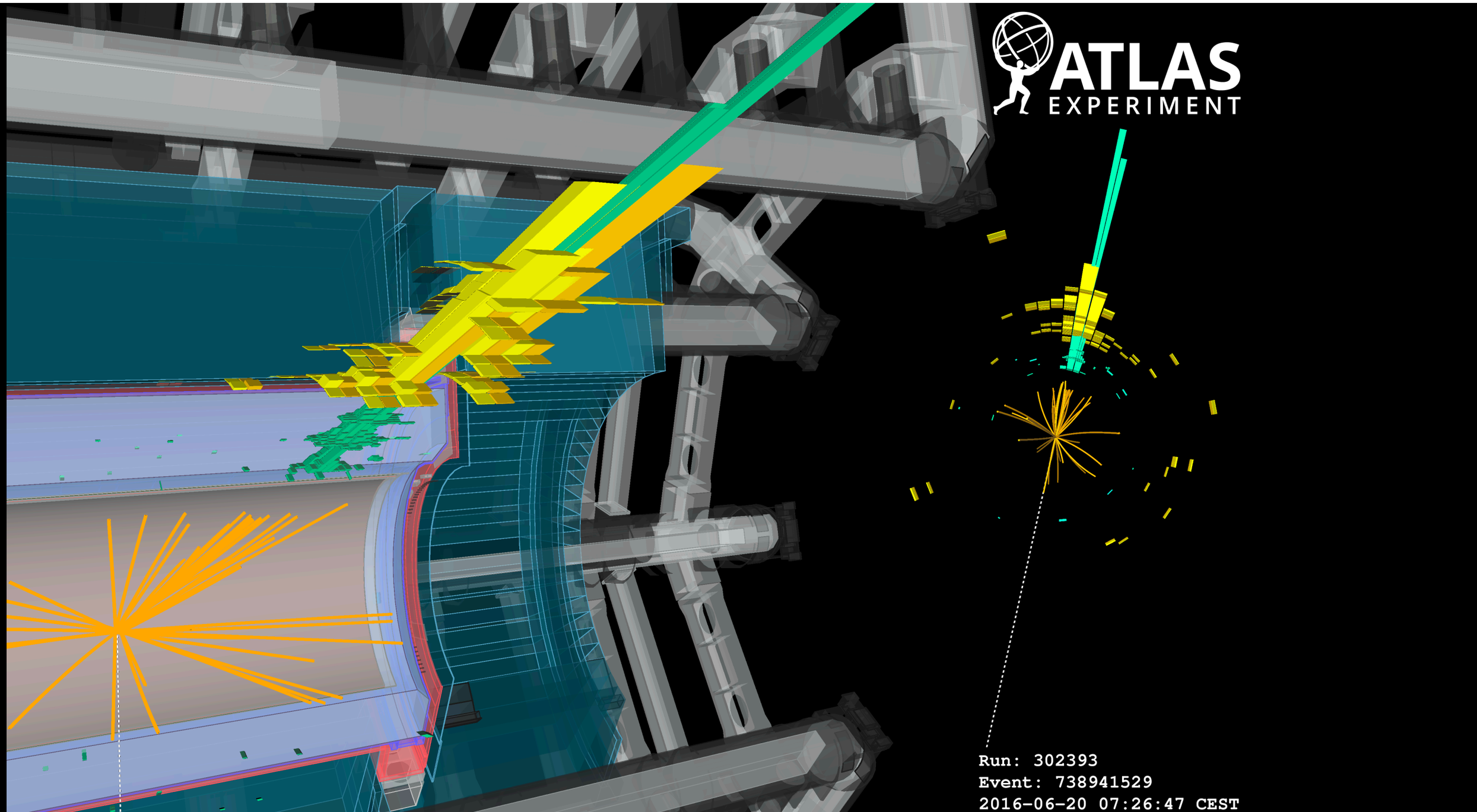
The collider ansatz



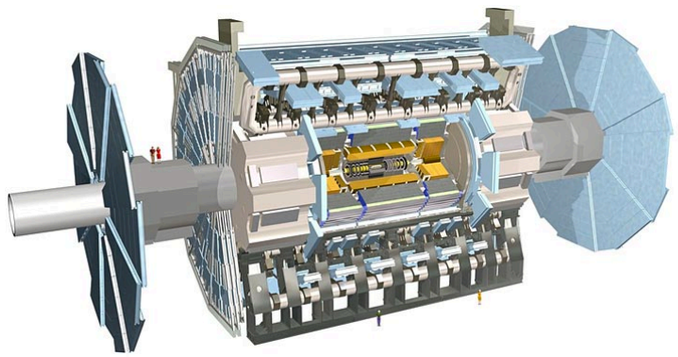
1. Particles detection and identification

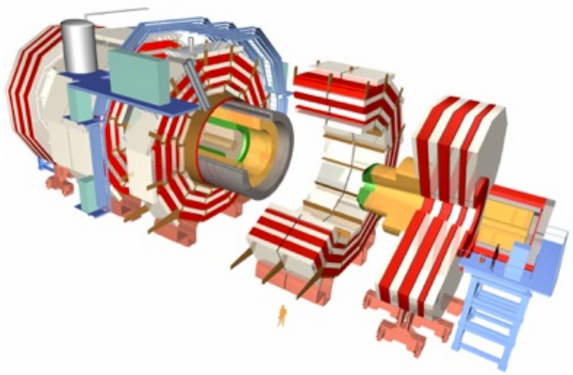
2. Production mechanism / theoretical framework

1. Detection and identification

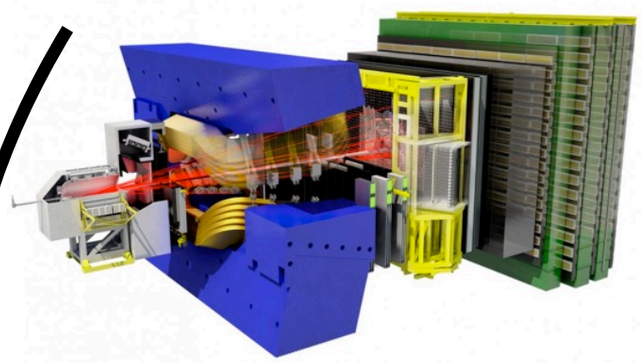


DM Collider experiments

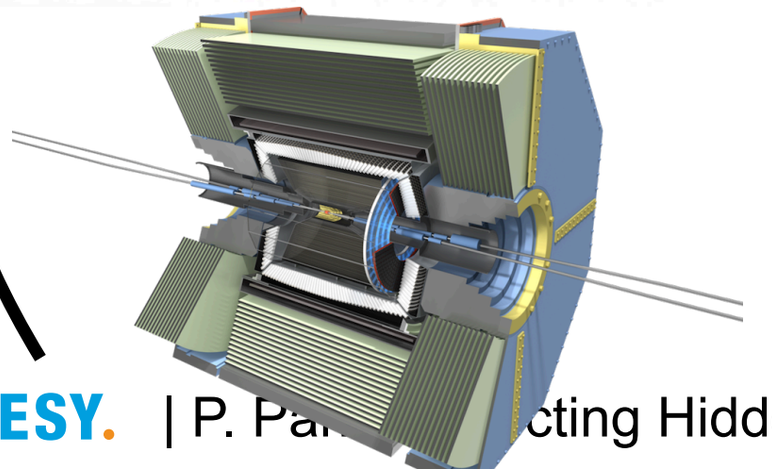




Focus	Mediator-models & SUSY
DM Results	Public Page
Overview :	DM Summary Paper



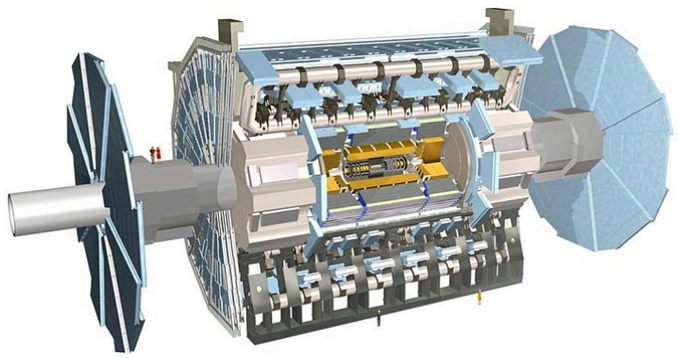
Focus	Mediator-models & SUSY
DM Results	EXOTICA, B2G
Overview (2018):	DM summary plots

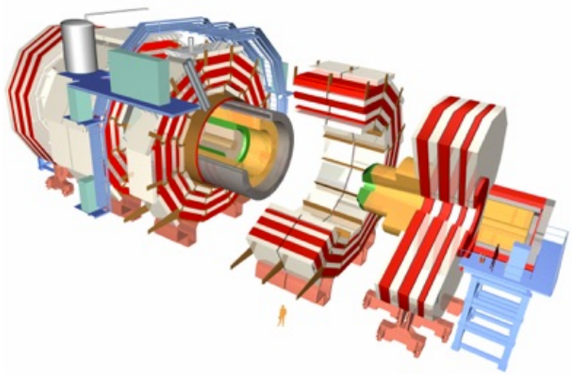


Focus	B-mesons, loops, resonance
DM Results	Public page

Focus	B-mesons, dark sector
DM Results	DMPuzzle2018, BelleII Book

DM Collider experiments





Focus	Mediator-models & SUSY
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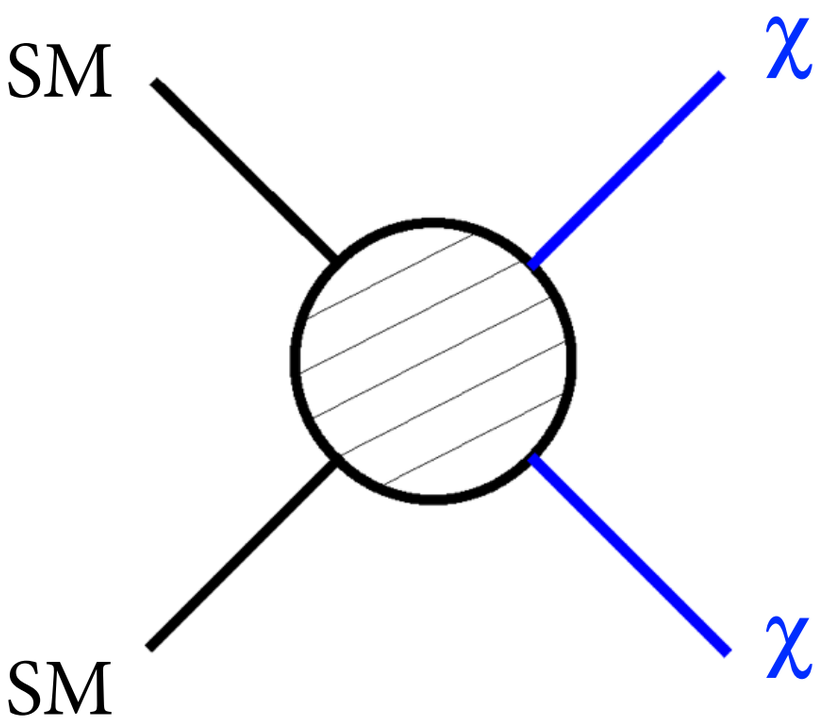
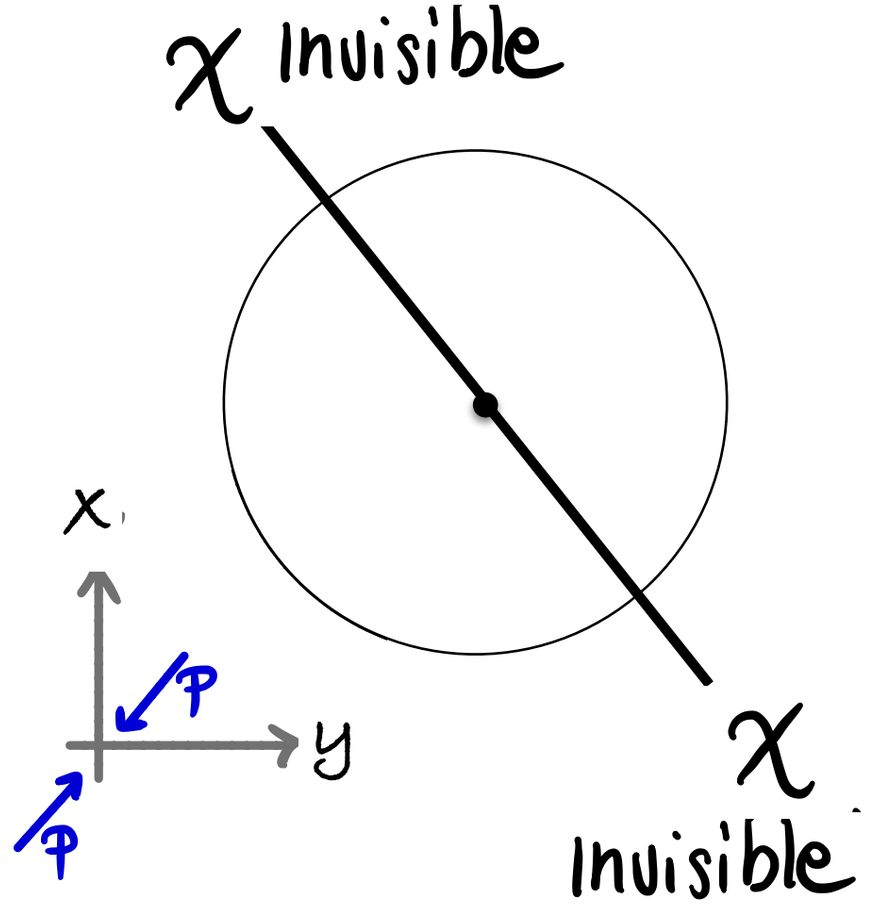
Focus	Mediator-models & SUSY
DM Results	EXOTICA, B2G
Overview:	DM summary plots

Disclaimer: The talk is heavy on ATLAS results but the two experiments have very similar programs and sensitivities!

Particles detection

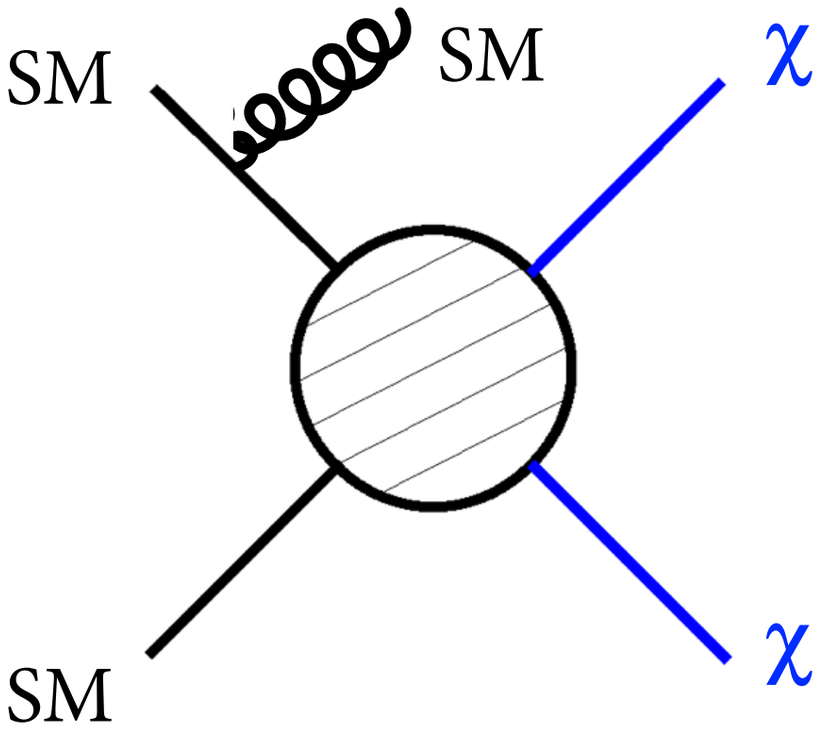
Events with only dark matter particles in the final state are undetectable in the hadronic collision environment

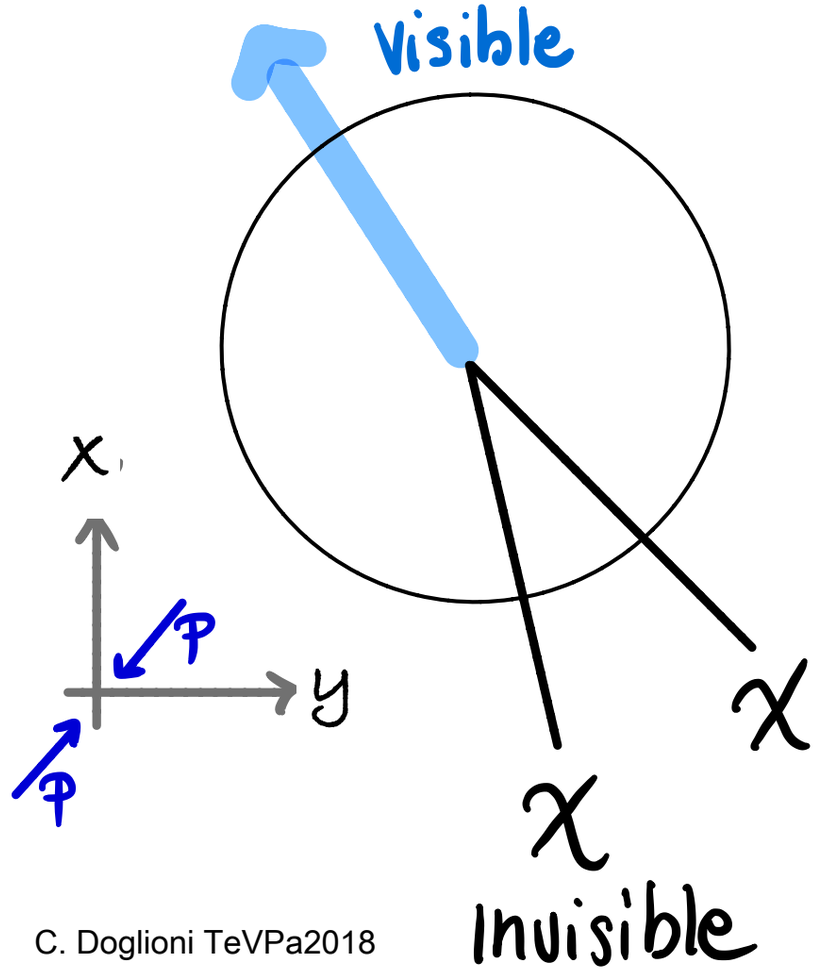




Particles detection

Dark matter is detected as momentum imbalance (missing energy) when produced in association with visible particles



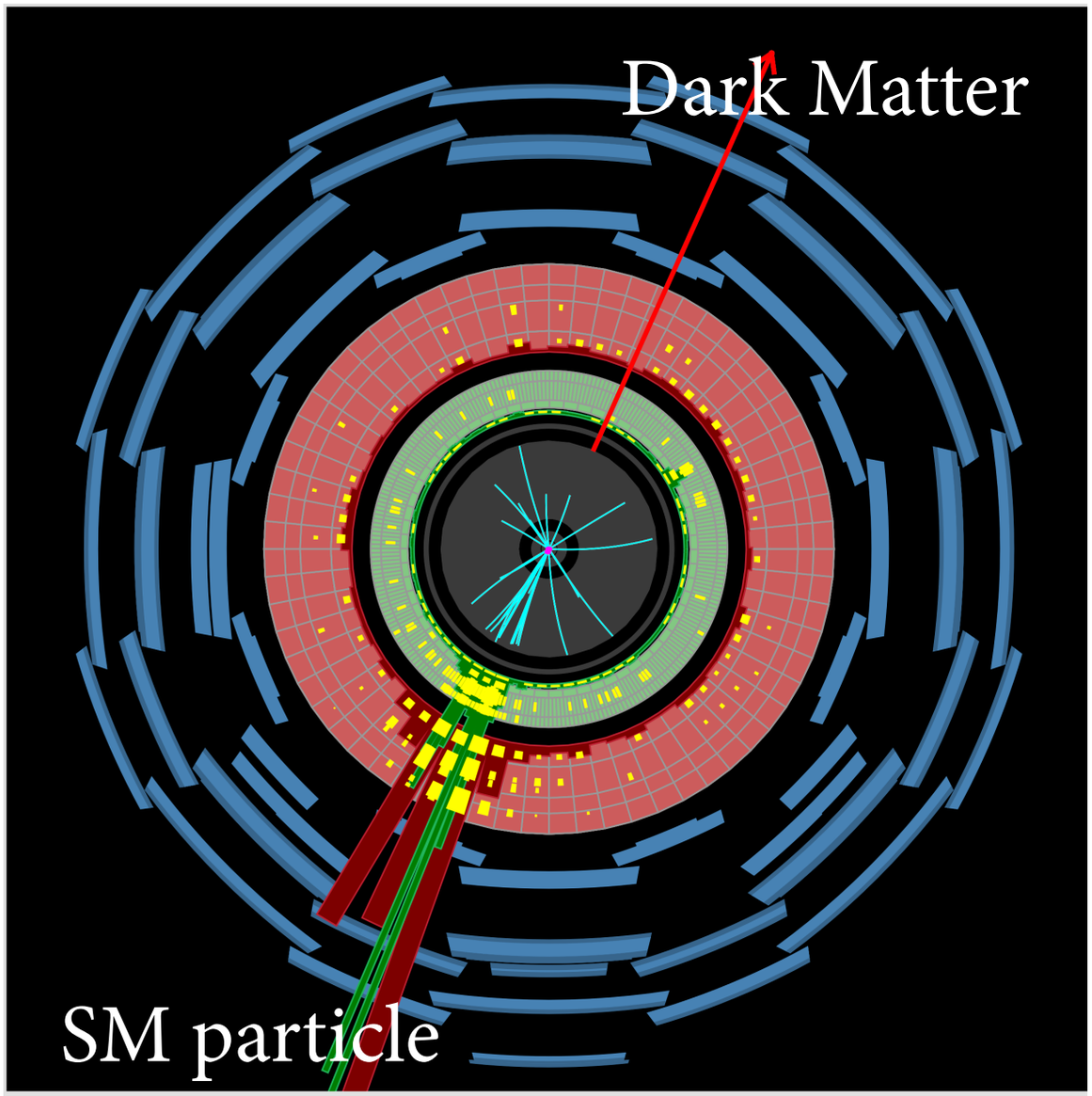


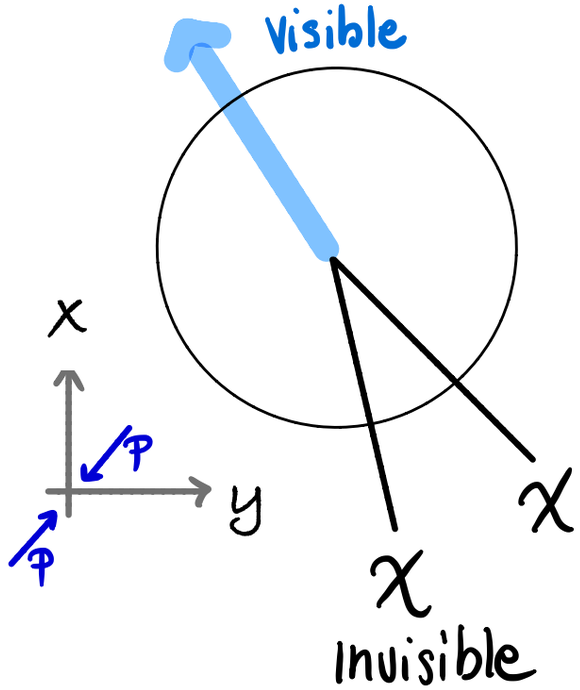
C. Doglioni TeVPa2018

Particles detection

Particles produced in the collision are detected as analogue signals by the sub-detectors, digitised, recorded and reconstructed *offline* as *particle-objects*. Their performance directly contributes to the dark matter identification

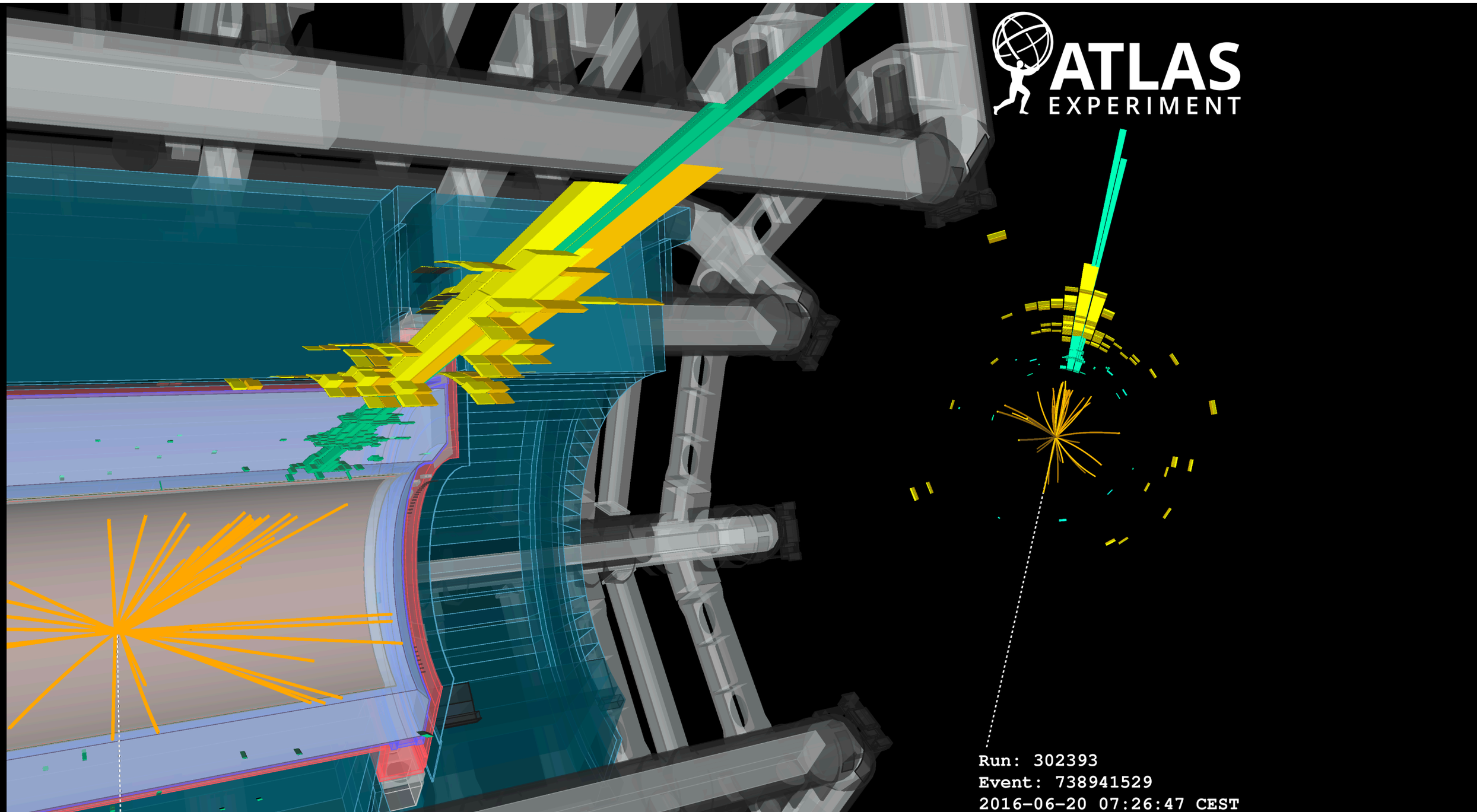
- Electrons
- Muons
- Photons
- jets
- b-jets/c-jets
- invisible particles



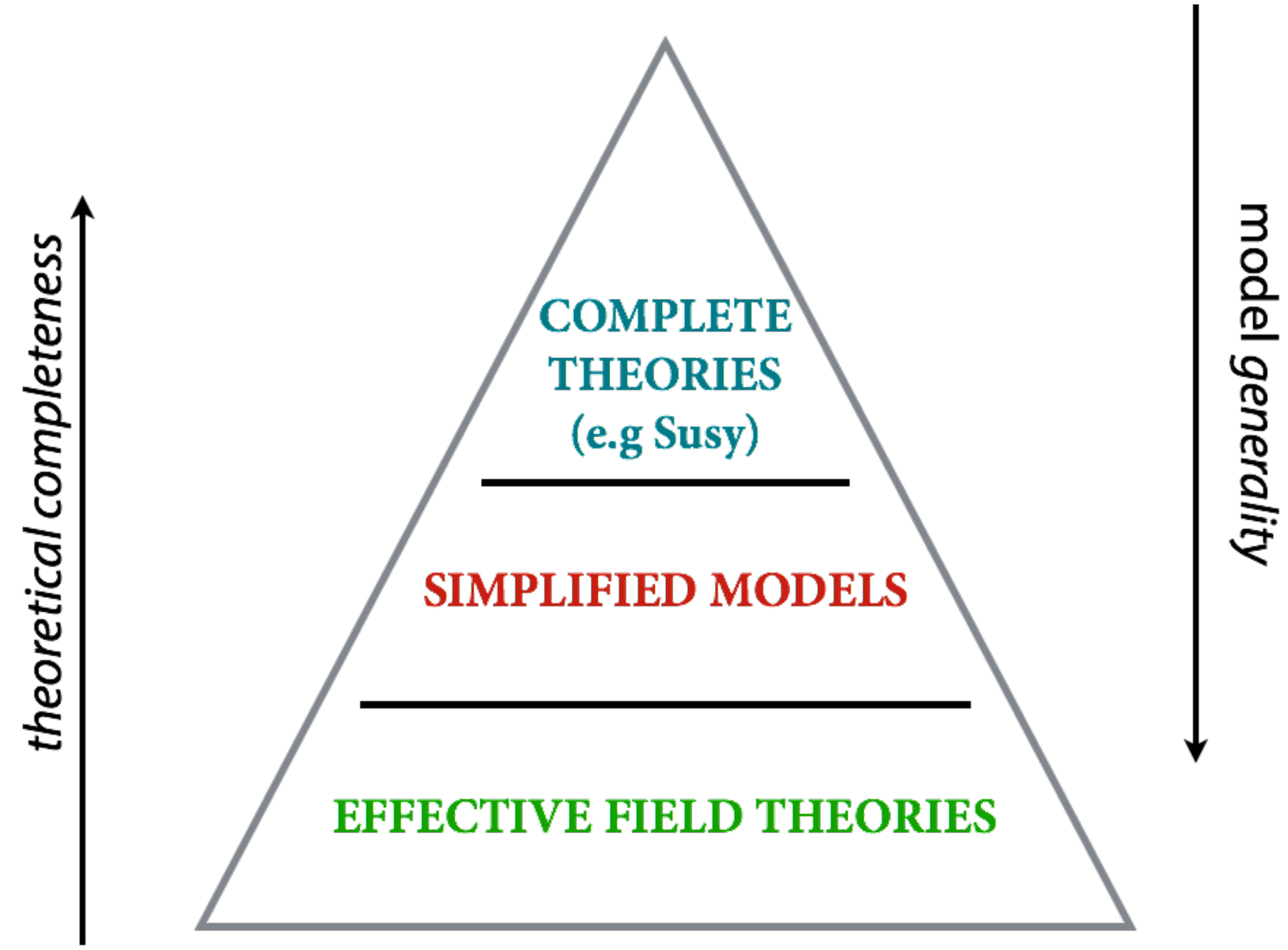


C. Doglioni TeVPa2018

2. Production mechanism



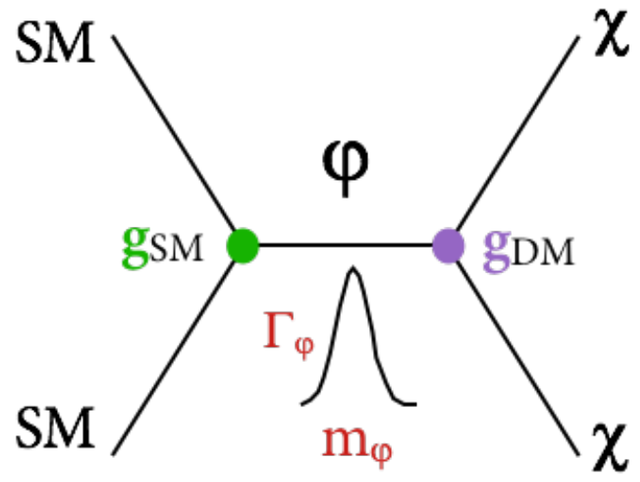
DM Theoretical framework



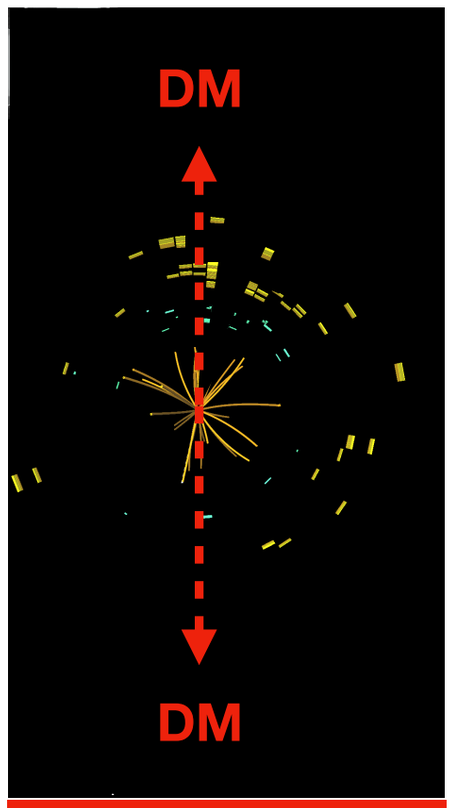
Mediator simplified models

- ★ Reduce a complex model to a simple one with **DM + mediator**
- ★ **Few free parameters:** mφ, mχ, gSM, gDM, Γφ
- ★ Nature of mediator and DM can (also) be **systematically classified based on their spin and CP**
- ★ **Very rich phenomenology**

arXiv:1507.00966 (and ref. therein) + LPCC WG



E_T^{miss} + X



Not Visible

Courtesy of O. Rifki

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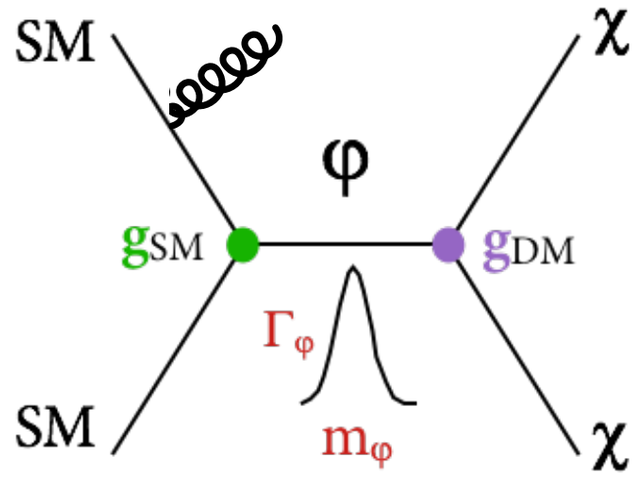
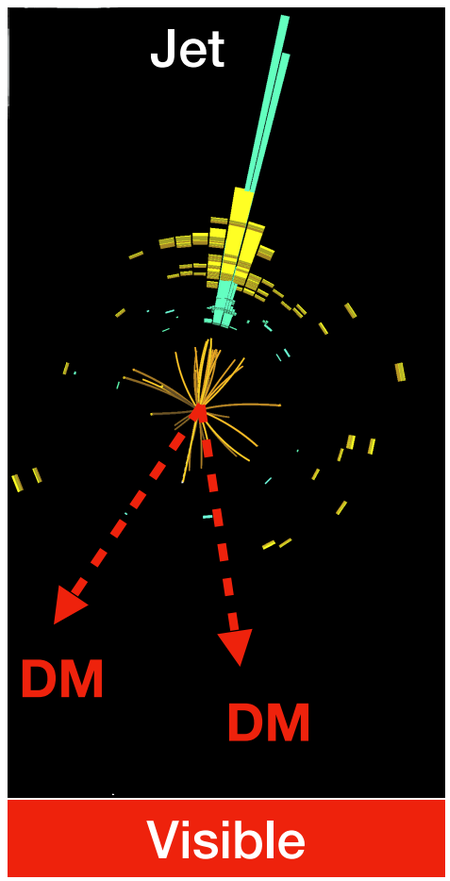


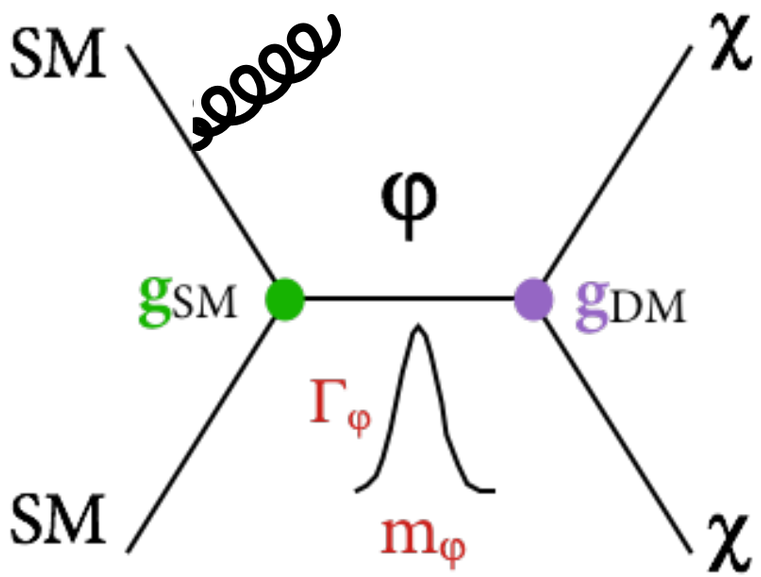
E_T^{miss} + X



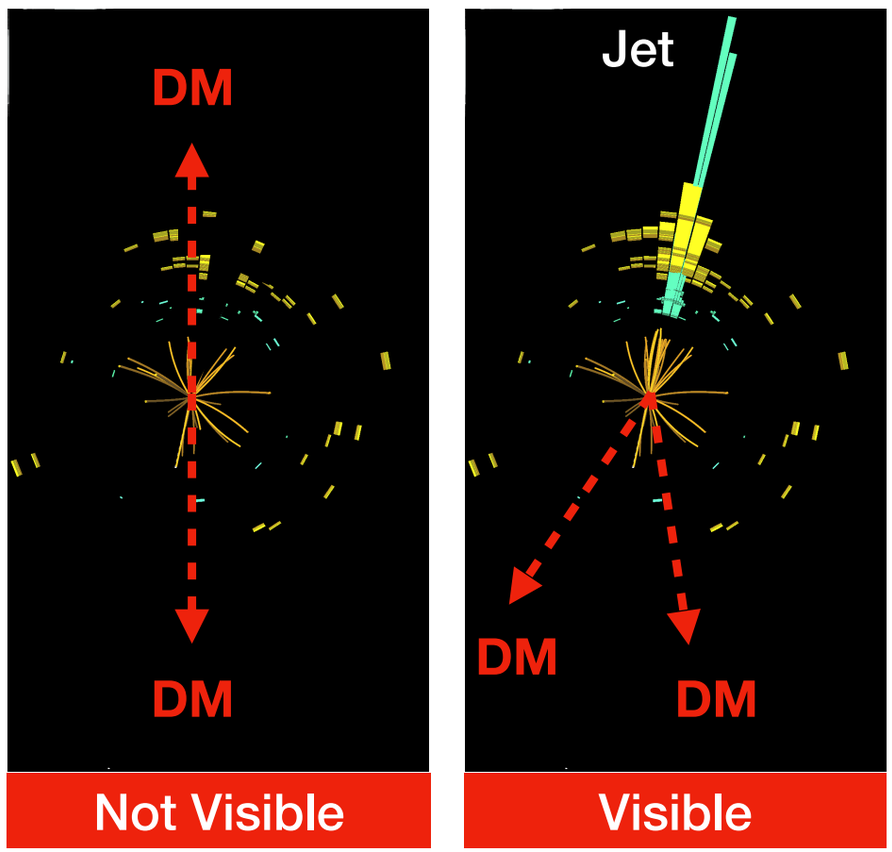
Courtesy of O. Rifki

Mediator simplified models

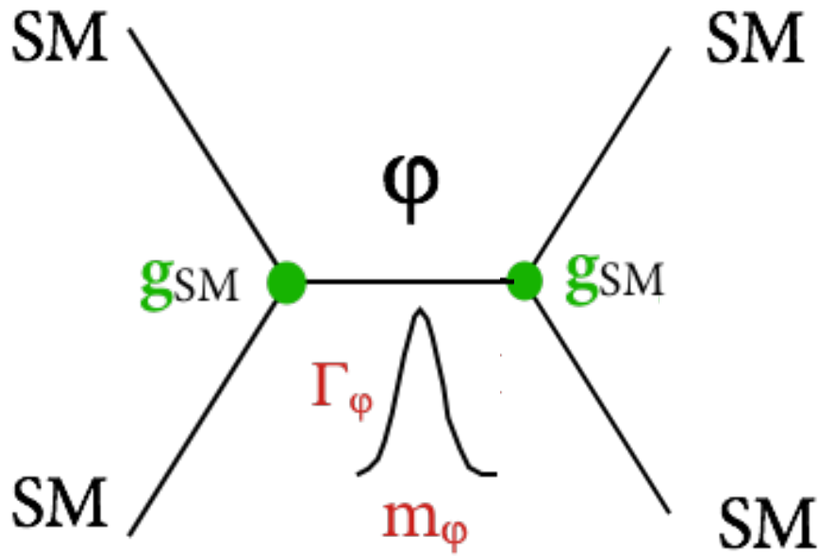
E_T^{miss} + X



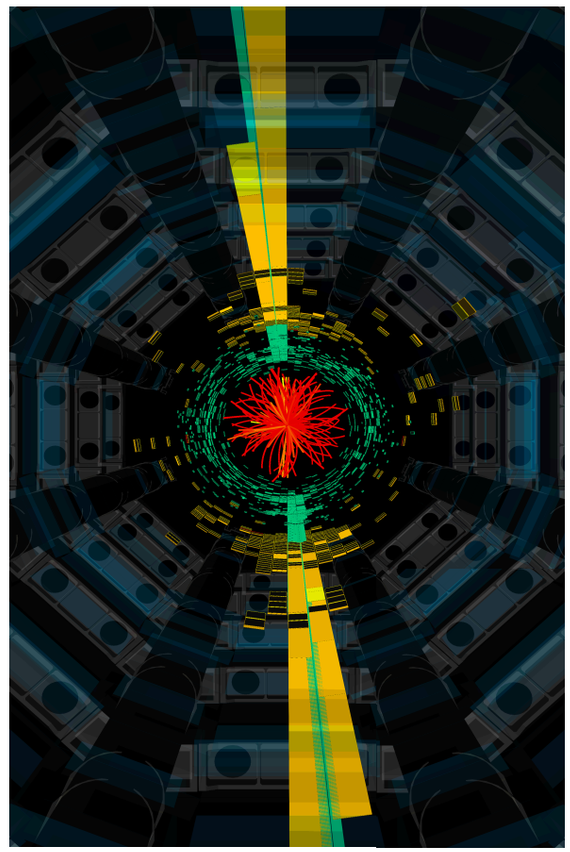
Dark matter recoiling against a known particle



Resonance



Messenger decaying back to known particles



Courtesy of O. Rifki

The strange case of spin-0 mediators

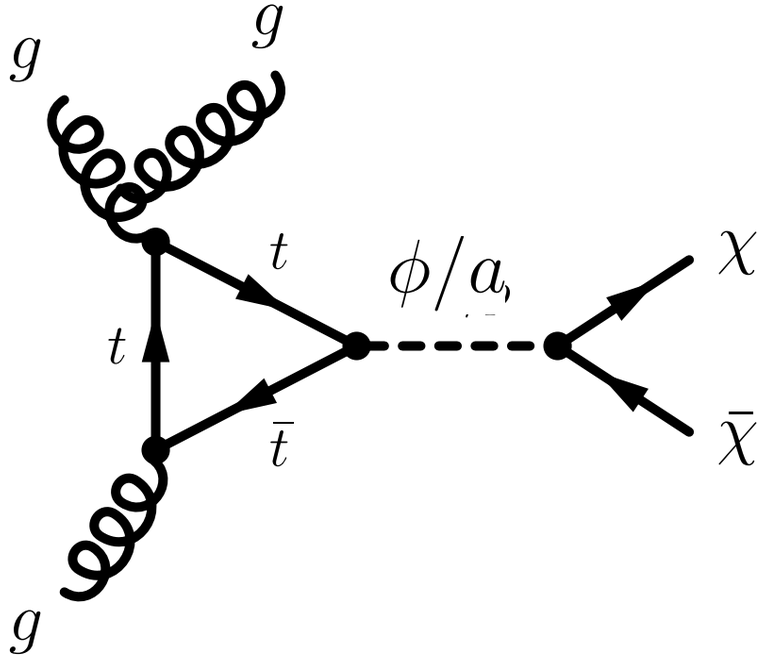
When the mediator behaves like the Higgs

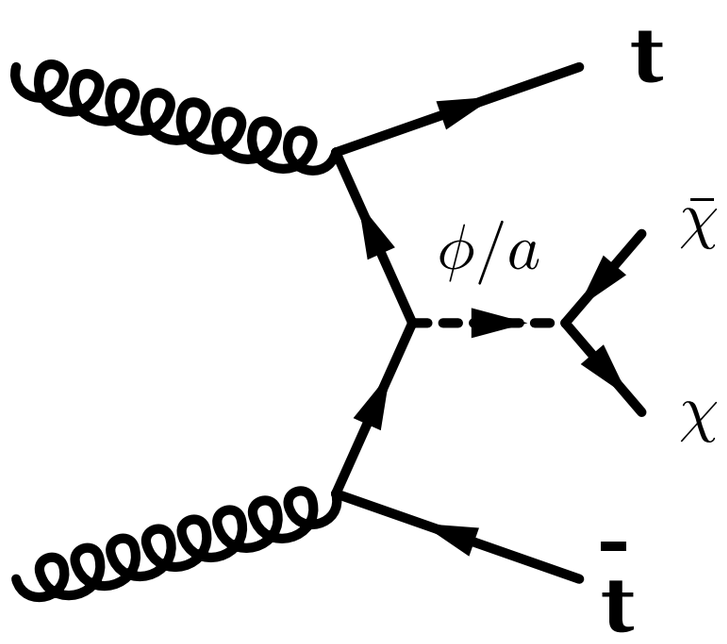
$$\mathcal{L} \sim \sum_f i g_v \frac{y_f}{\sqrt{2}} a \bar{f} \gamma^5 f$$

Enhanced cross-section for tops and bottoms

(small cross section for light quarks)

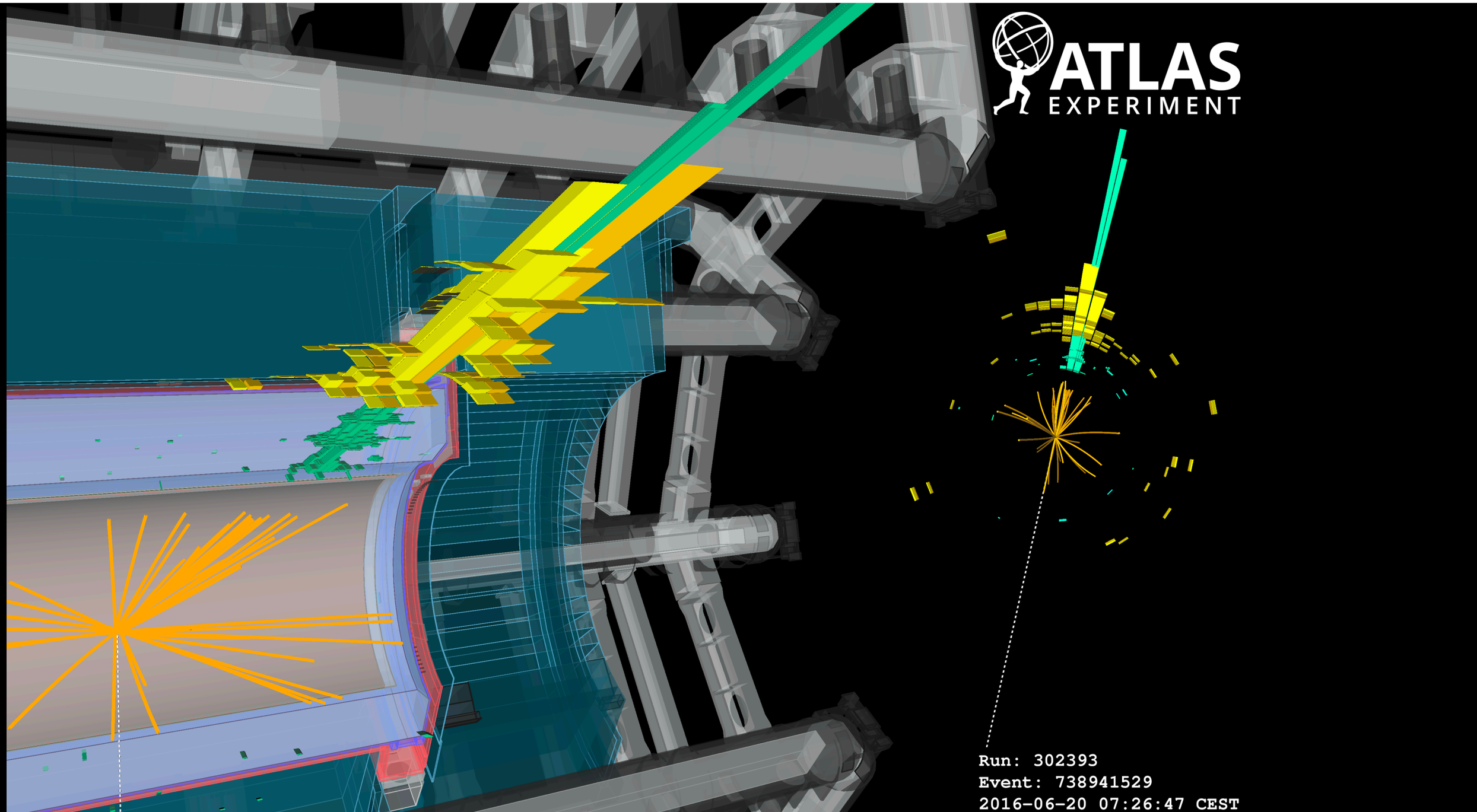
Needed to easily fulfil Flavour Constraints (MFV ansatz)



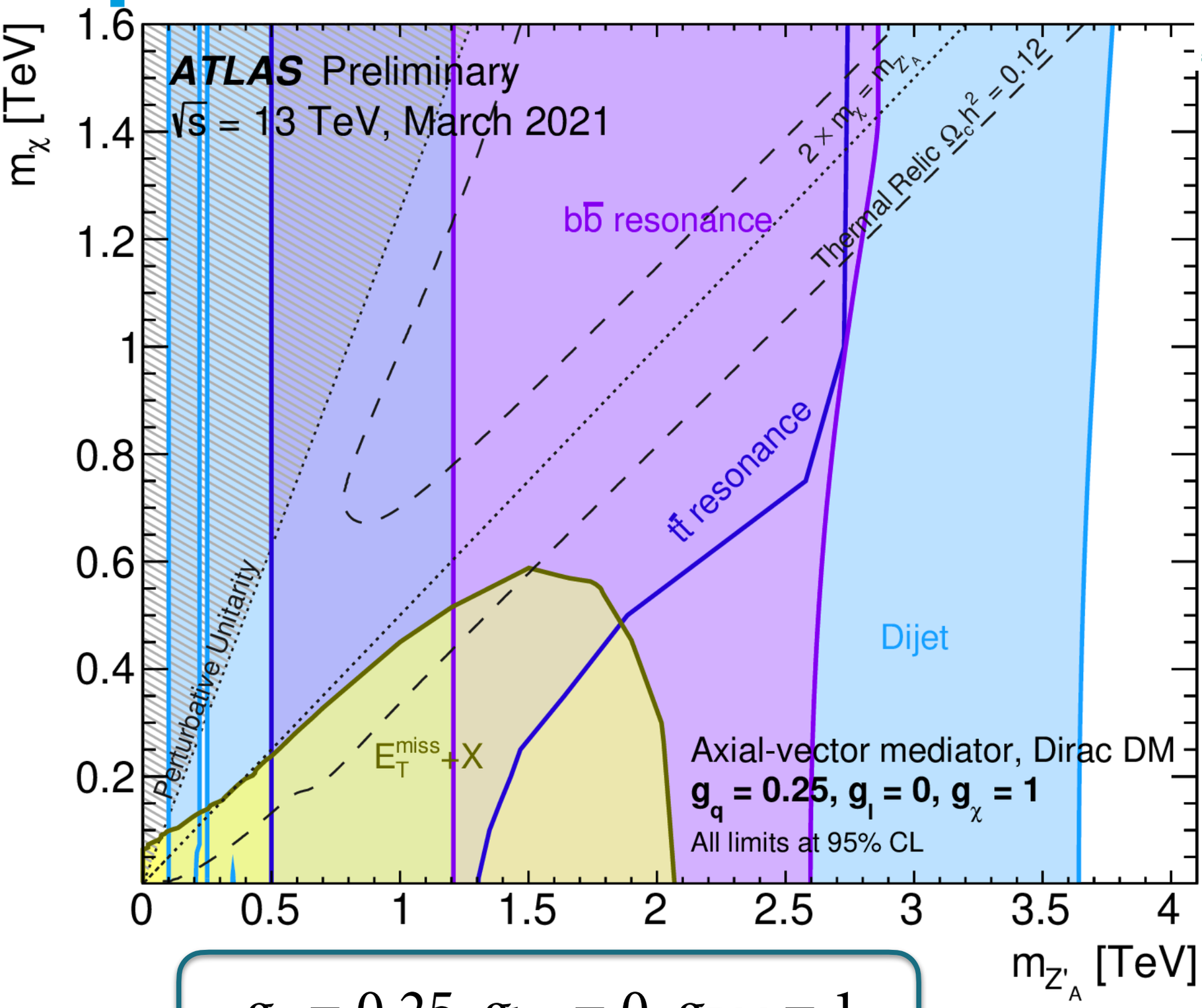


(*) will show later that there are more channels with top quarks that matter

3. Highlights for simplified models



Spin-1 mediators - masses



ATL-PHYS-PUB-2020-021

Dijet, 139 fb^{-1}
JHEP 03 (2020) 145

Dijet TLA, 29.3 fb^{-1}
PRL 121 (2018) 081801

Dijet+ISR, 79.8 fb^{-1}
PLB 795 (2019) 56

Boosted dijet+ISR, 36.1 fb^{-1}
PLB 788 (2019) 316

Boosted di-*b*+ISR, 80.5 fb^{-1}
ATLAS-CONF-2018-052

tt̄ resonance
36.1 fb^{-1}
EPJC 78 (2018) 565

bb̄ resonance
139 fb^{-1}
JHEP 03 (2020) 145

E_T^{miss}+X

E_T^{miss}+jet, 139 fb^{-1}
arXiv:2102.10874

E_T^{miss}+γ, 139 fb^{-1}
arXiv:2011.05259

E_T^{miss}+V(had), 36.1 fb^{-1}
JHEP 10 (2018) 180

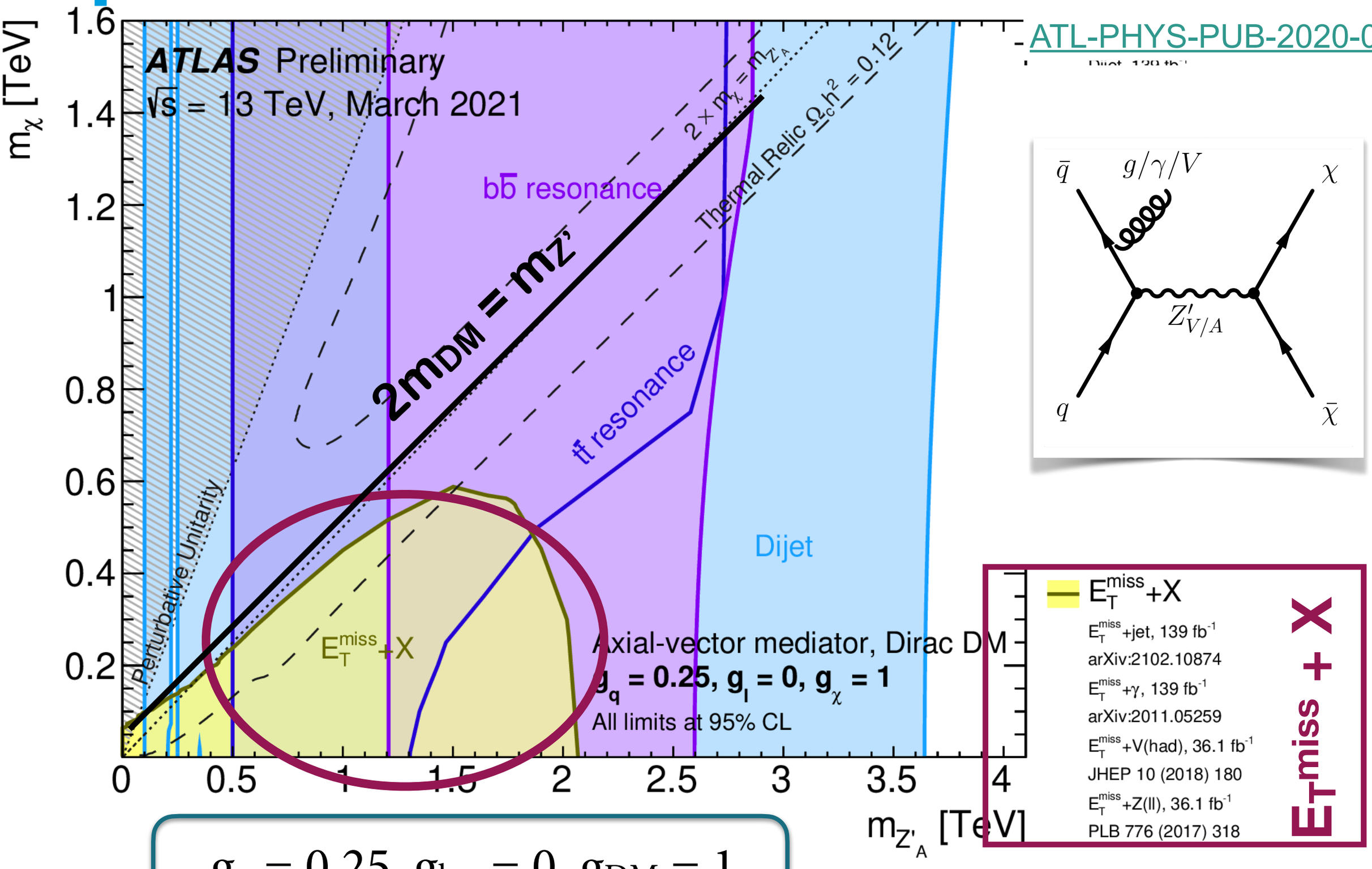
E_T^{miss}+Z(ll), 36.1 fb^{-1}
PLB 776 (2017) 318

E_T^{miss} + X

$$g_q = 0.25, g_{lep} = 0, g_{DM} = 1$$

Axial-vector mediator

Spin-1 mediators - masses

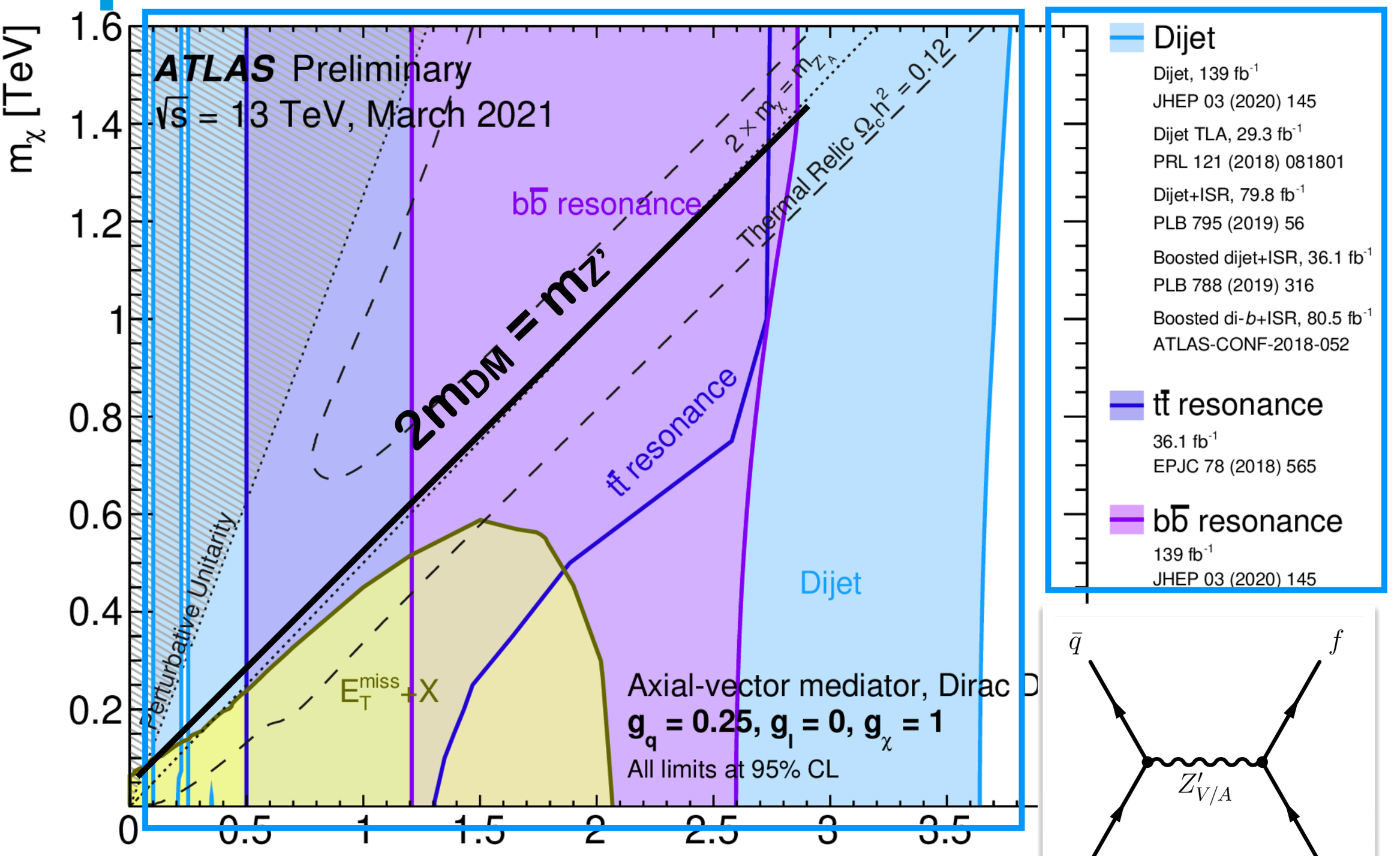


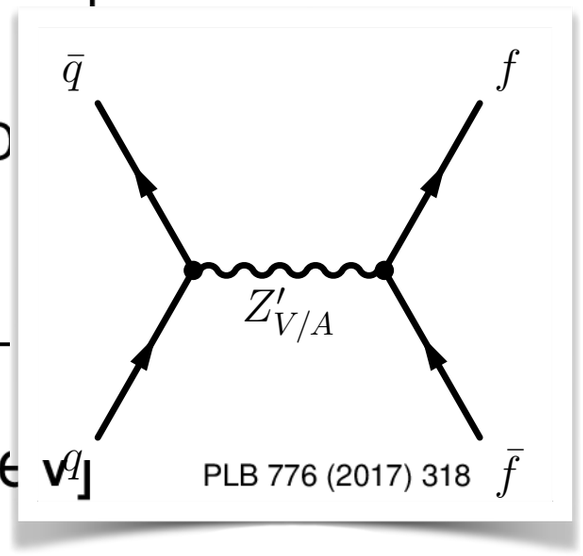
ATL-PHYS-PUB-2020-021

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Axial-vector mediator

Spin-1 mediators - masses

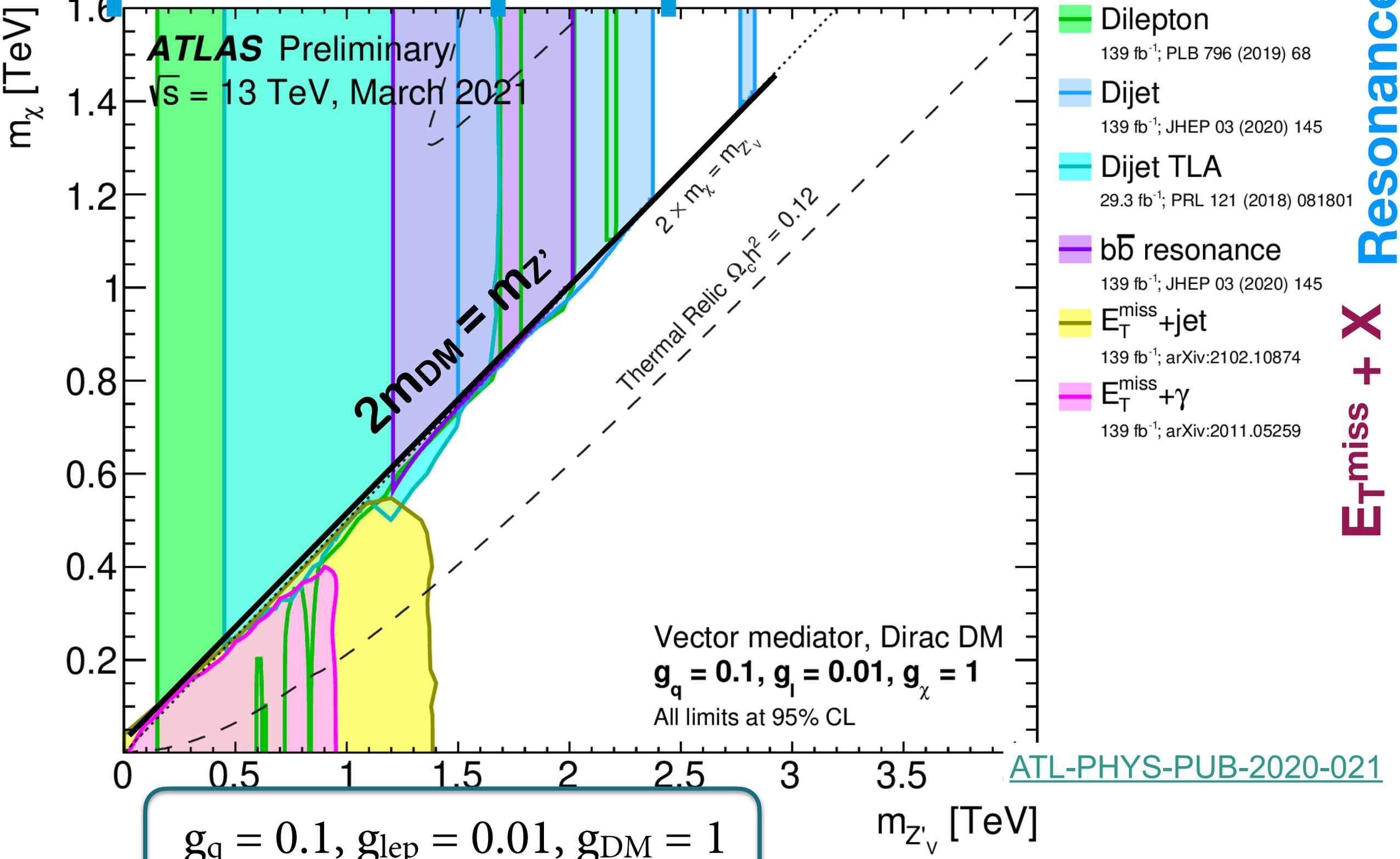




$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Axial-vector mediator

Spin-1 leptophilic case

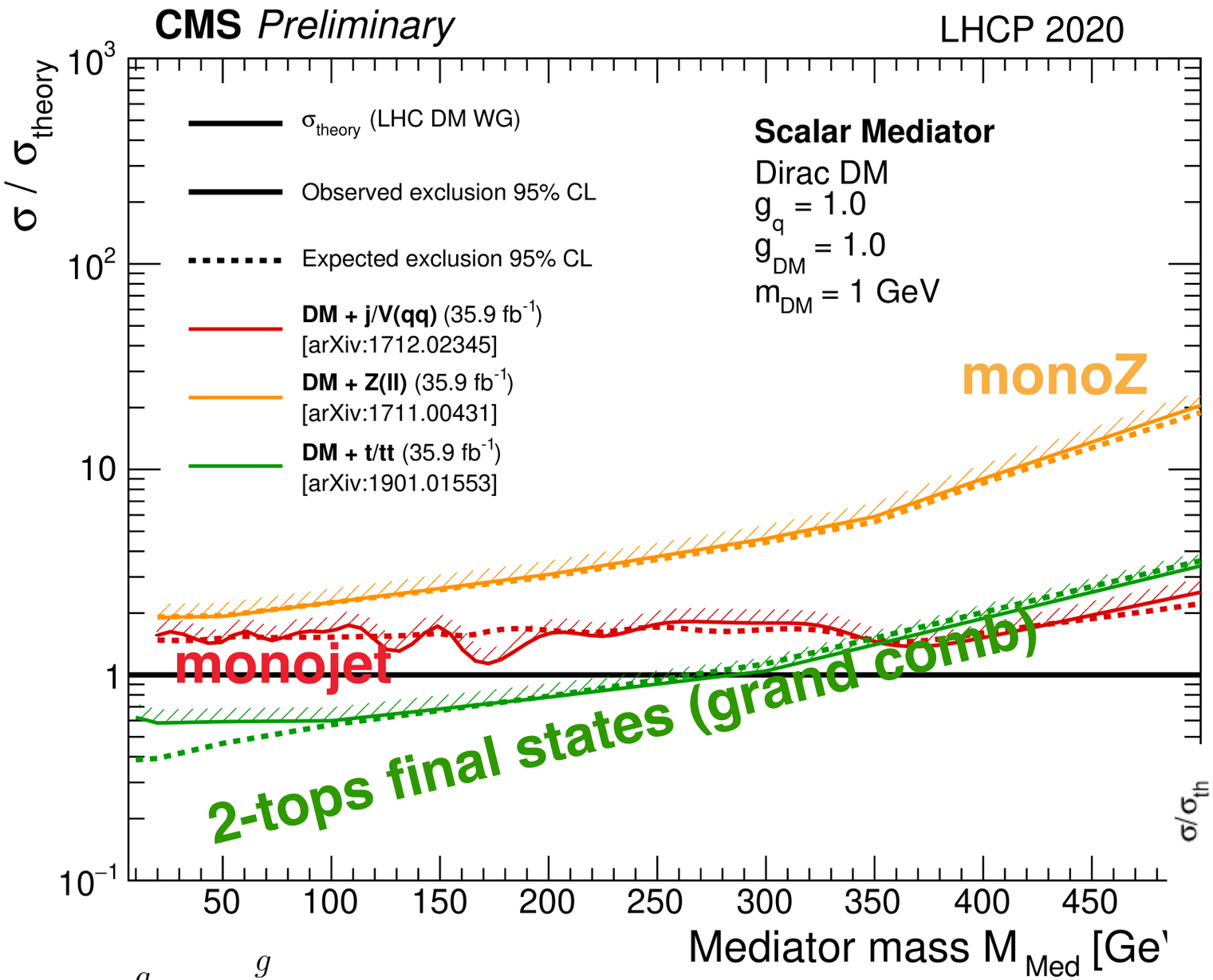


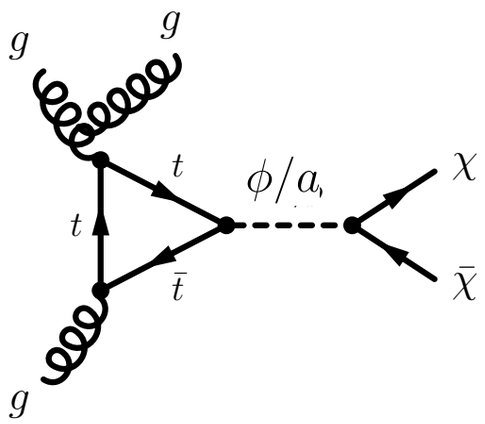
ATL-PHYS-PUB-2020-021

$$g_q = 0.1, g_{lep} = 0.01, g_{DM} = 1$$

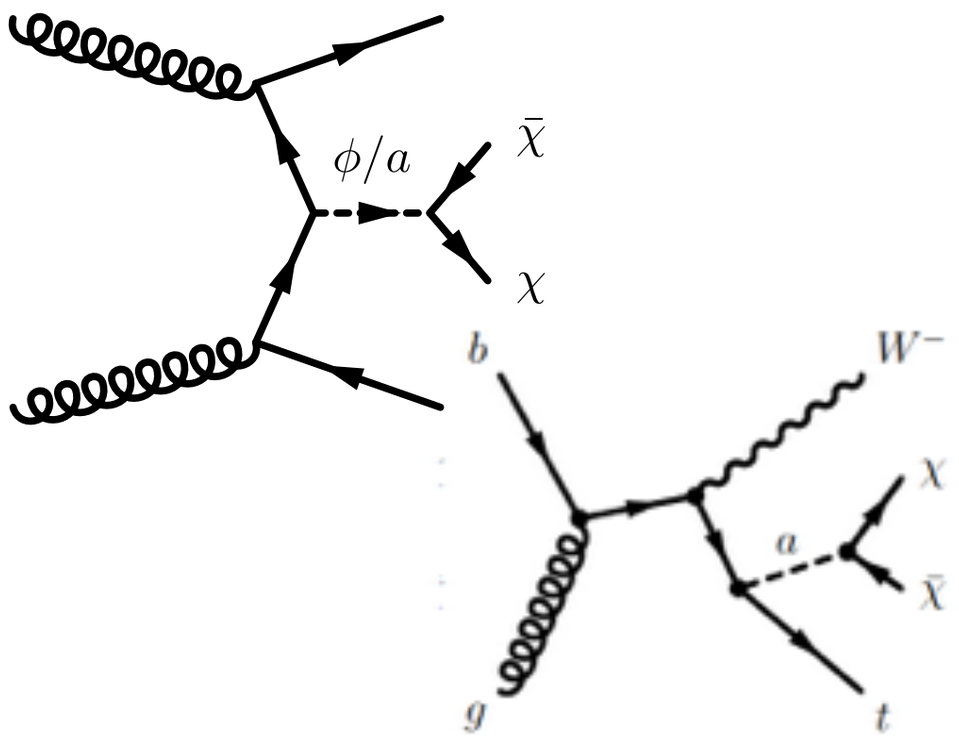
Vector mediator

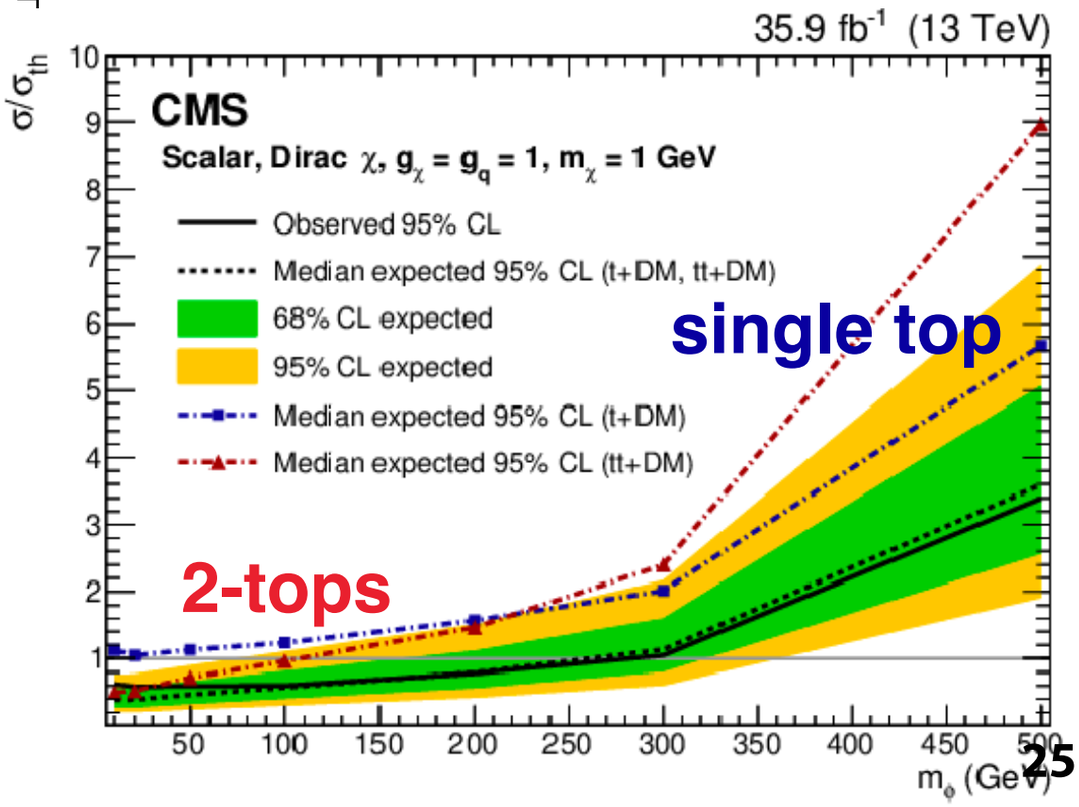
Spin-0 mediators (scalar)





DM Summary Plots

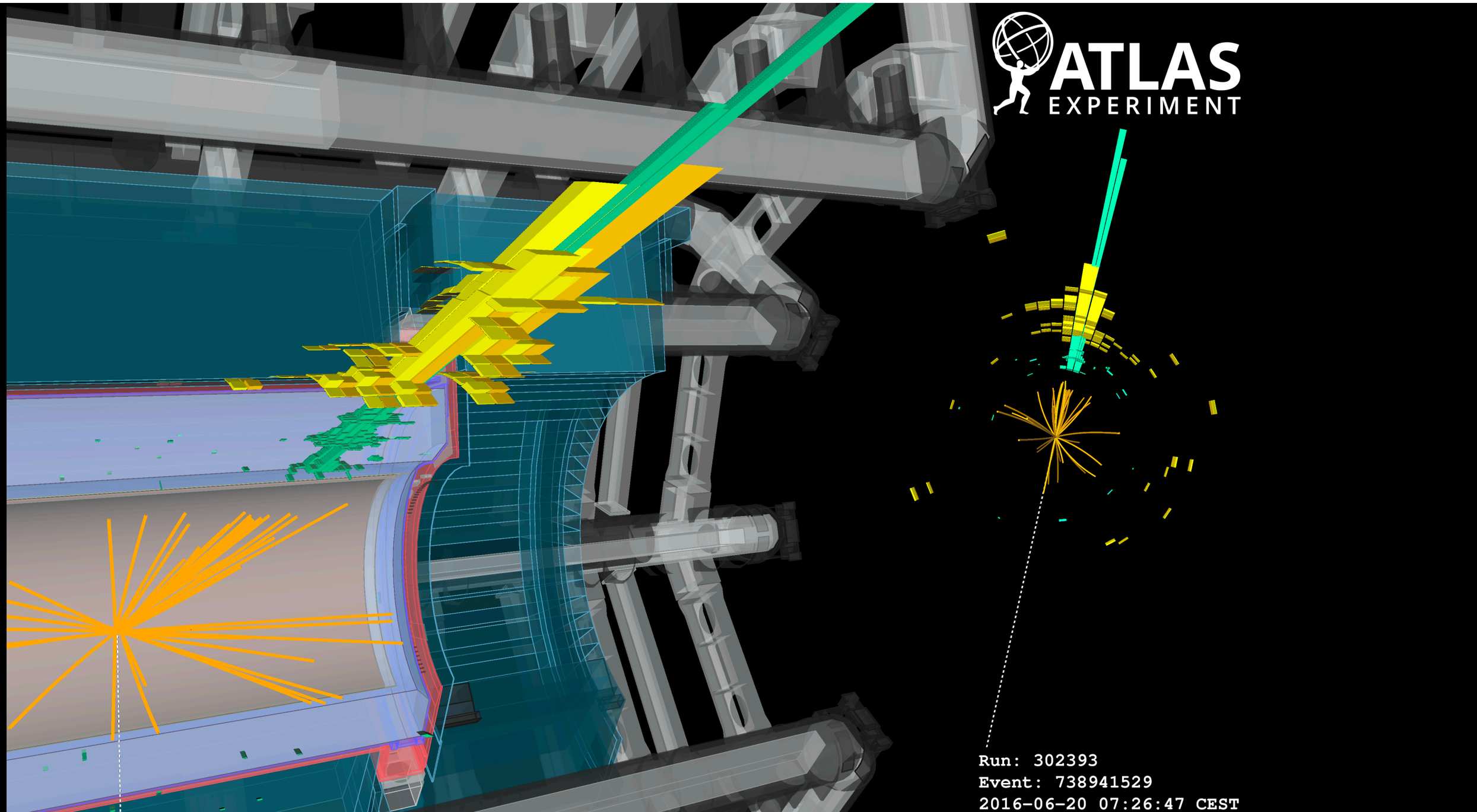




Considerations on the results

- ★ Simplified models are **good phenomenology proxies.**
- ★ Simplified models are simplified models.
- ★ **All exclusions need to be taken with a grain of salt.**
- ★ Simplified models are not full and complete theories, which might have **more complex topologies.**

4. highlights for less simplified models: 2HDMs

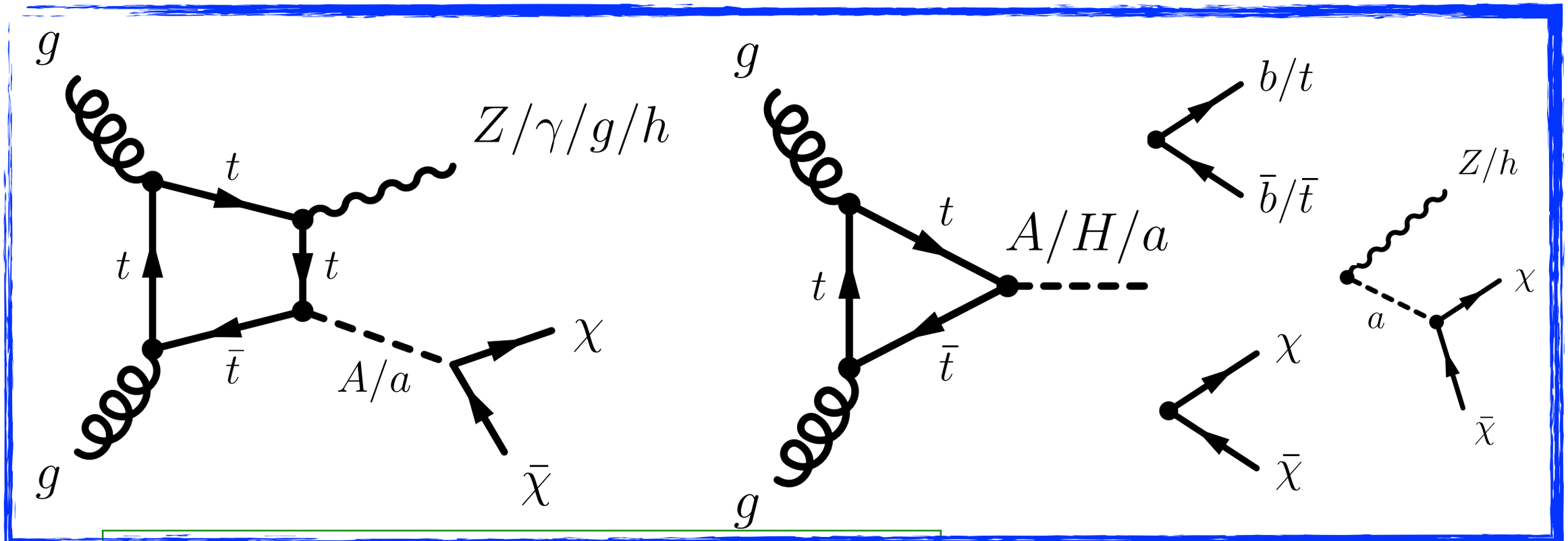


2HDM-based models

2HDM DM models

< TeV $H^{\pm}$	<TeV A	~10 GeV χ^0
125 GeV h	<TeV H	~10^2 GeV a

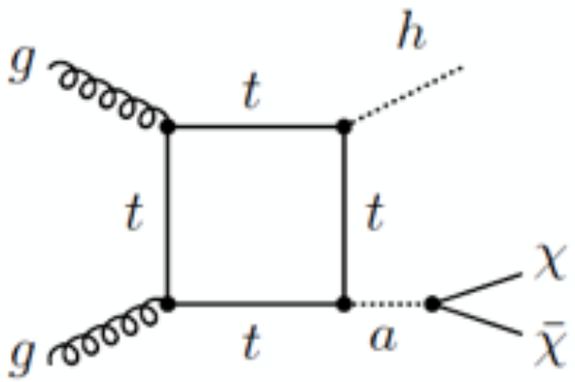
★ **Richer phenomenology:**
Higgs bosons productions and decays, mixing, many final states.

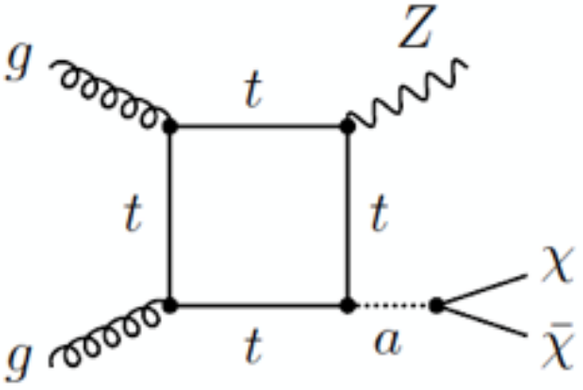


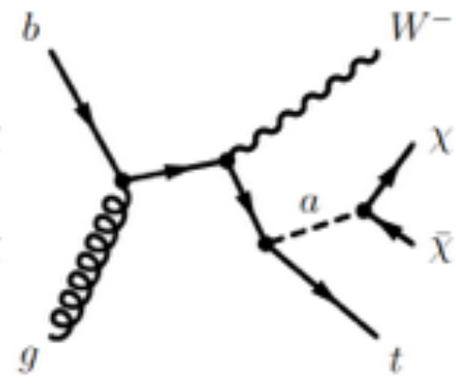
arxiv:1810.09420 (and ref. therein) + LPCC WG

2HDM-based models

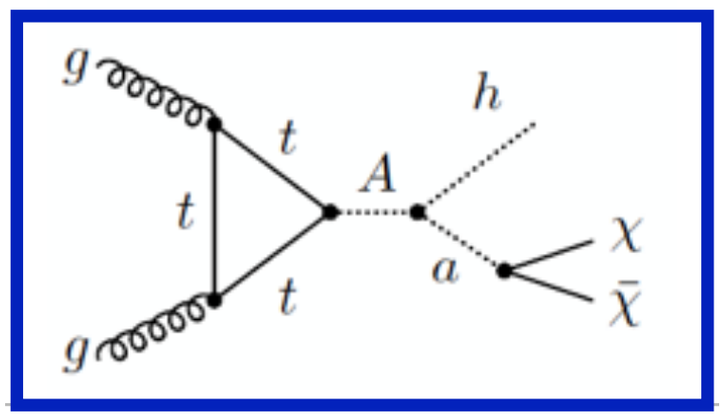
Non-resonant production/
also present in simplified model

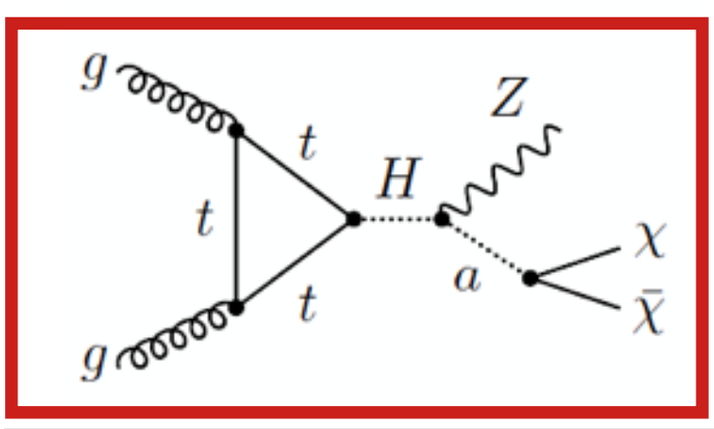


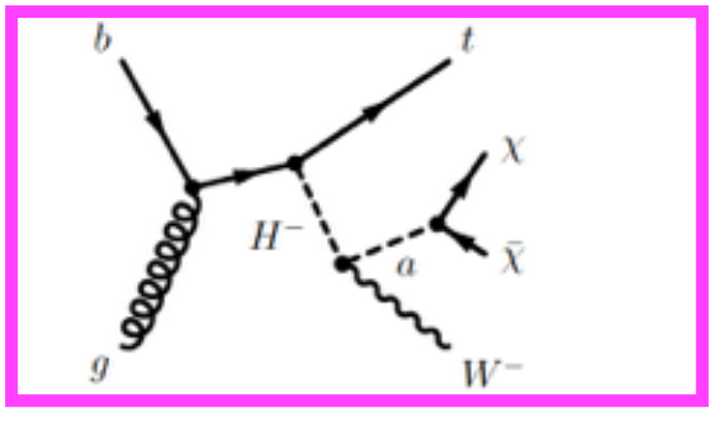


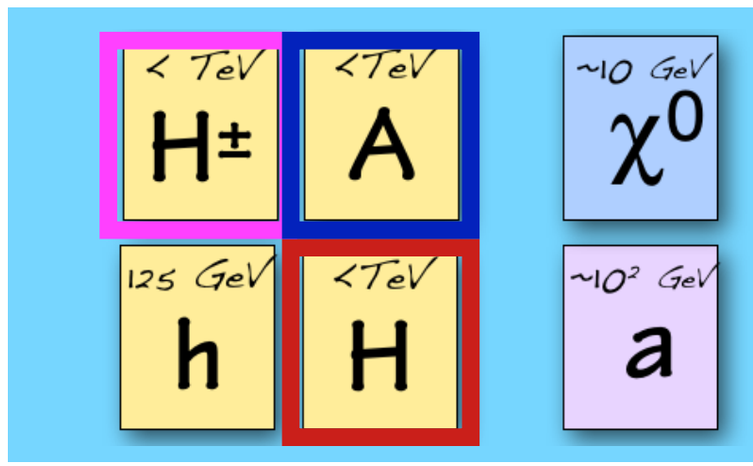


Resonant production/
new in 2HDM!





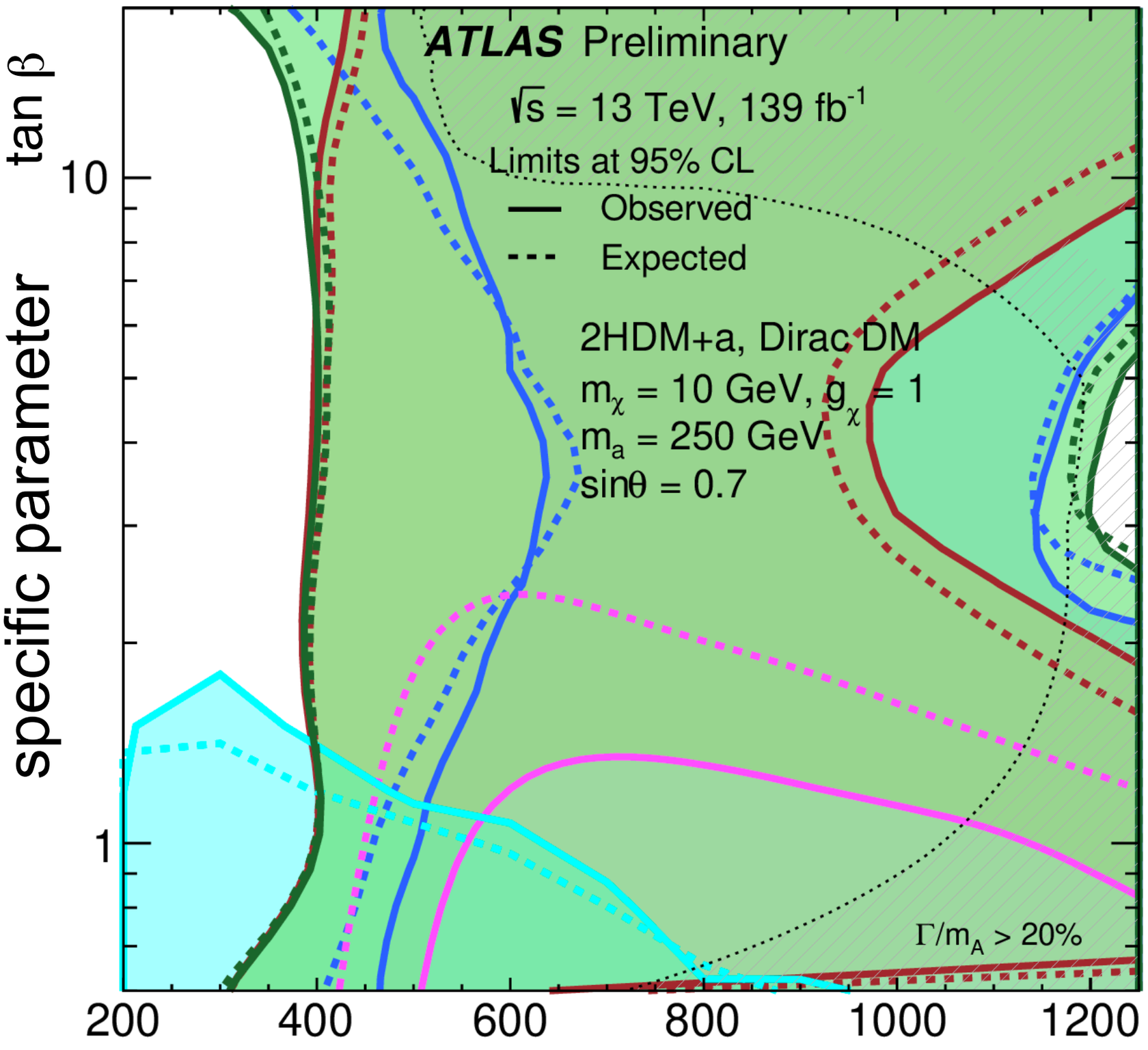




- Benchmarks set m(H) = m(A) = m(H±)
- Nature might differ, need to investigate all three signatures!

Results (I)

ATLAS-CONF-2021-036/



E_T^{miss}+h(bb̄), 139 fb^{-1}
ATLAS-CONF-2021-006

E_T^{miss}+Z(ll), 139 fb^{-1}
ATLAS-CONF-2021-029

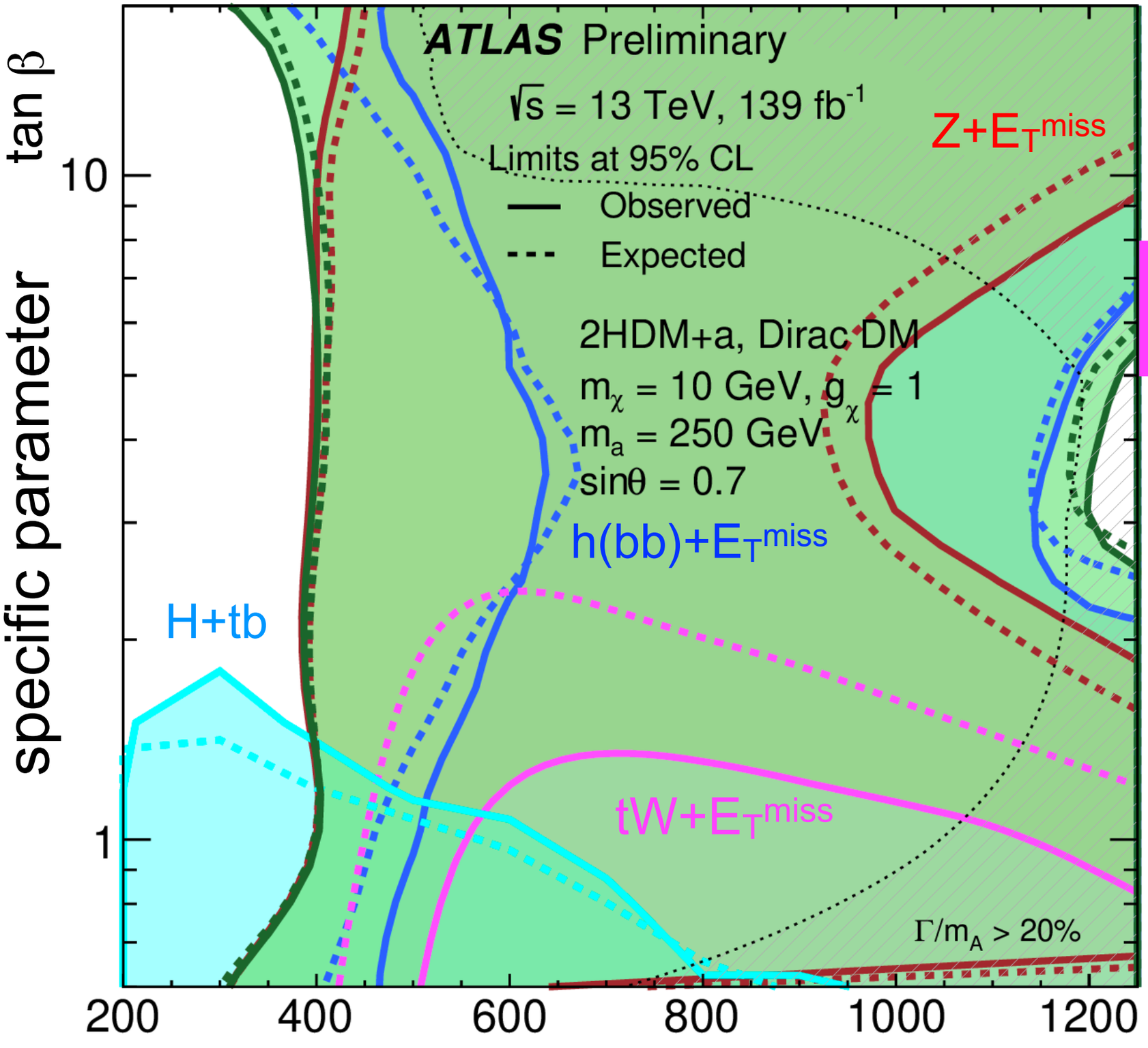
E_T^{miss}+Wt, 139 fb^{-1}
arXiv: 2011.09308

$H^{\pm}$tb, 139 fb^{-1}
JHEP 06 (2021) 145

Combination
E_T^{miss}+h(bb̄), E_T^{miss}+Z(ll)

Results (I)

ATLAS-CONF-2021-036/



E_T^{miss}+h(bb̄), 139 fb^{-1}
ATLAS-CONF-2021-006

E_T^{miss}+Z(ll), 139 fb^{-1}
ATLAS-CONF-2021-029

E_T^{miss}+Wt, 139 fb^{-1}
arXiv: 2011.09308

< TeV H±

$H^{\pm}$tb, 139 fb^{-1}
JHEP 06 (2021) 145

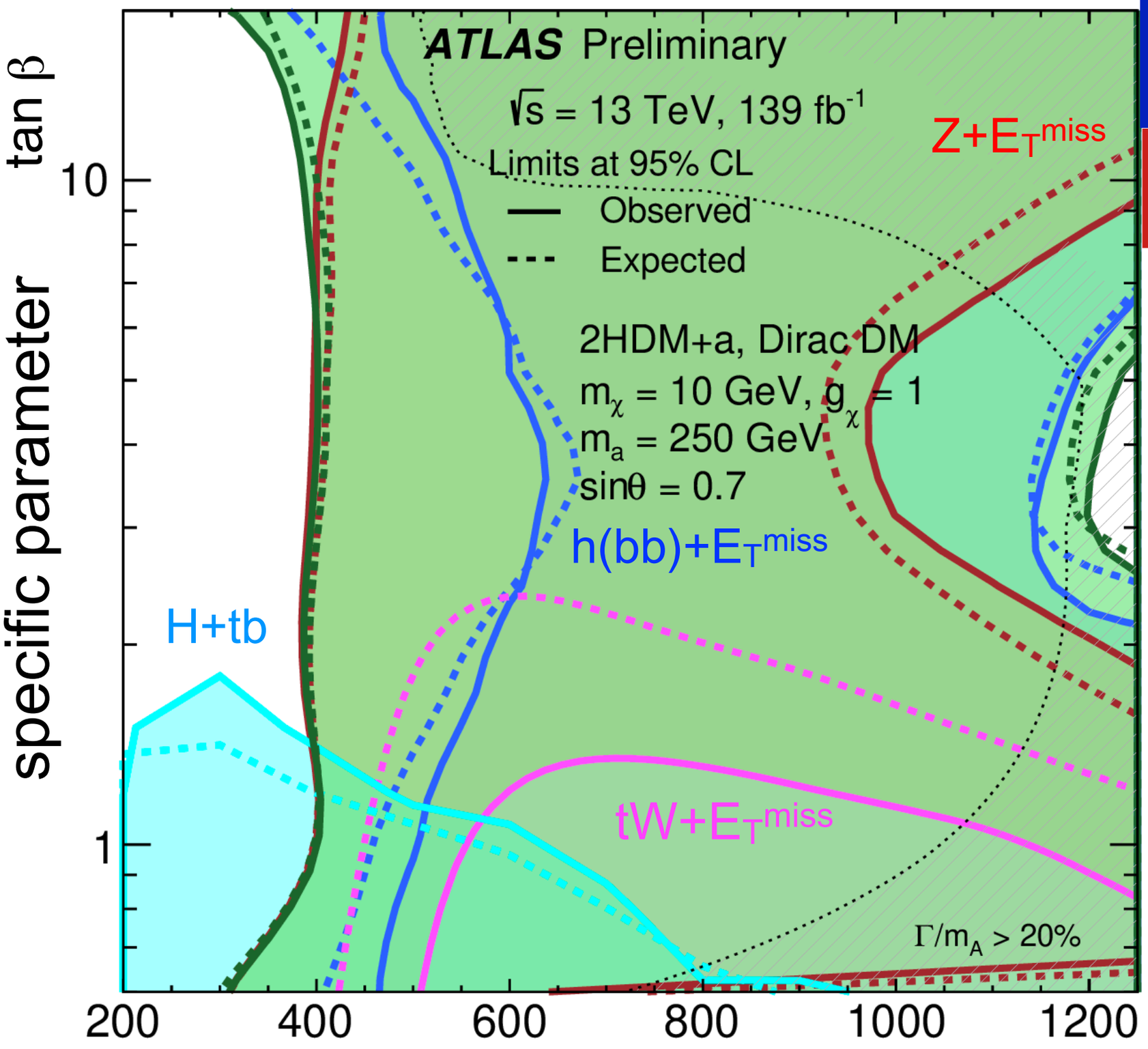
< TeV H±

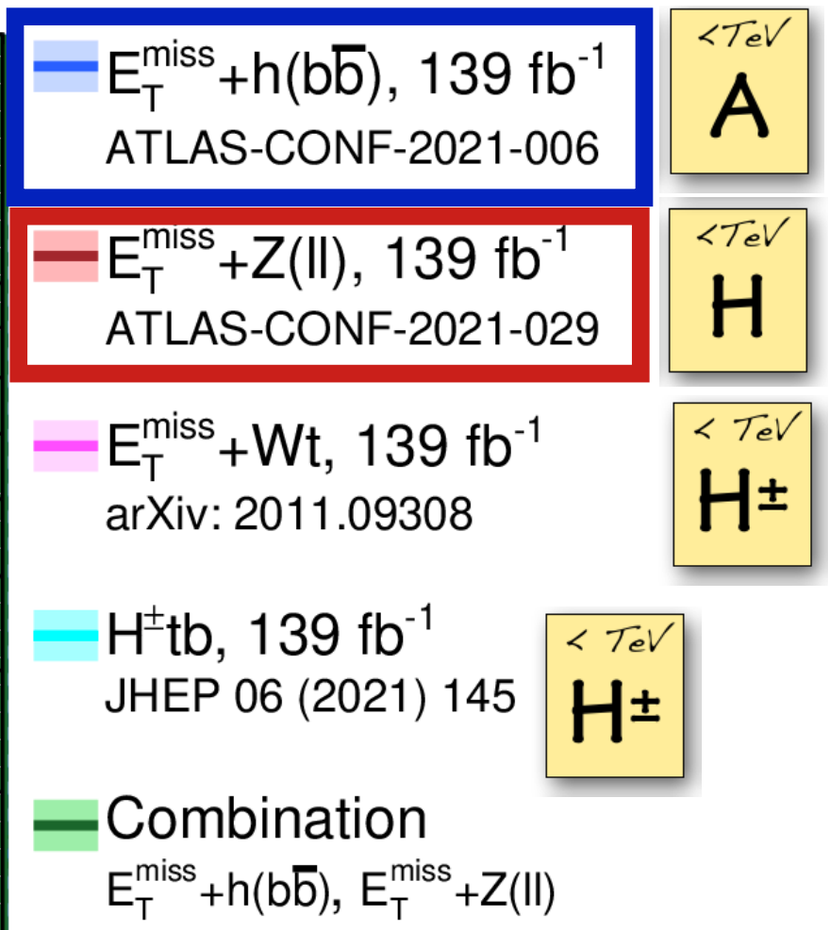
Combination
E_T^{miss}+h(bb̄), E_T^{miss}+Z(ll)

New analysis led by my YIG

Results (I)

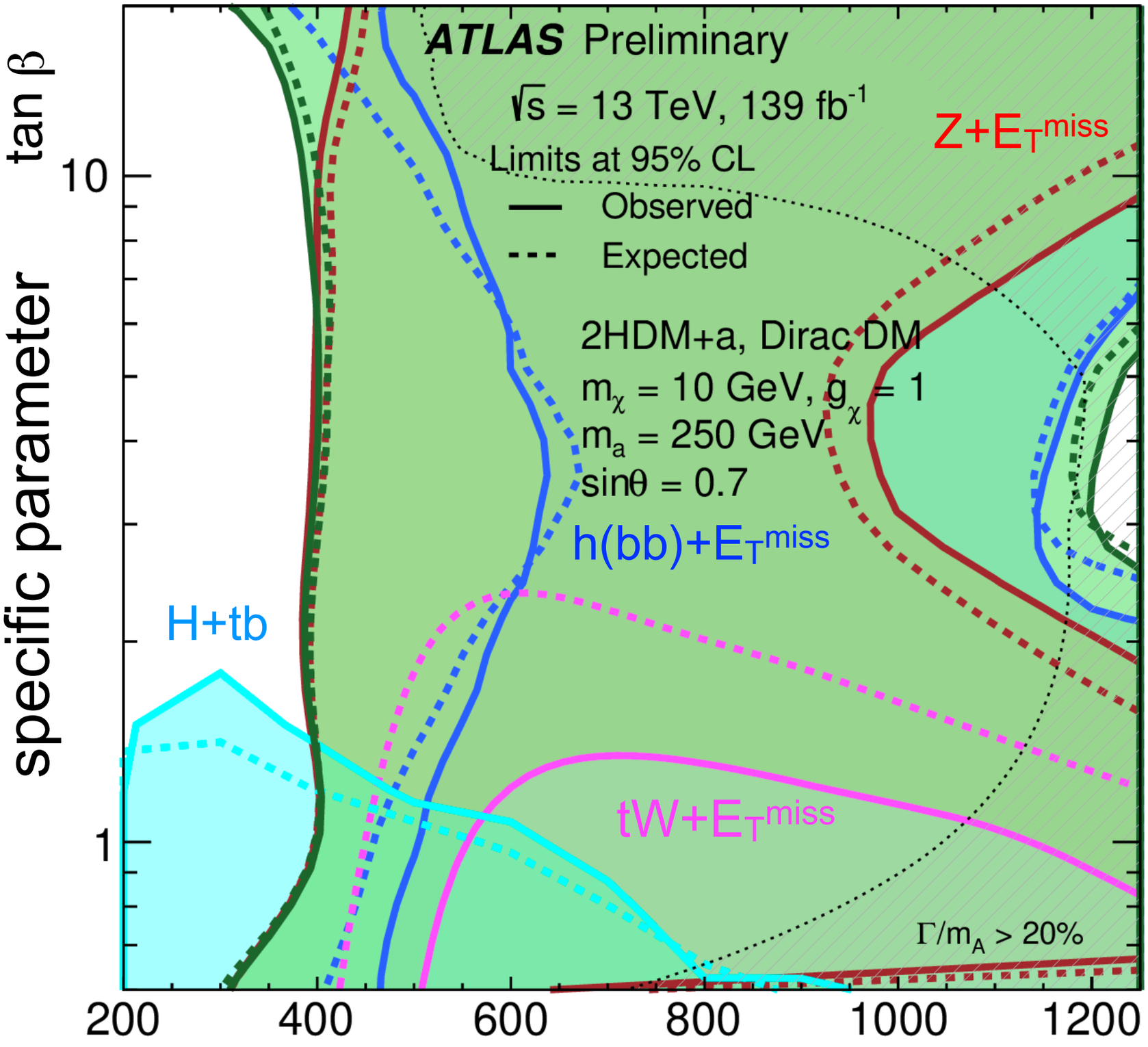
ATLAS-CONF-2021-036/





Results (I)

ATLAS-CONF-2021-036/



E_T^{miss}+h(bb̄), 139 fb^{-1}
ATLAS-CONF-2021-006

<TeV A

E_T^{miss}+Z(ll), 139 fb^{-1}
ATLAS-CONF-2021-029

<TeV H

E_T^{miss}+Wt, 139 fb^{-1}
arXiv: 2011.09308

< TeV H±

$H^{\pm}tb$, 139 fb^{-1}
JHEP 06 (2021) 145

< TeV H±

Combination
E_T^{miss}+h(bb̄), E_T^{miss}+Z(ll)

Combination h(bb) +E_T^{miss} and Z+E_T^{miss}

Further considerations

where to from here?

★ Many results with the full Run-2 datasets still in preparation but we can already plan ahead:
leave no stone unturned!

★ HL-LHC Yellow Report shows many projection on searches evolution in the next data-taking periods, reaching higher higher DM & mediator masses

★ LPCC DMWG working on establishing additional “less simplified” frameworks

Conclusions

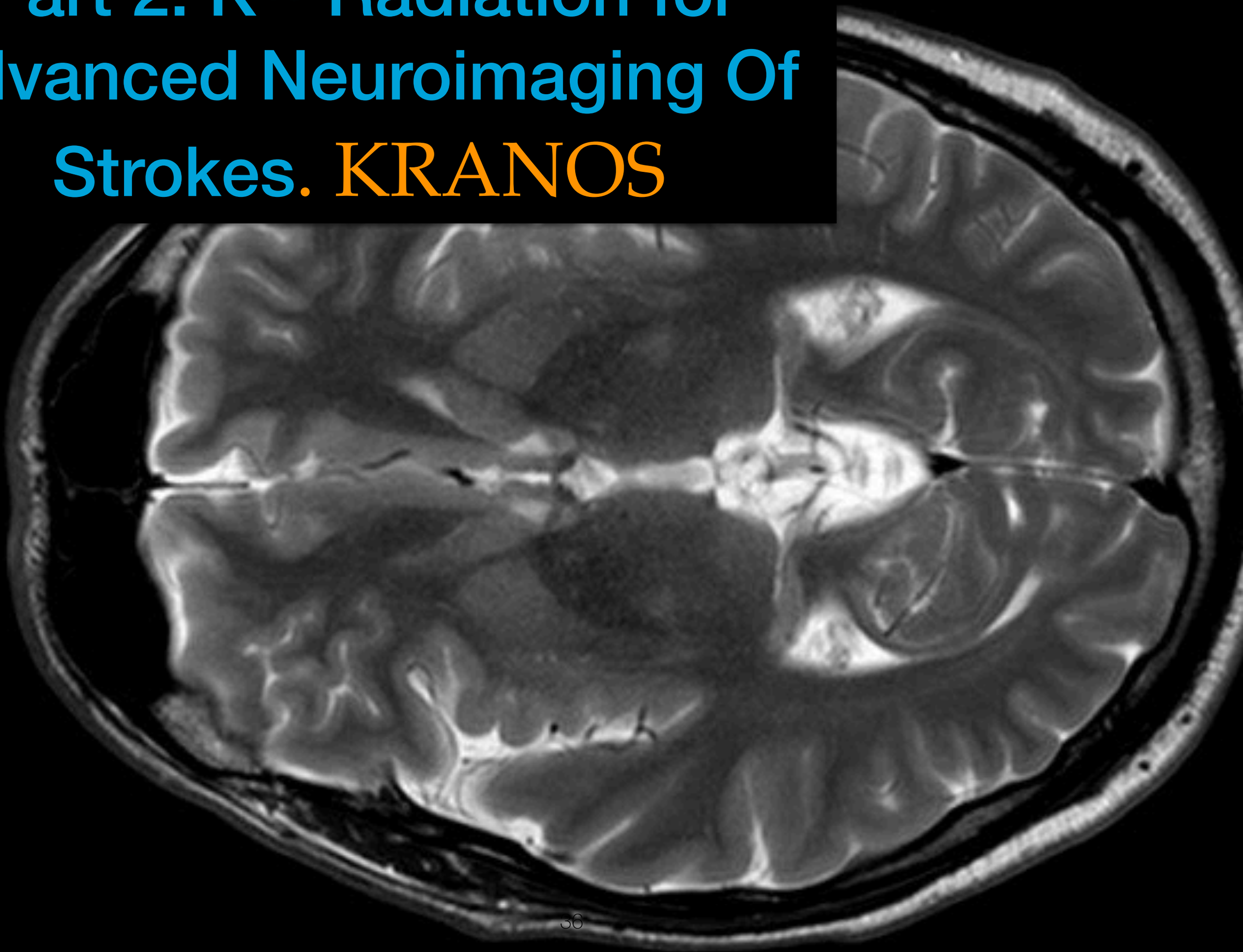
- Understanding the nature of dark matter is one of the greatest challenges in understanding our Universe
- Colliders have the potential to provide a unique tool to constrain and eventually measure dark matter properties and interactions

2012 The Higgs Boson discovery

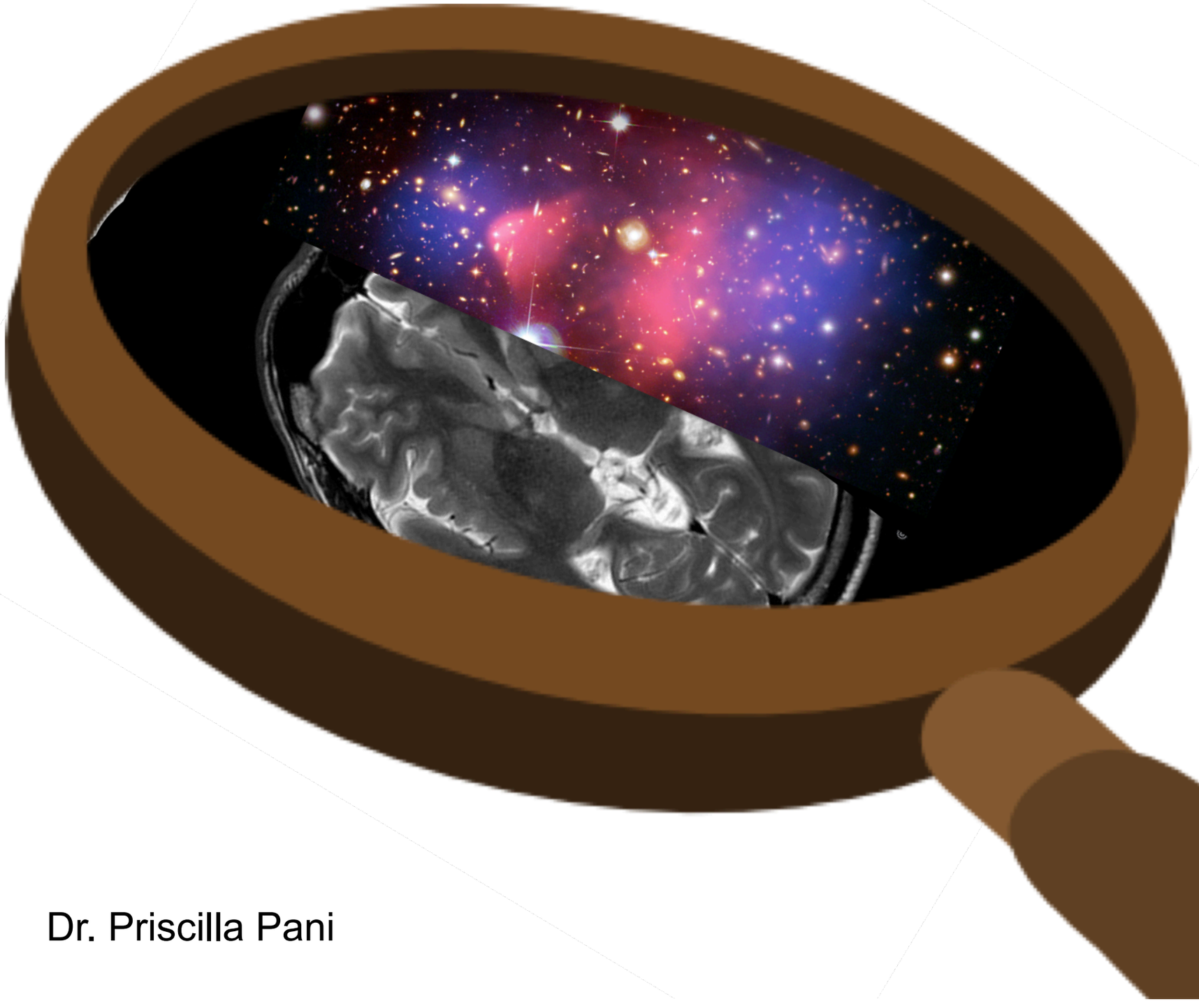
2016 The Gravitational Waves discovery

<2024 … ?

Part 2: K^{40} Radiation for Advanced Neuroimaging Of Strokes. KRANOS



Thanks for your attention!



Contact

DESY. Deutsches Elektronen-Synchrotron

www.desy.de

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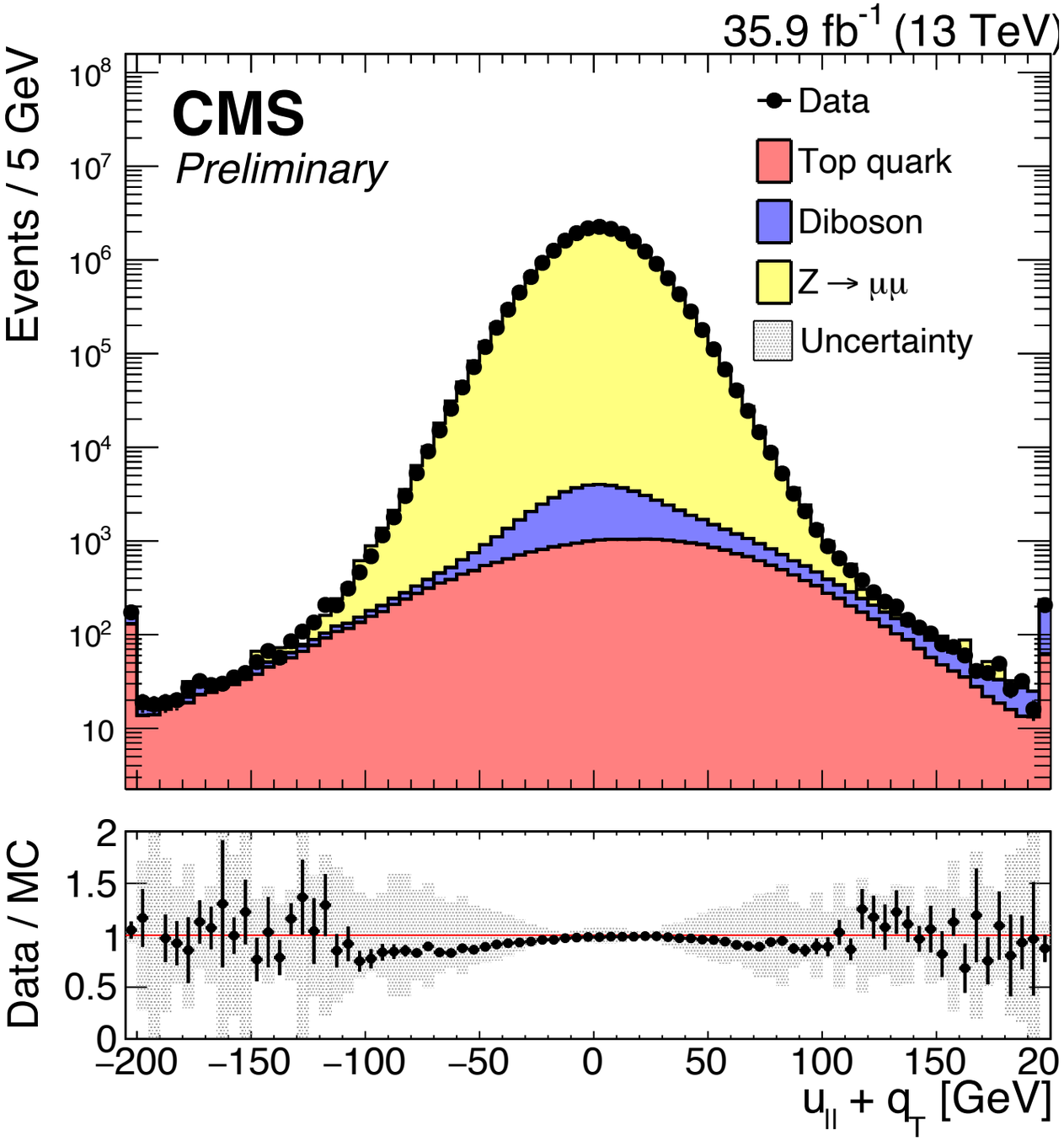
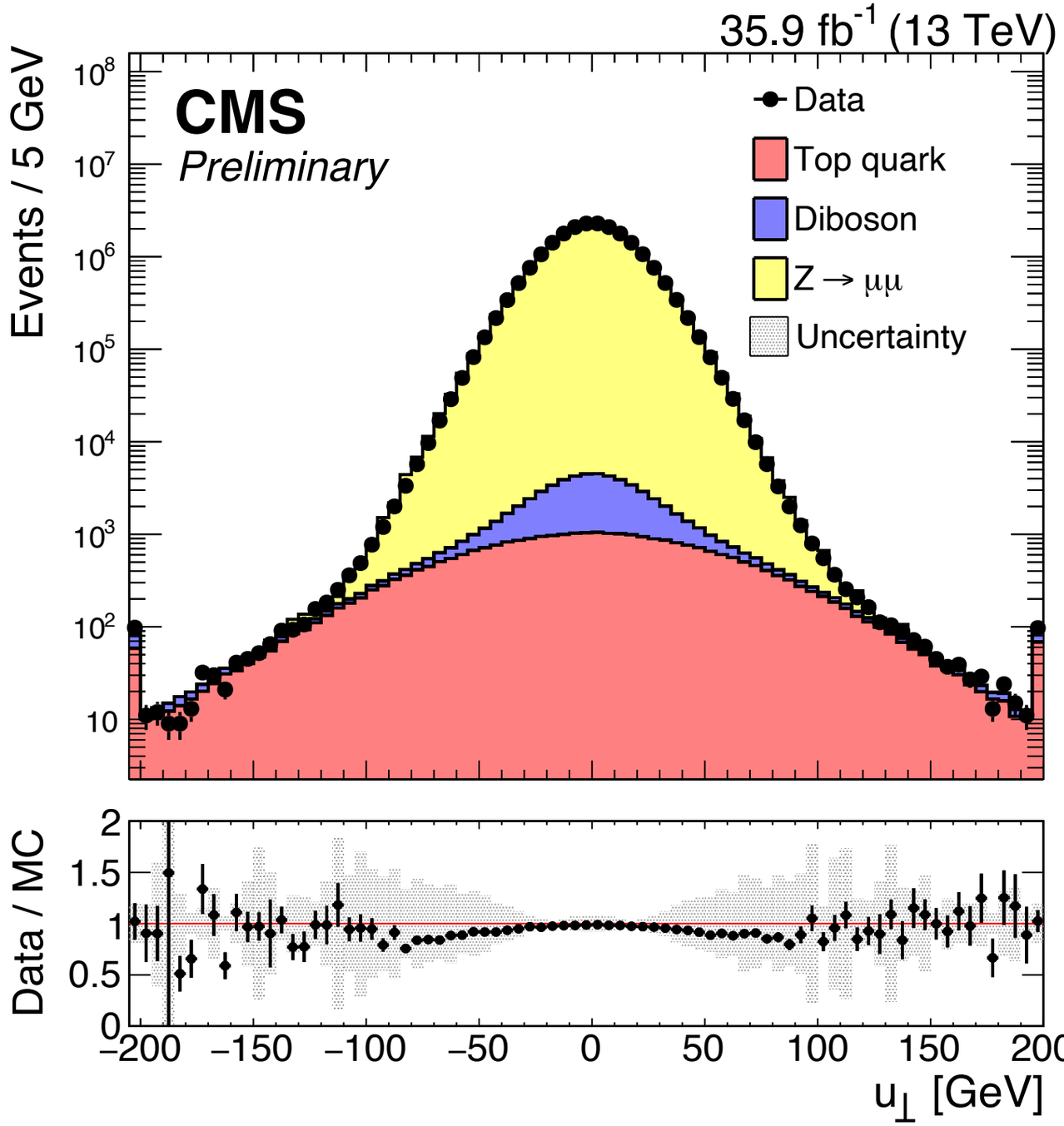
ATLAS Group Campus Zeuthen
priscilla.pani@desy.de

https://atlas.desy.de/external_grants/priscilla_pani_yig/

Backup

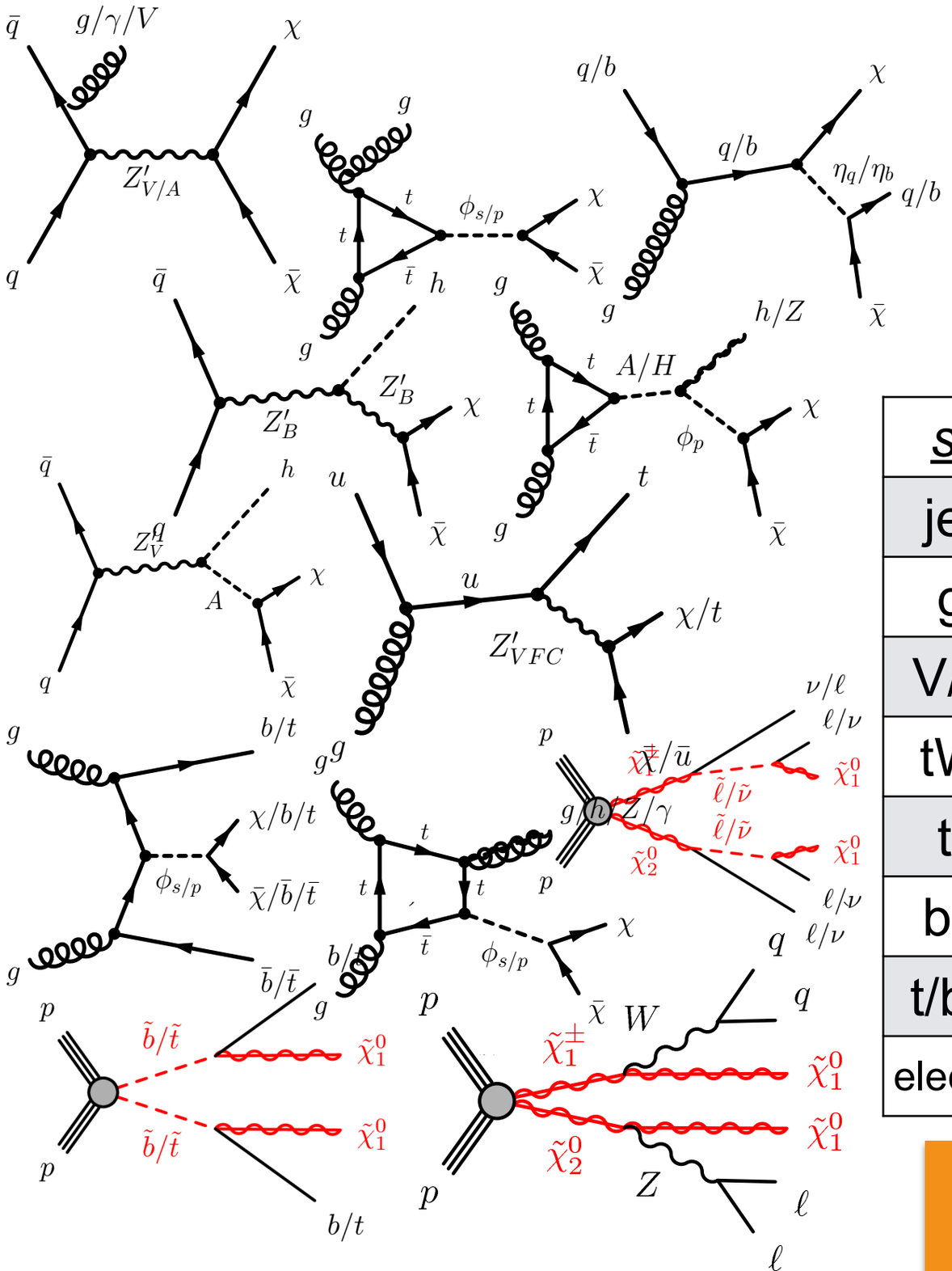
Missing Energy performance

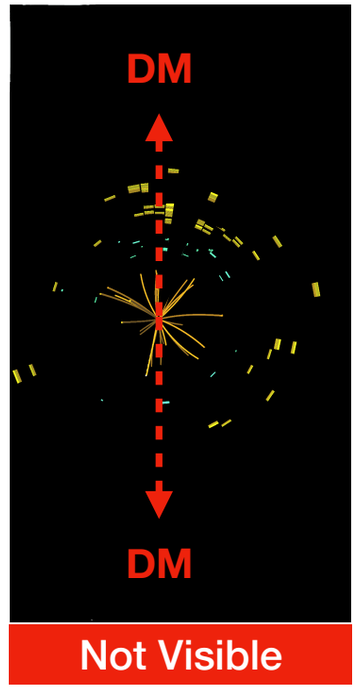


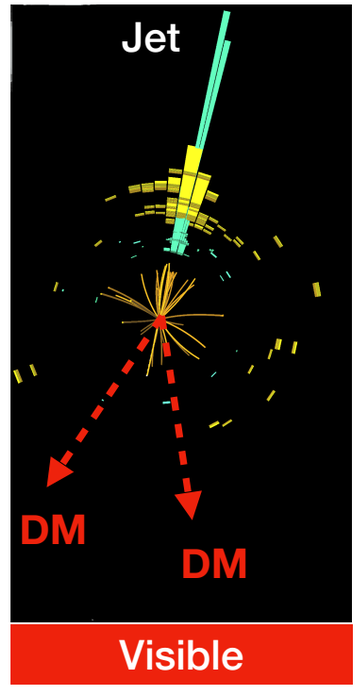


CMS-PAS-JME-17-001

Techniques 1 - E_T^{miss} + X







signature	*ATLAS Ref*	*CMS Ref*
jet+ E_T^{miss}	arXiv:2102.10874	see Summary
g+ E_T^{miss}	arXiv:2011.05259	see Summary
V/h+ E_T^{miss}	CONF-2020-054	arXiv:2008.04735
tW+ E_T^{miss}	arXiv:2011.09308	arXiv:1901.01553
tt+ E_T^{miss}	see Summary	arXiv:1807.06522
bb+ E_T^{miss}	arXiv:2101.12527	-
t/b squarks	public page	public page
electroweakinos	public page	public page

Disclaimer: just examples of (mostly) full data results

...

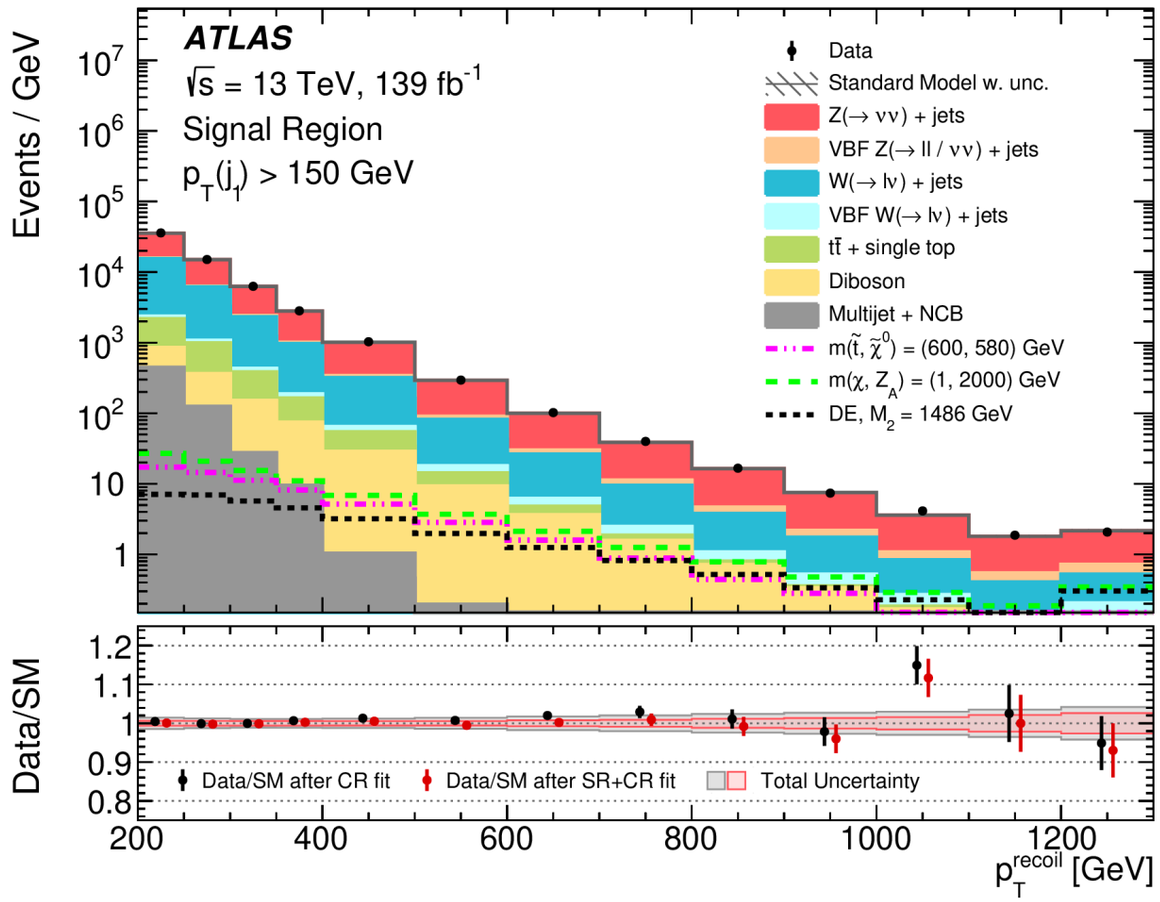
E_T^{miss} + X commonalities

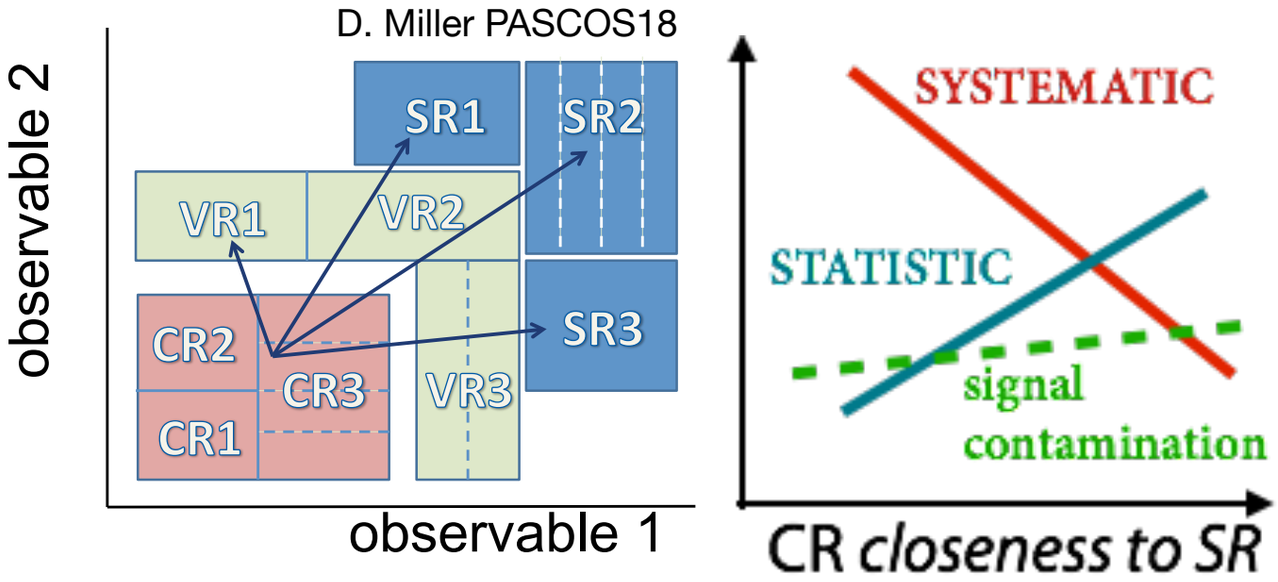
EXOT-2018-06

1) Definition of a set of Signal enriched Regions (SR)

2) Definition of a set of Control Regions (CR) to derive a data-driven normalisation of MC with transfer factors (TF).

3) Validation of the TF in the Validation Region (VR)

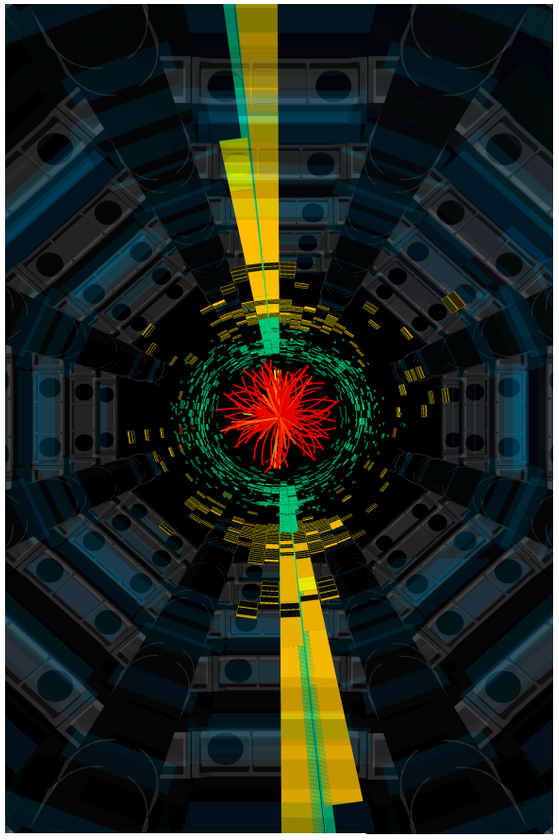


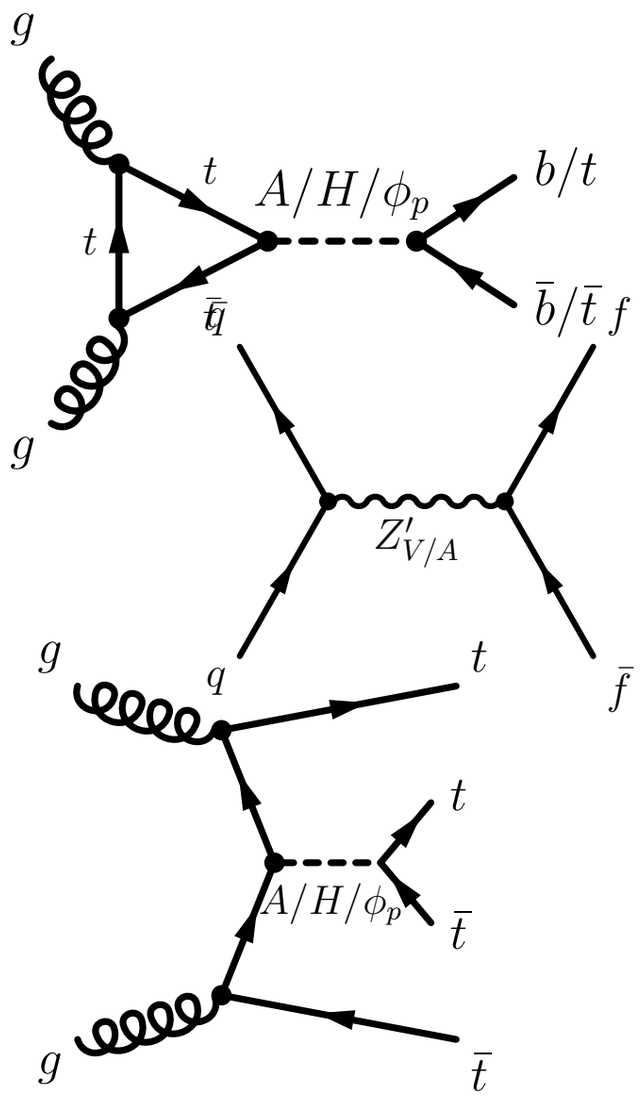


4) Unblinding ! check whether an excess is observed (p-value)

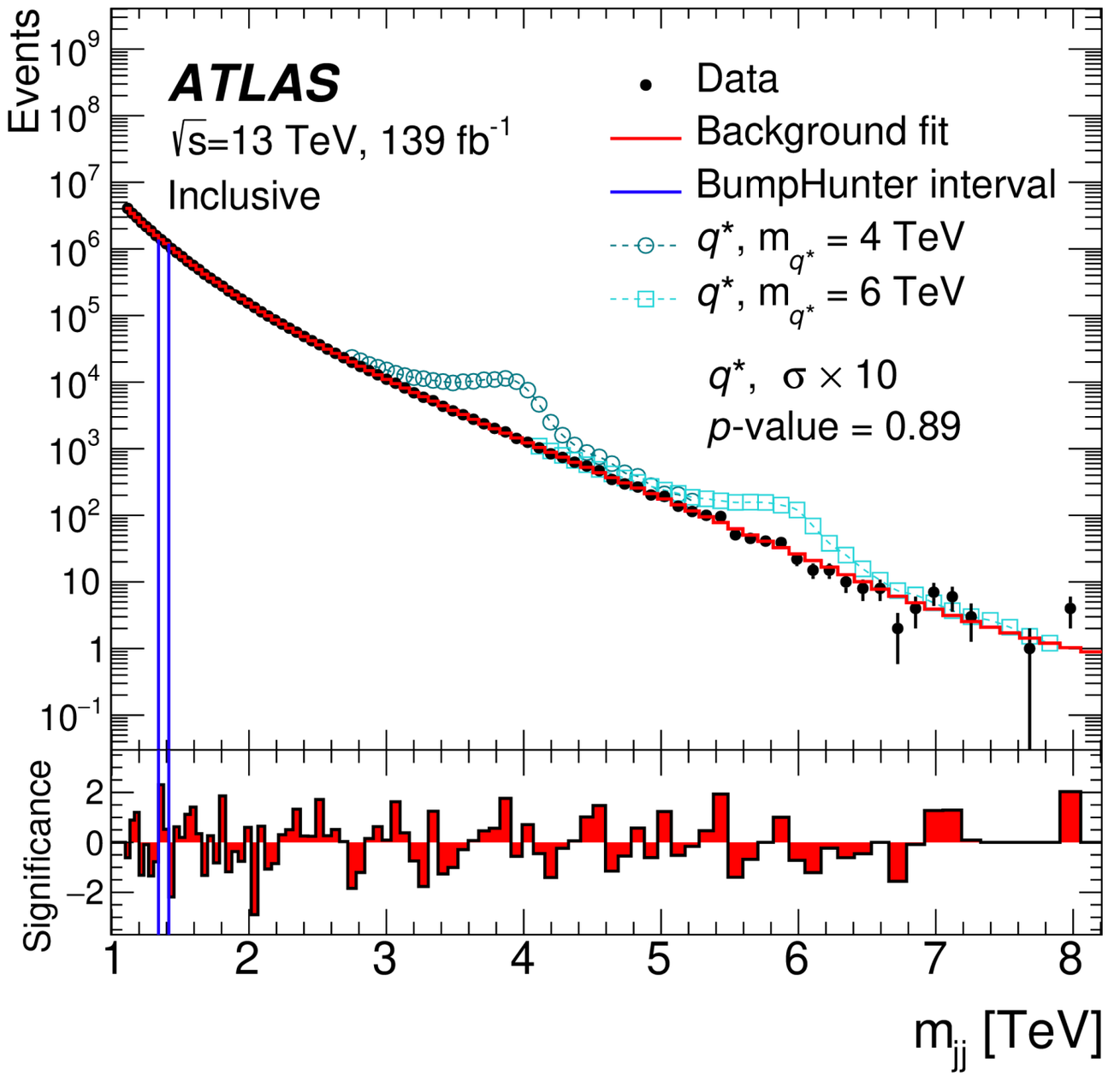
5) If no excess is found the results are interpreted in terms of limits on selected models.

Techniques 2 - resonances



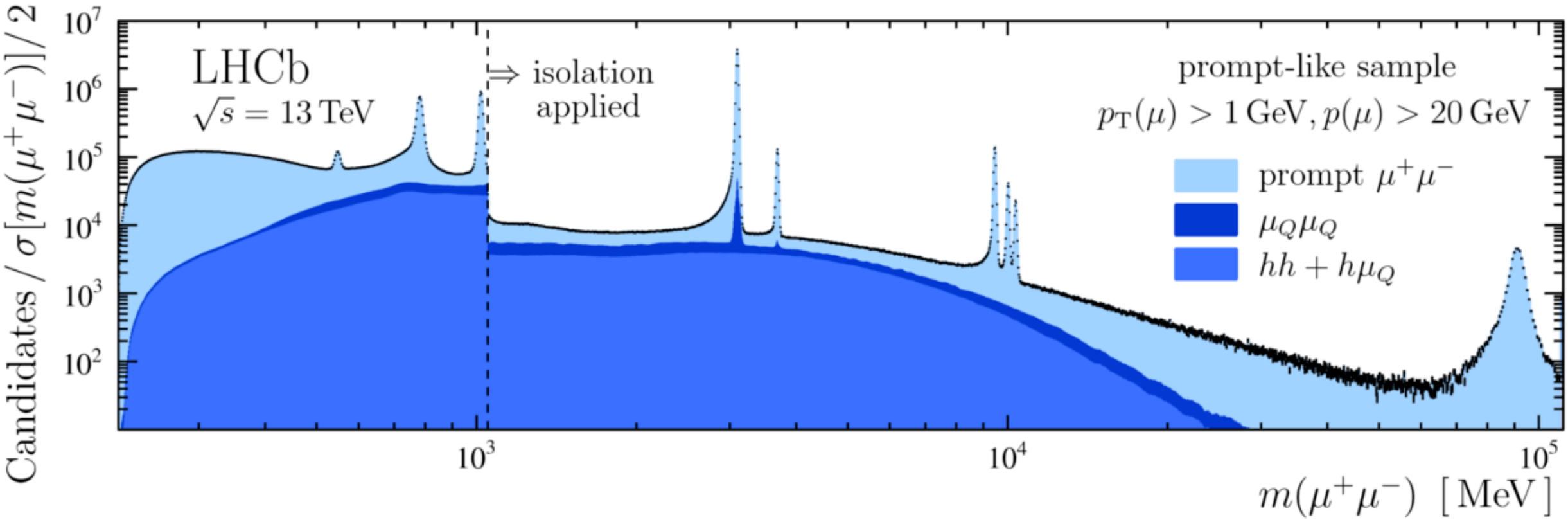


EXOT-2018-03

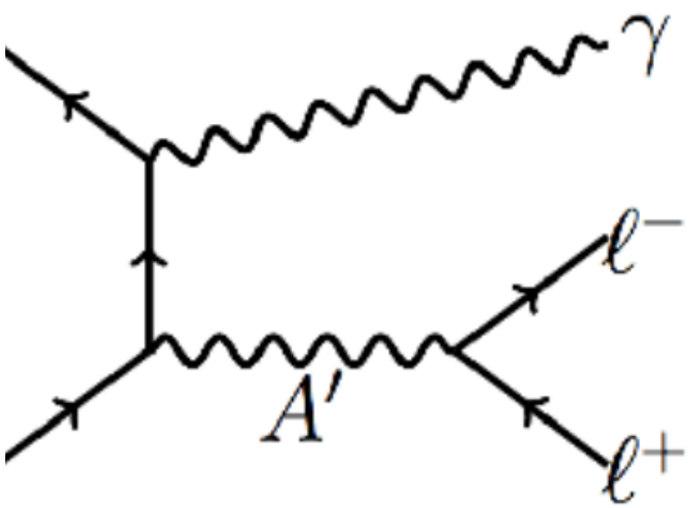


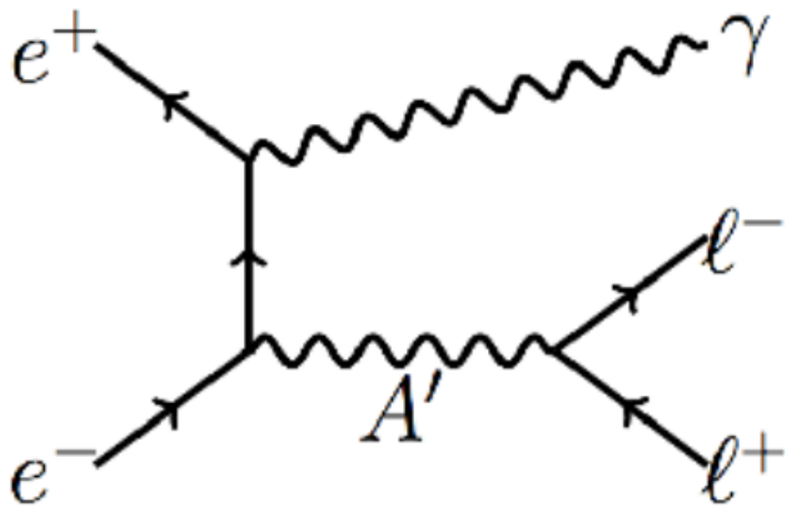
- ★ Low-mass determined by trigger (TLA/di-jet+ISR have the lowest mass sensitivity)
- ★ Sensitive to the mediator width

A word on Dark Photons



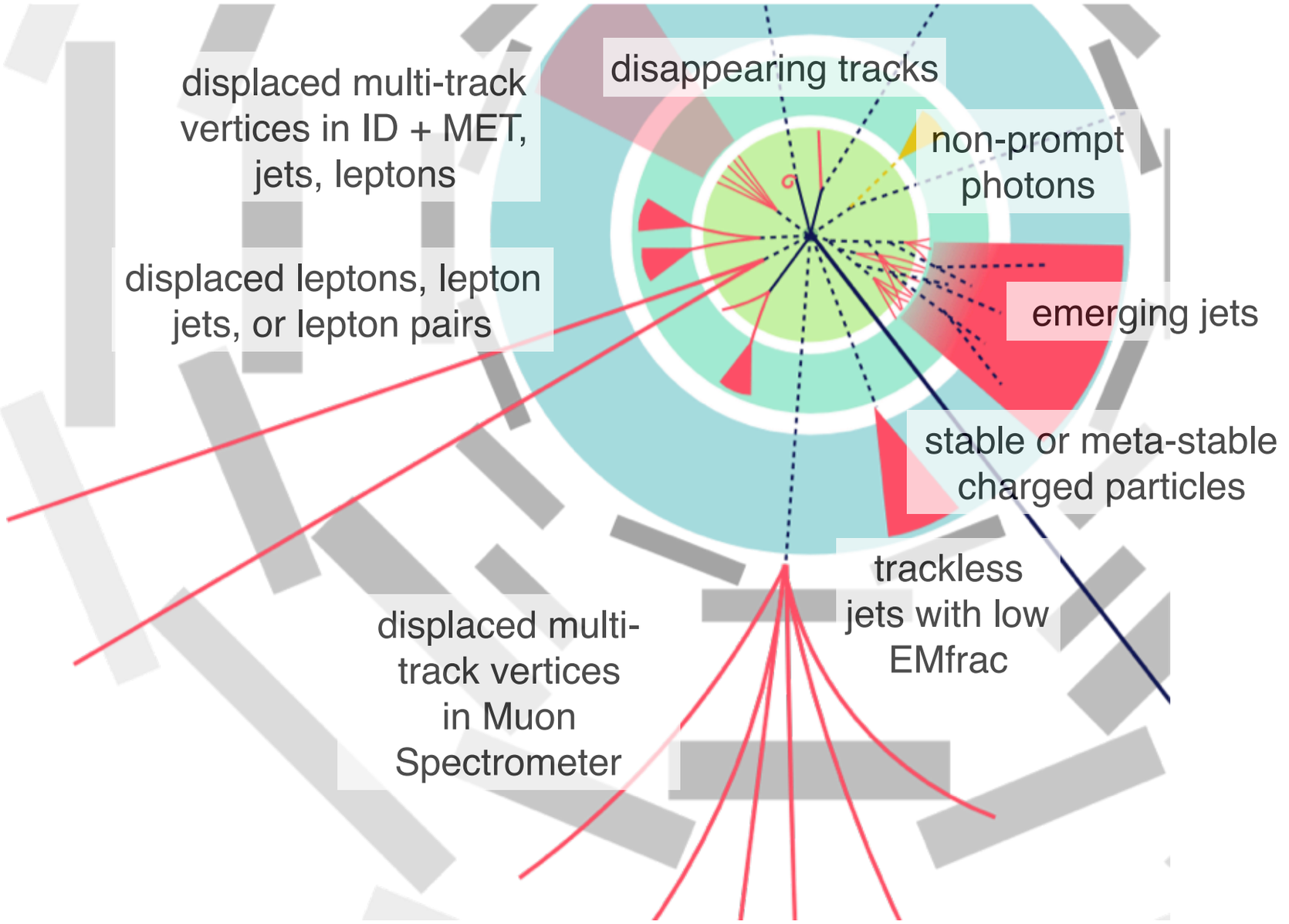
p





Techniques 3 - Long Lived Particles

- macroscopic decay length models
- hidden DM
- weak-scale hidden sectors
- SUSY LLPs
- ….

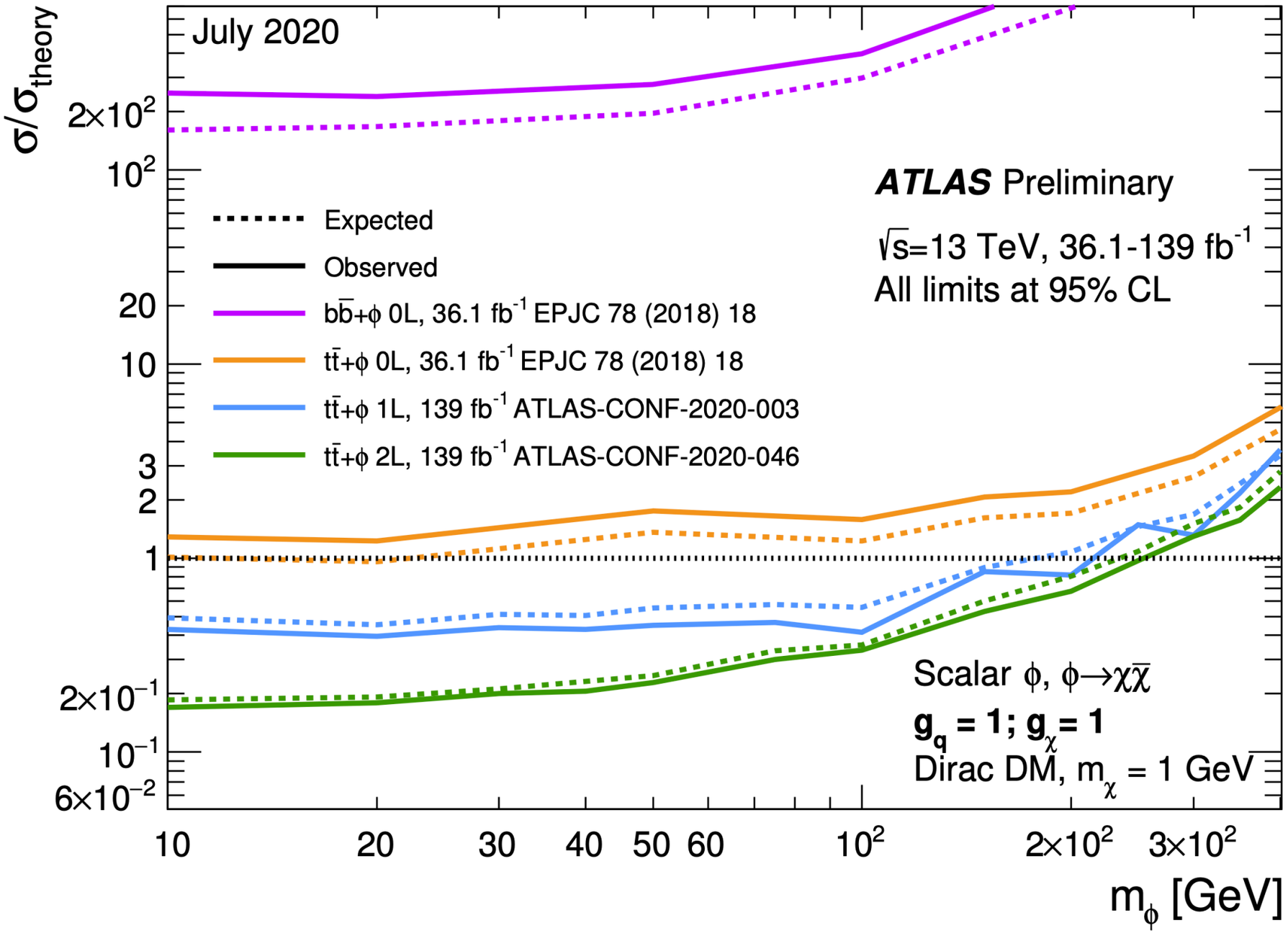


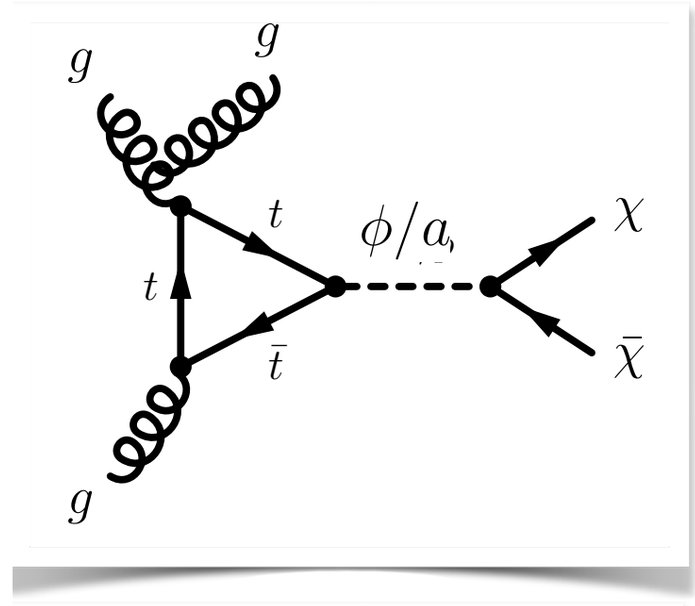
Well established in SUSY, less interpretation in other DM models.
Disclaimer: not covered further in the results!

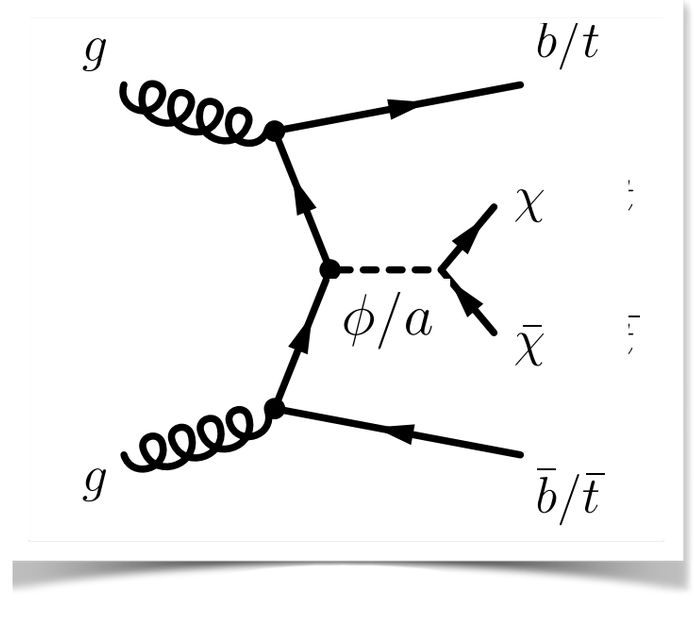
Spin-0 mediators

$$\mathcal{L} \sim \sum_f i g_v \frac{y_f}{\sqrt{2}} A \bar{f} \gamma^5 f$$

Needed to easily fulfil Flavour Constraints (MFV)

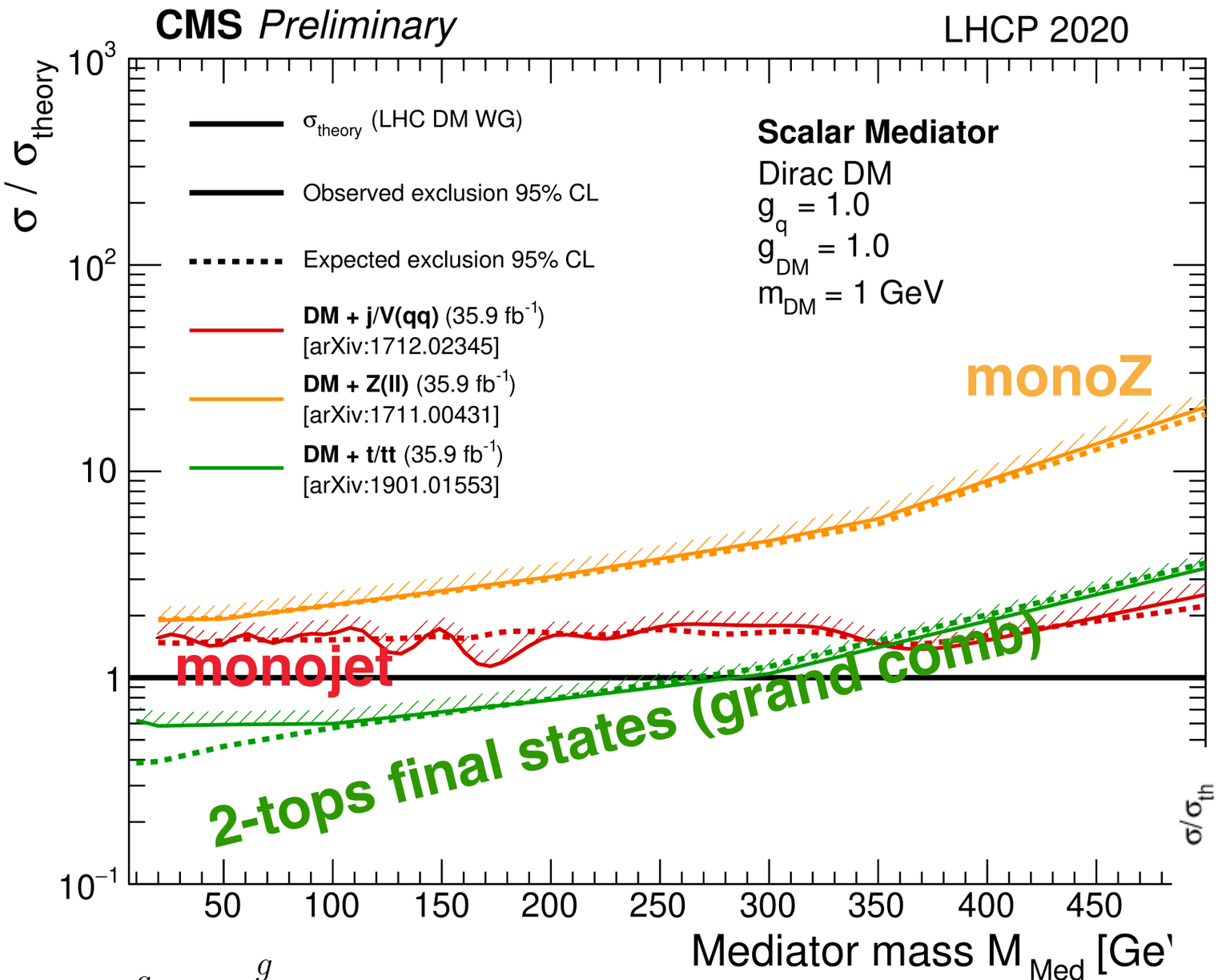


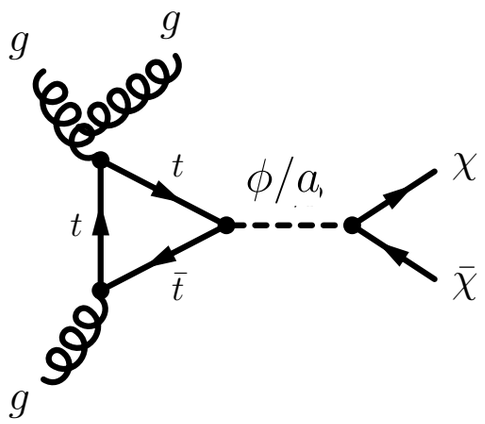




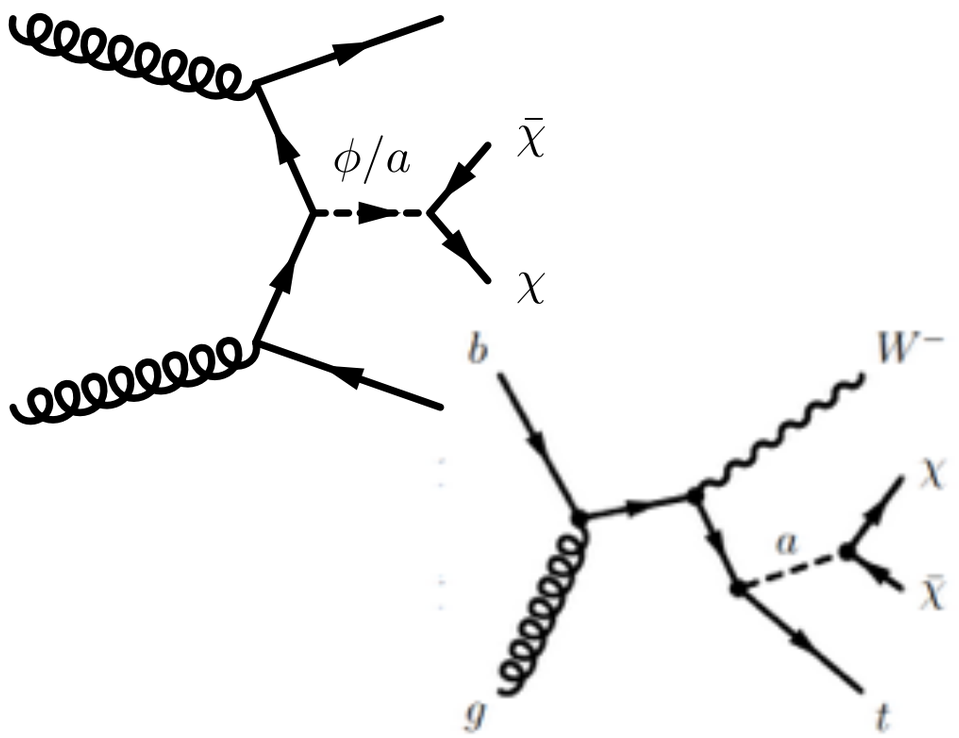
ATL-PHYS-PUB-2020-021

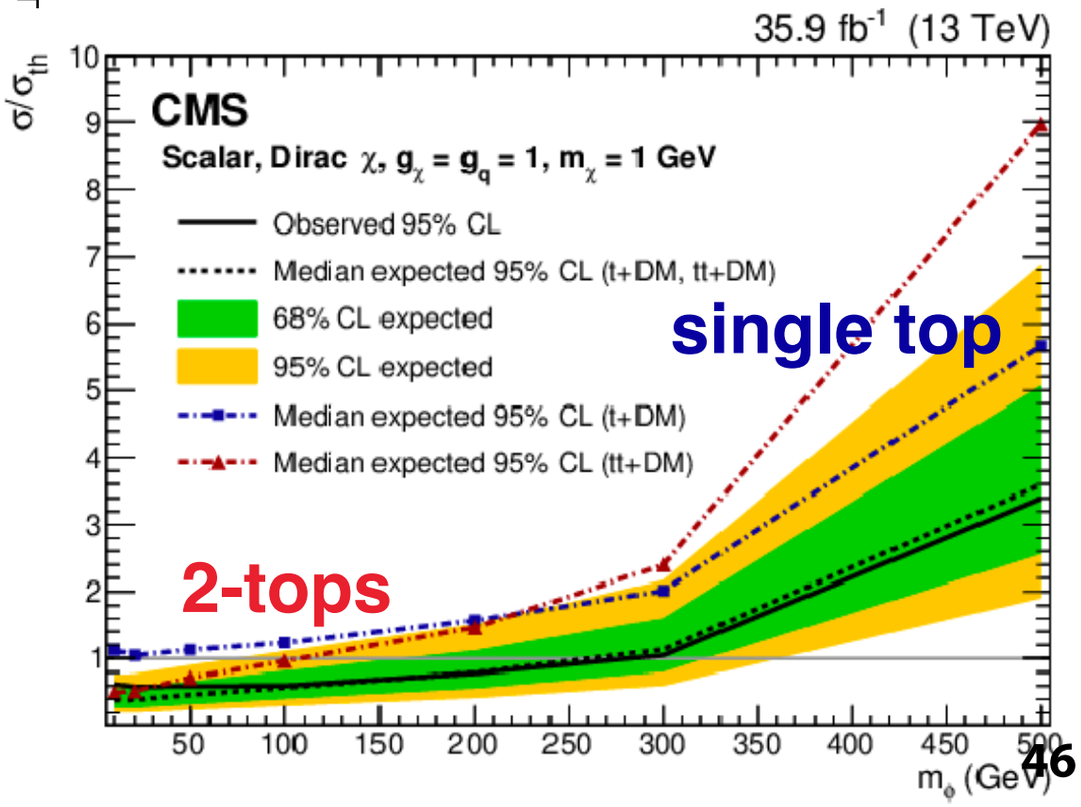
Spin-0 mediators (scalar)



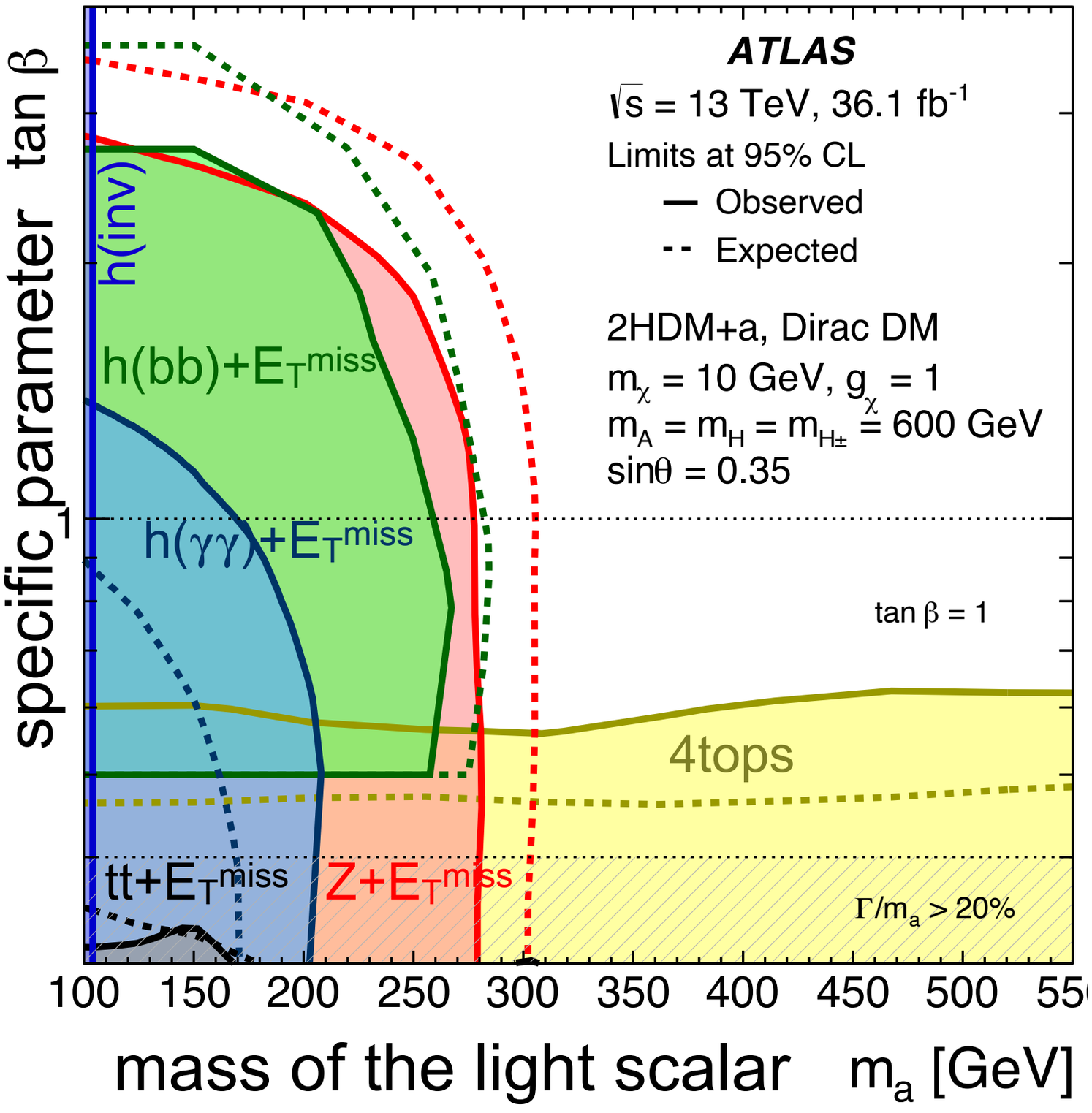


DM Summary Plots

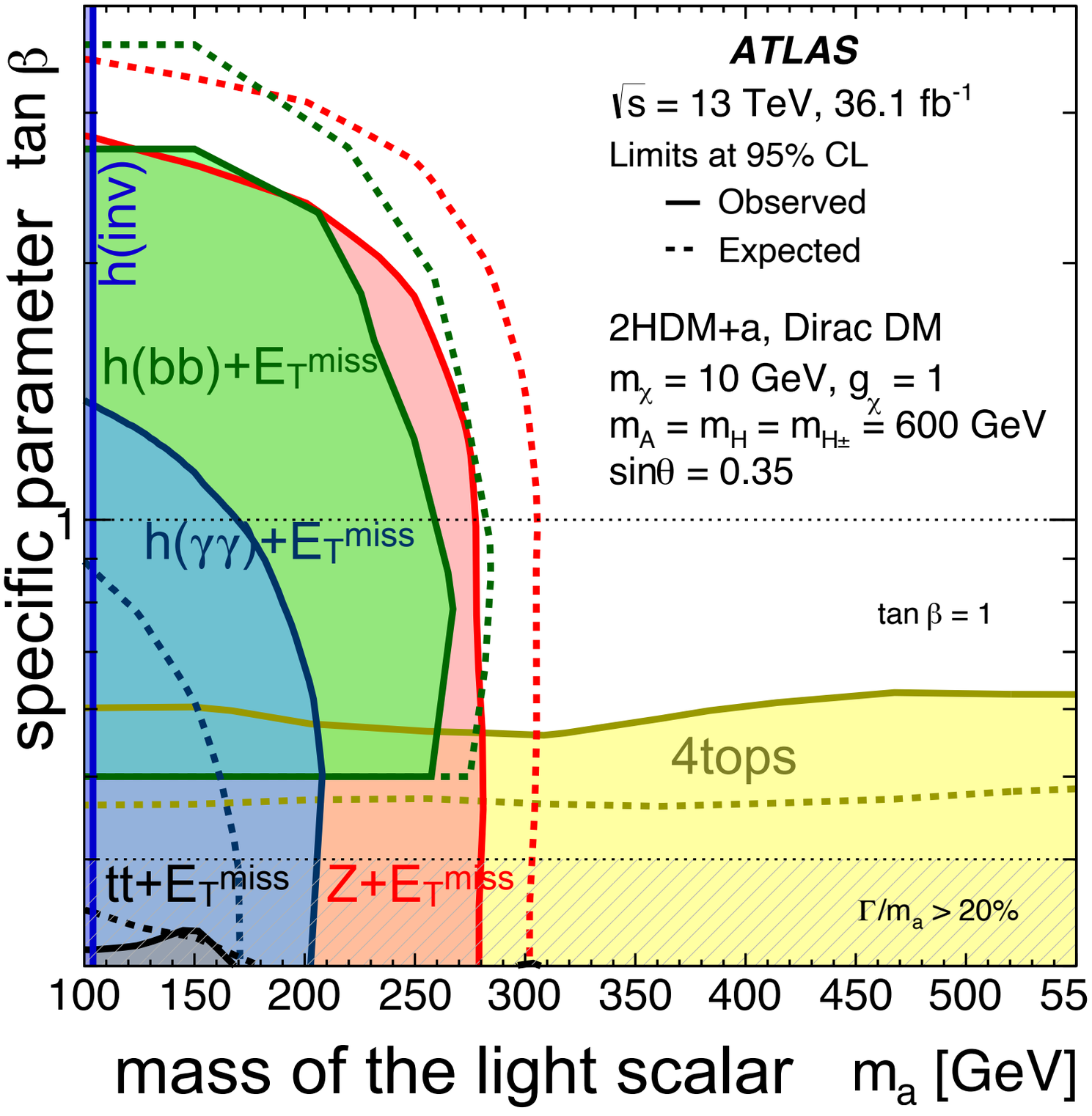




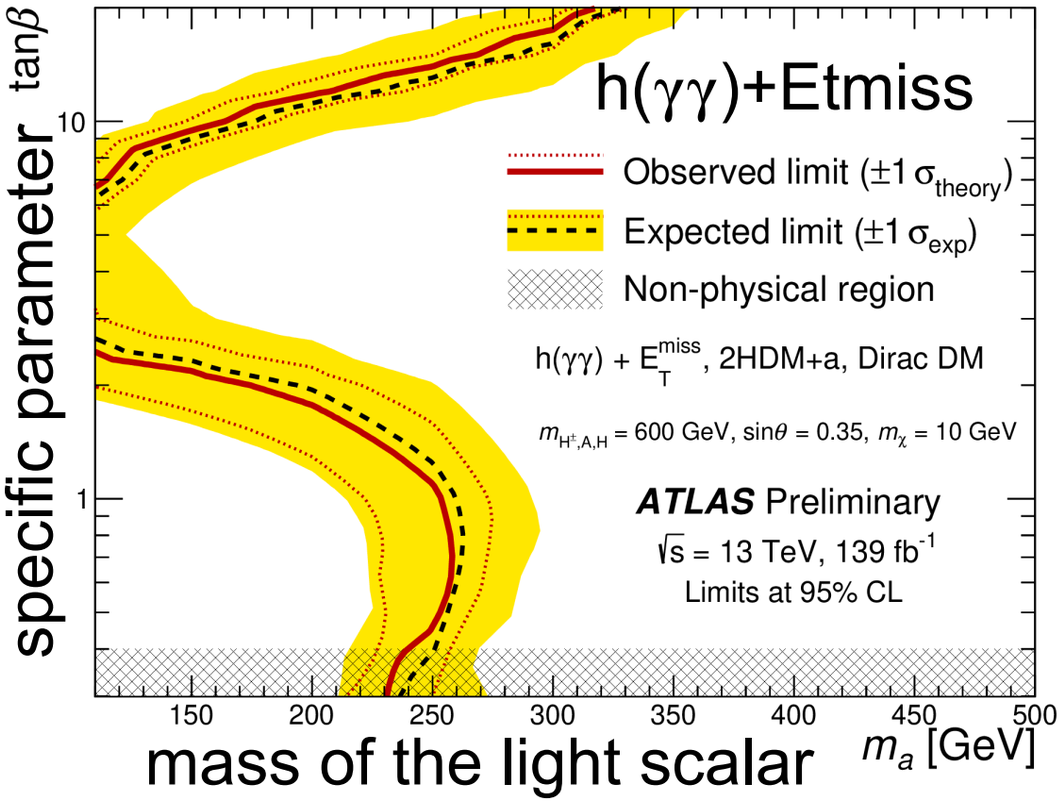
Results (I)


ATLAS
√s = 13 TeV, 36.1 fb-1
Limits at 95% CL
Observed
Expected
2HDM+a, Dirac DM
mχ = 10 GeV, gχ = 1
mA = mH = mH± = 600 GeV
sinθ = 0.35
tan β = 1
h(inv)
h(bb)+ETmiss
h(γγ)+ETmiss
4tops
tt+ETmiss
Z+ETmiss
Γ/ma > 20%
specific parameter tan β
mass of the light scalar ma [GeV]
100 150 200 250 300 350 400 450 500 55

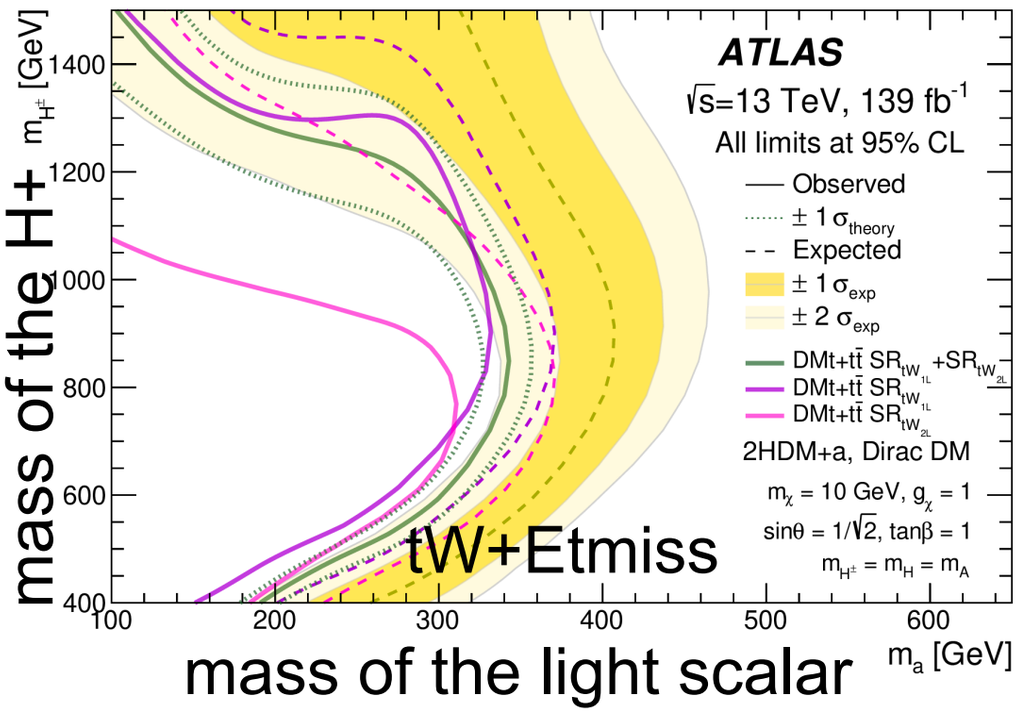
Results (I)



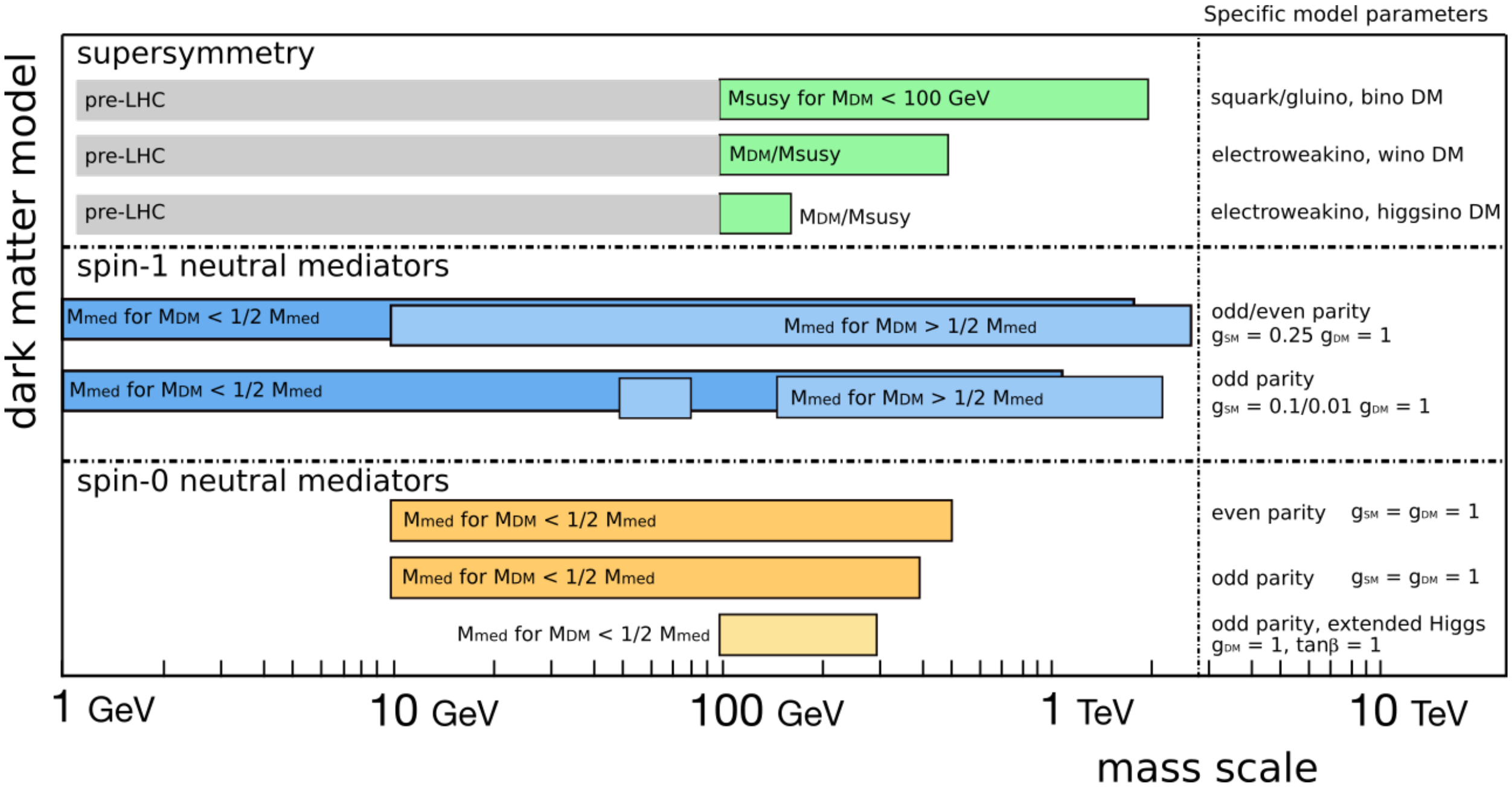
ATLAS-CONF-2020-054



EXOT-2018-43

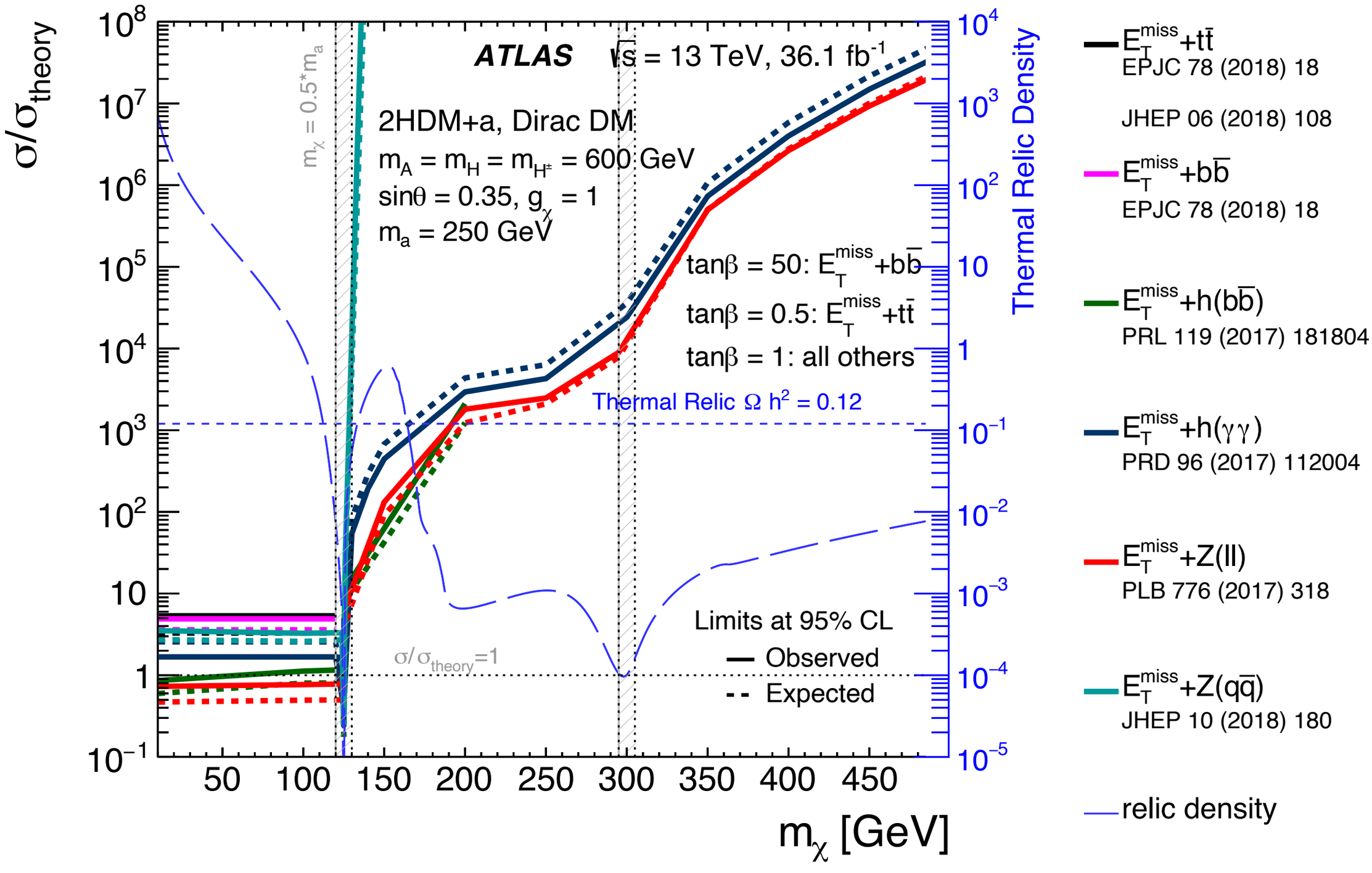


Mass scales overview

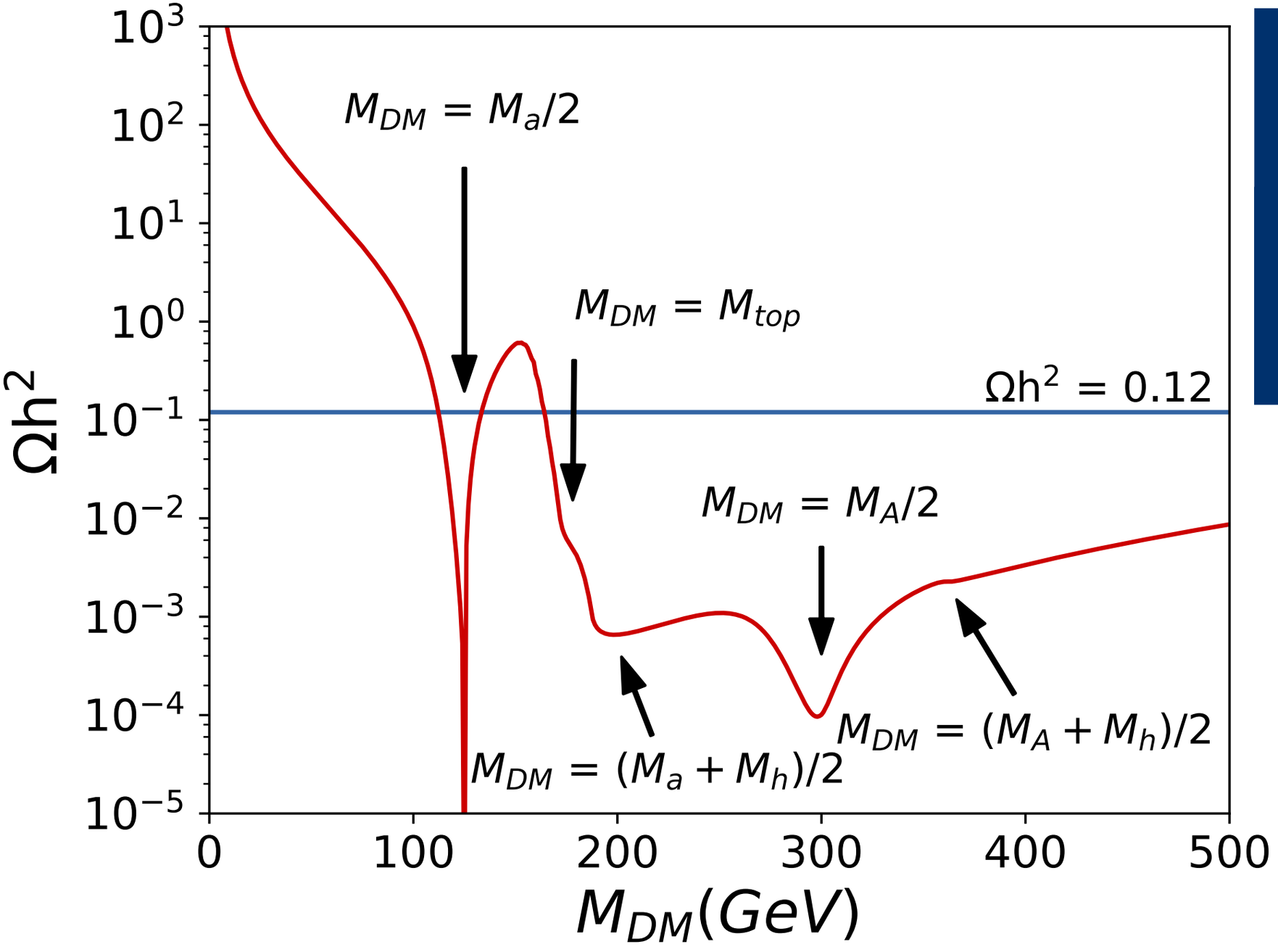


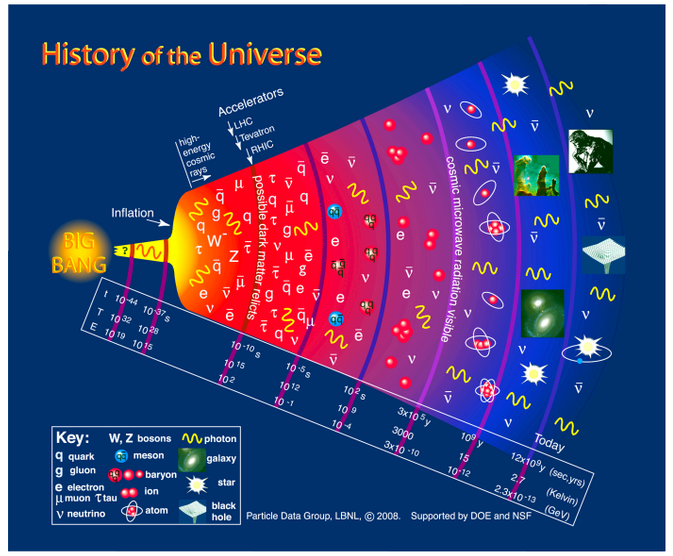
Physik Journal Issue August 2020

Relic density perspective

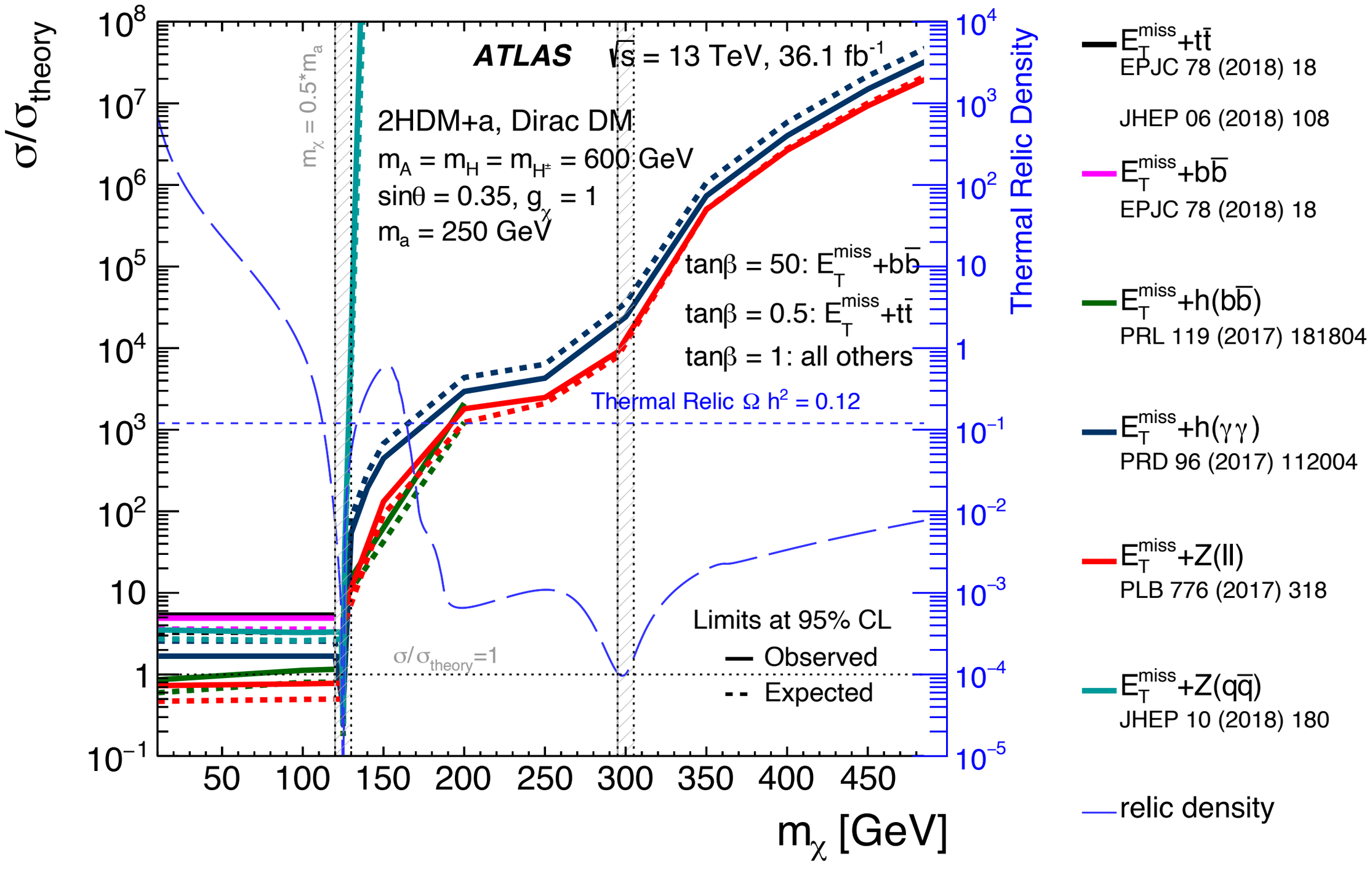


Understanding the relic prediction

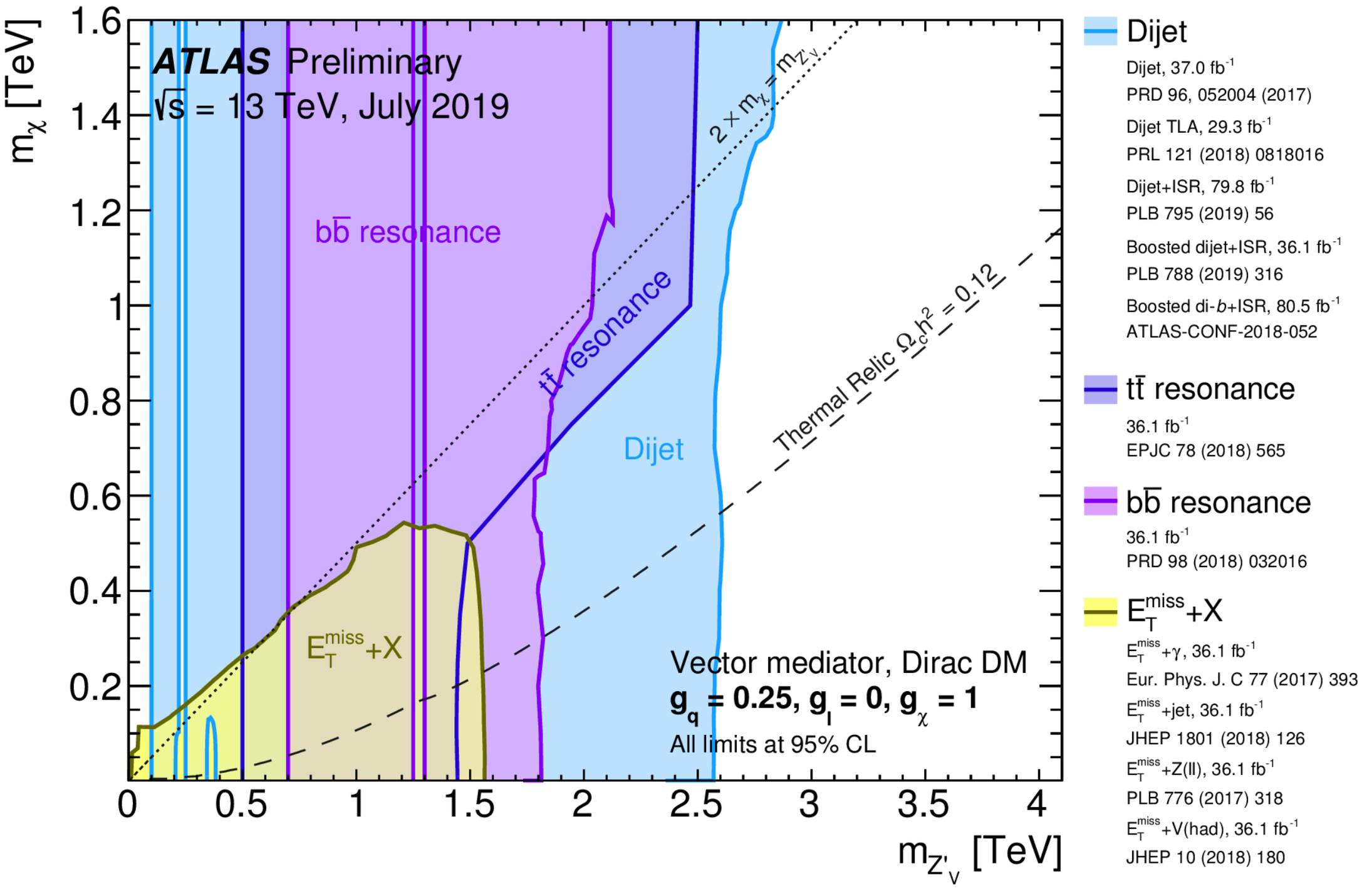




Relic density perspective



Spin-1: features explained



Dijet

Dijet, 37.0 fb^{-1}
PRD 96, 052004 (2017)

Dijet TLA, 29.3 fb^{-1}
PRL 121 (2018) 0818016

Dijet+ISR, 79.8 fb^{-1}
PLB 795 (2019) 56

Boosted dijet+ISR, 36.1 fb^{-1}
PLB 788 (2019) 316

Boosted di-*b*+ISR, 80.5 fb^{-1}
ATLAS-CONF-2018-052

tt̄ resonance

36.1 fb^{-1}
EPJC 78 (2018) 565

bb̄ resonance

36.1 fb^{-1}
PRD 98 (2018) 032016

E_T^{miss}+X

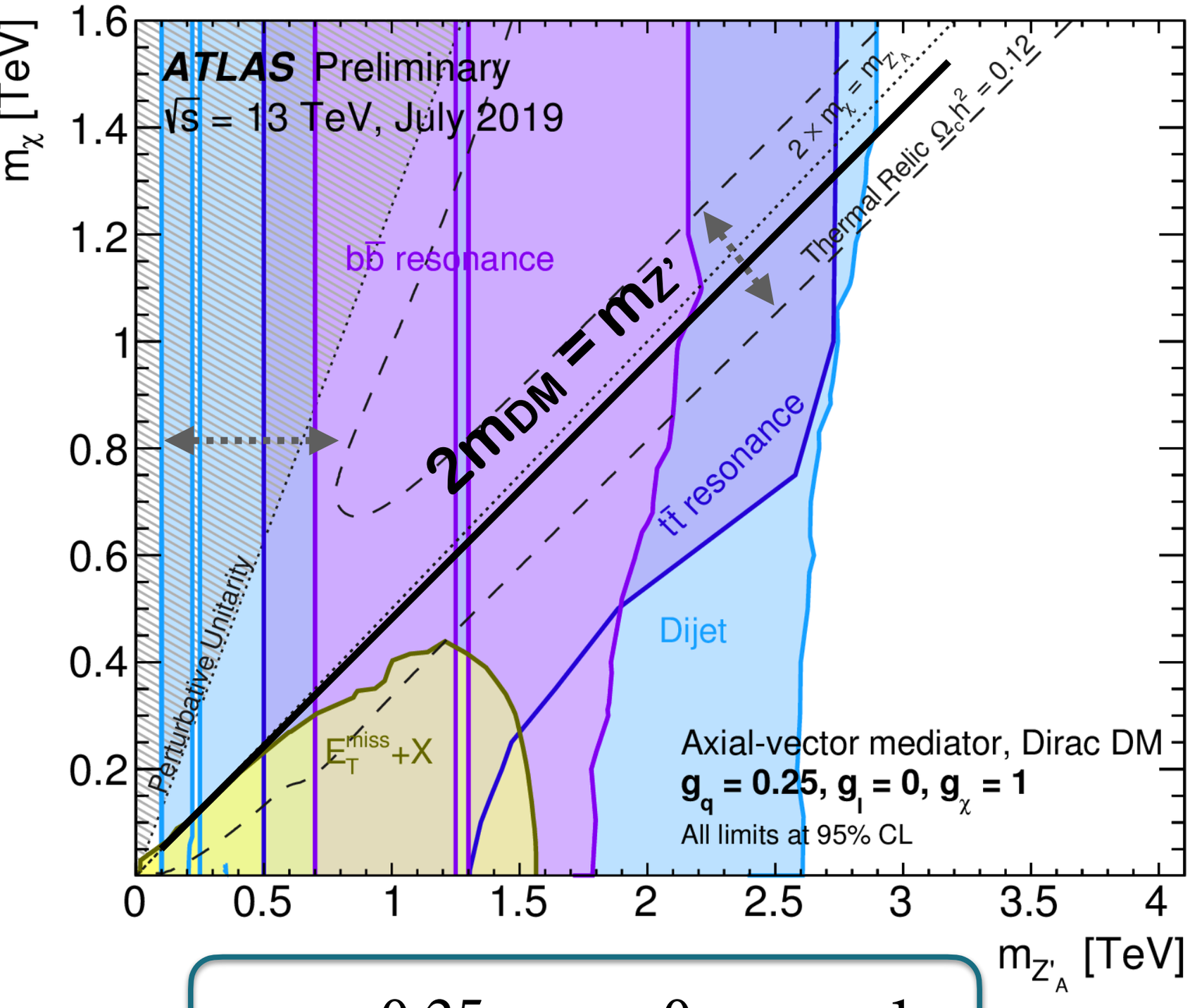
E_T^{miss}+γ, 36.1 fb^{-1}
Eur. Phys. J. C 77 (2017) 393

E_T^{miss}+jet, 36.1 fb^{-1}
JHEP 1801 (2018) 126

E_T^{miss}+Z(ll), 36.1 fb^{-1}
PLB 776 (2017) 318

E_T^{miss}+V(had), 36.1 fb^{-1}
JHEP 10 (2018) 180

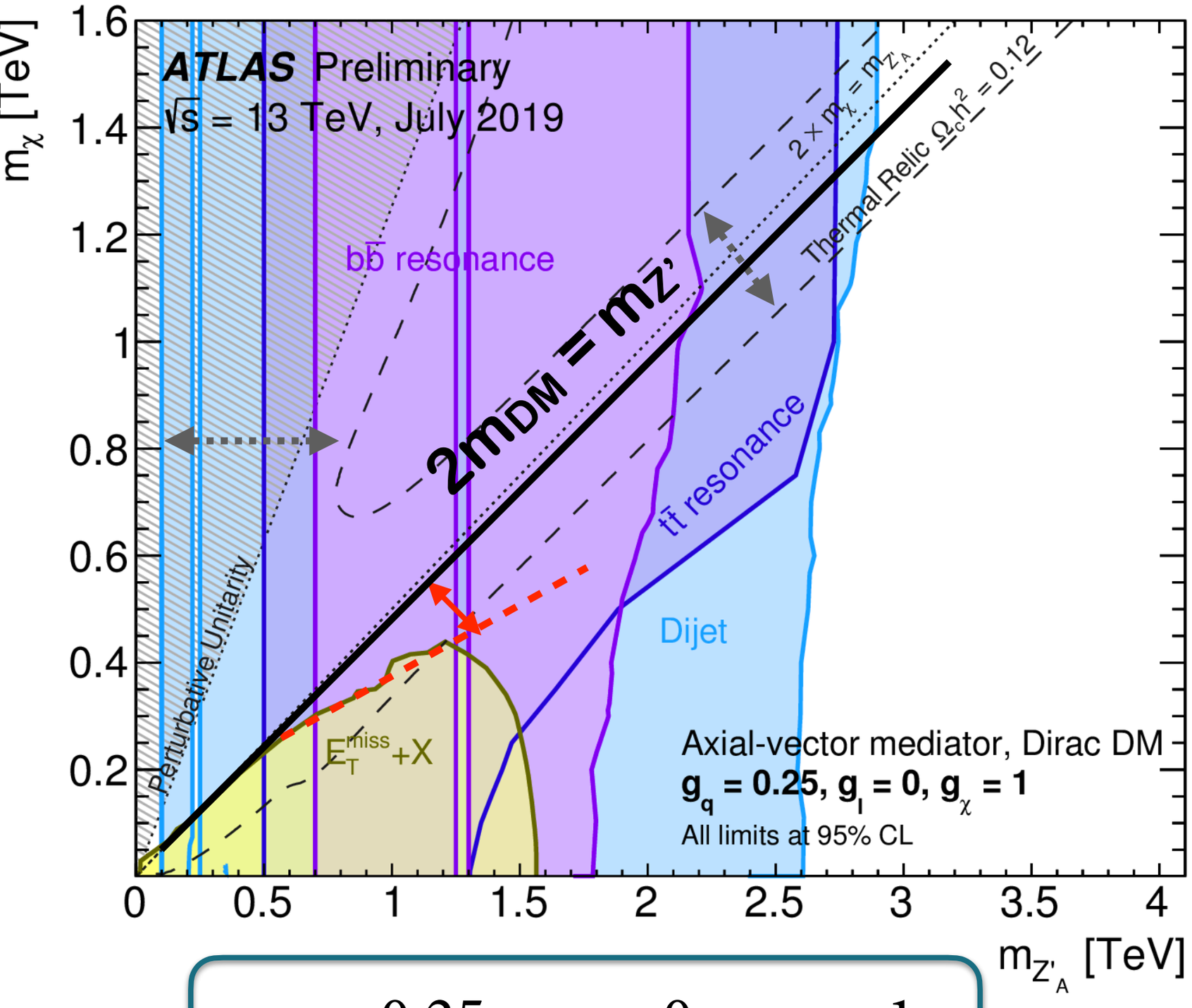
Spin-1: features explained



$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained

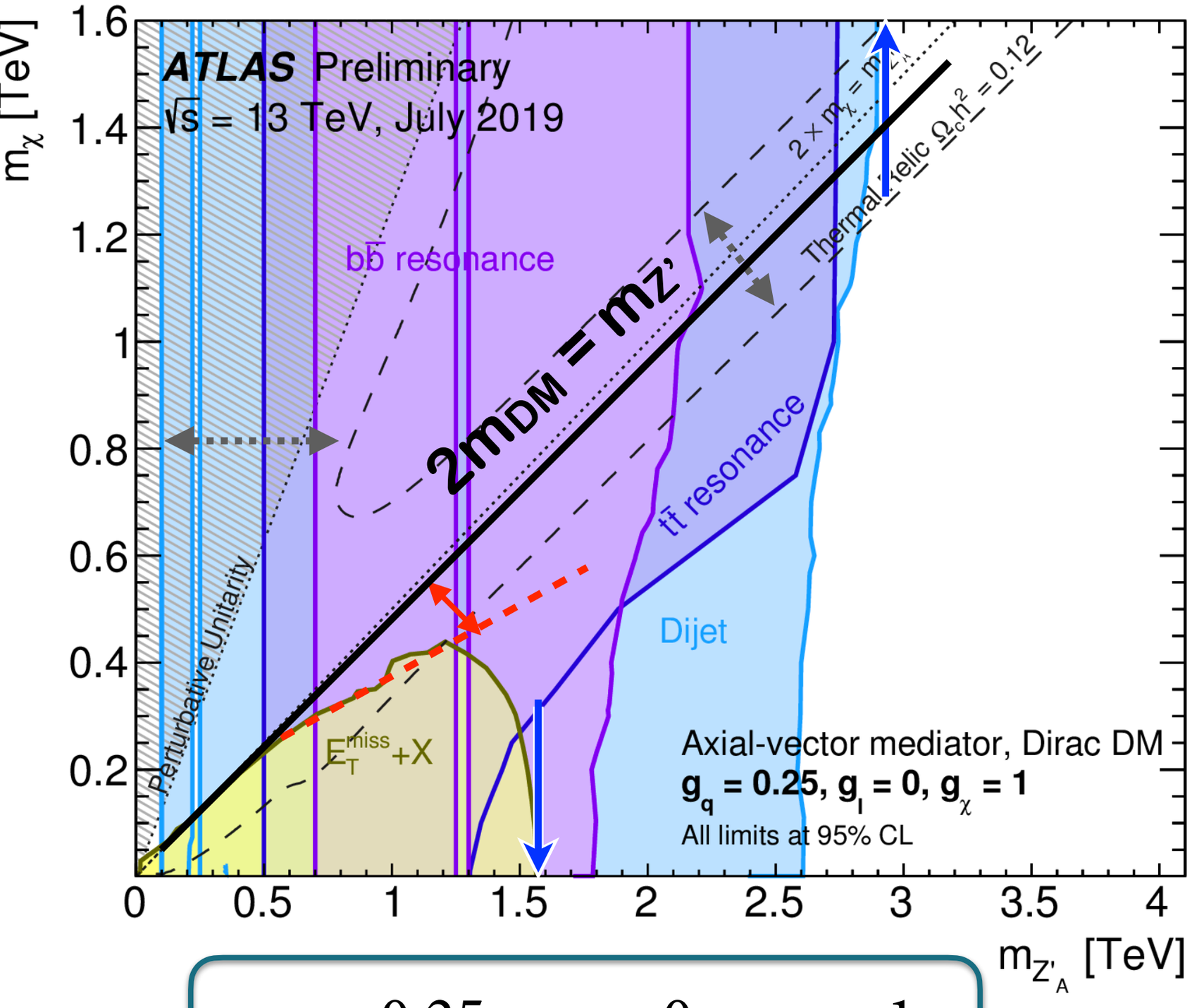


Loss of sensitivity due to mediator width effects

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained



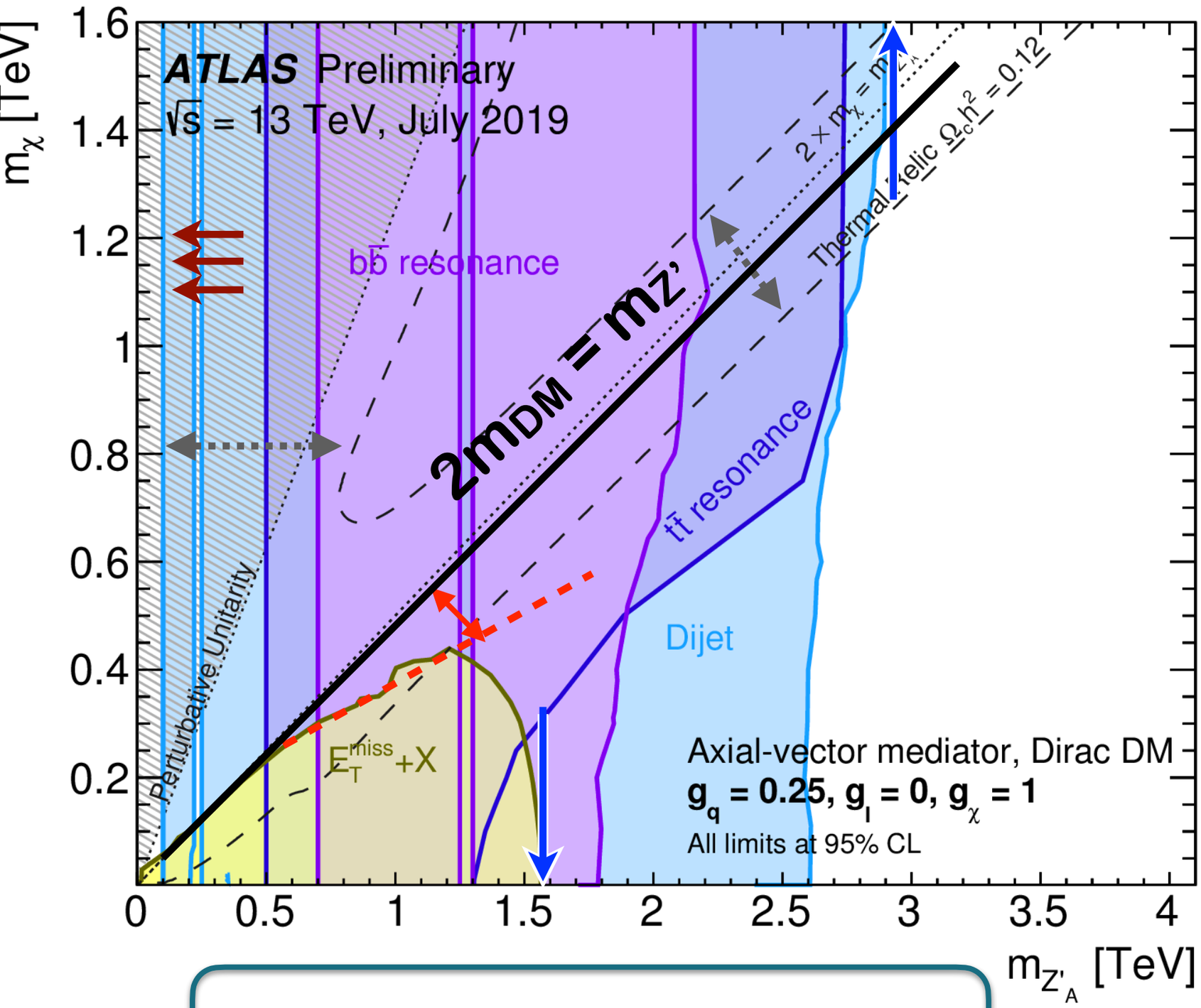
Loss of sensitivity due to mediator width effects

Highest mass reach, driven by E_T^{miss}/m_{jj} tails & statistics (jet+ E_T^{miss}/dijet)

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained



Loss of sensitivity due to mediator width effects

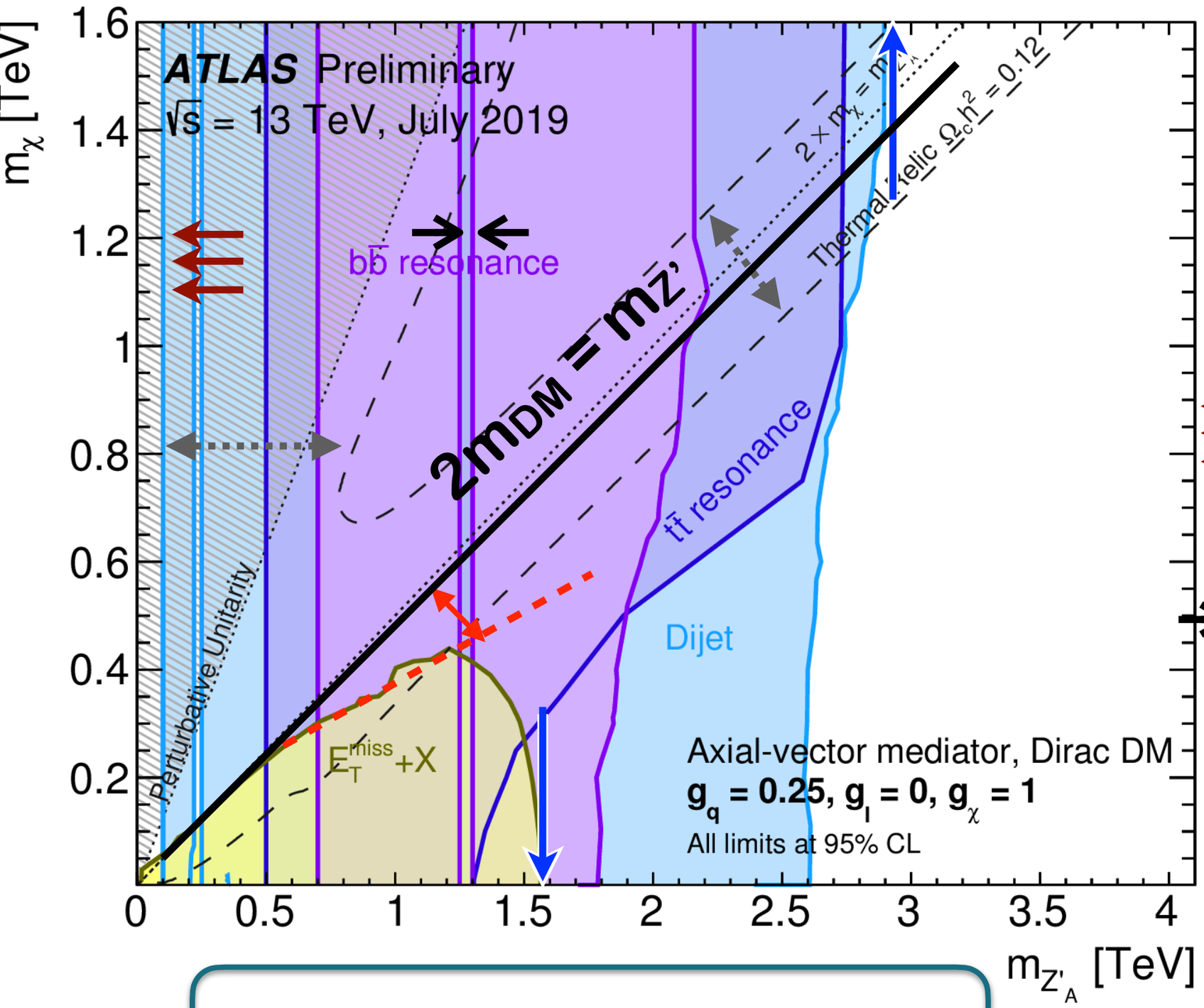
Highest mass reach, driven by E_T^{miss}/m_{jj} tails & statistics (jet+ E_T^{miss}/dijet)

Jet trigger thresholds limiting low-mass reach

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained



Loss of sensitivity due to mediator width effects

Highest mass reach, driven by E_T^{miss}/m_{jj} tails & statistics (jet+ E_T^{miss}/dijet)

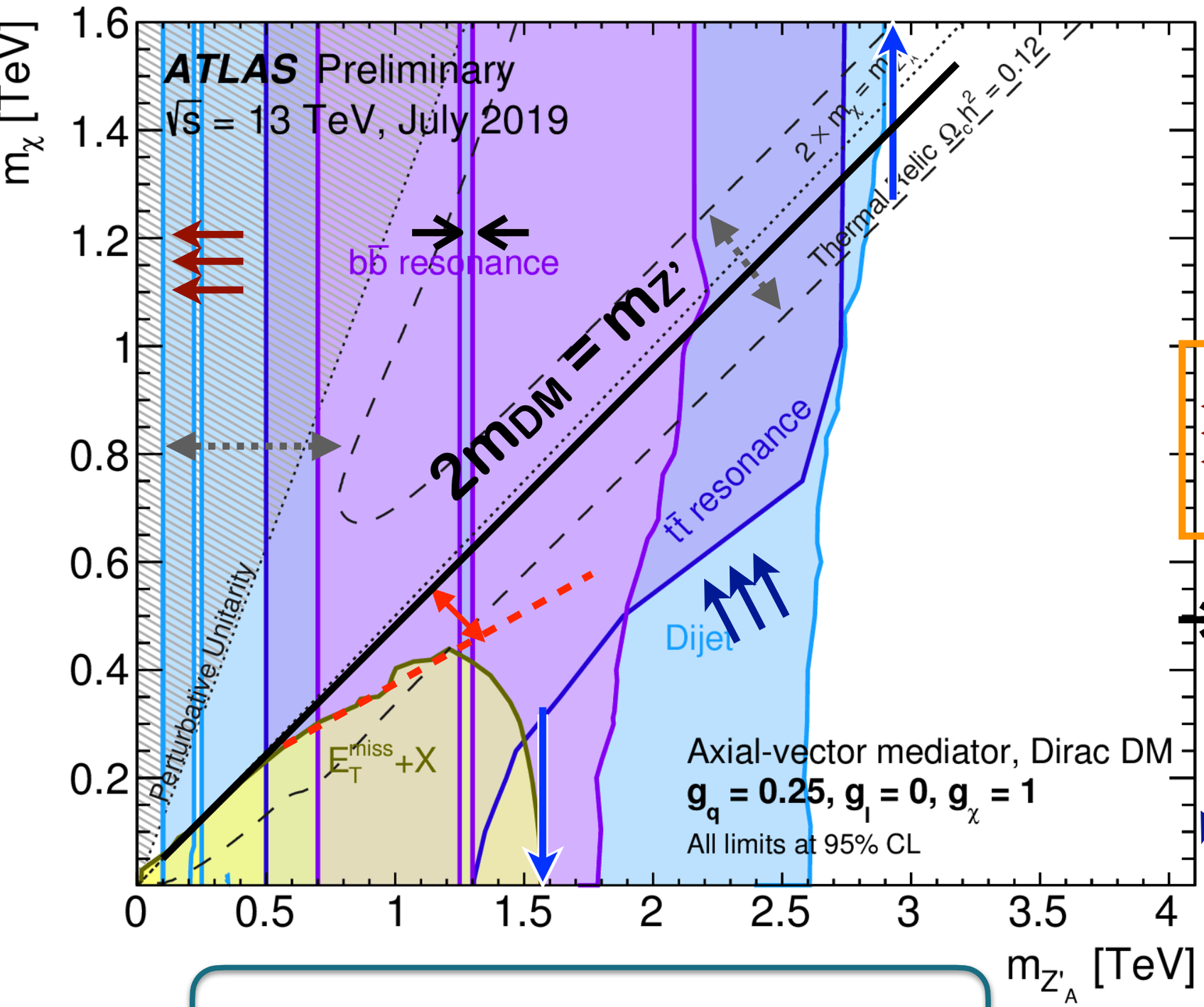
Jet trigger thresholds limiting low-mass reach

Change of trigger strategy & analysis width sensitivity

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained



Loss of sensitivity due to mediator width effects

Highest mass reach, driven by E_T^{miss}/m_{jj} tails & statistics (jet+ E_T^{miss}/dijet)

Jet trigger thresholds limiting low-mass reach

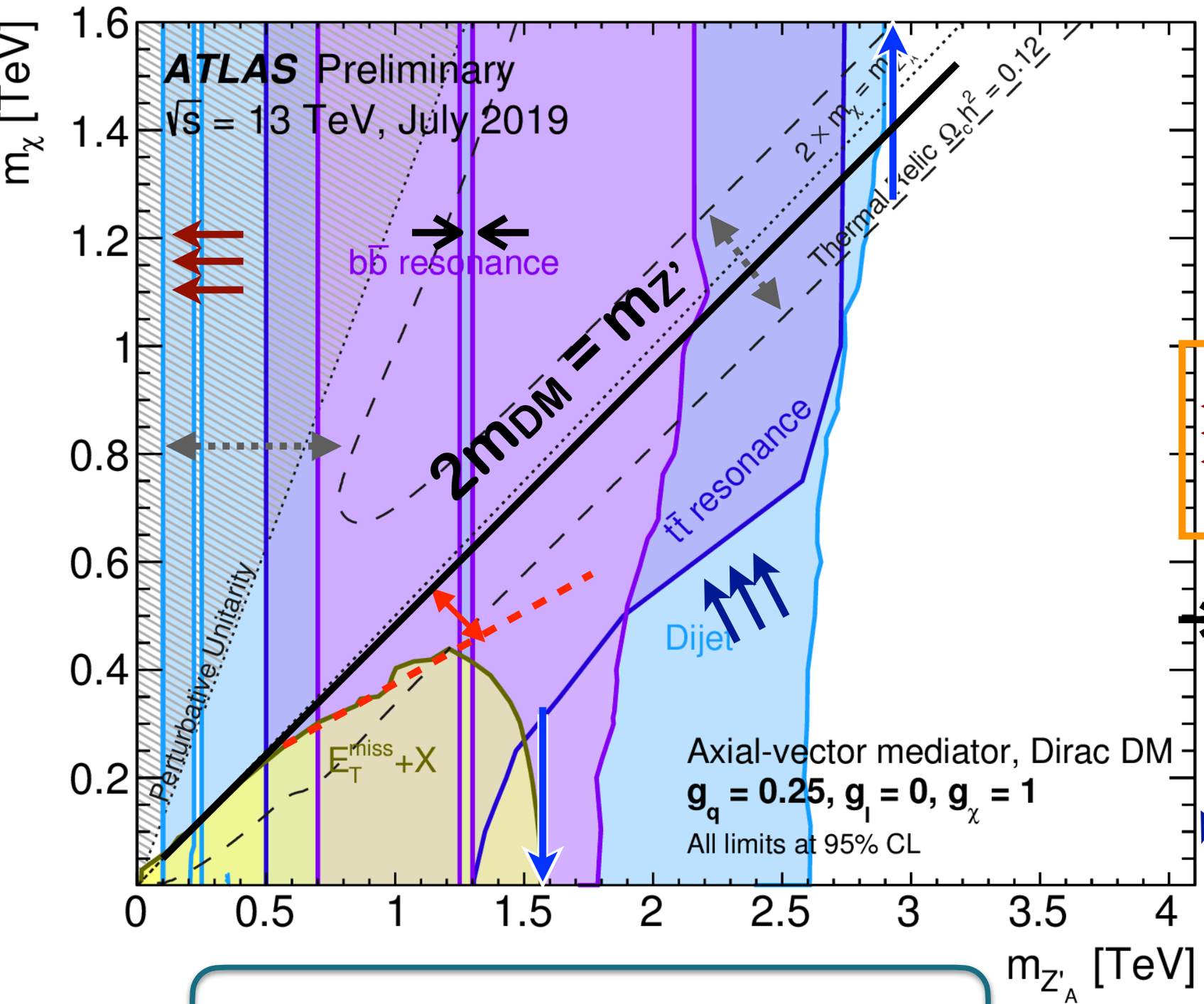
Change of trigger strategy & analysis width sensitivity

Increase of BR(Z'➡χχ) ⇒ loss of sensitivity for Z'➡tt

$$g_q = 0.25, g_{lep} = 0, g_{DM} = 1$$

Model's predicted relic density deplet
with respect to 0.12 thermal relic

Spin-1: features explained



Loss of sensitivity due to mediator width effects

Highest mass reach, driven by E_T^{miss}/m_{jj} tails & statistics (jet+ E_T^{miss}/dijet)

Jet trigger thresholds limiting low-mass reach

Change of trigger strategy & analysis width sensitivity

Increase of BR(Z'➡χχ) ⇒ loss of sensitivity for Z'➡tt

$$g_q = 0.25,\ g_{lep} = 0,\ g_{DM} = 1$$

Model's predicted relic density deplet with respect to 0.12 thermal relic