Searching for ttbar + Dark Matter with 2016 data from the CMS experiment

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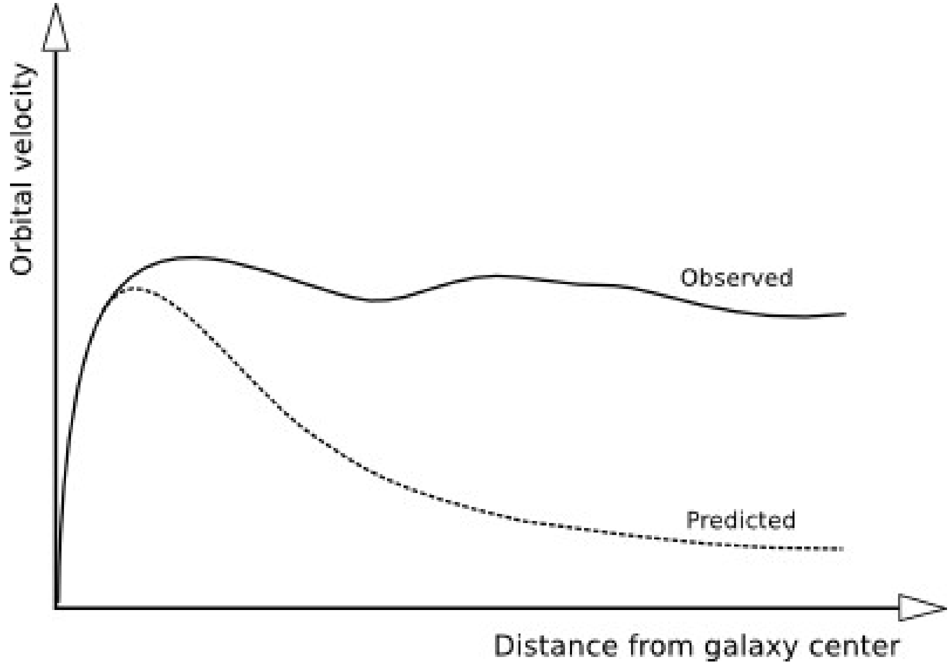
Nicole Stefanov (2017)
Kelly Beernaert and Gerrit van Onsem (2016)

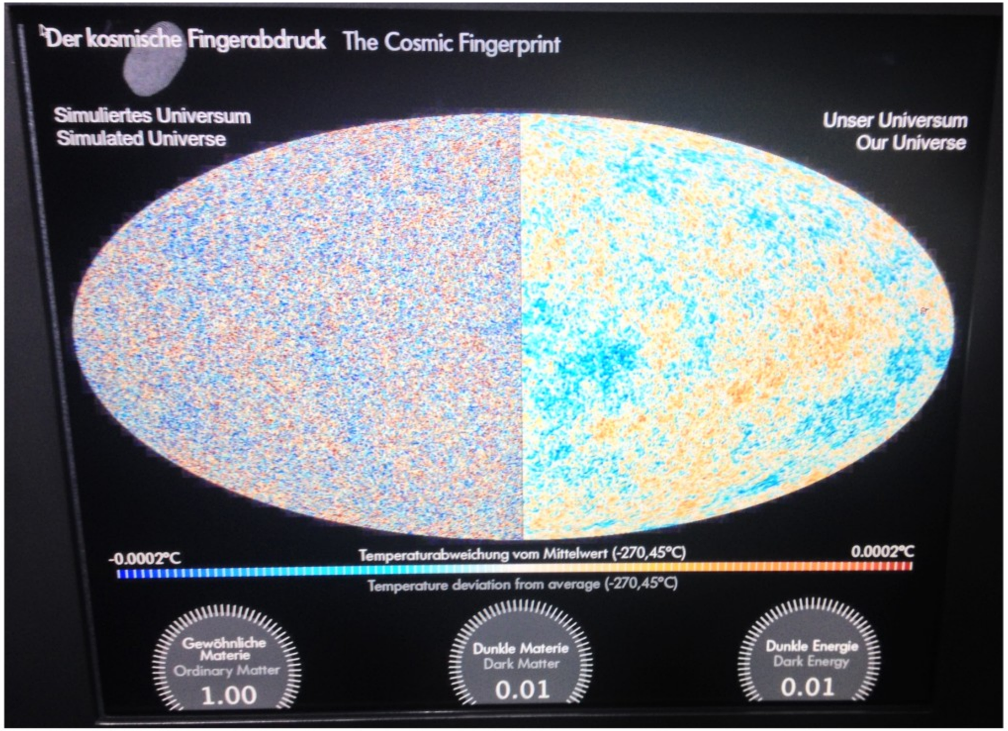
Motivation for dark matter searches



Source: http://en.citizendium.org/wiki/Galaxy_rotation_curve

- The first evidence of Dark Matter came from galactic rotation curves
- At small radii these suggest a matter distribution similar to what is observed in the form of luminous matter, but at large radii is instead consistent with a large “halo” of dark matter

Motivation for dark matter searches

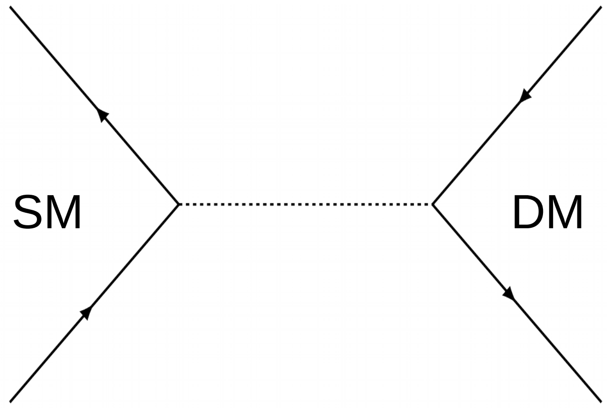


Source: Deutsches Museum München

- The development of large scale structure in the universe also cannot be explained by the amount of visible matter in the Cosmic Microwave Background
- Current Cosmological evidence suggests an energy budget of ~5% visible matter, ~25% dark matter and ~70% dark energy

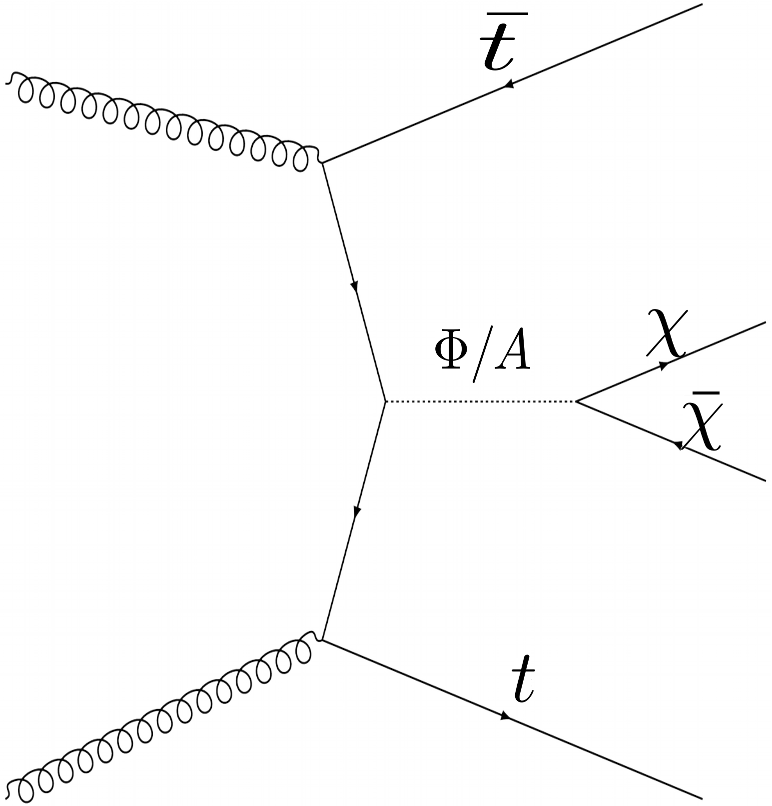
Thermal freeze out

- The simplest models of dark matter predict an interaction with the standard model mediated by a boson which is uncharged under the SM gauge group
- This mechanism allows Dark Matter to be in thermal equilibrium with Standard Model Matter in the early universe and then “freeze out” as the universe expanded and cooled to a temperature where the mediator could no longer be produced
- The measured density of dark matter in the universe suggests a mediator mass around the TeV scale – the “WIMP miracle”



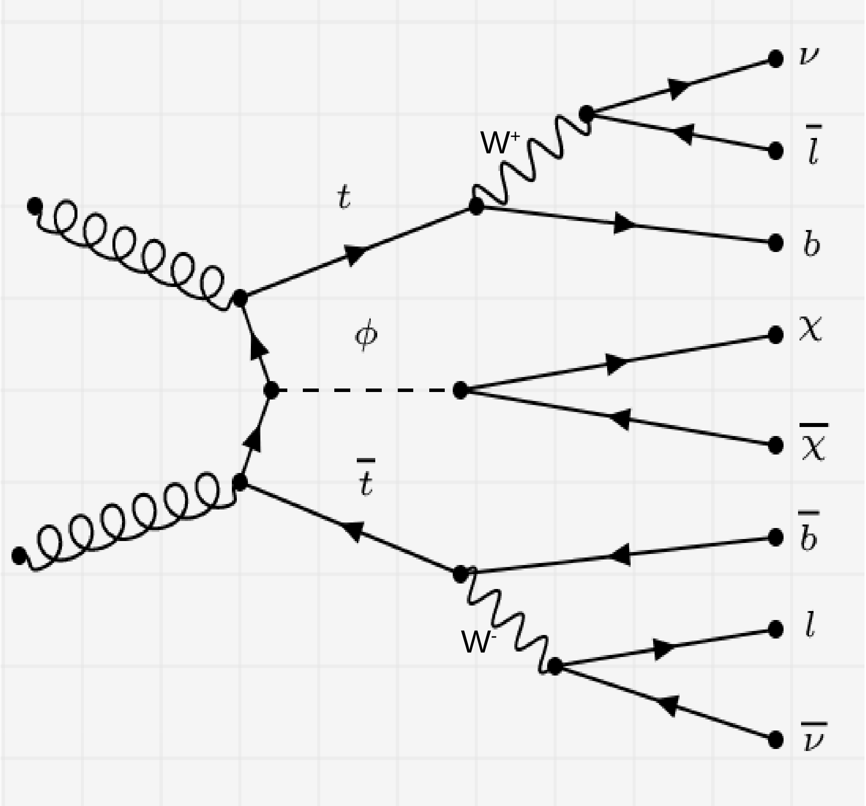
Why top quarks?

- Since the mediator is uncharged under SU(3)xSU(2)xU(1), it could couple to mass, and so the top quark, as the heaviest SM particle, is a good candidate for DM searches
- The LHC is also a “top factory”, producing a large number of $t\bar{t}$ events
- This process has four new parameters: the DM candidate and mediator masses, the coupling of the mediator to top quarks, and the branching ratio of the mediator to DM particles (which is assumed to be close to unity)



Analysis strategy - channel

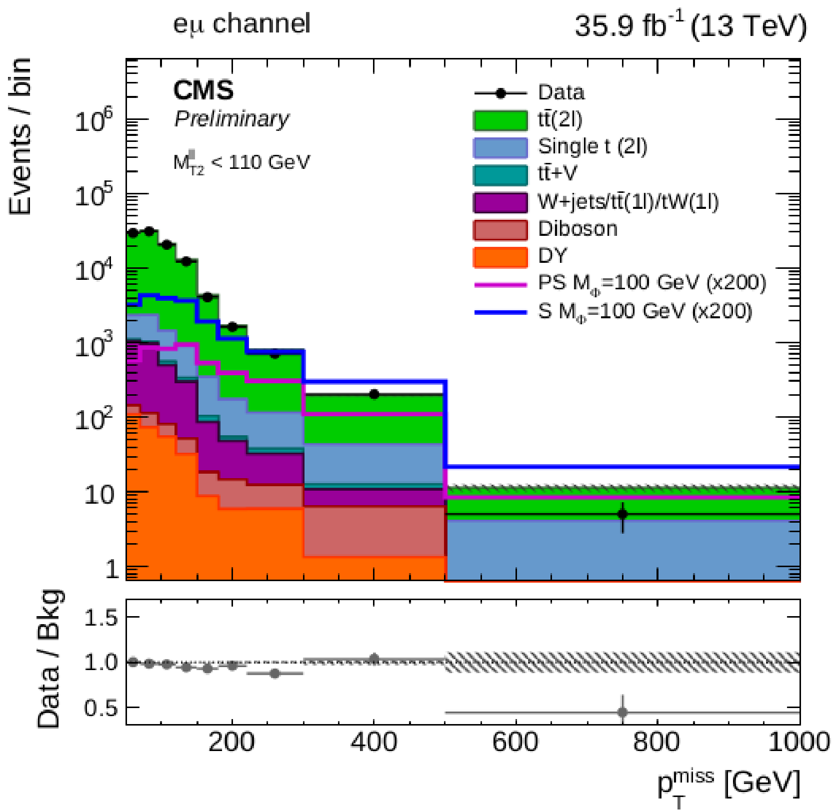
- A search was performed using 2016 CMS data (13 TeV)
- Split into three channels, depending on the decay mode of the W bosons coming from the tops: Dileptonic, Semi-leptonic and All-hadronic
- The DESY group focused on the dilepton channel- this has the benefit of a distinctive signal, but a drawback of large MET in the SM process

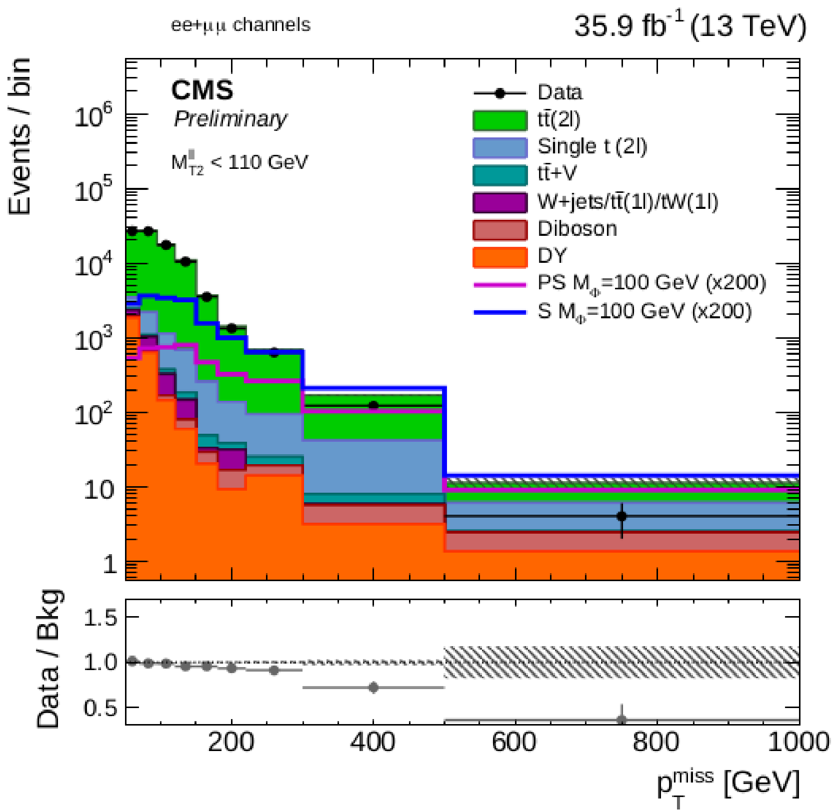


Analysis Strategy -event selection

- Used standard $t\bar{t}$ event requirements:
  - Dilepton and Single lepton triggers
  - An opposite signed lepton pair
  - Cuts on low invariant mass of the dilepton system and on a window around the Z pole to reduce Drell-Yan backgrounds
  - At least two high-pt jets, at least one of which is b tagged
  - MET cut (to further suppress Drell-Yan backgrounds)
- The $t\bar{t}$ system was then reconstructed by selecting jets which most closely match b-jet lepton invariant mass distributions, and then using the 4-momentum of these four particles, the MET and top and W mass constraints to constrain the neutrino momenta
- The reconstruction does not always work, and so the objects are “smeared” to account for detector mismeasurement, and the fraction of successful reconstructions after smearing gives a weight to the reconstruction

Analysis strategy- control distributions





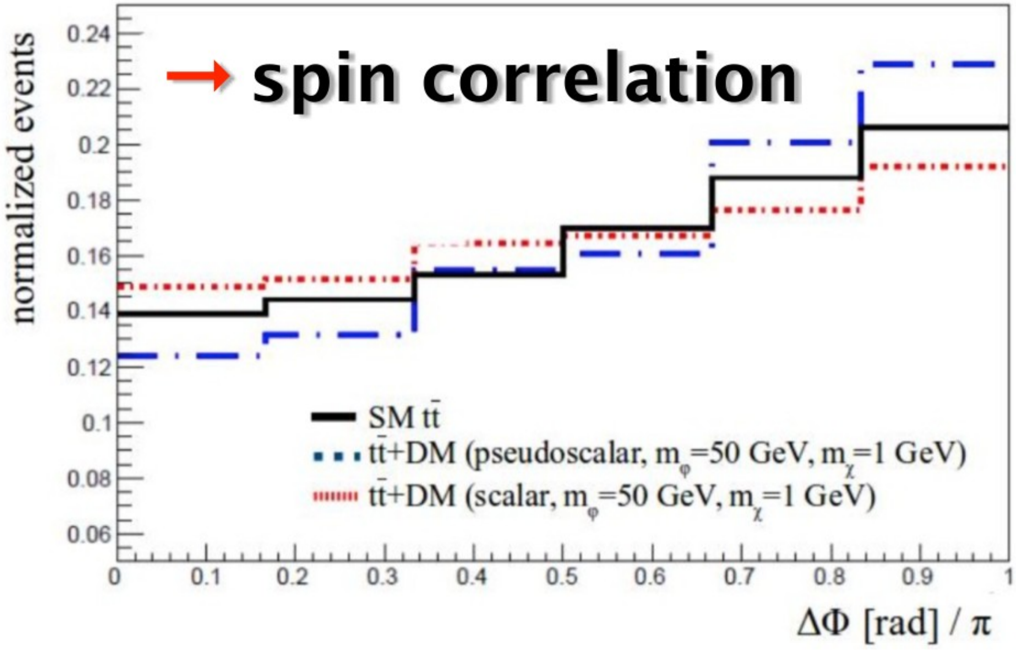
Source: CMS PAS EXO-17-014

Analysis Strategy - BDT

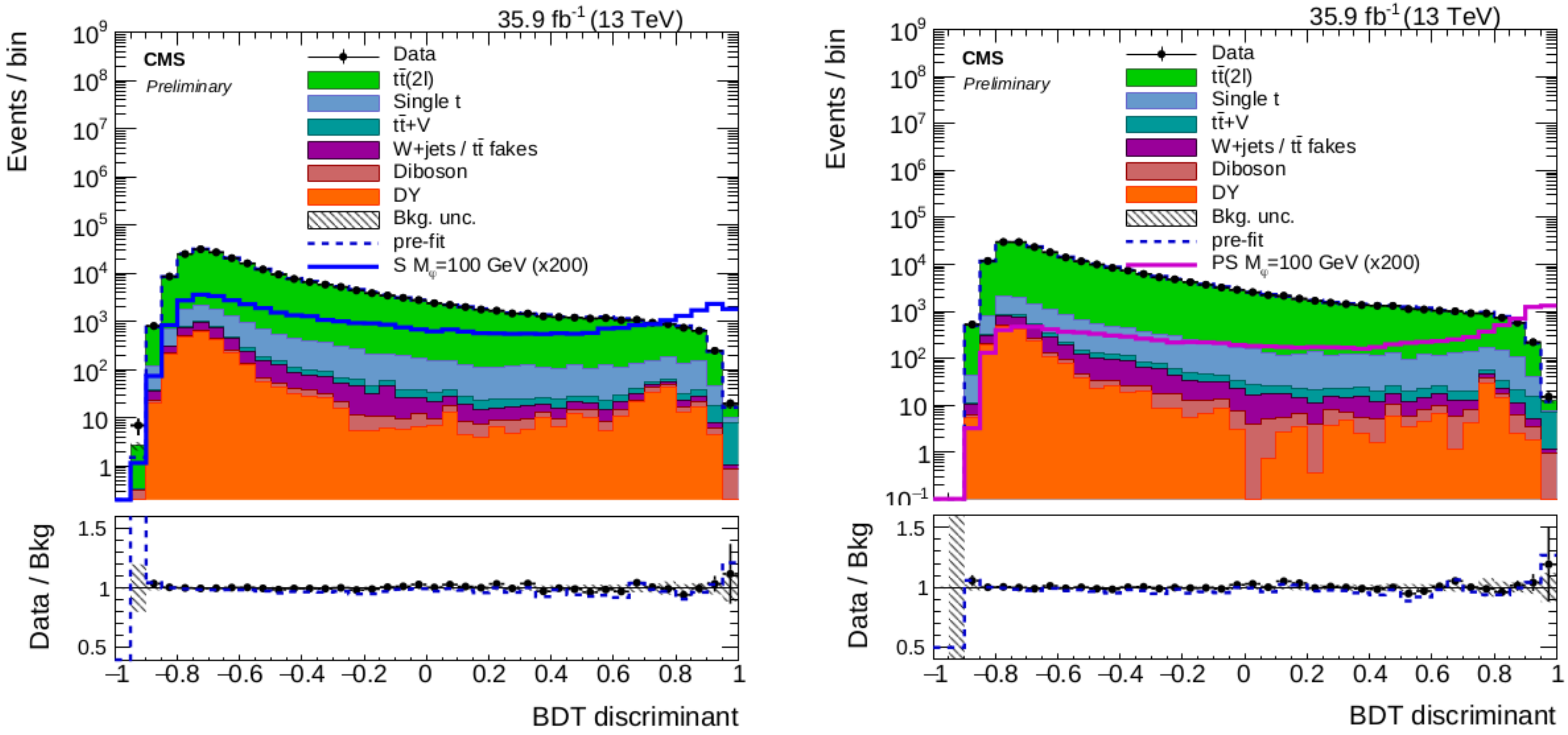
- A BDT was constructed to distinguish the signal events from the background, which was trained on variables known to have distinguishing power:
  - MET and MET significance
  - M_{T2}^{ll} and $M_{T2}^{lb,lb}$, which are bounded by top and W mass limits for SM $t\bar{t}$ processes, but not for events with DM
  - The weight assigned by the $t\bar{t}$ reconstruction algorithm- this tends to fail for events with DM due to the additional source of MET
  - $|\Delta\phi(p_T^{miss}, ll)|$,$|\Delta\eta(ll)|$, and $\cos\Phi_{ll}$, which are sensitive to the spin correlations of the $t\bar{t}$ system

$t\bar{t}$ Spin Correlations

- Top quarks have such a short lifetime that they decay before they hadronise
- This means that unlike the other quarks, the spin of the top quark is transferred to its decay products, and the information about the correlation of the spins of the top and antitop quarks can be recovered from the angle between the two leptons
- The emission of the DM mediator affects the spin correlation of the top quarks, and is hence detectable in the angle between the leptons



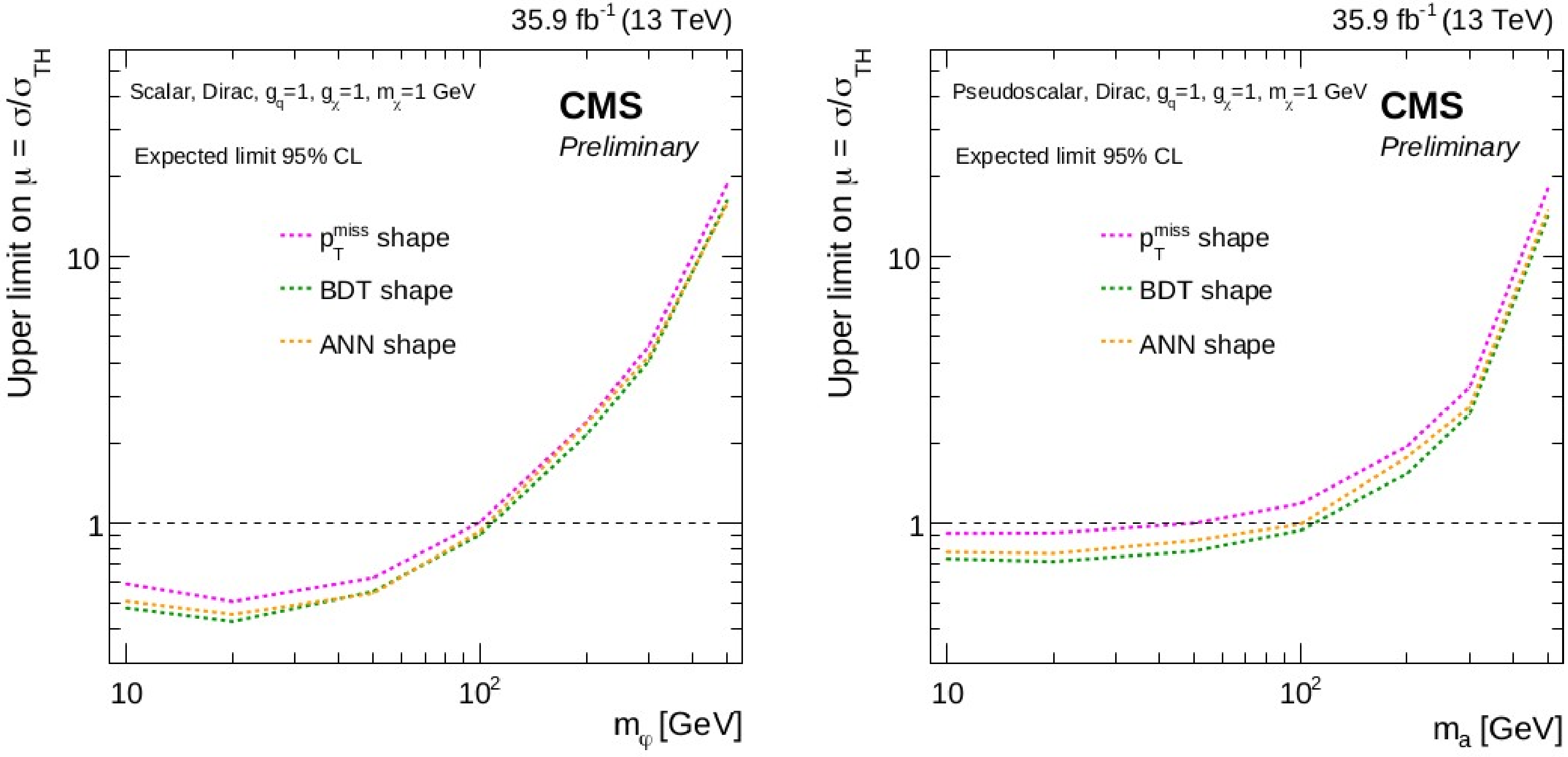
BDT distinguishing power



(a) scalar training (b) pseudoscalar training

Source: CMS PAS EXO-17-014

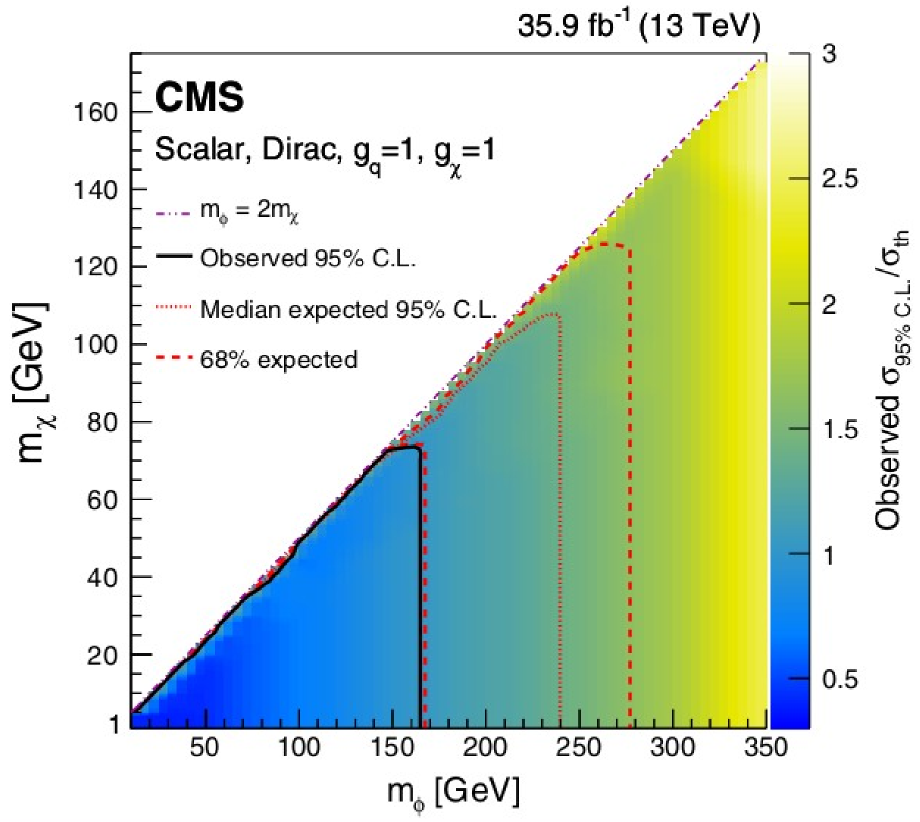
Dilepton Channel Limits

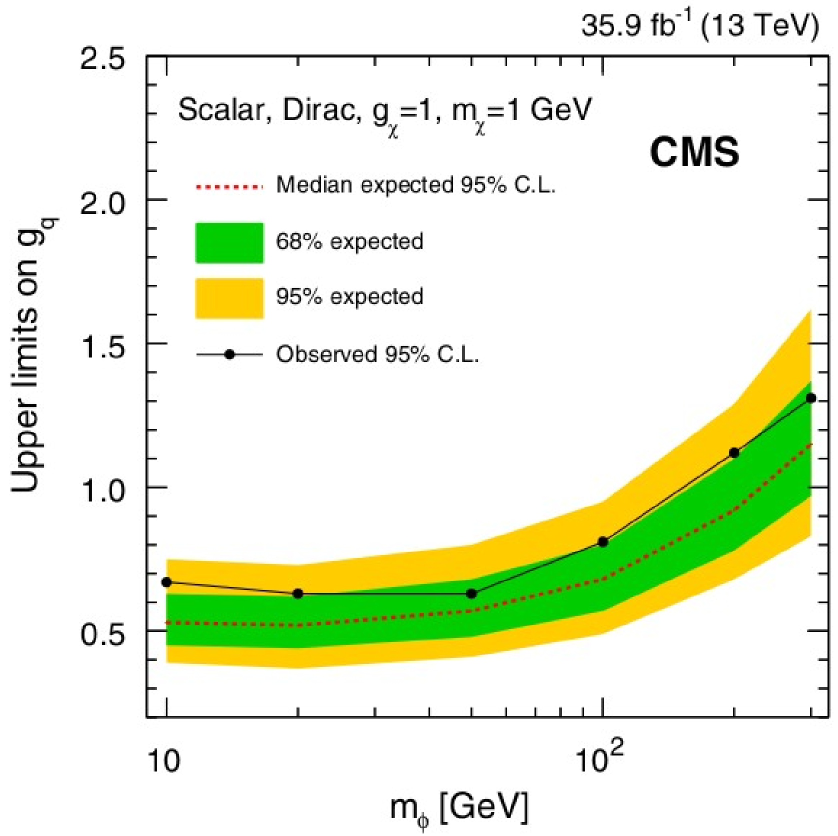


(a) scalar mediator (b) pseudoscalar mediator

Source: CMS PAS EXO-17-014

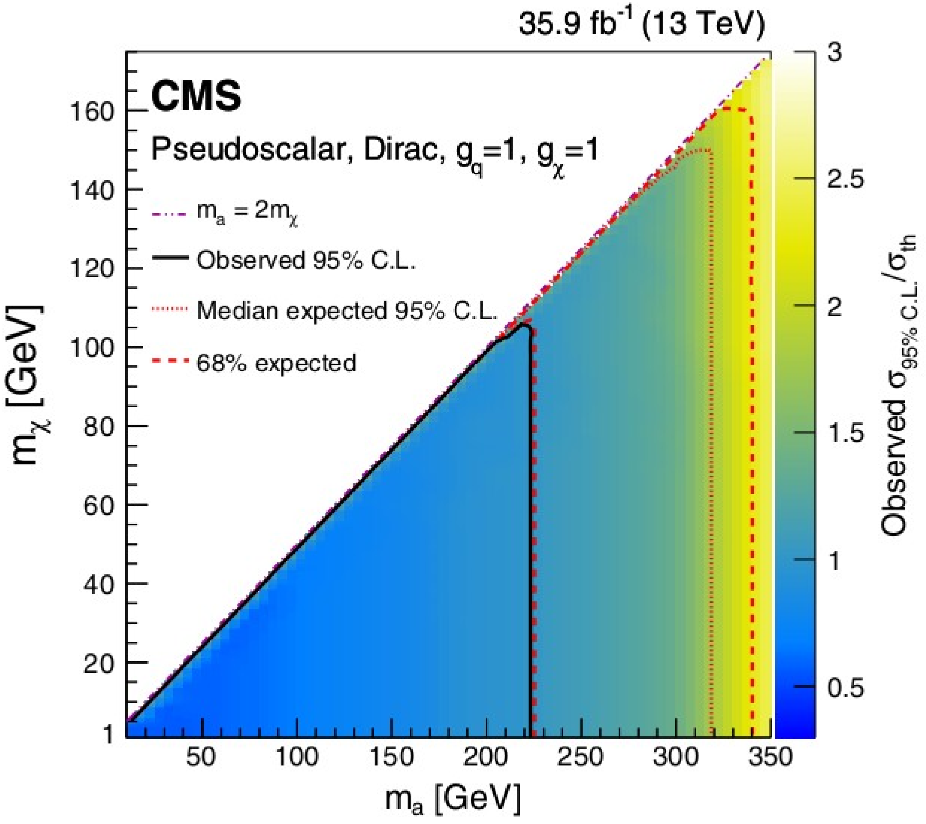
Combined Limits – Scalar Mediator

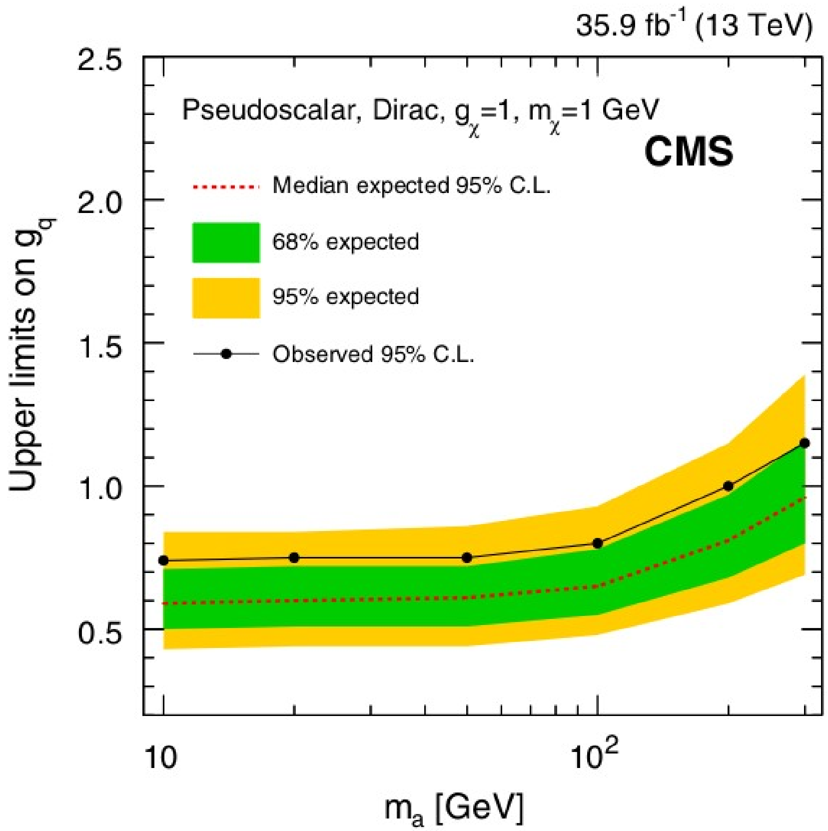




Source: CMS Collaboration, DOI: 10.1103/PhysRevLett.122.011803

Combined Limits – Pseudoscalar Mediator





Source: CMS Collaboration, DOI: 10.1103/PhysRevLett.122.011803

Outlook

- Currently working towards a full Run II analysis (with $137fb^{-1}$), which will add a single top signal region
- Considering using new machine learning techniques, such as Deep Neural Networks, which could be useful for directly analysing the 4-momenta of the particles
- Also looking to improve the ttbar reconstruction by allowing for some MET to come from the DM mediator
- Hope to be able to find hints of a signal or exclude the majority of the parameter space, which may suggest Dark Matter is not as simple as the original WIMP models suggested