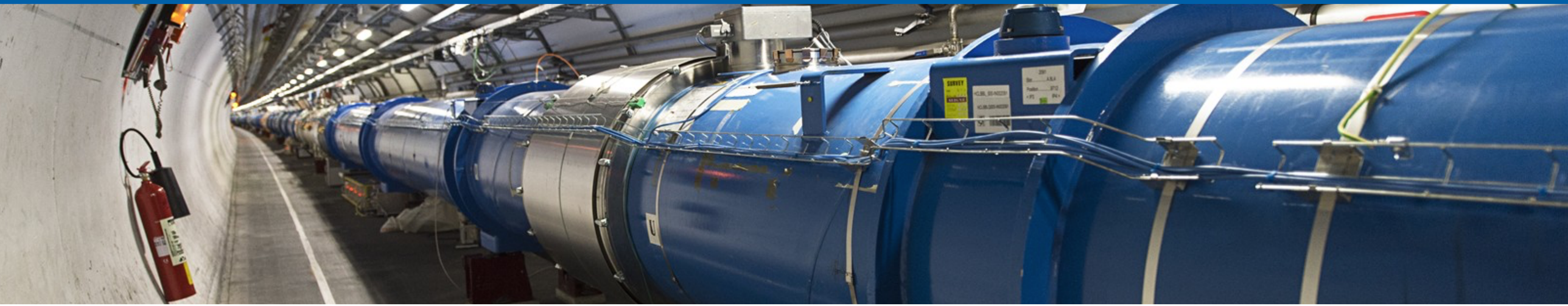


Dark matter results from ATLAS and CMS

Matteo Cremonesi

On Behalf of the ATLAS and CMS Collaborations

In this talk:

- Description of the general approach for dark matter searches at the LHC
  - both experimental techniques and theoretical interpretation
- Collection of results from ATLAS and CMS experiment, with focus on:
  - the Mono-X program (i.e. no dijet or SUSY reinterpretations)
  - newest results, based on data collected in 2016

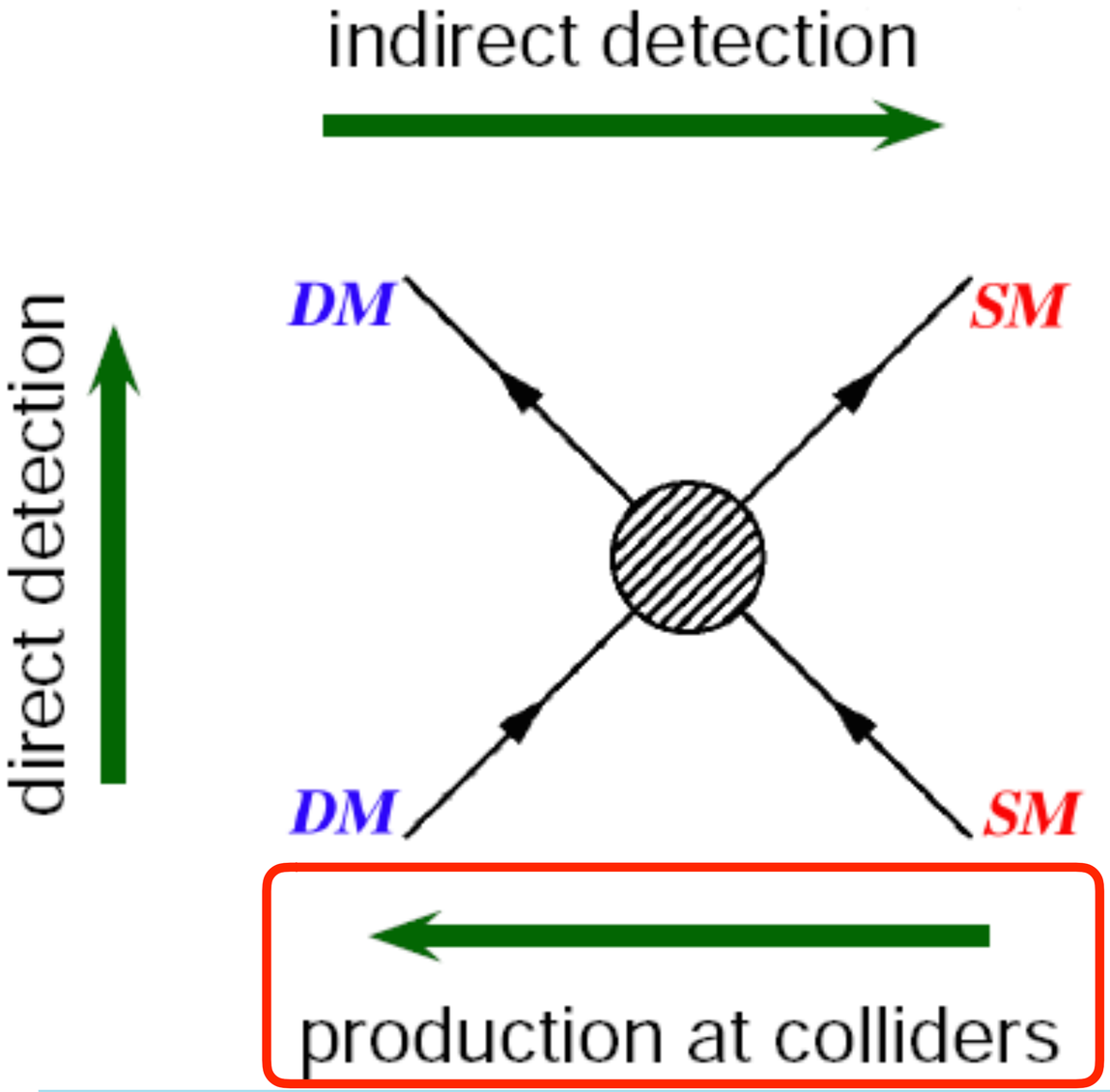
for full results, please visit the ATLAS/CMS Exotica webpage:
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ExoticsPublicResults
https://twiki.cern.ch/twiki/bin/view/AtlasPublic/SupersymmetryPublicResults
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsEXO
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsSUS

Introduction

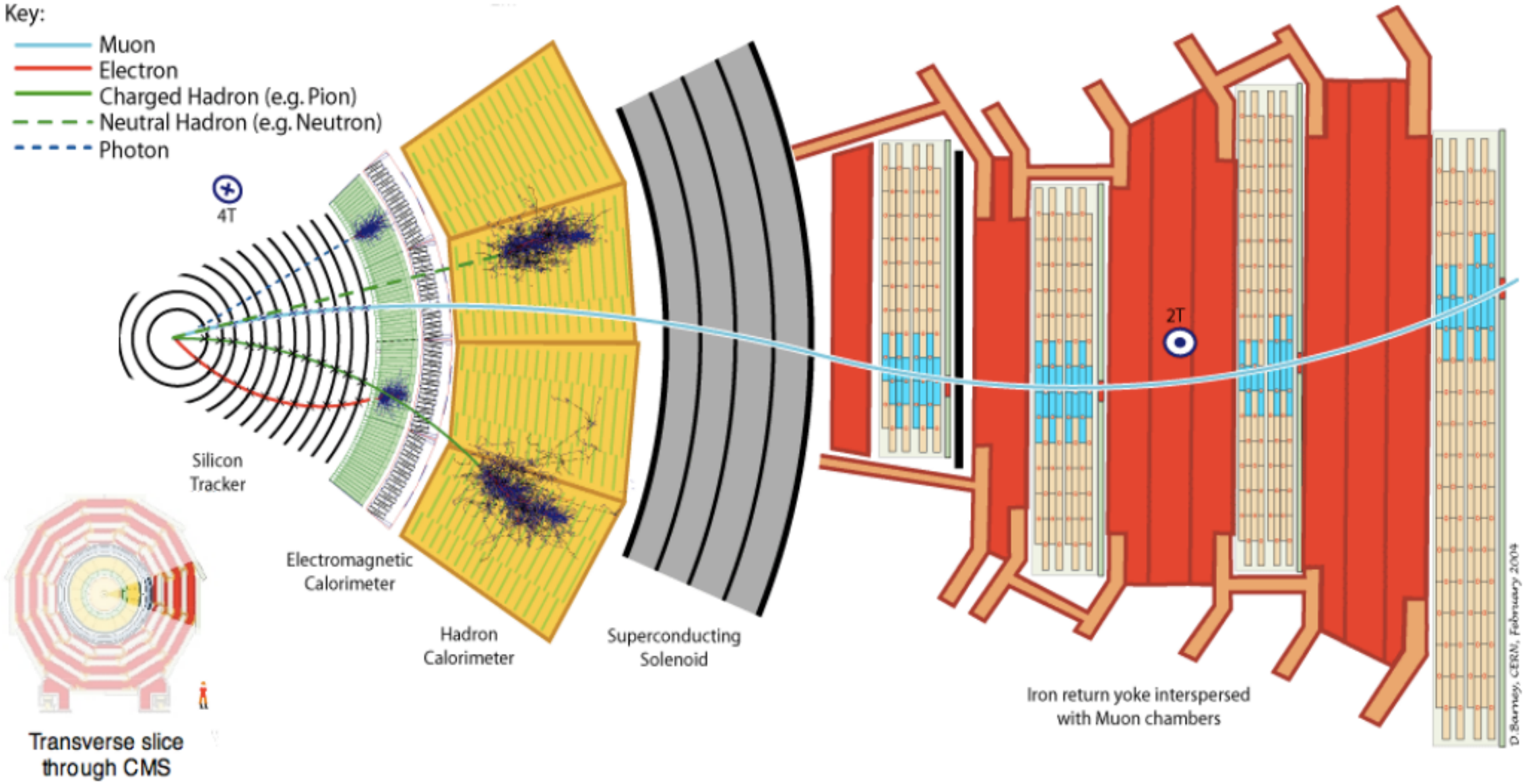
- From **cosmological observations,** 85% of the matter comprised of dark matter (**DM**)
- What we know:
  - DM does not interact electro-magnetically
  - DM interacts gravitationally

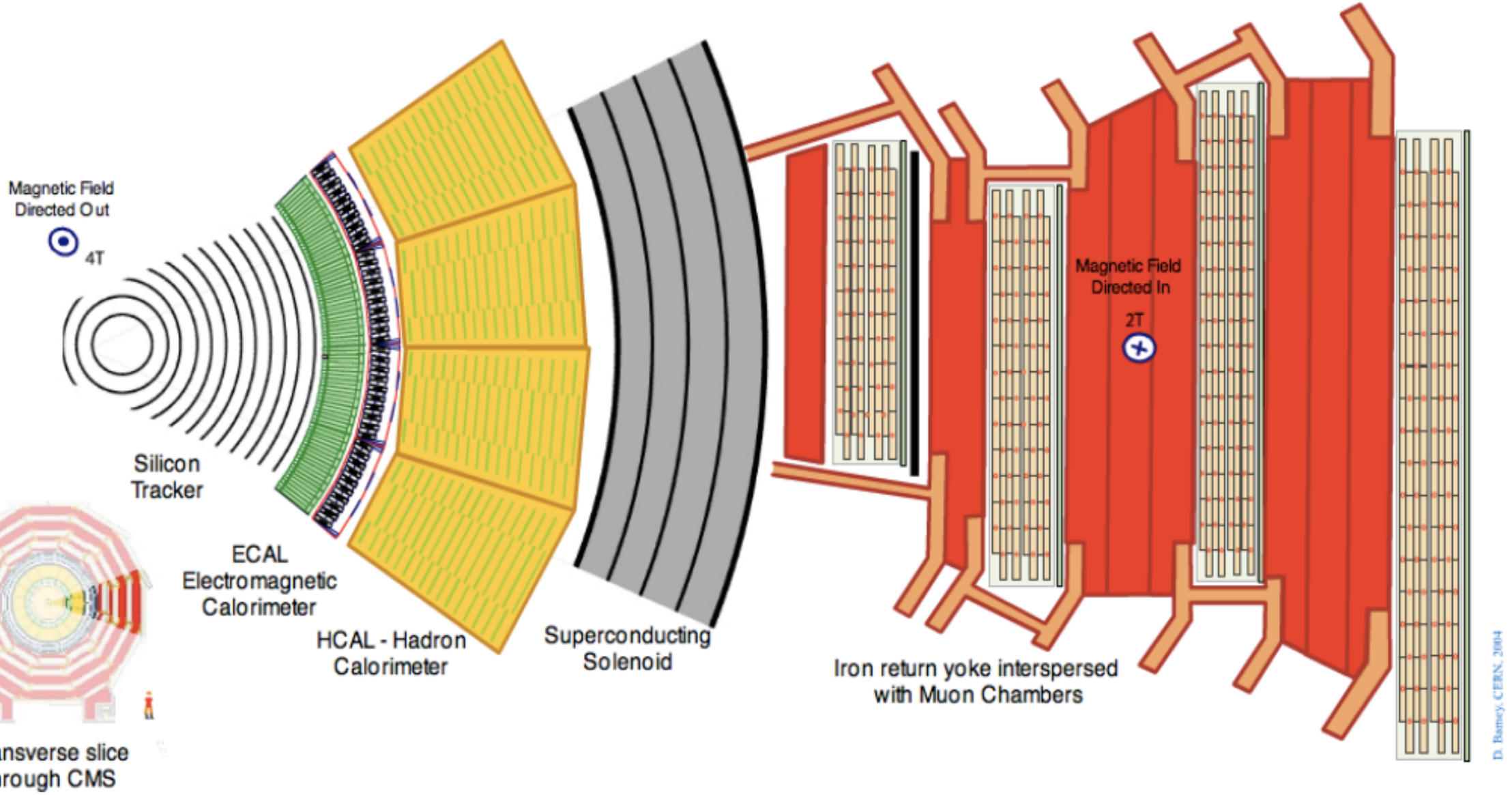
We know nothing about its nature and properties

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

Fermilab

Mono-X Searches

Collider experiments are NOT designed

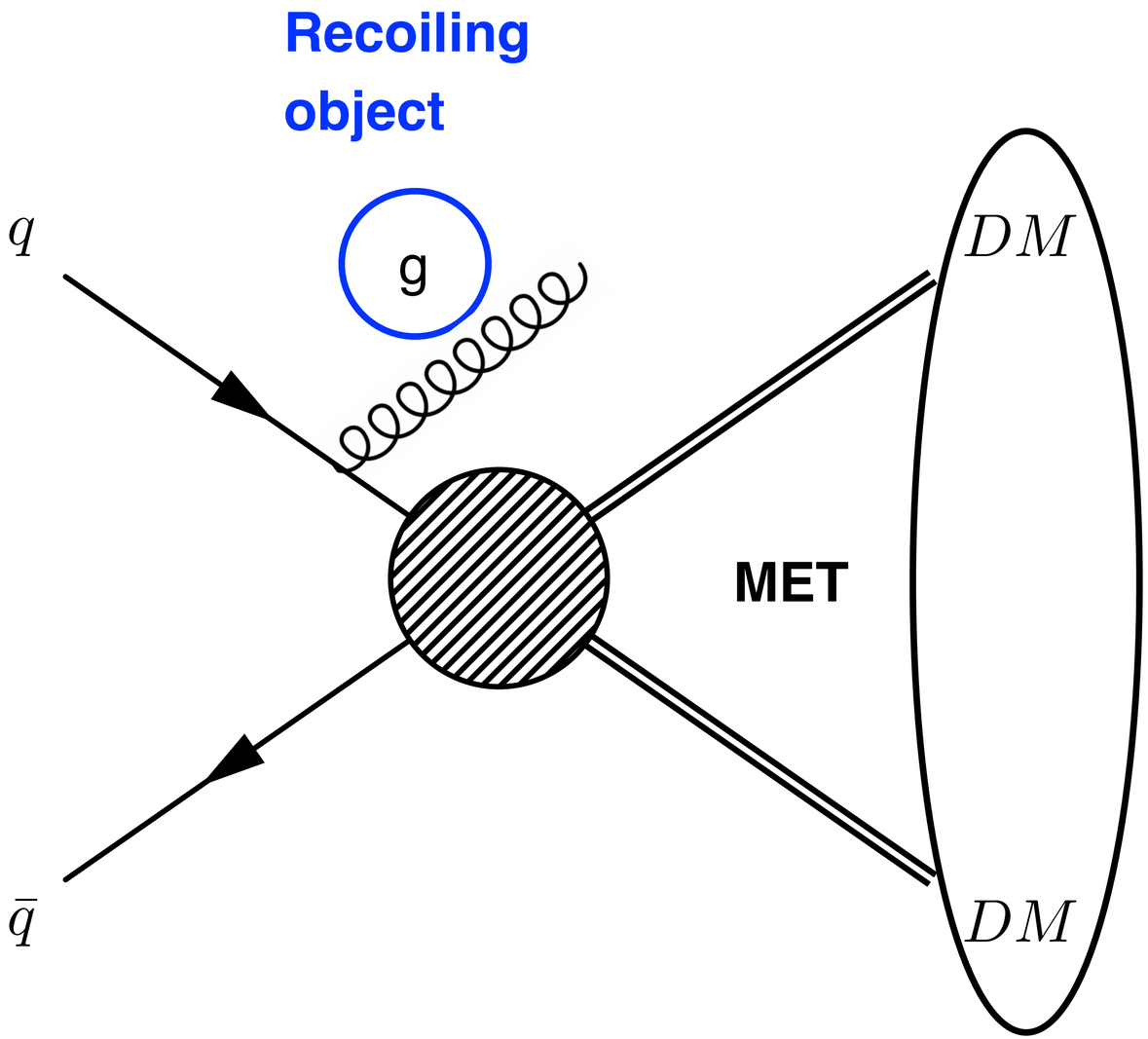
to directly reconstruct DM

Experimental approach:

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

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

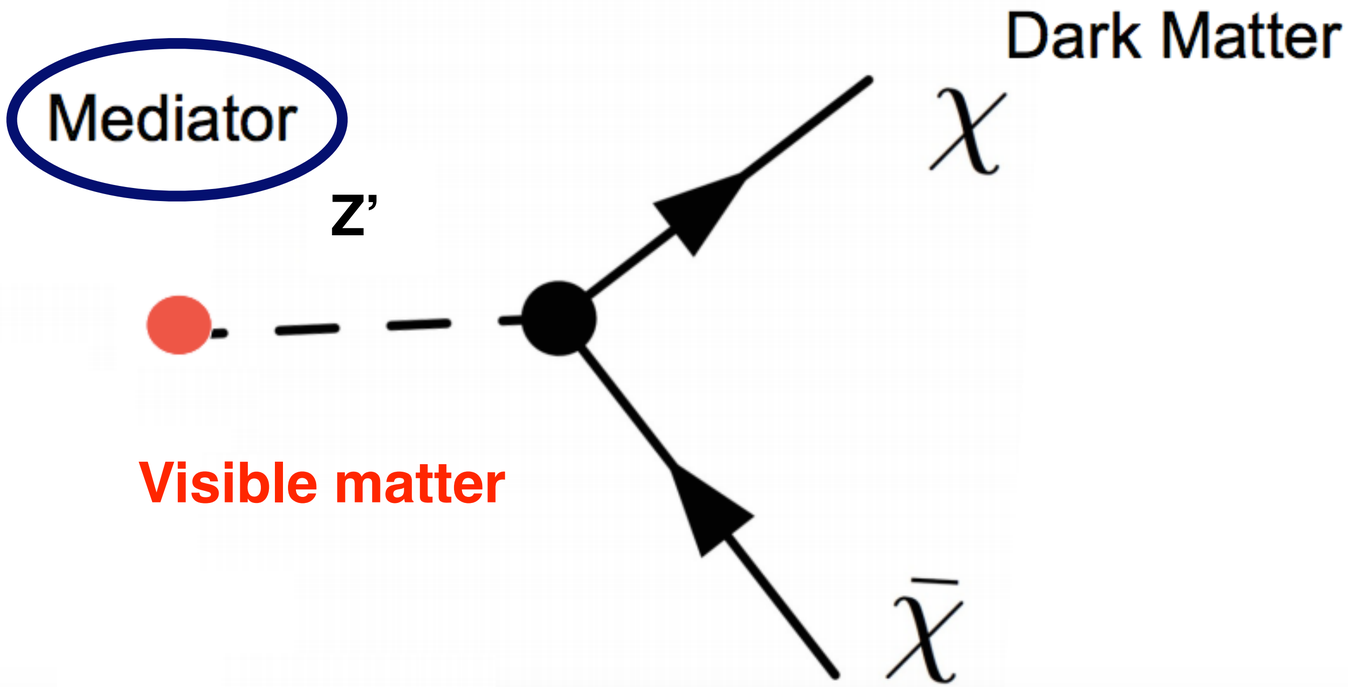
$$MET = -\Sigma_{All\ particles}\ p_T$$



Fermilab

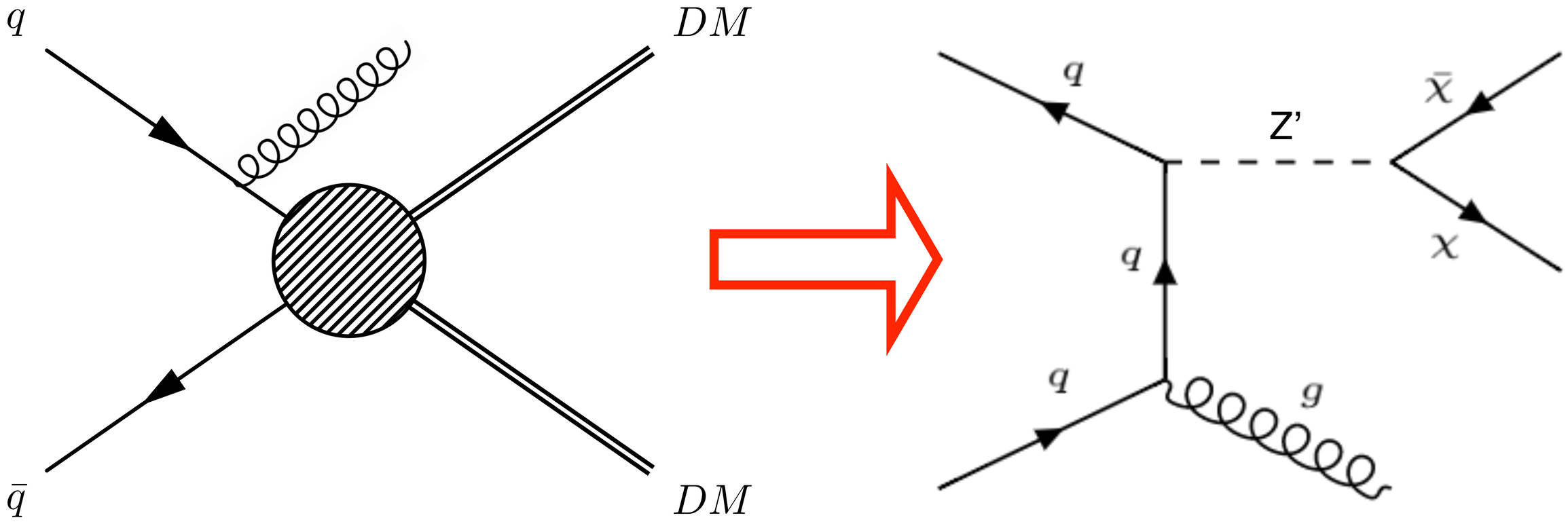
Why at Colliders

- If DM interacts, it does through a **mediator**
- At colliders, unique possibility to search for the mediator and measure its properties
  - mass, spin



Fermilab

From EFT to Simplified Models

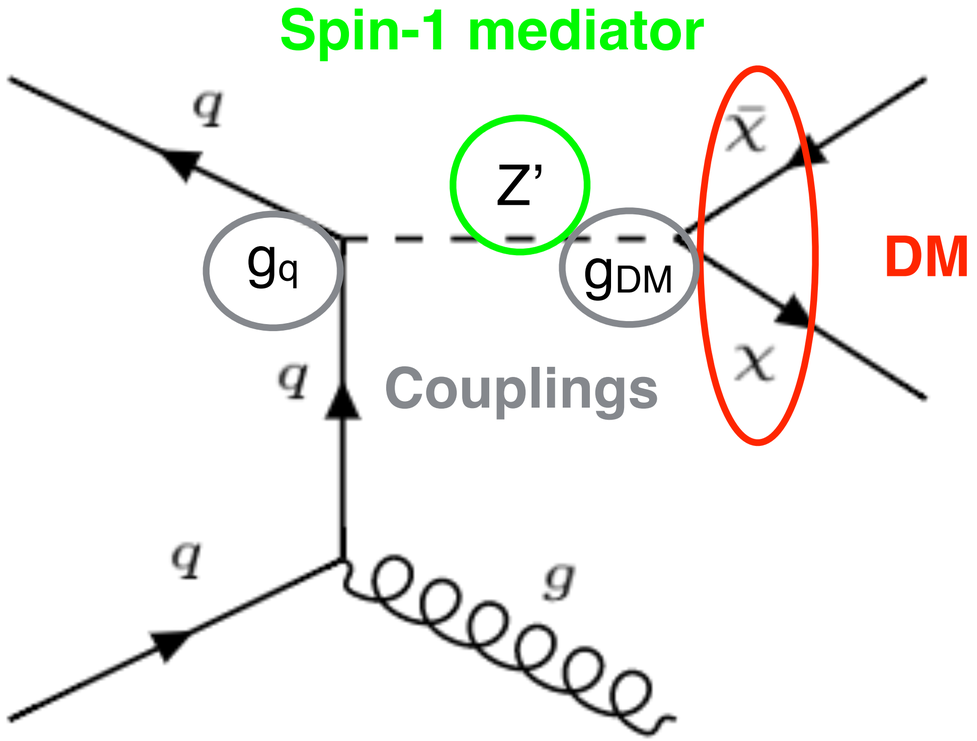


Simplified Models

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

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

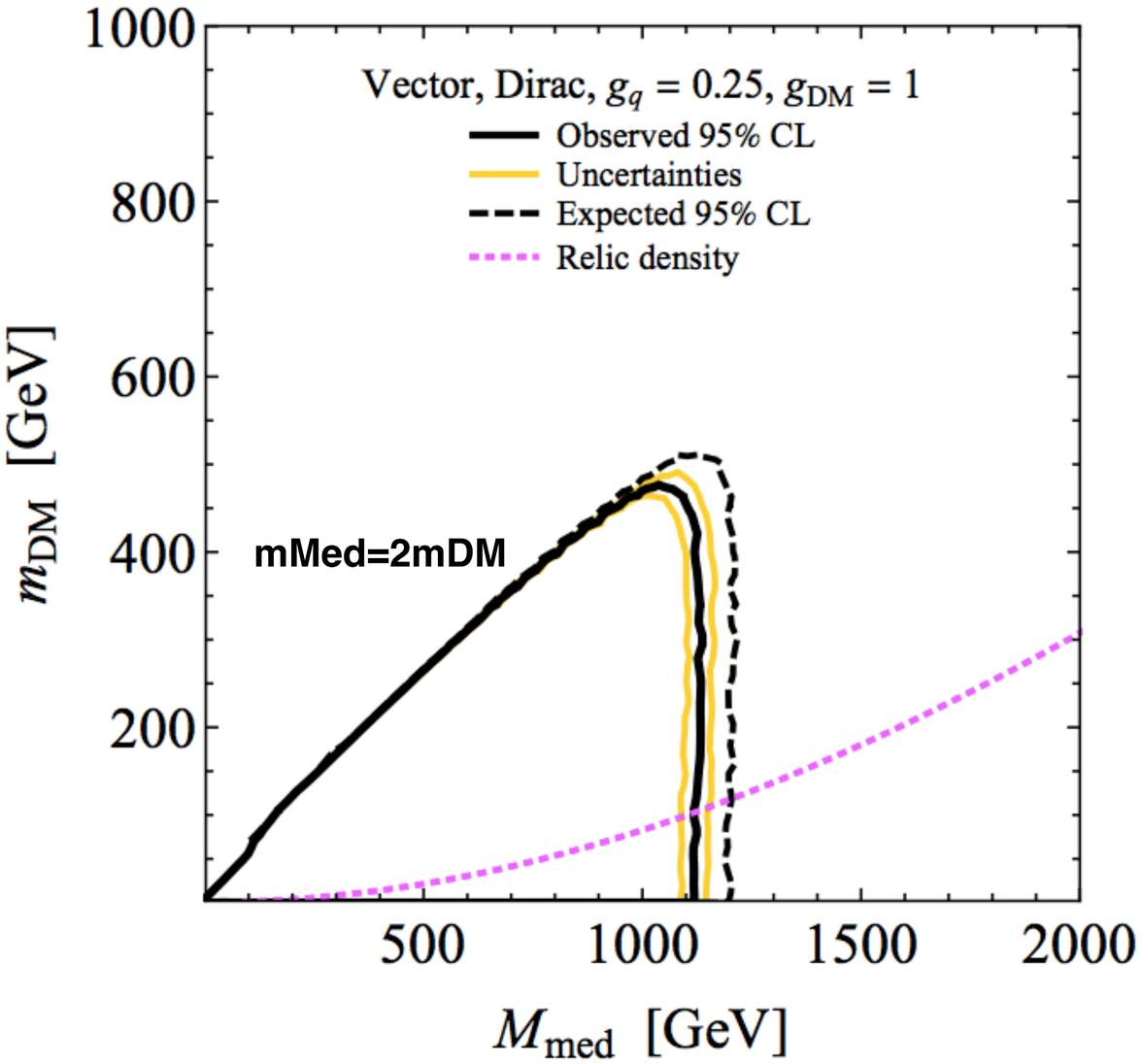
- **DM:**
  - single fermionic particle
  - stable and non-interacting
- **Mediator**
  - shapes of kinematic distributions not altered by coupling variations
    - **g_{SM}=0.25, g_{DM}=1(spin-1)**
    - **g_{SM}=1, g_{DM}=1(spin-0)**
  - Axial/Vector, Scalar/Pseudoscalar
  - minimal decay width (e.g.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

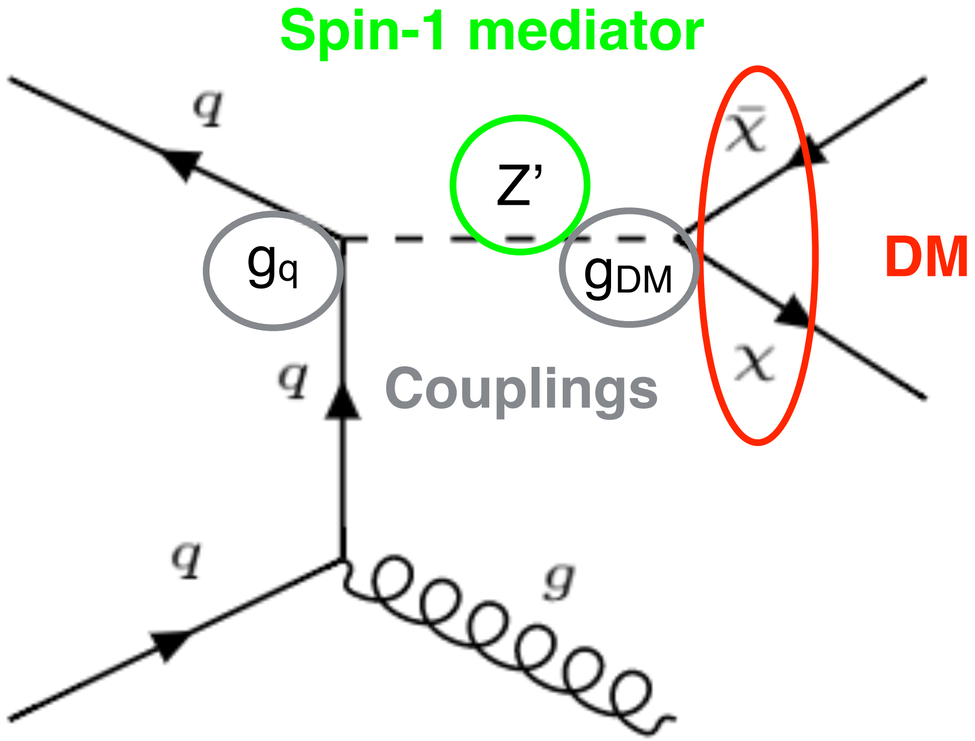


LHC DM Forum, arxiv:1507.00966v1

Fermilab

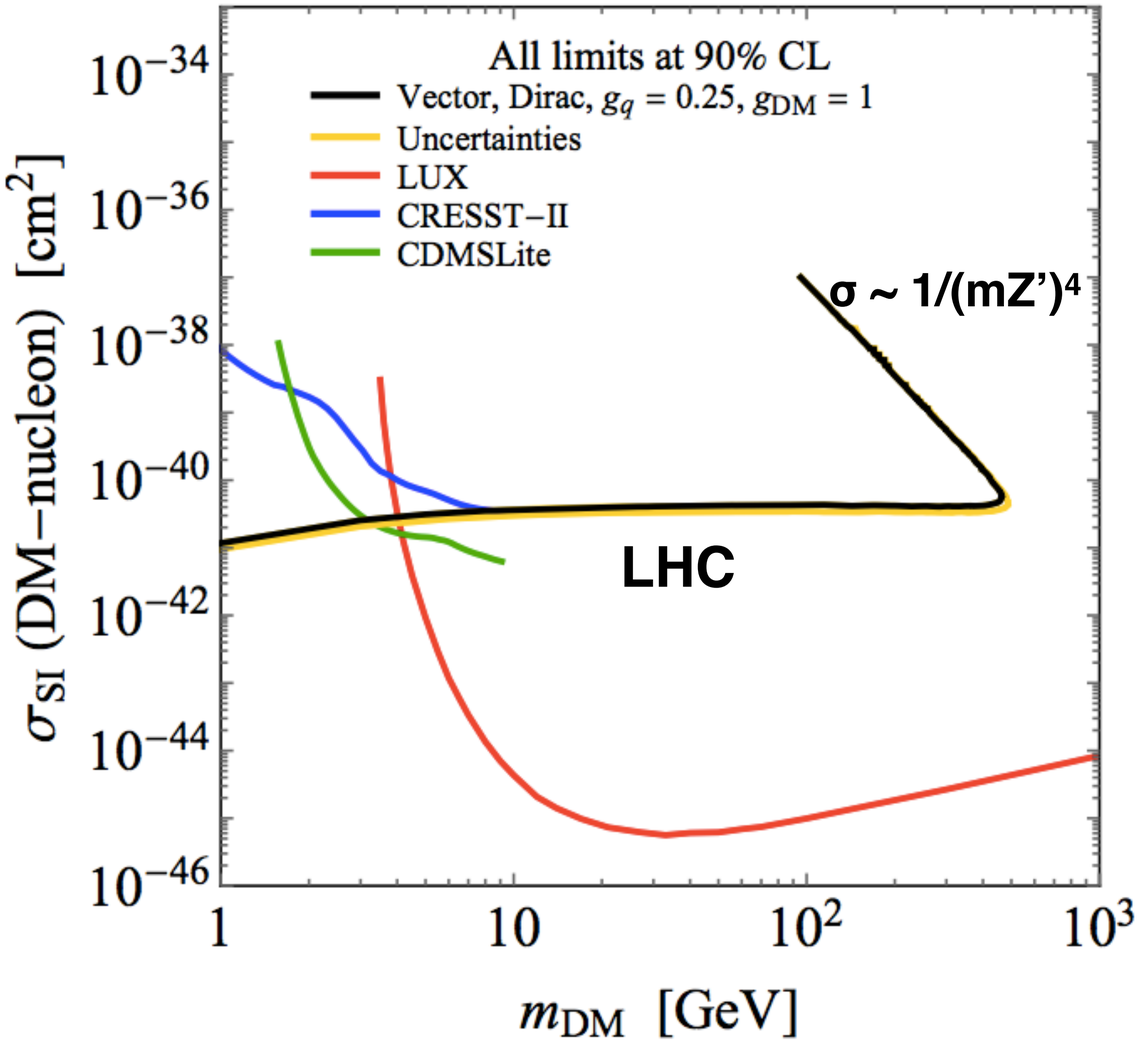
Presentation of Results

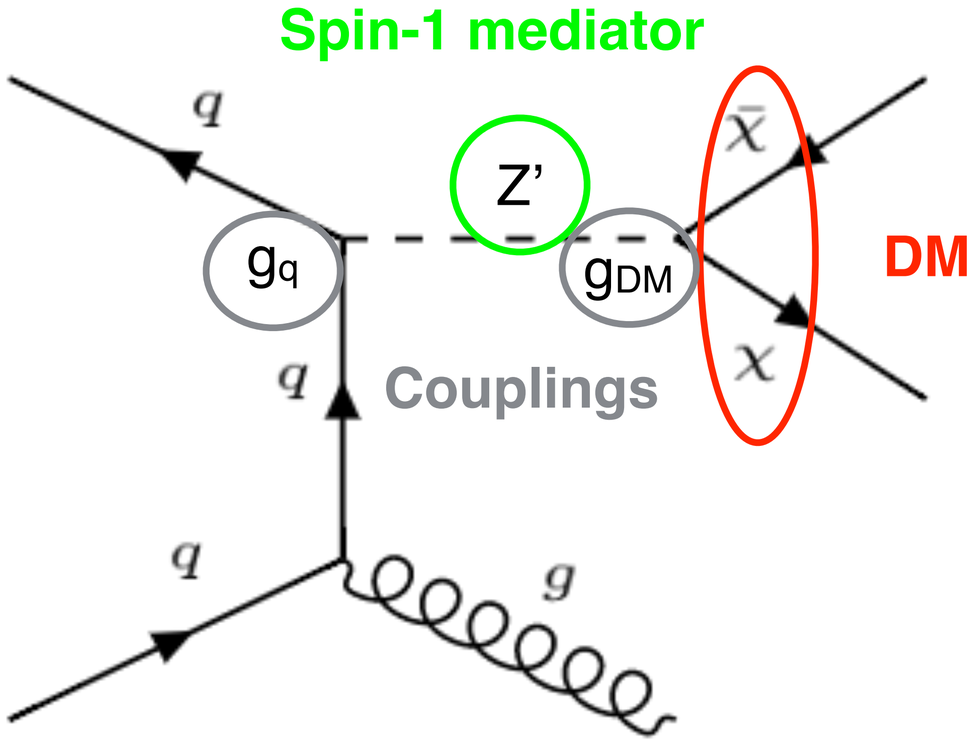




LHC DM WG, arxiv:1603.04156

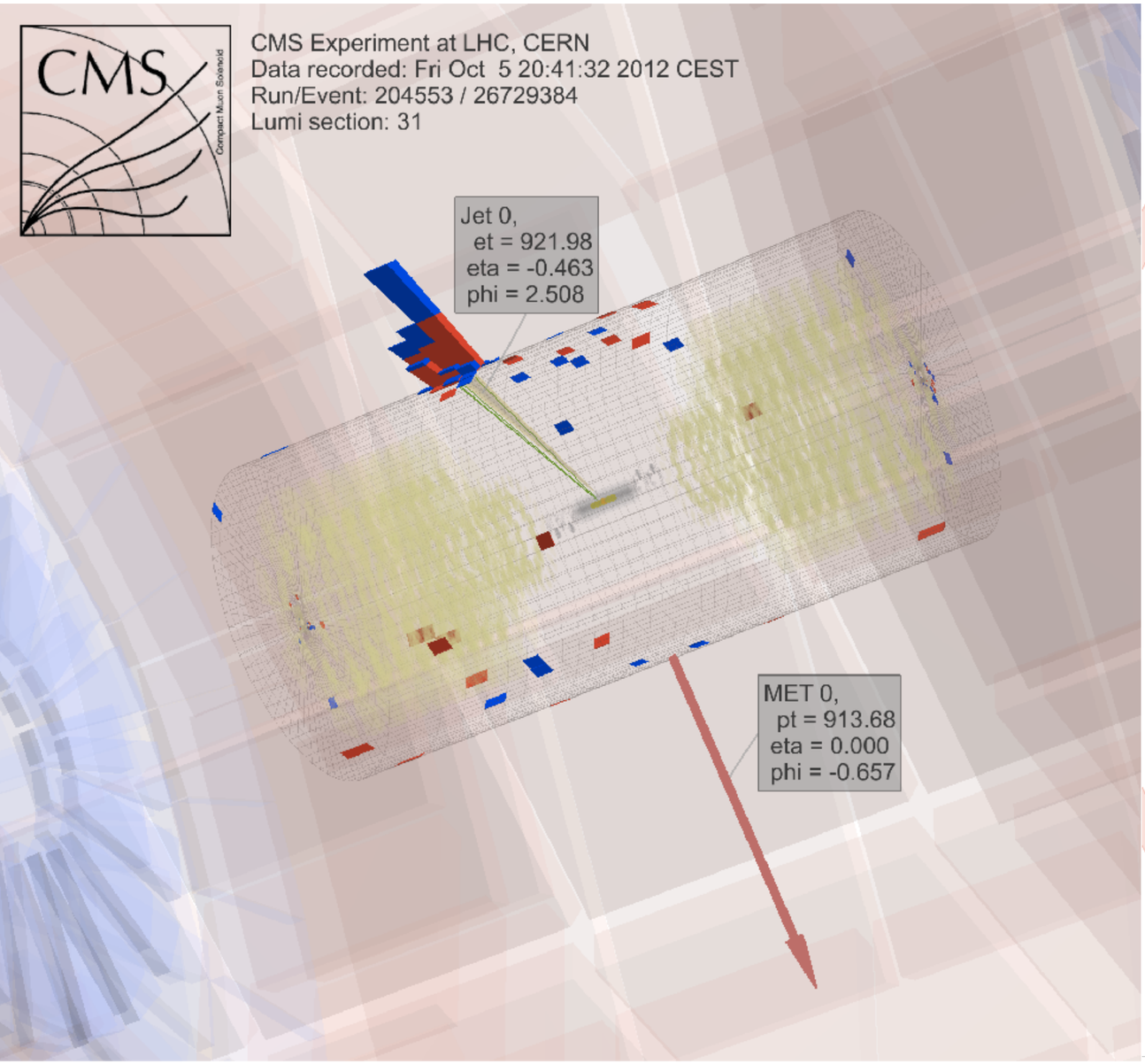
Presentation of Results

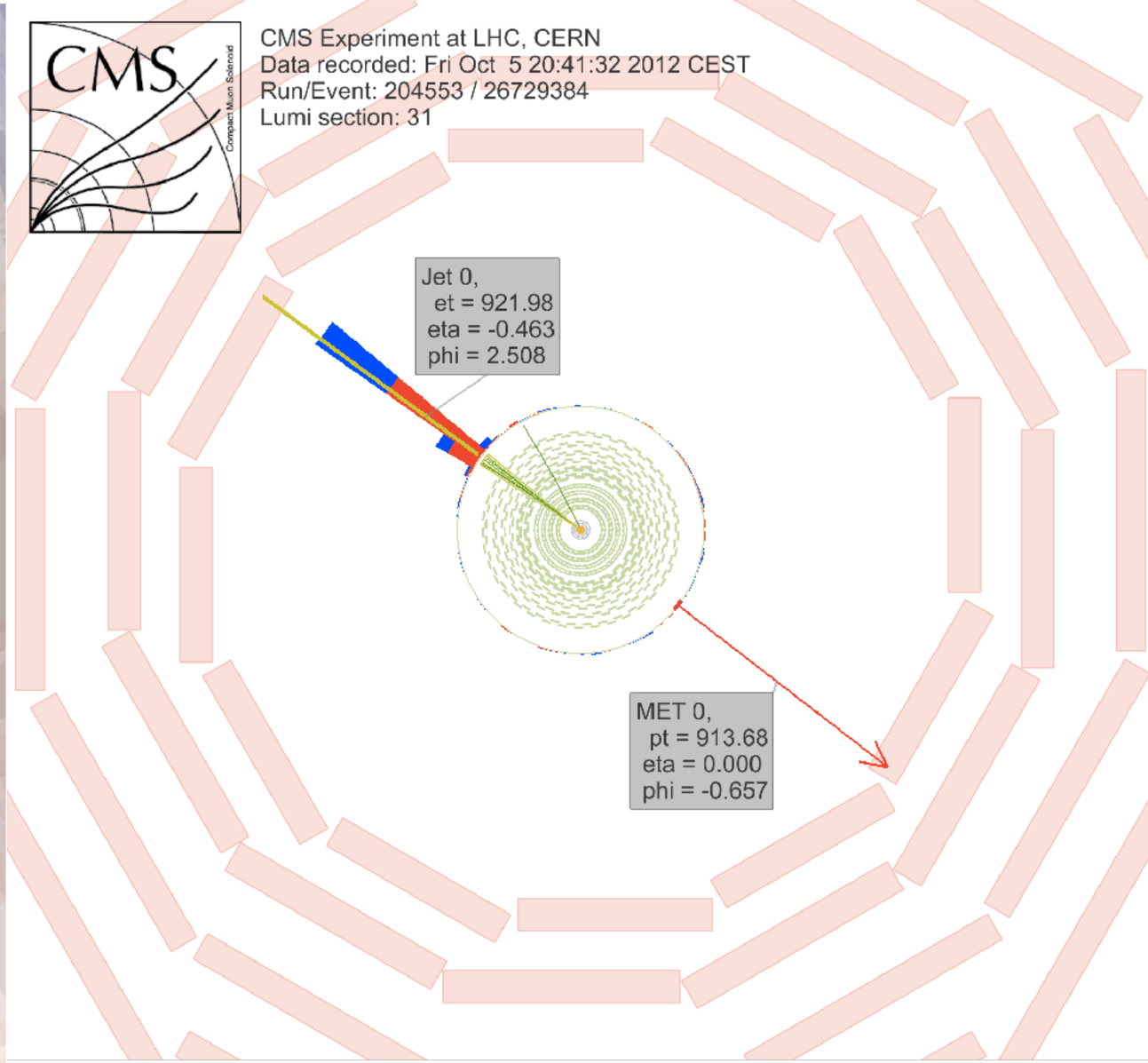




LHC DM WG, arxiv:1603.04156

Fermilab


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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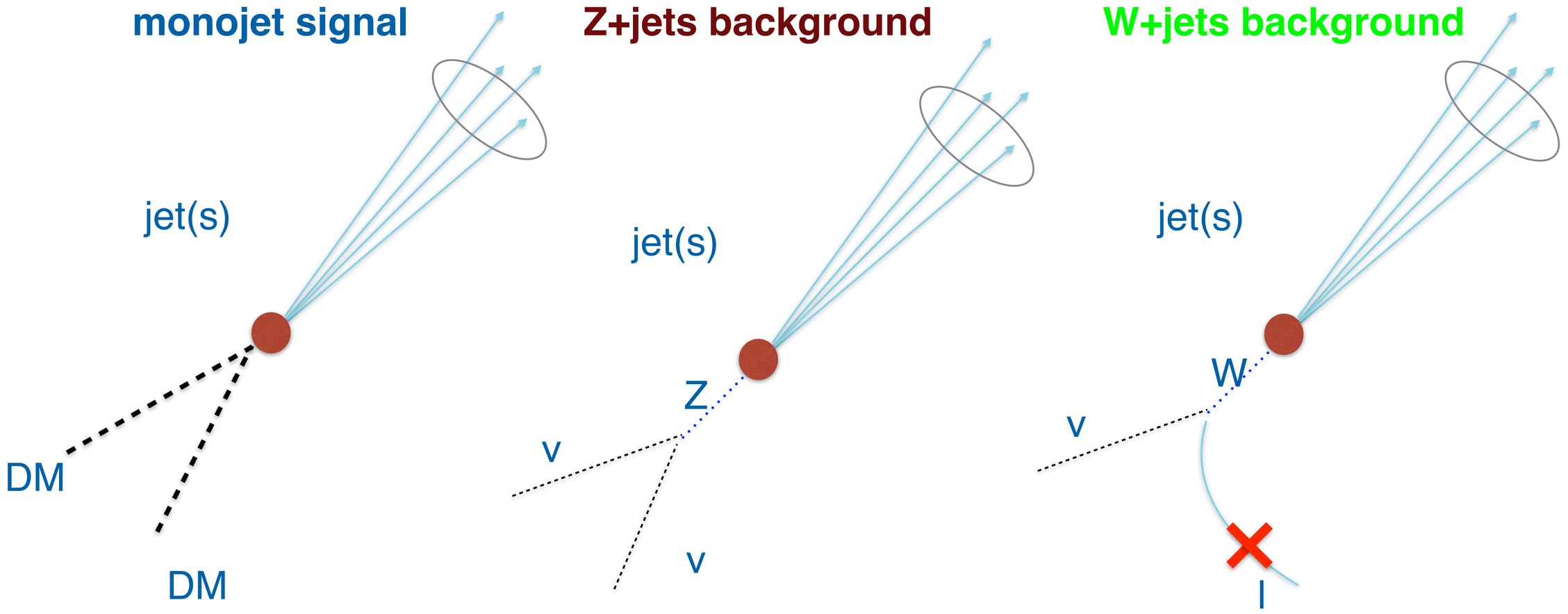
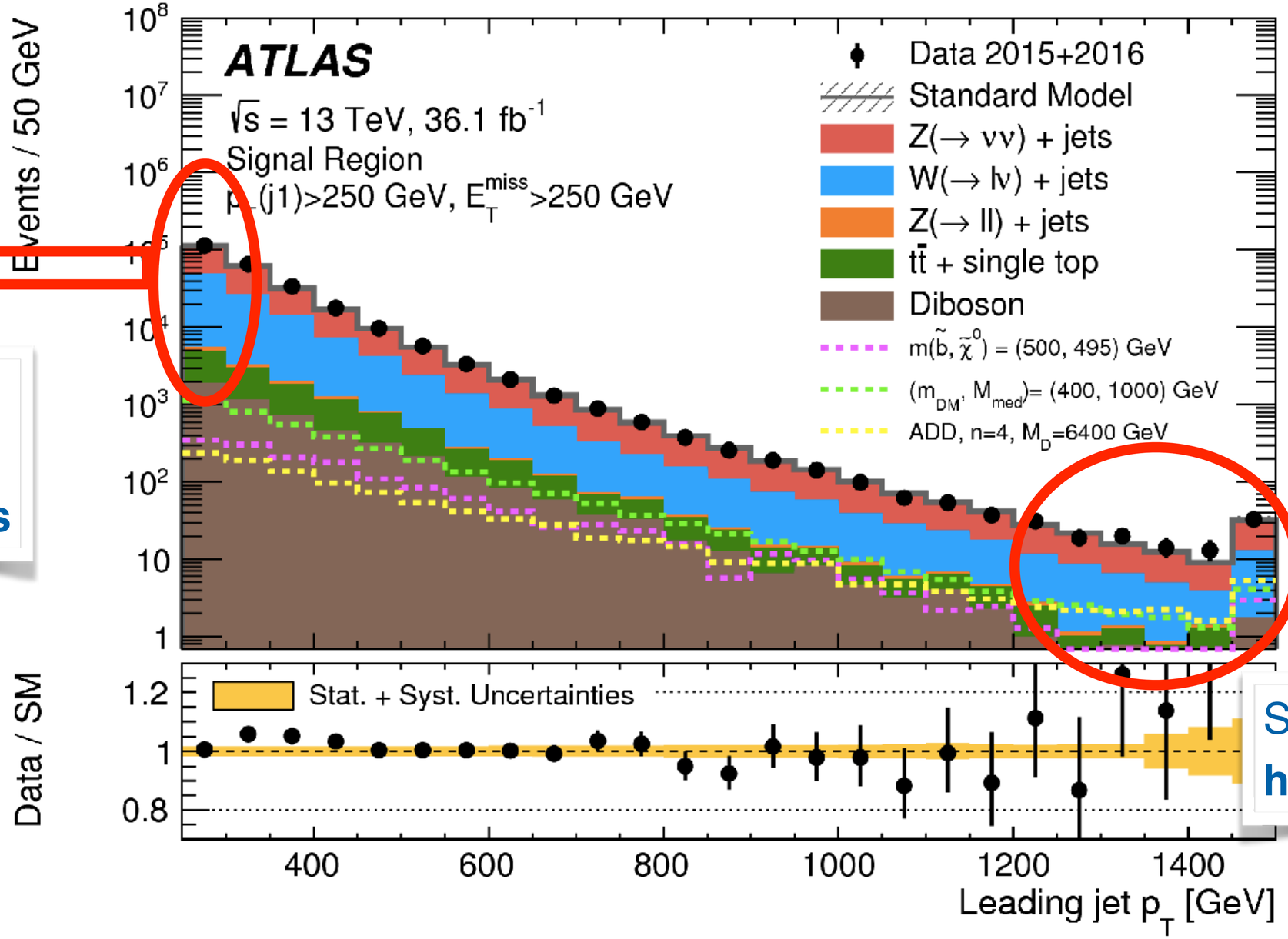
Jet 0,
et = 921.98
eta = -0.463
phi = 2.508
MET 0,
pt = 913.68
eta = 0.000
phi = -0.657

Fermilab

Mono-jet Signature





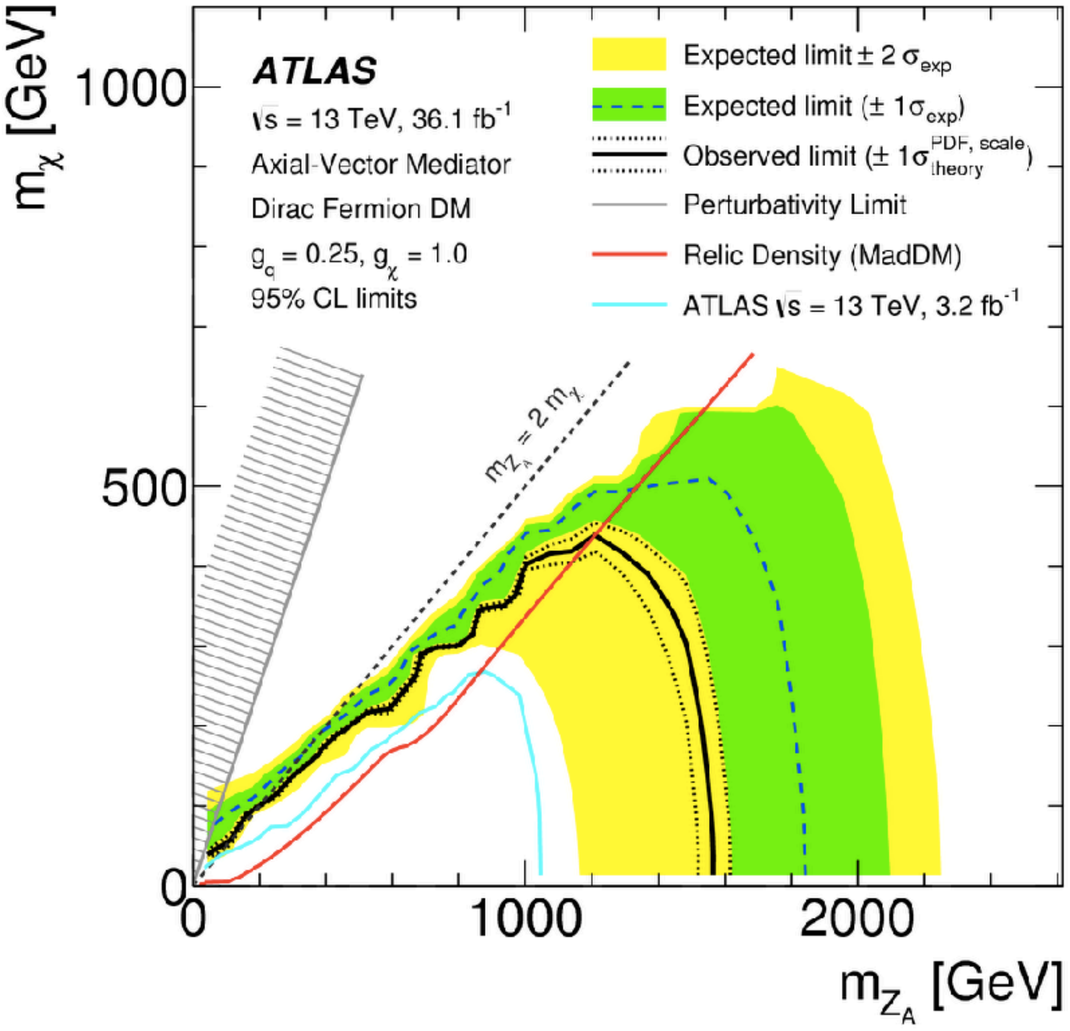
Largest backgrounds from **W/Z+jets**

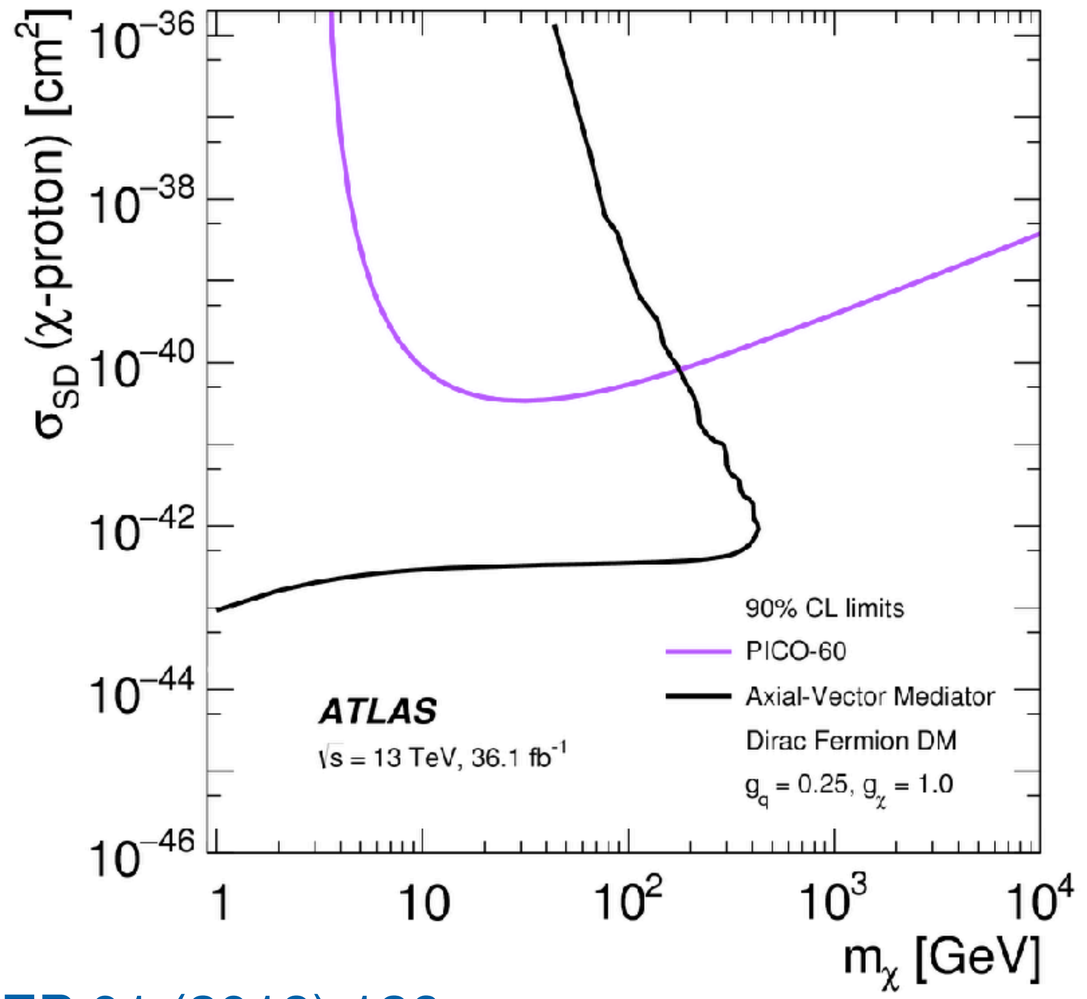
Signal populates **high MET**

Fermilab

Mono-jet Results

13 TeV, 2015+2016 dataset





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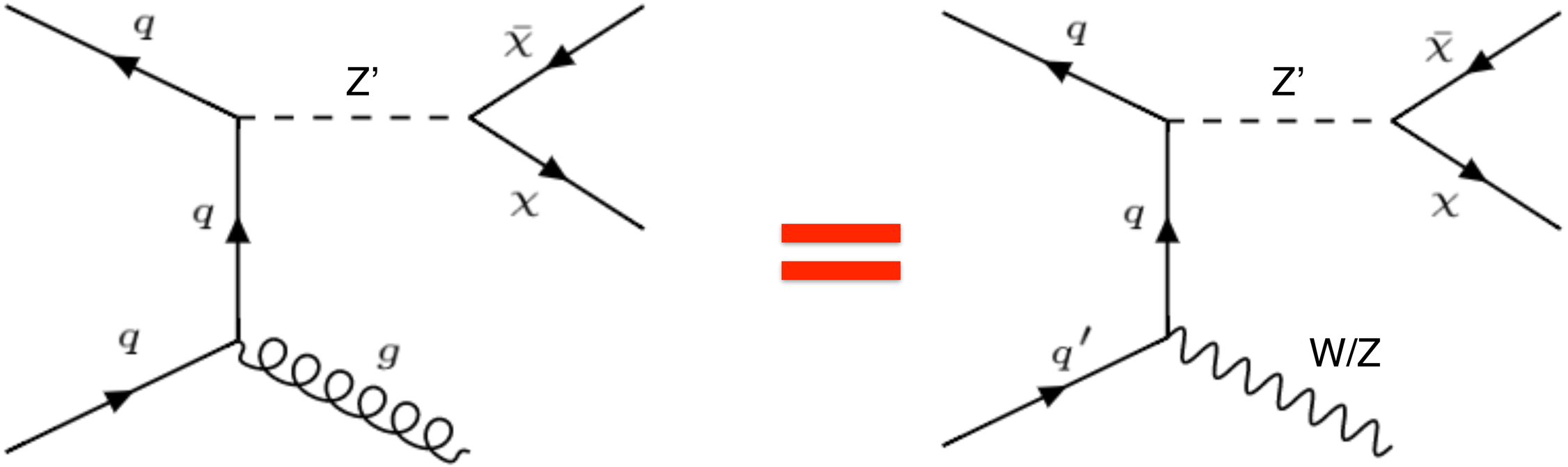
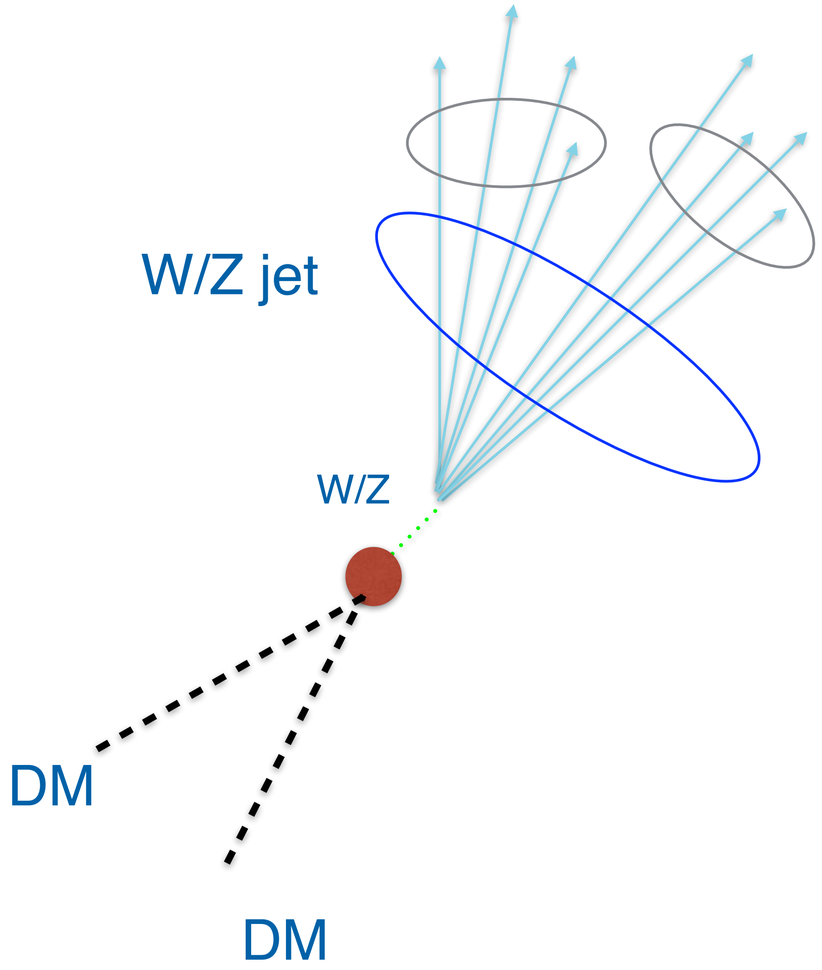
Fermilab


q
Z'
$\bar{\chi}$
q
χ
q
g
=
q
Z'
$\bar{\chi}$
q
χ
q'
W/Z

Hadronic Mono-V Signature

Boosted W/Z boson decaying hadronically

=> large-radius jet recoiling against MET

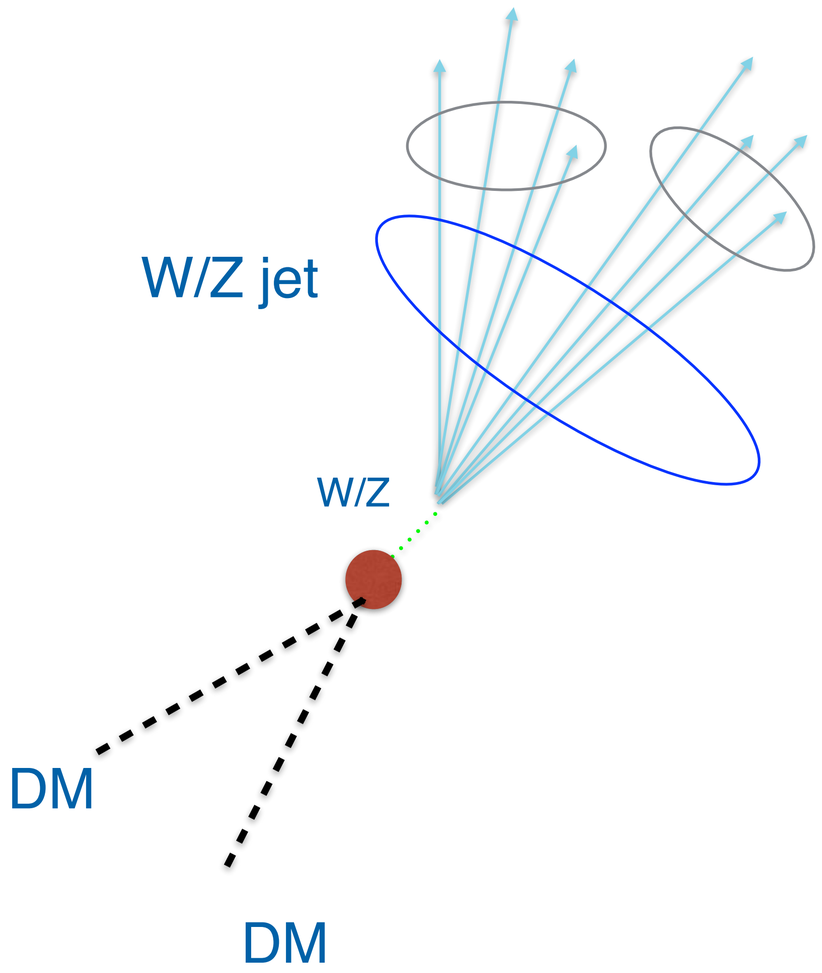


Fermilab

W/Z-tagging Large-Cone Jets

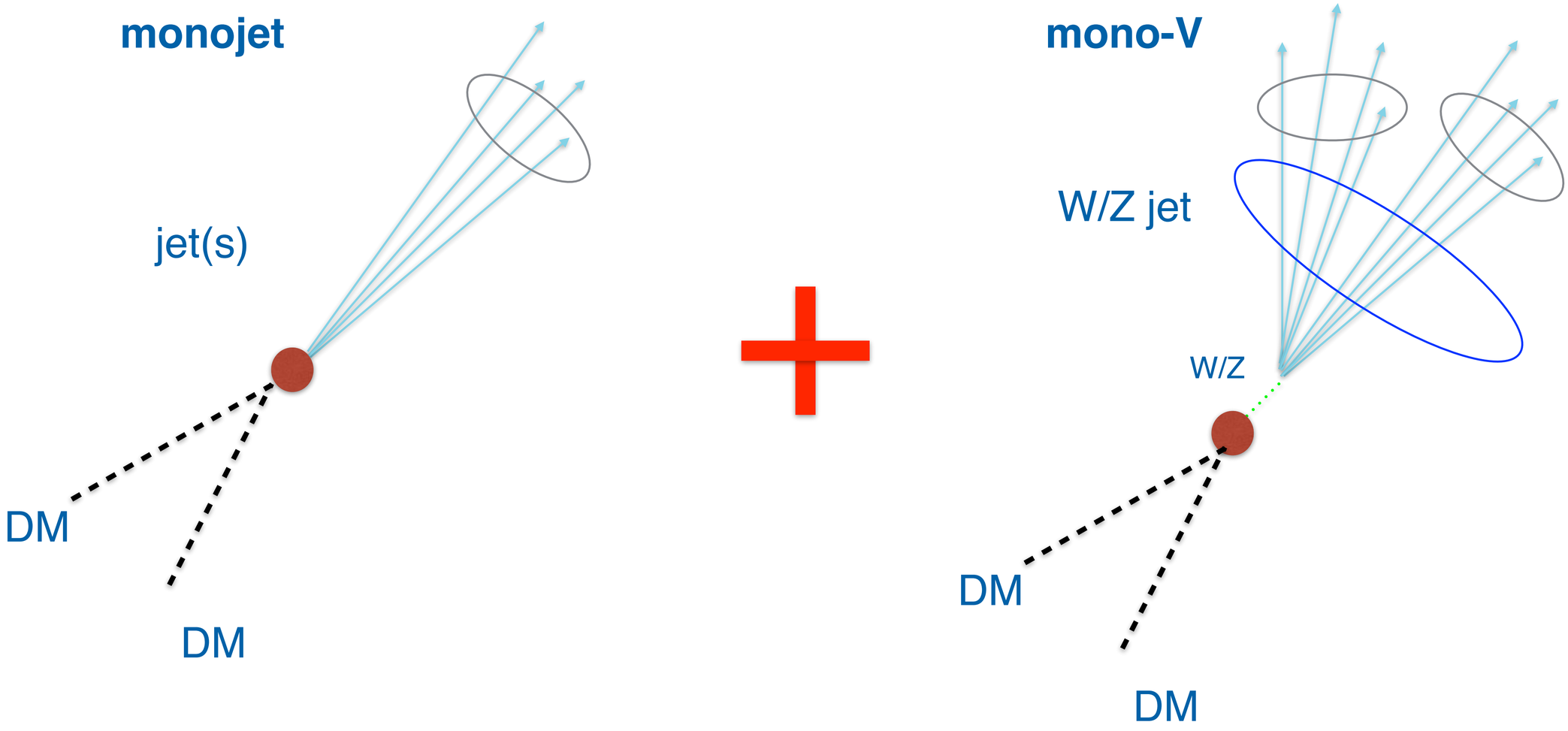
High momentum large-radius jet with

- invariant mass ~mW/Z (80-90 GeV)
- two prongs identified by studying jet substructure



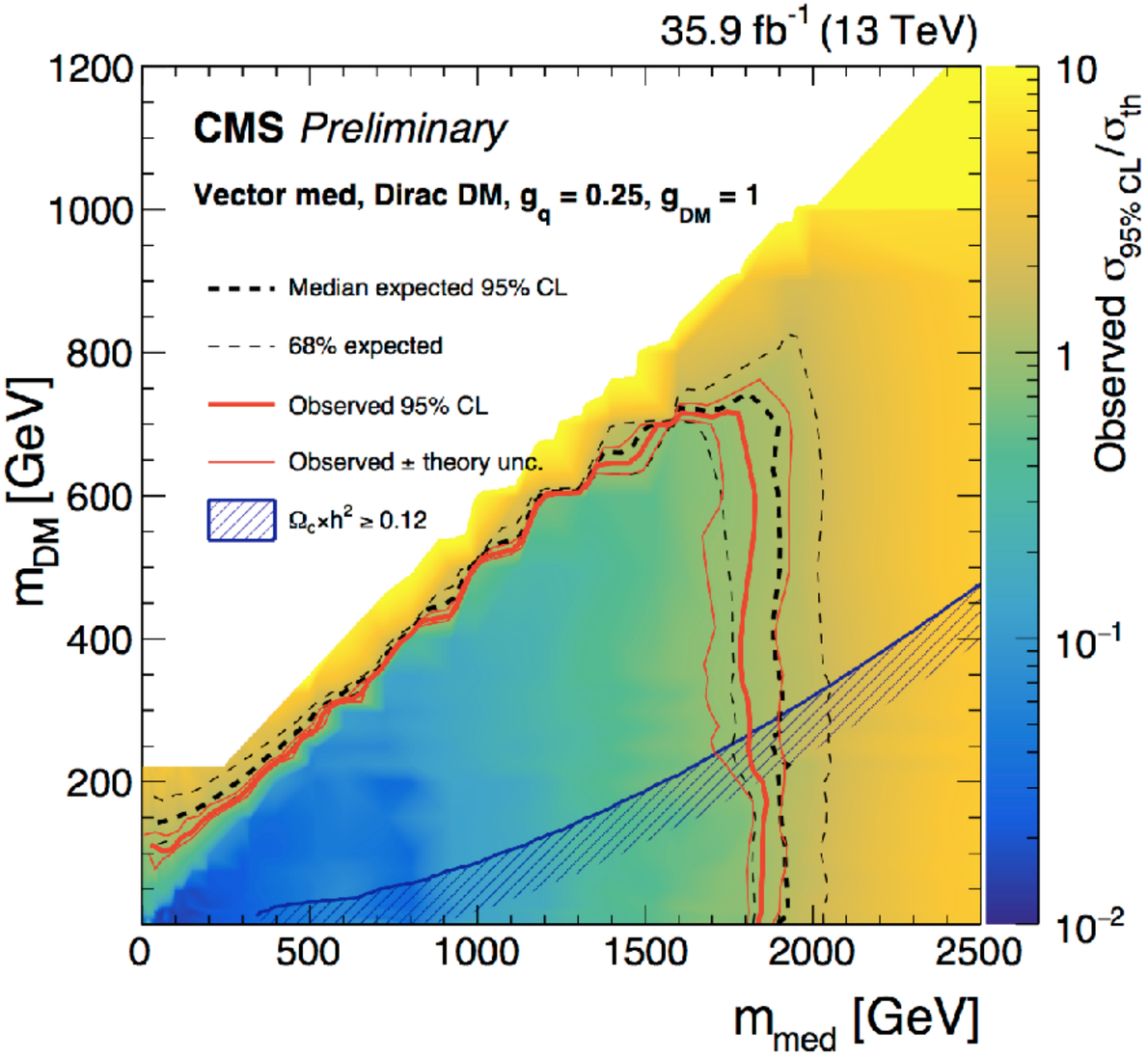
Fermilab

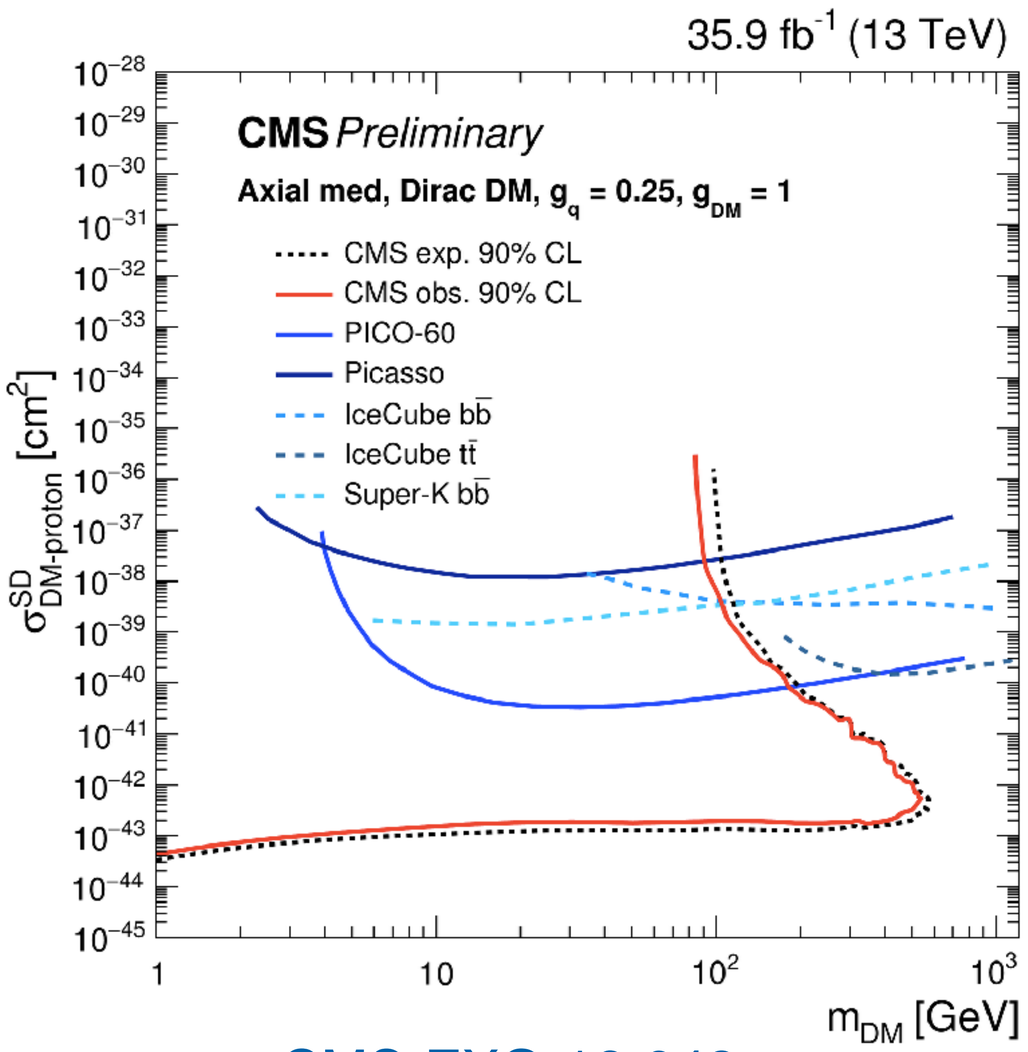
Monojet/Mono-V Combination



Mono-jet + Hadronic Mono-V Results

13 TeV, 2016 dataset



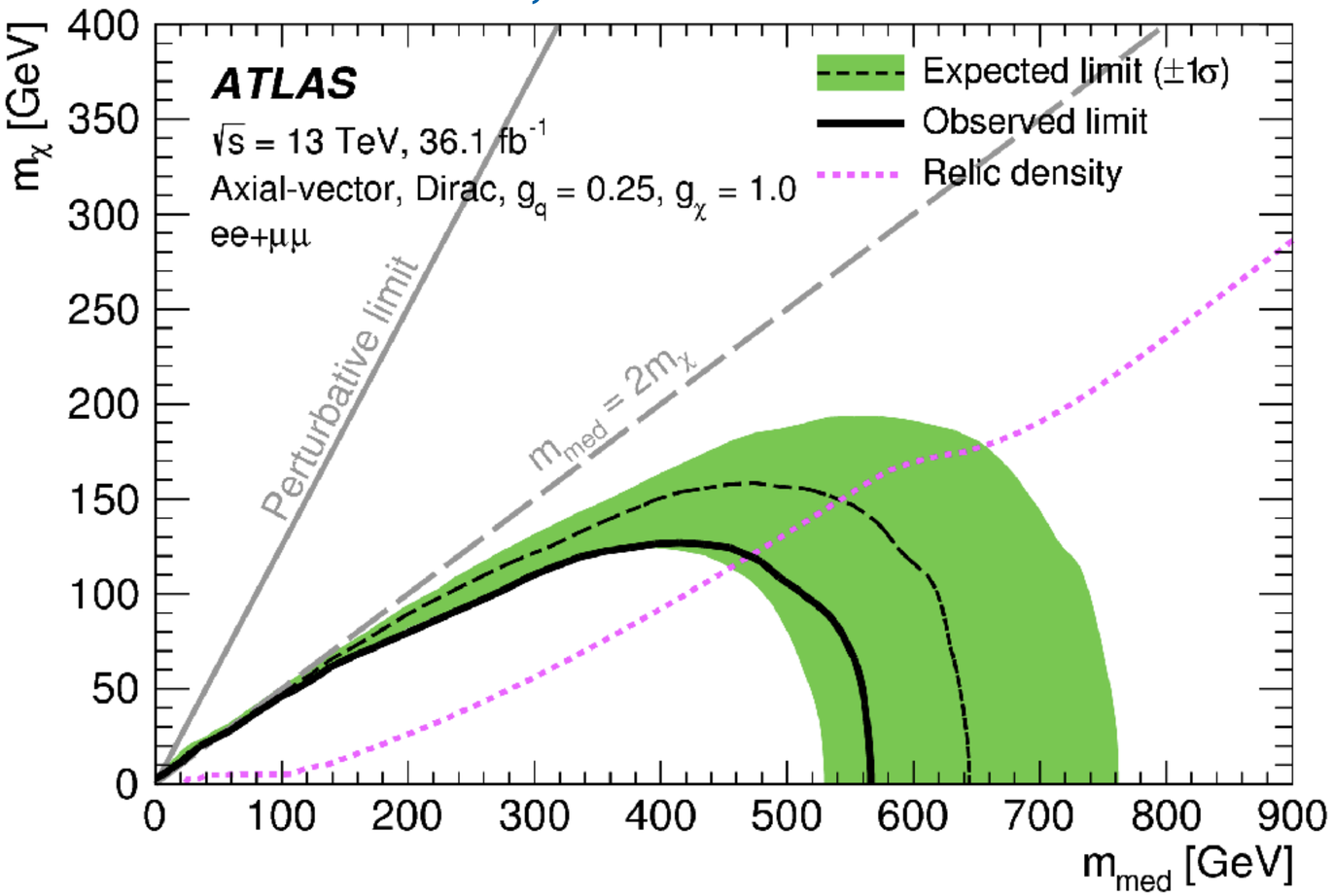


CMS-EXO-16-048

Fermilab

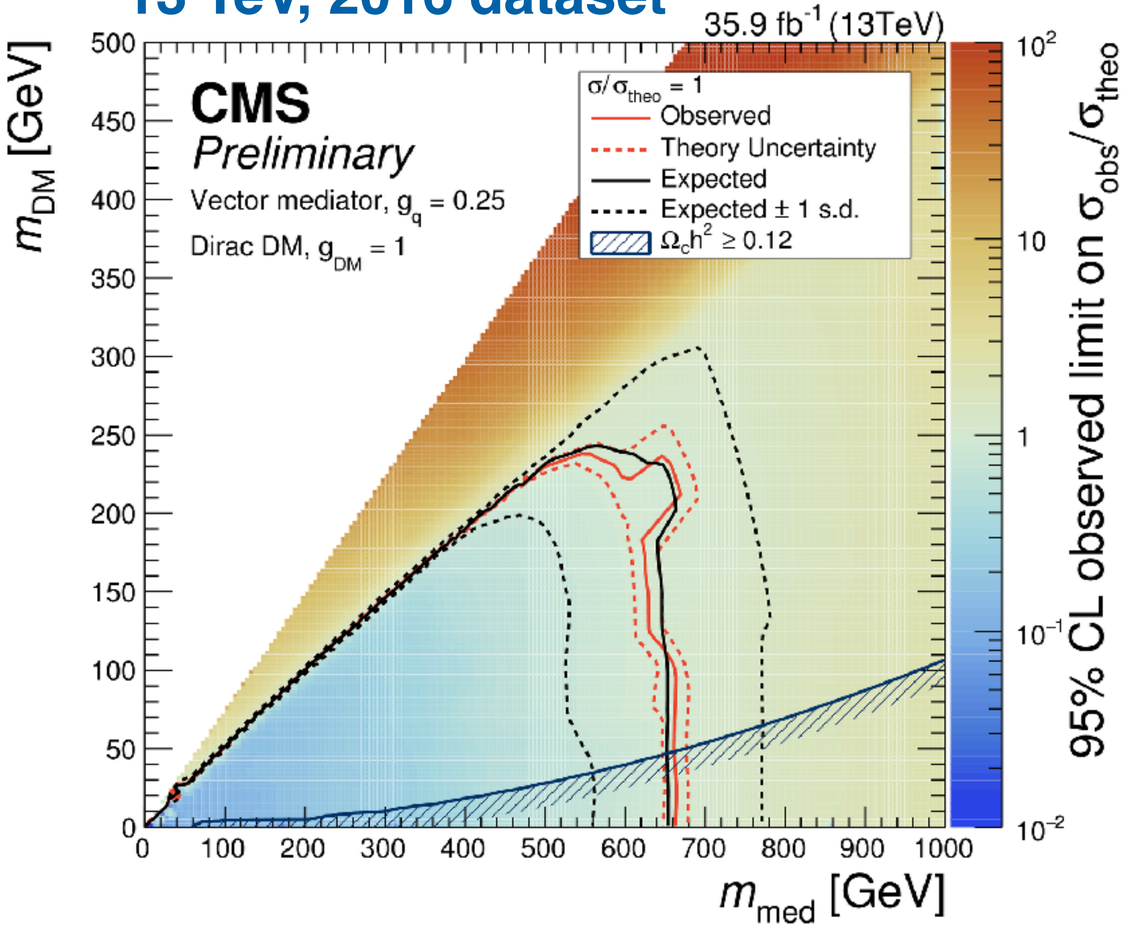
Leptonic Mono-Z Results

13 TeV, 2015+2016 dataset



PLB 2017.11.049

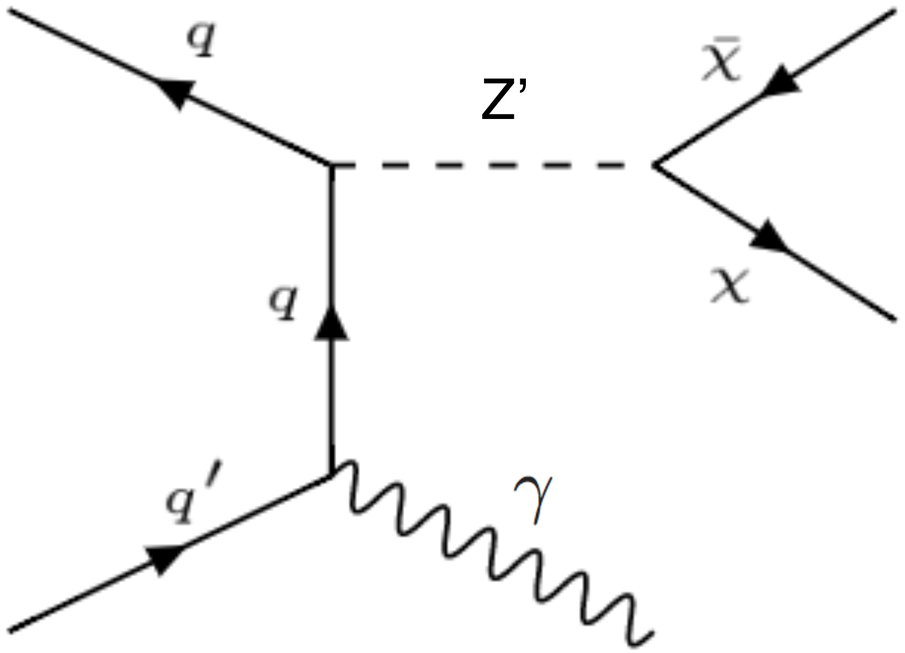
13 TeV, 2016 dataset



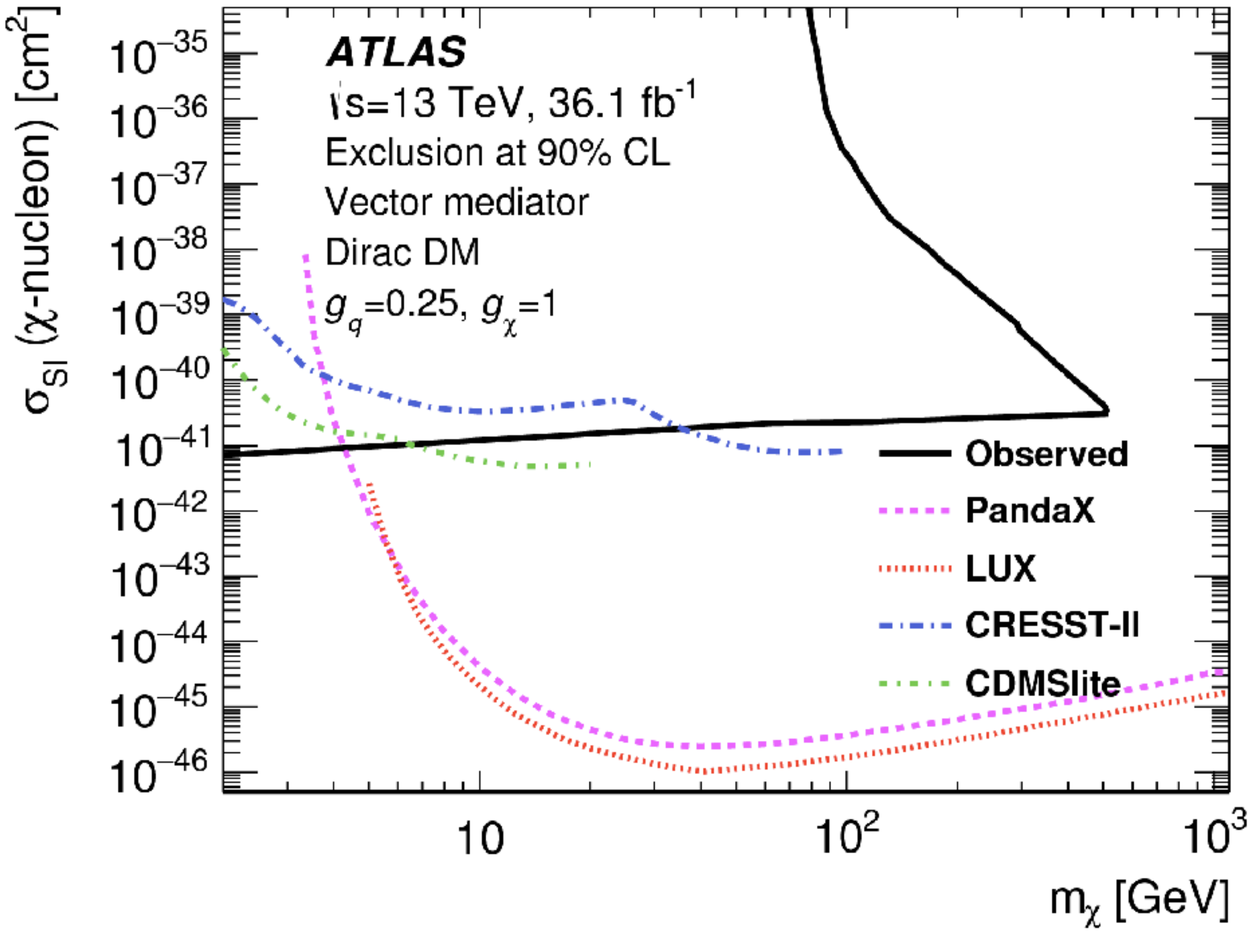
CMS-EXO-16-052

Fermilab

Mono-photon Results



13 TeV, 2015+2016 dataset



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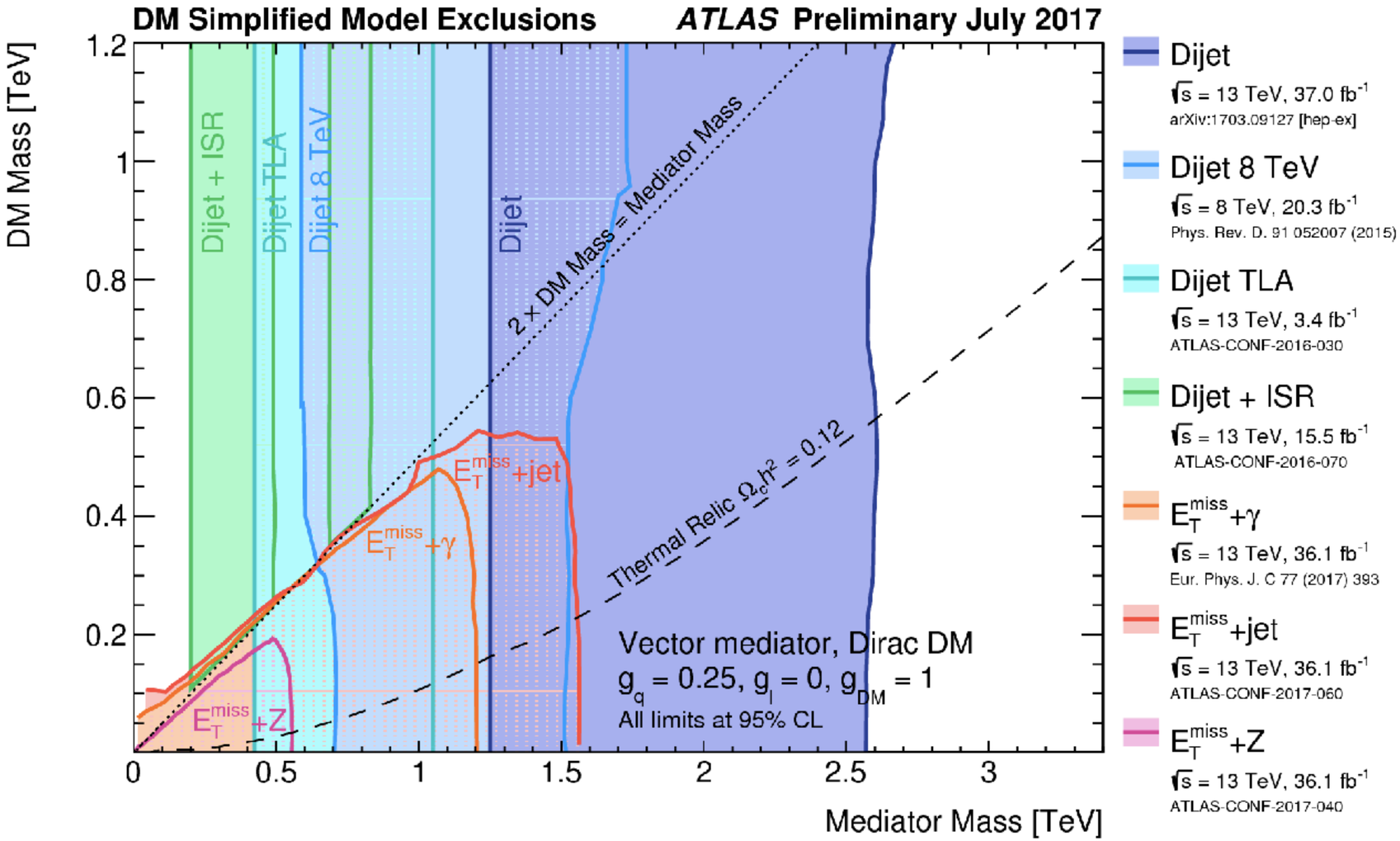
Fermilab

Comparison

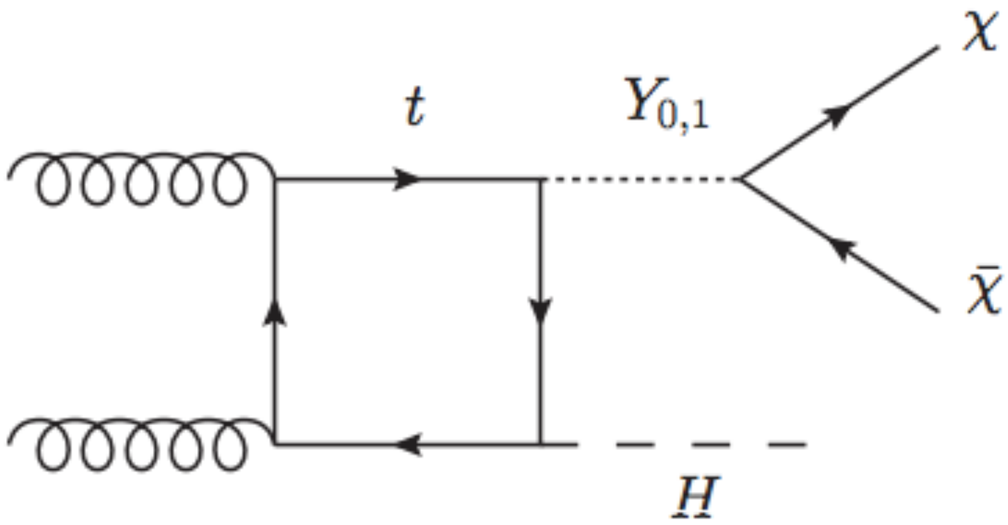


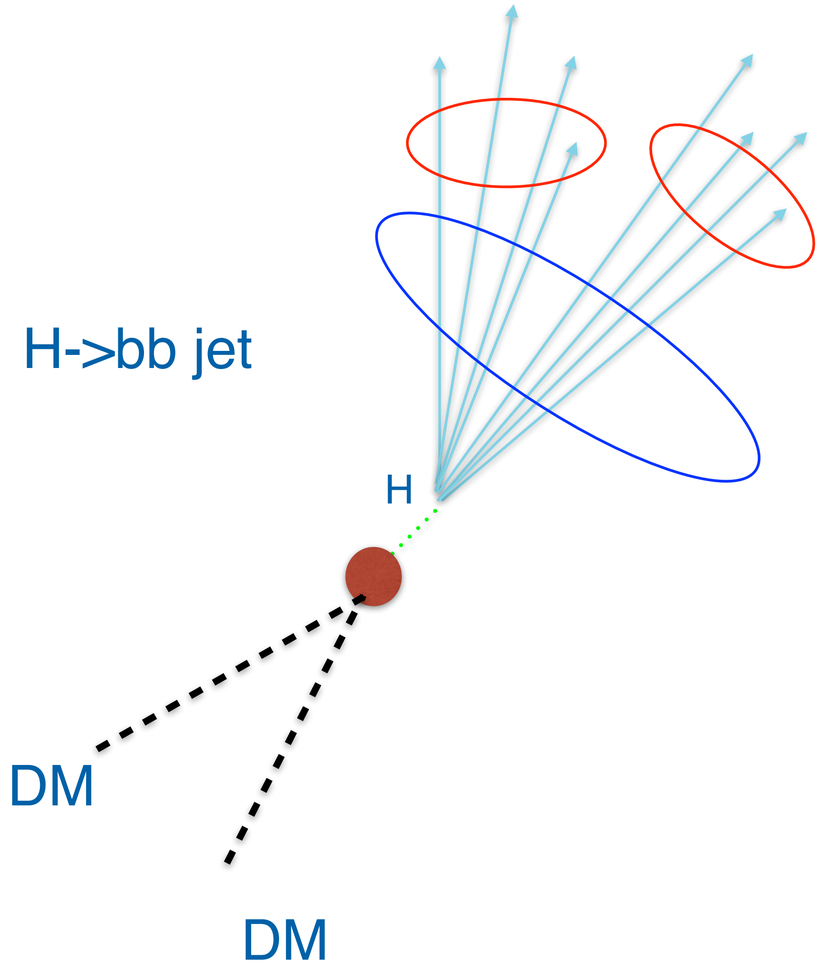
Fermilab

Hadronic Mono-H(->bb) Signature

Boosted Higgs boson decaying to a b-quark pair

=> large-radius jet and MET





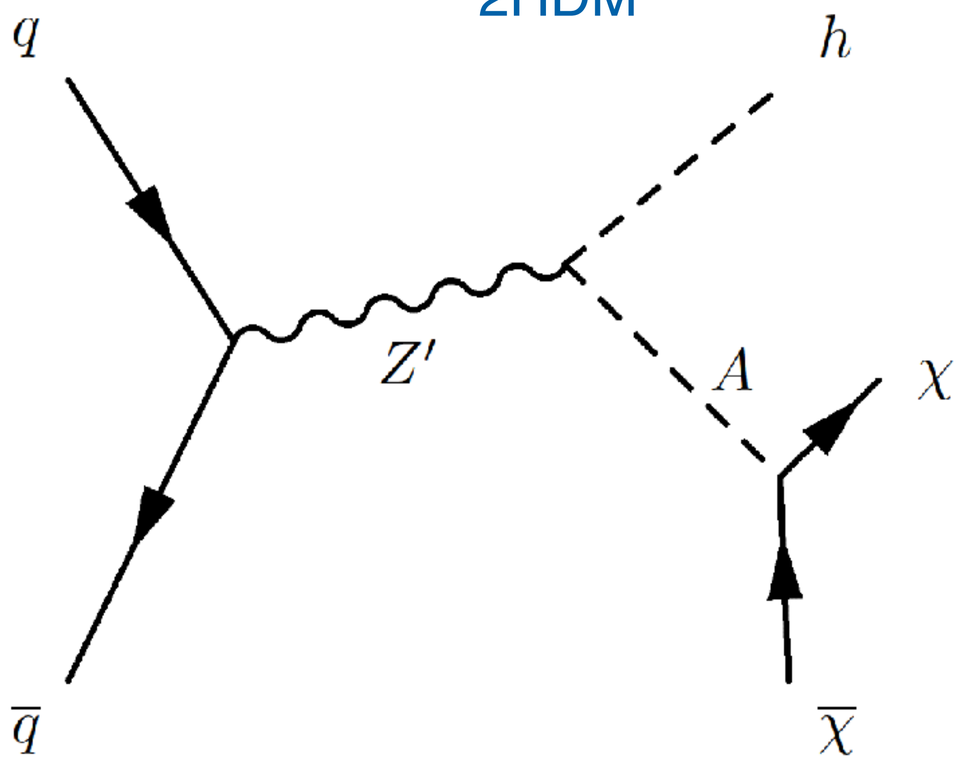
Fermilab

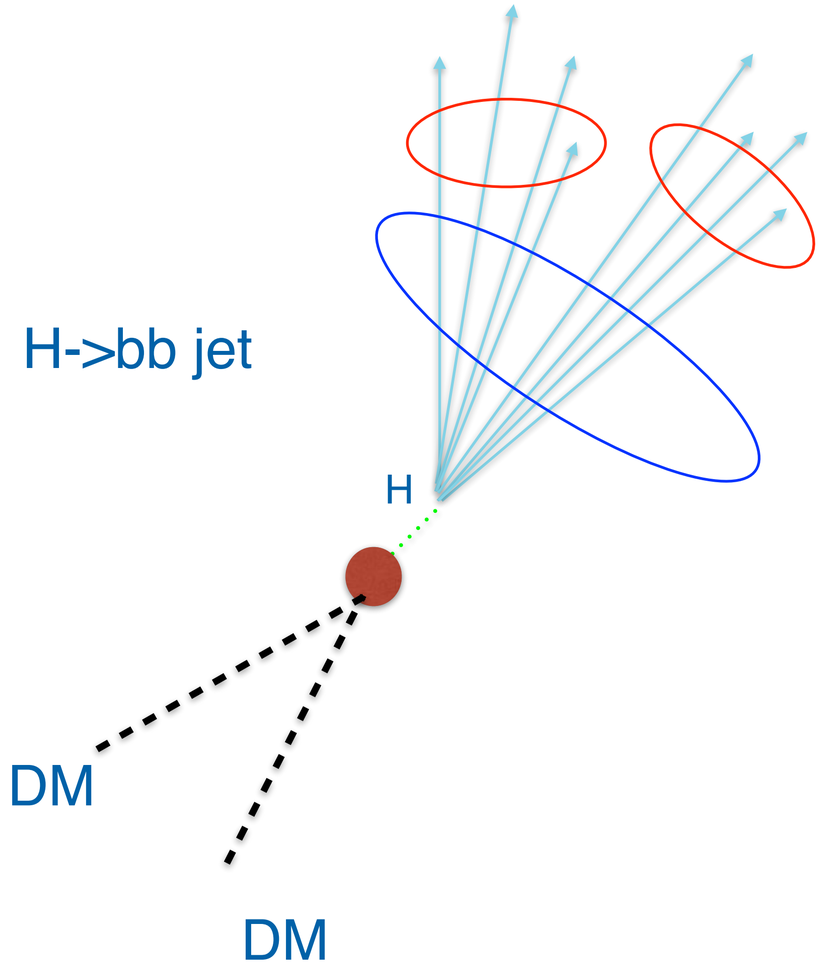
Hadronic Mono-H(->bb) Signature

Boosted Higgs boson decaying to a b-quark pair

=> large-radius jet and MET

2HDM





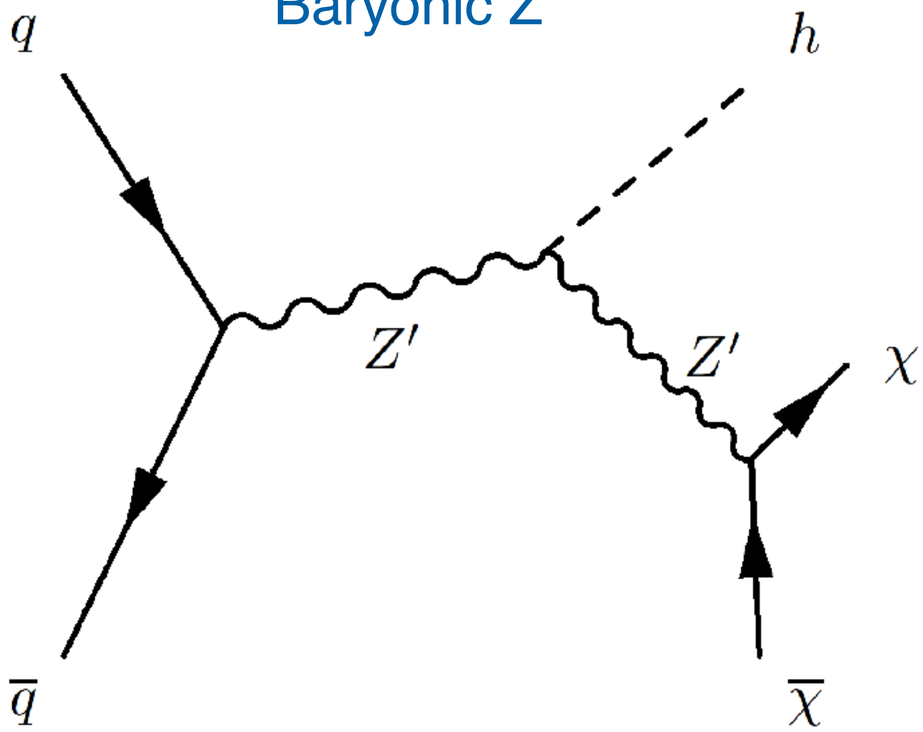
Fermilab

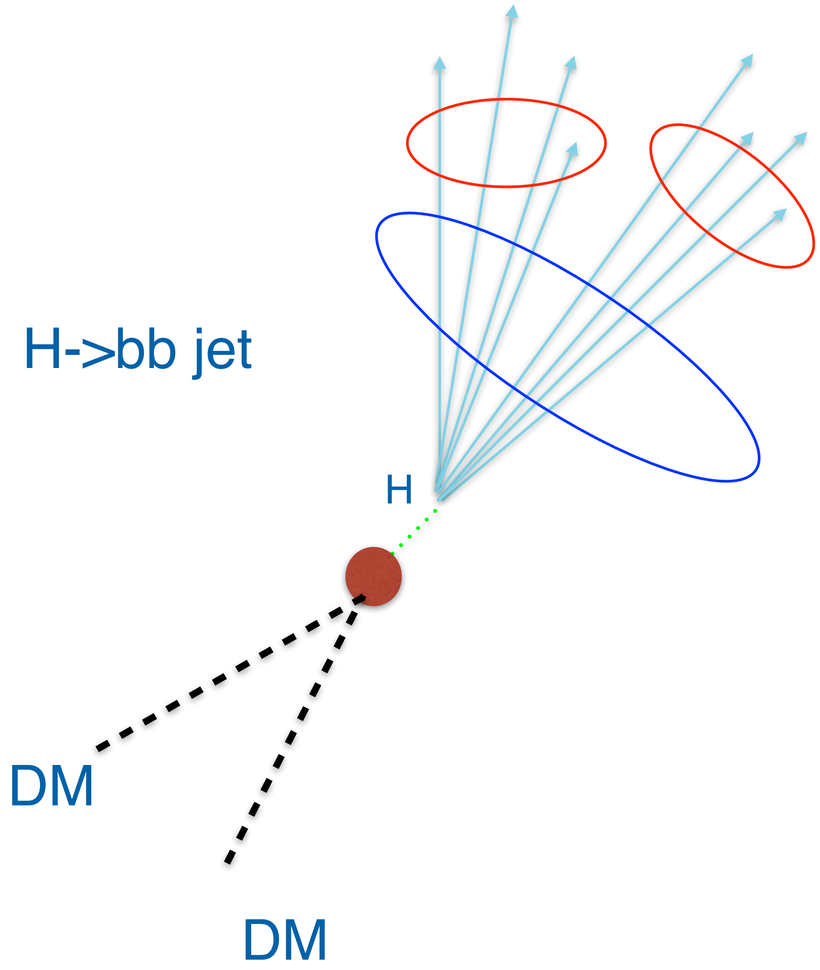
Hadronic Mono-H(->bb) Signature

Boosted Higgs boson decaying to a b-quark pair

=> large-radius jet and MET

Baryonic Z'



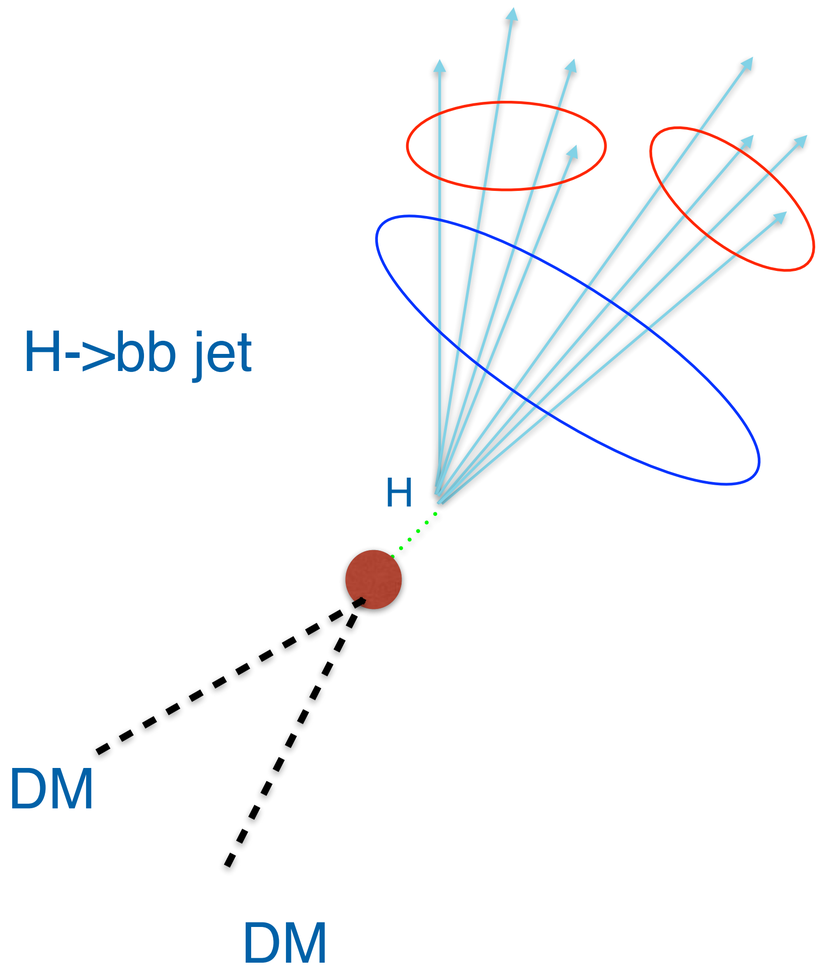


Fermilab

Higgs-Tagging Large-Cone Jets

High momentum large-radius jet with

- invariant mass ~mHiggs (125 GeV)
- two prongs identified by studying jet substructure
- b-quark identification inside the large-radius jet cone

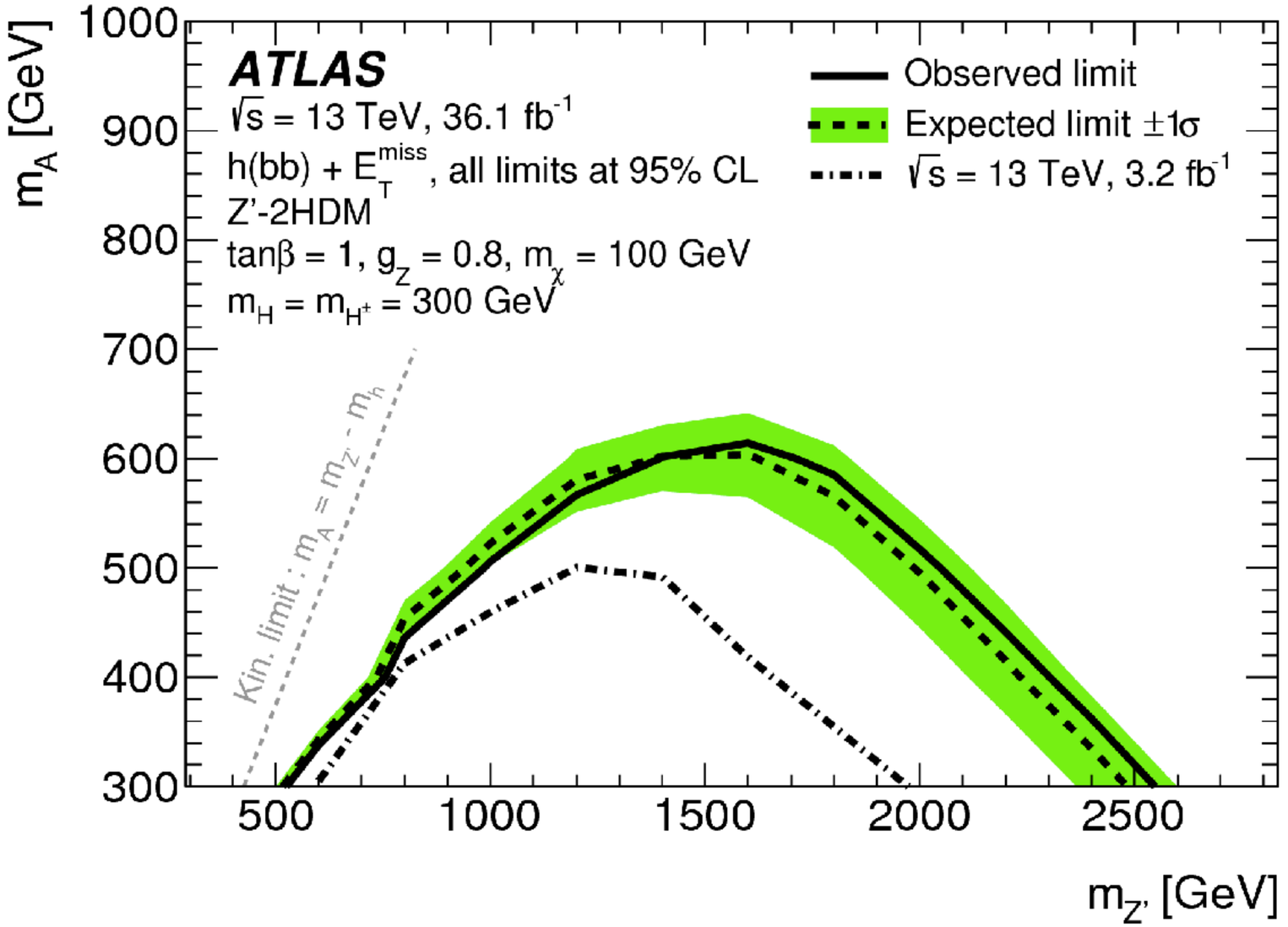


Fermilab

Mono-H(->bb) Results

13 TeV, 2015+2016 dataset

PRL **119**, 181804

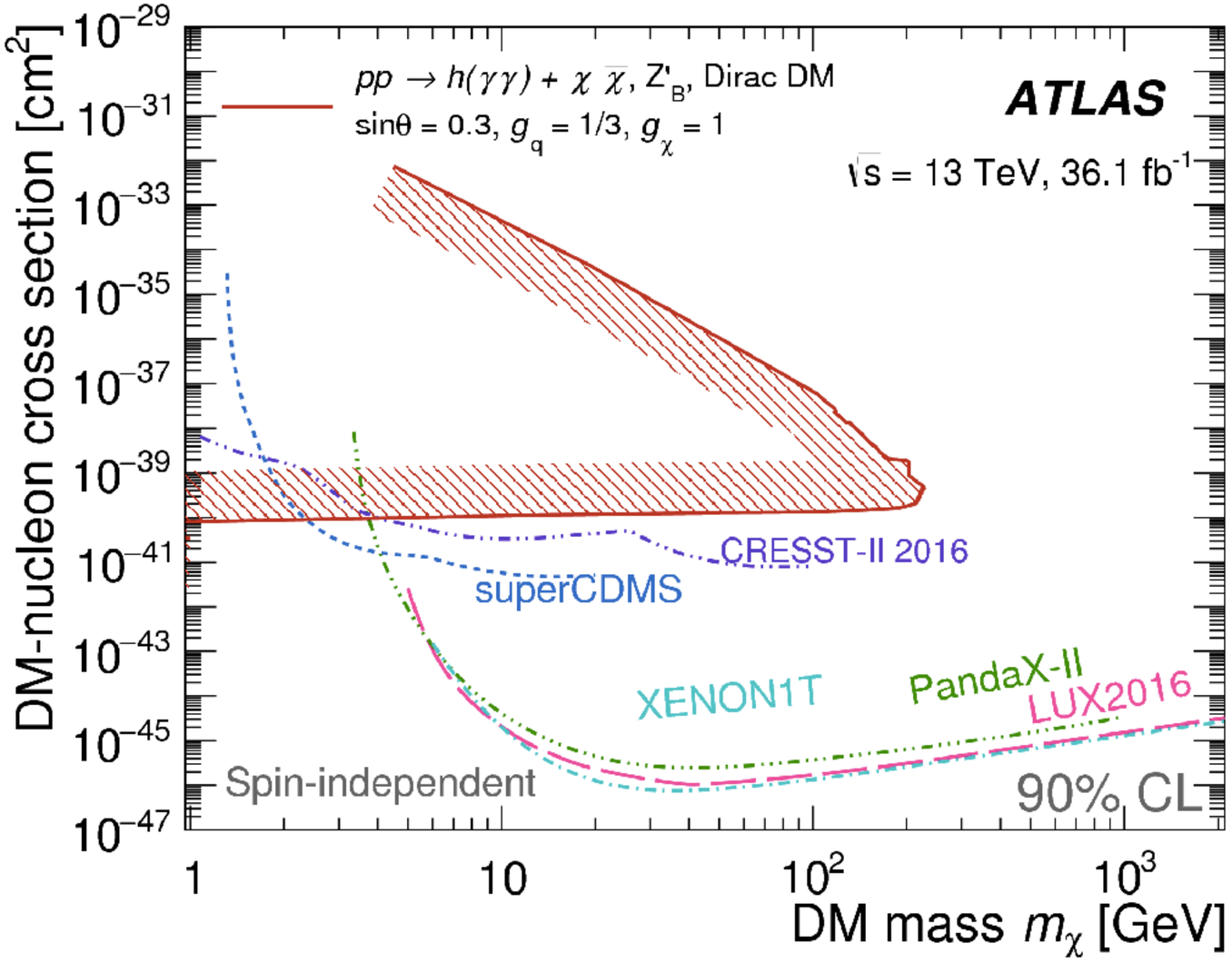


Fermilab

Mono-H(->γγ) Results

13 TeV, 2015+2016 dataset

PRD **96**, 112004

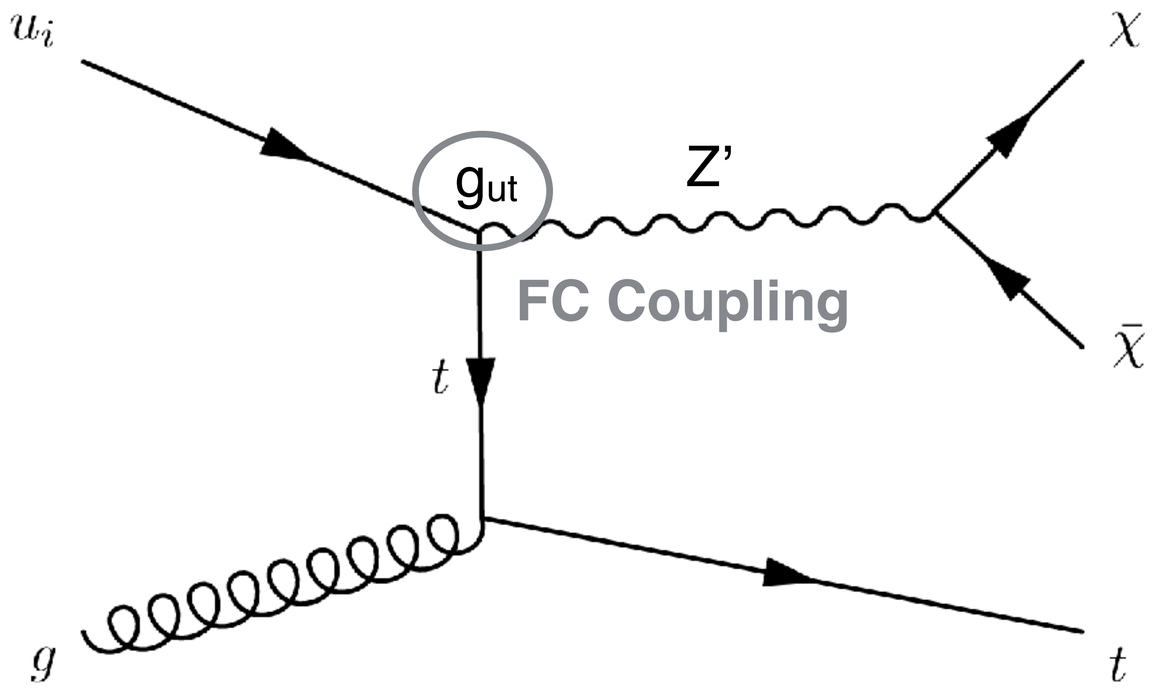


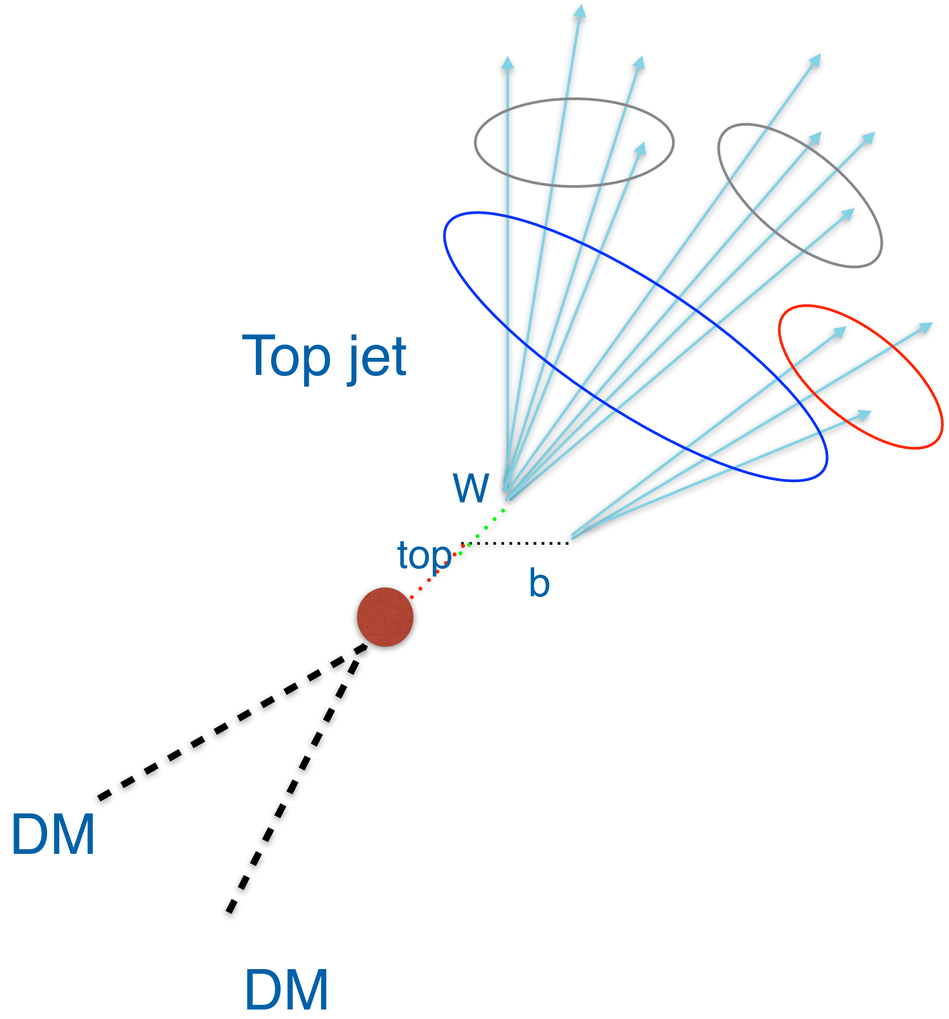
Fermilab

Hadronic Mono-top Signature

Boosted top quark decaying hadronically

=> large-radius jet and MET



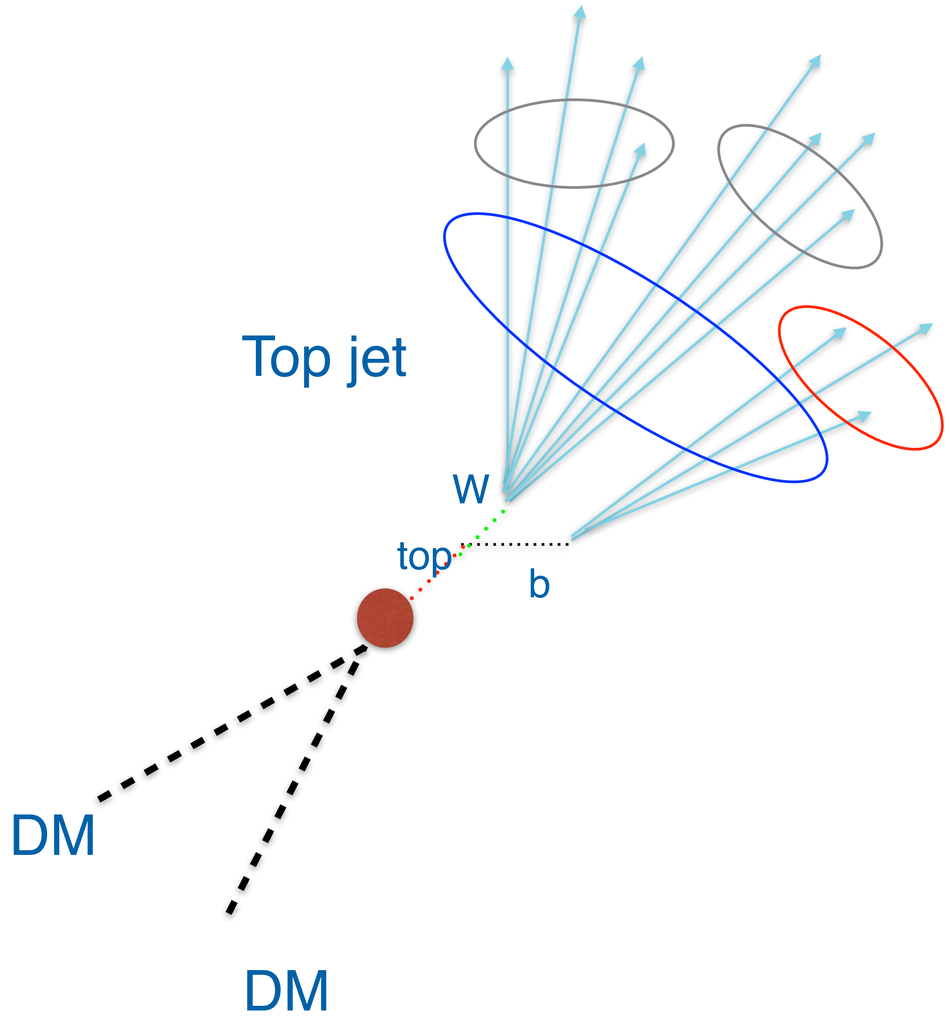


Fermilab

Top-Tagging Large-Cone Jets

High momentum large-radius jet with

- invariant mass ~mtop (175 GeV)
- three prongs identified by studying jet substructure
- b-quark identification inside the large-radius jet cone

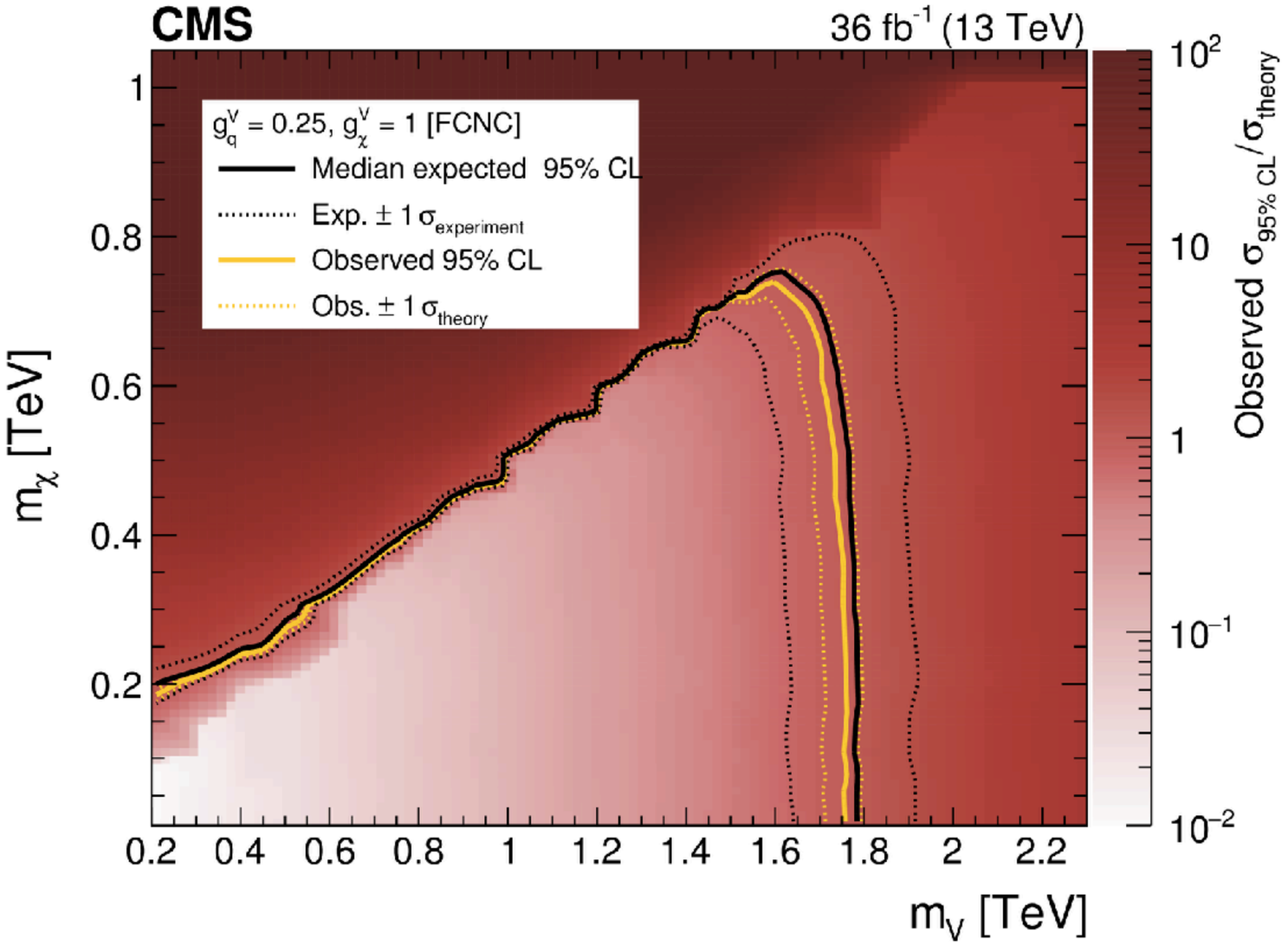


Fermilab

Hadronic Monotop Results

13 TeV, 2016 dataset

arXiv:1801.08427



Fermilab

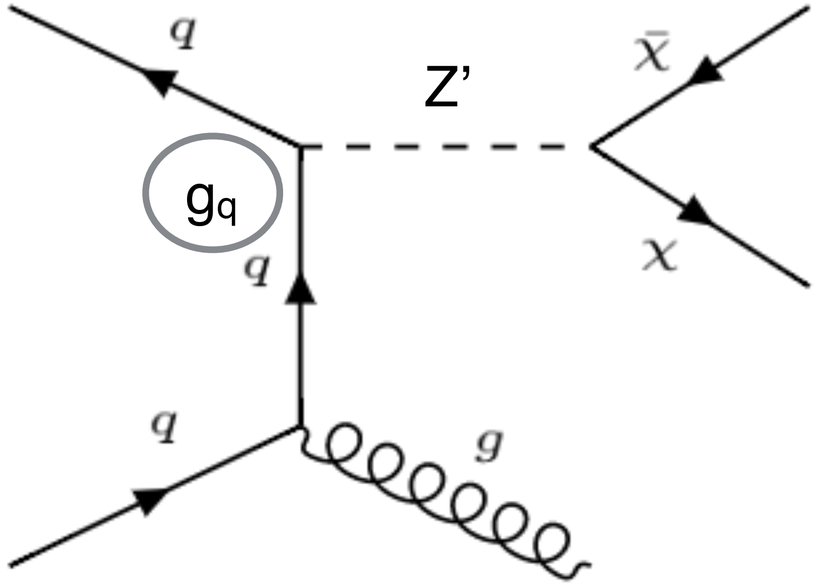
Conclusions

- Broad program of DM searches at the LHC, complementary to DD/ID
- Still no sign of DM, new dataset collected in 2017 still needs to be analyzed
  - doubling the current statistics
  - new results expected by the summer

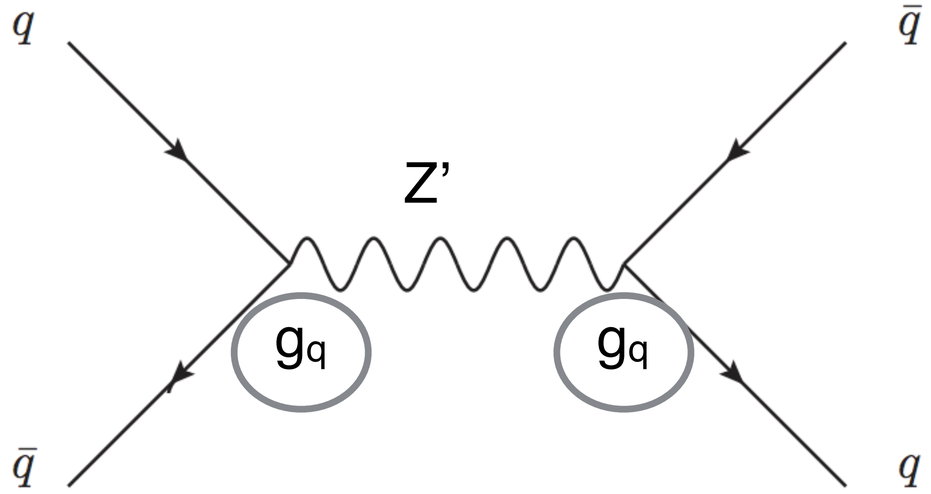
Backup

Dijet DM Interpretation

mono-jet



classic dijet



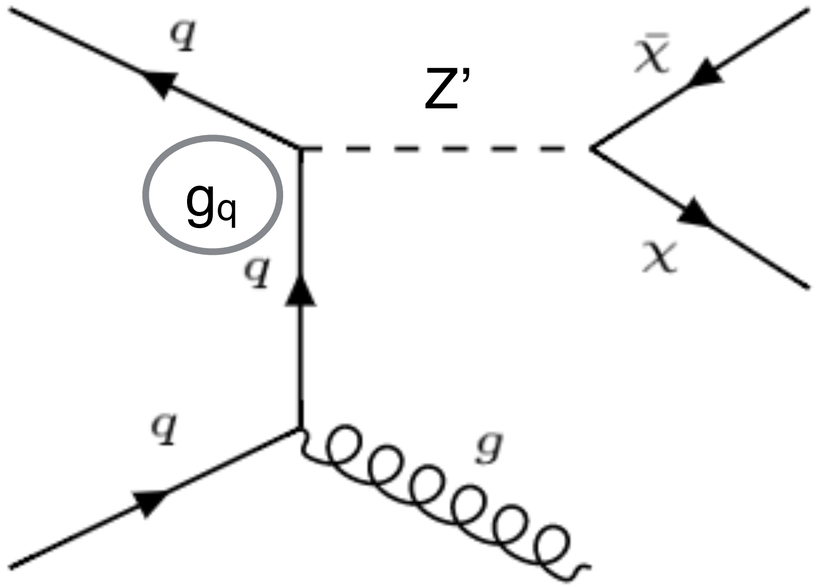
Z' is possibly same particle

=> interpret in single model with same coupling

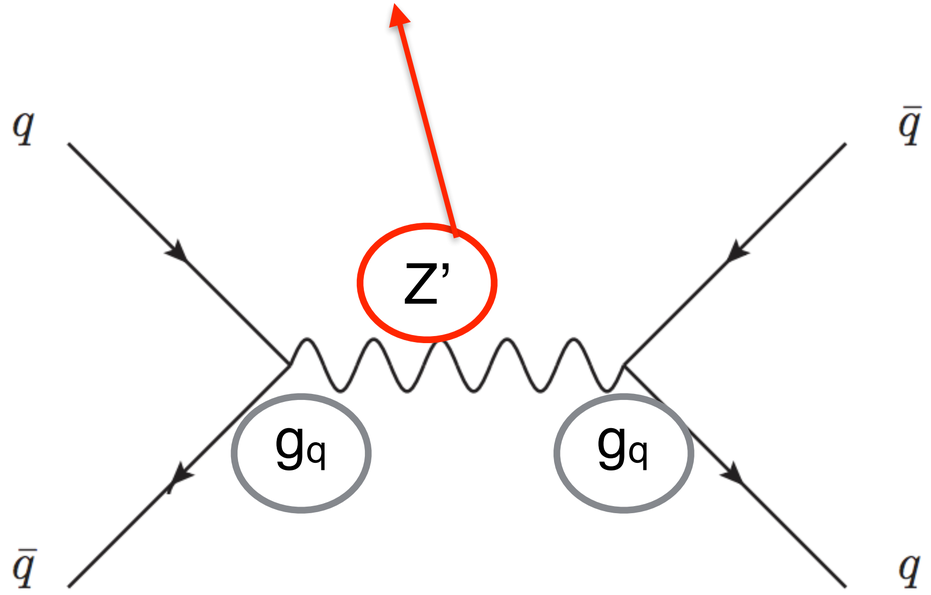
Fermilab

Dijet DM Interpretation

mono-jet



light boosted resonances

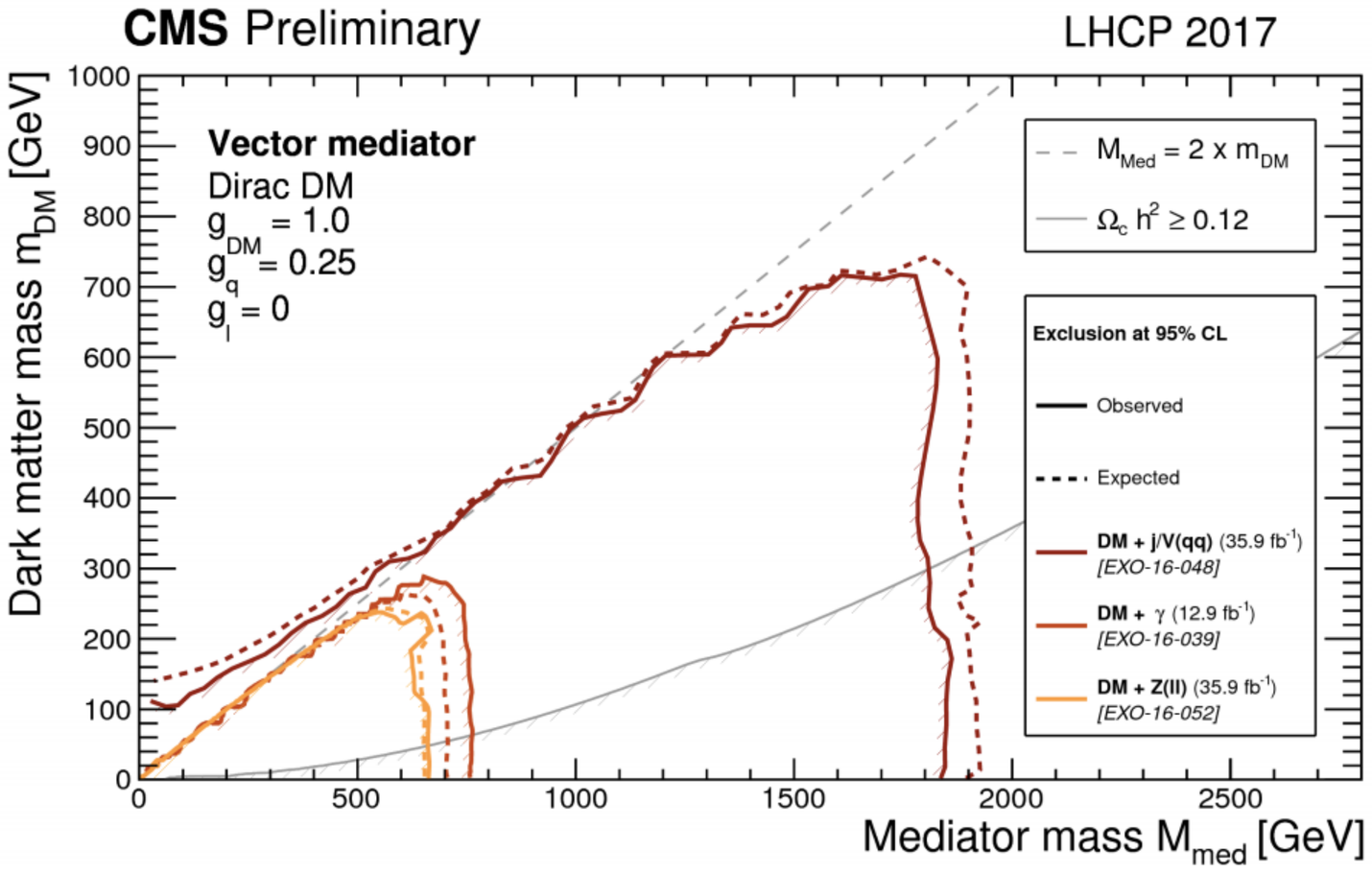


Z' is possibly same particle

=> interpret in single model with same coupling

Fermilab

Dijet DM Interpretation



- BR of mediator to jets depends on m_{DM}:
  - for **large m_{DM}**, BR to jets is 100%
  - for **m_{DM} around 1 GeV**, BR to DM is about the same as BR to jets
    - dijet signal rate drops by a factor of ~2
  - above $m_{DM} = M_{Med}/2$ the limit is constant

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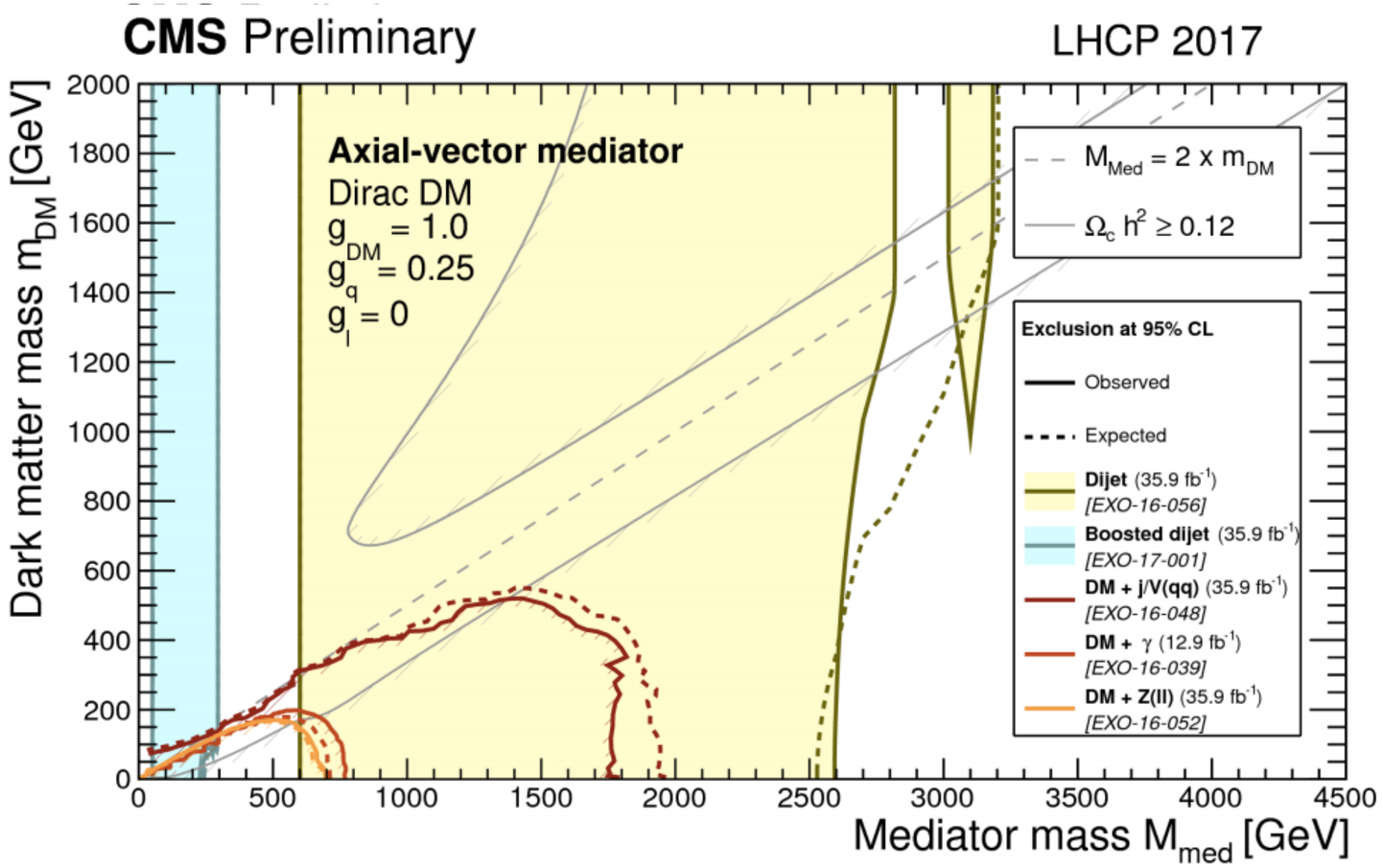
Dijet DM Interpretation



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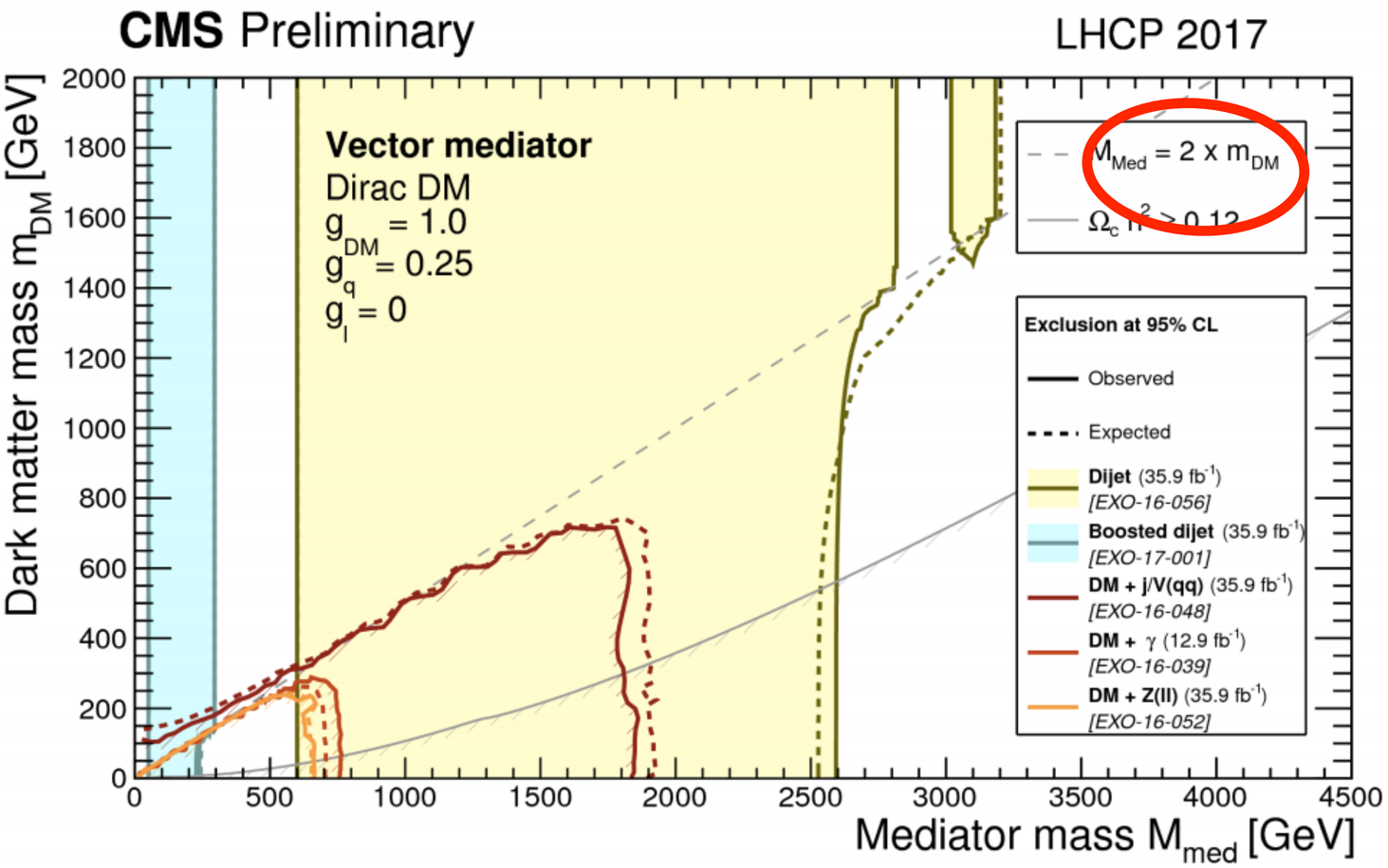
Dijet DM Interpretation



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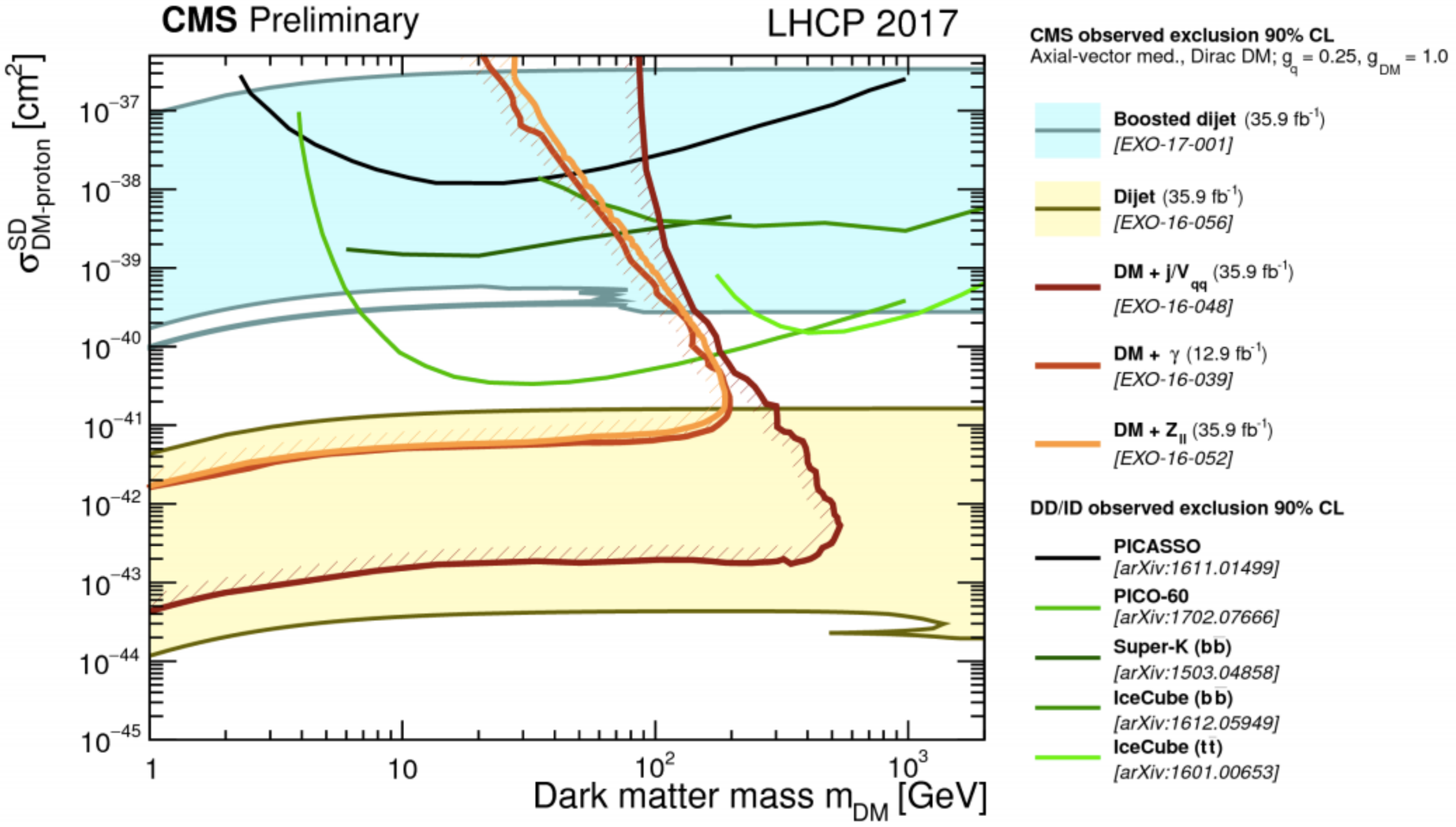
Comparison



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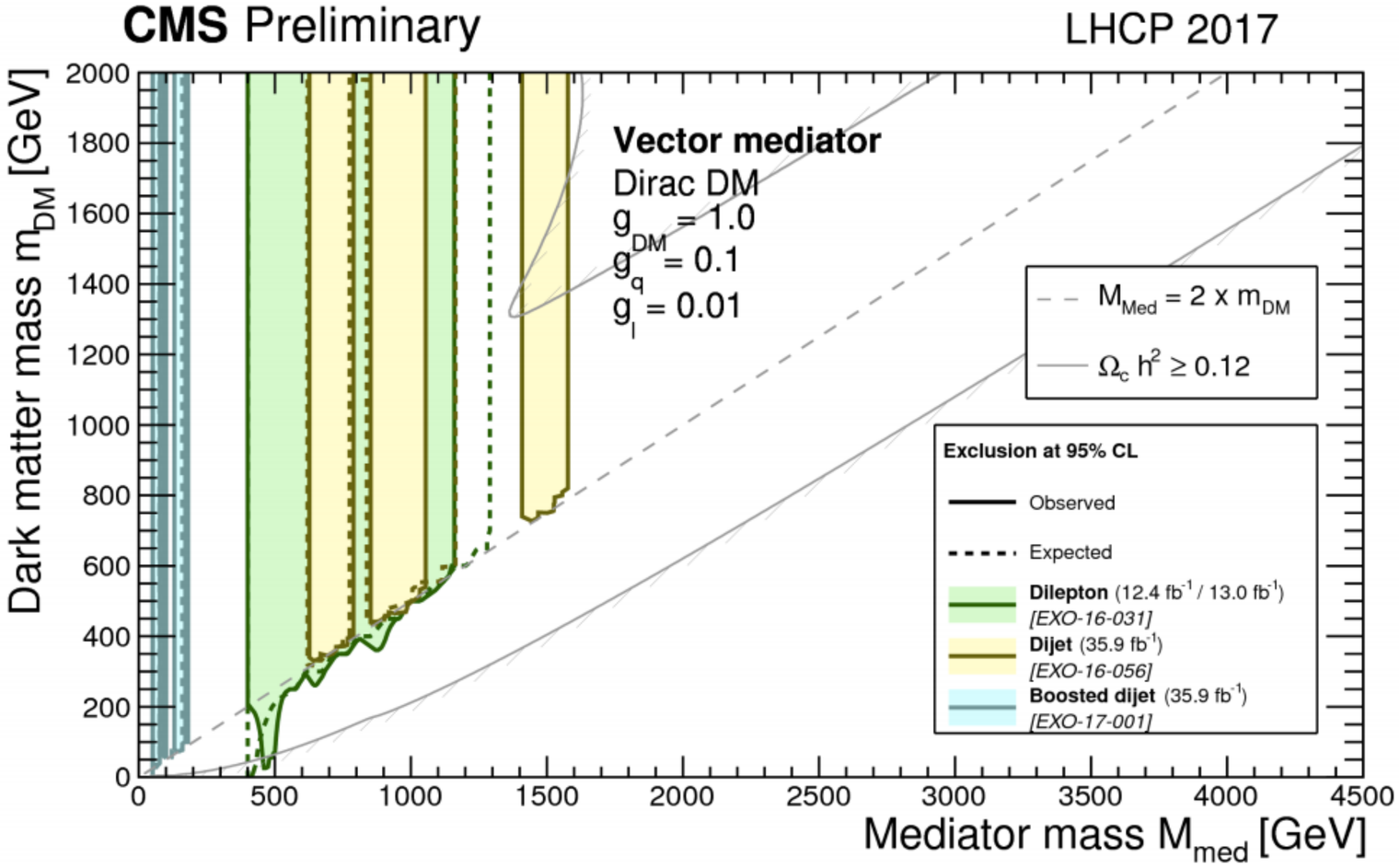
Dijet DM Interpretation



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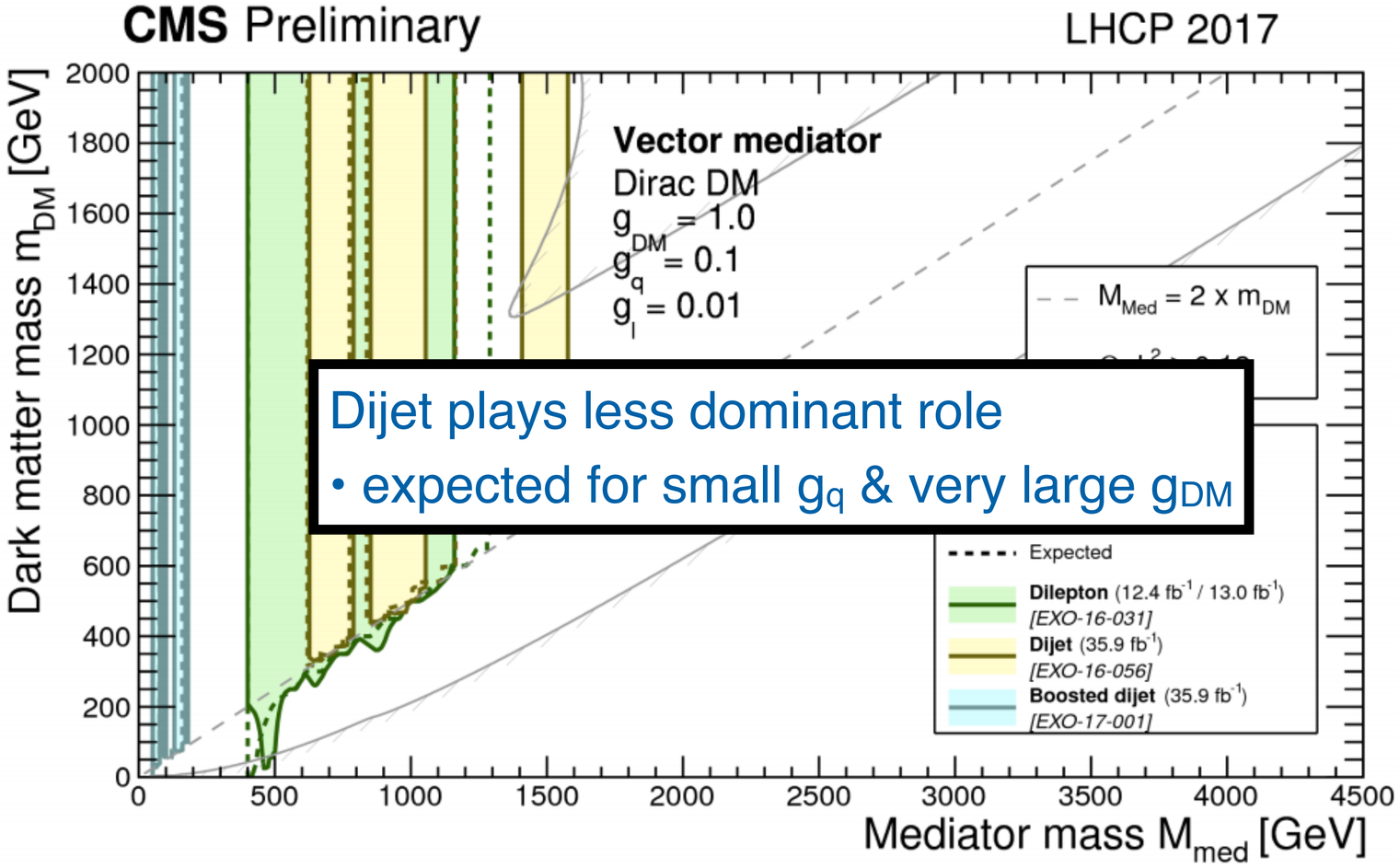
Dijet DM Interpretation



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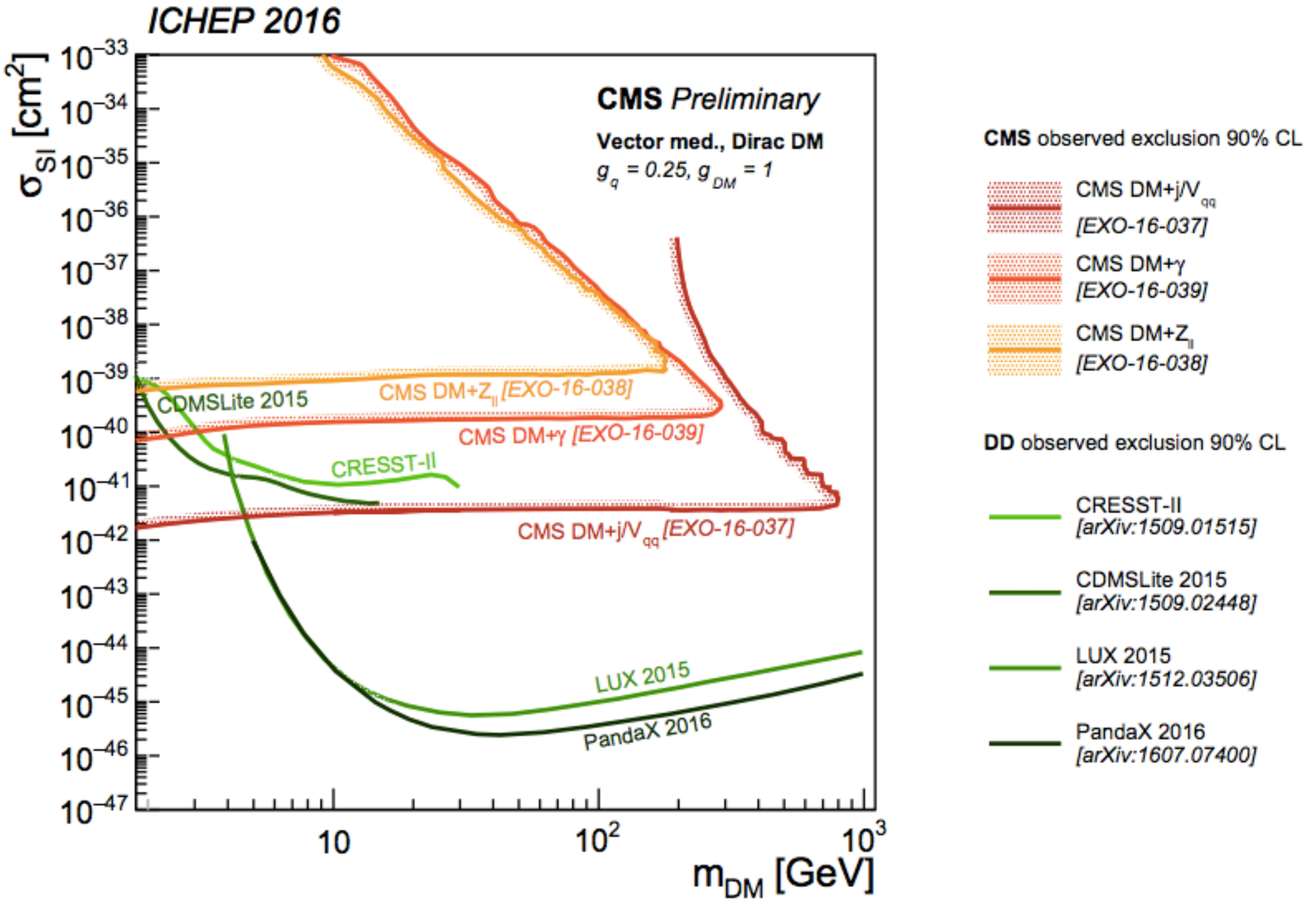
Dijet Limit Conversion

- Take the limits on gaussian-shaped resonances
- Compare these to MadGraph predictions for signal rates and shapes, after parton shower, detector smearing, and analysis cuts
- Not a full MC interpretation
  - from other studies we expect that it will match a full MC very well
  - Z' limits in the 13 TeV paper and it agrees with those in the large m_{DM} limit



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

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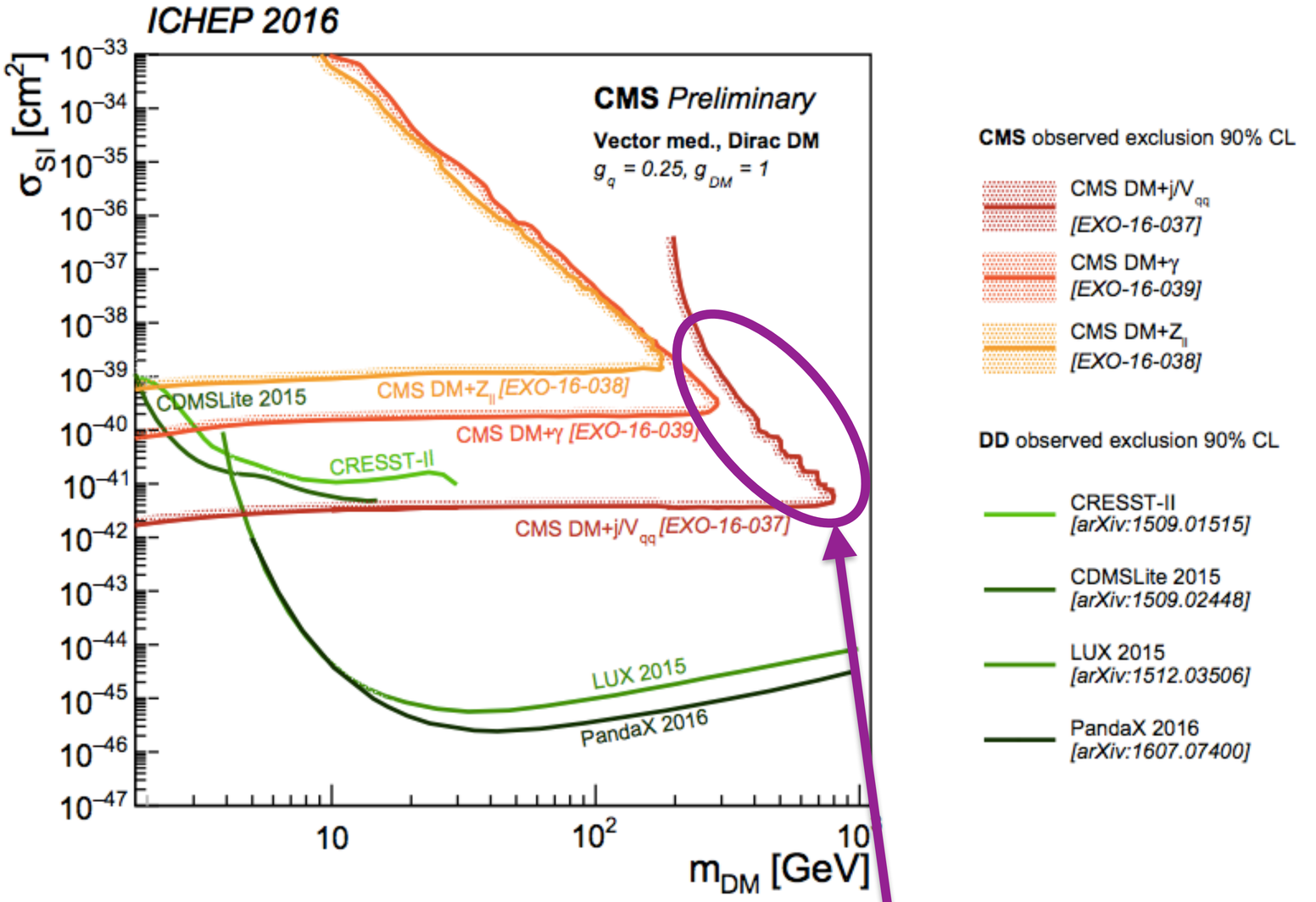

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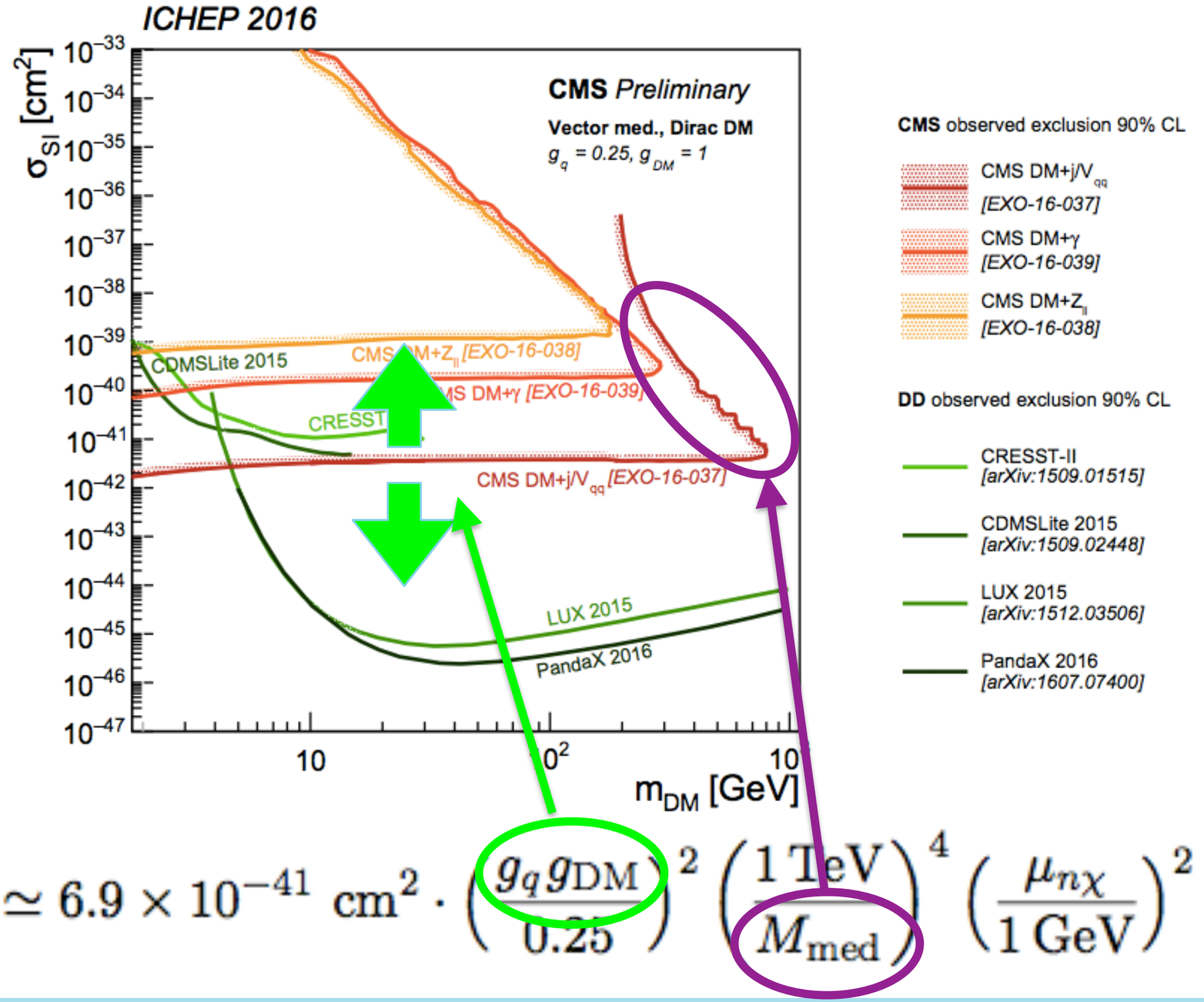

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DM Limit Conversion

- Assumption of coupling is one of the most limiting factors
- Collider limits are converted into nucleon-scattering cross section
- SI-DM nucleon scattering cross section:

$$\sigma_{\mathrm{SI}} = \frac{f^2(g_q) g_{\mathrm{DM}}^2 \mu_{n\chi}^2}{\pi M_{\mathrm{med}}^4}$$

- DM-nucleon reduced mass: $\mu_{n\chi} = m_n m_{\mathrm{DM}} / (m_n + m_{\mathrm{DM}})$ $m_n \simeq 0.939\,\mathrm{GeV}$
- Vector Mediator-nucleon coupling: $f(g_q) = 3 g_q$
- => $\sigma_{\mathrm{SI}} \simeq 6.9 \times 10^{-41}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{\mathrm{DM}}}{0.25}\right)^2 \left(\frac{1\,\mathrm{TeV}}{M_{\mathrm{med}}}\right)^4 \left(\frac{\mu_{n\chi}}{1\,\mathrm{GeV}}\right)^2$