Dark Matter Searches at the LHC

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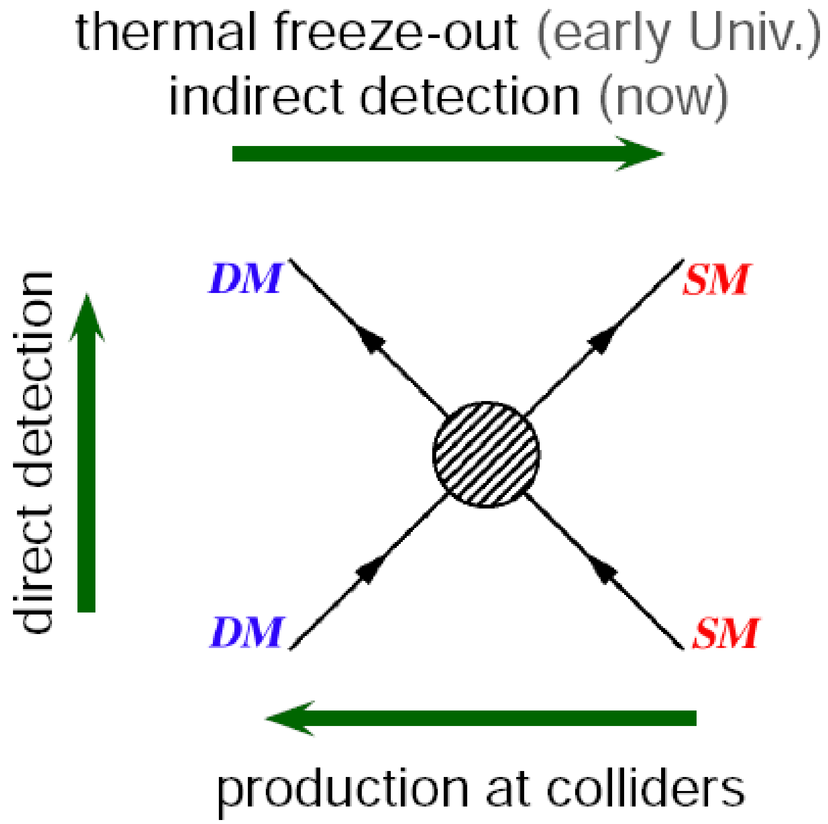
Dark Ghosts 2018

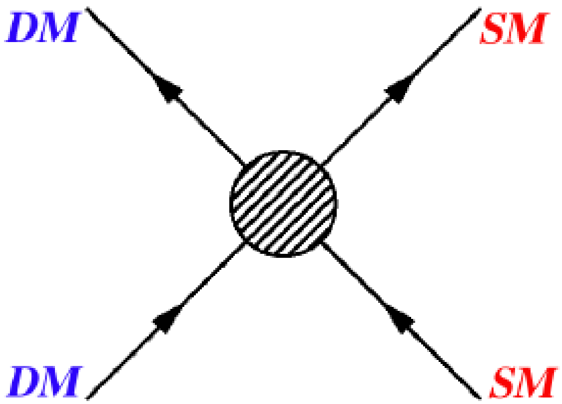
Content

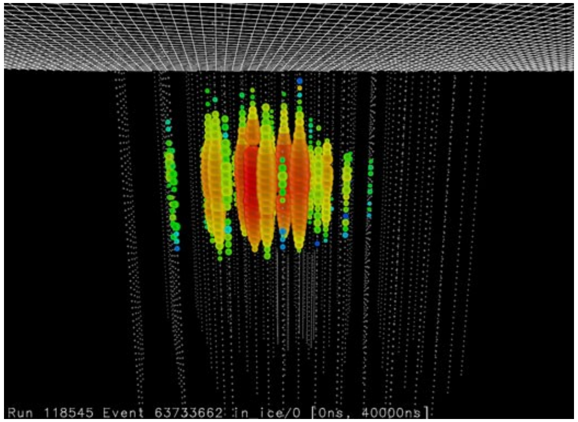
- Setting the scene
- DM production at the LHC
  - direct versus cascade production
  - simplified models
- Experimental status: searches for DM at LHC
  - searches for direct DM production
  - connecting to the visible
  - interpretation; comparison beyond LHC
  - SUSY and Higgs
- New frontiers
- Outlook

Setting the scene



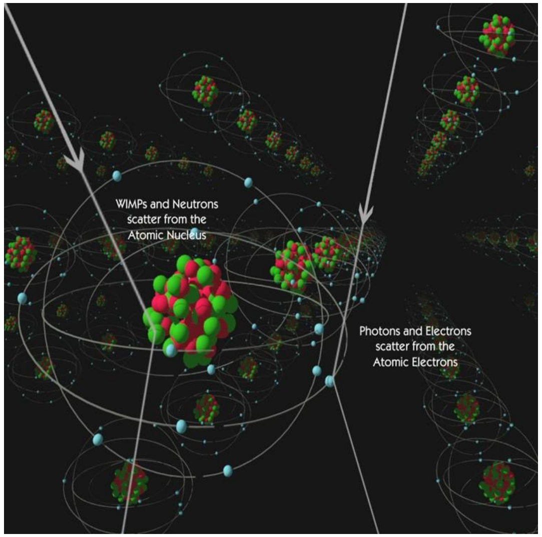
Setting the scene

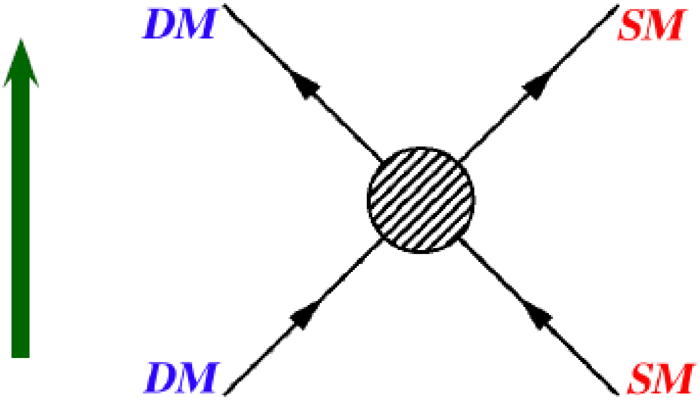




break it!

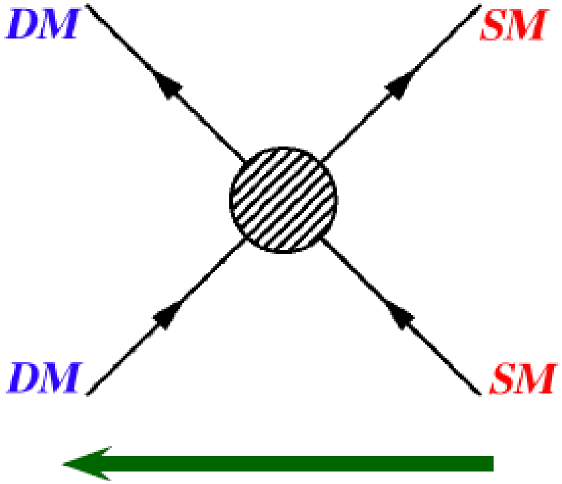
Setting the scene





shake it!

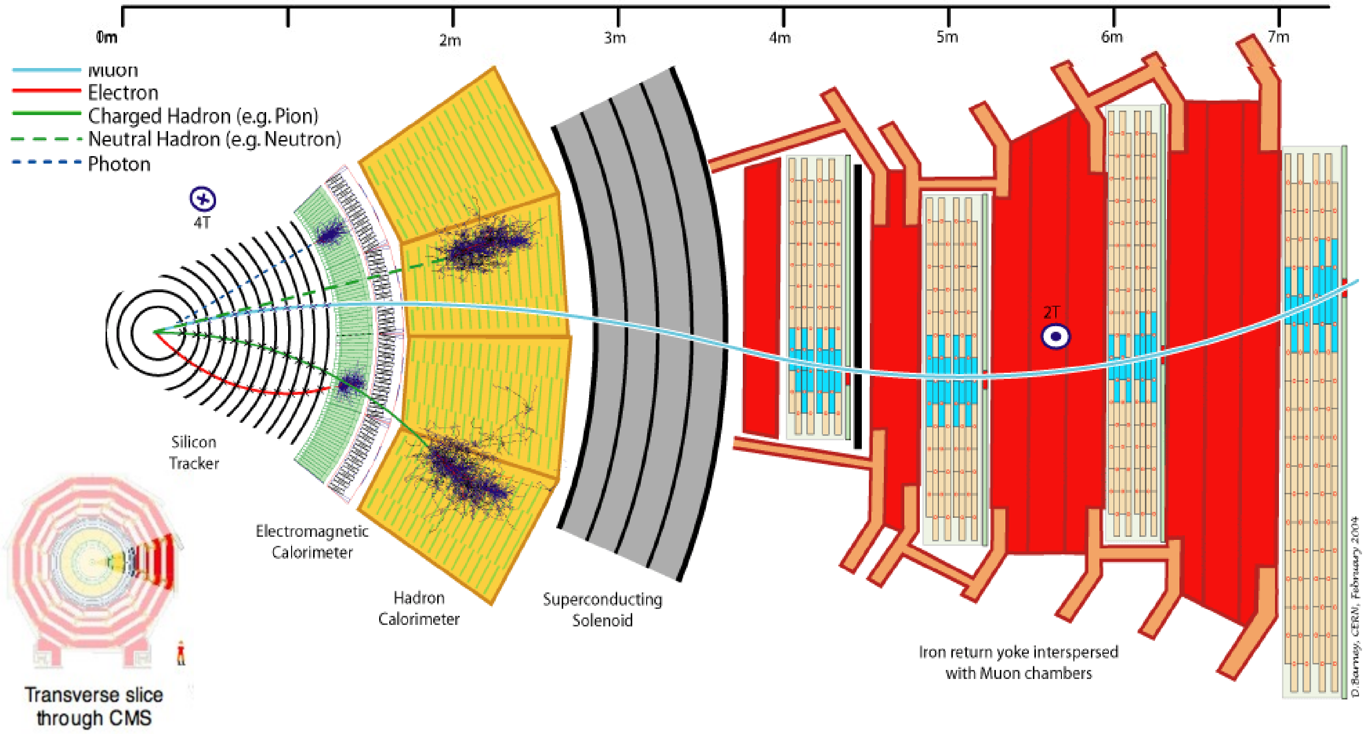
Setting the scene



make it!

Setting the scene

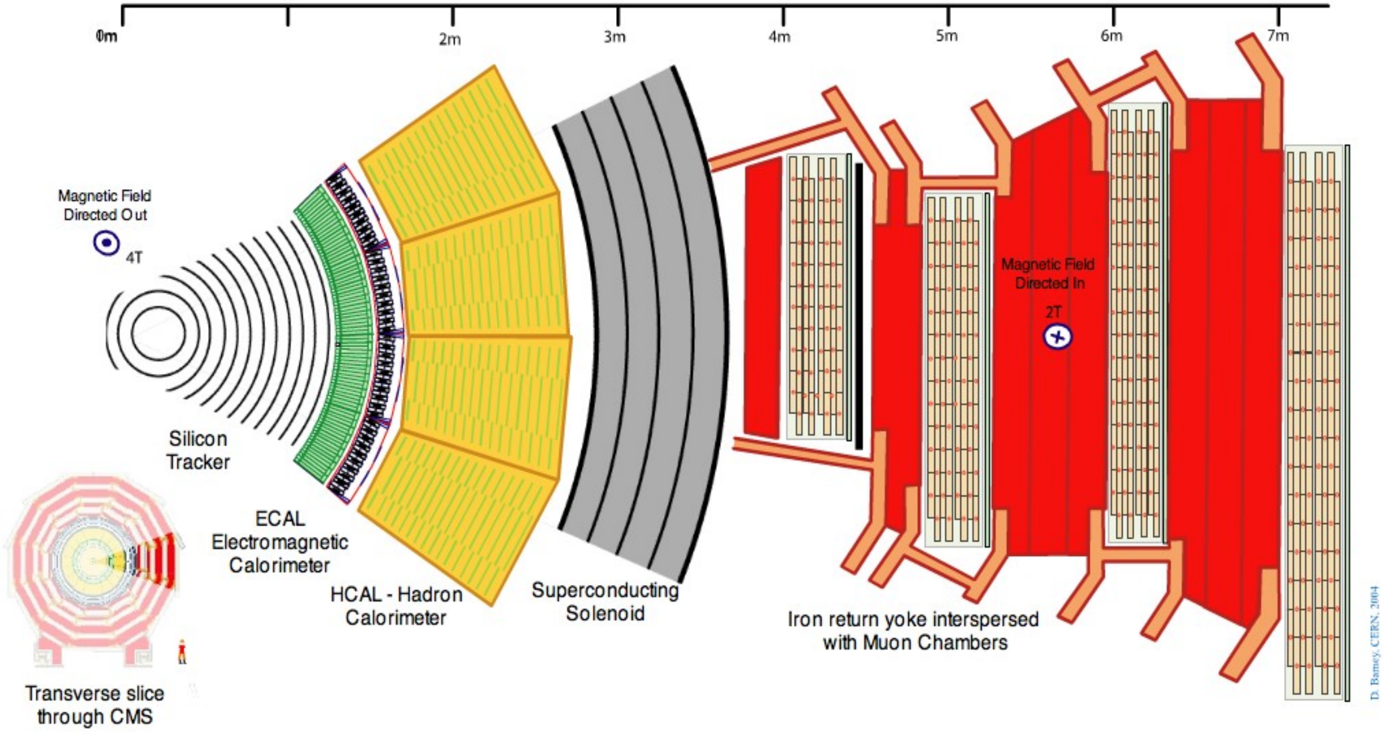
Collider experiments as DM hunters



Setting the scene

Collider experiments as DM hunters

- focus on WIMP-like particles: no interaction in detector

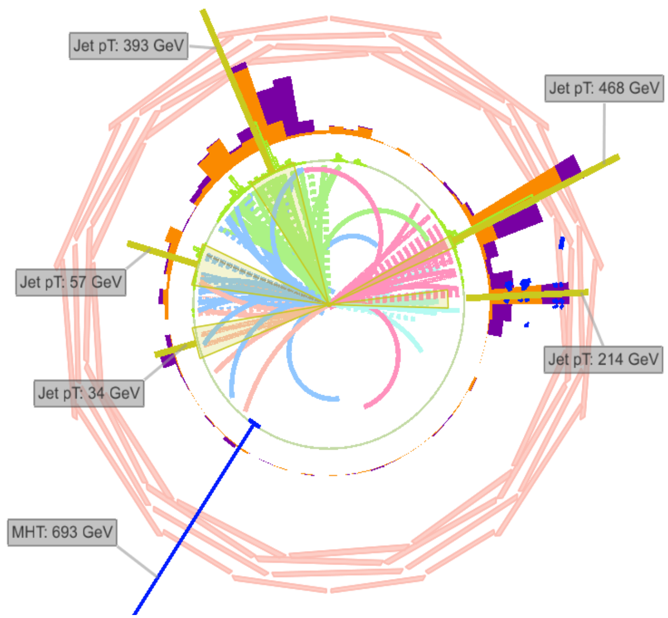


Setting the scene

Collider experiments as DM hunters

- experimental signature is transverse momentum imbalance
  - many tens of publications using MET as key observable

MET + X



CMS-PAS-SUS-10-005

Setting the scene

Collider experiments as DM hunters

- once we find a deviation, interpretation will be challenging!
  - colliders cannot prove stability beyond the apparatus
  - colliders may not distinguish single from multiple new invisible particles
  - colliders provide poor mass resolution on the invisible (if any)
  - colliders may have no handle on nature of interaction, particle type, quantum numbers,...
- the discovery paper may not mention “Dark Matter” at all

- it's a vast field at LHC
  - but it's only contributing in certain regions of phase space → complementarity!
  - there's a world beyond the WIMP

- I can only touch upon some key messages...

DM production in the lab

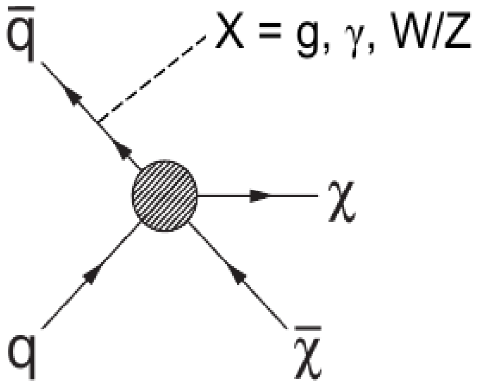
LHC search categorisation

DM from cascade decays

- example: SUSY
  - with R parity always 2 LSP's yielding observable momentum imbalance (MET)

DM produced directly

- pair production
  - but back-to-back DM particles are invisible
- ISR diagrams provide probe recoiling against DM pair



DM production in the lab

LHC search categorisation

DM from cascade decays

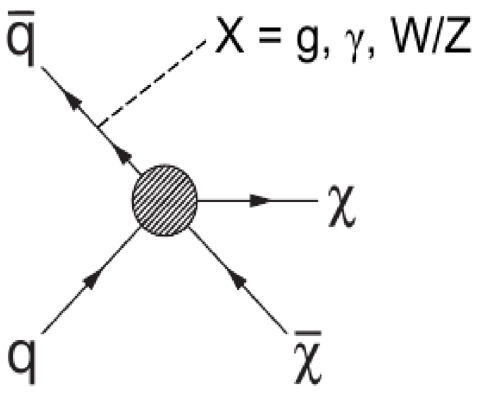
- example: SUSY
  - with R parity always 2 LSP's yielding observable momentum imbalance (MET)

artificial distinction?

- example: Higgs portal
  - still large invisible H decay width allowed

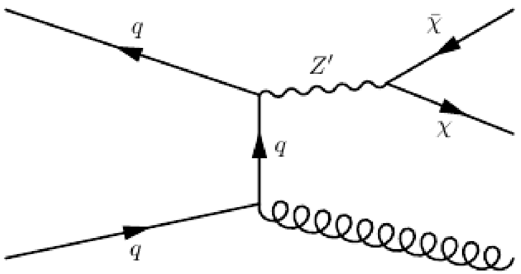
DM produced directly

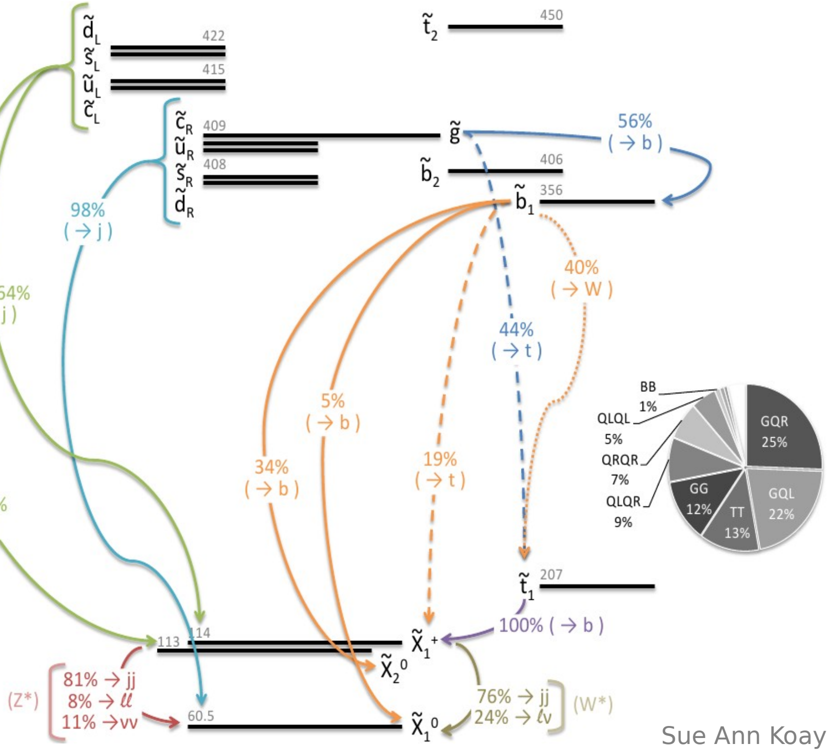
- pair production
  - but back-to-back DM particles are invisible
- ISR diagrams provide probe recoiling against DM pair



Modelling DM production

- simplified models: SM + only few particles
  - new physics restricted to what is relevant for a certain topology
  - aim for maximal experimental coverage of that topology
  - mediator and interactions specified explicitly
  - building blocks for recasting results in full models
  - parameter scans manageable



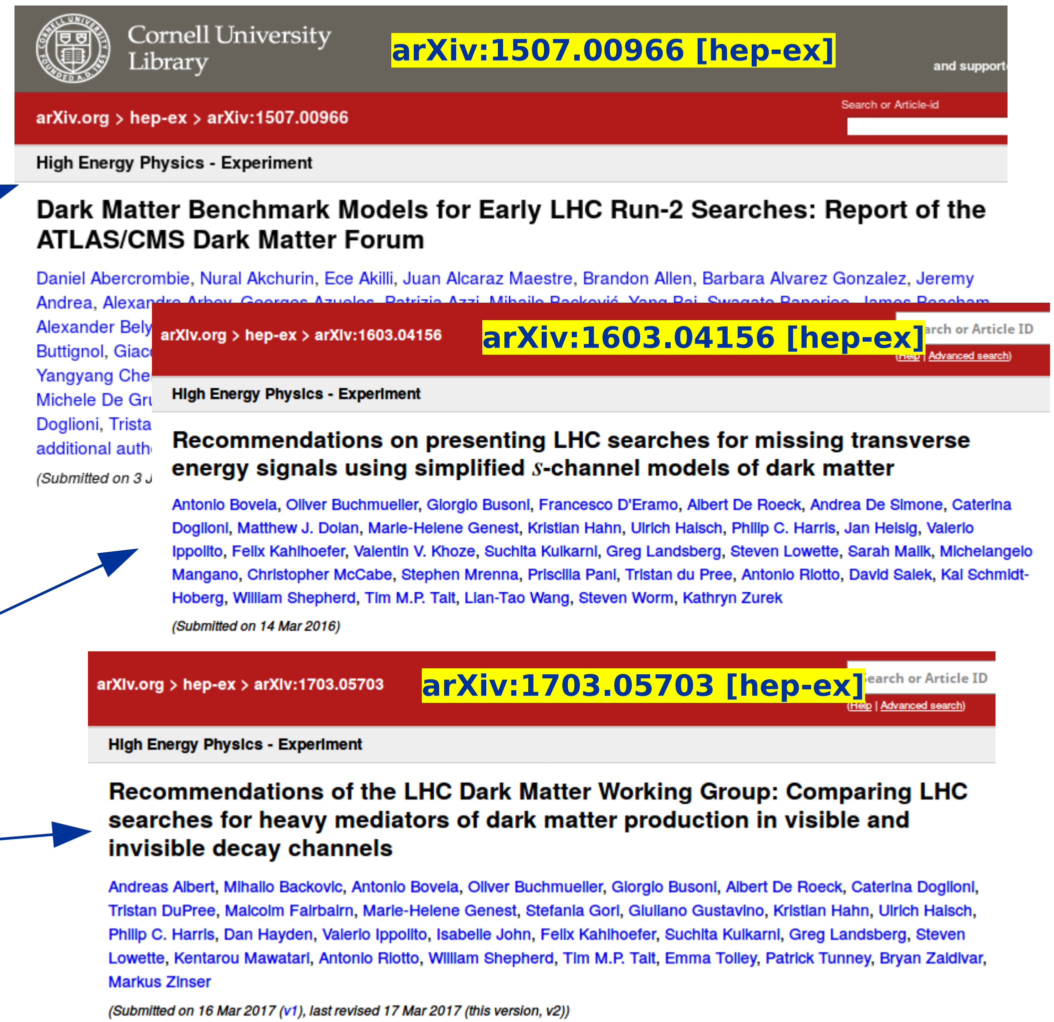


Breakdown of an example SUSY benchmark point

Sue Ann Koay

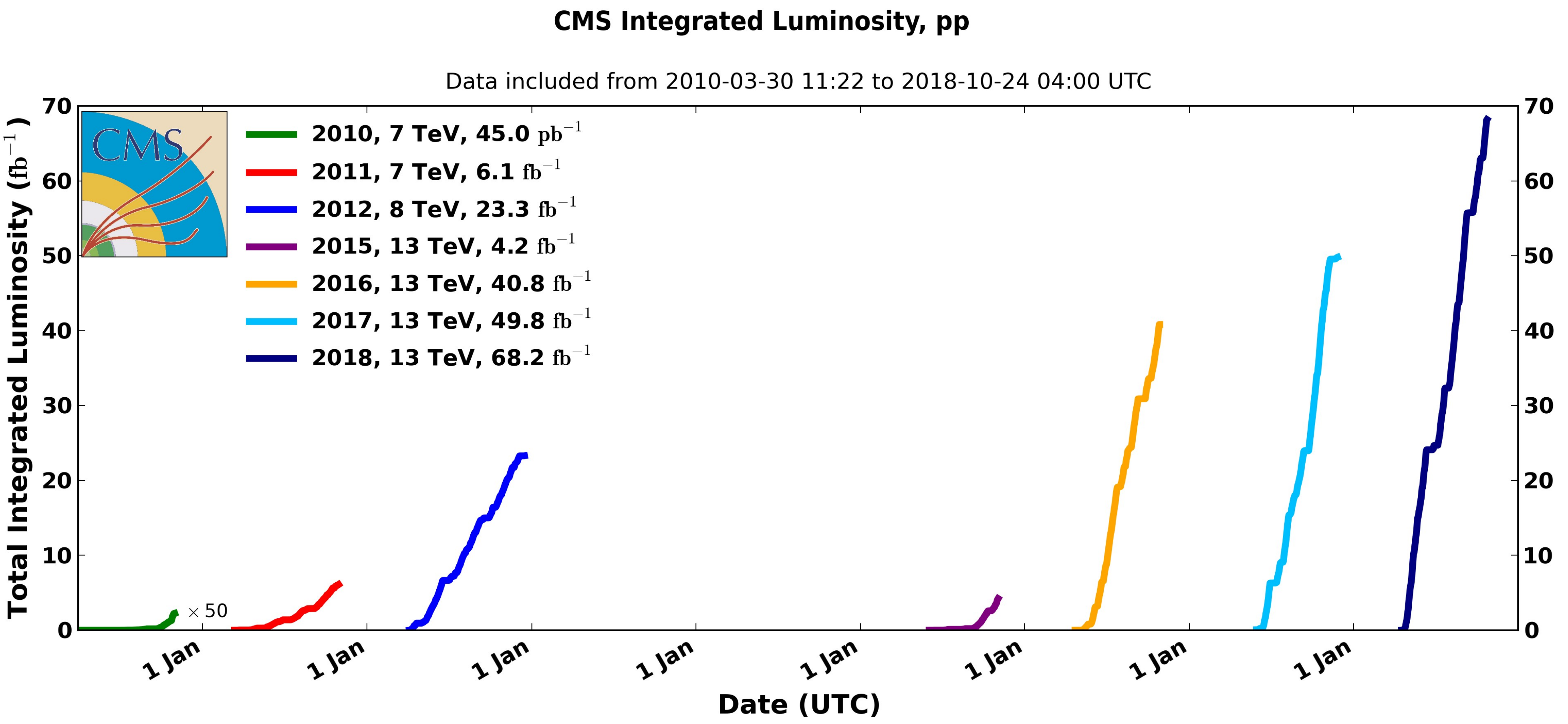
Modelling DM production

- 13TeV direct DM production searches now standardized on simplified models
- 2015: LHC DM Forum
  - bottom-up guidelines for LHC dark-matter searches at the start of LHC Run-2
  - wide consensus in community summarized in extensive report
- continues in LPCC Dark Matter Working Group
  - https://lpcc.web.cern.ch/lpcc/index.php?page=dm_wg
  - common basis to present LHC results wrt other LHC and non-LHC experiments
  - common basis for comparison of LHC DM searches to visible mediator searches (in dijet and dilepton channels)



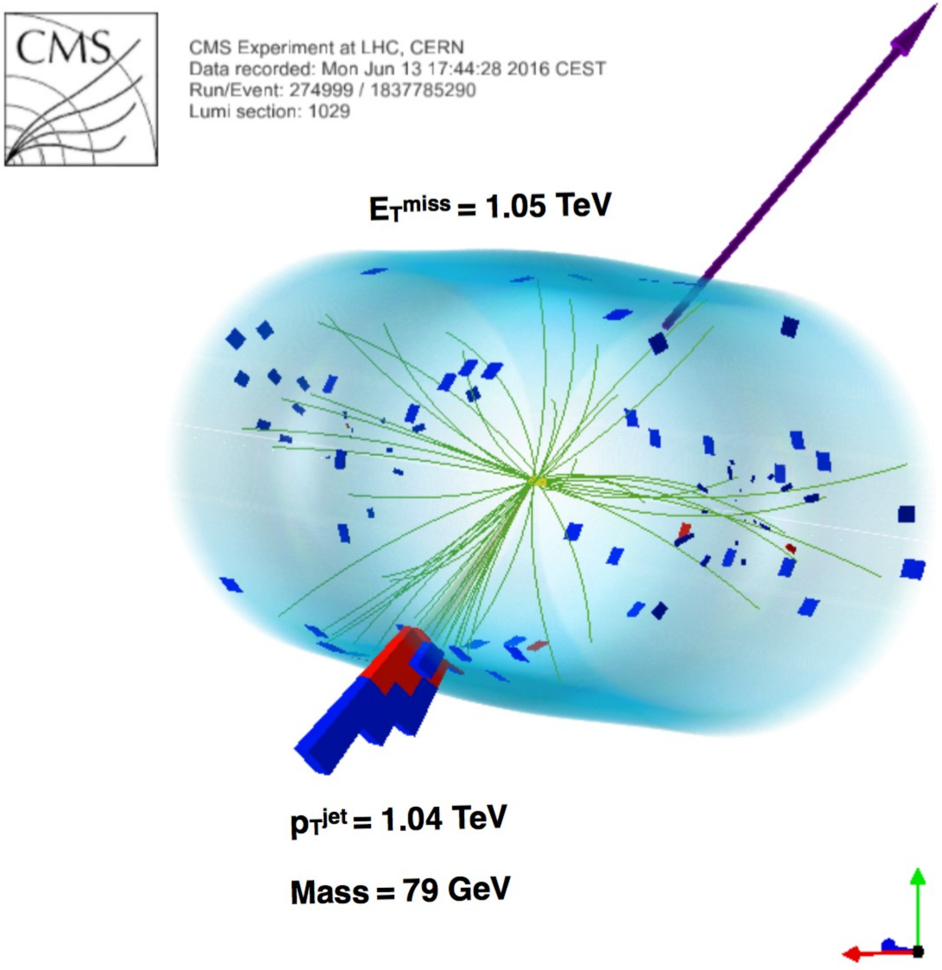
Experimental status

#MoarData

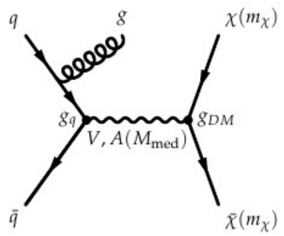


Experimental status

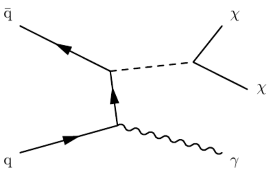
Spectacular spectacular!



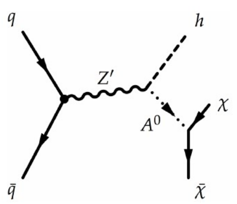
Direct DM searches



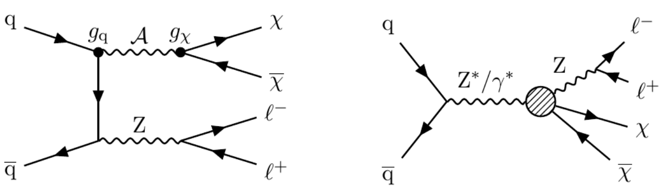
MonoJet



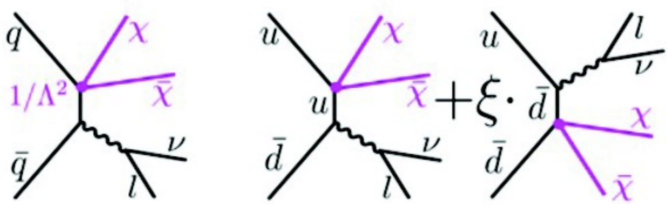
MonoPhoton



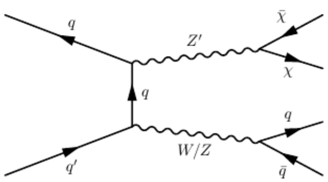
MonoHiggs



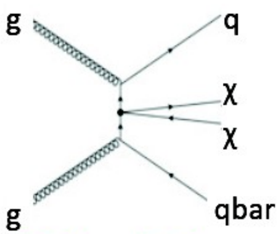
MonoZ (leptonic)



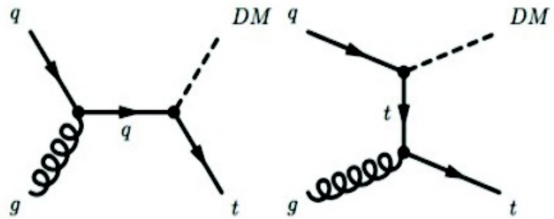
MonoW (monoLepton)



MonoW/Z (Hadronic)



BBbar /TTbar

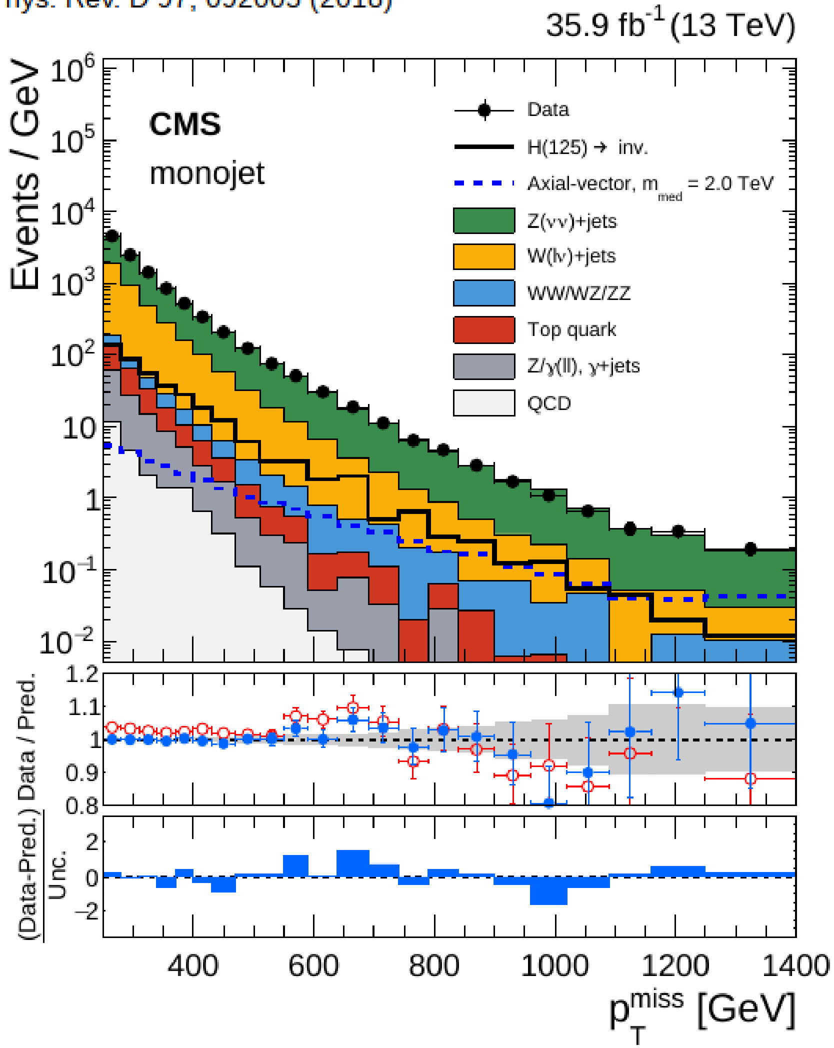


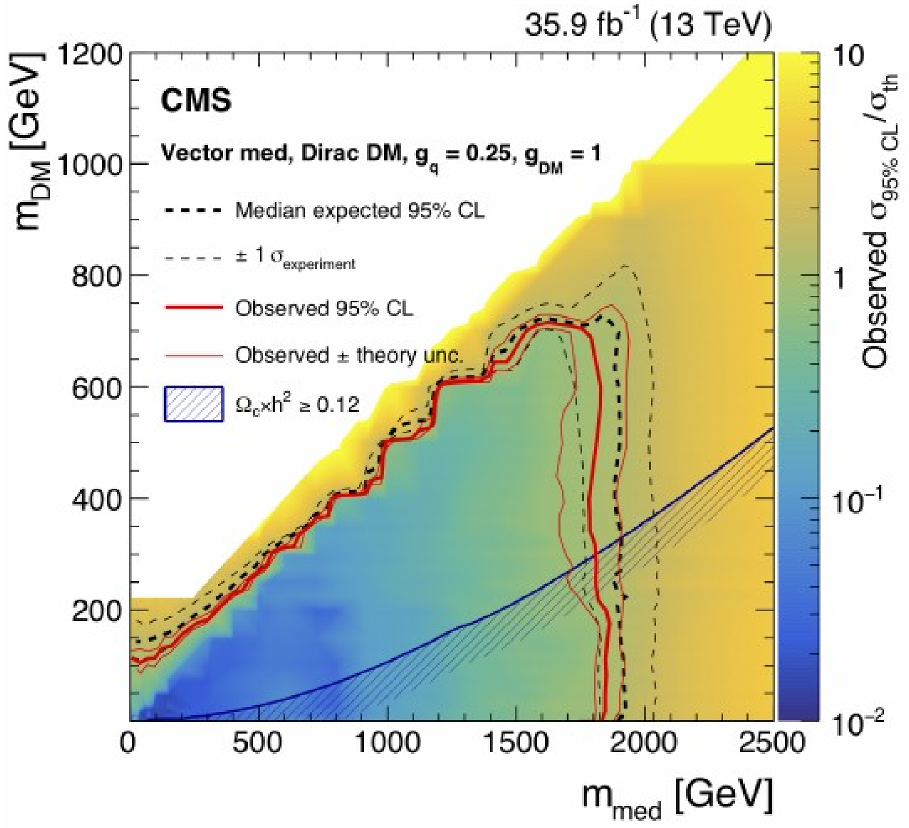
MonoTop

Direct DM searches

Monojet search as poster child example

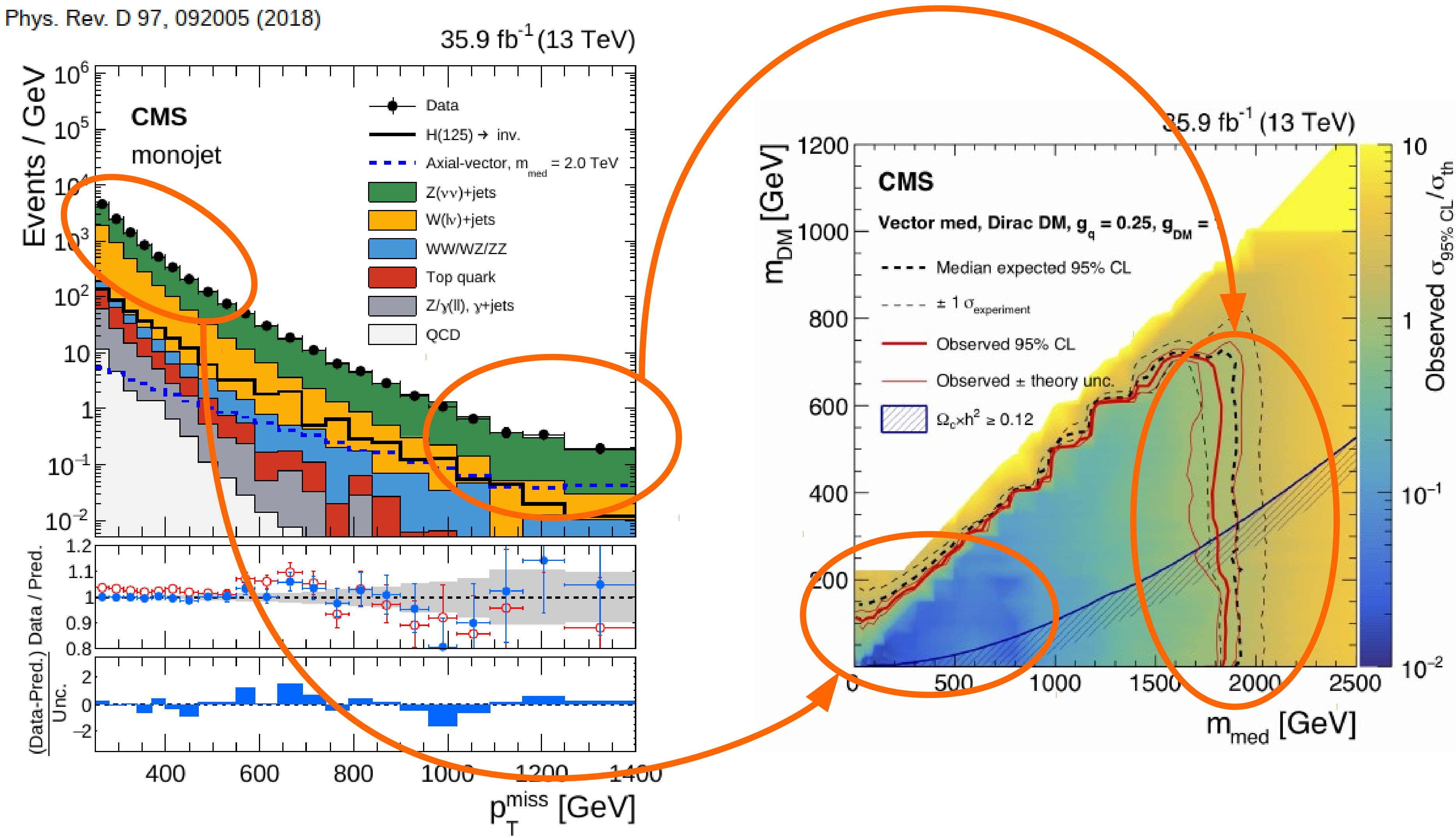
Phys. Rev. D 97, 092005 (2018)





Direct DM searches

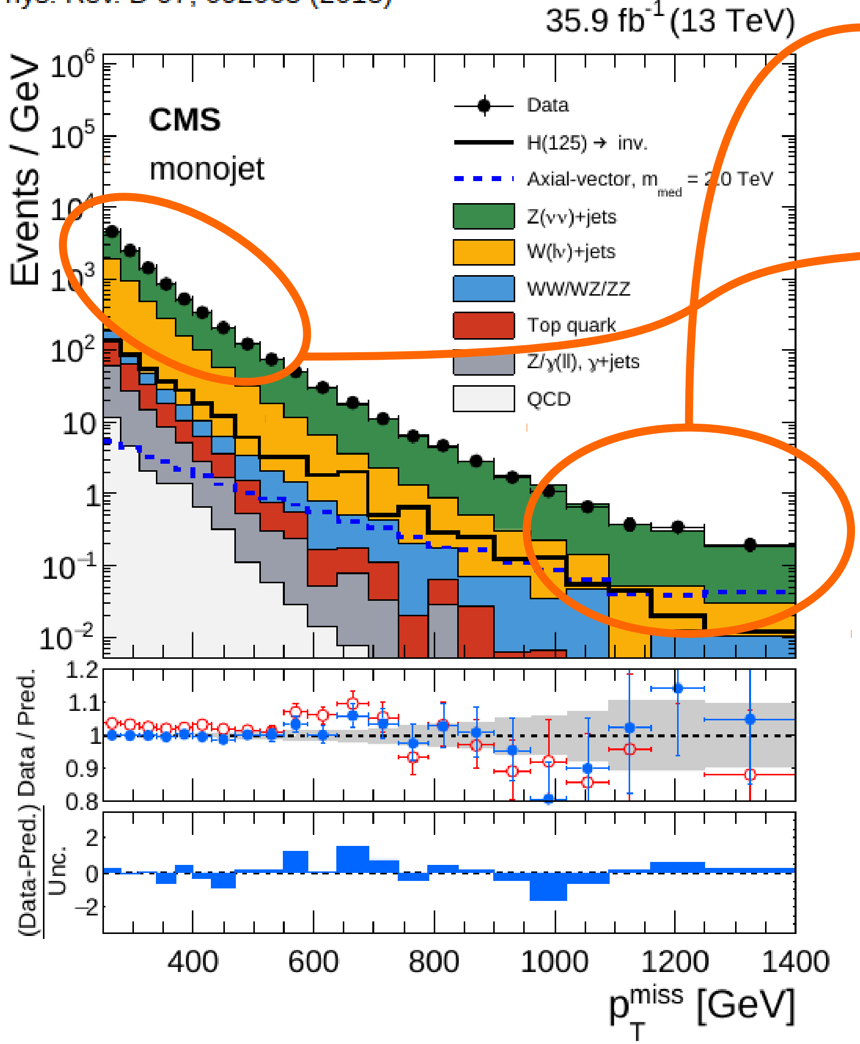
Monojet search as poster child example



Direct DM searches

Monojet search as poster child example

Phys. Rev. D 97, 092005 (2018)

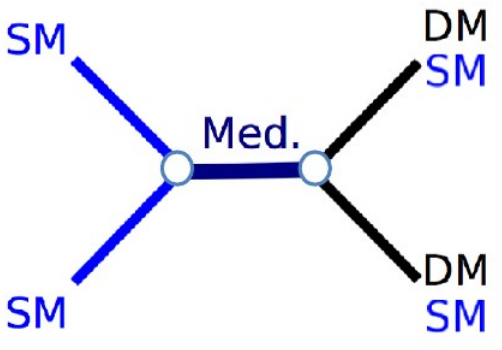


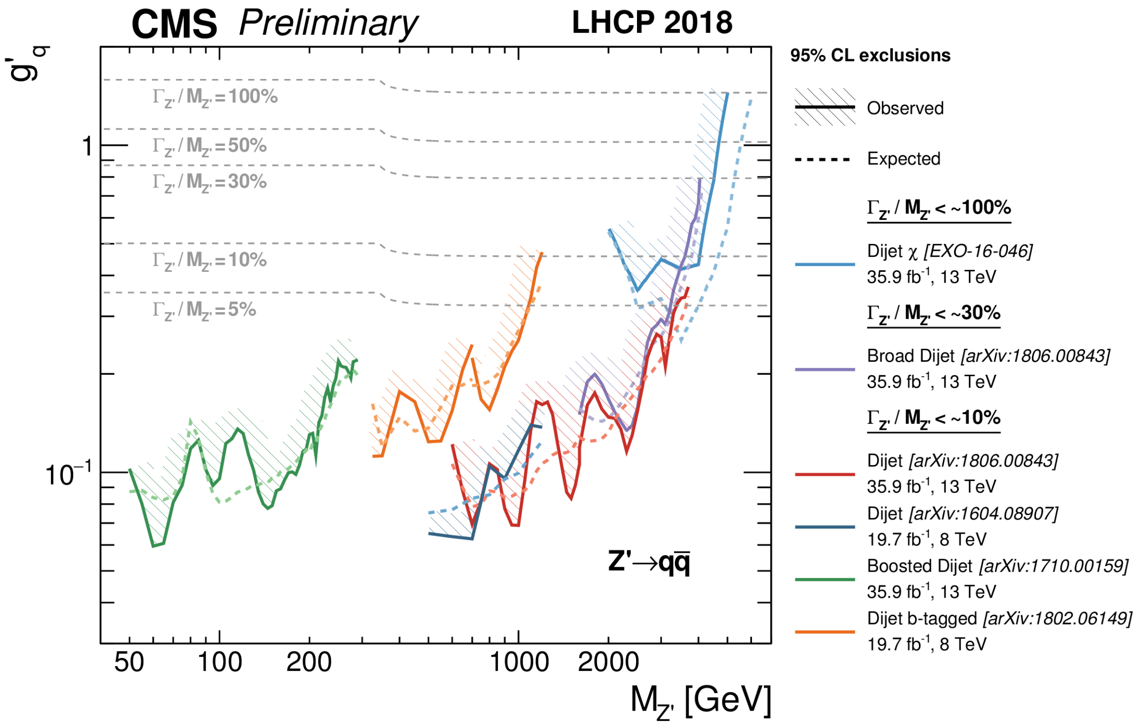
- statistically limited
  - needs much bigger datasets
- systematically limited
  - no low-hanging fruits left
  - can only improve with very hard work
  - more difficult at higher lumi
- theoretical uncertainties already incredibly well controlled
  - NLO QCD+EWK
  - https://arxiv.org/abs/1705.04664

Indirect constraints on DM

Next avenue: link to visible

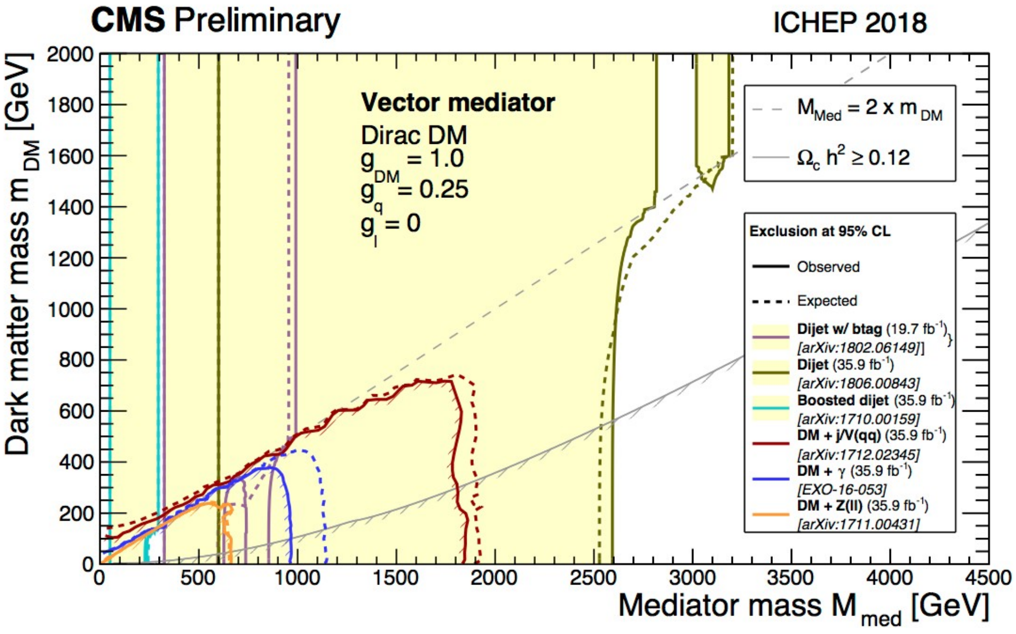
- interaction may still be probed
  if dark matter inaccessible
  - quark (jet) final states guaranteed
  - muon and electron pairs possibly too
- thus we can indirectly constrain
  dark matter models
  - constraints on couplings
  - from searches in dijet
    and dilepton final states
  - model dependency!

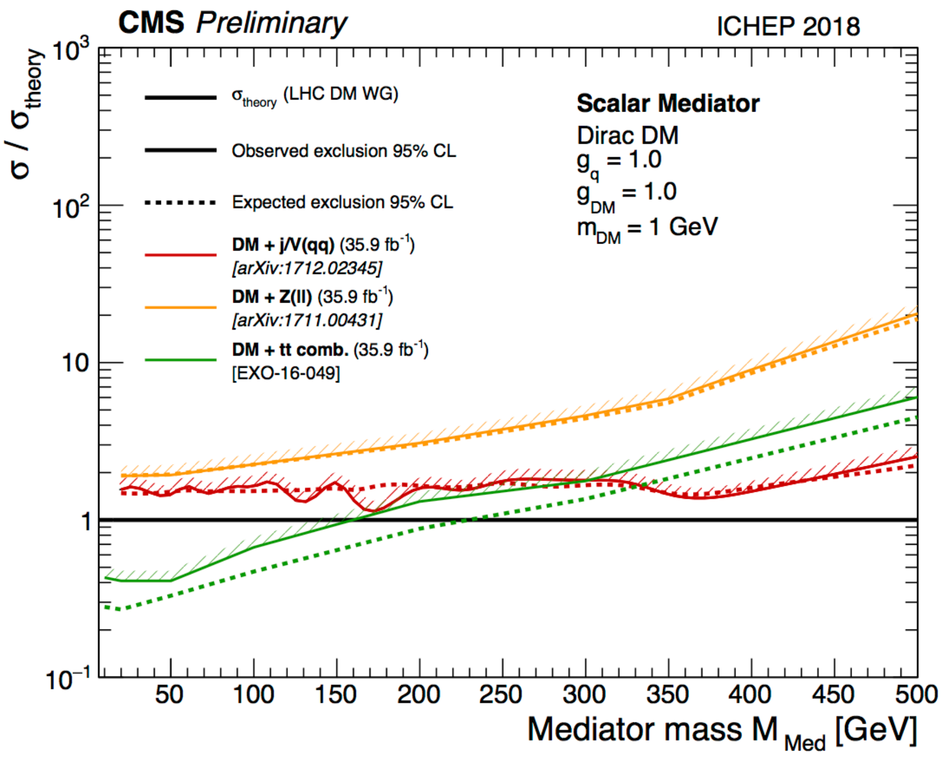




Interpretation results

Many models, many parameters

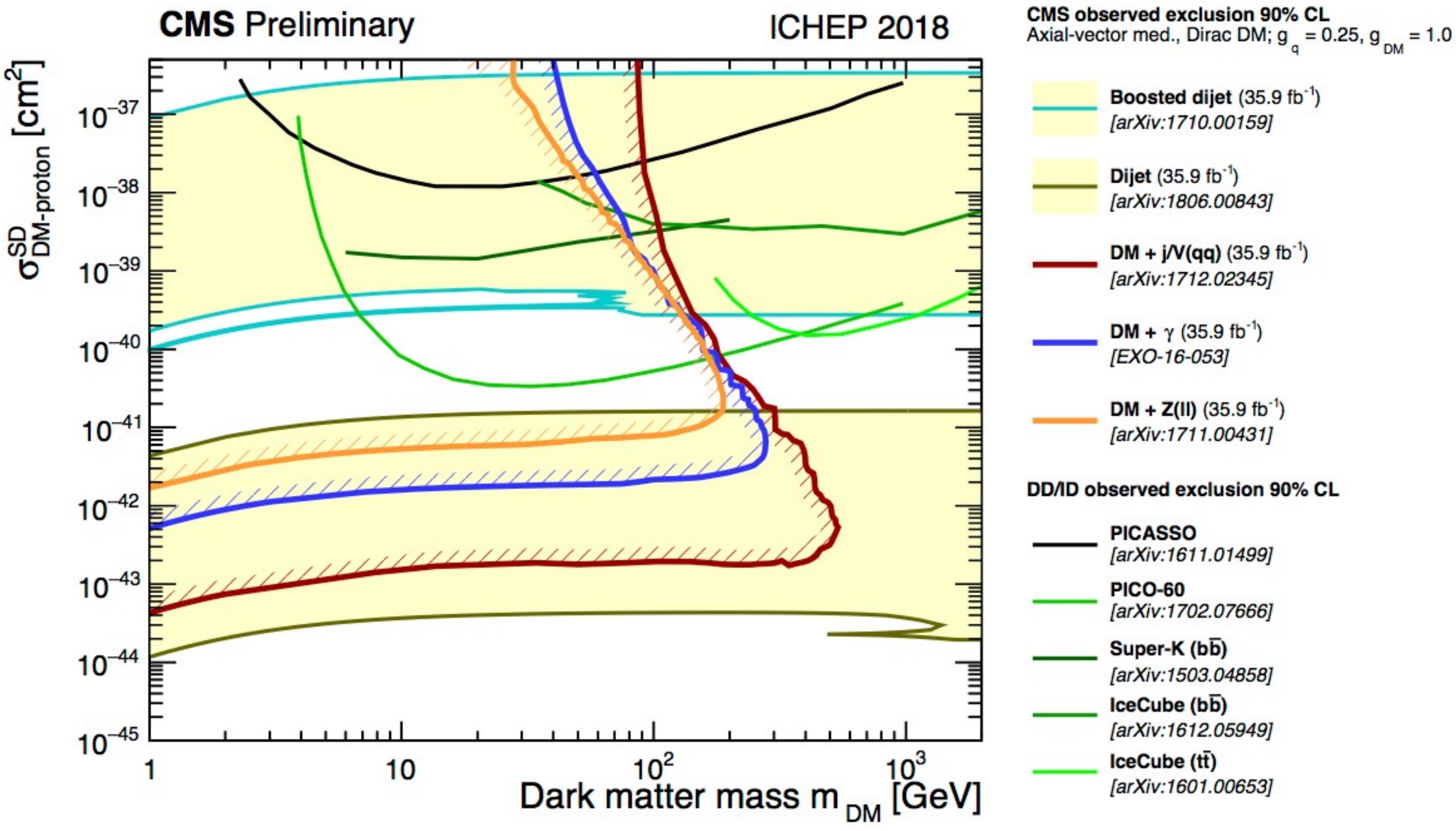




Interpretation results

Interpretations beyond LHC

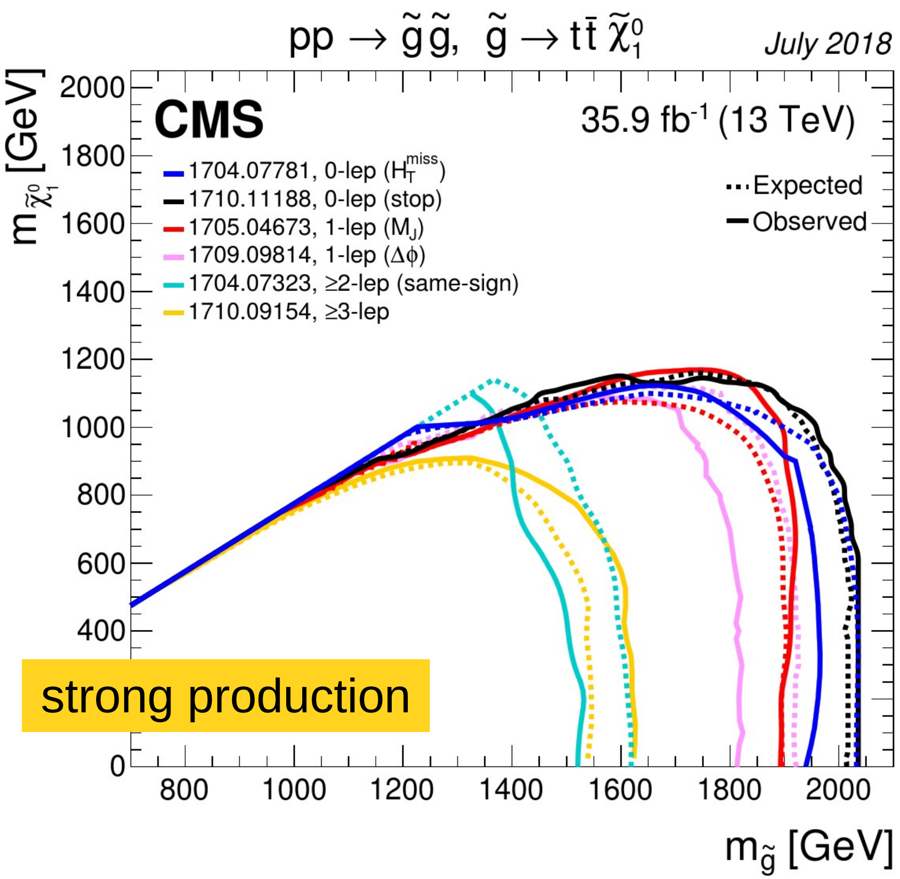
- demonstrates complementarity
- beware: strong model dependency!

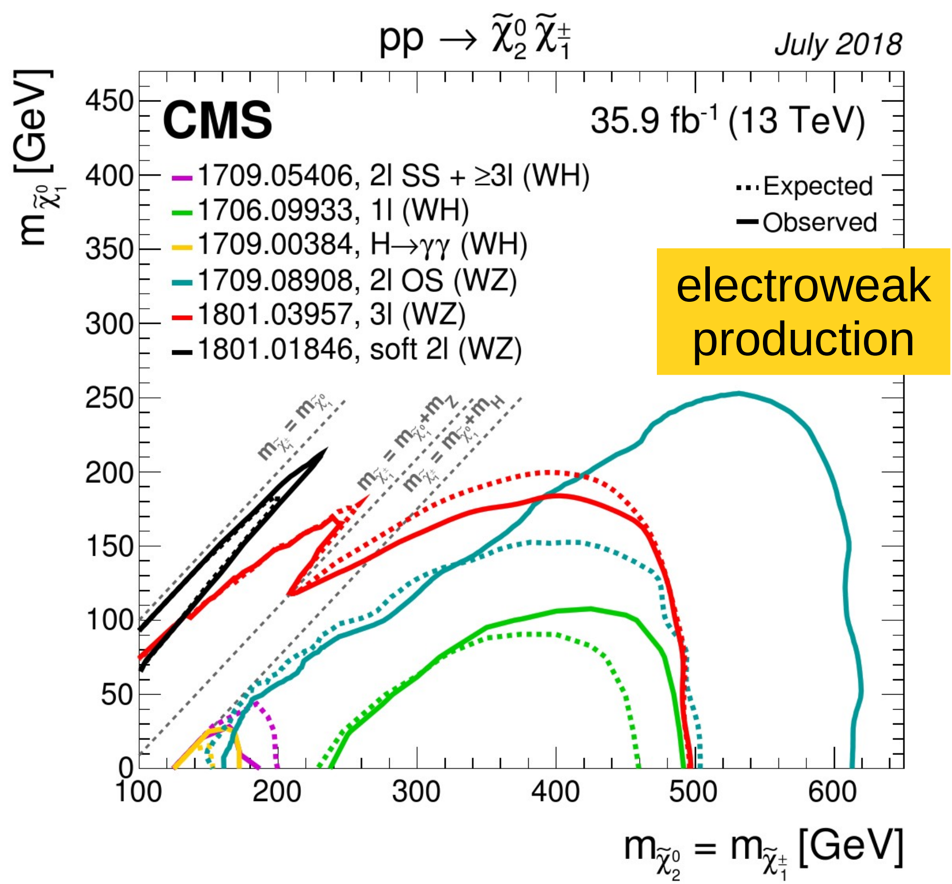


SUSY and DM

What about WIMPs from cascades?

- multitude of searches using SUSY simplified models
- same overall picture on statistics versus systematics

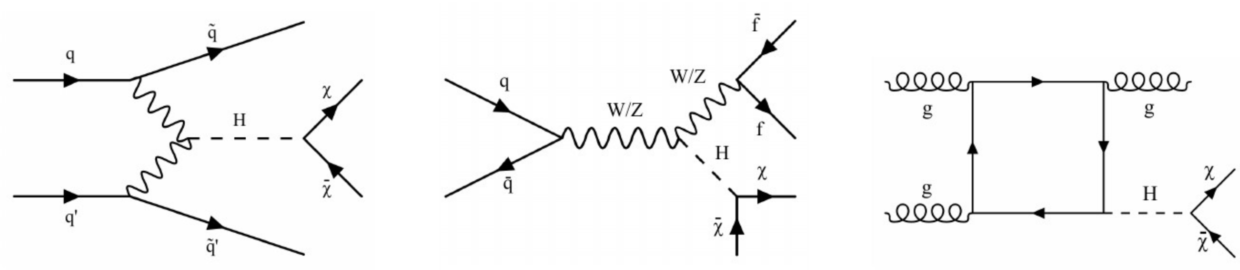




Higgs and DM

Higgs as a portal to DM

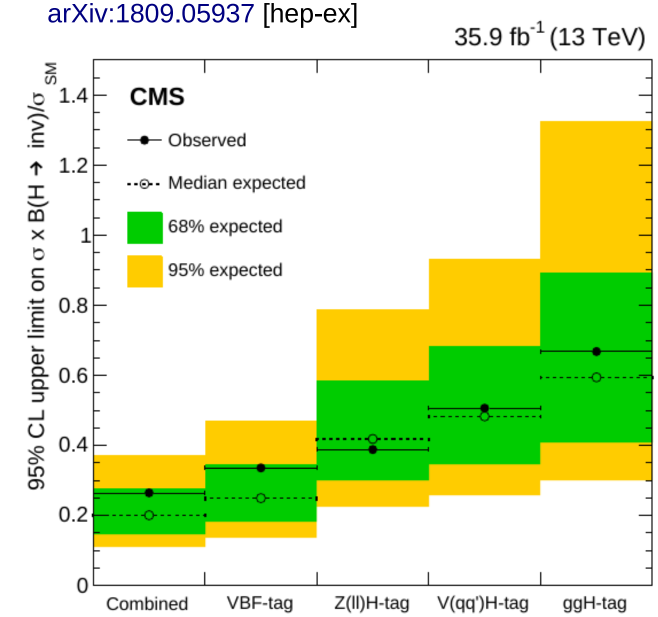
- analyses targeted on specific production modes
  - also ttH, H→DM interpretations possible

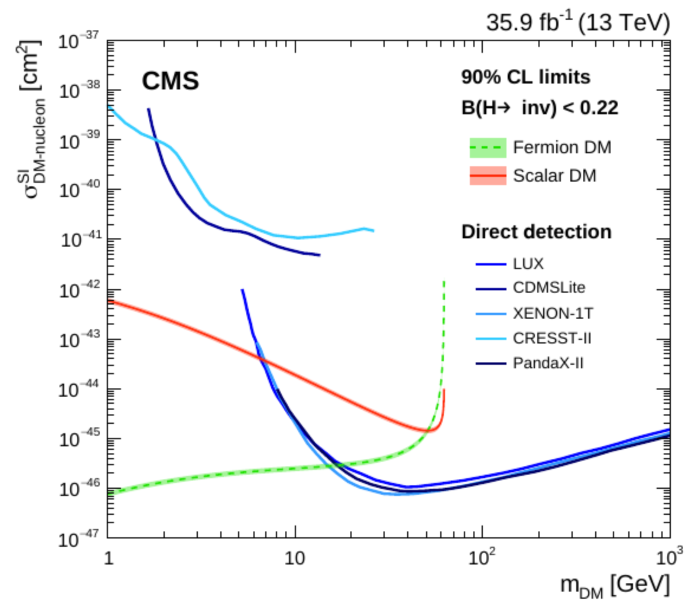


- good progress recently, still room for more
  - but no miracles either

- BR(H→inv) < 26% @95%CL
- limited to $m_{DM} < m_H / 2$

arXiv:1809.05937 [hep-ex]





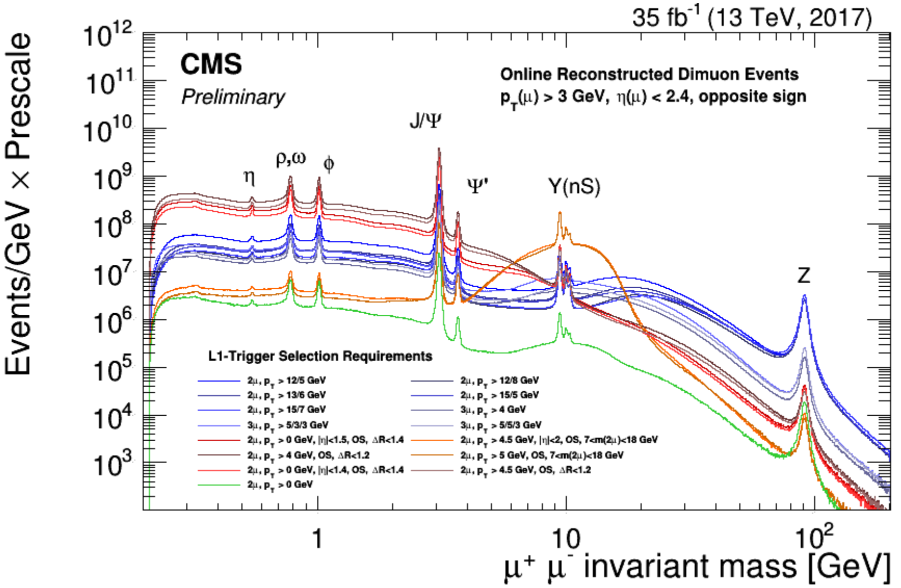
Next frontiers

Venture beyond WIMPs

- WIMPs from long-lived decays
- heavy neutral leptons
- axion-like particles
- dark sectors portals (hidden valleys, dark photons,...)
- SIMPs
- ...

Experimental frontiers

- low mass resonances
- long-lived particles
- soft signatures
- ...



- vibrant field: a lot of work on triggers, reconstruction, backgrounds, simulation,...
  - also LHCb and Heavy-Ion community active!

Next frontiers

New exotic signatures!

- only a selection

arXiv.org > hep-ph > arXiv:1612.00850

High Energy Physics - Phenomenology

Triggering Soft Bombs at the LHC

Simon Knapen, Simone Pagan Griso, Michele Papucci, Dean J. Robinson

arXiv.org > hep-ph > arXiv:1502.05409

High Energy Physics - Phenomenology

Emerging Jets

Pedro Schwaller, Daniel Stolarski, Andreas Weiler

arXiv.org > hep-ph > arXiv:1503.00009

High Energy Physics - Phenomenology

Semi-visible Jets: Dark Matter Undercover at the LHC

Timothy Cohen, Mariangela Lisanti, Hou Keong Lou

arXiv.org > hep-ph > arXiv:1706.07407

High Energy Physics - Phenomenology

Novel signatures for long-lived particles at the LHC

Shankha Banerjee, Geneviève Bélanger, Biplob Bhattacherjee, Fawzi Boudjema, Rohini M. Godbole, Swagata Mukherjee

arXiv.org > hep-ph > arXiv:1708.08951

High Energy Physics - Phenomenology

Stable Sexaquark

Glennys R. Farrar

arXiv.org > hep-ph > arXiv:1810.09400

High Energy Physics - Phenomenology

A Heavy Metal Path to New Physics

Marco Drewes, Andrea Giammanco, Jan Hajer, Michele Lucente, Olivier Mattelaer

arXiv.org > hep-ph > arXiv:1503.05505

High Energy Physics - Phenomenology

Simplified SIMPs and the LHC

Nadir Daci, Isabelle De Bruyn, Steven Lowette, Michel H.G. Tytgat, Bryan Zaldivar

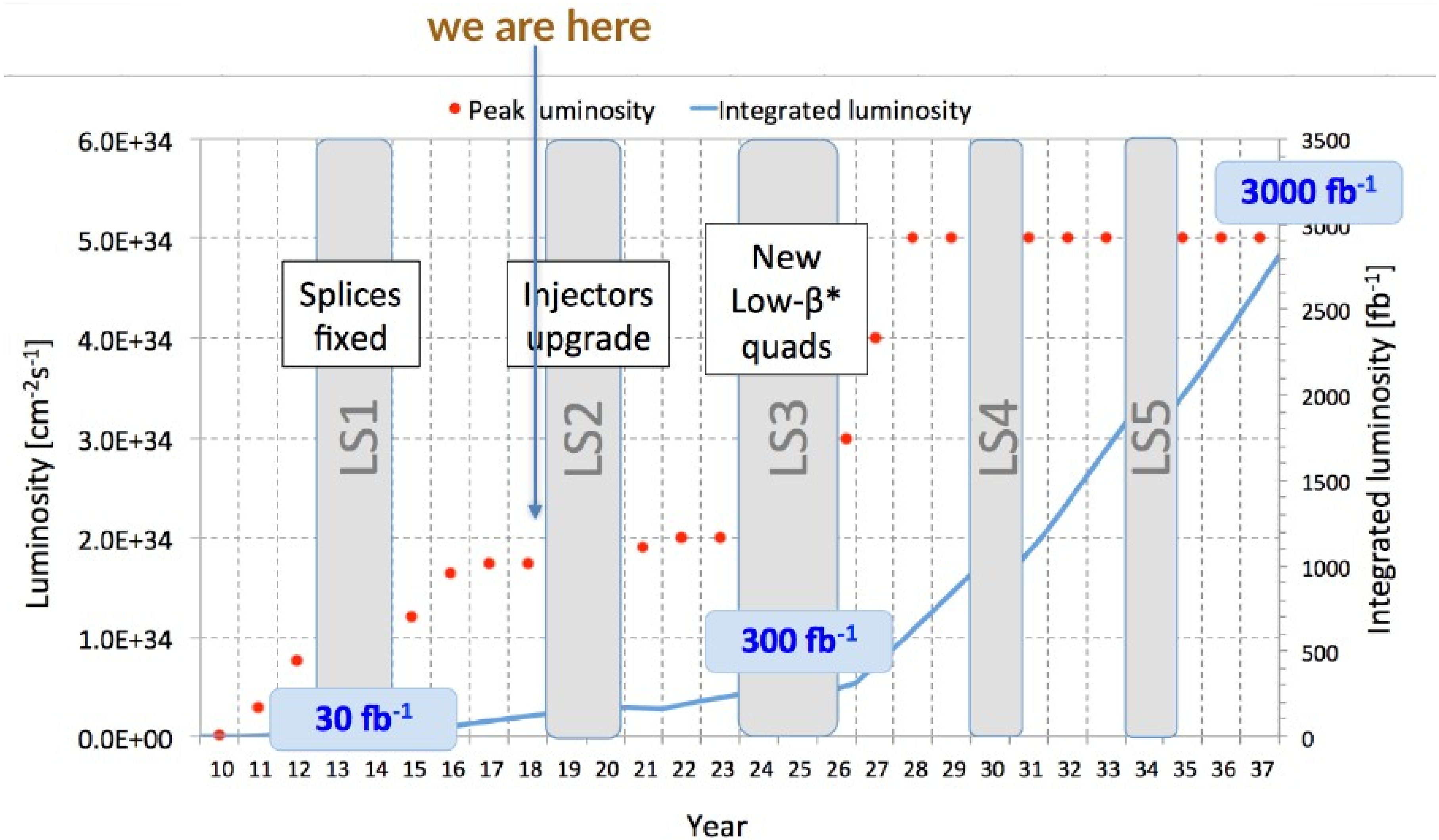
Conclusions

Dark Matter is a hot topic at the LHC

- bread-and-butter signatures intensely searched for
  - LHC is very competitive if mediator can be produced on-shell and/or DM is light
- connection to search for new mediator in visible decay channels
  - dijets, dileptons,...
- branching out to new frontiers
  - beyond the WIMP, beyond experimental comfort zones

- only ~50/fb analysed so far at 13TeV, much more to come

Outlook



we are here
Peak luminosity
Integrated luminosity
6.0E+34
5.0E+34
4.0E+34
3.0E+34
2.0E+34
1.0E+34
0.0E+00
Luminosity [cm^{-2}s^{-1}]
Splices fixed
Injectors upgrade
New Low-β* quads
LS1
LS2
LS3
LS4
LS5
30 fb^{-1}
300 fb^{-1}
3000 fb^{-1}
3500
3000
2500
2000
1500
1000
500
0
Integrated luminosity [fb^{-1}]
10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
Year

Outlook

4 years to 100 years of dark matter!

FIRST ATTEMPT AT A THEORY OF THE ARRANGEMENT AND MOTION OF THE SIDEREAL SYSTEM[1]

By J. C. KAPTEYN[2]

ABSTRACT

First attempt at a general theory of the distribution of masses, forces, and velocities in the stellar system.—(1) *Distribution of stars.* Observations are fairly well represented, at least up to galactic lat. 70°, if we *assume that the equidensity surfaces are similar ellipsoids of revolution,* with axial ratio 5.1, and this enables us to compute quite readily (2) *the gravitational acceleration at various points due to such a system,* by summing up the effects of each of ten ellipsoidal shells, in terms of the acceleration due to the average star at a distance of a parsec. The *total number of stars* is taken as 47.4×10^9. (3) *Random and rotational velocities.* The nature of the equidensity surfaces is such that the stellar system cannot be in a steady state unless there is a general rotational motion around the galactic polar axis, in addition to a random motion analogous to the thermal agitation of a gas. In the neighborhood of the axis, however, there is no rotation, and the behavior is assumed to be like that of a gas at uniform temperature, but with a gravitational acceleration ($G\eta$) decreasing with the distance ρ. Therefore the density Δ is assumed to obey the barometric law: $G\eta=-\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$; and taking the mean random velocity $\bar{u}$ as 10.3 km/sec., the author finds that (4) *the mean mass of the stars* decreases from 2.2 (sun=1) for shell II to 1.4 for shell X (the outer shell), the average being close to 1.6, which is the value independently found for the average mass of both components of visual binaries. In the galactic plane the resultant acceleration—gravitational minus centrifugal—is again put equal to $-\bar{u}^2(\delta\Delta/\delta\rho)/\Delta$, $\bar{u}$ is taken to be constant and the average mass is assumed to decrease from shell to shell as in the direction of the pole. The angular velocities then come out such as to make the linear rotational velocities about constant and equal to 19.5 km/sec. beyond the third shell. If now we suppose that part of the stars are rotating one way and part the other, the relative velocity being 39 km/sec., we have a quantitative explanation of the phenomenon of star-streaming, where the relative velocity is also in the plane of the Milky Way and about 40 km/sec. It is incidentally suggested that when the theory is perfected it may be possible to determine *the amount of dark matter* from its gravitational effect. (5) The *chief defects of the theory* are: That the equidensity surfaces assumed do not agree with the actual surfaces, which tend to become spherical for the shorter distances; that the *position of the center of the system* is not the sun, as assumed, but is probably located at a point some 650 parsecs away in the direction galactic long. 77°, lat. −3°; that the average mass of the stars was assumed to be the same in all shells in deriving the formula for the variation of $G\eta$ with ρ on the basis of which the variation of average mass from shell to shell and the constancy of the rotational velocity were derived—hence either the assumption or the conclusions are wrong; and that no distinction has been made between stars of different types.

Astrophysical Journal 55 (1922) 302