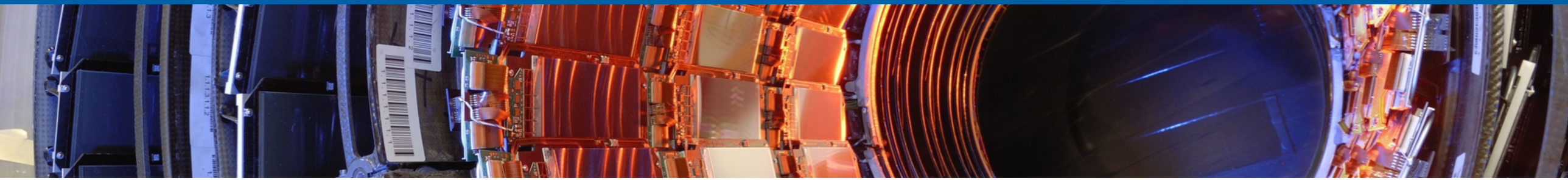


LHC DM Searches

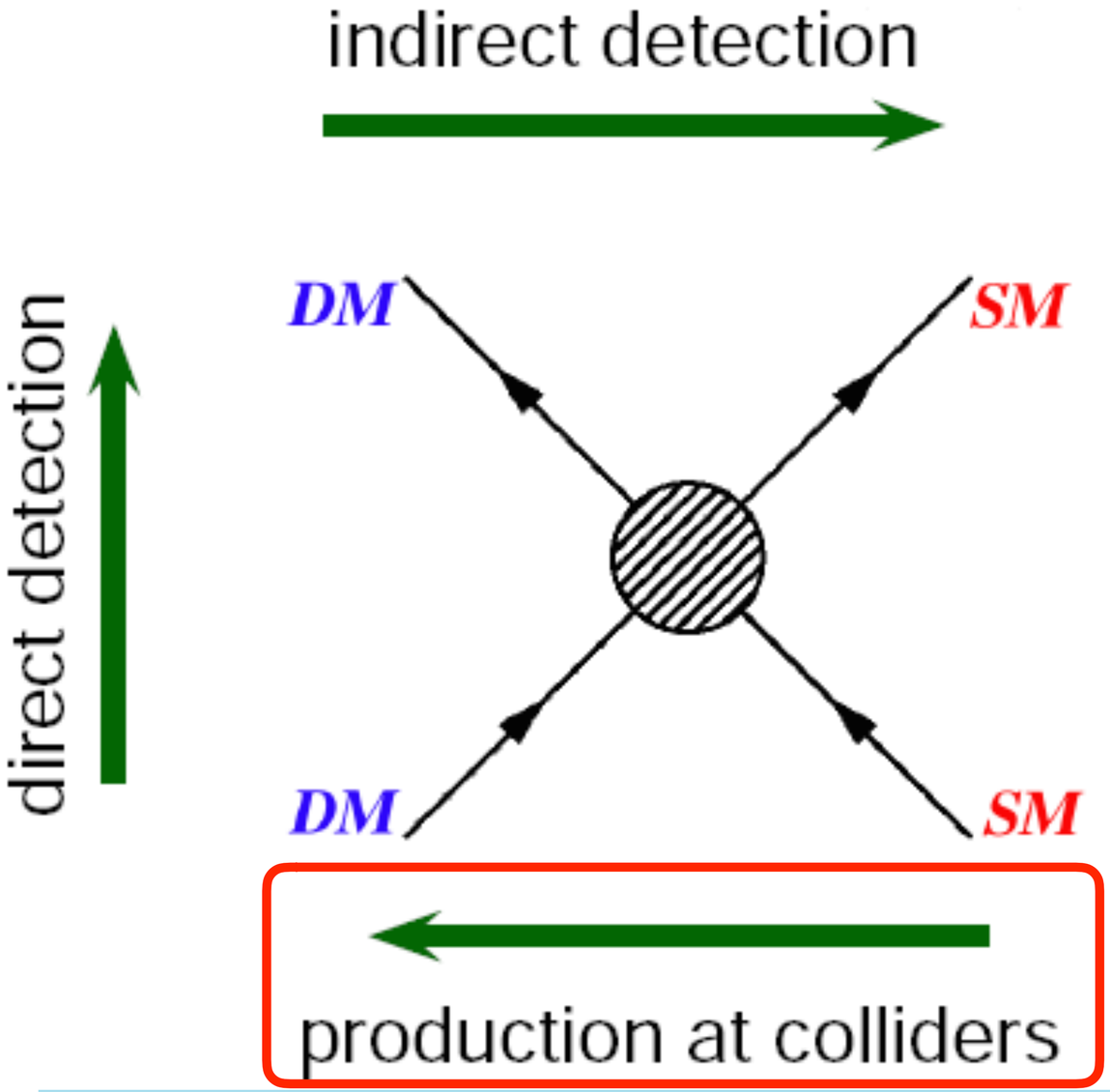
M. Cremonesi **[FNAL]**

on behalf of the ATLAS and CMS collaborations

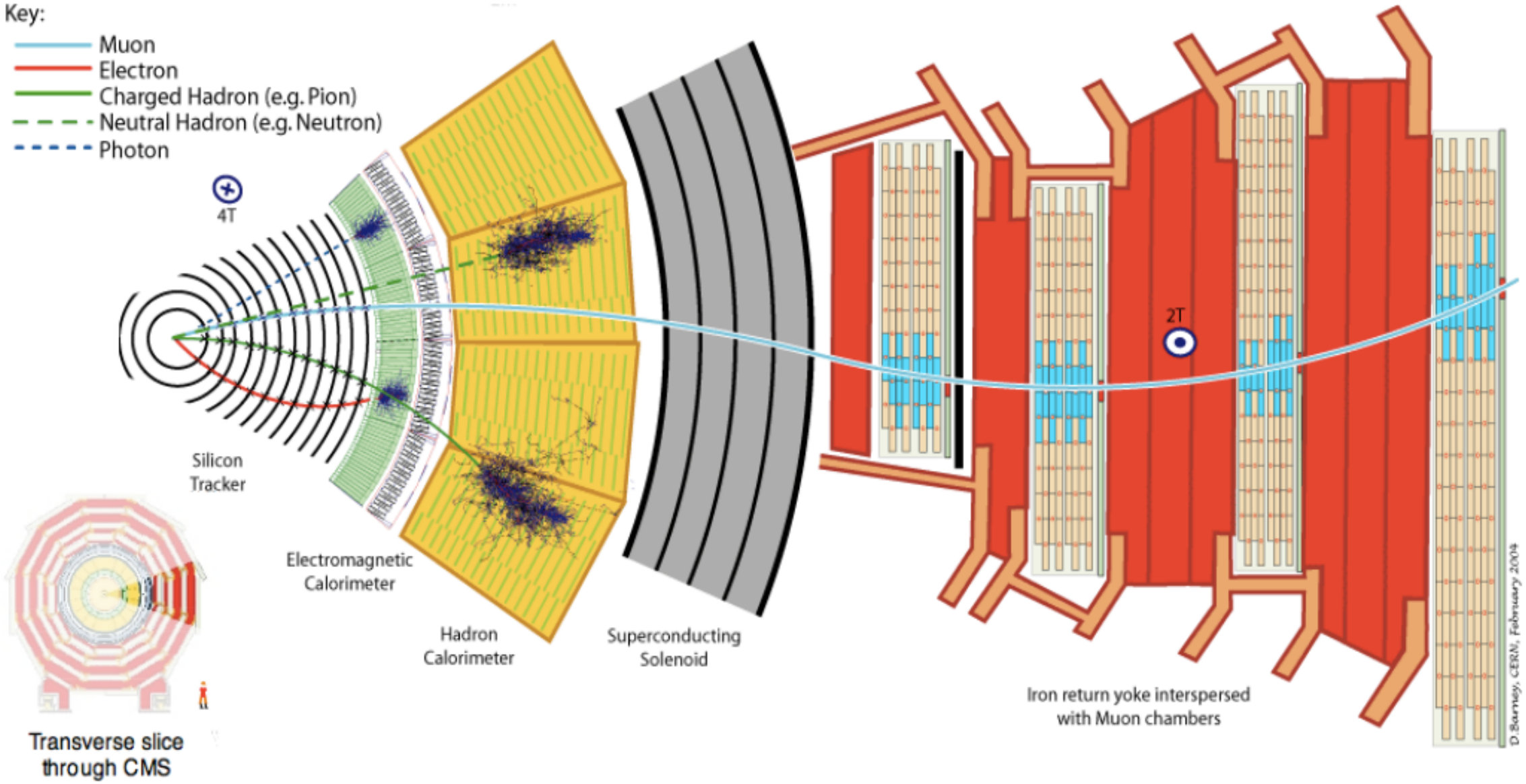
In this talk:

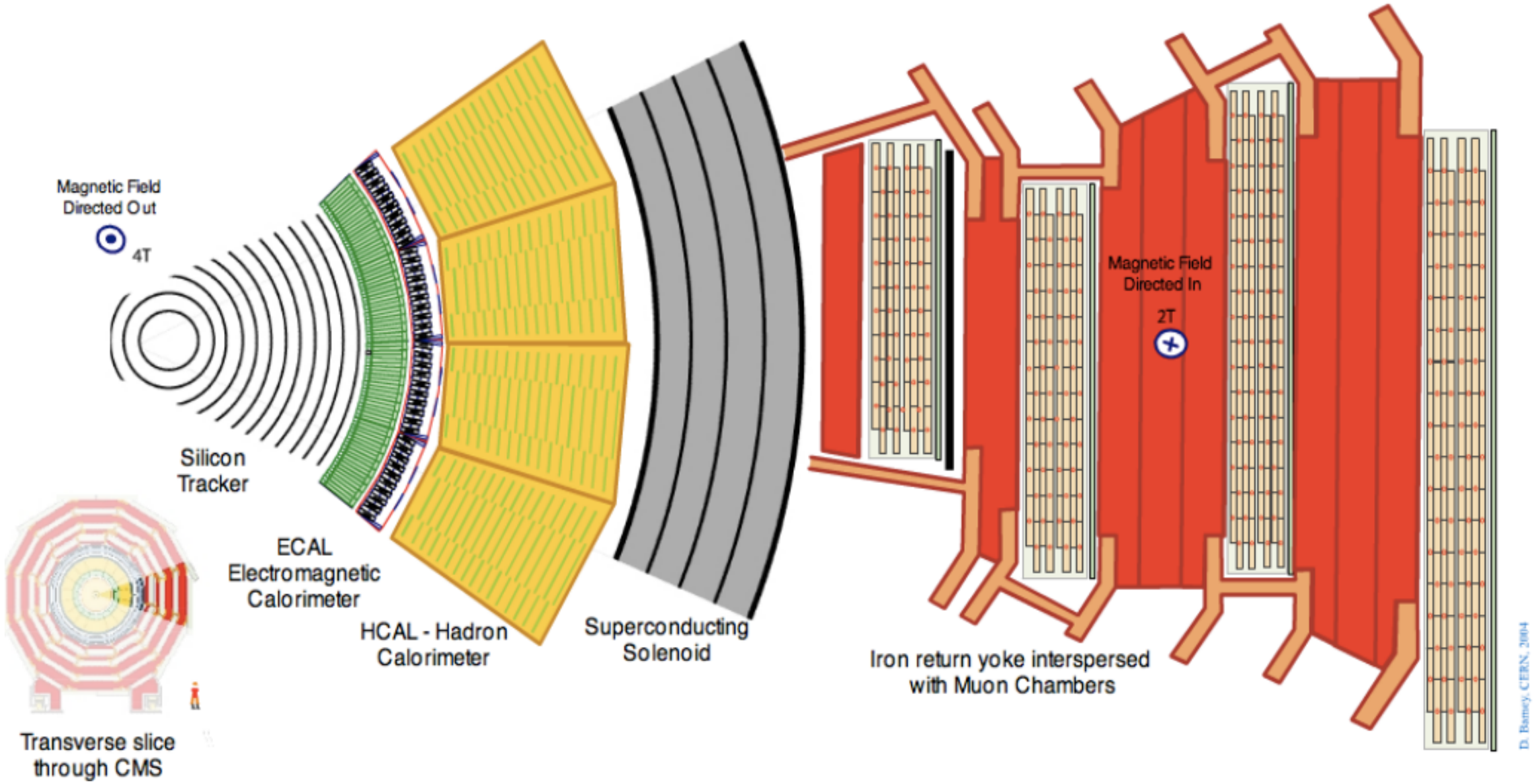
- Description of the general approach for dark matter searches at the LHC
  - Will use one interpretation as a guide through the experimental approach, will expand to other interpretations at the end.
- Collection of results from ATLAS and CMS experiment, with focus on:
  - the **mono-X** program (i.e. no SUSY reinterpretations)
  - newest results, based on data collected in RunII
    - mostly 2015+2016
    - Some results with more statistics are also included

Search for DM



- **Direct detection (DD)**: look for nuclear recoil produced when a DM particle collides with an atomic nucleus of a target.
- **Indirect detection (ID)**: look for the products of the annihilation or the decay of DM particles.
- **Collider approach**: DM production


Key:
Muon
Electron
Charged Hadron (e.g. Pion)
Neutral Hadron (e.g. Neutron)
Photon
4T
2T
Silicon Tracker
Electromagnetic Calorimeter
Hadron Calorimeter
Superconducting Solenoid
Iron return yoke interspersed with Muon chambers
D.Barney, CERN, February 2004
Transverse slice through CMS


Magnetic Field
Directed Out
4T
Silicon
Tracker
ECAL
Electromagnetic
Calorimeter
HCAL - Hadron
Calorimeter
Superconducting
Solenoid
Magnetic Field
Directed In
2T
Iron return yoke interspersed
with Muon Chambers
Transverse slice
through CMS
D. Barney, CERN, 2004

Mono-X Searches

Collider experiments are NOT designed

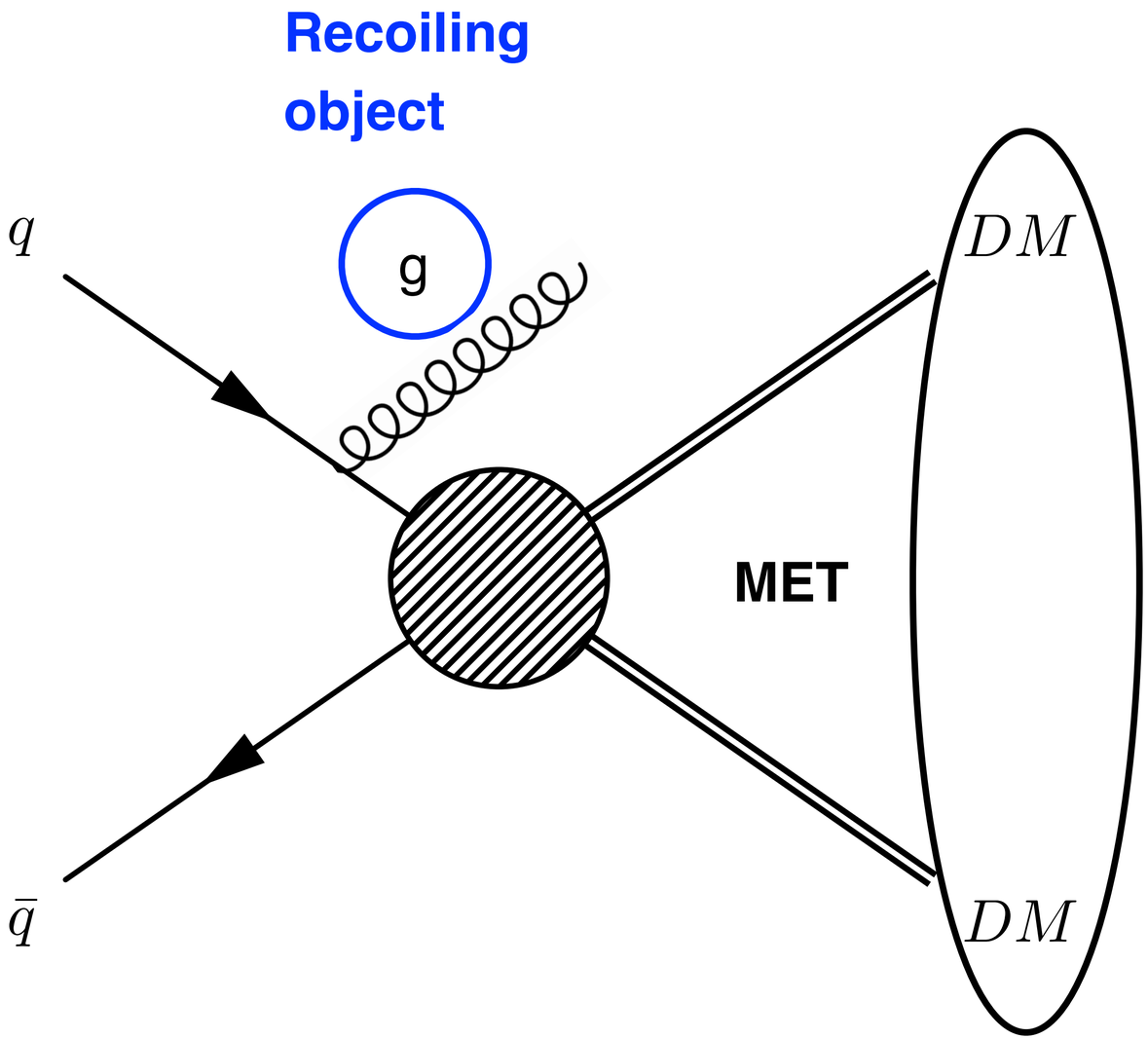
to directly reconstruct DM

Experimental approach:

- Identify events using **recoiling object(s)**
  - Initial state radiation (ISR) of a particle X:

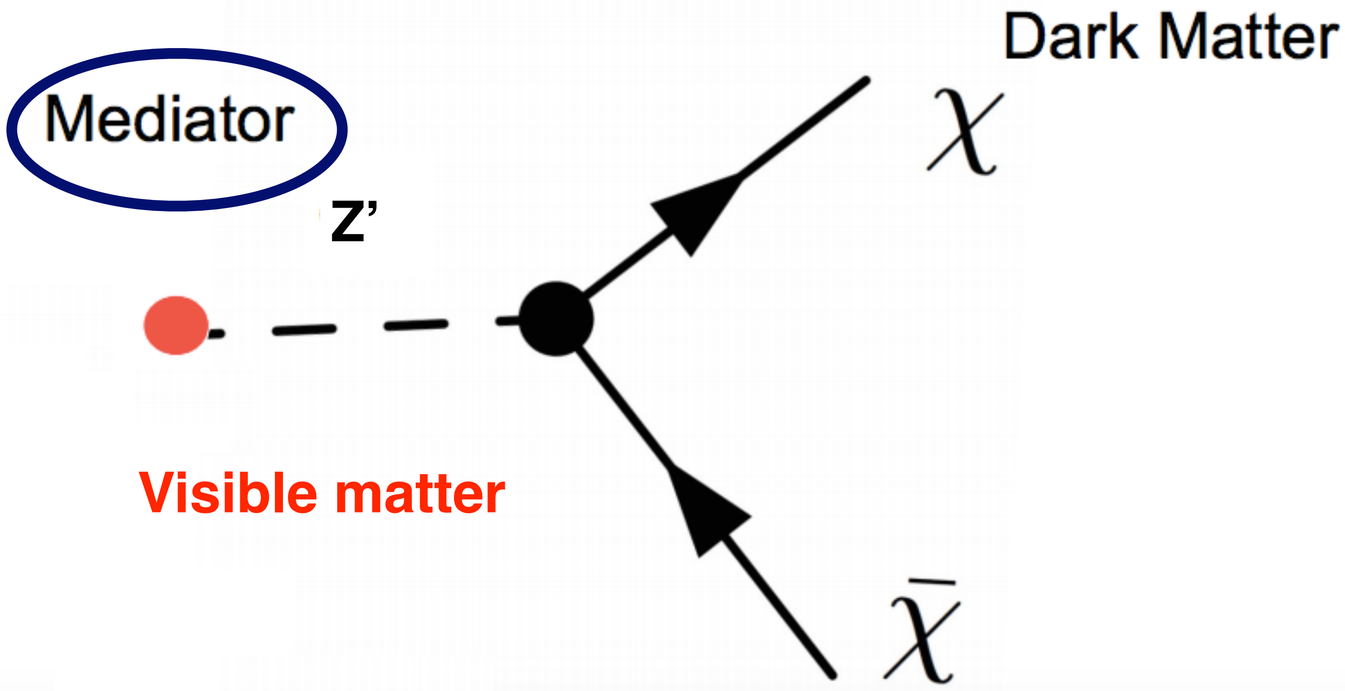
    X = jet/gamma/W/Z
- measure missing transverse momentum (**MET**)

$$MET = -\Sigma_{All\ particles}\ p_T$$

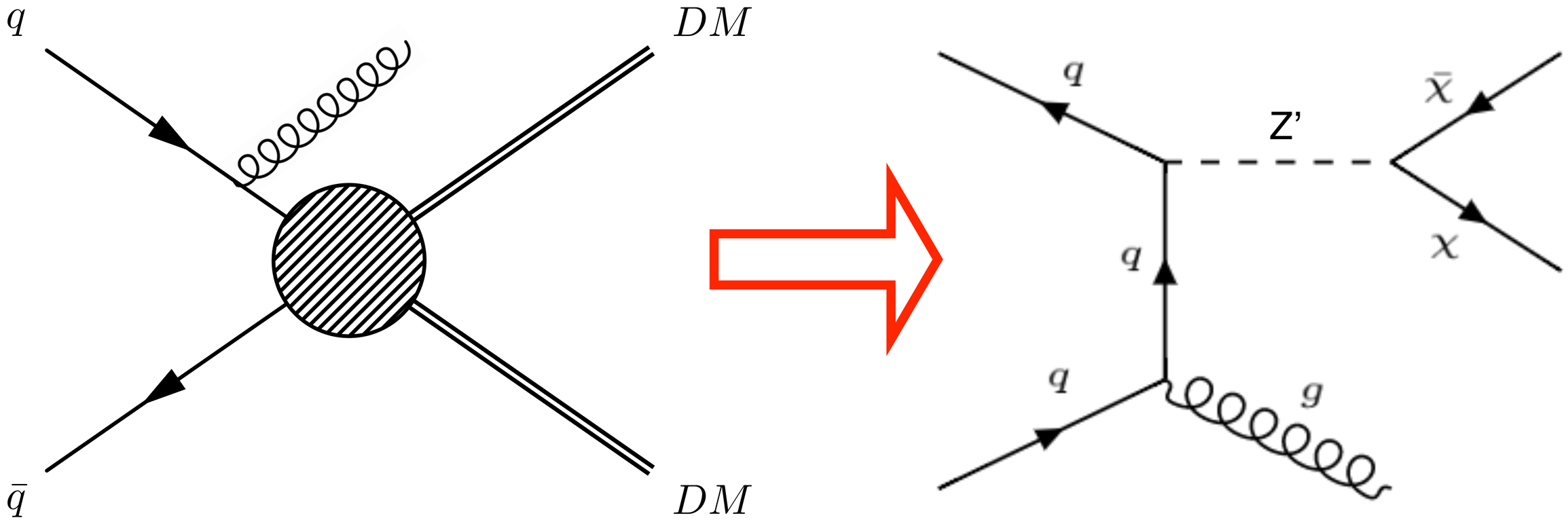


Why at Colliders

- If DM interacts, it does through a **mediator**
- At colliders, unique possibility to search for the mediator and measure its properties
  - Like mass, spin; they change the kinematic distributions used in the analyses



From EFT to Simplified Models

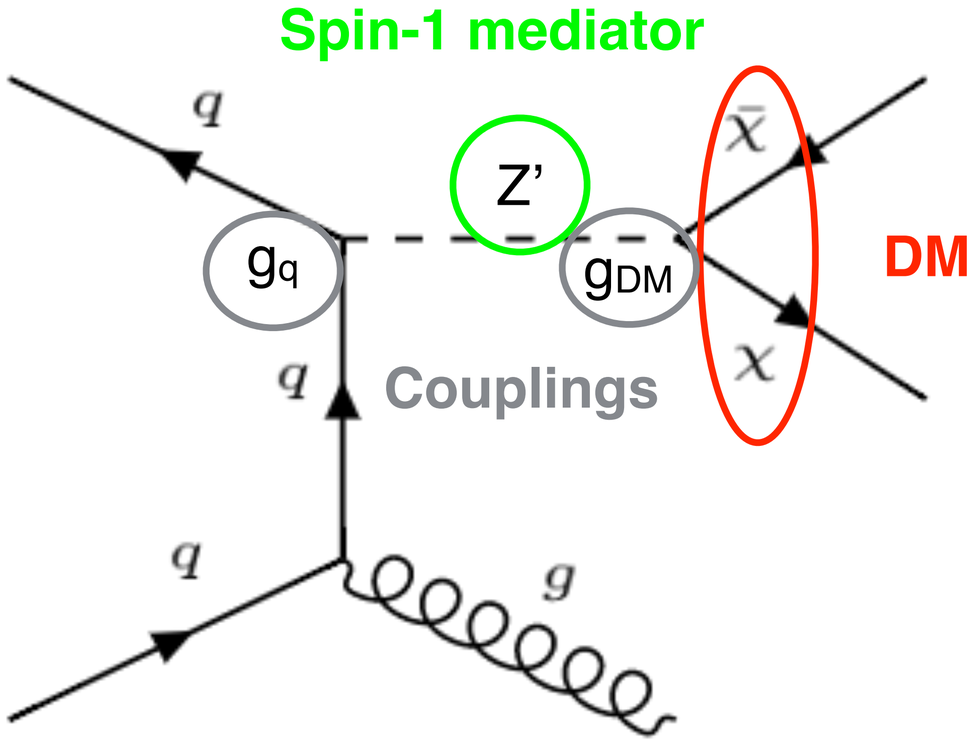


Simplified Models

Model described by a small number of **free parameters**:

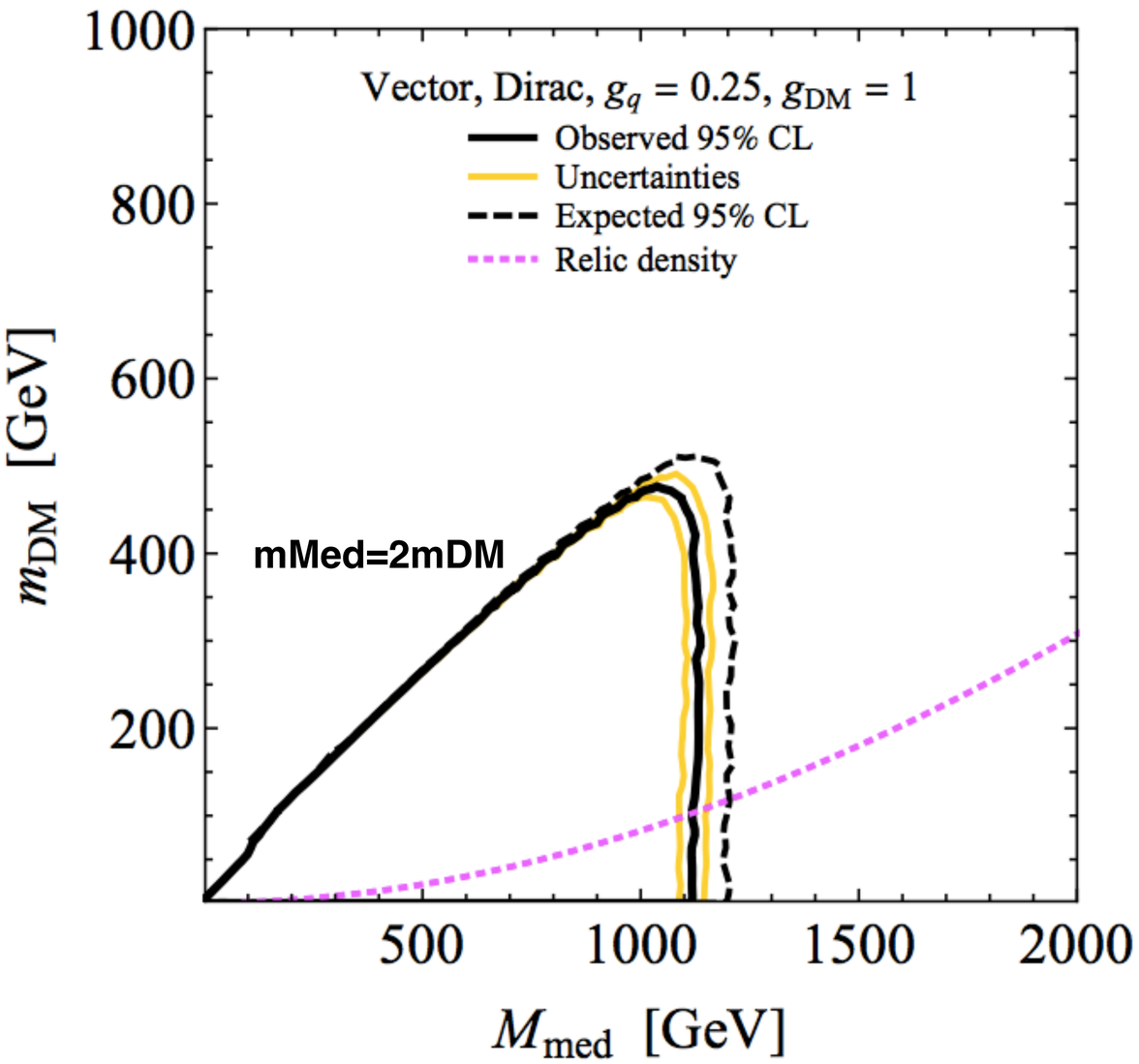
- **M_{med}, M_{DM}, g_{SM}, g_{DM}**

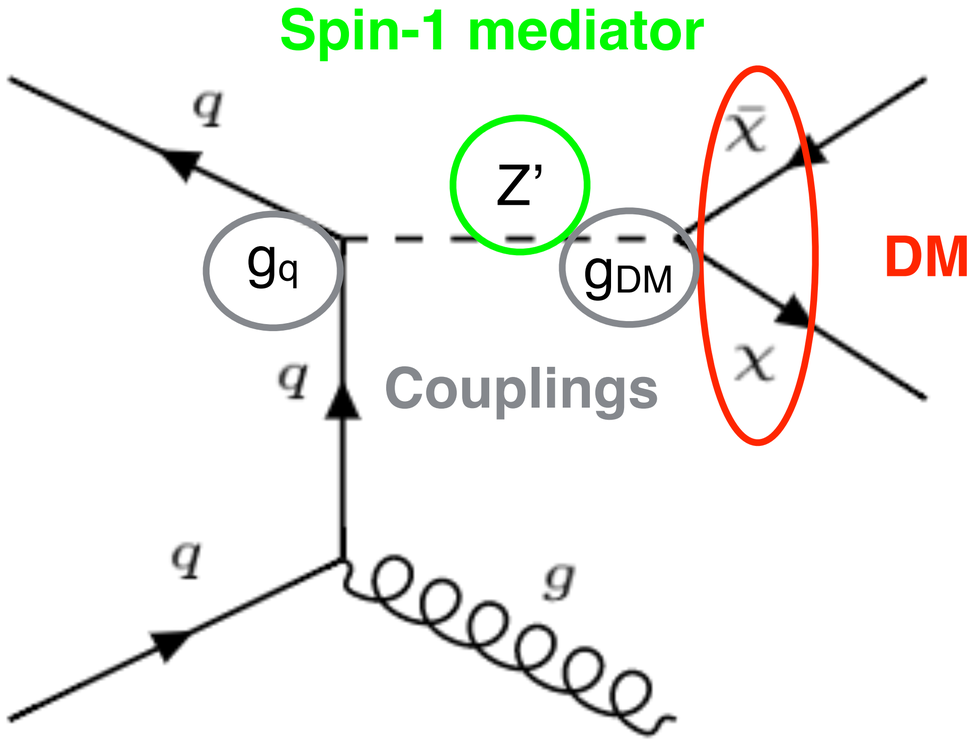
- **DM:**
  - single particle
  - stable and non-interacting
- **Mediator**
  - to first order, shapes of kinematic distributions not altered by coupling variations
    - **g_q=0.25, g_{DM}=1(spin-1)**
    - **g_q=1, g_{DM}=1(spin-0)**
  - Axial/Vector, Scalar/Pseudoscalar
  - minimal decay width (e.g. to DM and to quarks)



LHC DM Forum: arxiv:1507.00966v1

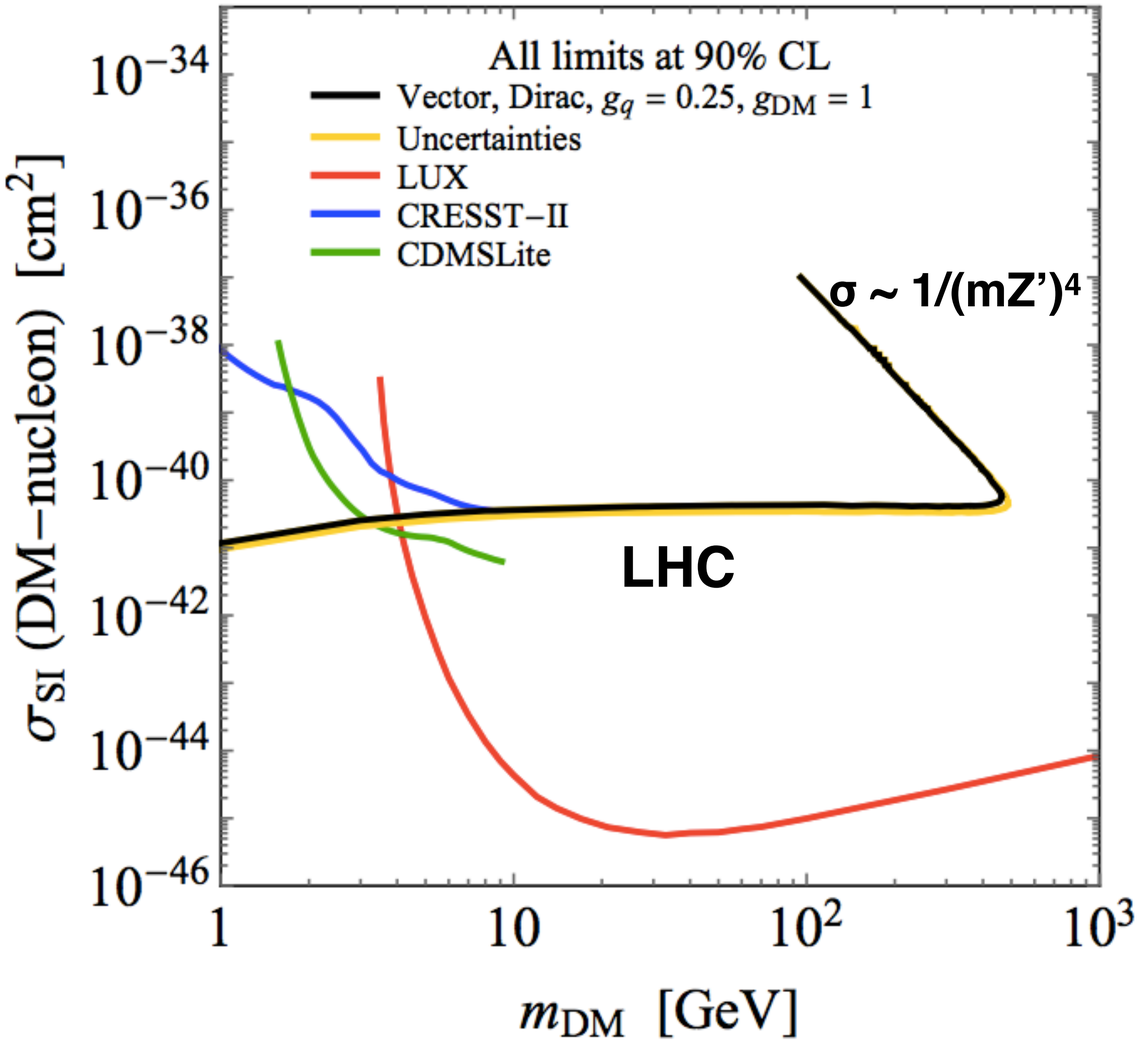
Presentation of Results

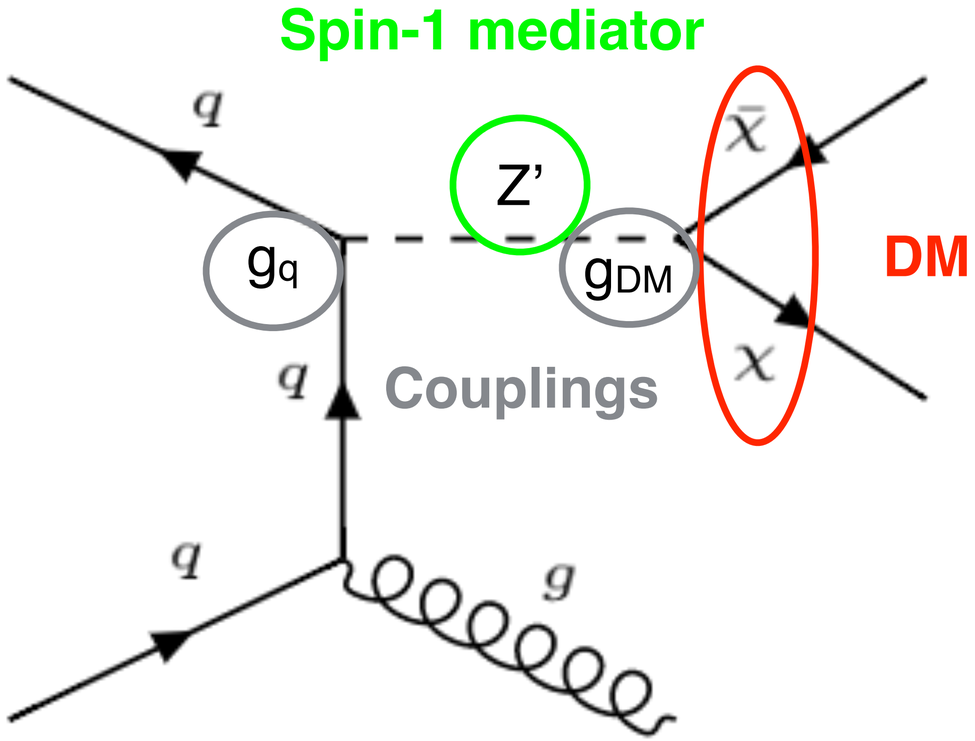




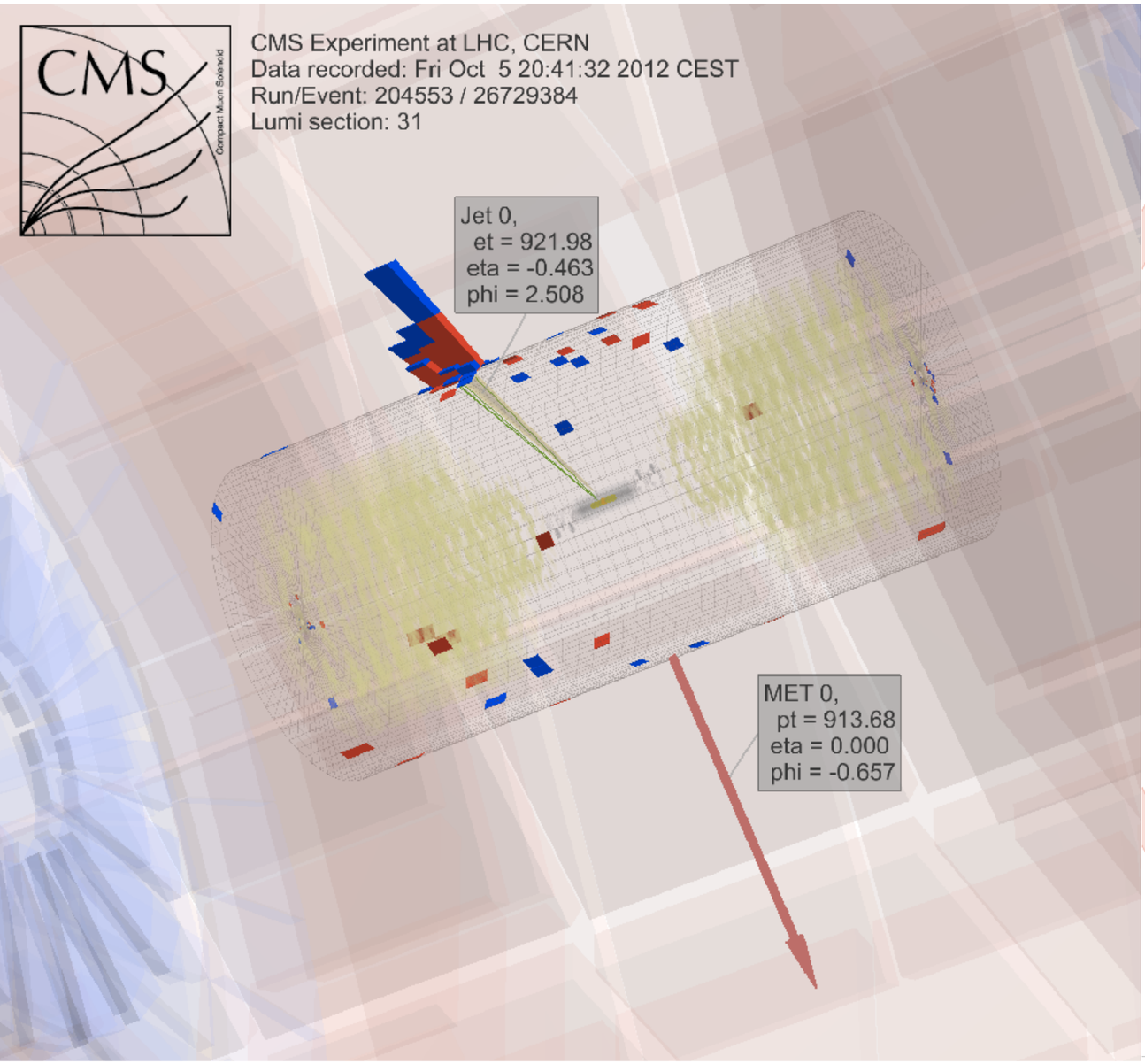
LHC DM WG: arxiv:1603.04156

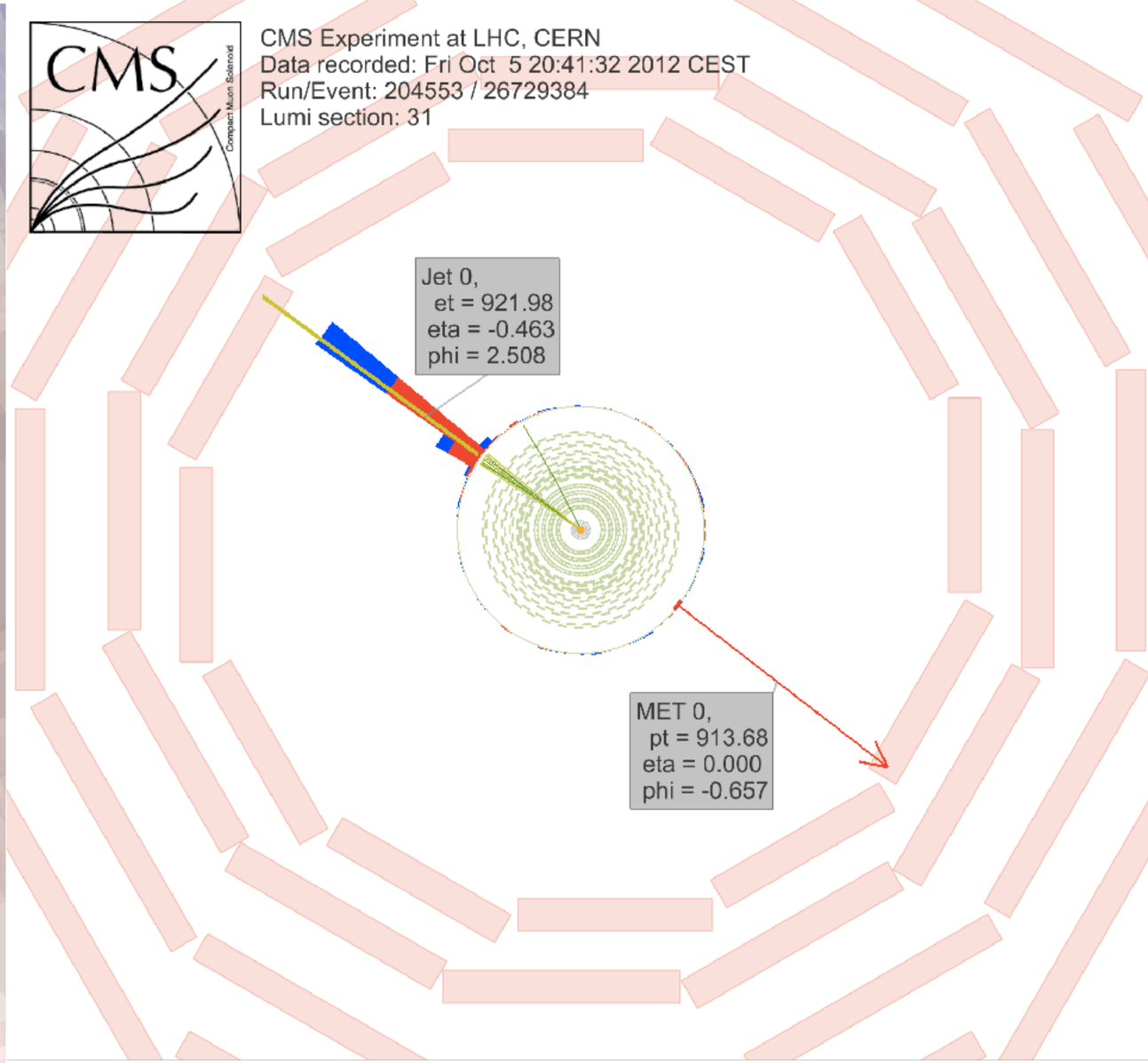
Presentation of Results





LHC DM WG: arxiv:1603.04156


CMS Experiment at LHC, CERN
Data recorded: Fri Oct 5 20:41:32 2012 CEST
Run/Event: 204553 / 26729384
Lumi section: 31
Jet 0,
et = 921.98
eta = -0.463
phi = 2.508
MET 0,
pt = 913.68
eta = 0.000
phi = -0.657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Lumi section: 31
Jet 0,
et = 921.98
eta = -0.463
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MET 0,
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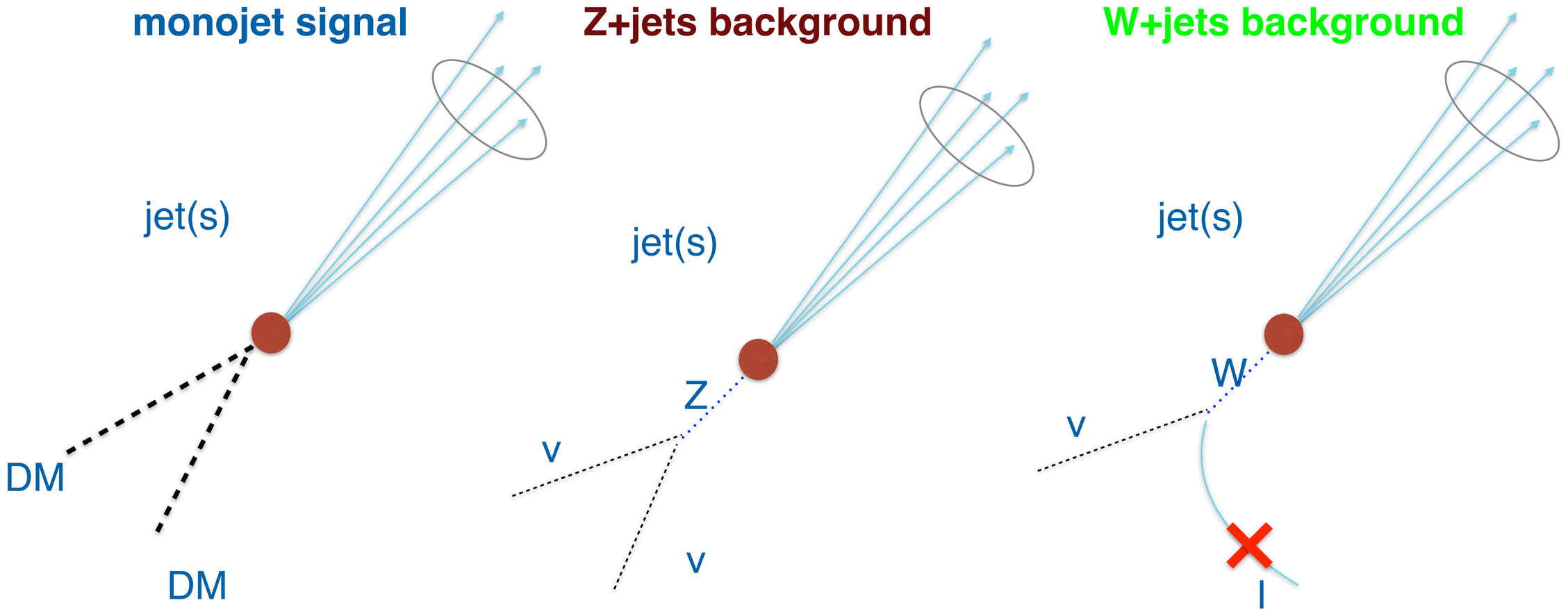
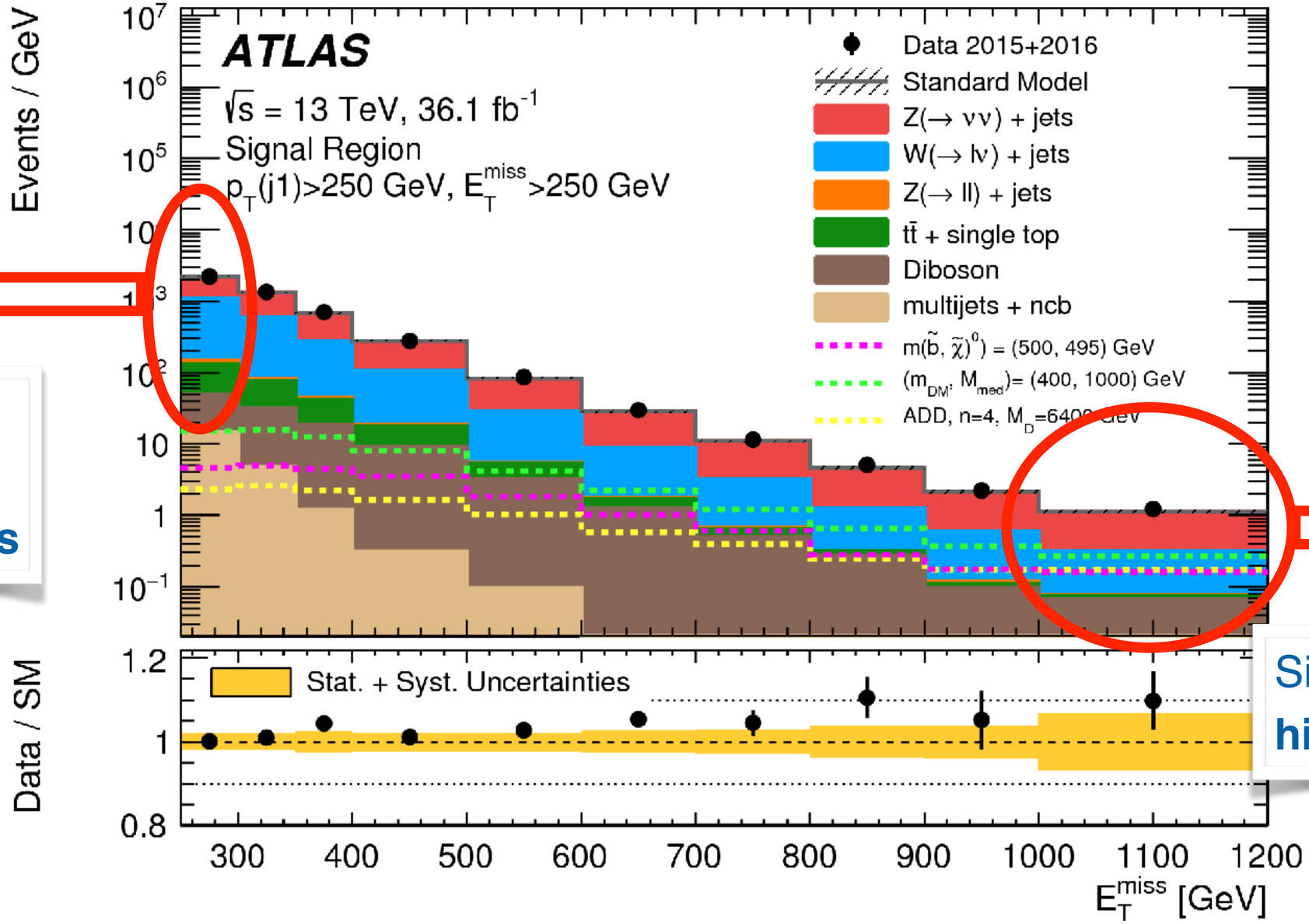
Mono-jet Signature



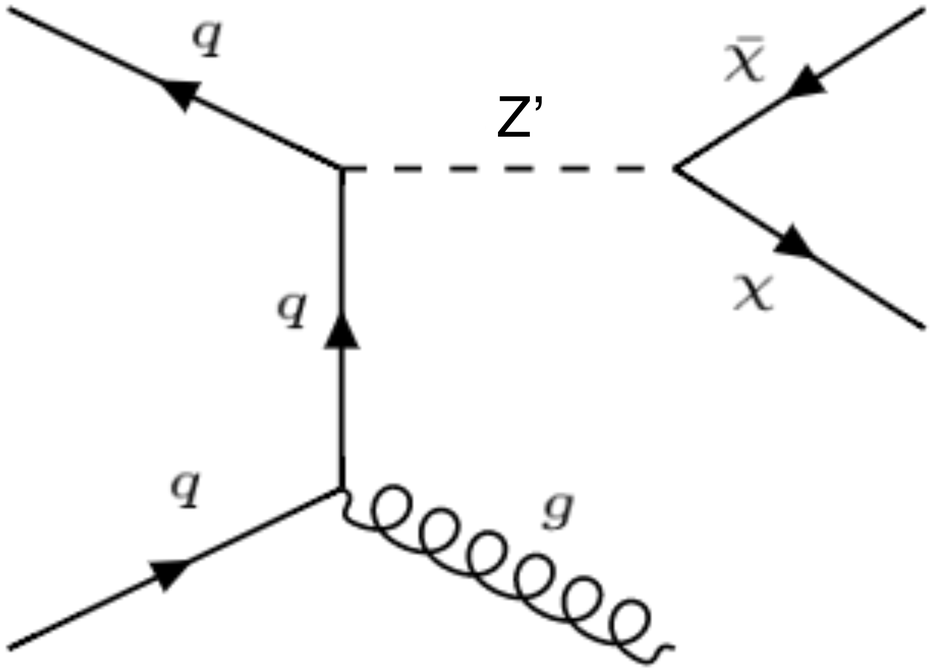
arXiv:1903.01400



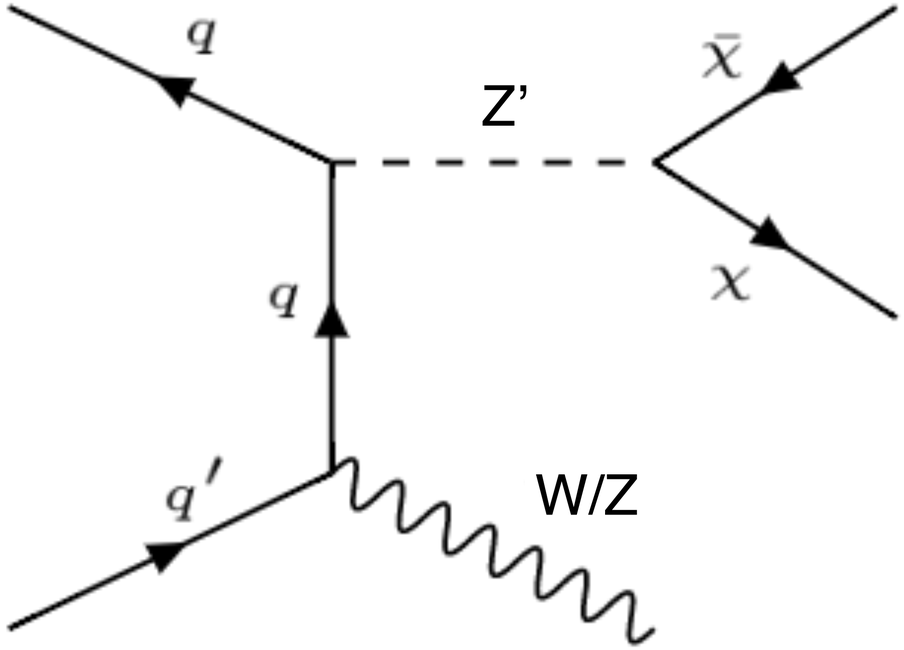
Largest backgrounds from **W/Z+jets**

Signal populates **high MET**

monojet

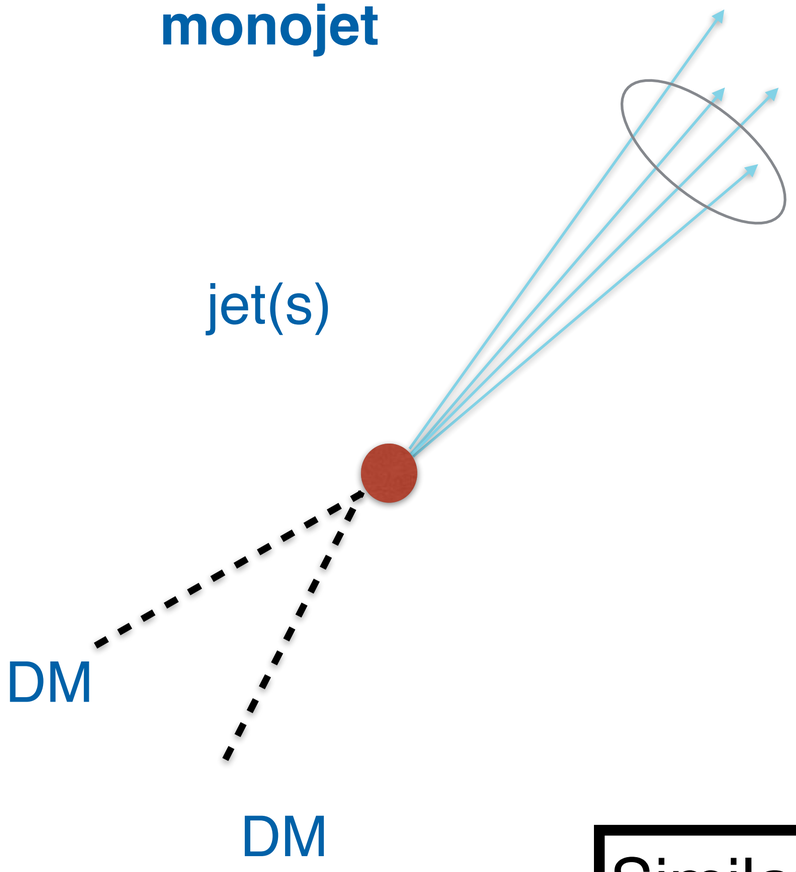


mono-V



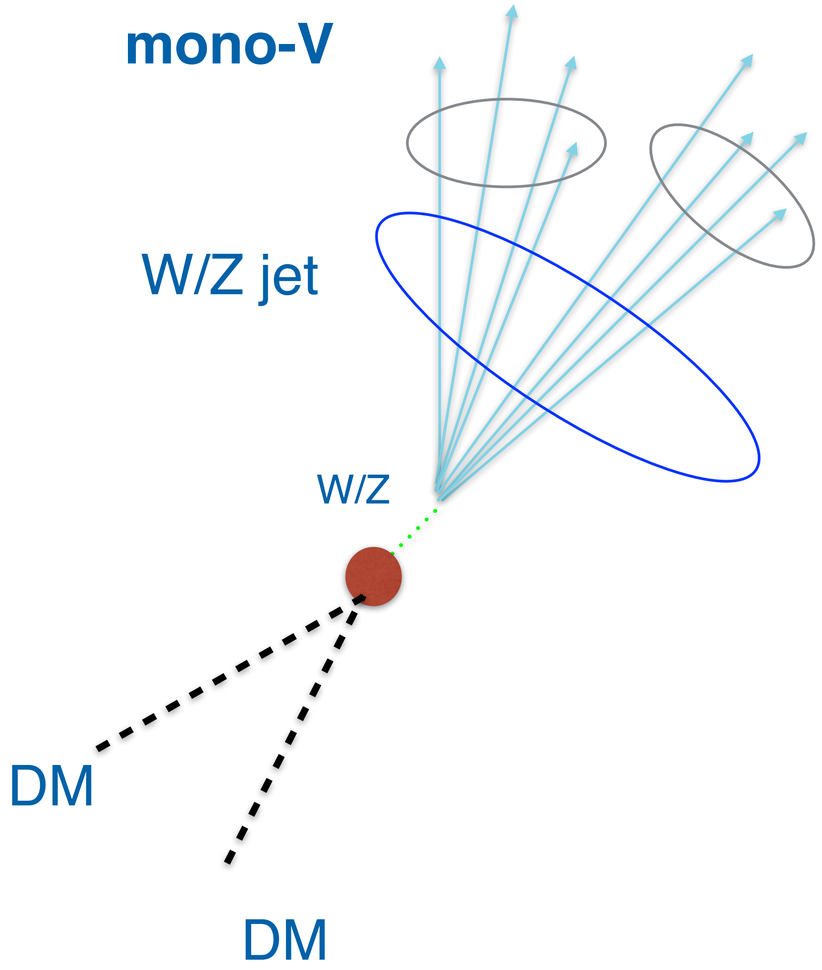
Same theoretical model

monojet



=

mono-V



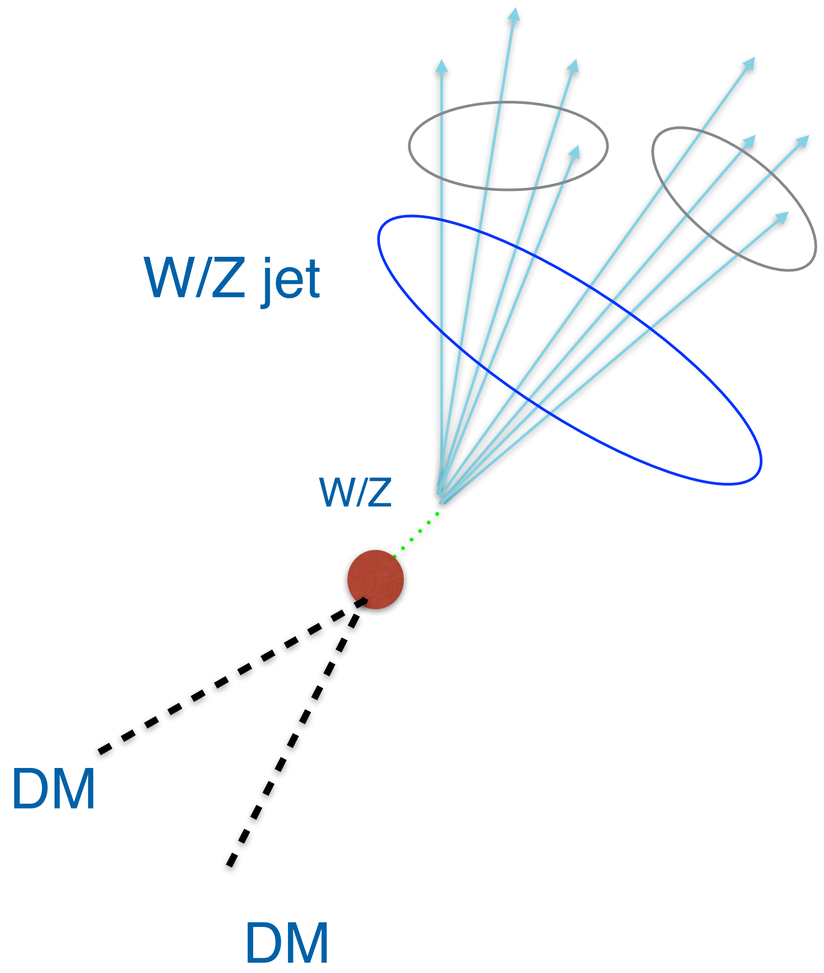
Similar experimental approach

Hadronic Mono-V Signature

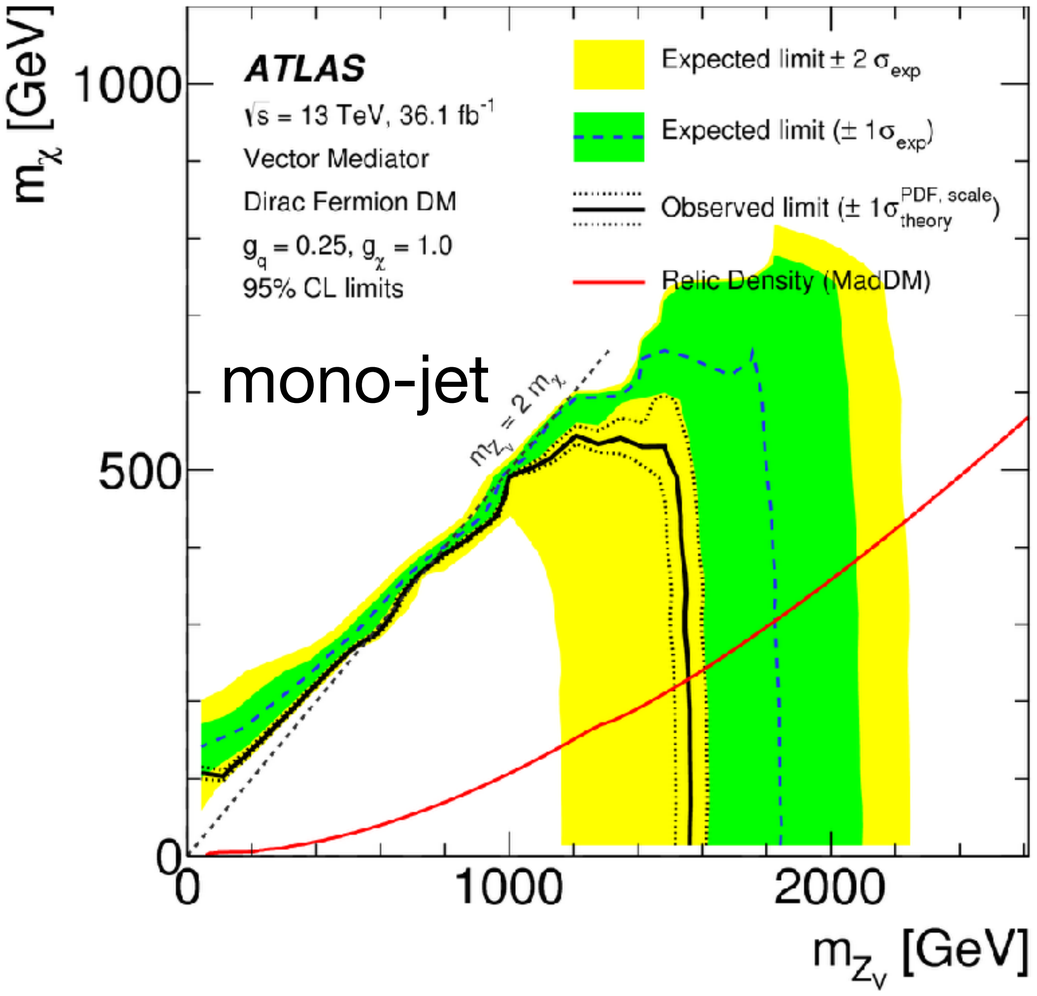
Boosted W/Z boson decaying hadronically

=> MET recoiling against large-radius jet with

- invariant mass ~ 80-90 GeV
- two prongs identified by studying jet substructure

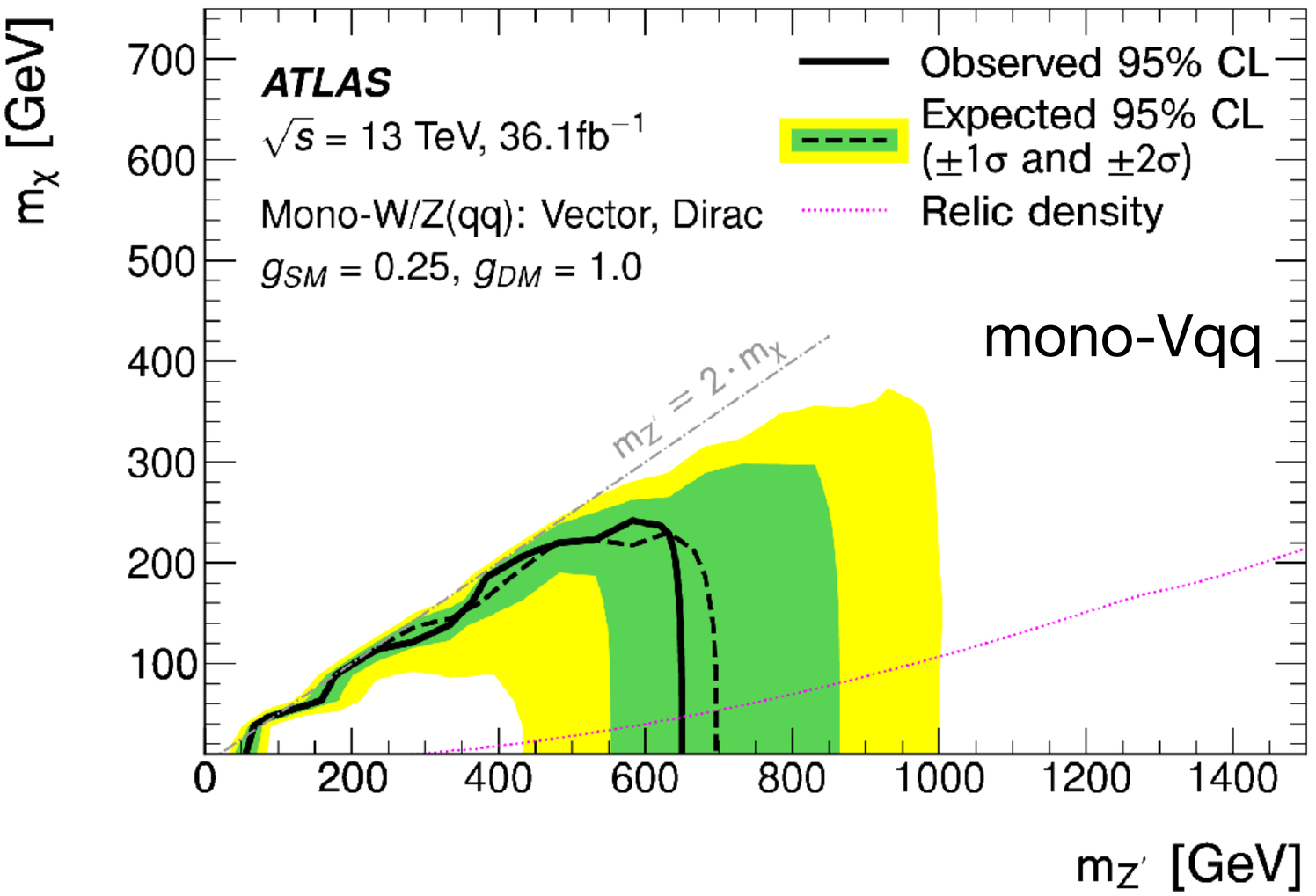


JHEP 01 (2018) 126



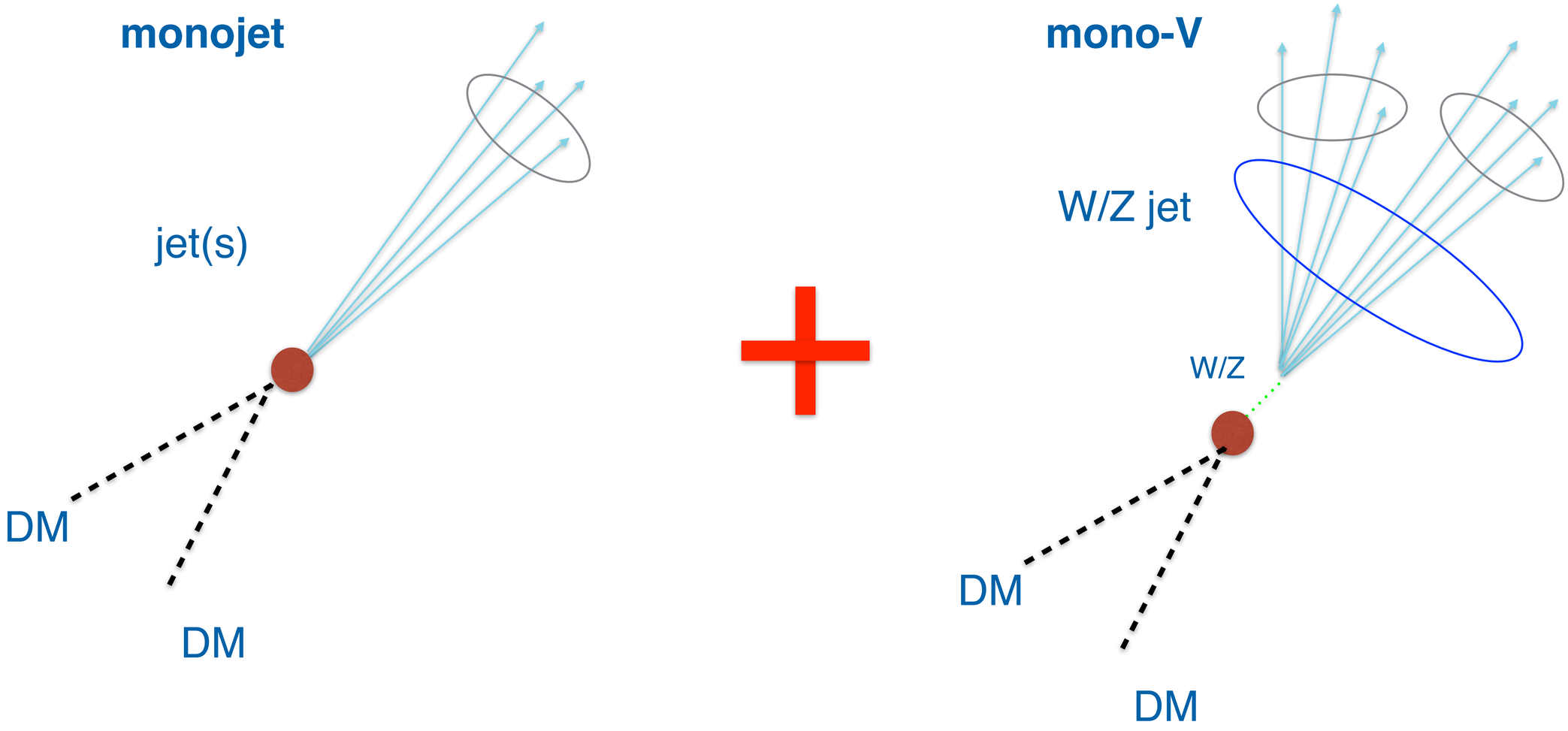
mono-jet drives sensitivity

JHEP 10 (2018) 180

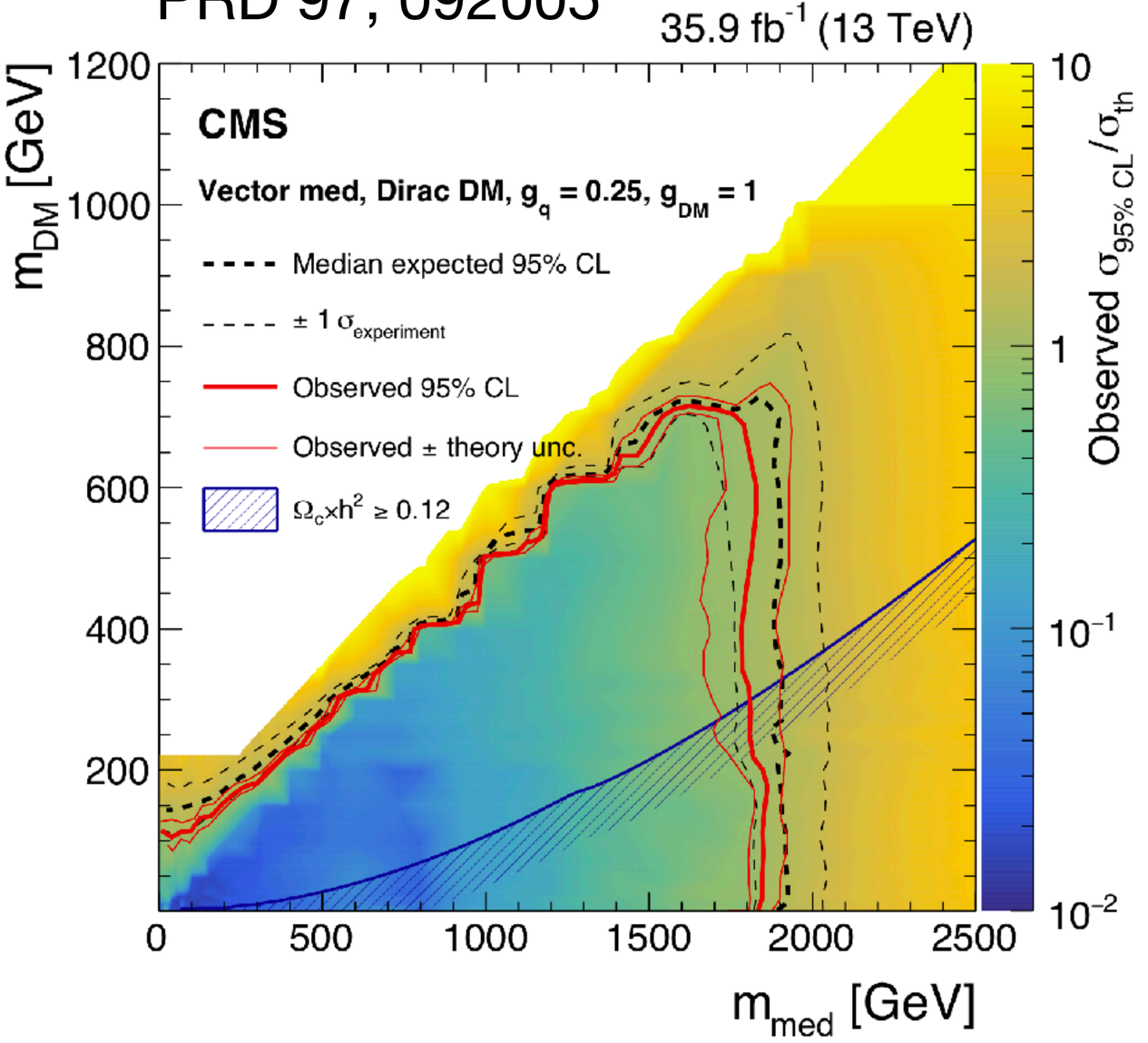


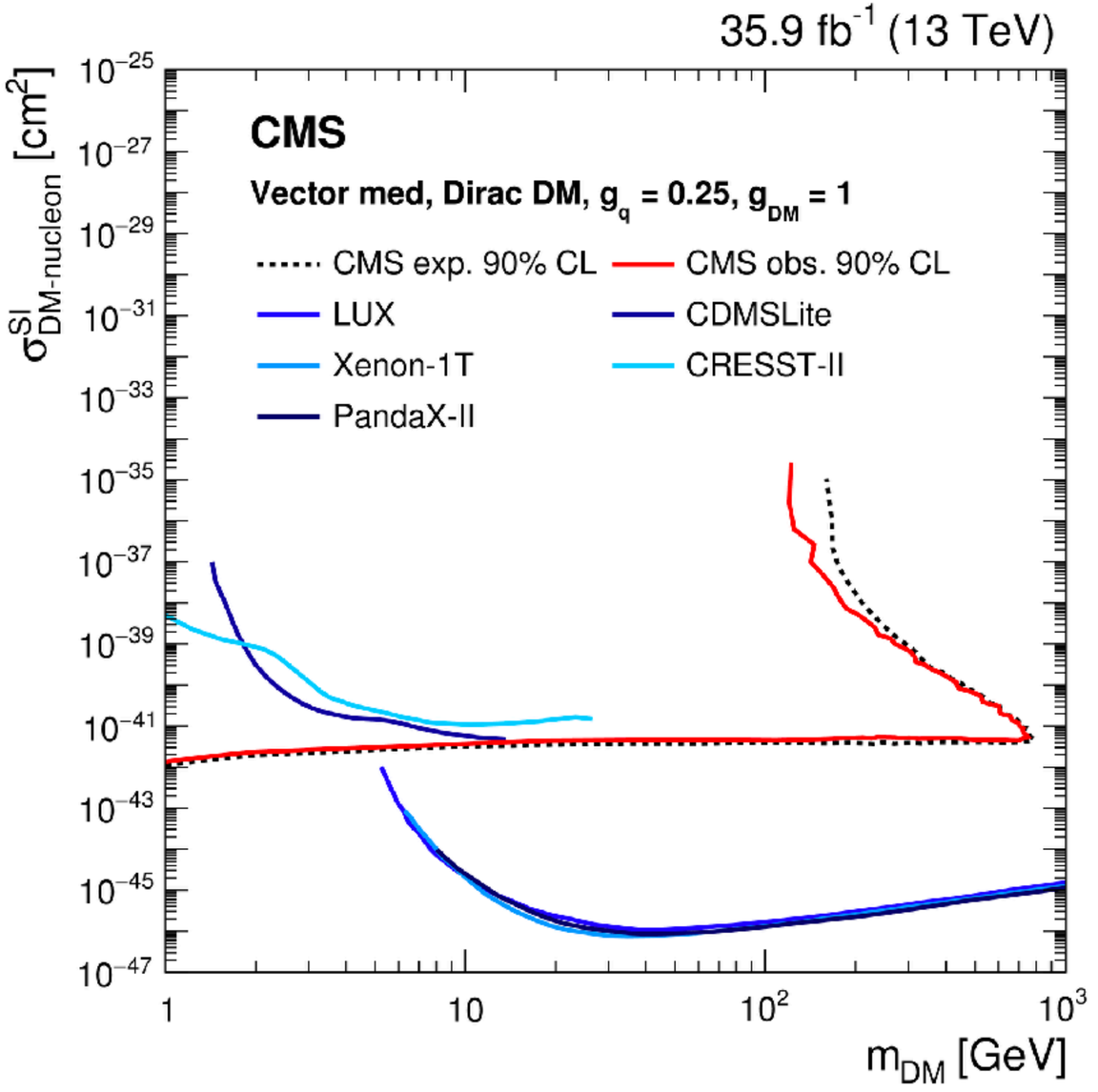
mono-Vqq strongest channel after monojet

Monojet/Mono-V Combination



PRD 97, 092005



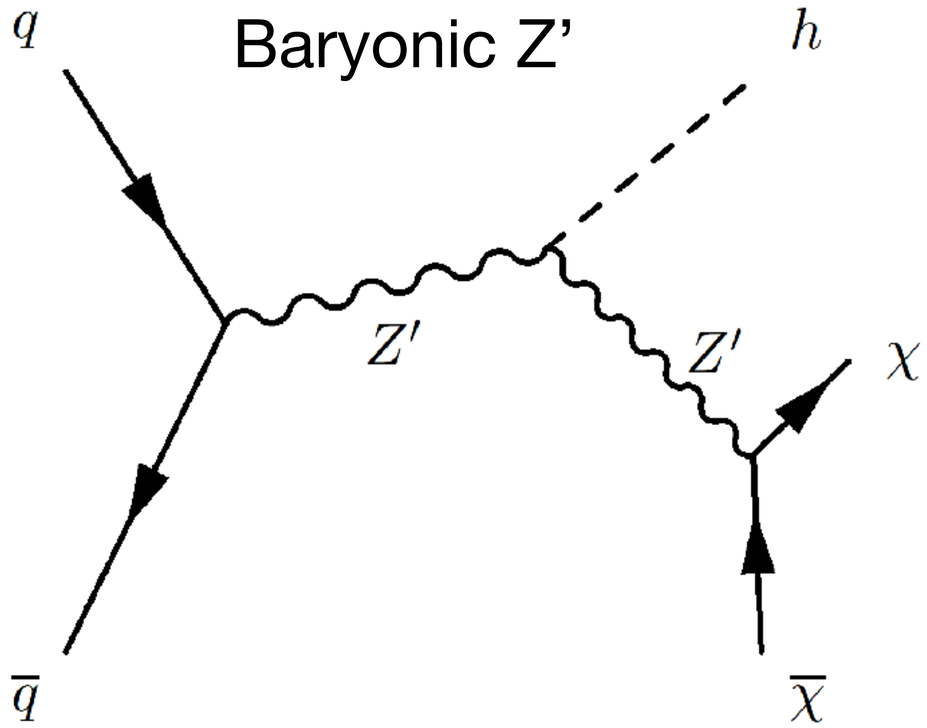


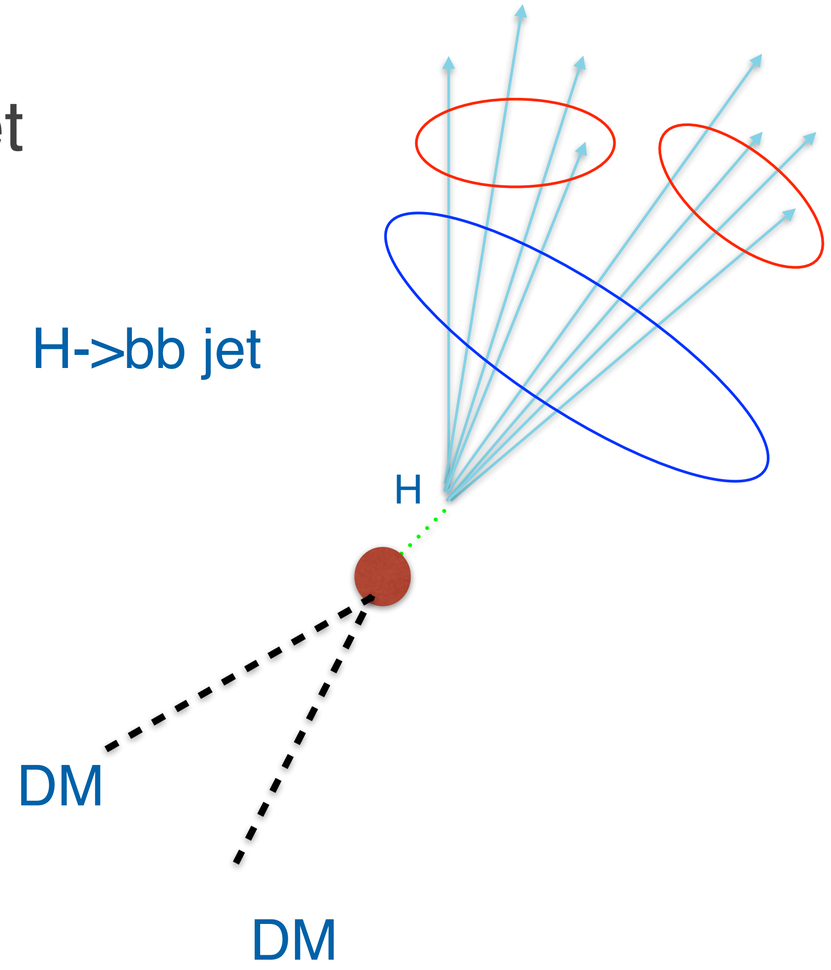
Combination extends the mass reach

Hadronic Mono-H(->bb) Signature

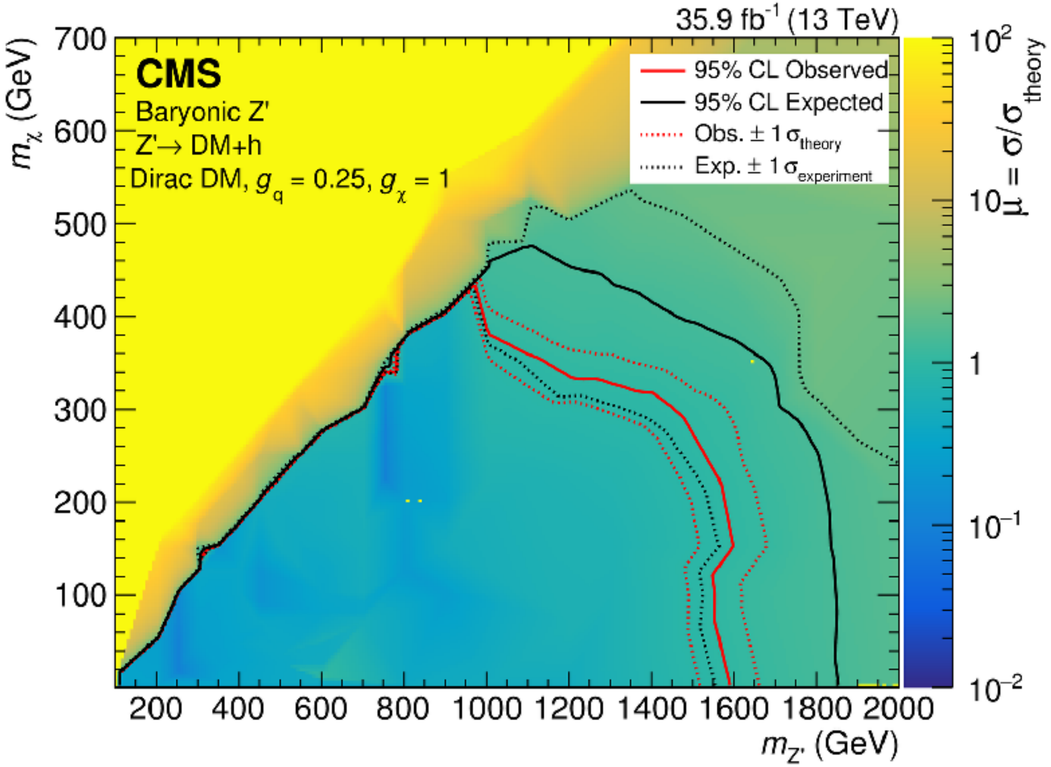
Boosted Higgs boson decaying to a b-quark pair

=> MET recoiling against a Higgs large-radius jet



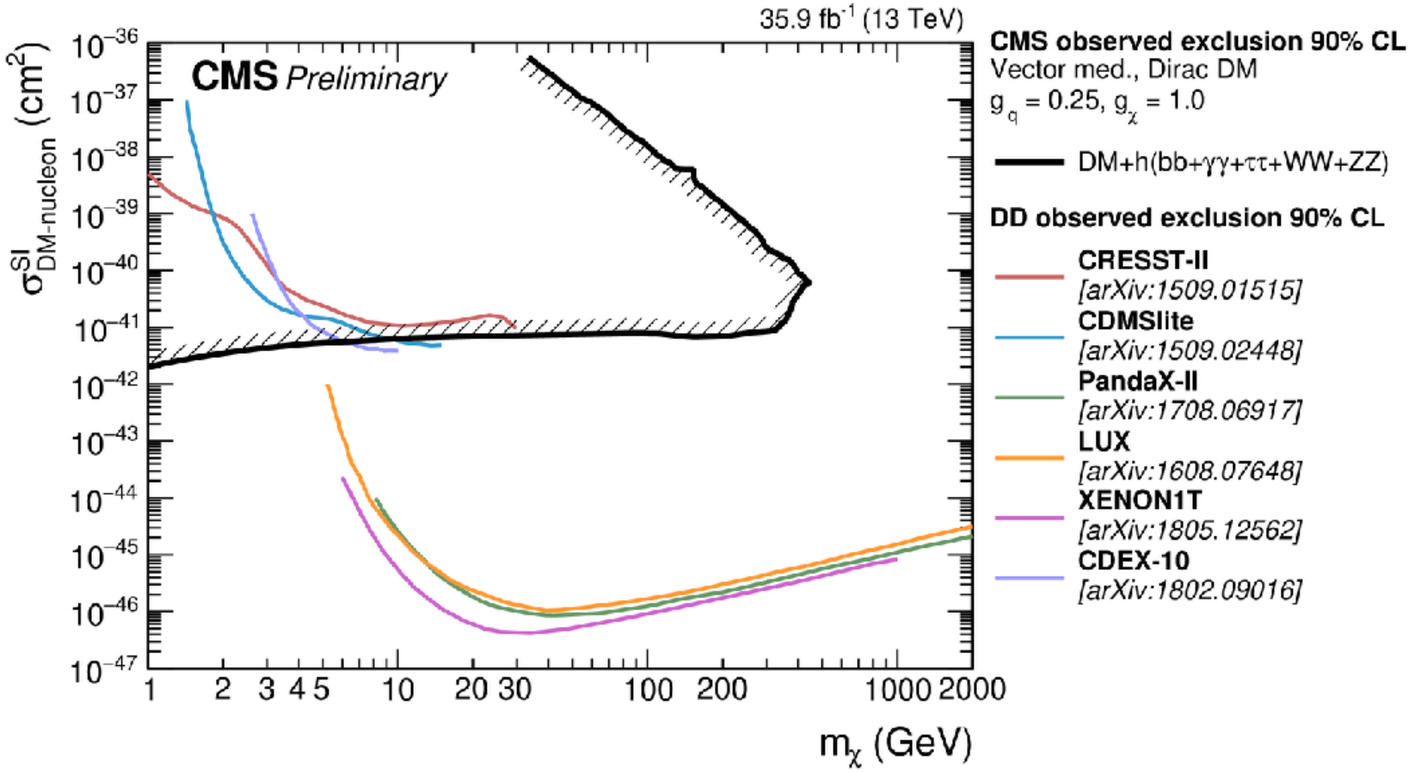


Mono-Hbb



EPJC 79 (2019) 280

Mono-H Combination

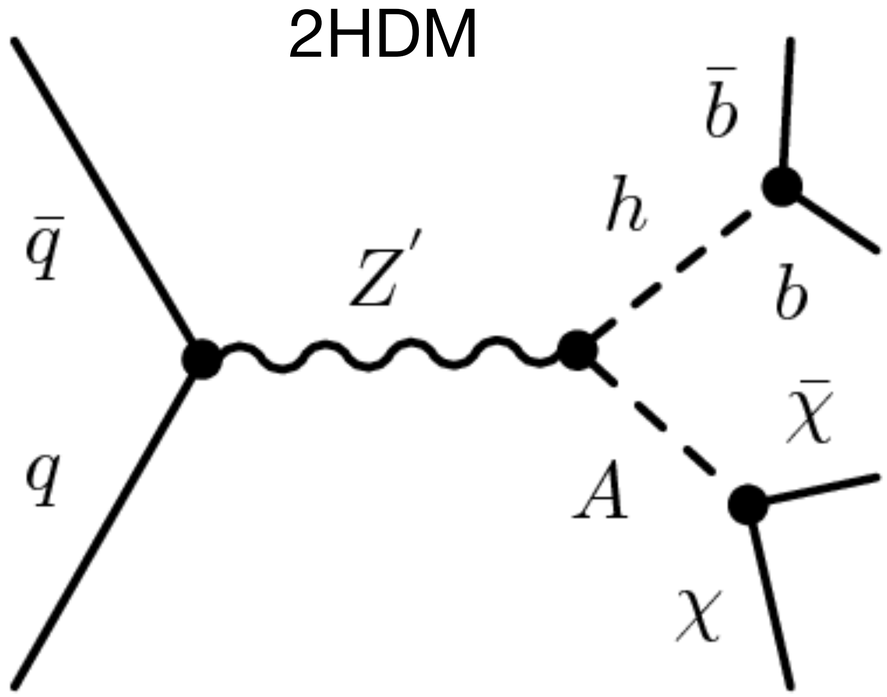


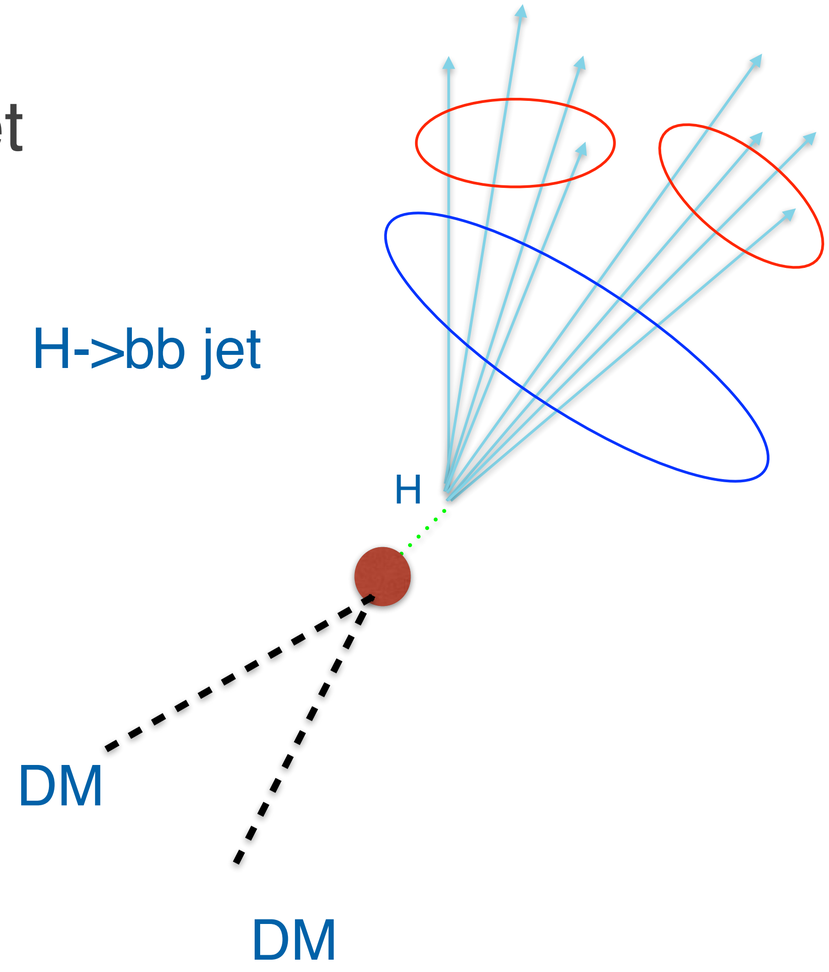
PAS EXO-18-011

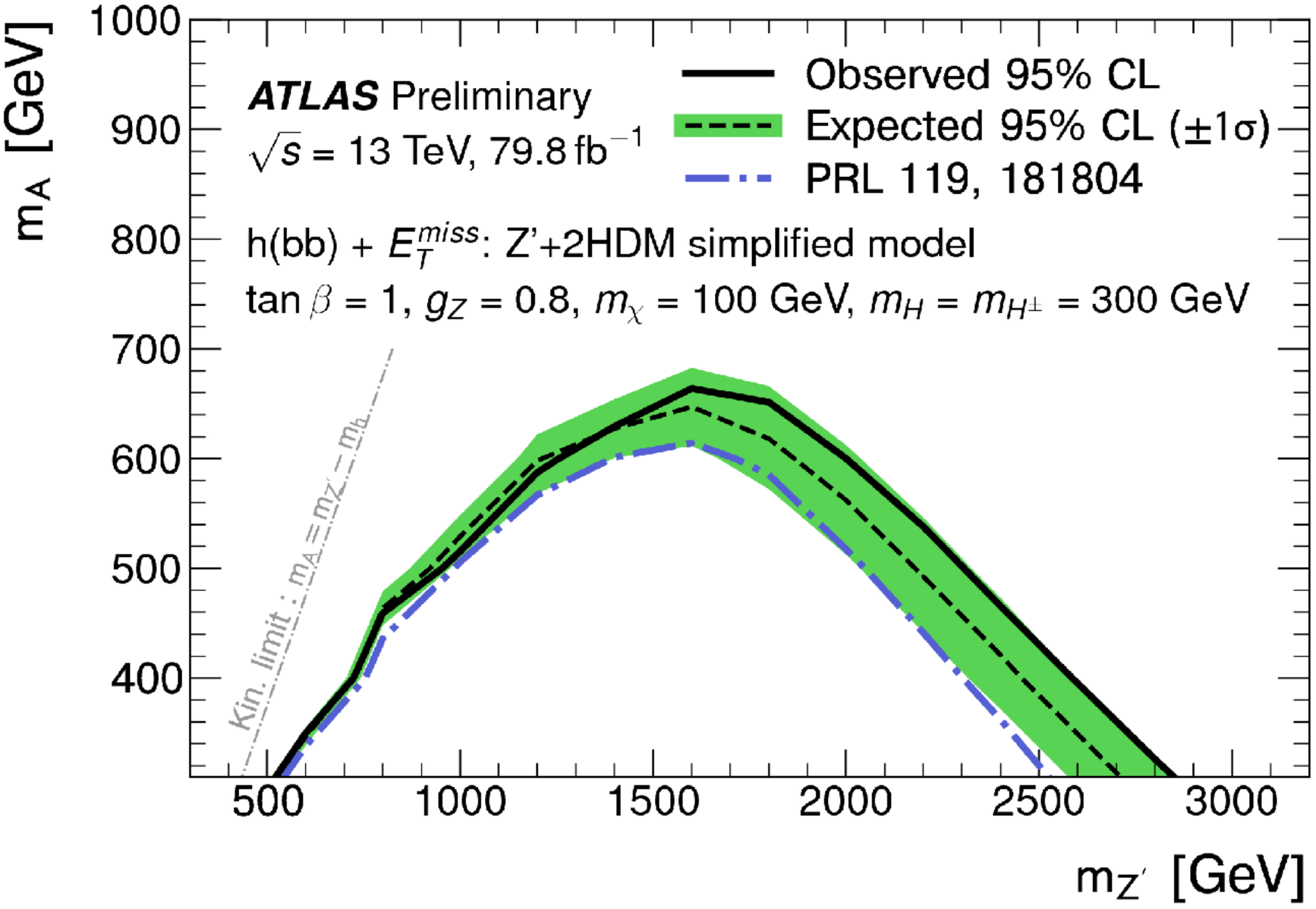
Hadronic Mono-H(->bb) Signature

Boosted Higgs boson decaying to a b-quark pair

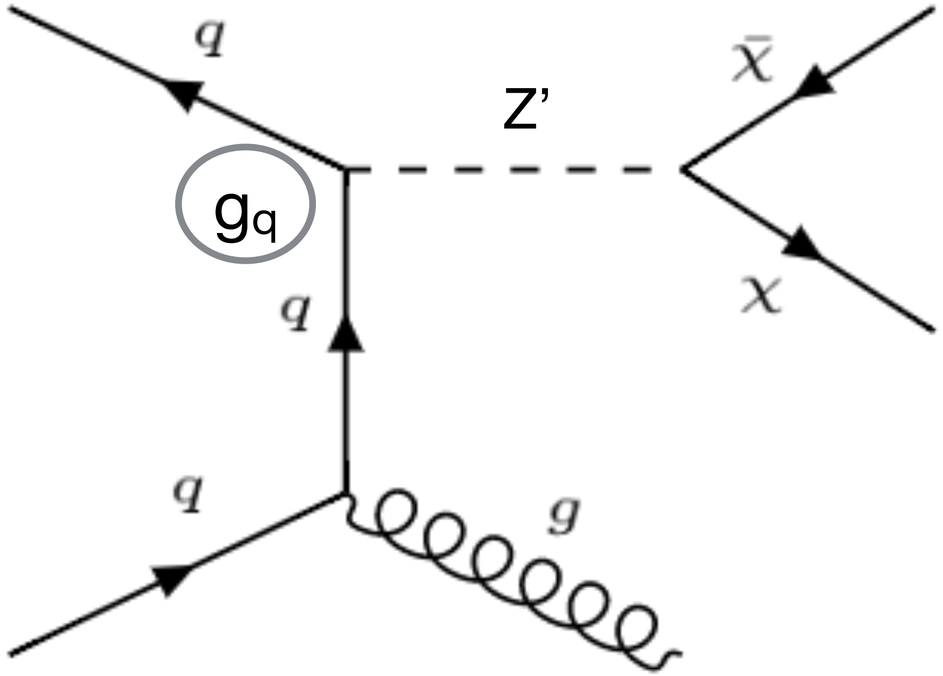
=> MET recoiling against a Higgs large-radius jet

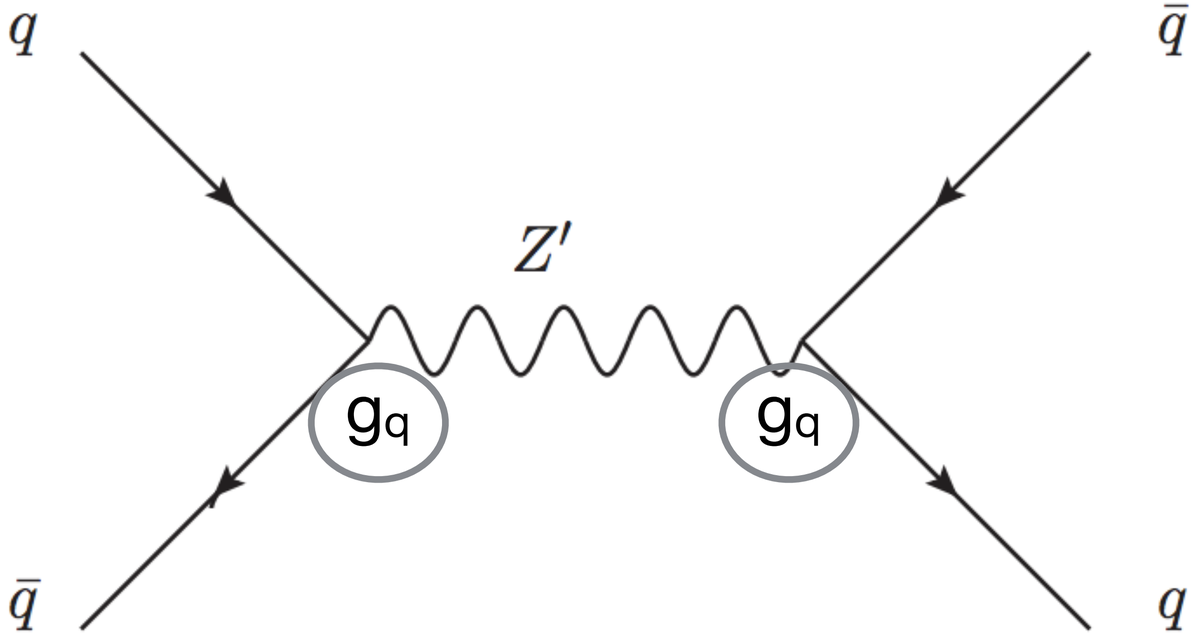





ATLAS Preliminary
√s = 13 TeV, 79.8 fb⁻¹
Observed 95% CL
Expected 95% CL (±1σ)
PRL 119, 181804
h(bb) + E_T^miss: Z'+2HDM simplified model
tan β = 1, g_Z = 0.8, m_χ = 100 GeV, m_H = m_H± = 300 GeV
Kin. limit : m_A = m_Z' − m_h
m_A [GeV]
m_Z' [GeV]
1000
900
800
700
600
500
400
500
1000
1500
2000
2500
3000

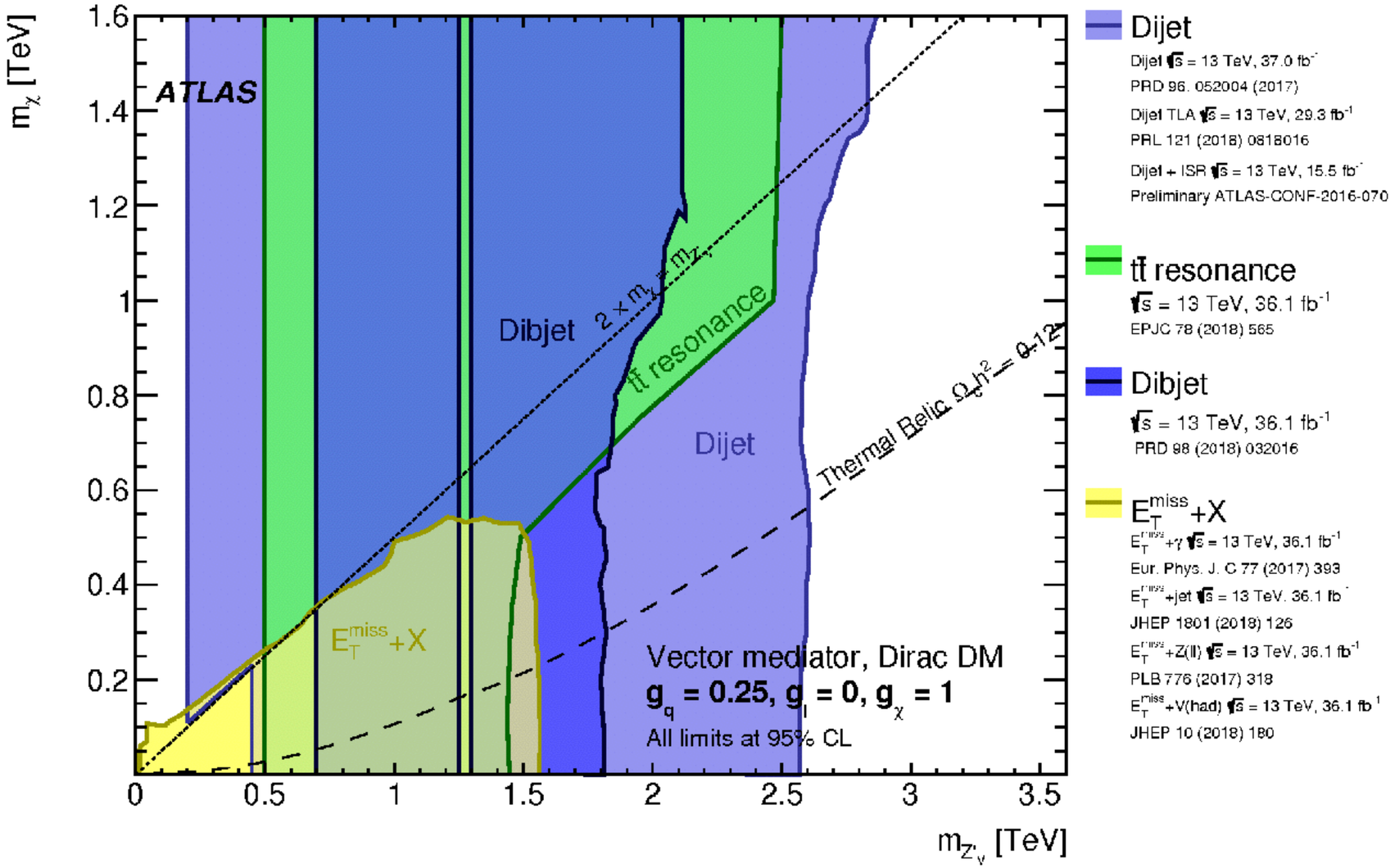
Dijet DM Interpretation





Interpret dijet as DM mediator searches, in single model with **same coupling**

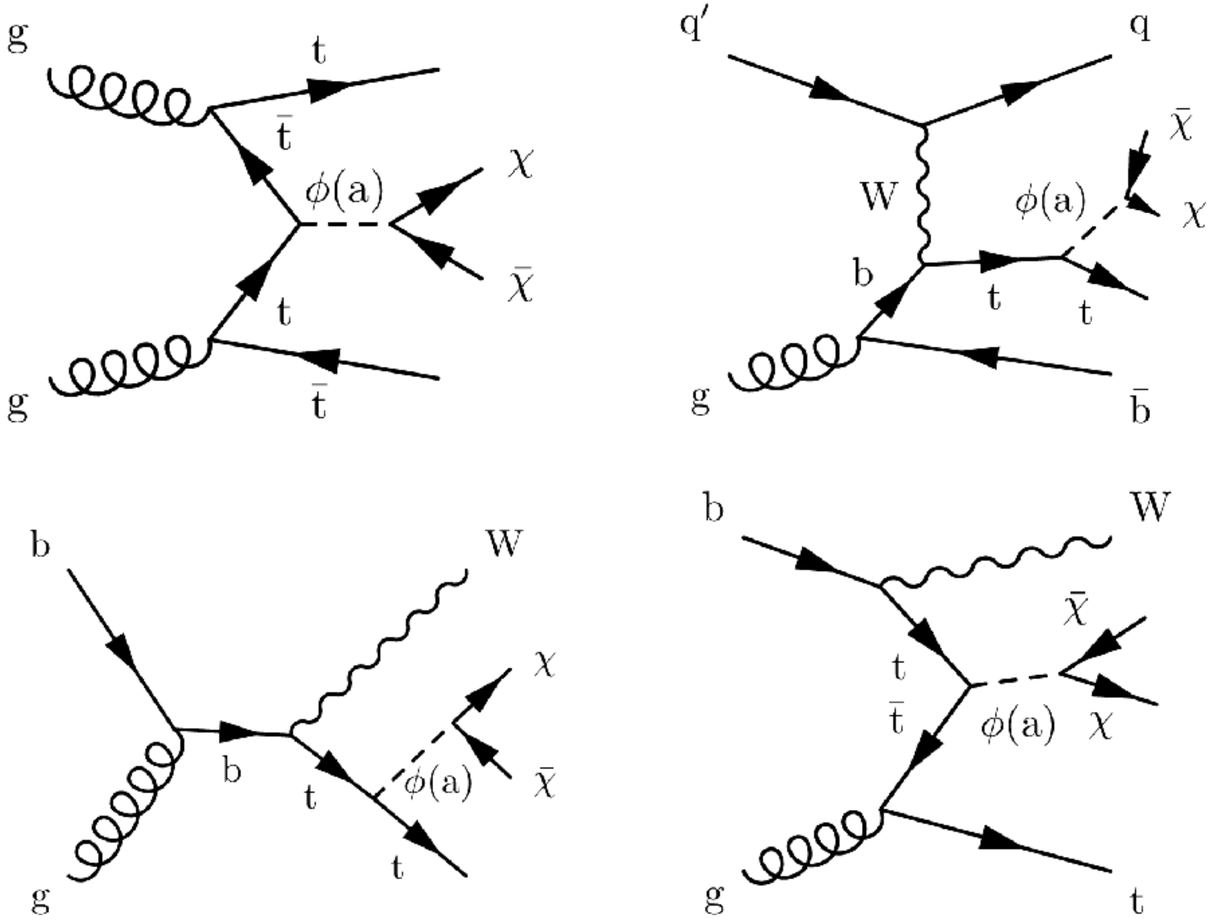
- Large portion of the phase space excluded by dijet
- Dijet limits are sensitive to the coupling variation

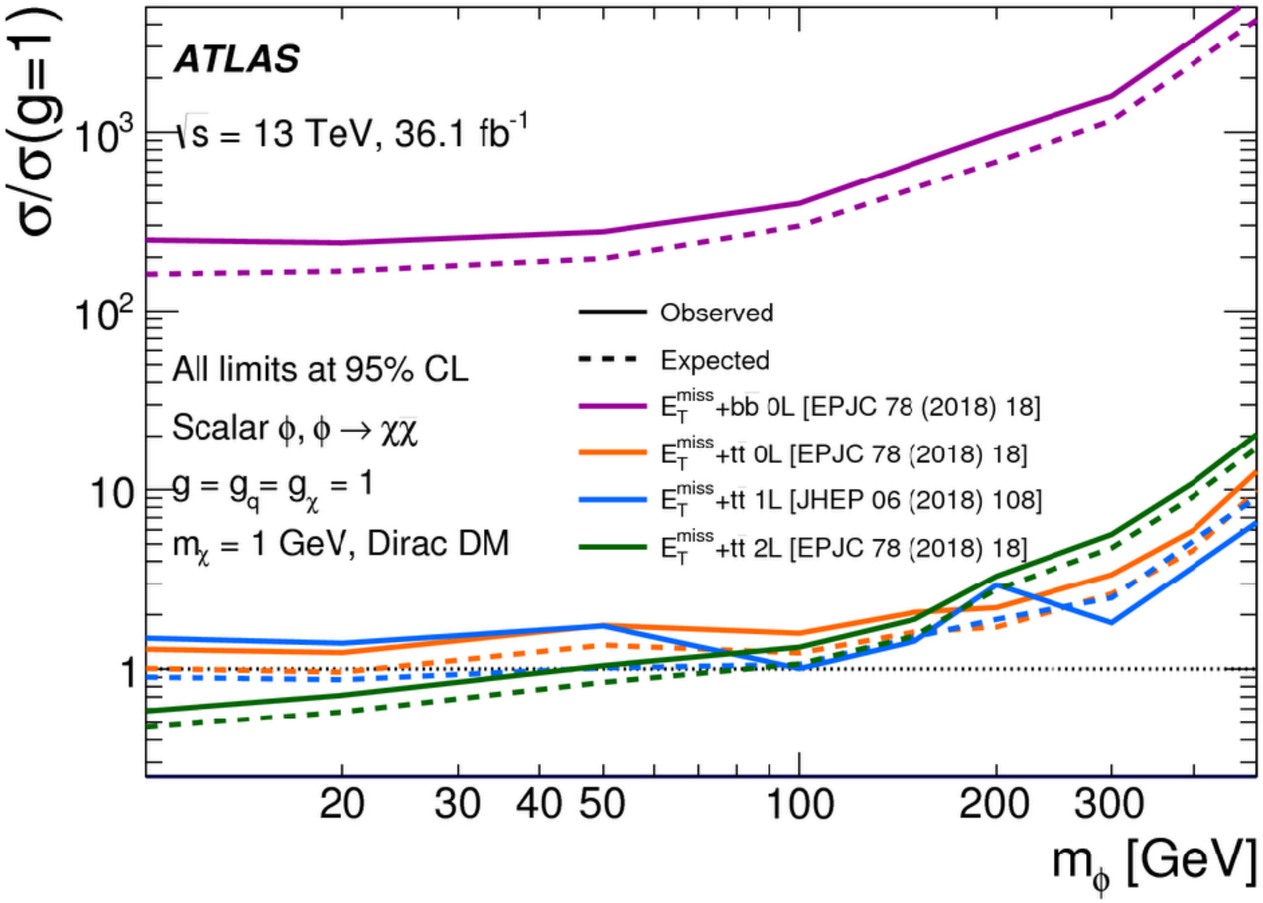


arXiv:1903.01400

Fermilab

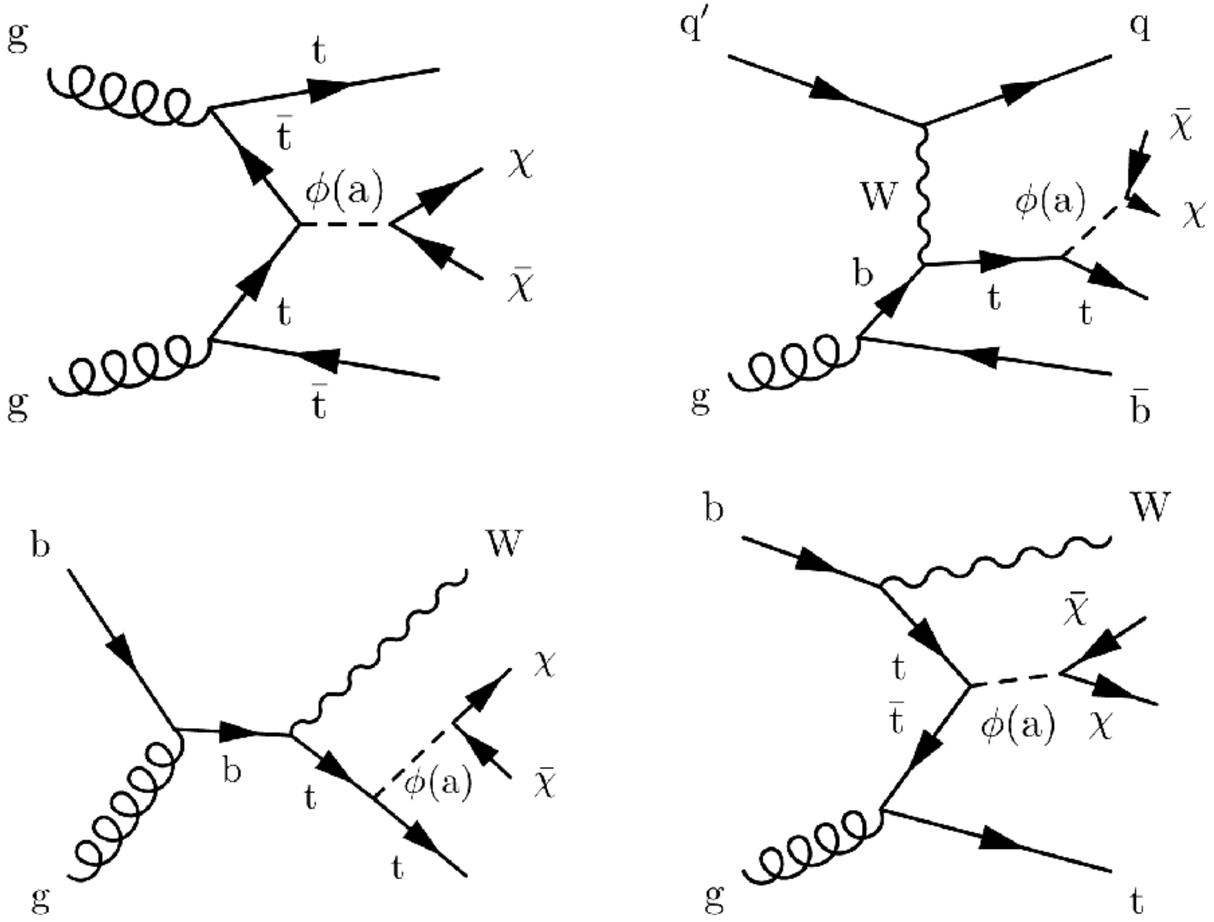
Scalar Mediator

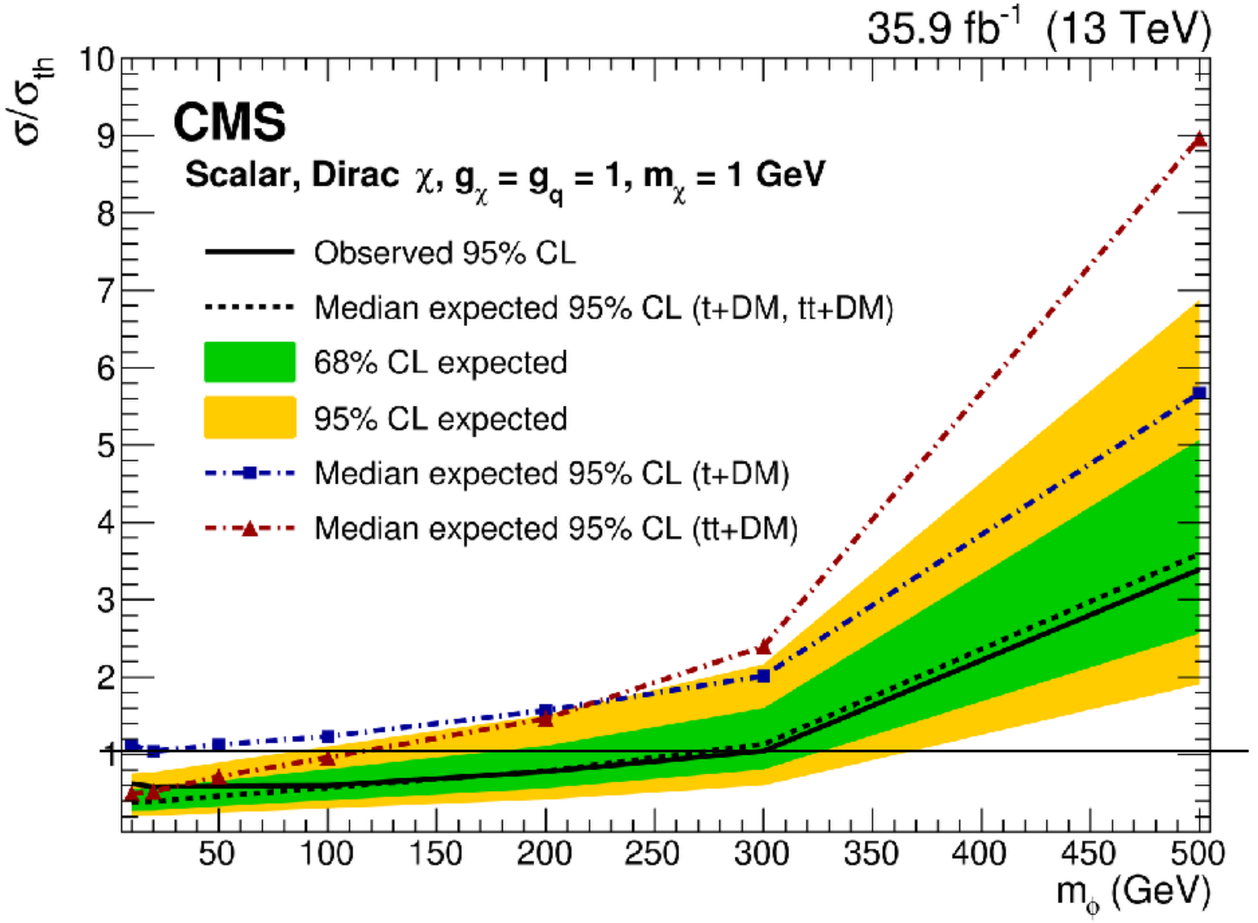




arXiv:1903.01400

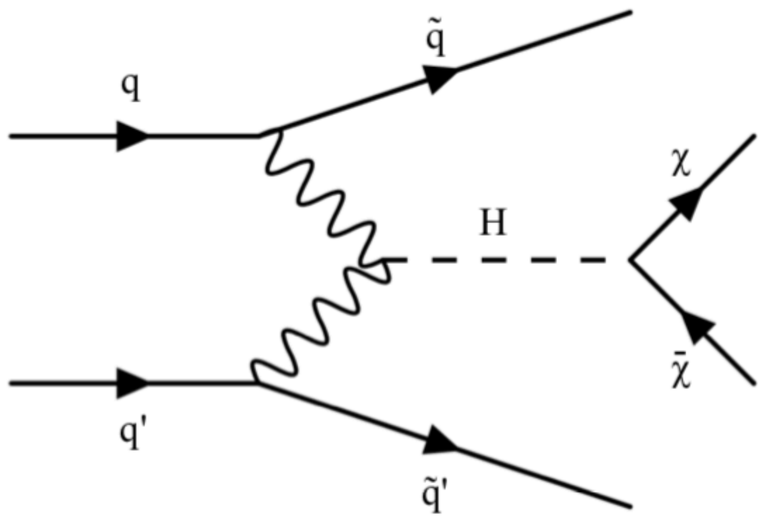
Scalar Mediator



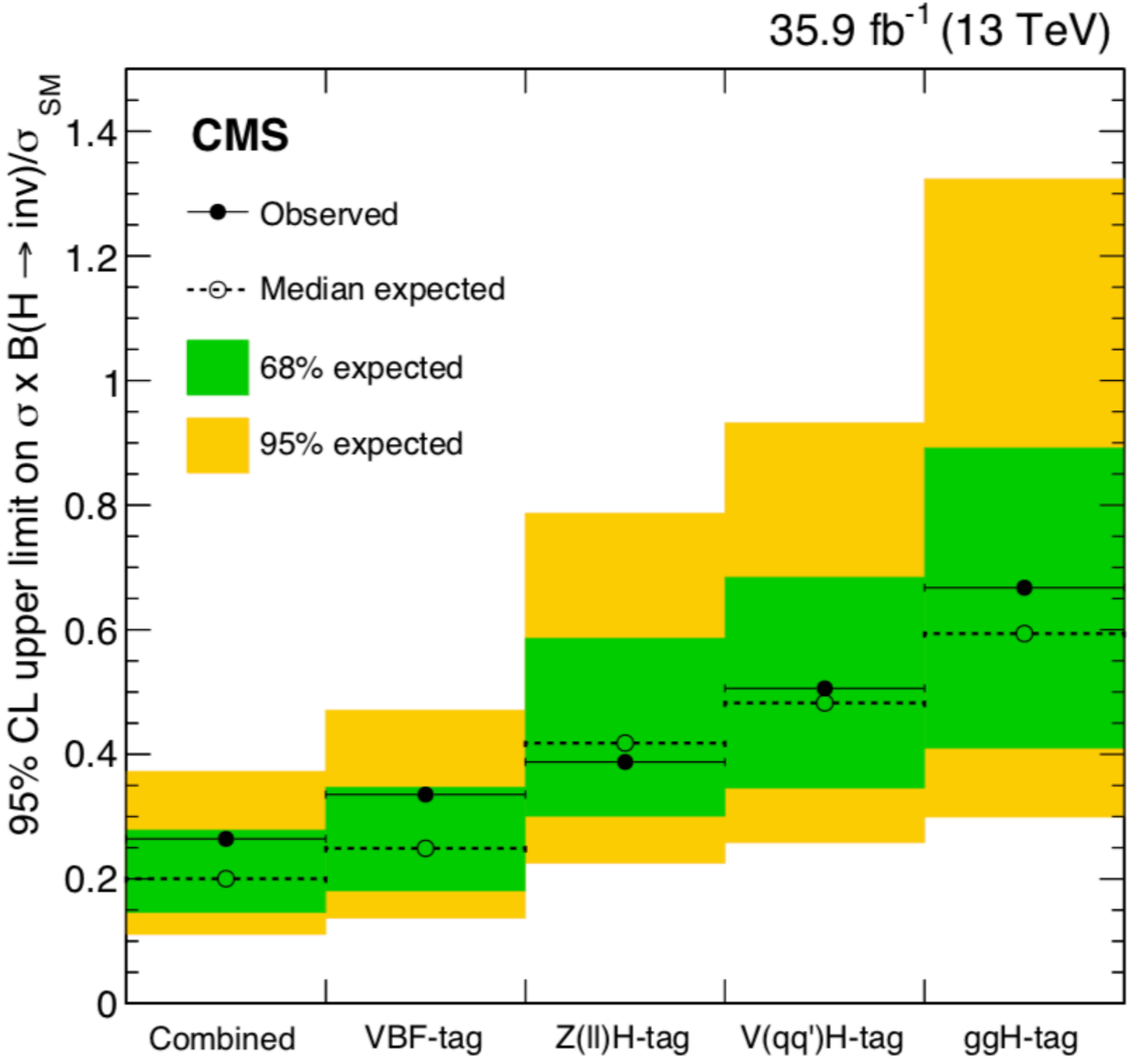


CMS-EXO-18-010

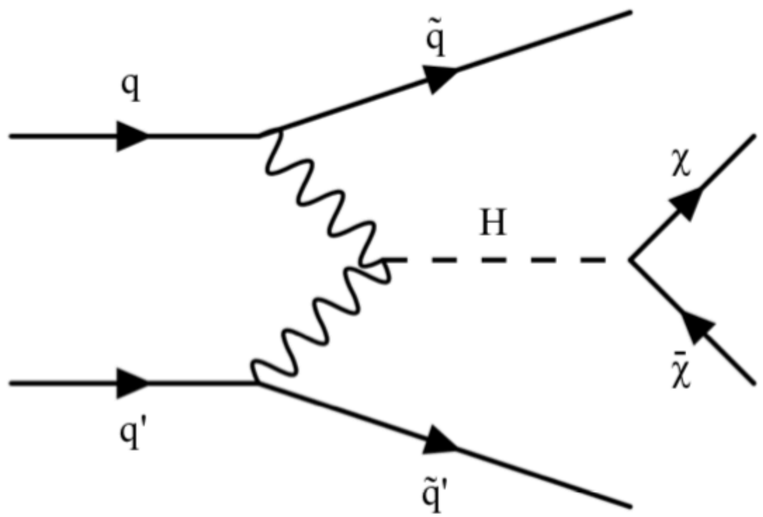
Higgs Invisible

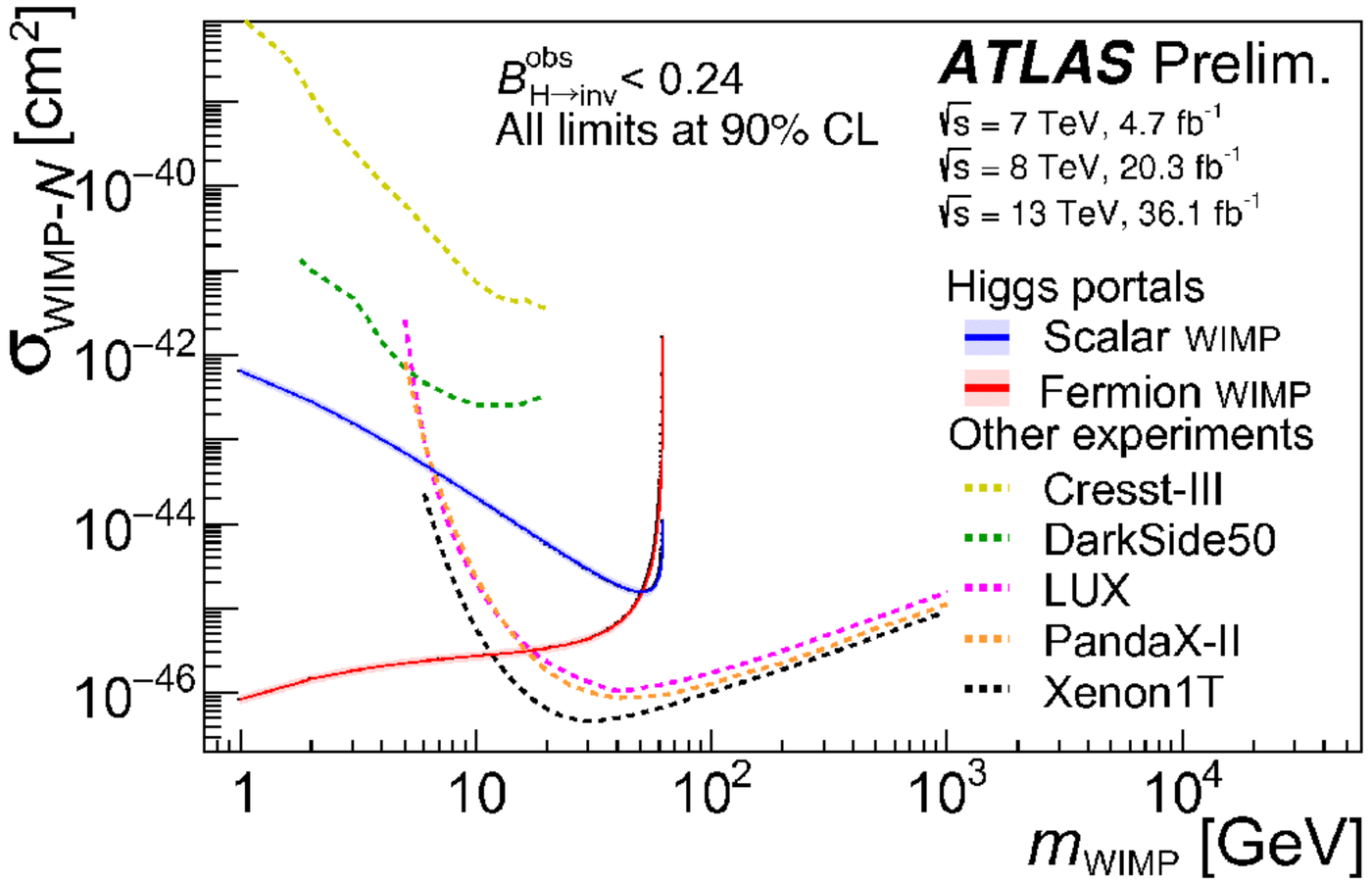


arXiv:1809.05937



Higgs Invisible





ATLAS-CONF-2018-054

Conclusions

- Broad program of DM searches at the LHC
- Allowed parameter space for DM models substantially reduced, new dataset collected in 2017/18 still needs to be fully analyzed
  - 4x the current statistics
  - new results with full RunII dataset expected by the end of 2019
- Complementarity with ID and DD detection, simplified models allow for a direct comparison
- New theoretical interpretations
  - next-generation DM model, provide the simplest theoretically consistent extension of the DM simplified model
  - Pseudoscalar mediator (2HDM+a), LHCDMWG white paper: arXiv:1810.09420

for full results, please visit the ATLAS/CMS Exotica webpage:

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

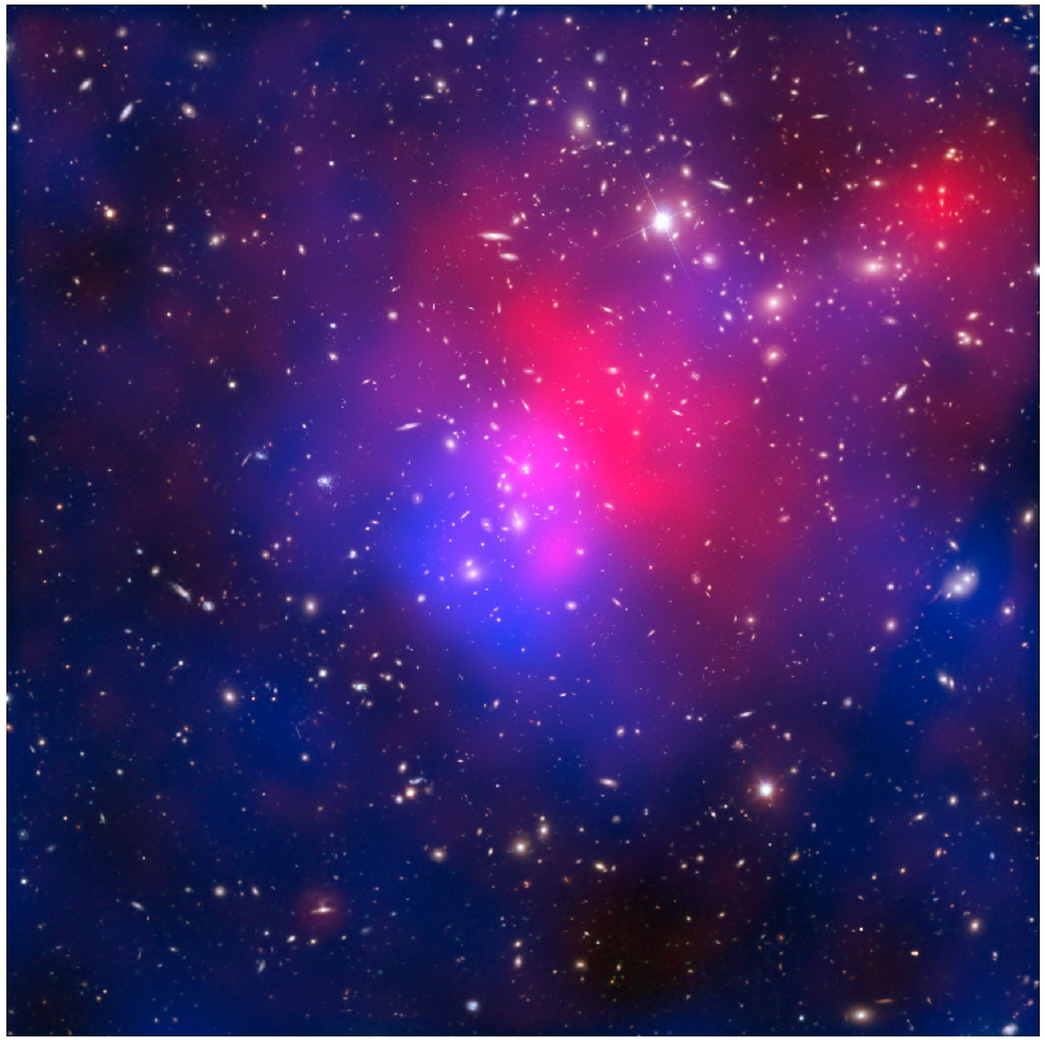
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/EXO/index.html

http://cms-results.web.cern.ch/cms-results/public-results/preliminary-results/SUS/

Backup

Dark Matter



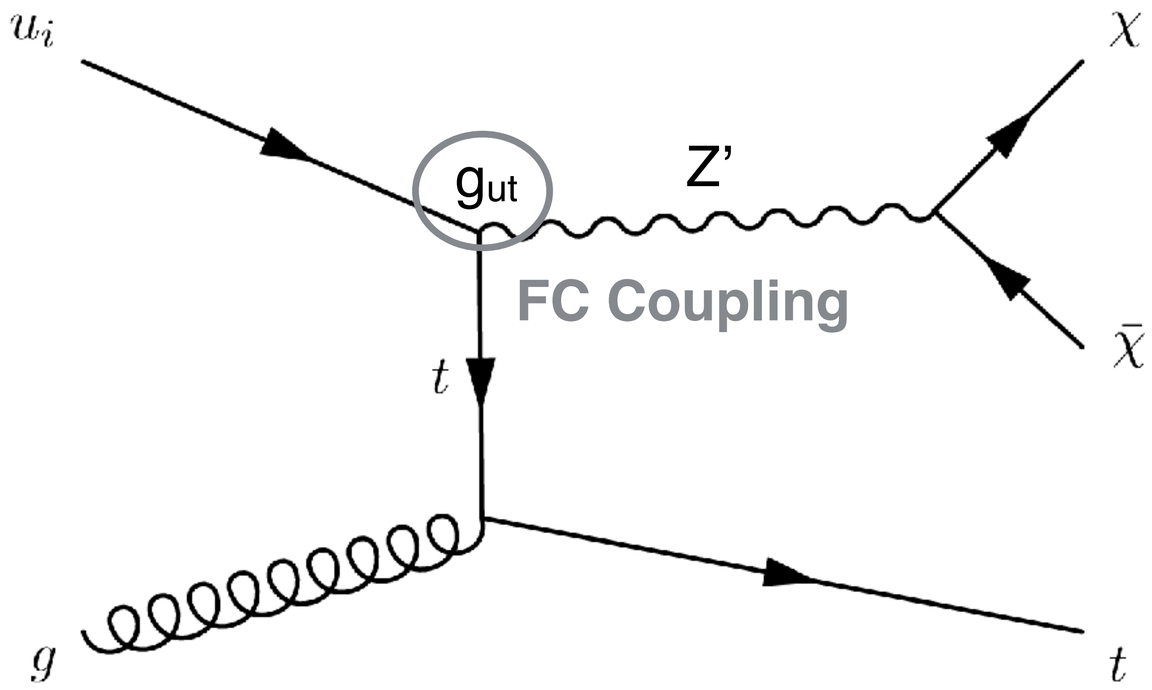
- From **cosmological observations,** 85% of the matter comprised of dark matter (**DM**)
- What we know:
  - DM does not interact electro-magnetically
  - DM interacts gravitationally

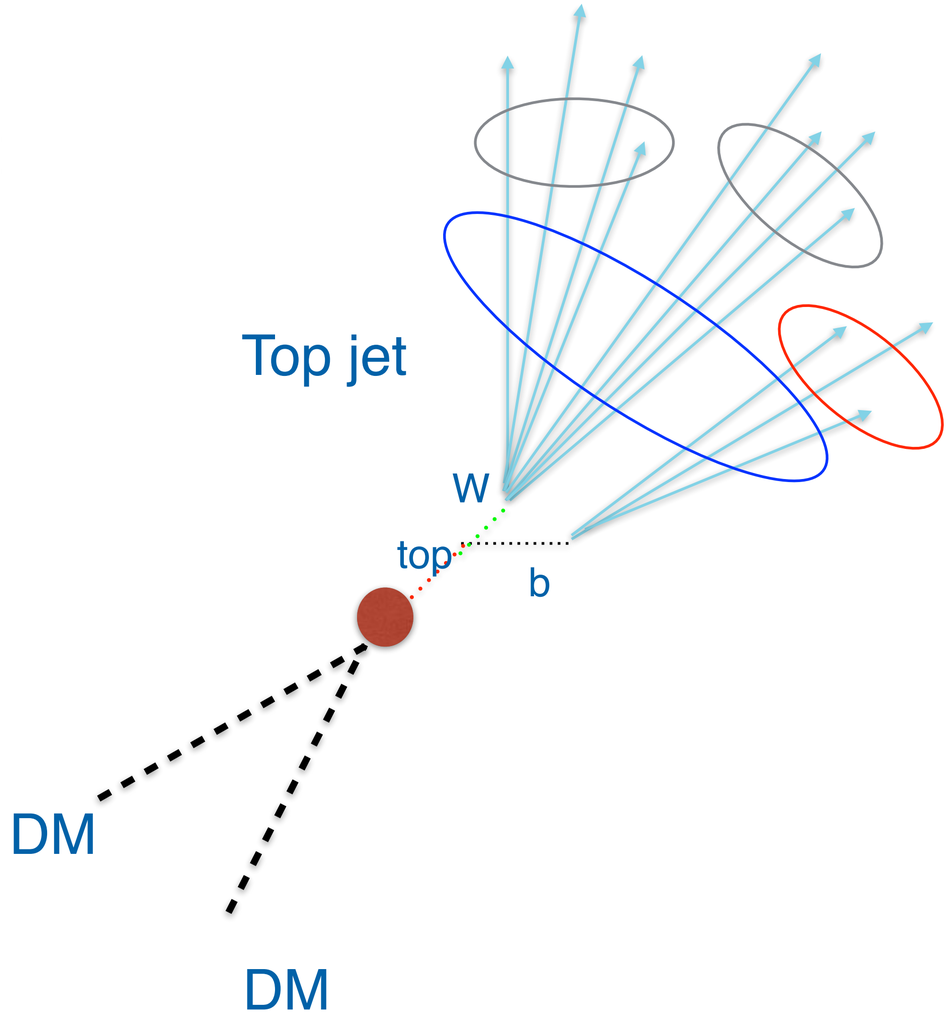
We know nothing about its nature and properties

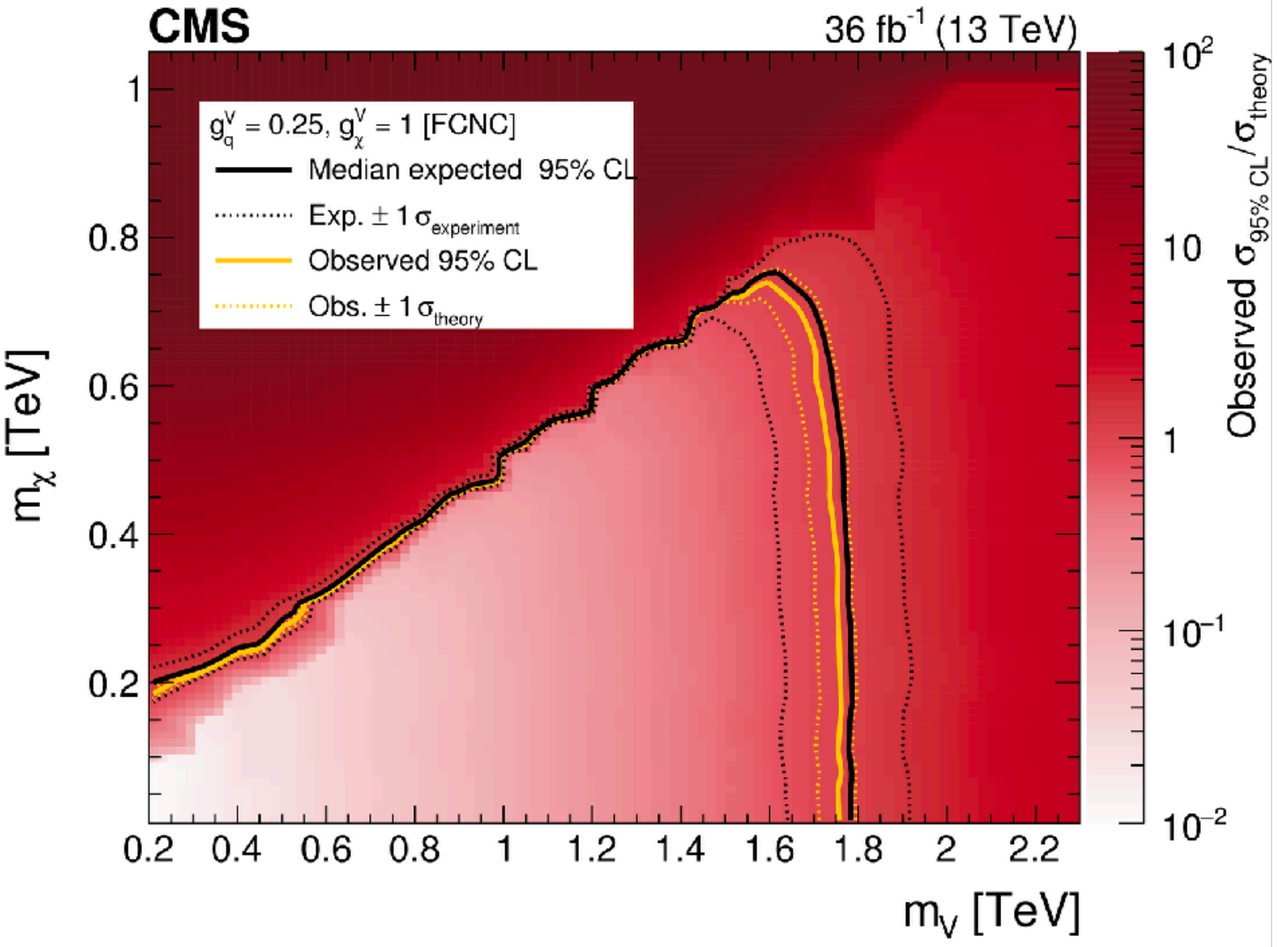
Hadronic Mono-top Signature

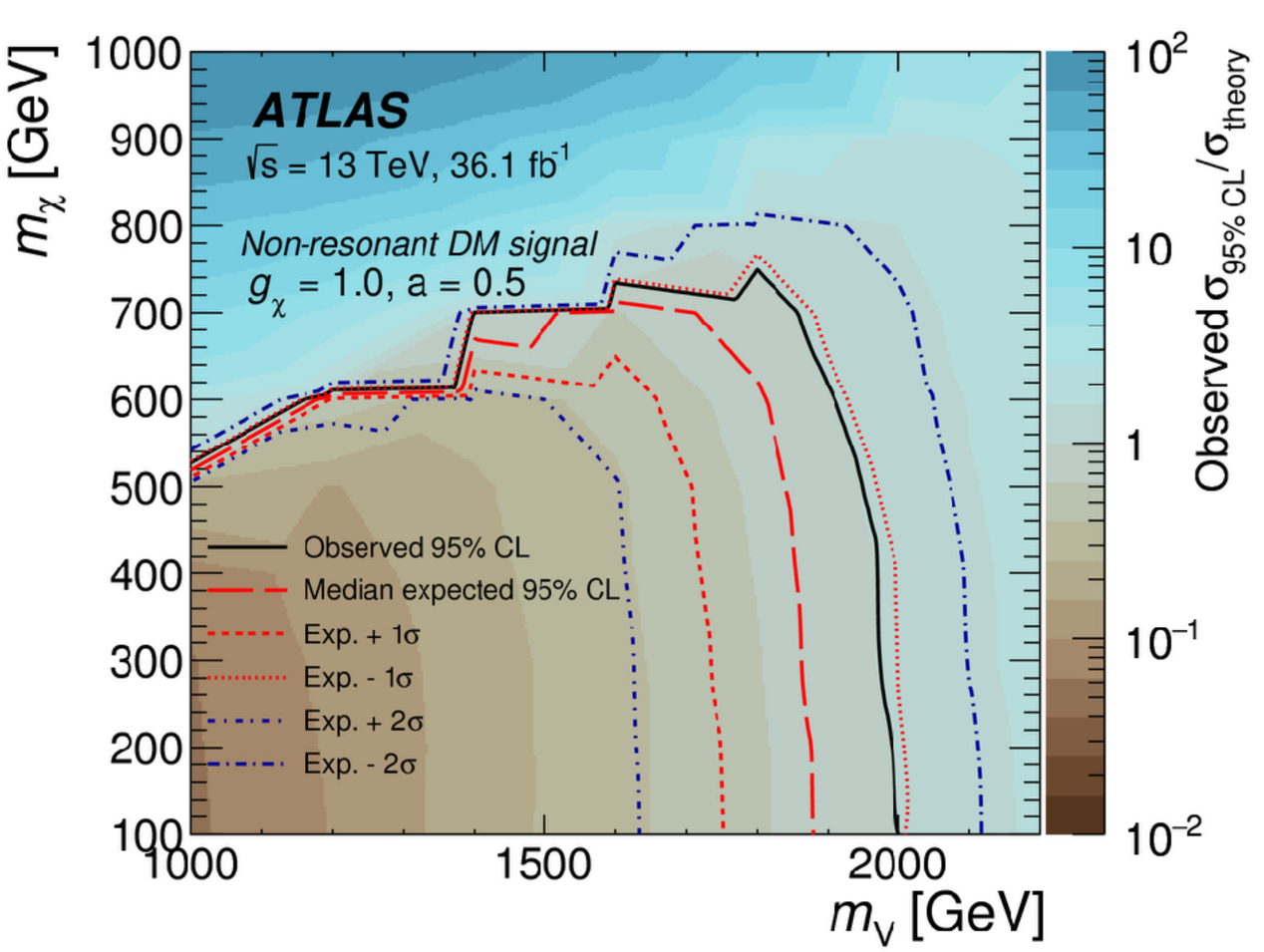
Boosted top quark decaying hadronically

=> MET recoiling against top large radius jet









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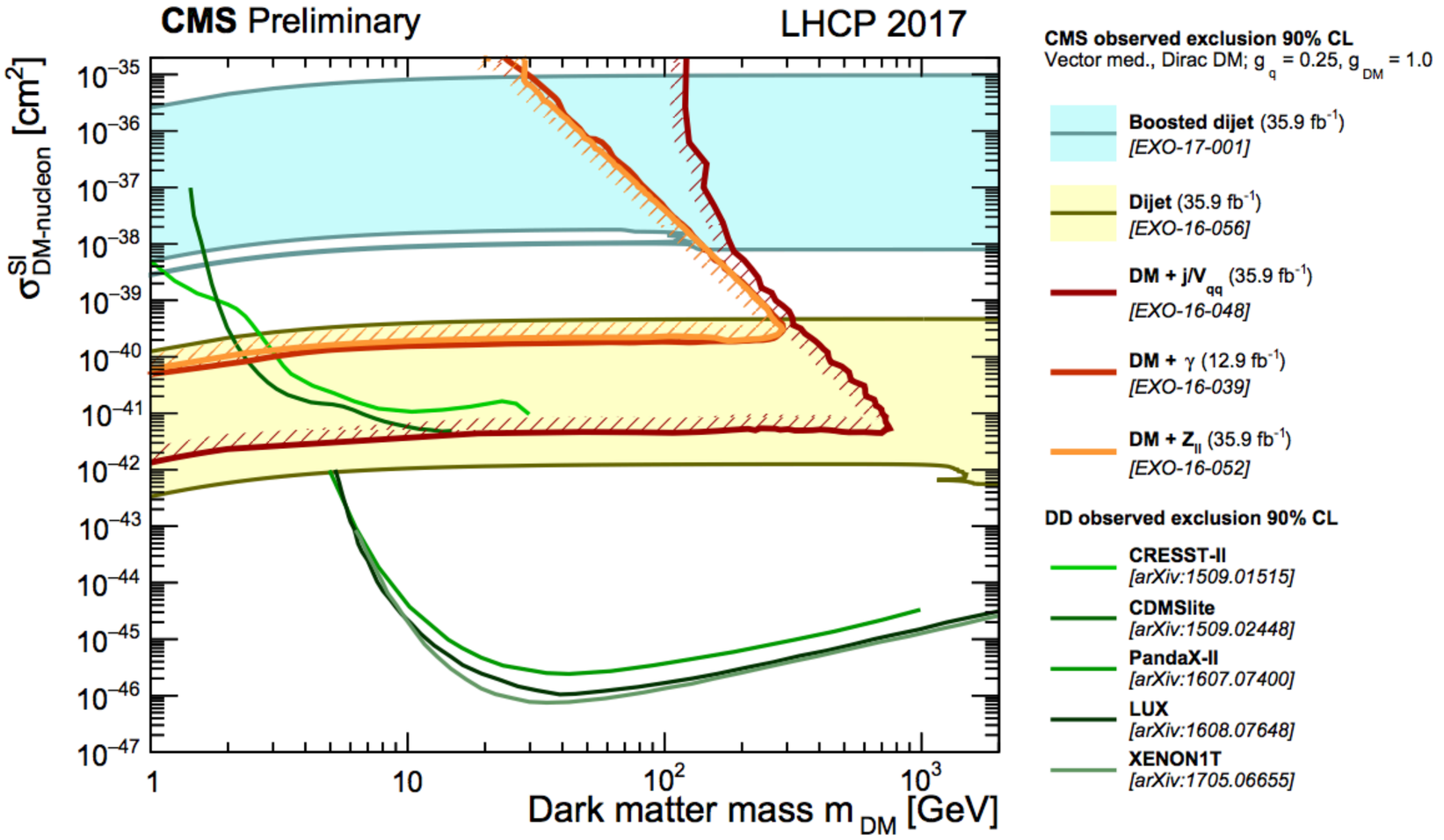
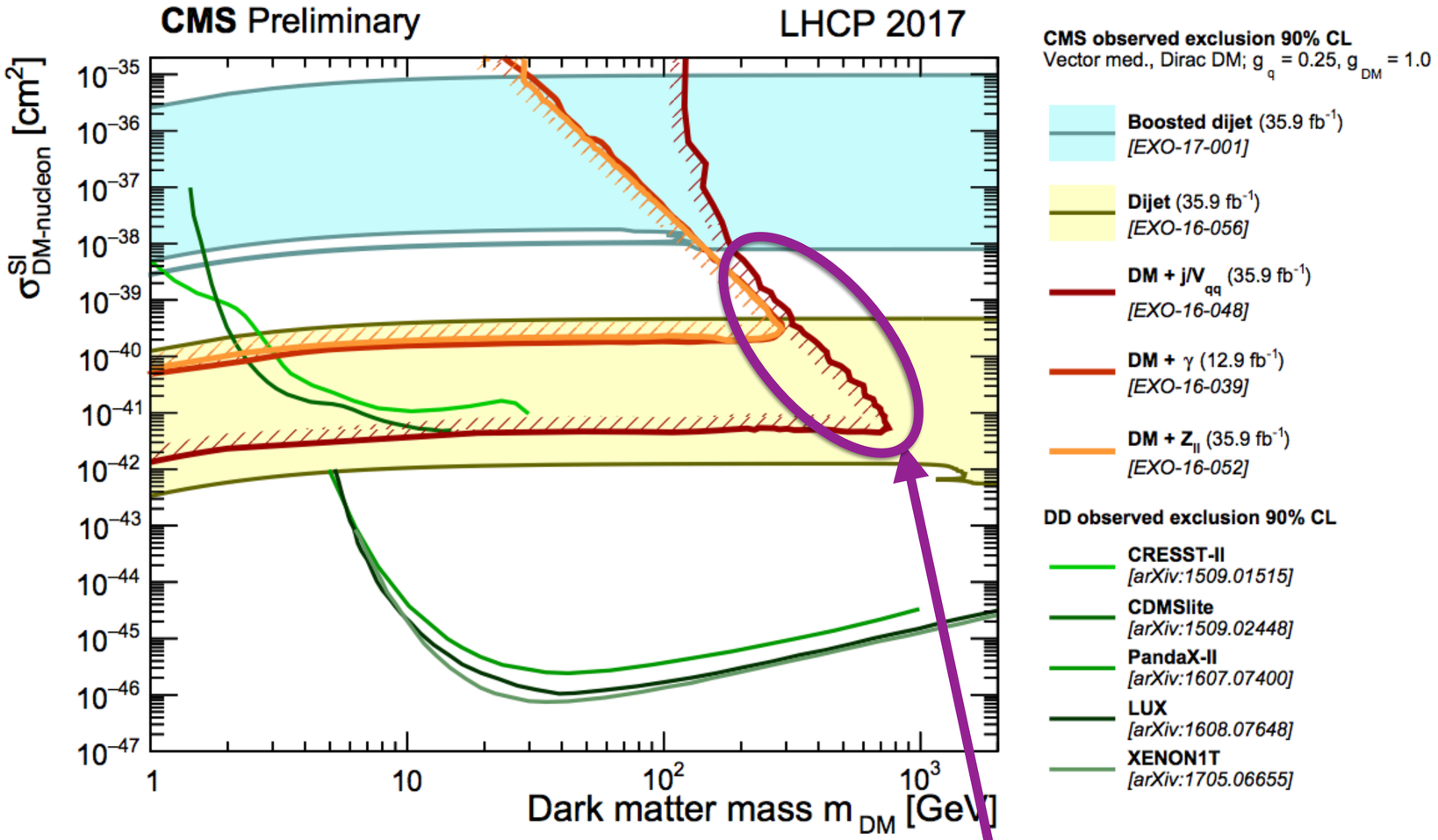


$$\sigma_{\mathrm{SI}} \simeq 6.9 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2$$



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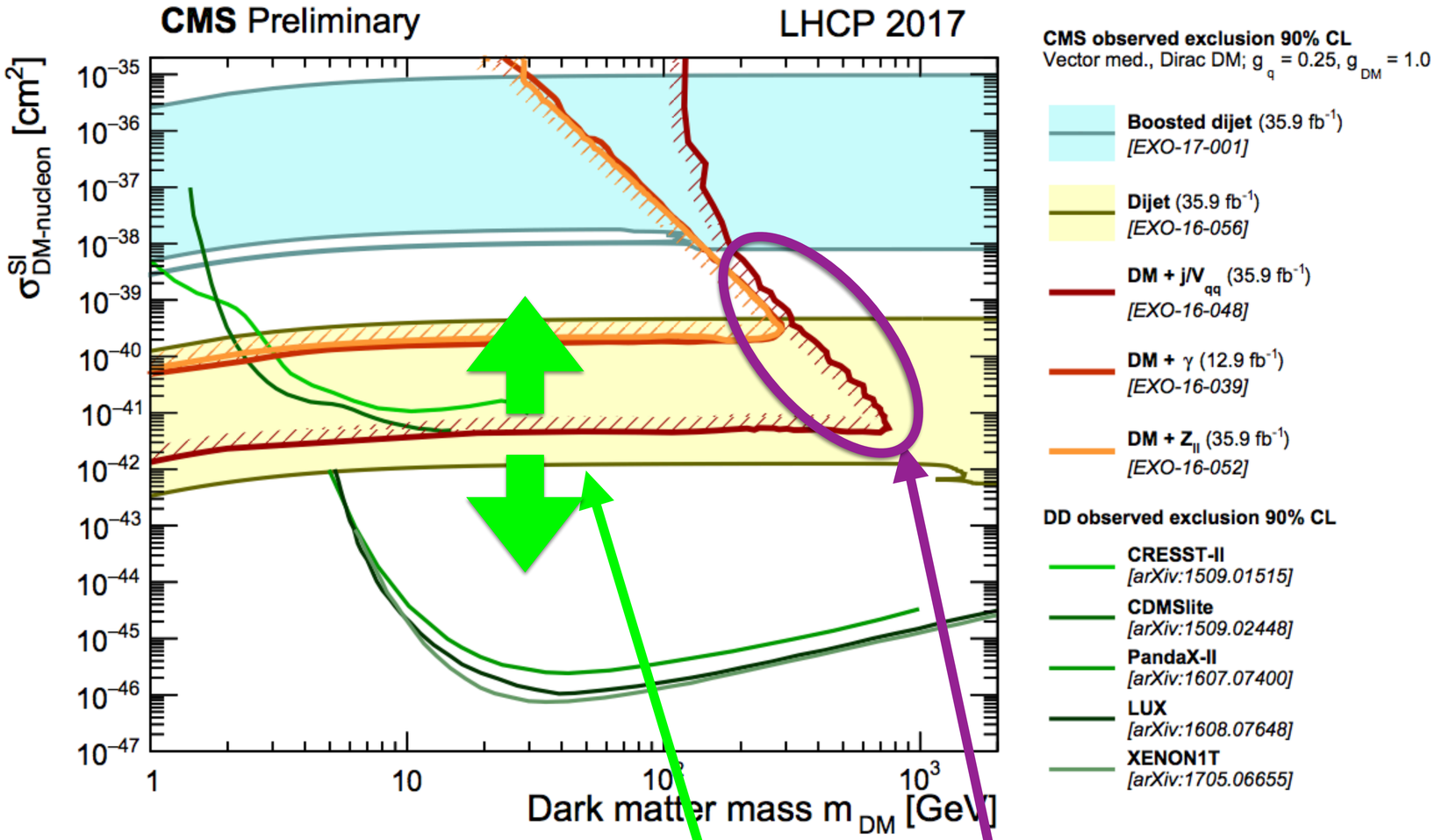

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Limitations

- Results from colliders are model dependent
  - assumption of couplings affects the limits
- Hard to compare with direct/indirect detection, even though we are practically looking at the same model

Introducing *Y*

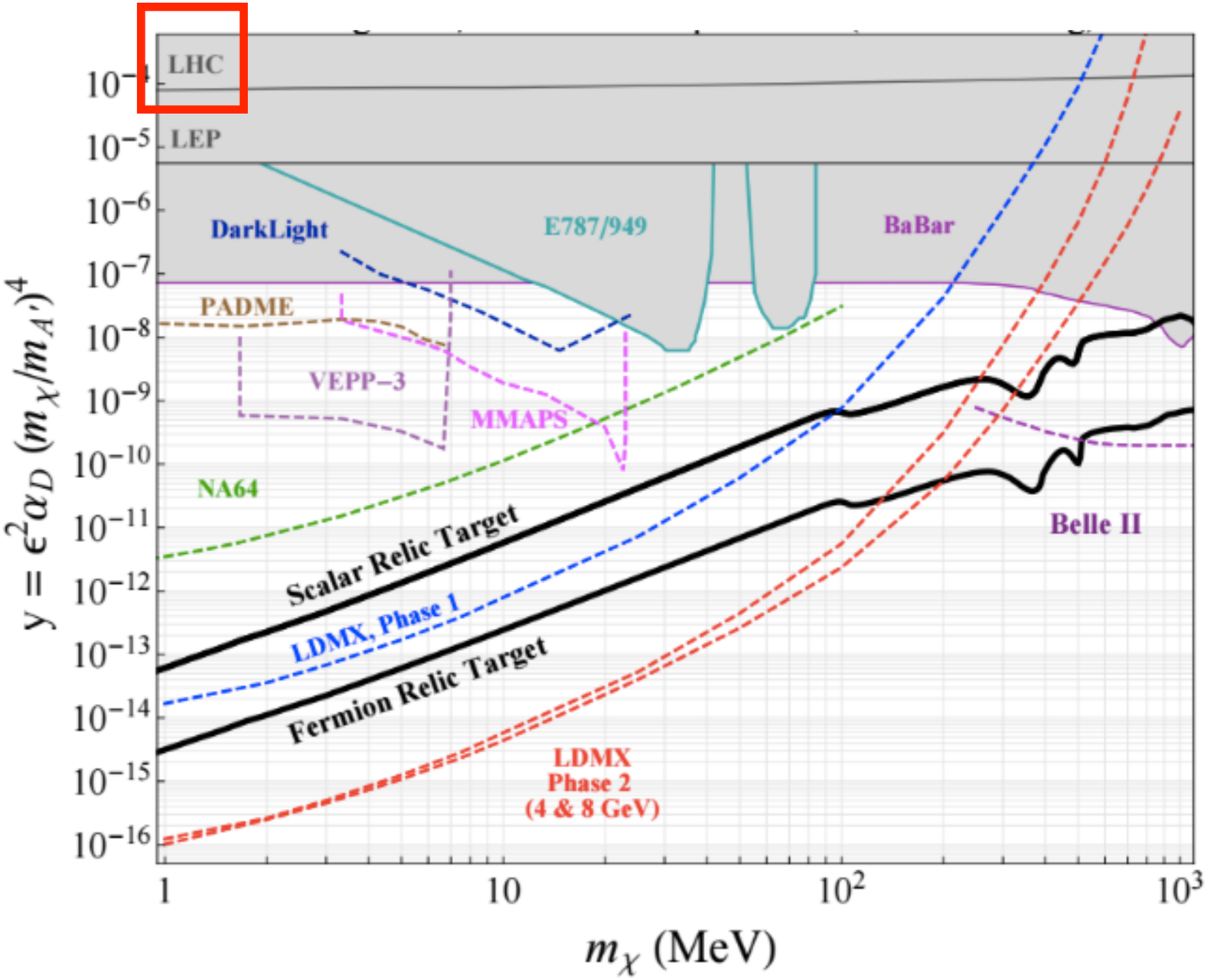
annihilation cross section $\boldsymbol{\sigma_v} \sim g_{DM}^2 g_q^2 m_{DM}^2 / m_{Med}^4 = \mathbf{Y} m_{DM}^2$ | $\mathbf{Y} = g_{DM}^2 g_q^2 m_{DM}^4 / m_{Med}^4$

- **Y** is a convenient variable to quantify sensitivity:
  - for each choice of m_{DM} there is a unique value of **Y** independently of the individual values of g_x, g_q, m_V.
- Direct detection constraints are also naturally expressed as functions of **Y** and m_{DM}
- Accelerator-based constraints are not, since they depend on the choice of g_{DM}, g_q, m_{Med}

Introducing *Y*

$$\sigma_{LHC} \sim g_q^2 = \mathbf{Y}\ (1/g_{DM}^2)\ m_{Med}^4/m_{DM}^4$$

- σ_{LHC} can still be given in terms of **Y**
- **Y** can be measured by making assumption on (m_{Med}/m_{DM}) and g_{DM}
  - g_{DM} large
  - m_{Med}/m_{DM} order of unity


LHC
LEP
DarkLight
E787/949
BaBar
PADME
VEPP–3
MMAPS
NA64
Scalar Relic Target
LDMX, Phase 1
Fermion Relic Target
LDMX
Phase 2
(4 & 8 GeV)
Belle II
$y = \epsilon^2 \alpha_D \, (m_\chi / m_{A'})^4$
m_χ (MeV)
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
10^{-10}
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^{-15}
10^{-16}
1
10
10^2
10^3