Dark Matter and Searches at the LHC

Albert De Roeck

CERN, Geneva, Switzerland

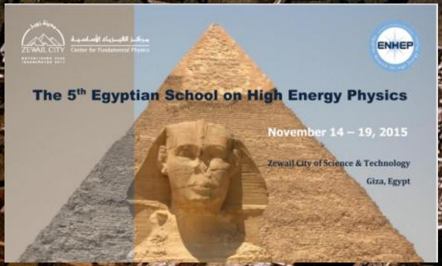
Antwerp University Belgium

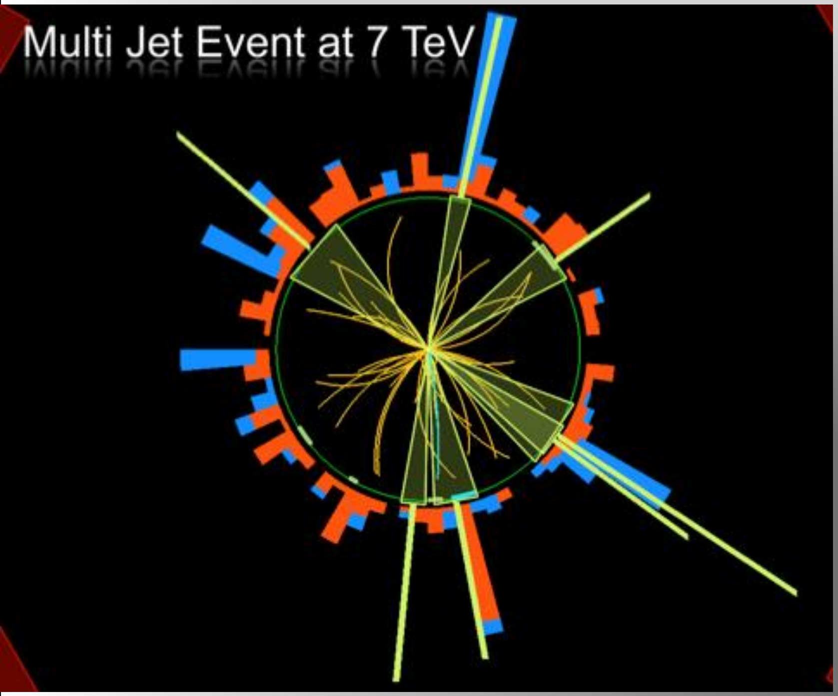
UC-Davis California USA

IPPP, Durham UK

NTU, Singapore

November 14-19   Cairo, Egypt





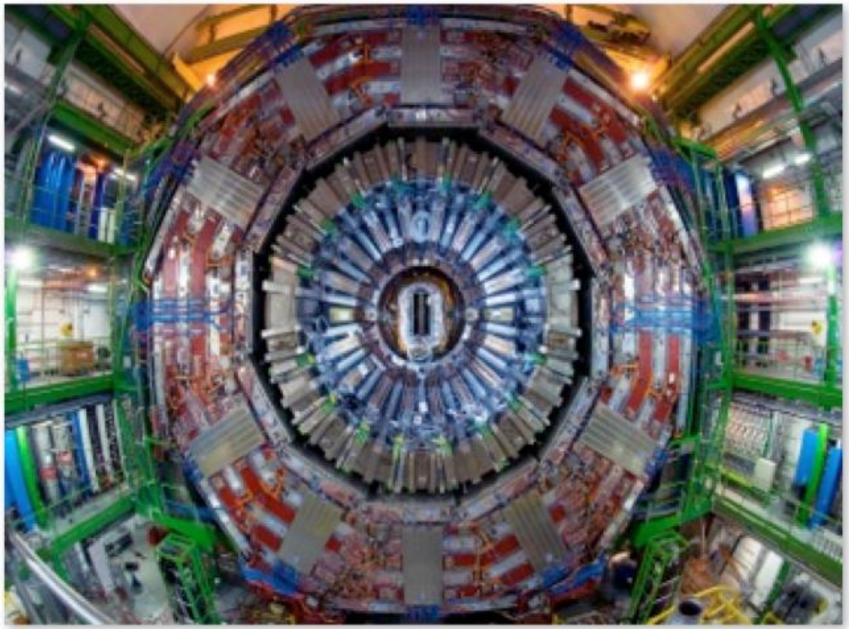
Outline

- Introduction: dark matter and the WIMP miracle
- The Higgs and dark matter
- Supersymmetry searches
- Generic searches via missing E_T, so called mono-objects
  New: mono-Higgs production
- Summary

Dark Matter: Complementary Searches?

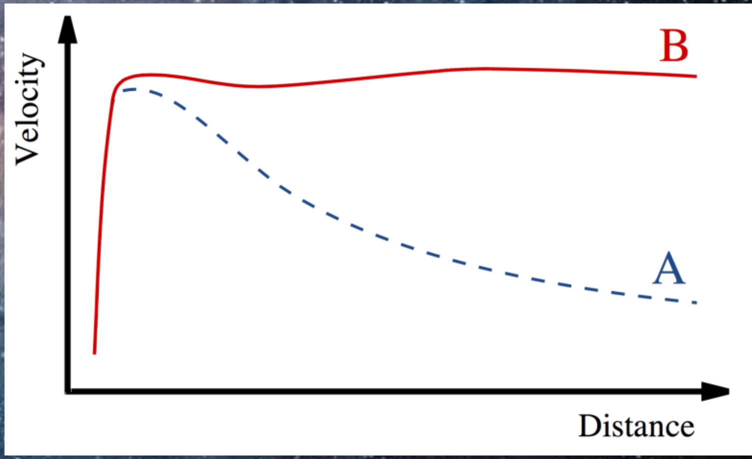
After the discovery of the Higgs particle @ the LHC:
Dark matter is the next important physics problems to tackle for the LHC

The search is complementary to other experimental techniques used.



Dark Matter: The Next Challenge

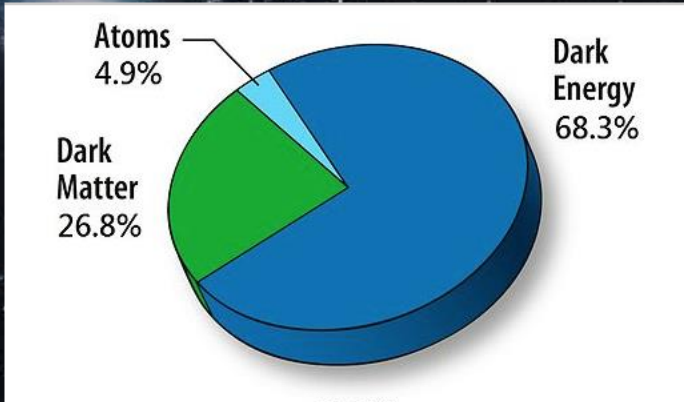
Astronomers found that most of the matter in the Universe must be invisible Dark Matter



'Supersymmetric' particles ?

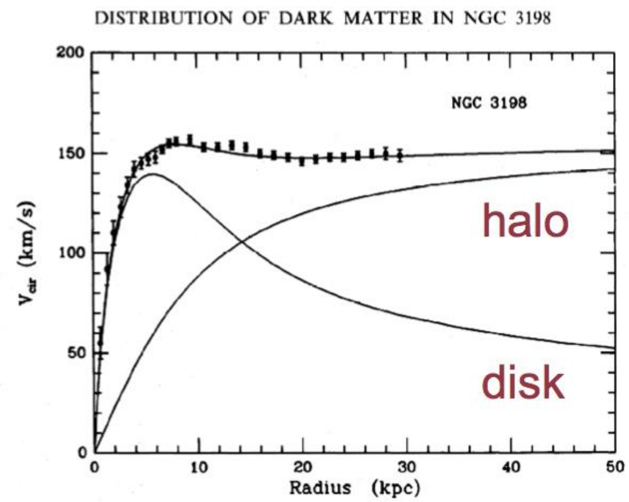
F. Zwicky 1898-1974

Vera Rubin ~ 1970

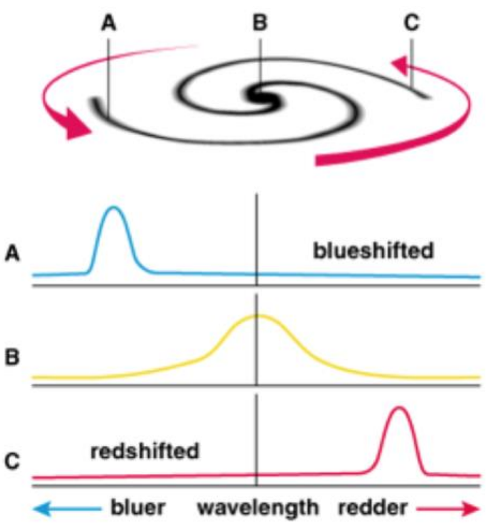


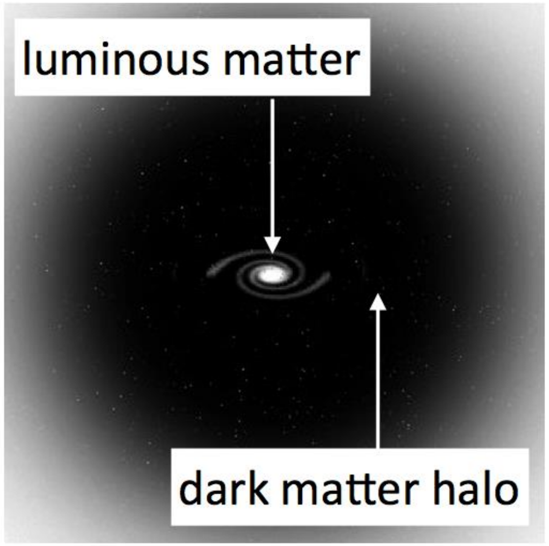
Galactic Rotation

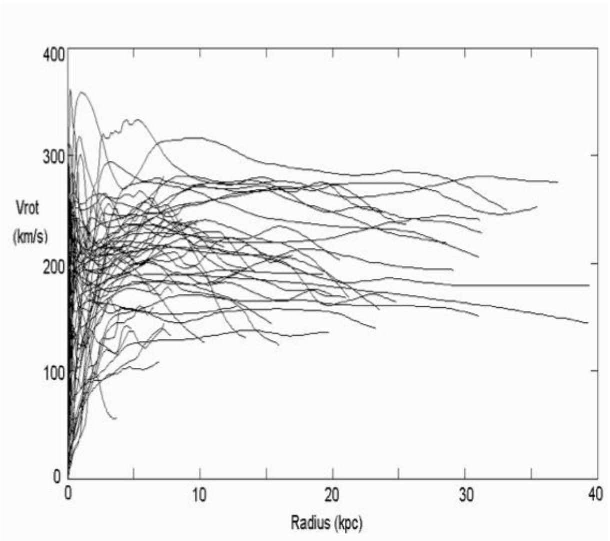
- Starting in the 1970’s, measured velocity vs. radius of edge-on spiral galaxies
- They found them to be flat, consistent with ~10x as much “dark” mass...



...and not just one galaxy

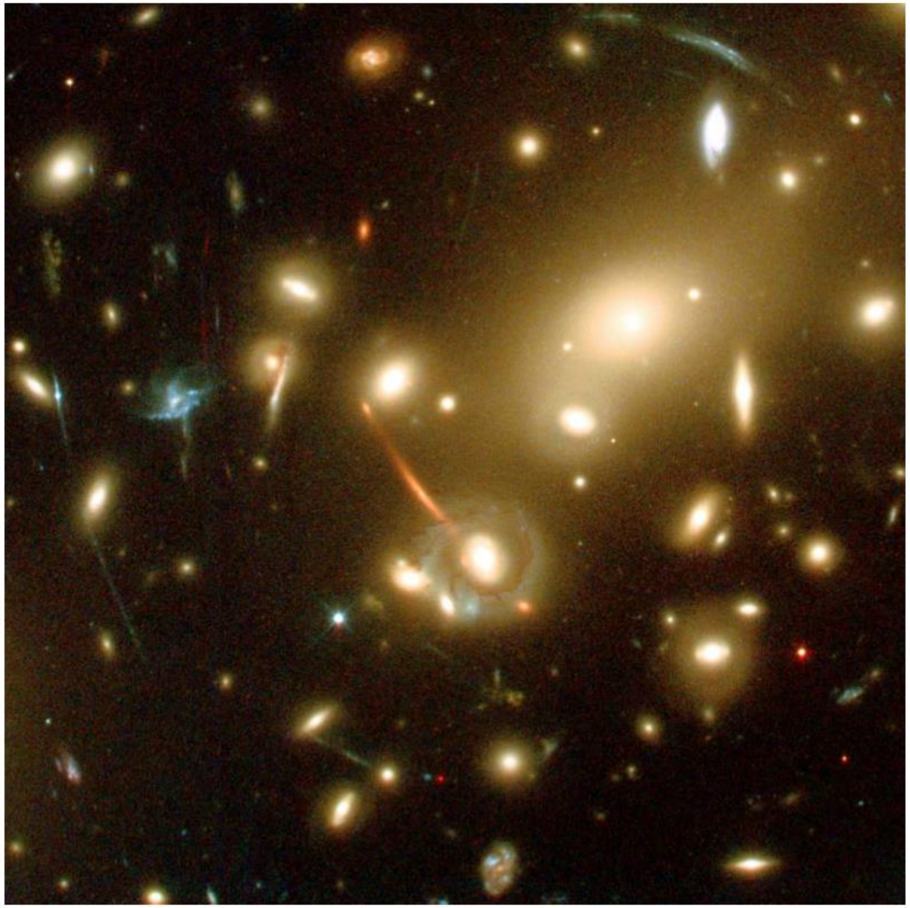




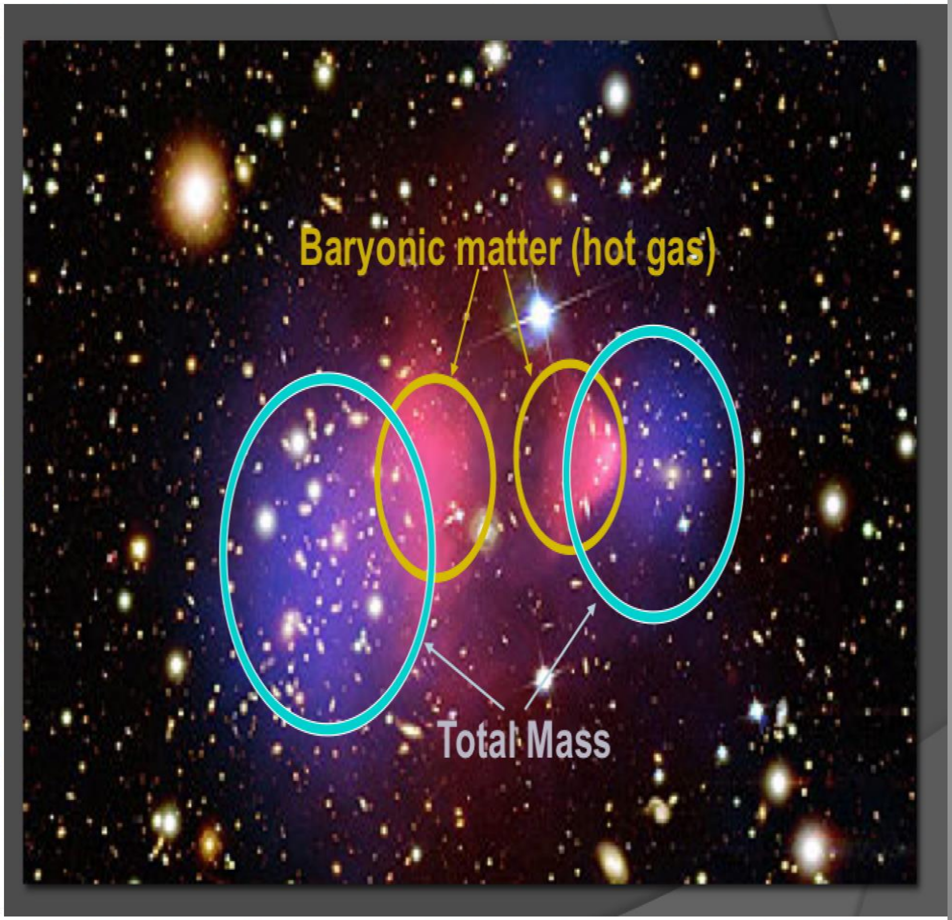


Evidence Piling-up

- Gravitational Lensing
  - much more lensing than can be explained by visible mass



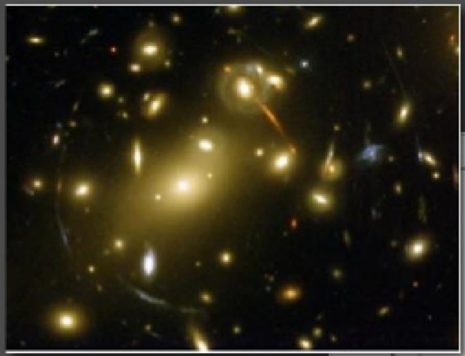
- Bullet Cluster; colliding galaxies
  - Composite x-ray, visible image, 10x DM

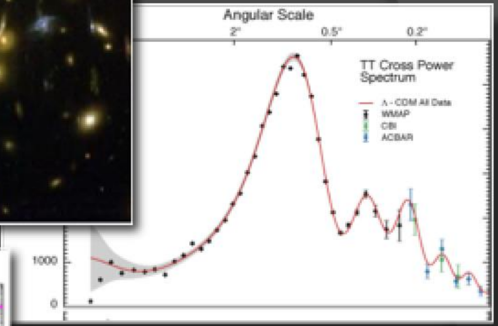


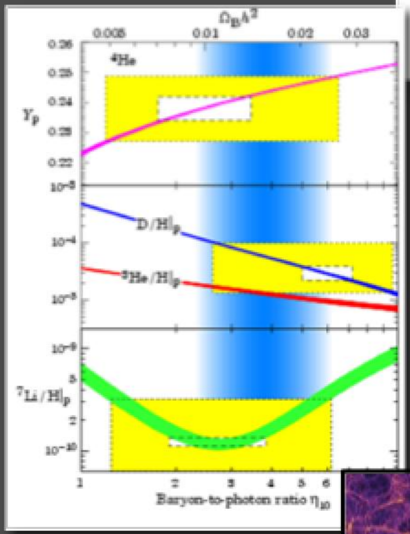
Evidence Piling-up

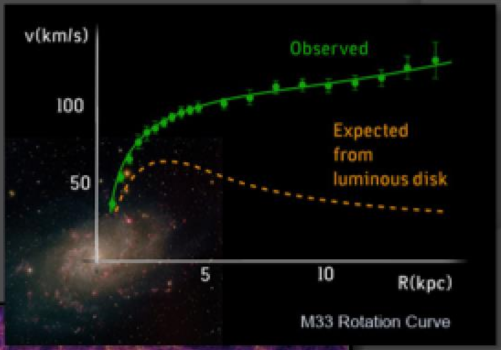
- There is a wide variety of evidence indicating that dark matter exists
- Each of these observations infer dark matter's presence uniquely through its gravitational influence
- To-date, no (non-controversial) observations have been made of dark matter's electroweak or other non-gravitational interactions

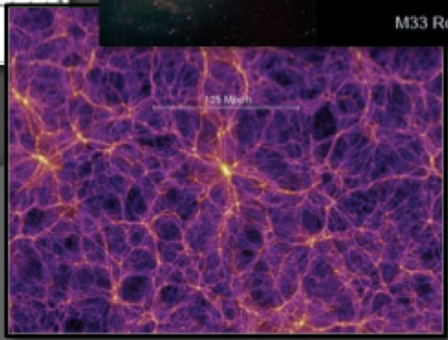
Instead of dark matter, might we not understand gravity?











Particle Dark Matter?

- We know only little about the nature of dark matter:
  - Cold (non-relativistic)
  - Stable
  - Dark and collisionless (no electric charge or QCD color)
- No particle contained in the Standard Model fulfills these criteria
- This leaves us with a vast range of possibilities from Planck/GUT scale "WIMPzillas" to ultra-light axions
- Dark matter candidates in the form of weakly interacting particles with masses in the GeV-TeV range (WIMPs) stand out for their
  - Testability
  - Theoretical motivation (solution to electroweak hierarchy problem)
  - The "WIMP Miracle"

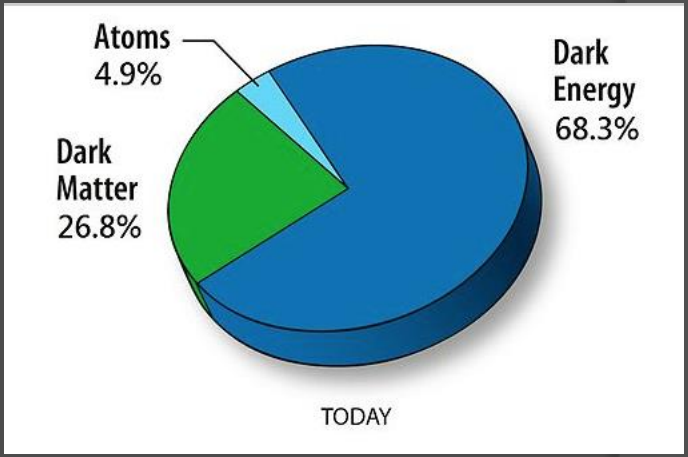
The observed density of dark matter is of the magnitude expected for a thermal relic weakly-interacting massive (~1-1000 GeV) particle (WIMP).

Particle Dark Matter?

The Dark Matter Candidate Zoo

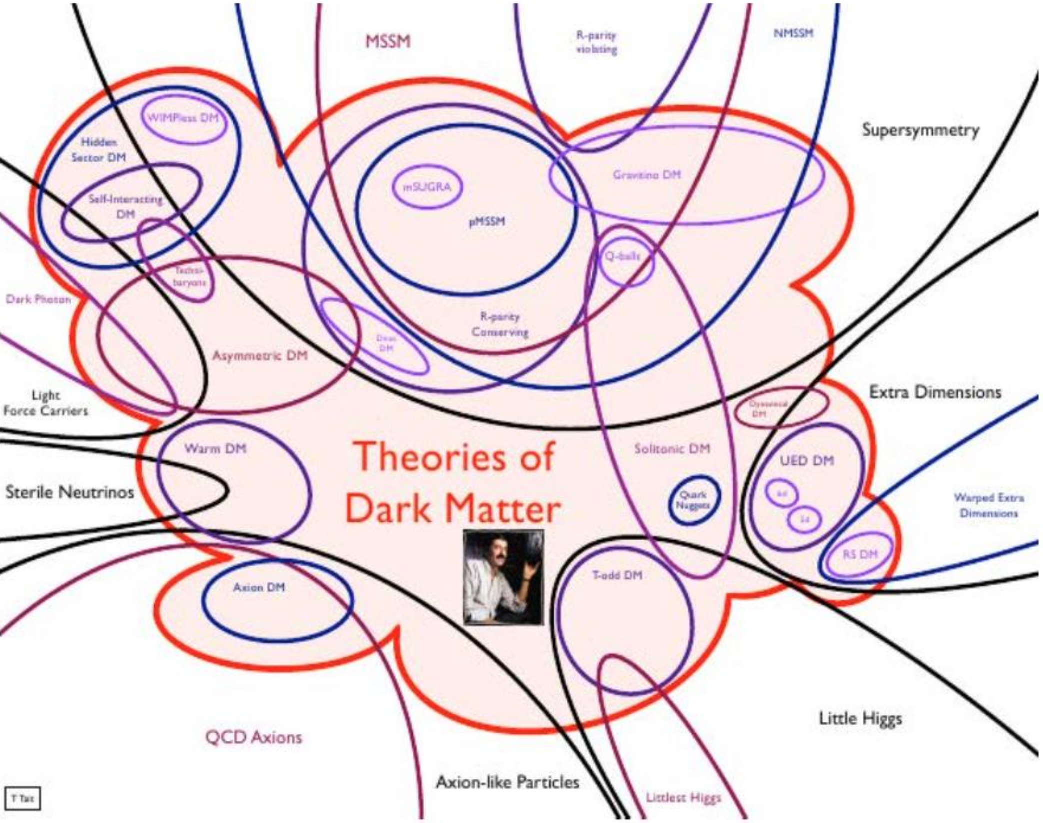
From D. Hooper

- Neutralinos (higgsino, bins, winos, singlinos)
- Axinos
- Gravitinos
- Sneutrinos
- Axions
- Sterile neutrinos
- 4^{th} generation neutrinos
- Kaluza-Klein photons
- Kaluza-Klein gravitons
- Brane world dark matter/D-matter
- Little higgs dark matter
- Light scalars
- Superheavy states (*ie.* “WIMPzillas”)
- Self-interacting dark matter
- Super-WIMPs
- Asymmetric dark matter
- Q-balls (and other topological states)
- CHAMPs (charged massive particles)
- Cryptons, mirror matter, and many, many, many others…

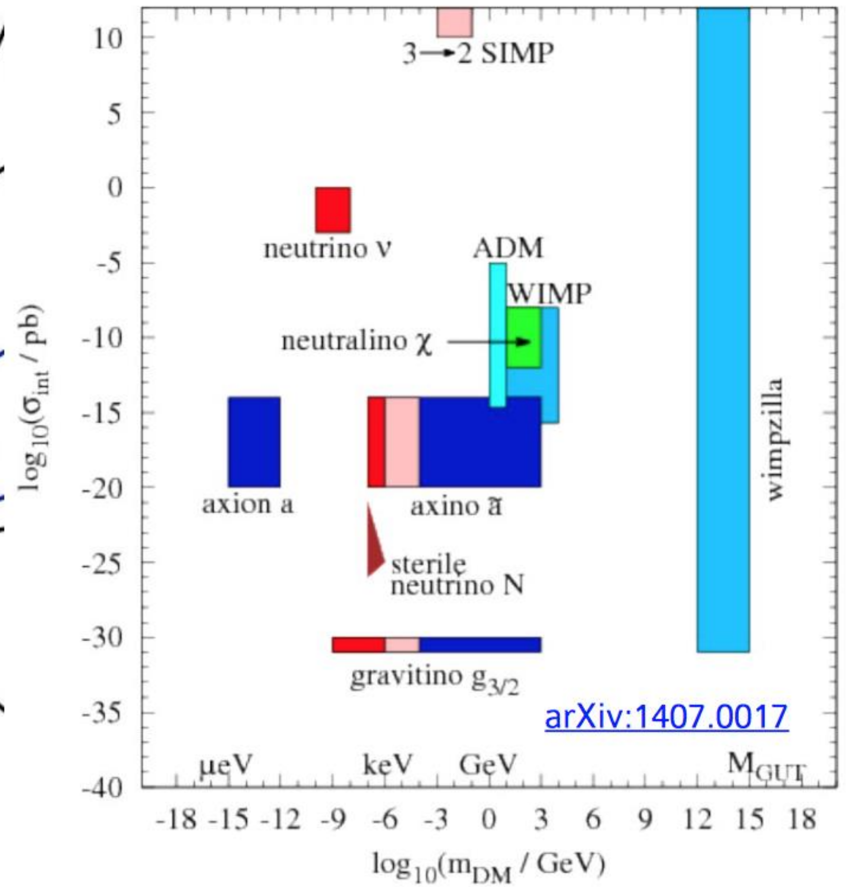


The ‘Standard Model’ of the Universe
indicated by astrophysics and cosmology

Theories on Dark Matter



Tim Tait, DM@LHC 2013

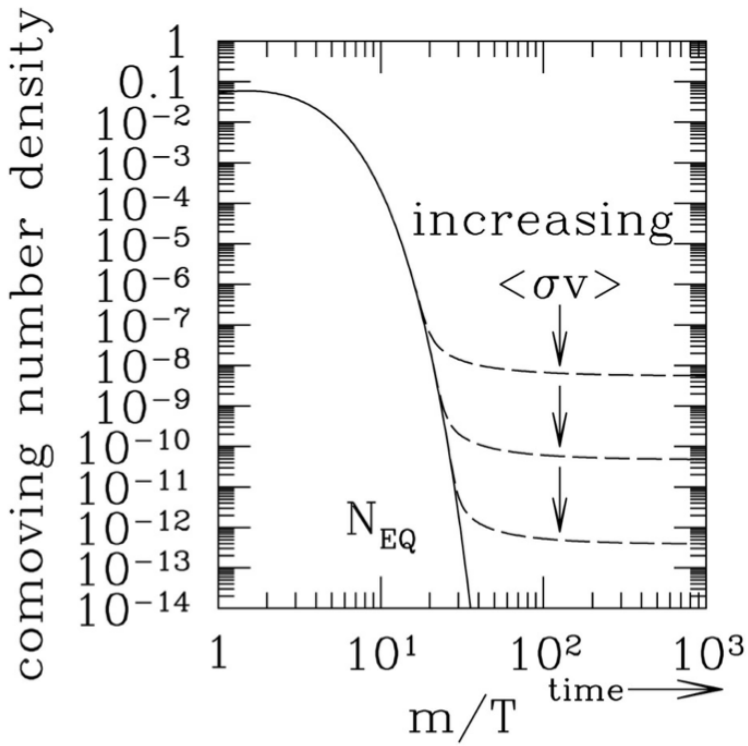


(Our) **preferred DM candidate**
matches cosmological observations (e.g. thermal relic density):
dark, stable, cold, weakly interacting with SM particles,
mass of up to a few TeV → a **WIMP**

WIMPs

- Perhaps Dark Matter is a particle with weak-scale mass?
  - *Weakly Interacting Massive Particles (WIMPs)*
  - Produced in the Big Bang, interact via $\chi + \chi \rightarrow q + q$

- As the universe expands and the temperature drops...
  - WIMPs become diluted, interact less often and ‘freeze out’.
  - Higher cross-section (<σv>) yields lower relic density

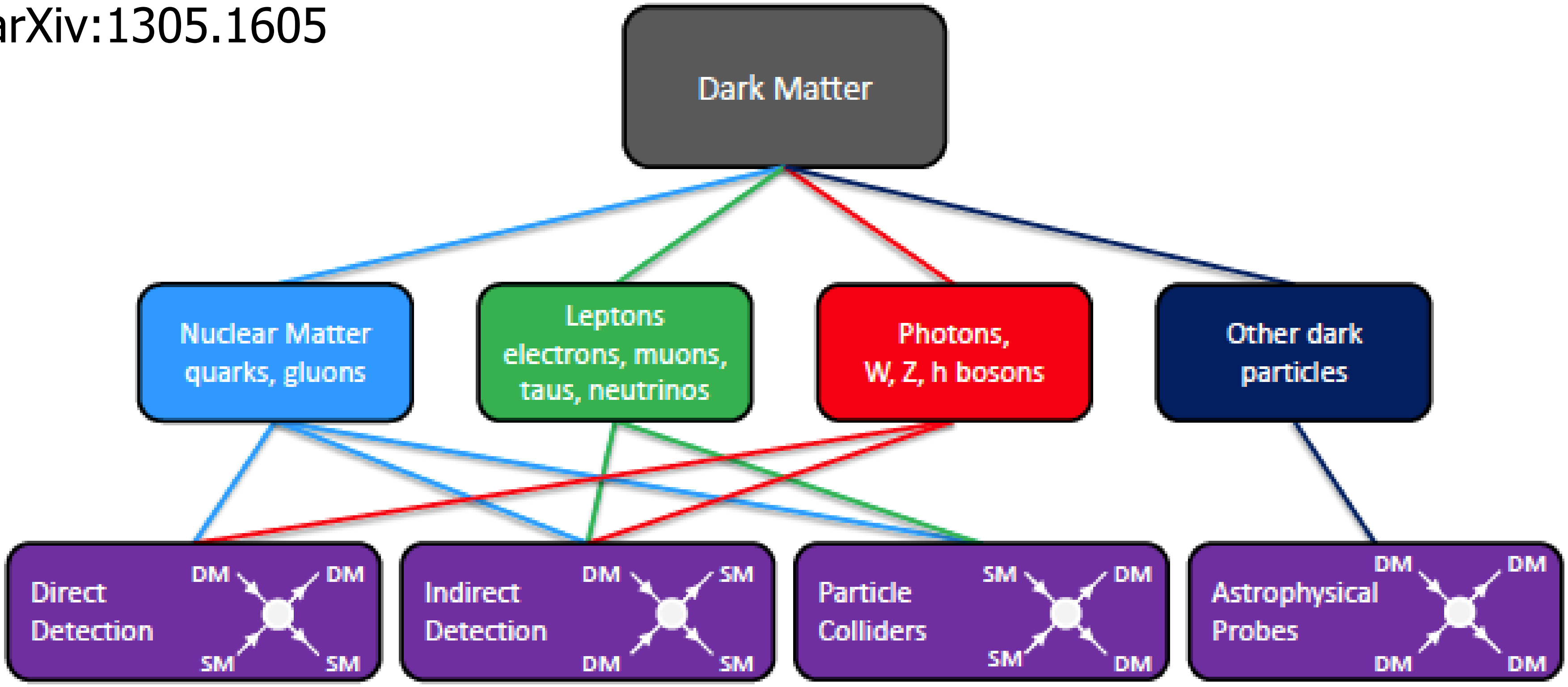


Weakly-interacting massive particles naturally provide the right relic abundance - “WIMP miracle”

Searches for Dark Matter

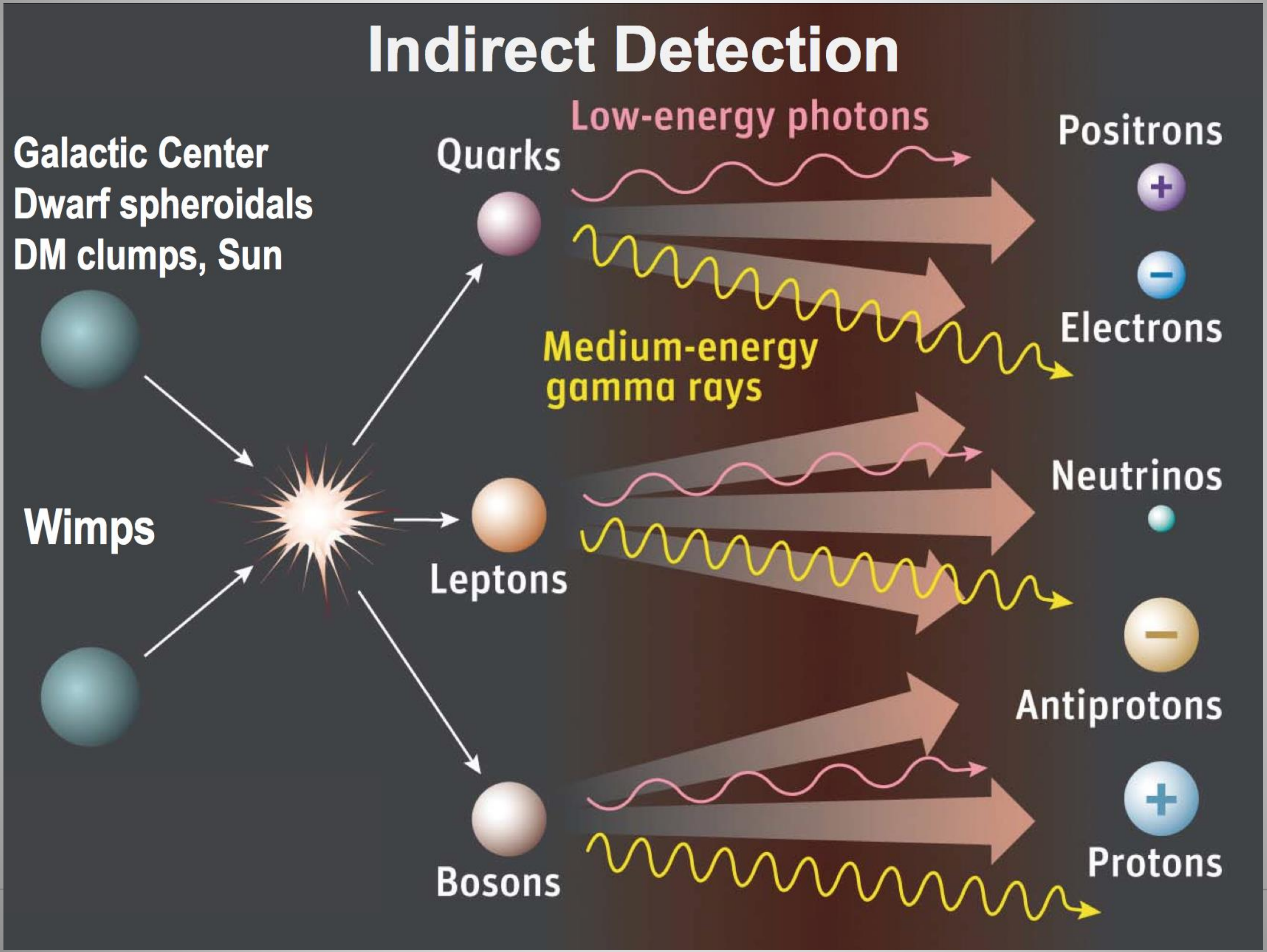
Search for WIMP candidates in events with Missing Transverse Momentum
EG: SUSY searches, monojet and mono-photon searches, W' searches…

arXiv:1305.1605

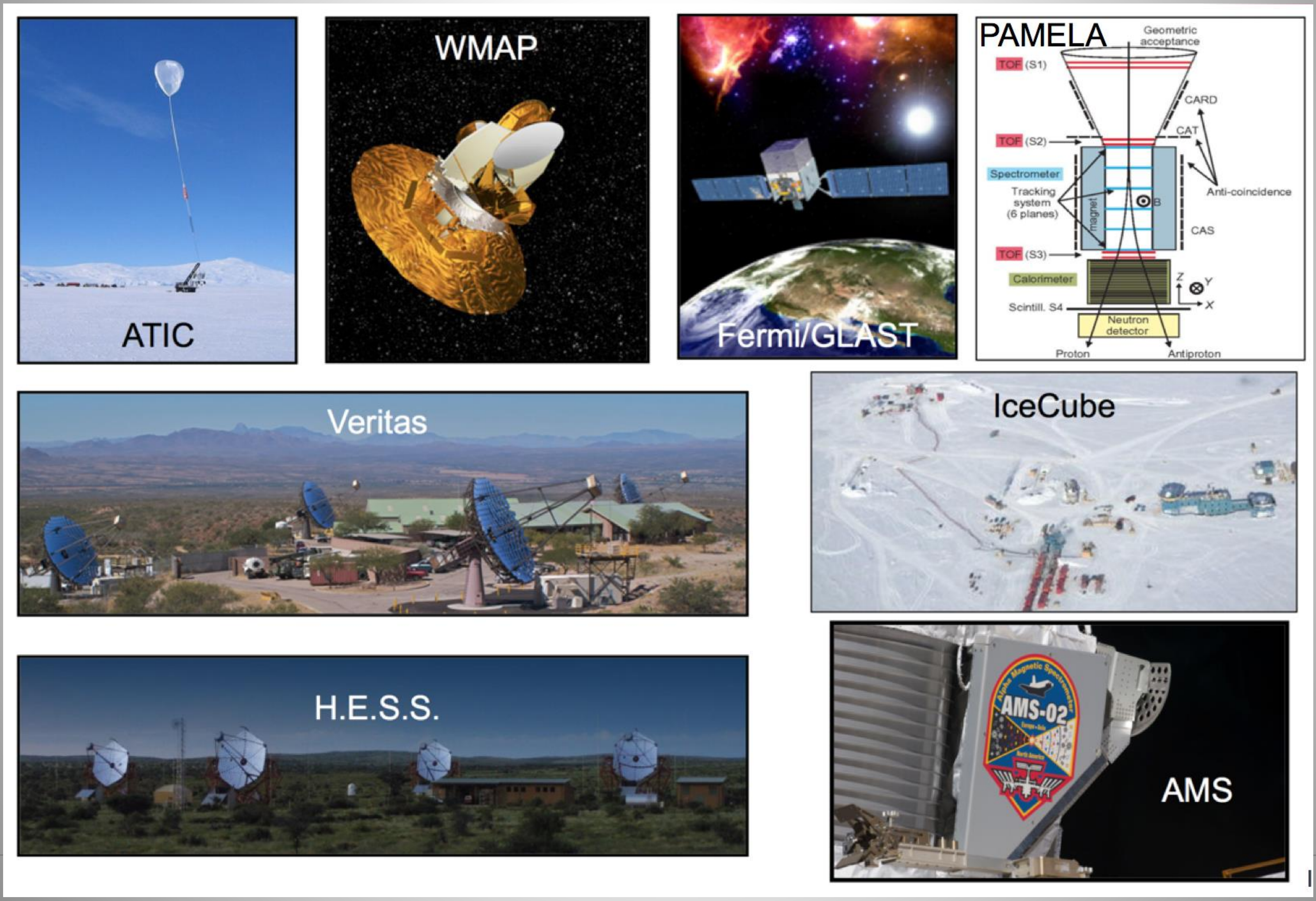


+ CAST experiment, searching for axion DM

Dark Matter: Indirect Detection



Indirect Detection Experiments



Indirect Detection

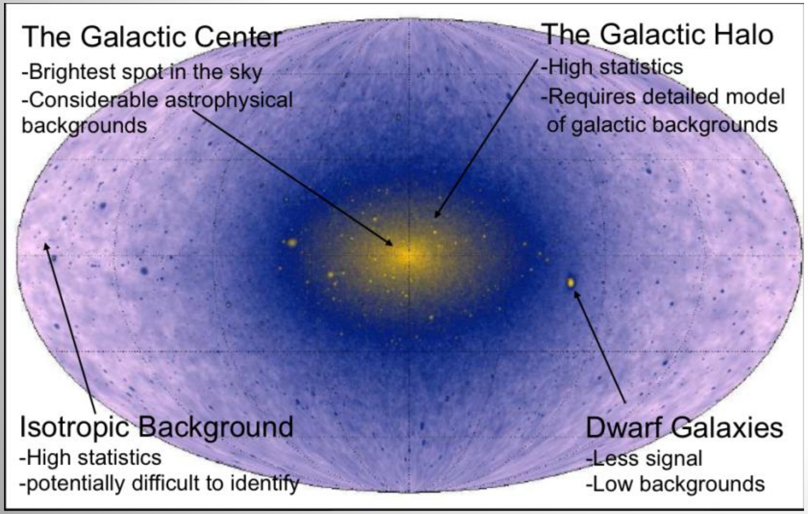
Some scientists are believers!!

arXiv:1402.6703v1

The Characterization of the Gamma-Ray Signal from the Central Milky Way: A Compelling Case for Annihilating Dark Matter

Tansu Daylan,[1] Douglas P. Finkbeiner,[1,2] Dan Hooper,[3,4] Tim Linden,[5] Stephen K. N. Portillo,[2] Nicholas L. Rodd,[6] and Tracy R. Slatyer[6,7]

Using gamma-ray data from the FERMI satellite
DM ~ 40 GeV annihilation into b anti-b quarks?

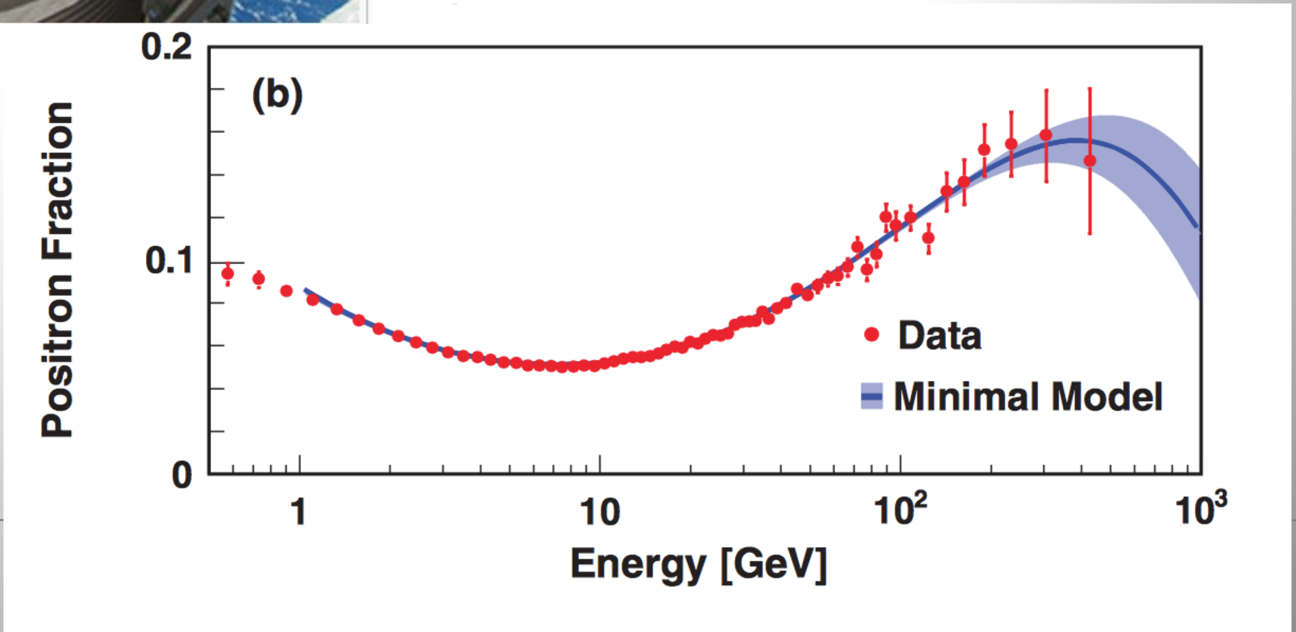


Also the 3.5 KeV line: light axion-like particle annihilation?

Dark Matter Searches in Space

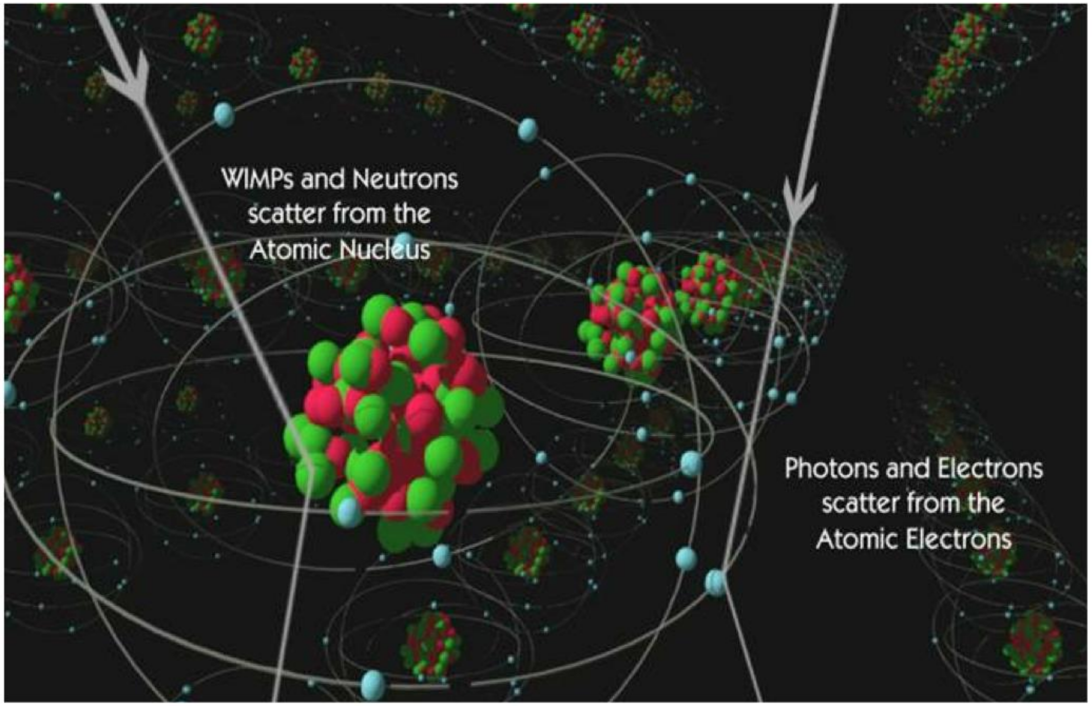
Searching for anti-matter in space.
A Dark Matter signal?

Difficulty: astrophysical sources…?



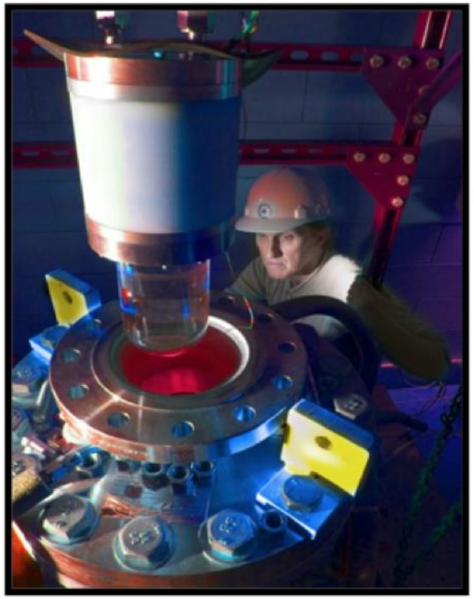
Dark Matter: Direct Detection

- Direct detection experiments: nuclear recoil from DM collision
  - Extremely sensitive, extremely difficult... extremely successful!
  - Excesses observed but not confirmed (10 GeV DM candidate?)
- Need for independent verification from non-astrophysical experiments
  - Low mass region not accessible to direct detection experiments
  - Limited by threshold effects, energy scale, bkgnds; spin-dependent couplings difficult...

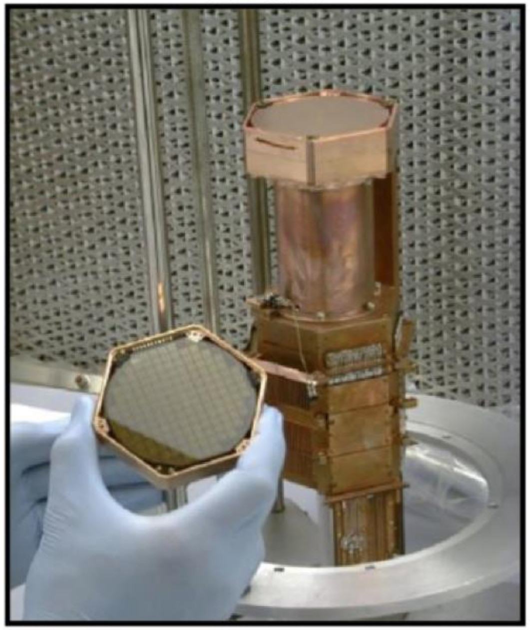


Direct Detection: Examples

COUPP

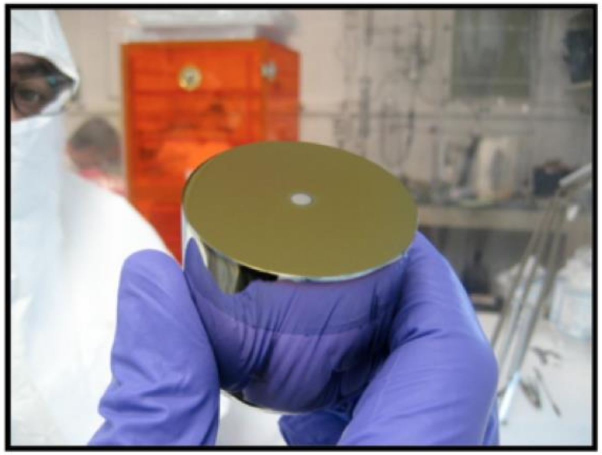


CDMS



CRESST

CoGeNT



(+ EDELWEISS, DAMA, EURECA, ZEPLIN, DEAP, ArDM, WARP, LUX, SIMPLE, PICASSO, DMTPC, DRIFT, KIMS, DARKSIDE…)

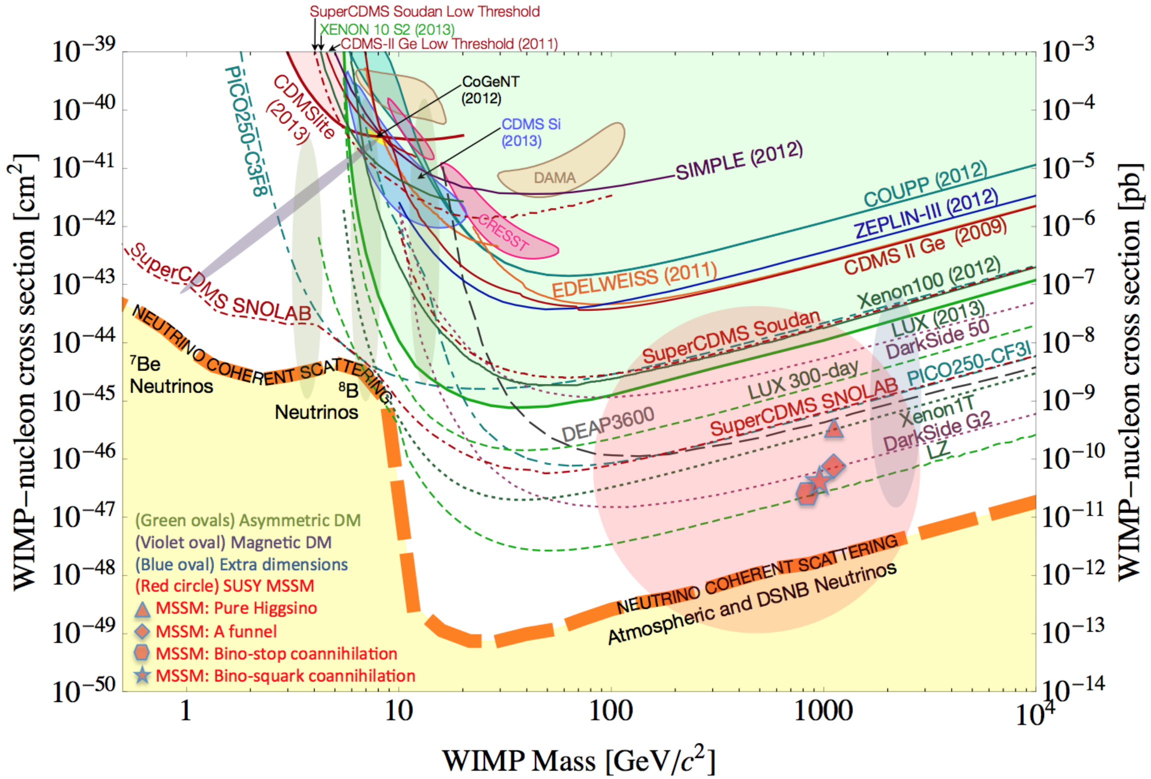
Xenon

Direct Searches for Dark Matter

State of the art today:
Driven by the results of
the LUX experiment

Intensive campaign of direct detection experiments since more than ~20 years

No (real) sign so far…

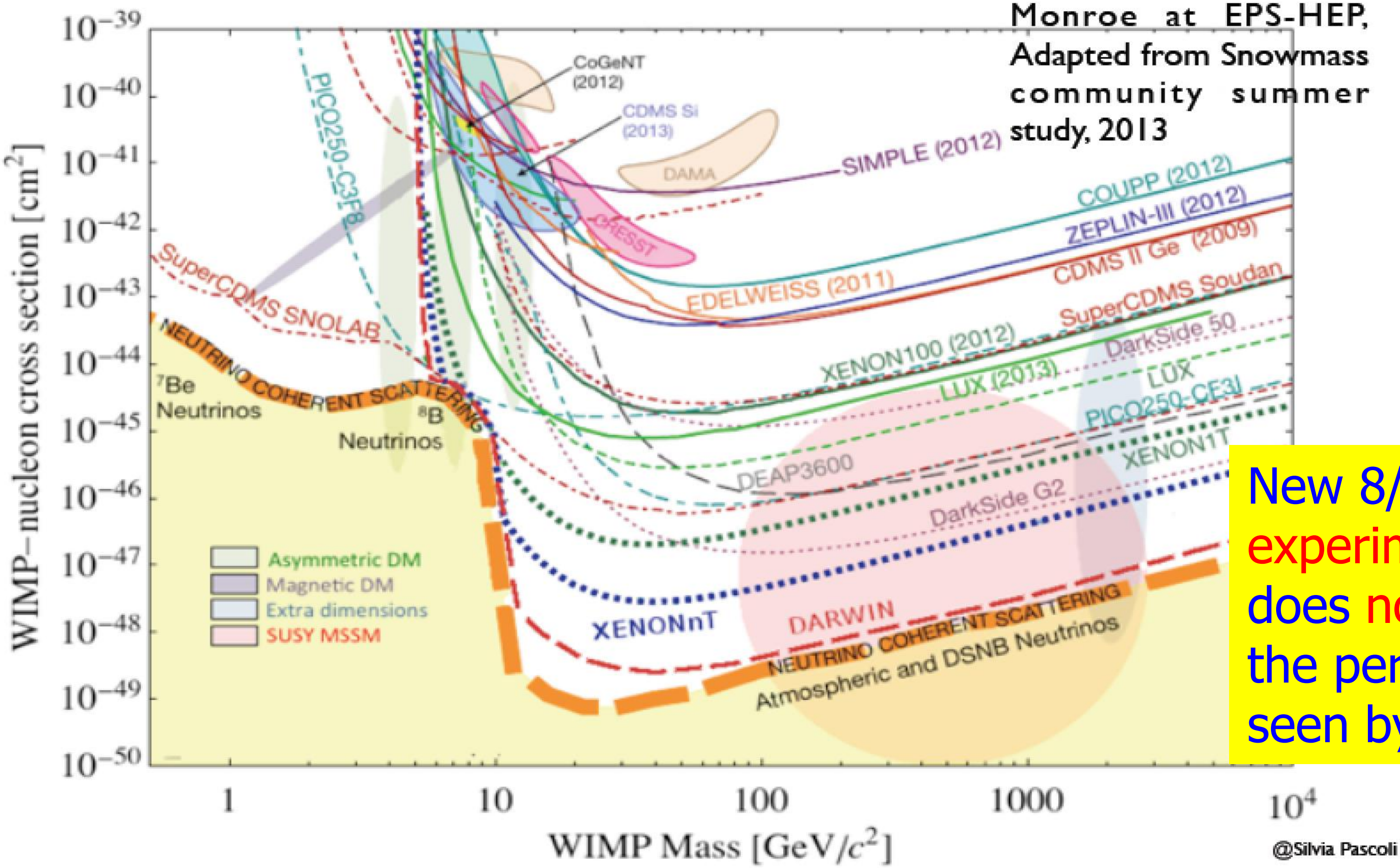


Direct Searches for Dark Matter

Underground low noise experiments

No non-ambiguous signal yet!!

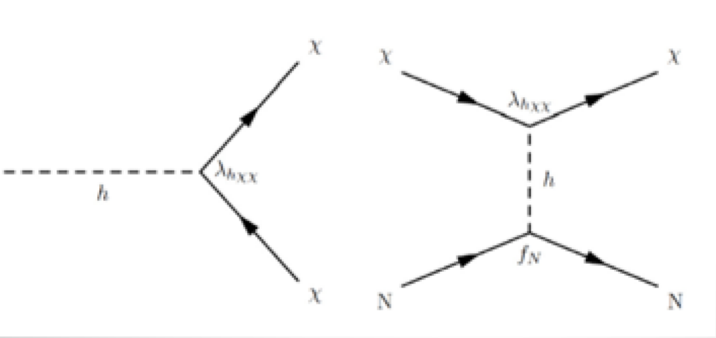
There is a very large number of projects which are under construction or being planned for the future.



New 8/9/15: XMASS experiment (Japan) does not confirm the periodical effect seen by DAMA/LIBRA

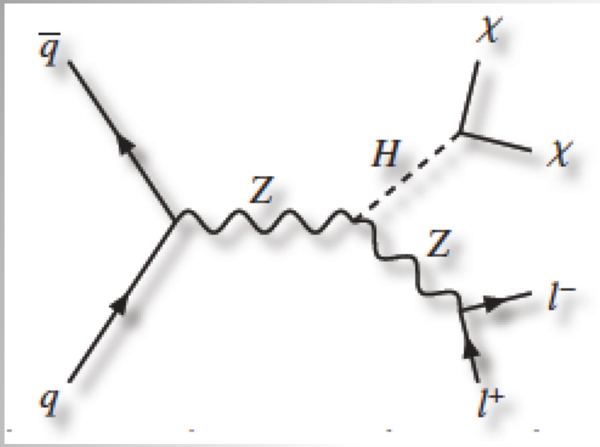
The LHC

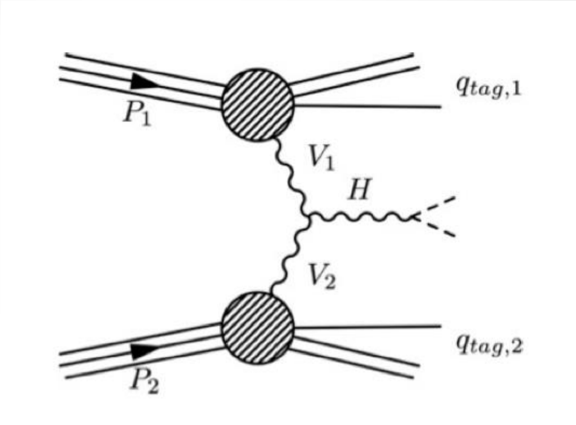
Dark Matter and the Higgs



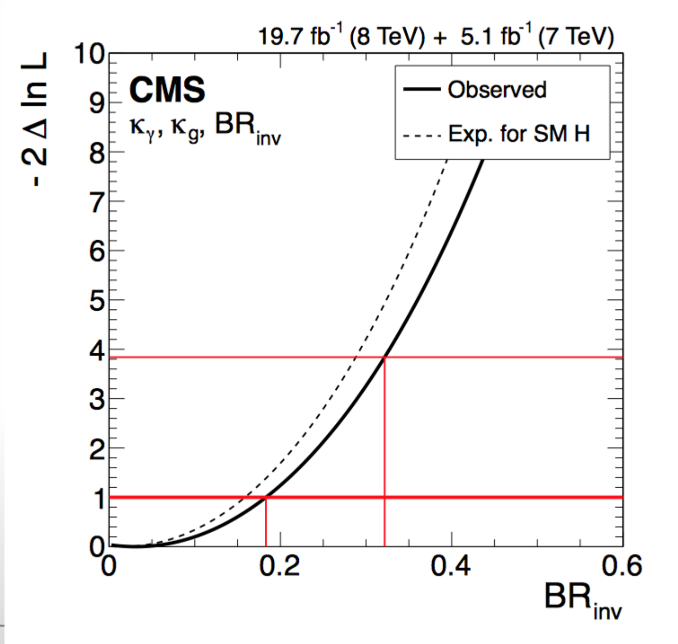
"higgs portal models"
Eg: arXiv:1205.3169

Invisible Higgs Decay Channel



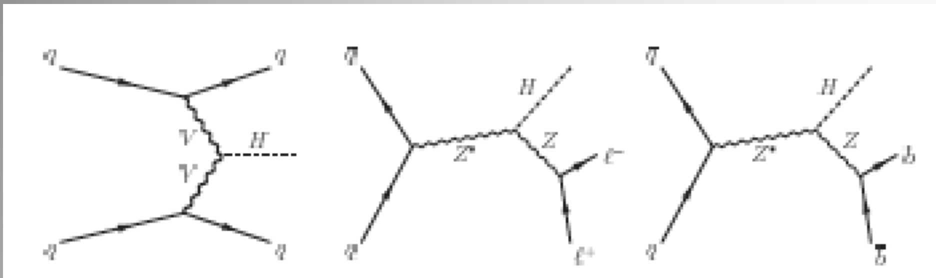


arXiv:1412.8662



- Possible decay of the Higgs in dark matter particles (if $M<M_H/2$)
- Different searches:
  - -Direct search
    Look for the invisible decay channels
  - -Indirect search
    Make a global fit of all production and decays (and some modest assumptions)

Invisible Higgs Decay Channel



Search for invisible Higgs decays using

Z+H → 2 leptons + missing E_T

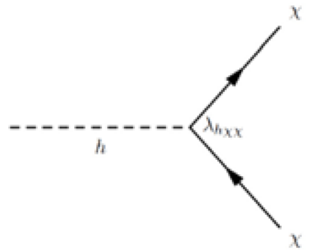
VBF H → 2 jets + missing E_T

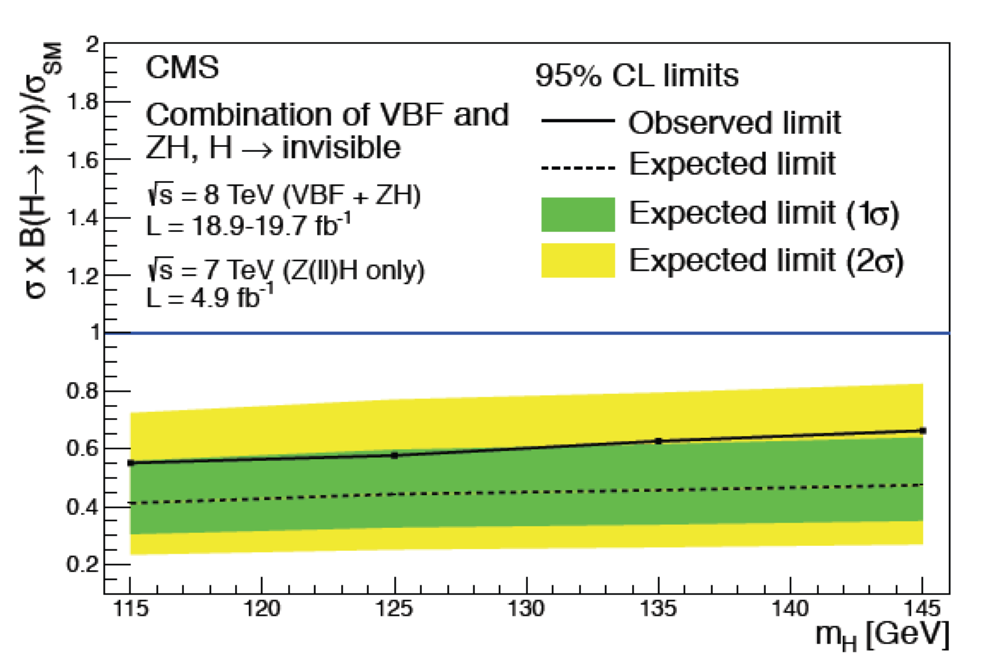
Possible decay in Dark Matter particles (if $M<M_H/2$): Higgs Portal Models

Combined result from the three channels

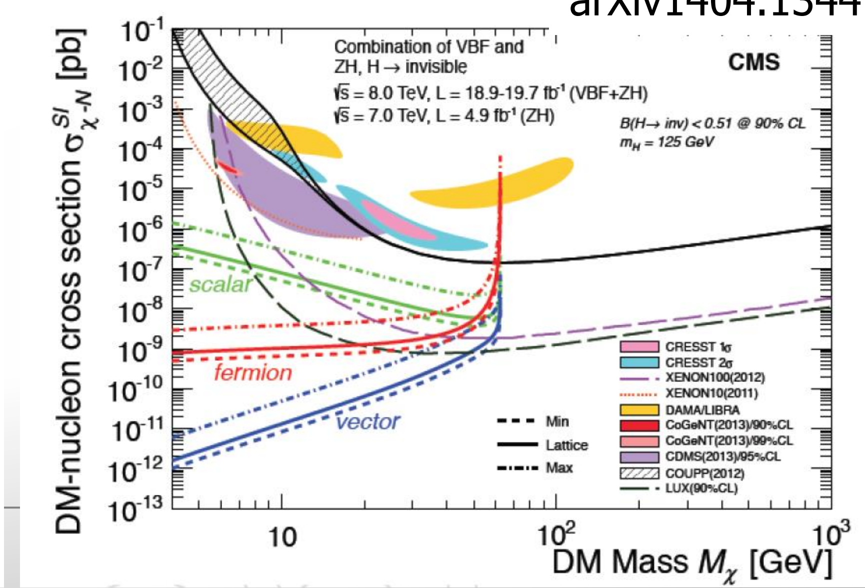
BR(H→invisible)<58%(44% exp) at 95% CL.

for a Higgs with a mass of 125 GeV





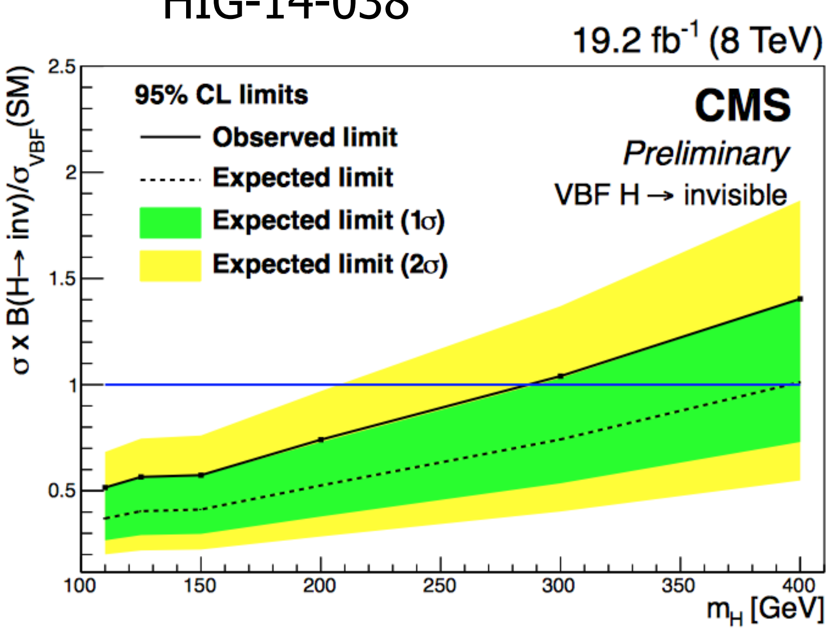
arXiv1404.1344



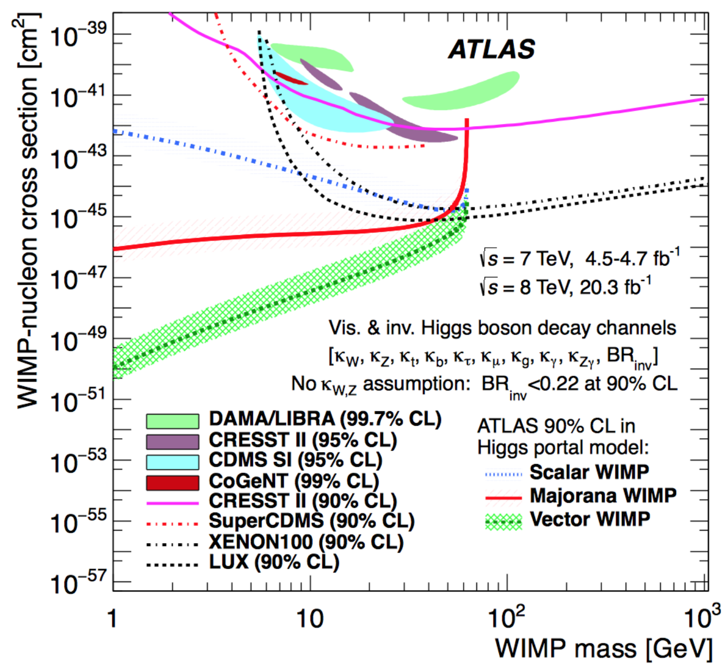
New: Invisible Higgs in VBF

- CMS: VBF process with p_T > 35(30) GeV, M_{jj} > 700 GeV and $\Delta\eta_{jj}$ > 3.5 parked dataset with 11 fb^{-1} in run1. The BR(H $\rightarrow$ inv) = 0.57 (0.40) observed (expected) at 95% CL.
- ATLAS: First VBF analysis: 0.28 (0.31) observed (expected)
- CMS All channel combination 47% (35%) obs (exp).

HIG-14-038



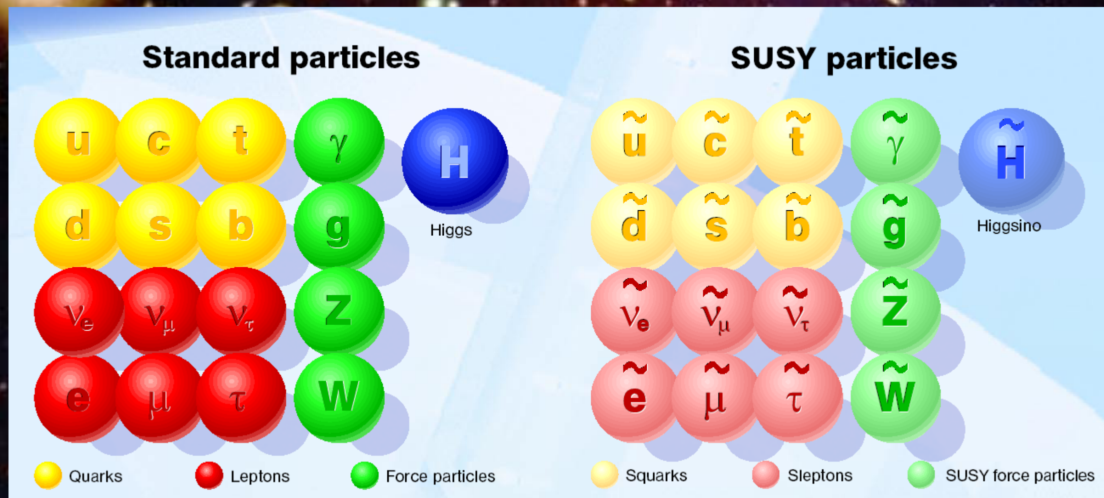
arXiv:1509.00672

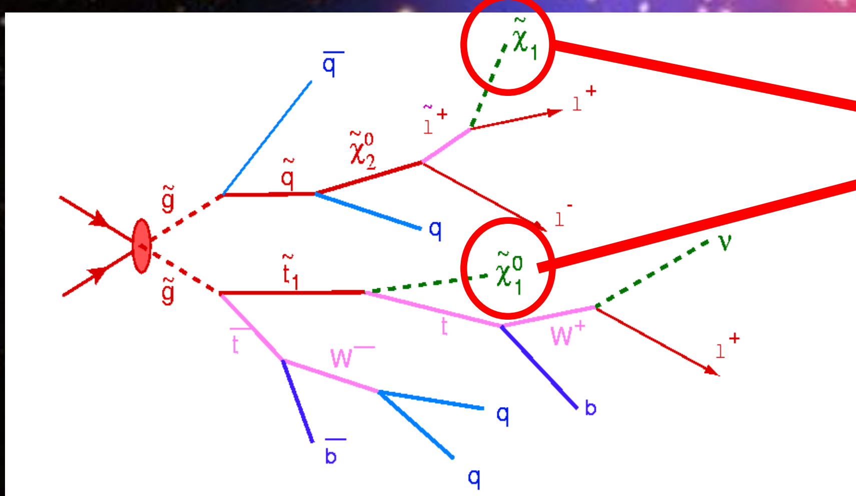


Searches for Supersymmetry

Supersymmetry was not "invented" to solve the dark matter problem, but can provide a great solution!
WIMP Dark Matter candidate comes for free … (in many cases)

Supersymmetry: a new symmetry in Nature?





Candidate particles for Dark Matter

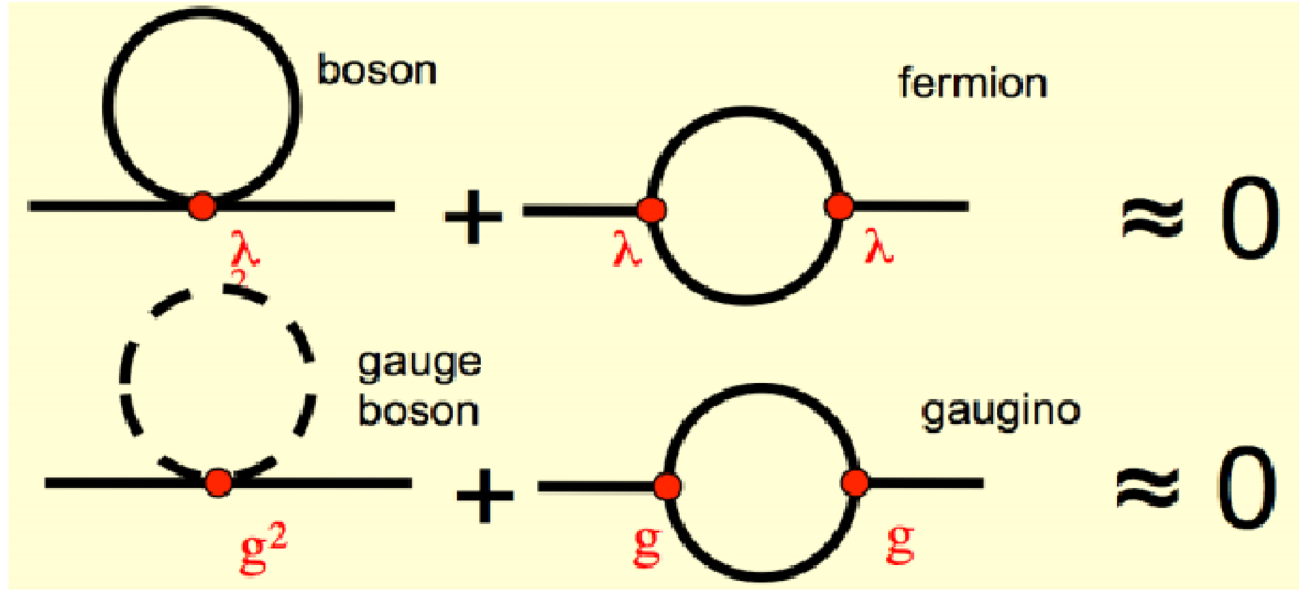
⇒ Produce Dark Matter in the lab

SUSY particle production at the LHC

Picture from Marusa Bradac

Supersymmetry

Supersymmetry (SUSY) → assumes a new hidden symmetry between the bosons (particles with integer spin) and fermions (particles with half integer spin). Stabelize the Higgs mass up to the Planck scale



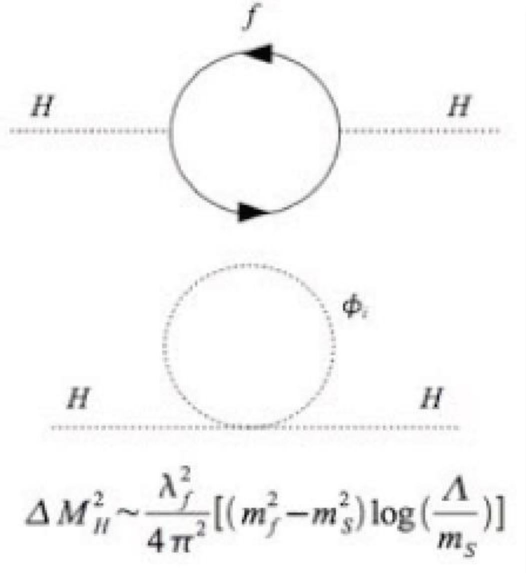
Fermion and boson loops cancel, provided $m_{\tilde{f}} \leq$ TeV.

Why weak-scale SUSY ?

- stabilises the EW scale: $|m_F - m_B| < O(1\ \text{TeV})$
- predicts a light Higgs $m_h < 130$ GeV
- accomodates gauge unification
- accomodates heavy top quark
- dark matter candidate: neutralino, sneutrino, gravitino, ...
- consistent with EW precision tests

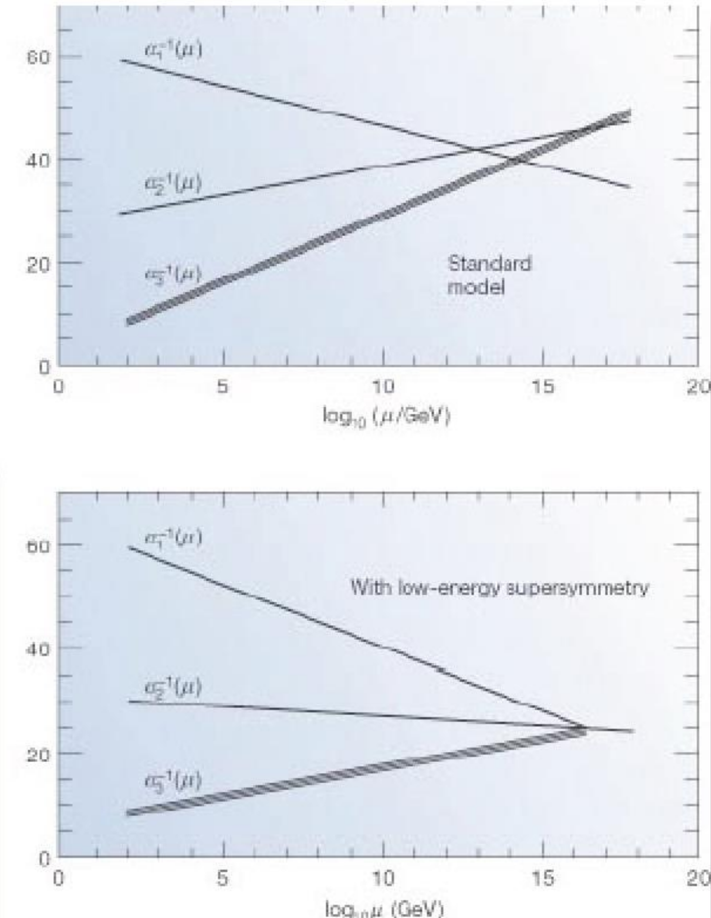
Discovering SUSY – A revolution in particle physics!!

Summary: Why SUSY is good for you!!



- Elegant solution to the hierarchy problem (i.e., why the Higgs mass is not at the Planck scale)

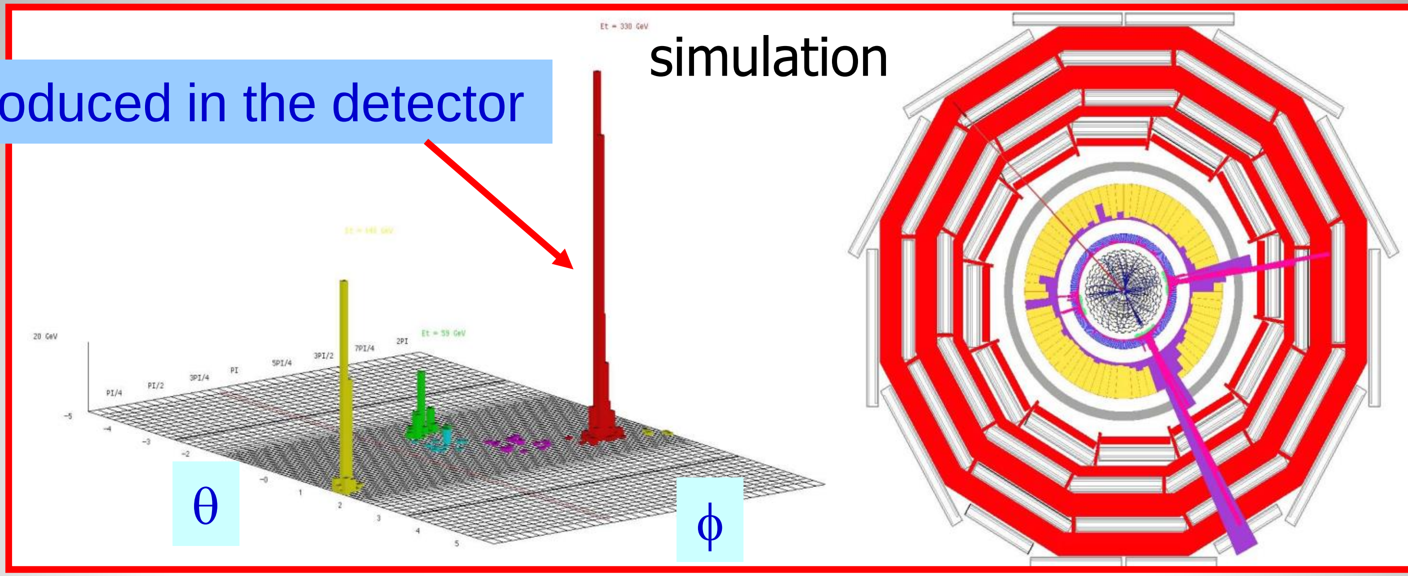
- Gauge unification

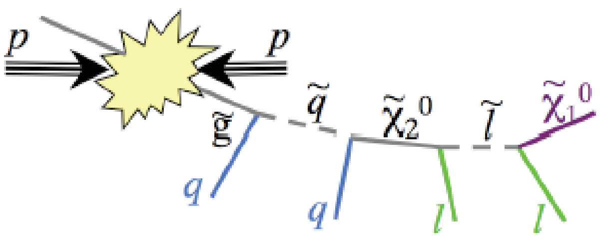


- Dark matter candidate with the right abundance

Detecting Supersymmetric Particles

Energy produced in the detector



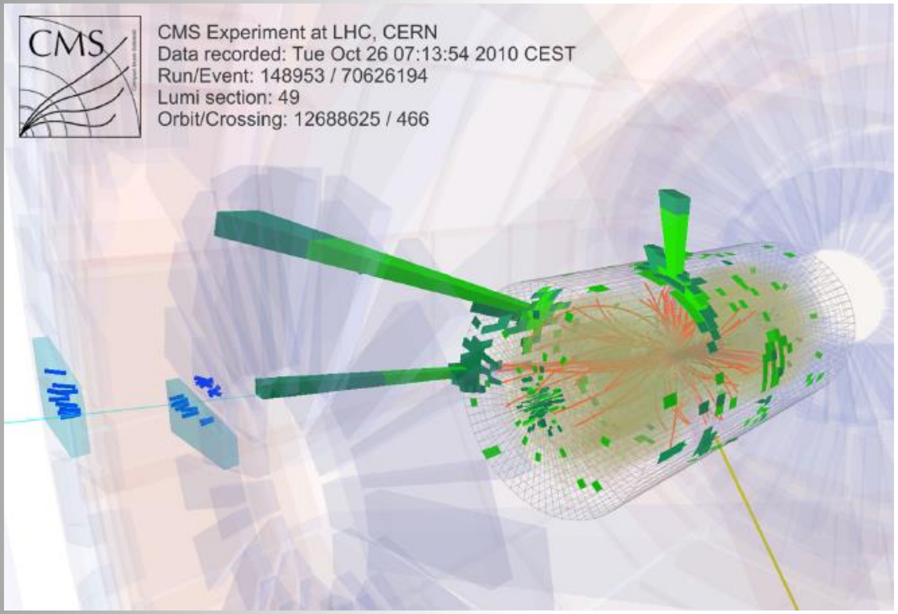


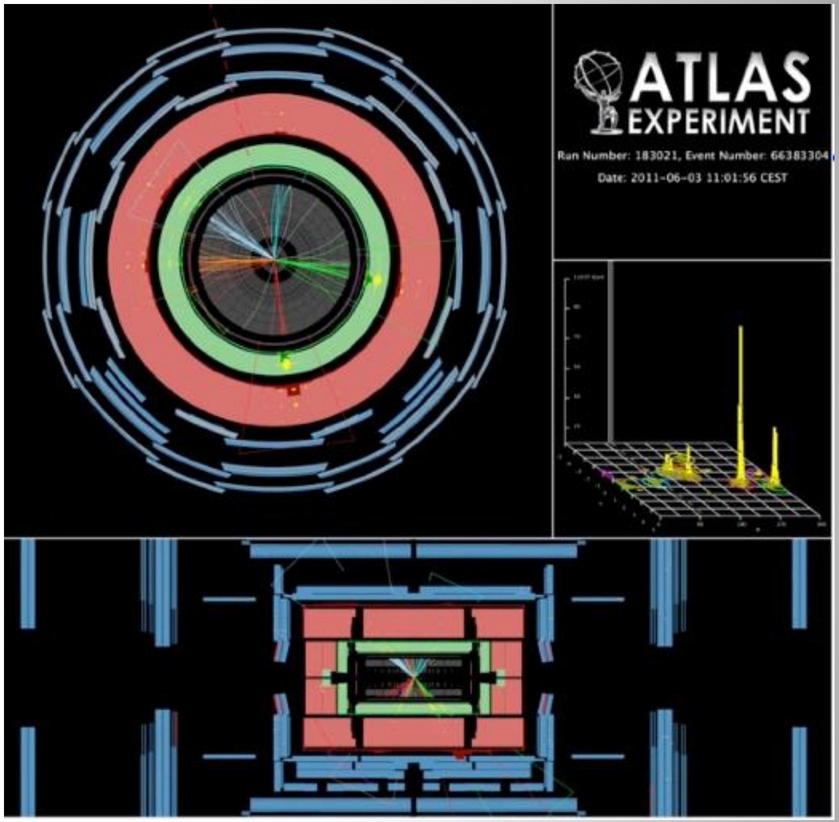
Supersymmetric particles decay and produce a cascade of jets, leptons and missing transverse energy (MET) due to escaping ‘dark matter’ particle candidates

Very prominent signatures in CMS and ATLAS

…Some Interesting Collisions…

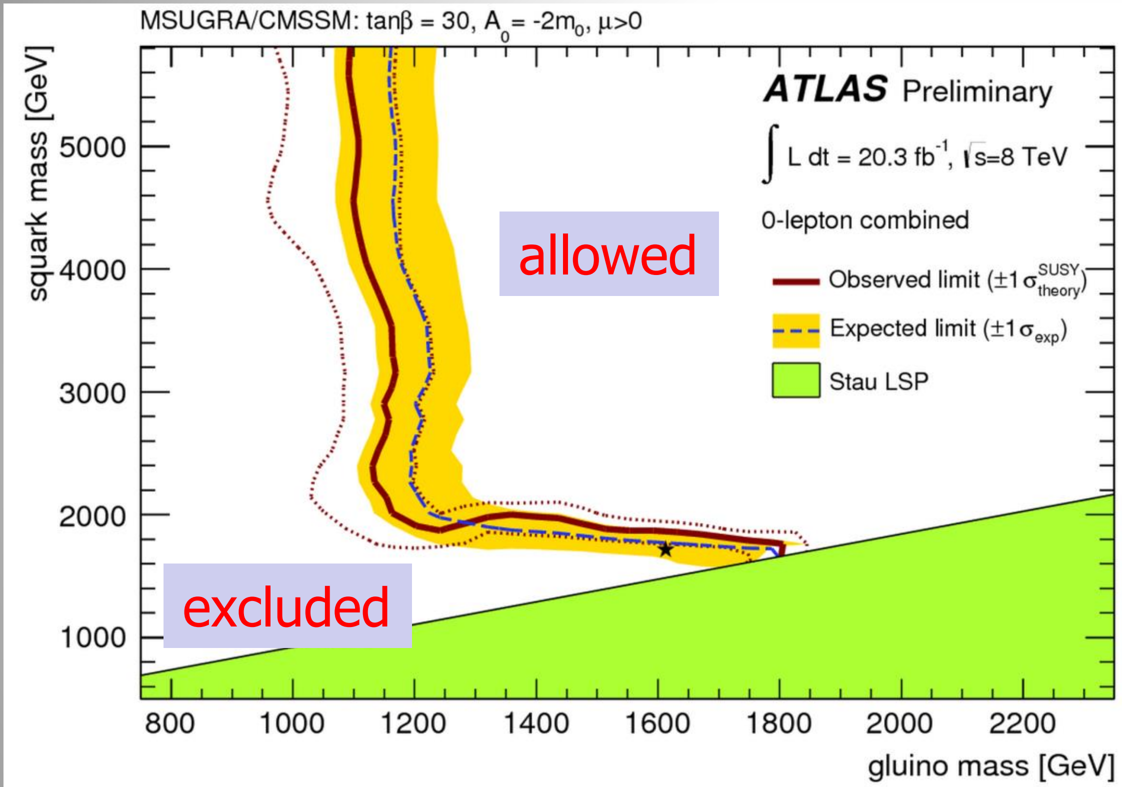
…already in 2010…





- Events with five jets of particles and large missing energy which could come from a possible dark matter particle
- But a few events is not enough too prove we have something new No visible excess has been building up with time…

SUSY Searches: No signal yet to date…



- So far NO clear signal of supersymmetric particles has been found
- We can exclude regions where the new particles could exist.
- Searches will continue for the higher energy in 2015

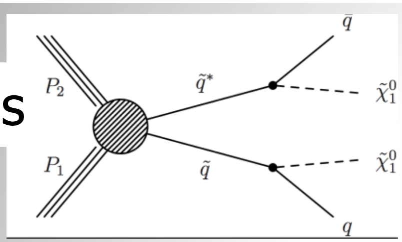
Plenty of searches ongoing: with jets, leptons, photons, W/Z, top, Higgs, with and without large missing transverse energy

Also special searches for more contrived model regions

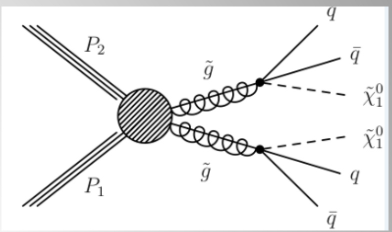
Limits on Squarks and Gluinos

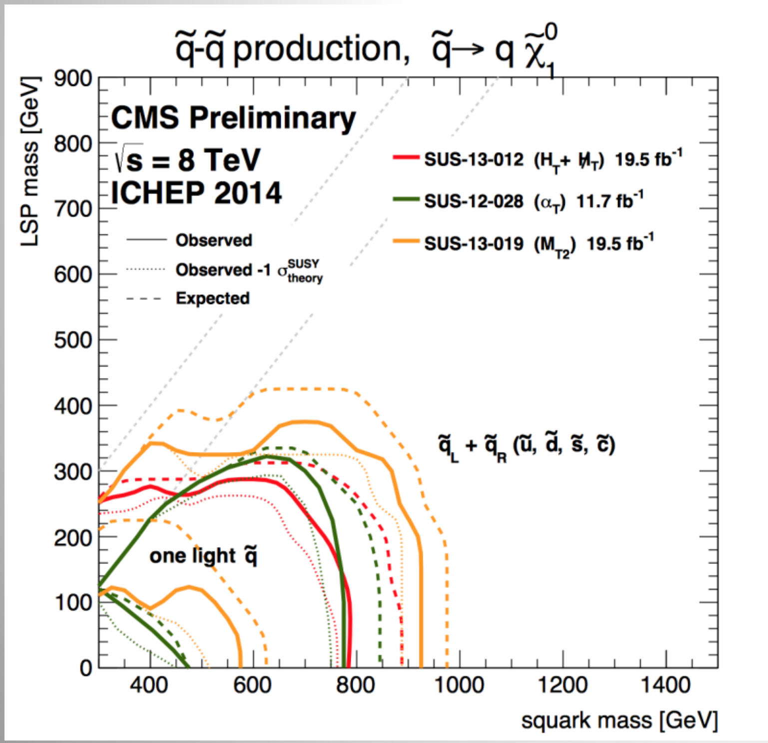
Results depend on the topologies studies, assumed mass of the LSP etc.

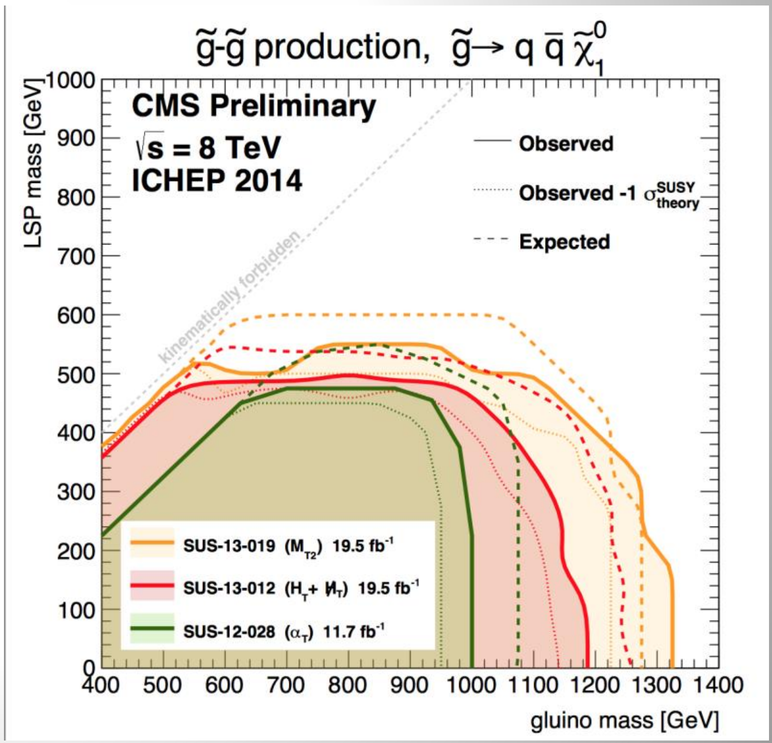
Examples



Popular presentation of data:
Simplified ModelS (SMS)







Combined limits typically > 1-1.3 TeV on sparticle masses

What is really needed from SUSY?

End 2011: Revision!

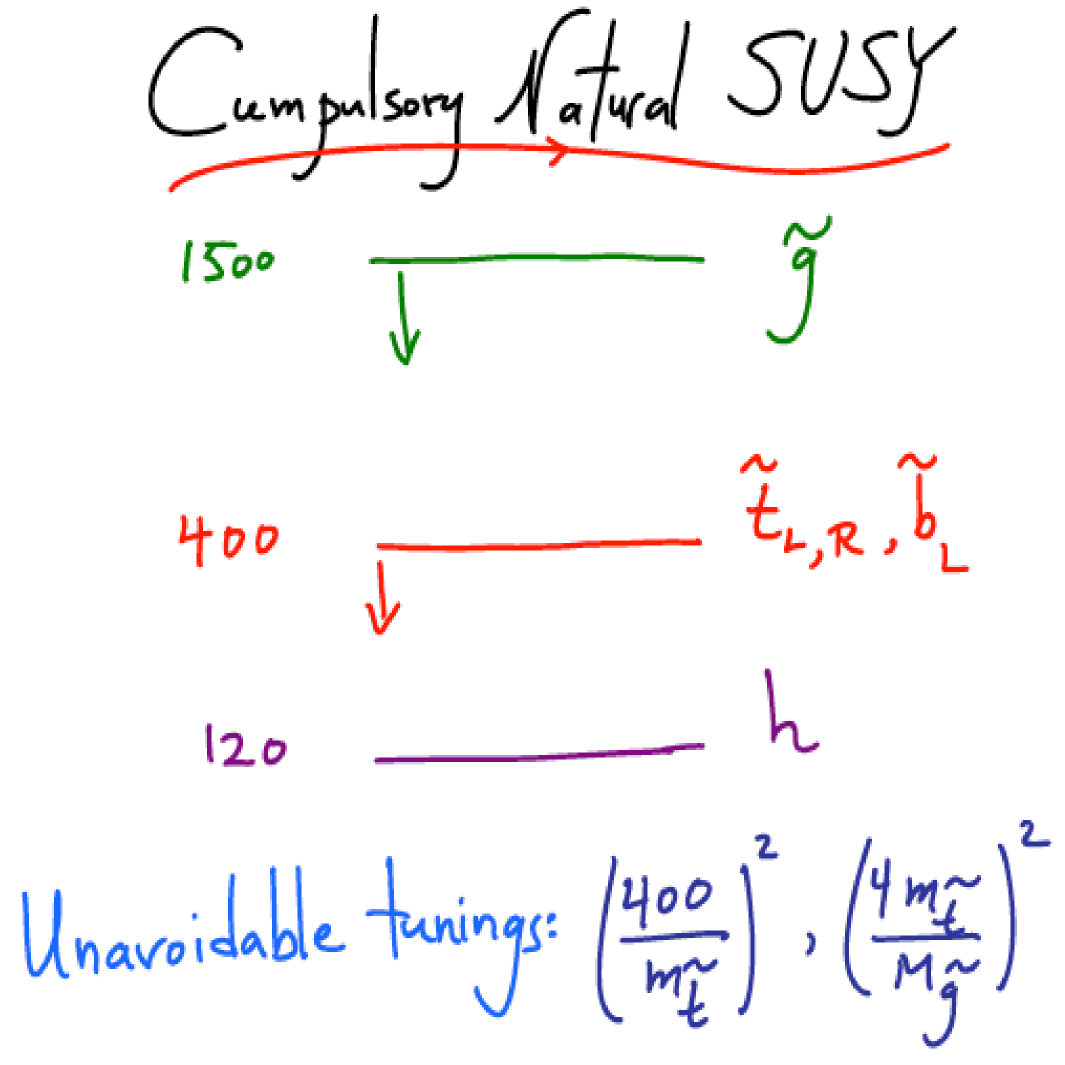
N. Arkani-Ahmed
CERN Nov 2011

Papucci, Ruderman, Weiler arXiv:1110.6926

LHC data end 2011
Stops > 200-300 GeV
Gluino > 600-800 GeV

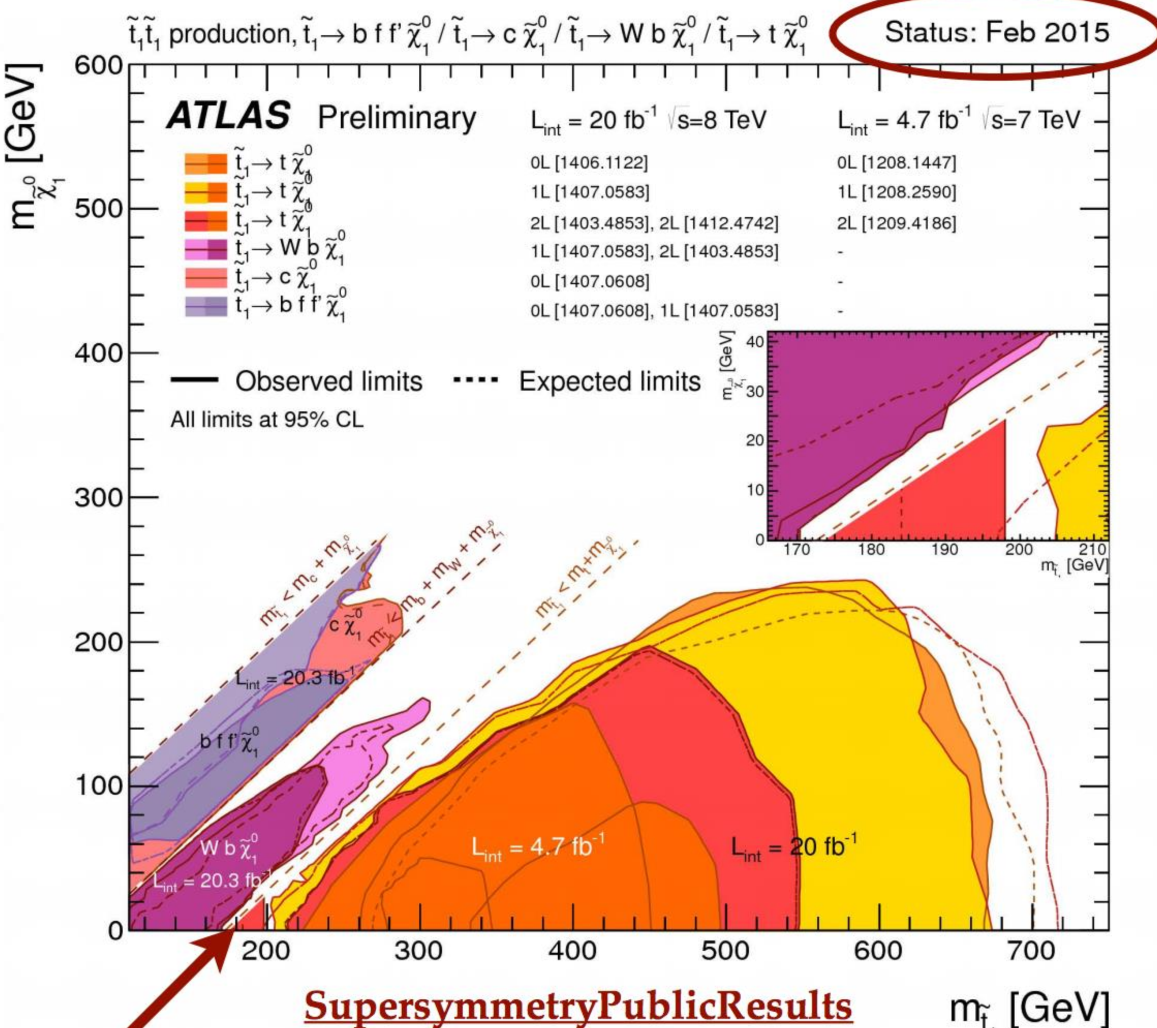
Moving away from constrained SUSY models to 'natural' models

Natural SUSY survived LHC so far, but we are getting close to push it to its limits!

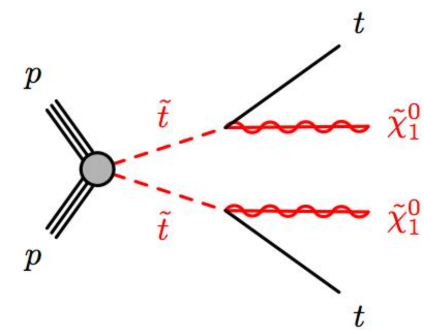


Natural SUSY?

Direct Stop Searches



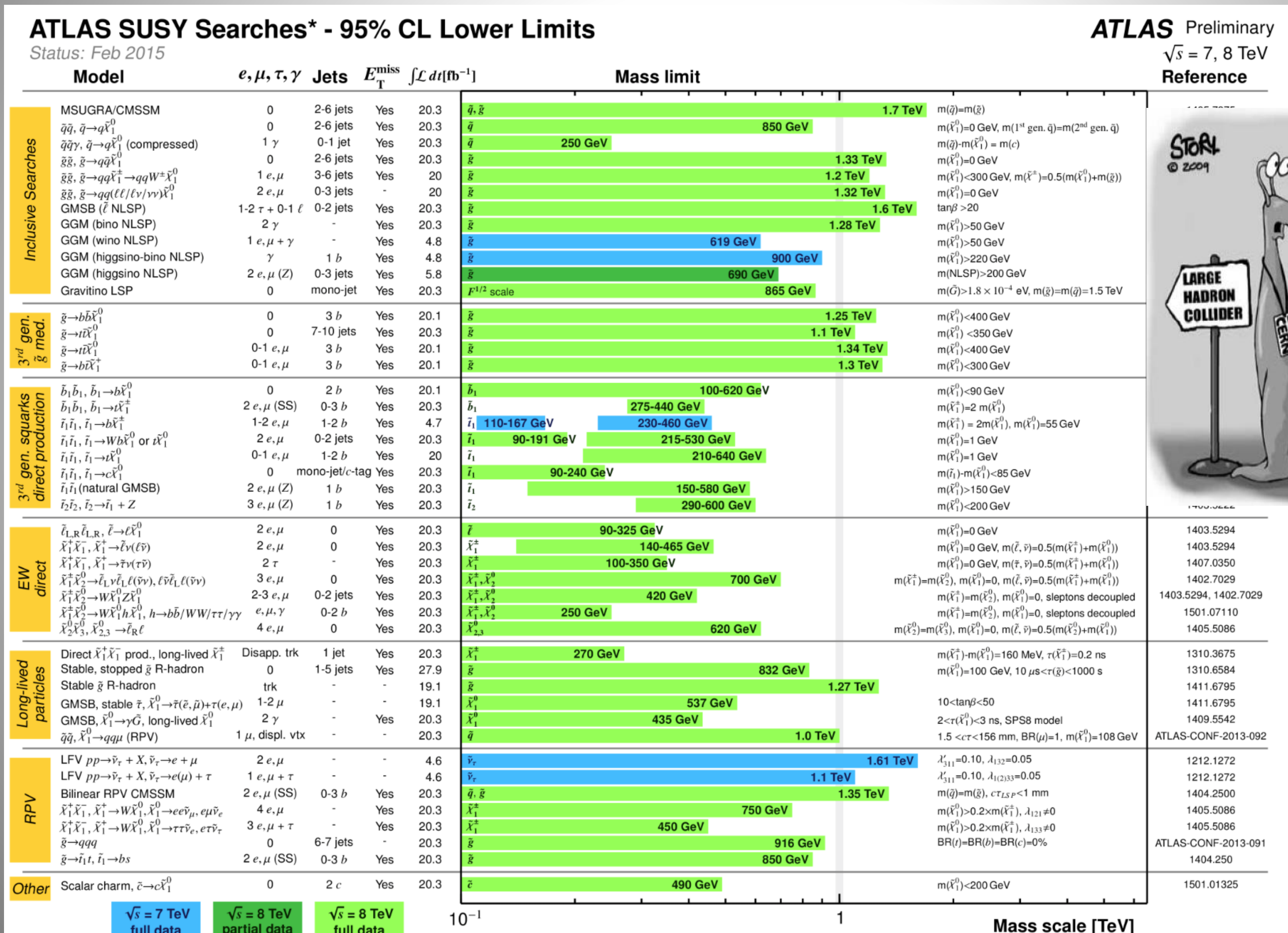
SupersymmetryPublicResults



- Stealth stop region ($m_{\tilde{t}} \sim m_t$) nearly closed by precision $t\bar{t}$ measurements!

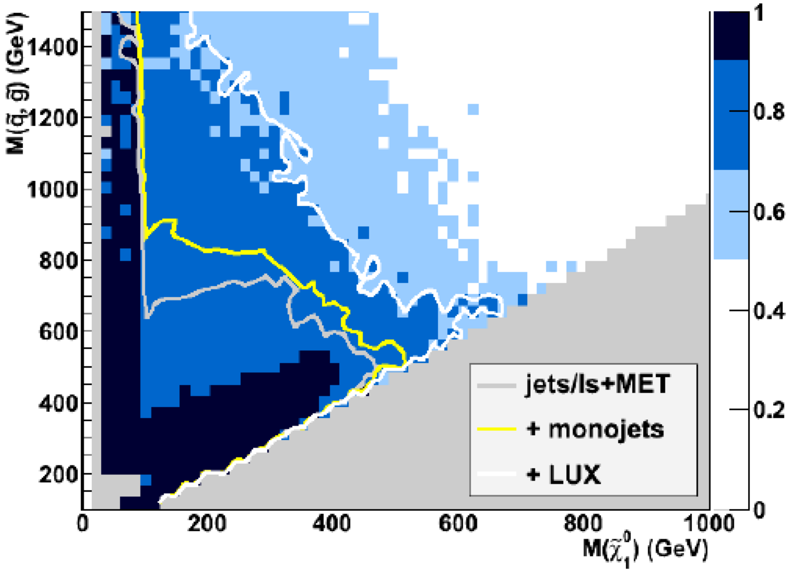
Summary of SUSY Searches

In short: no sign of SUSY with the data collected so far (similar for CMS)



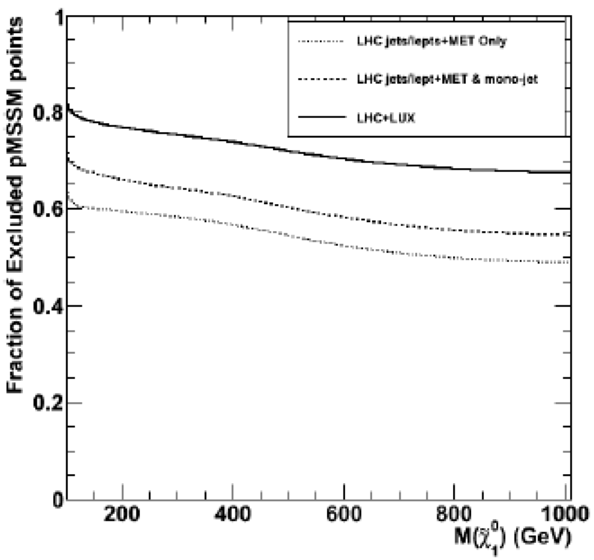
Dark Matter SUSY Space Left?

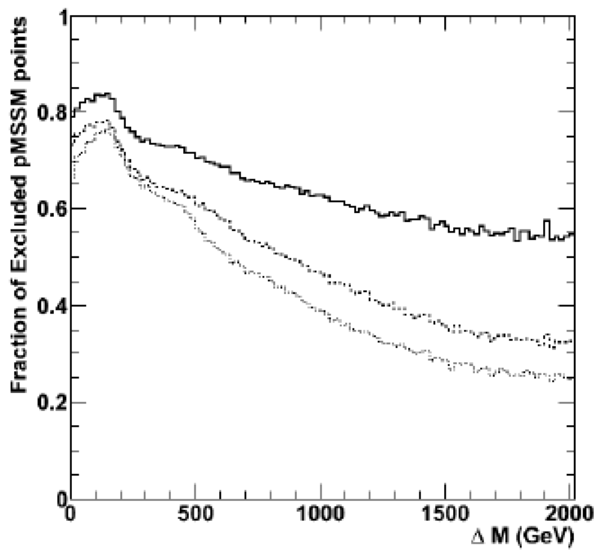
arXiv:1311.7641



- Use the pMSSM SUSY model (19 parameters)
- Use all the ATLAS SUSY Data + mono-jet searches + LUX DM results

- Check what fraction of pMSSM solutions that is excluded.



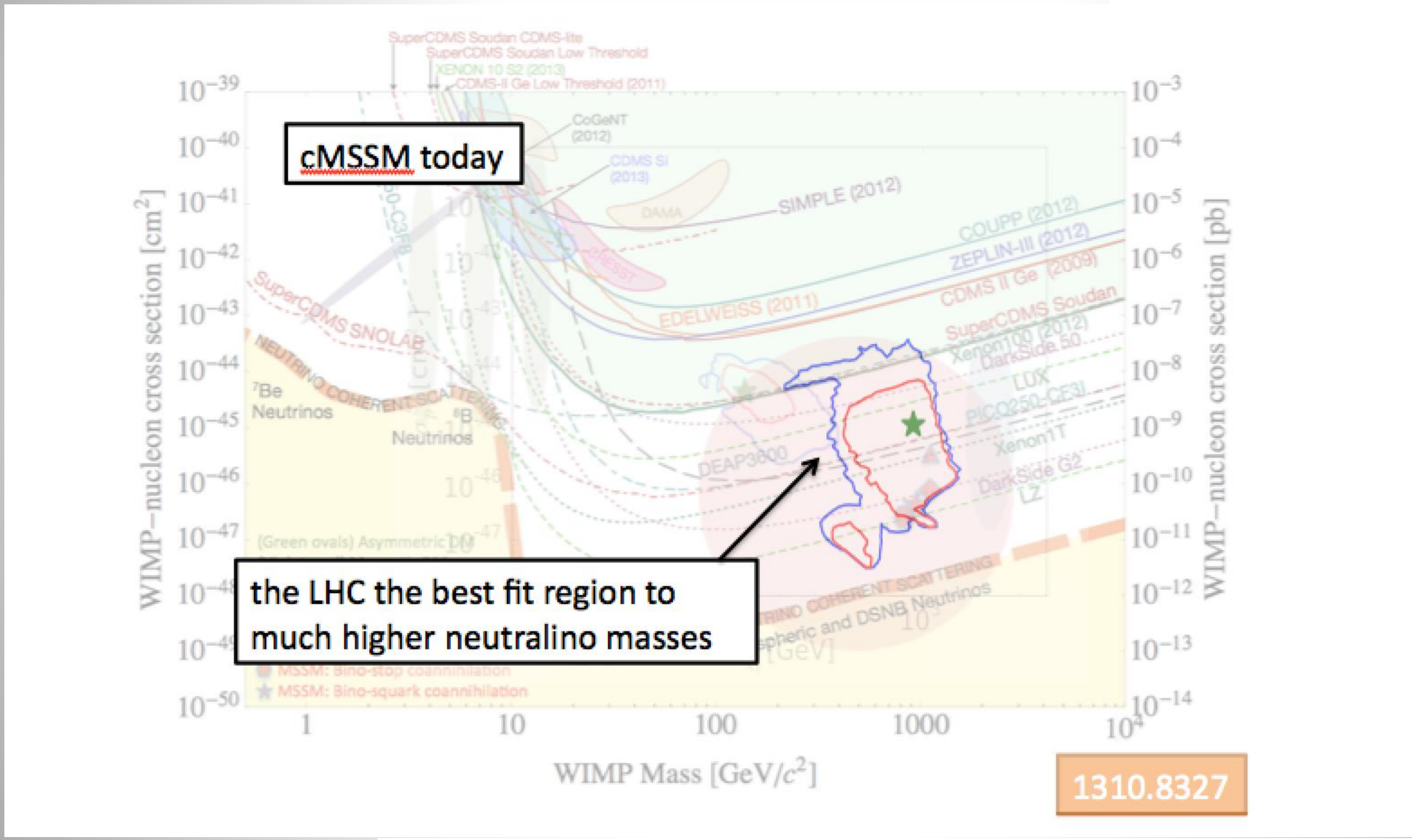


60-80% of the solutions excluded as function of the neutralino mass

Constrained SUSY Models: Now

O. Buchmuller, … ADR, Ellis... et al: arXiv:13125250

Study of the allowed DM space in CMSSM model



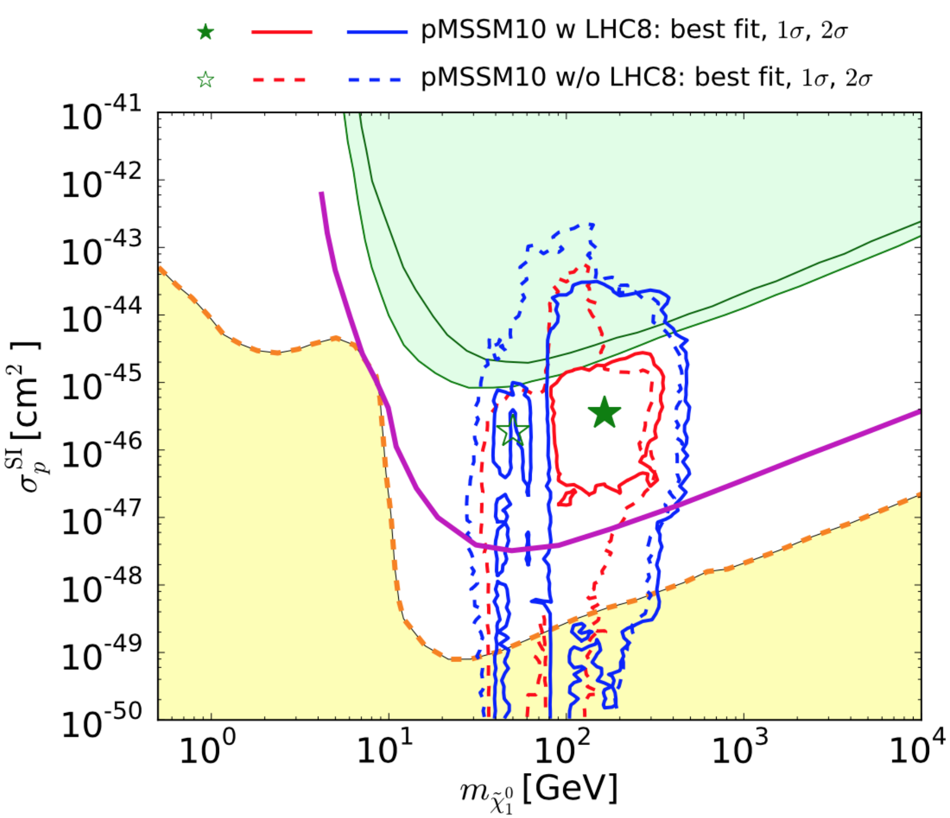
Region allowed in the CMSSM
includes constraints of the Run-I LHC searches (SUSY) and precision data, g-2, cold dark matter constraints…

Available SUSY Space: Update

arXiv:1504.03260

The pMSSM10 after LHC Run 1

K.J. de Vries[a], E.A. Bagnaschi[b], O. Buchmueller[a], R. Cavanaugh[c,d], M. Citron[a], A. De Roeck[e,f], M.J. Dolan[g], J.R. Ellis[h,e], H. Flächer[i], S. Heinemeyer[j], G. Isidori[k], S. Malik[a], J. Marrouche[e], D. Martínez Santos[l], K.A. Olive[m], K. Sakurai[h], G. Weiglein[b]



Region allowed in the pMSSM10 (10 parameter SUSY space) includes constraints of the Run-I LHC searches (SUSY) and precision data, g-2, dark matter constraints…

$$
\begin{aligned}
\text{3 gaugino masses} &: M_{1,2,3}\,, \\
\text{2 squark masses} &: m_{\tilde{q}_1} = m_{\tilde{q}_2} \neq m_{\tilde{q}_3}\,, \\
\text{1 slepton mass} &: m_{\tilde{\ell}}\,, \\
\text{1 trilinear coupling} &: A\,, \qquad (1)\\
\text{Higgs mixing parameter} &: \mu\,, \\
\text{Pseudoscalar Higgs mass} &: M_A\,, \\
\text{Ratio of vevs} &: \tan\beta\,.
\end{aligned}
$$

Once and a while it hits the blogosphere!

nature International weekly journal of science

Home | News & Comment | Research | Careers & Jobs | Current Issue

Mysterious galactic signal points LHC to dark matter

High-energy particles at centre of Milky Way now within scope of Large Hadron Collider.

Davide Castelvecchi

05 May 2015

Rights & Permissions

A. Mellinger, CMU; T. Linden, Univ. of Chicago/NASA G

γ-rays (shown in false colour) emitted from the Galactic Centre are giving the LHC a firm target in it hunt for dark matter.

It is one of the most disputed observations in physics. But an explanation may be in sight for a mysterious excess of high-energy photons at the centre of the Milky Way. The latest analysis suggests that the signal could come from a dark-matter particle that has just the right mass to show up at the world's largest particle accelerator.

The Large Hadron Collider (LHC), housed at the CERN particle-physics laboratory near Geneva, Switzerland, is due to restart colliding protons this summer after a two-year hiatus (see 'LHC 2.0: A new view of the Universe'). Physicists there have told *Nature* that they now plan to make the search for such a particle a top target for the collider's second run.

Resolution may be just around the corner. In addition to being produced at the LHC, the neutralino could also be within the shooting range of next-generation underground experiments that are trying to catch dark-matter particles that happen to fly through Earth, says physicist Albert De Roeck, who works on the CMS, one of the two LHC detectors that will hunt for dark matter. If such a particle is indeed the cause of the γ-rays, he says, "it seems that the dark-matter signals should be observed very soon now".

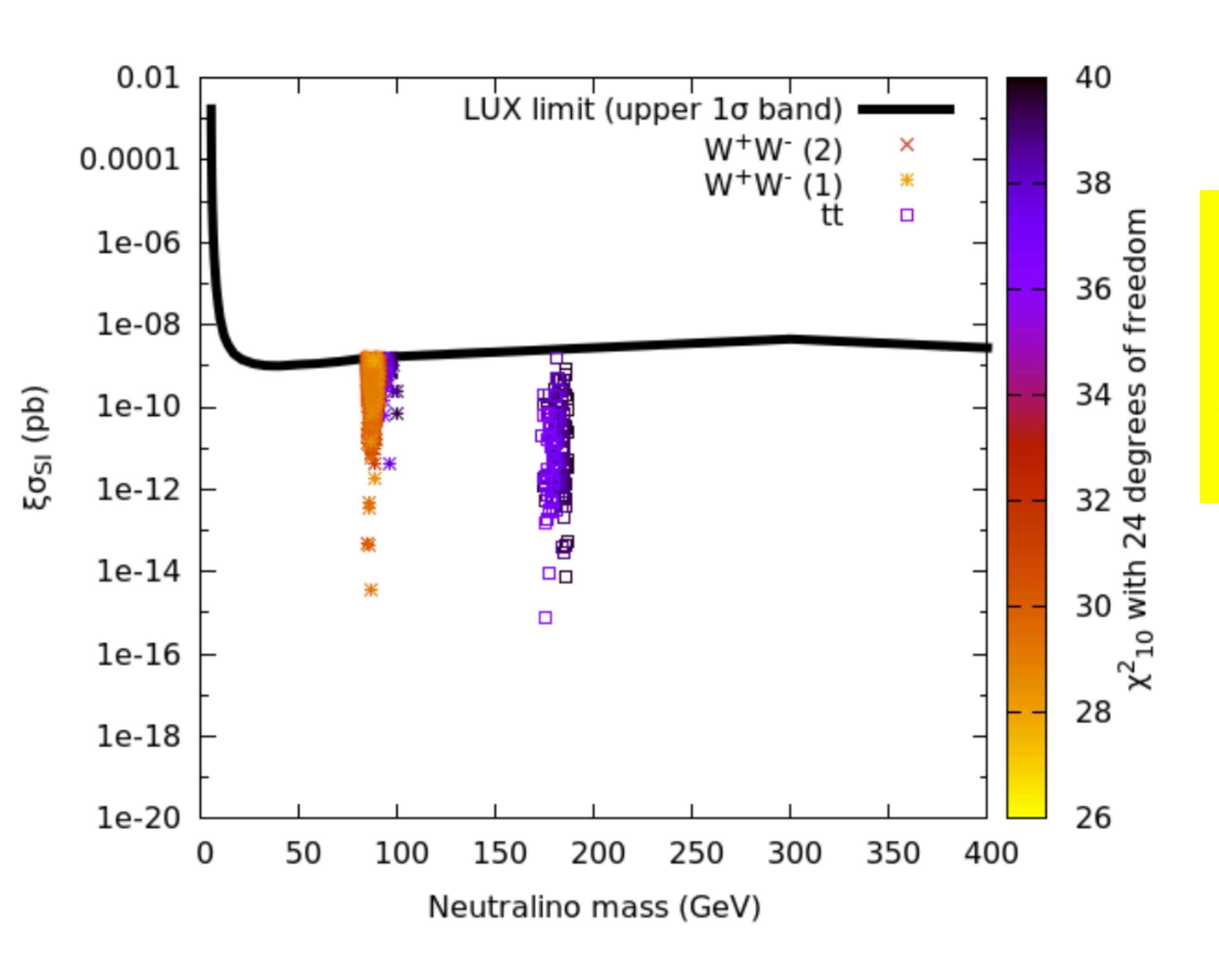
A description of the Galactic Center excess in the Minimal Supersymmetric Standard Model

Abraham Achterberg,[a] Simone Amoroso,[e] Sascha Caron,[a,b] Luc Hendriks,[a] Roberto Ruiz de Austri,[c] Christoph Weniger[d]

arXiv:1502.05703

Search for Models compatible with the FERMI-LAT excess and LHC limits

Where Dark Matter Should Be Found…



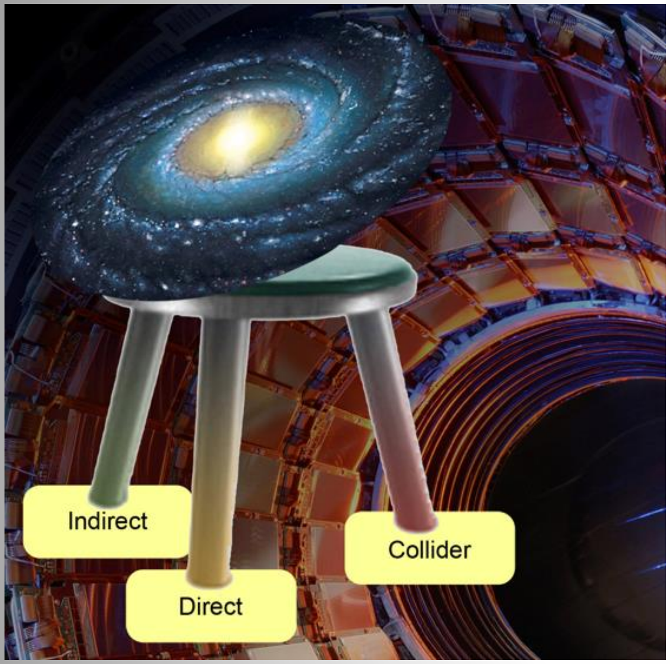
pMSSM solutions:
FERMI-LAT excess
Due to DMDM->WW
or DMDM->toptop
annihilation

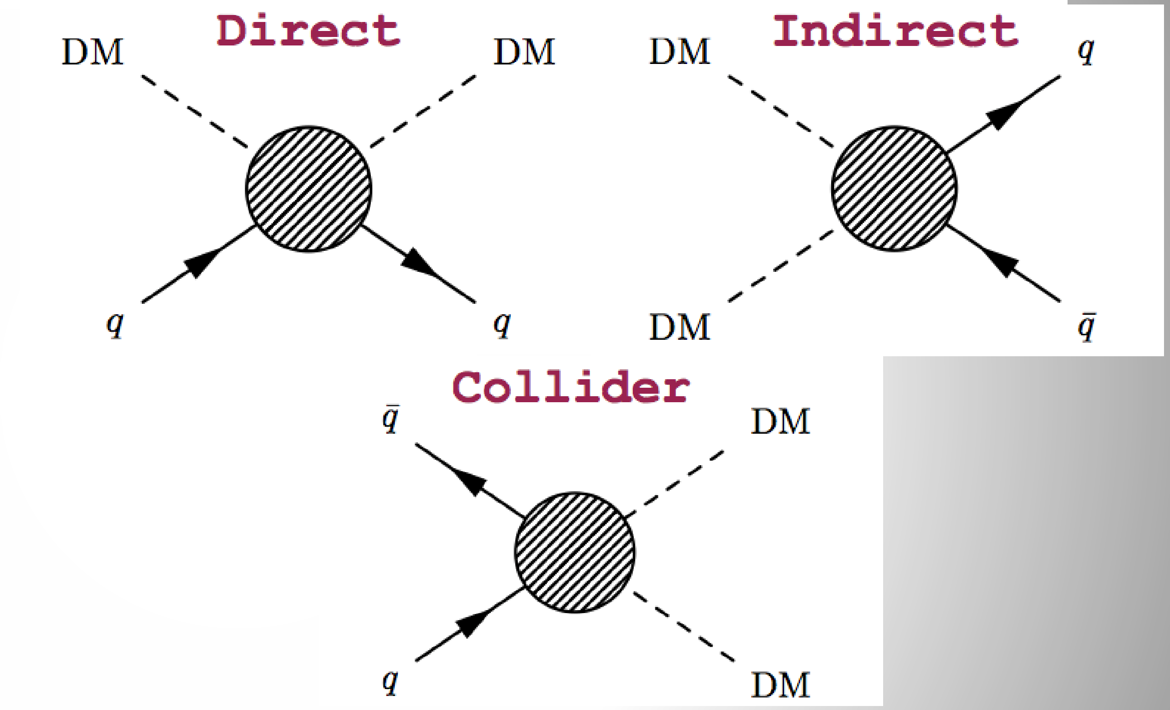
Who will get there first? The LHC? Direct Searches? To be continued…

General Searches for Dark Matter

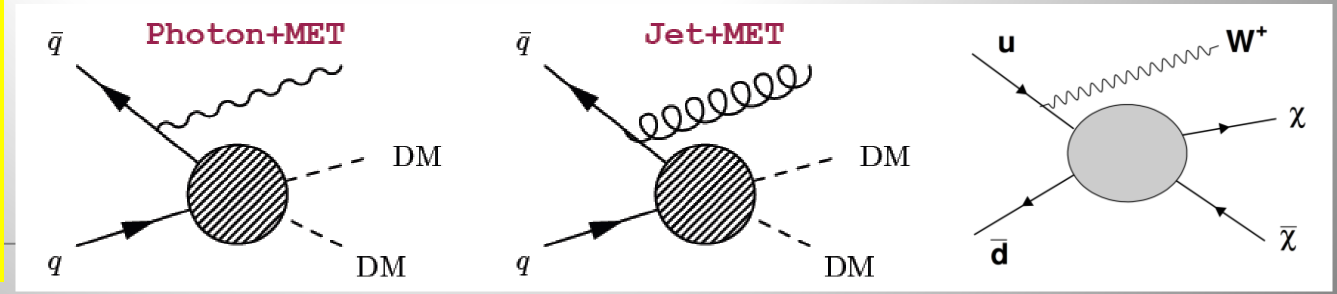
The Generic Dark Matter Connection

Searches for mono-jets and mono-photons can be used to search for Dark Matter (DM)





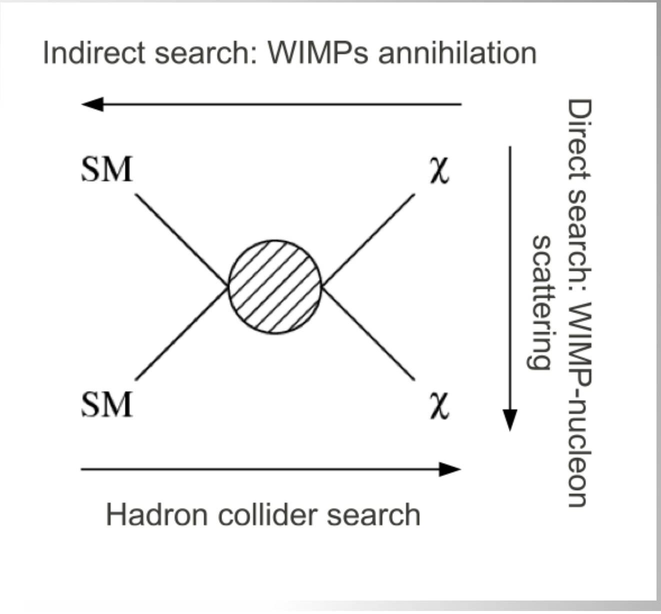
Use effective theory or better simplified models to relate measurements to Dark Matter studies



Dark Matter Interpretation

Convert experimental search results into limits on DM quantities
Two ways:

- Effective field theory (EFT):
  - Mediator too heavy to be generated directly
  - Contact interation with suppression scale $M_\star \sim \frac{M}{\sqrt{g_\chi g_{SM}}}$, with g_χ and g_{SM} the couplings to Standard Model (SM) and DM, and M the mediator mass
- Simplified models: Popular in Supersymmetry
  - Specified massive mediator
  - UV-complete (no validity issue)



Name	Initial state	Type	Operator
D1	qq	scalar	$\frac{m_q}{M_\star^3}\bar{\chi}\chi\bar{q}q$
D5	qq	vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\chi\bar{q}\gamma_\mu q$
D8	qq	axial-vector	$\frac{1}{M_\star^2}\bar{\chi}\gamma^\mu\gamma^5\chi\bar{q}\gamma_\mu\gamma^5 q$
D9	qq	tensor	$\frac{1}{M_\star^2}\bar{\chi}\sigma^{\mu\nu}\chi\bar{q}\sigma_{\mu\nu}q$
D11	gg	scalar	$\frac{1}{4M_\star^3}\bar{\chi}\chi\alpha_s(G^a_{\mu\nu})^2$

Types of interactions chosen in the studies @ LHC

Discussions on the region of validity for the EFTs…

Data Interpretation EFTs

- Pair-production of χ characterised by a contact interaction with operators

$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{q}\gamma^\mu q)}{\Lambda^2}$$

vector --> spin independent (SI)

$$\mathcal{O}_{AV} = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{q}\gamma^\mu\gamma_5 q)}{\Lambda^2}$$

axial-vector --> spin-dependent (SD)

- Cross section depends on the mass (m_χ) and the scale Λ (for couplings g_χ, g_q)

$$\sigma_{SI} = 9\frac{\mu^2}{\pi\Lambda^4}$$

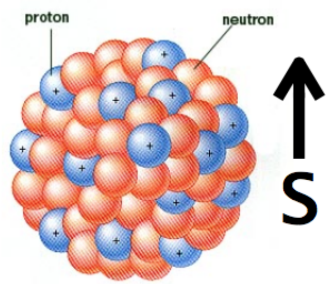
$$\sigma_{SD} = 0.33\frac{\mu^2}{\pi\Lambda^4}$$

spin-independent
and spin-dependent
cross sections

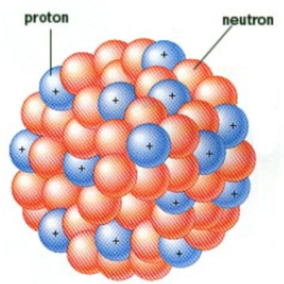
$$\Lambda = M/\sqrt{g_\chi g_q} \qquad \mu = \frac{m_\chi m_p}{m_\chi + m_p}$$

[Bai, Fox and Harnik, JHEP 1012:048 (2010), Goodman, Ibe, Rajaraman, Shepherd, Tait, Yu, Phys.Rev.D82:116010 (2010), Beltran, Hooper, Kolb, Krusberg, Tait, JHEP 1009:037 (2010)]

Spin Dependent and Independent σ



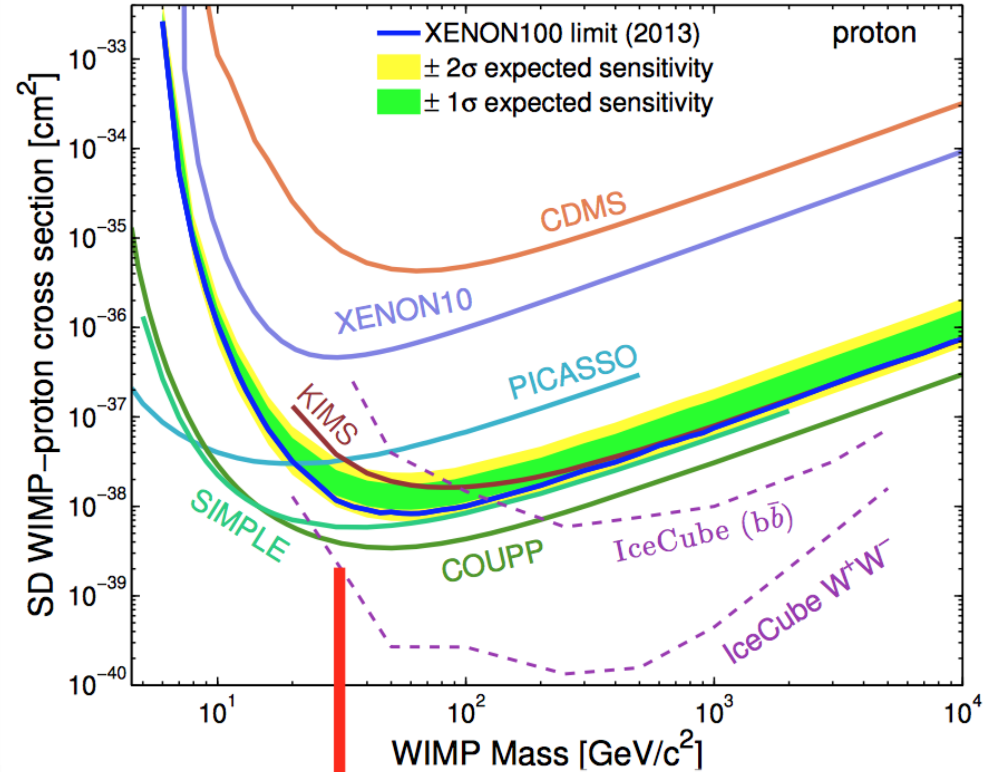
$\sigma^{SD}_{\chi N}$



$\sigma^{SI}_{\chi N} \sim A^2 \sigma^{SD}_{\chi N}$

$A^2 \sim 17000$ for Xenon

$\sigma^{SD}_{\chi N}$ **limit**

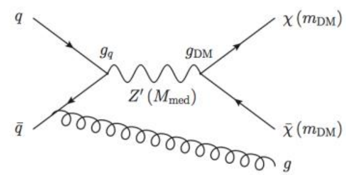


$\sigma^{SI}_{\chi N}$ **limit** is 10^5 times more stringent

Mono-object Searches in CMS

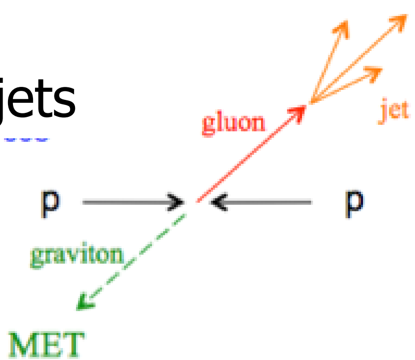
- Mono-jets: Generally the most powerful
- Mono-photons: First used for dark matter Searches
- Mono-Ws: Distinguish dark matter couplings to u- and d-type of quarks
- Mono-Zs: Clean signature
- Mono-Tops: Couplings to tops
- Mono-Higgs: Higgs-portals
- Higgs Decays?

Effective Field Theories for DM interpretation are under scrutiny!
Alternatives such as SMS proposed

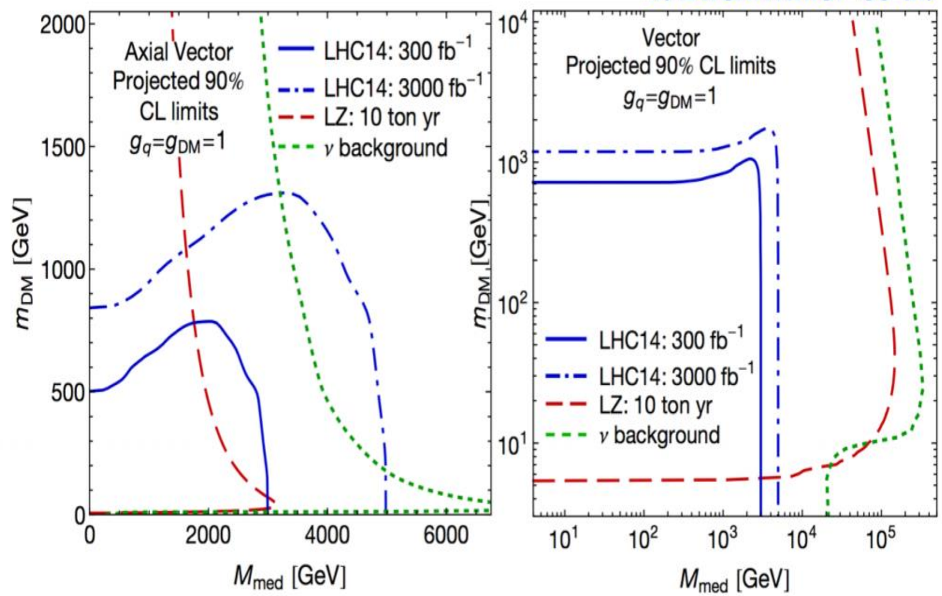


arXiv:1407.8257
arXiv:1411.0535

Example Monojets



Dark Matter?

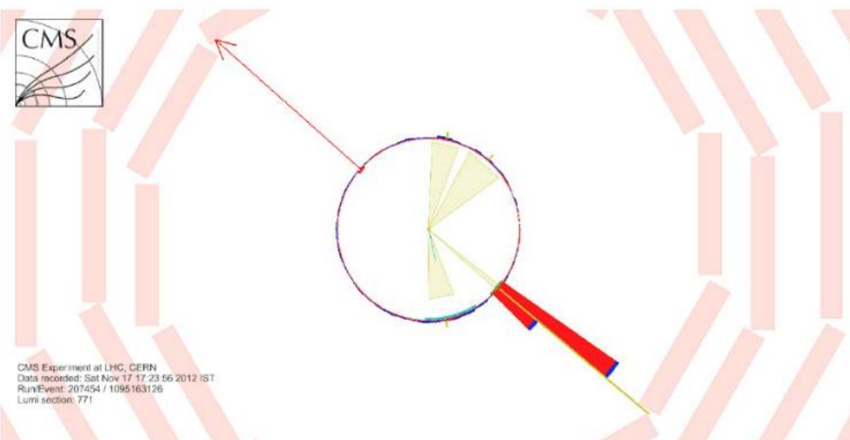


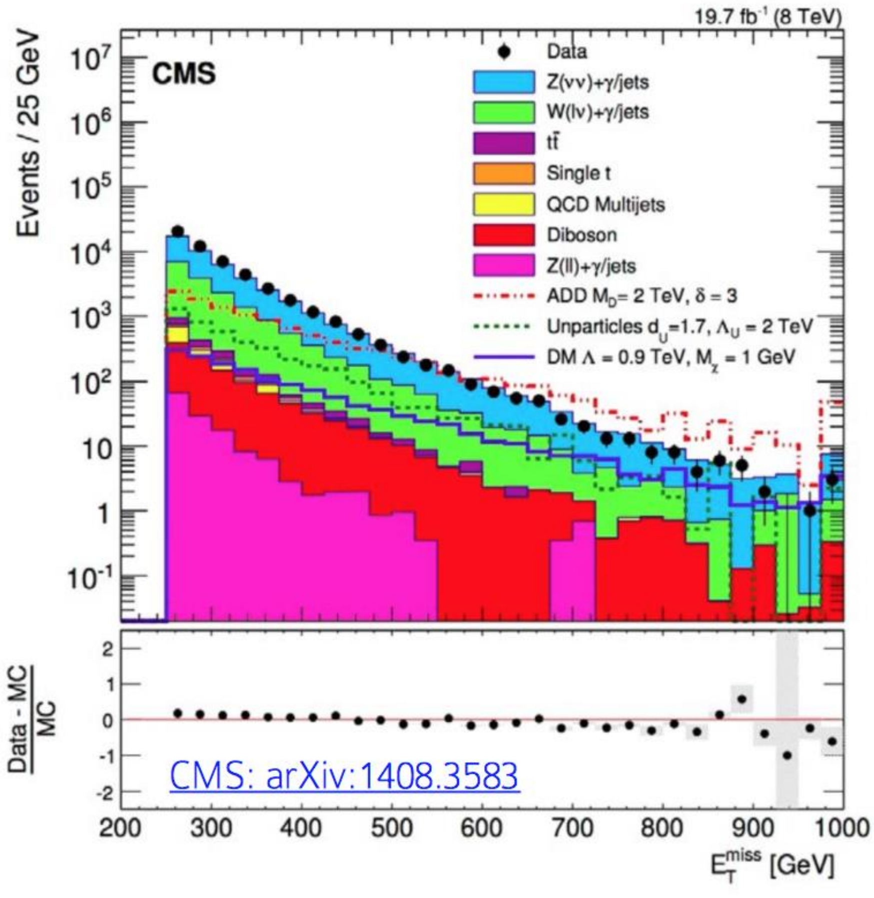
Mono-X Searches

Invisible DM particles **escape detection:**

LHC experiment strategy: tag events using **recoiling** object(s), measure **missing transverse momentum (Missing E_T)**

CMS: arXiv:1410.8812



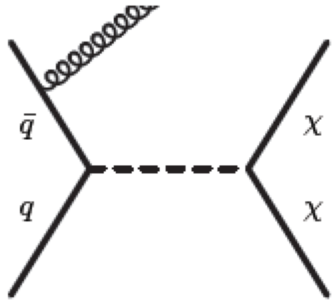


CMS: arXiv:1408.3583

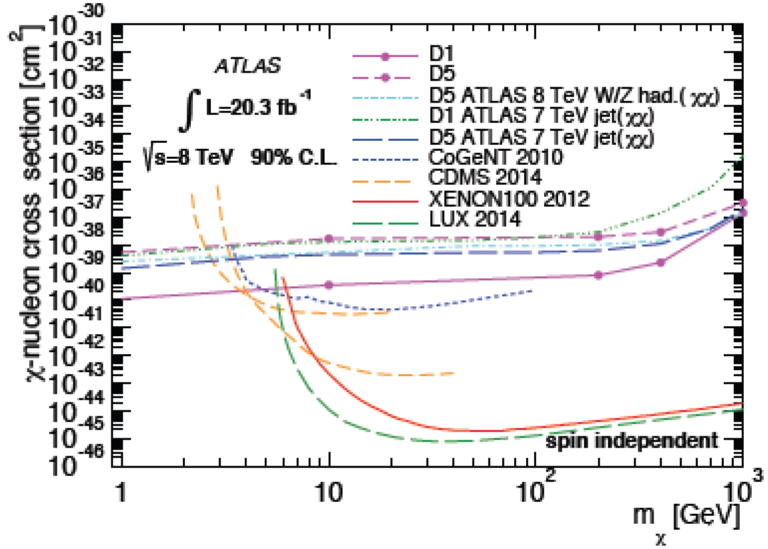
Dark Matter signature:
excess in **tails of E_T distribution**
(searches also sensitive to other models)

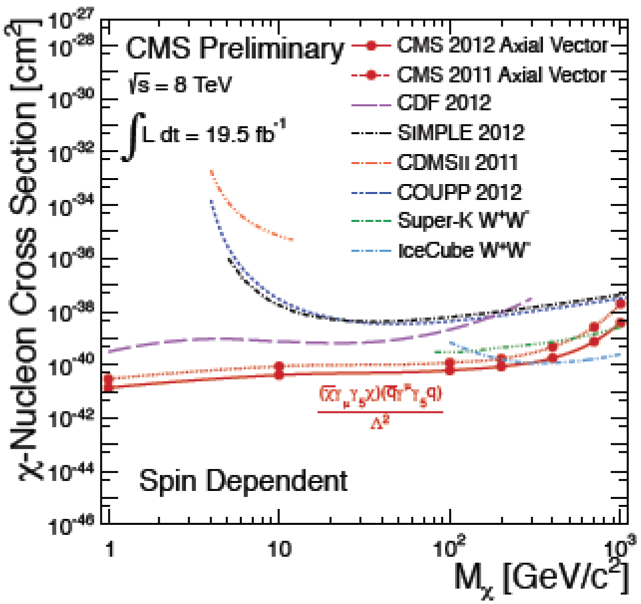
Some Recent Results (EFTs)

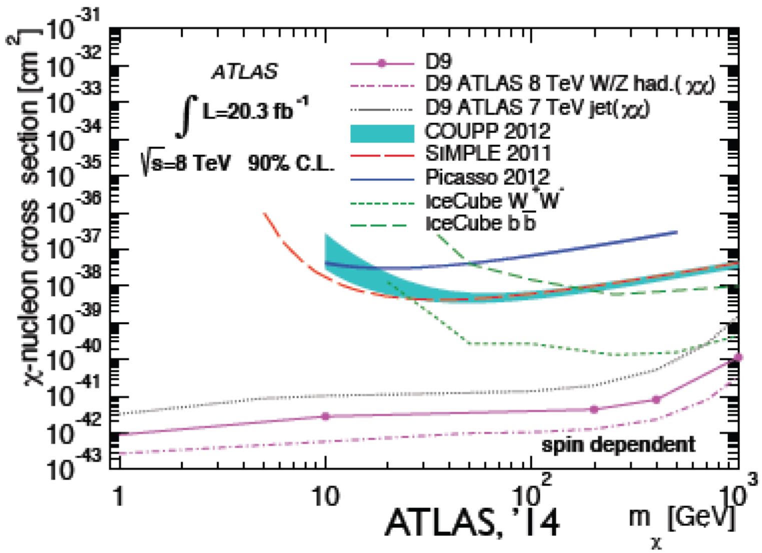
The cross section can be estimated to be



$$\sigma \sim \alpha_s g_{\rm DM}^2 g_q^2 \frac{p_T^2}{M^4}$$







@Silvia Pascoli

The Search for Mono-Higgs Next?

Mono-Higgs: a new collider probe of dark matter

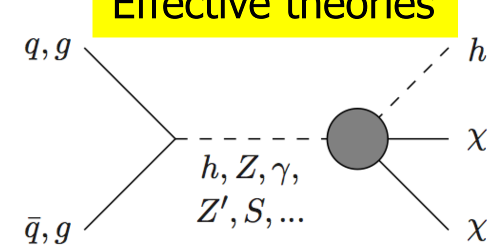
Linda Carpenter,[1] Anthony DiFranzo,[2] Michael Mulhearn,[3] Chase Shimmin,[2] Sean Tulin,[4] and Daniel Whiteson[2]

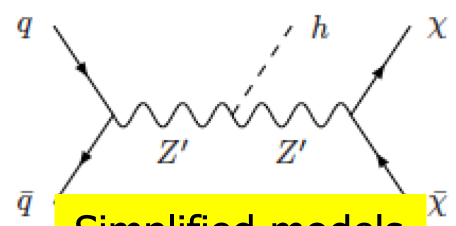
[1] *Department of Physics and Astronomy, Ohio State University, OH*
[2] *Department of Physics and Astronomy, University of California, Irvine, CA 92697*
[3] *Department of Physics, University of California, Davis, CA 95616*
[4] *Department of Physics and Astronomy, University of Michigan, MI*

ATLAS arXiv:1506.01081

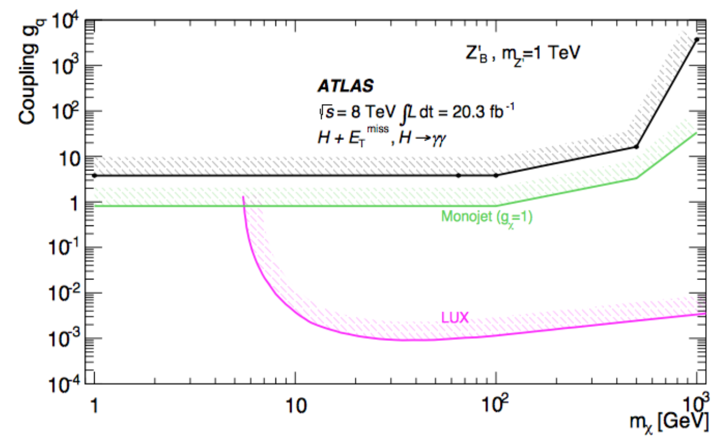
The next mono-object to study?
No ISR, but coupling to the DM directly

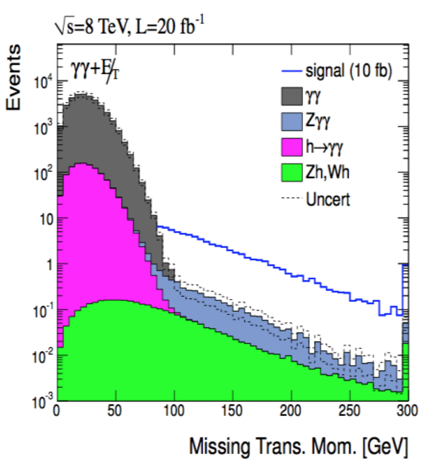
Effective theories

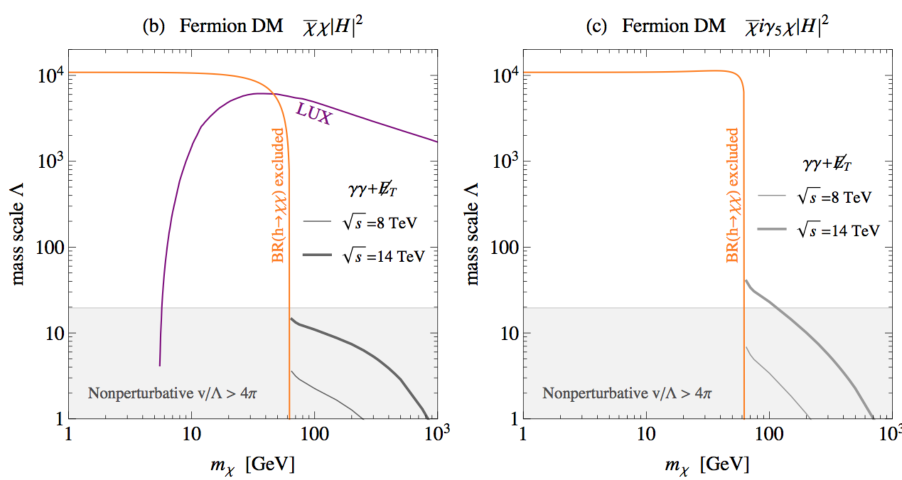




Simplified models







Result: Promising for 14 TeV?

2015: LHC-Wide Dark Matter Group

- **ATLAS-CMS Dark Matter Forum formed in Nov 2014**
- **Primary goal of forum : form consensus on the use of simplified models and EFTs to guide early Run-2 searches, by bringing together expertise on DM from experimental and theory communities.**

This forum will be followed up by a LPC with a new DM study group

LHC-Wide Dark Matter Group

- Final report of the DM forum, to be submitted to arXiv end of month

- 150 page document, detailing the recommended set of DM simplified models, presentation of EFT results, matrix element implementation etc

- Document reviewed by external reviewers

- ~150 signatories: CMS, ATLAS, theorists

Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Matter Forum

July 6, 2015

Daniel Abercrombie *MIT, USA*
Nural Akchurin *Texas Tech University, USA*
Ece Akilli *Université de Genève, DPNC, Switzerland*
Juan Alcaraz Maestre *Centro de Investigaciones Energéticas Medioambientales y Tecnológicas (CIEMAT), Spain*
Brandon Allen *MIT, USA*
Barbara Alvarez Gonzalez *CERN, Switzerland*
Jeremy Andrea *Institut Pluridisciplinaire Hubert Curien/Département Recherches Subatomiques, Université de Strasbourg/CNRS-IN2P3, France*
Alexandre Arbey *Université de Lyon and Centre de Recherche Astrophysique de Lyon, CNRS and Ecole Normale Supérieure de Lyon, France and CERN Theory Division, Switzerland*
Georges Azuelos *University of Montreal and TRIUMF, Canada*
Patrizia Azzi *INFN Padova, Italy*
Mihailo Backović *Centre for Cosmology, Particle Physics and Phenomenology (CP3), Université catholique de Louvain, Belgium*
Yang Bai *Department of Physics, University of Wisconsin-Madison, USA*
Swagato Banerjee *University of Wisconsin-Madison, USA*
James Beacham *Ohio State University, USA*
Alexander Belyaev *Rutherford Appleton Laboratory and University of Southampton, United Kingdom*
Antonio Boveia (editor) *CERN, Switzerland*
Amelia Jean Brennan *The University of Melbourne, Australia*
Oliver Buchmueller *Imperial College London, United Kingdom*
Matthew R. Buckley *Department of Physics and Astronomy, Rutgers University, USA*
Giorgio Busoni *SISSA and INFN, Sezione di Trieste, Italy*
Michael Buttignol *Institut Pluridisciplinaire Hubert Curien/Département Recherches Subatomiques, Université de Strasbourg/CNRS-IN2P3, France*
Giacomo Cacciapaglia *Université de Lyon and Université Lyon 1, CNRS/IN2P3, UMR5822, IPNL, France*
Regina Caputo *Santa Cruz Institute for Particle Physics, Department of Physics and Department of Astronomy and Astrophysics, University of California at Santa Cruz, USA*
Linda Carpenter *Ohio State University, USA*
Nuno Filipe Castro *LIP-Minho, Braga, and Departamento de Física e Astronomia, Faculdade de Ciências da Universidade do Porto, Portugal*
Guillelmo Gomez Ceballos *MIT, USA*
Yangyang Cheng *University of Chicago, USA*
John Paul Chou *Rutgers University, USA*
Arely Cortes Gonzalez *IFAE Barcelona, Spain*

Using Simplified ModelS (SMS) as in SUSY

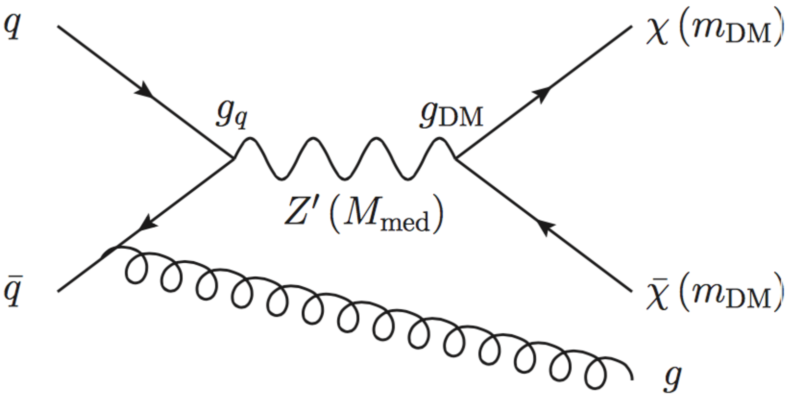
➡ Assume interaction exists between SM and DM

➡ DM is single particle, Dirac fermion

➡ Minimal Flavor Violation

➡ Assume minimal decay width for particle mediating interaction

➡ These assumptions only add a limited number of new particles and new interactions to the SM. Simplified models can be used as starting points to build more complete theories.



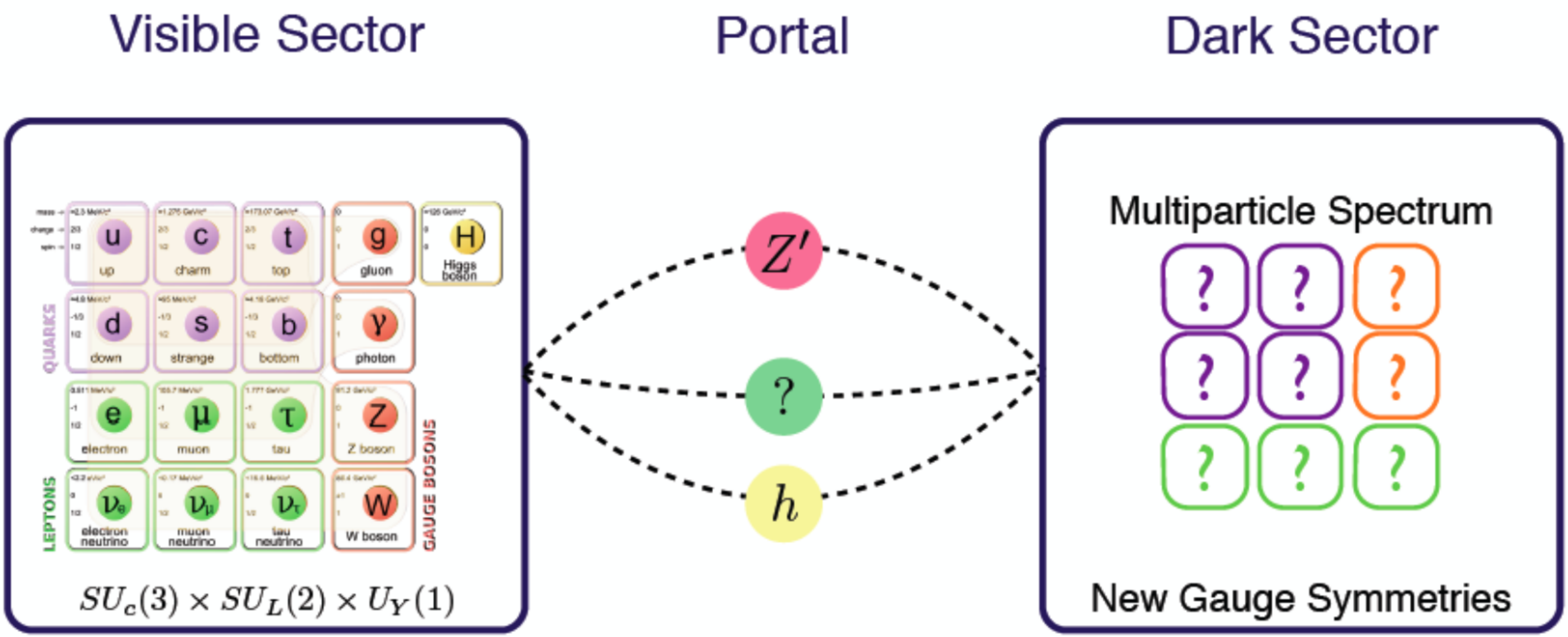
Factorised approach does not always lead to full theories but useful as a starting point giving a distinct but complementary set of signatures to explore.

Cite: “Why should 5% of the mass density have all the fun?”

Mirror DM? Mini micro-meteorites of dark matter?

Dark matter as a cancer hazard ? arXiv:1509.05139

Olga Chashchina, Zurab Silagadze



More on Dark Matter in Egypt Soon

CTP@BUE

HOME TOPICS PROGRAMME ACCOMMODATION REGISTER CONTACT

ORGANISERS

- **Nicola de Filippis** (Politecnico and INFN Bari)
- **Albert de Roeck** (Antwerp/CERN)
- **Amr El-Zant** (CTP-BUE, Cairo)
- **Joseph Silk** (IAP/JHU/Oxford)

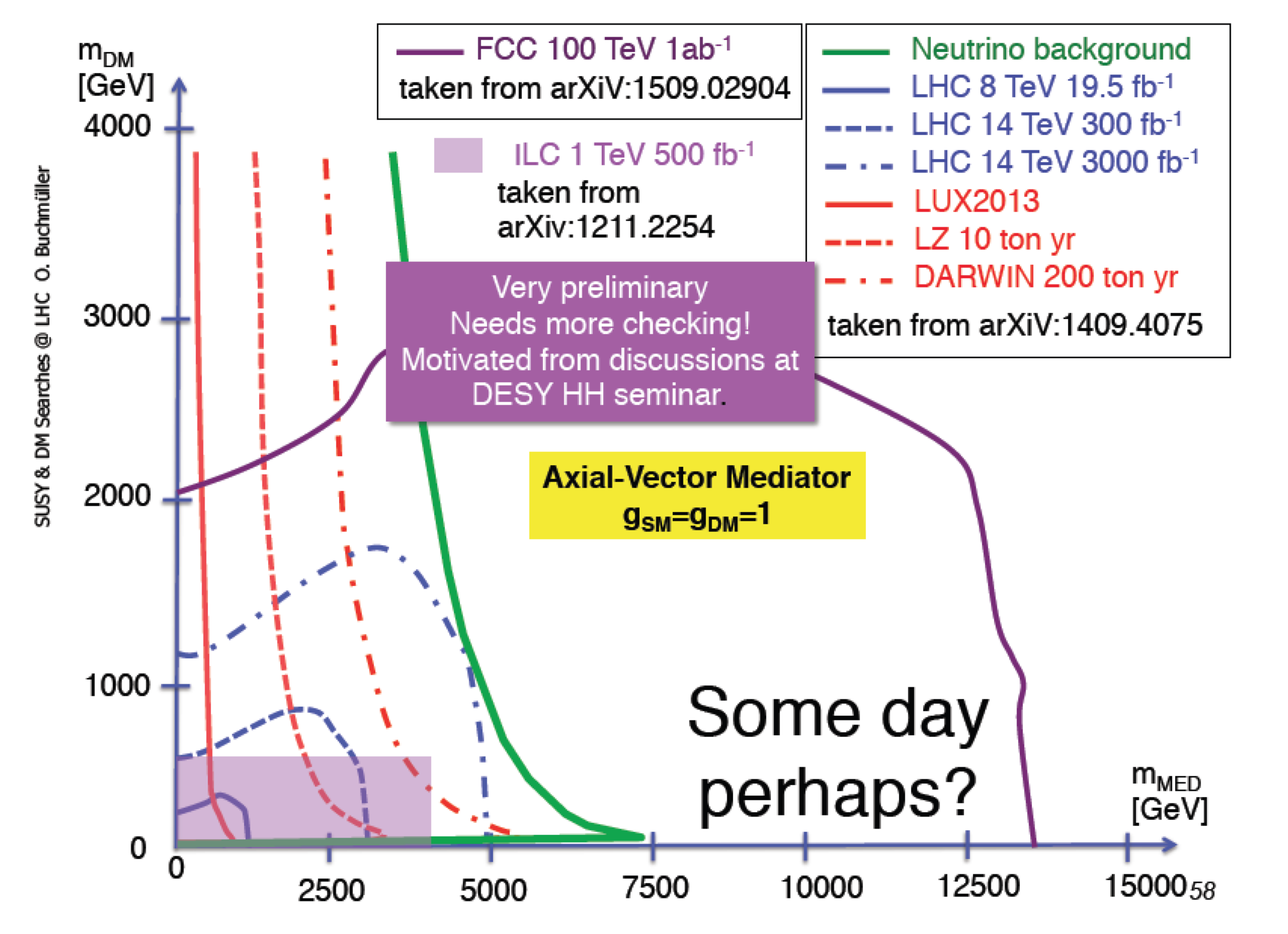
This meeting aims to bring together members of the astro-particle physics community - particularly those involved in dark matter dynamics, physics of the early universe and indirect detection signals -- with those working in dark matter searches at the LHC and in direct detection experiments. We aim this to be a forum for presentations, and informal interdisciplinary discussion, of the prospects for dark matter phenomenology, in light of the launch of Run 2 at the LHC and planned upgrades of direct search experiments, as well as recently planned experiments to explore the low energy hidden sector.

http://dmc.ctp-bue.org

Summary

- Dark Matter is an important open point in fundamental physics right now and the LHC data can contribute to the quest.
- The Higgs particle may couple to DM or may even decay into it. Invisible decays and deviations from SM Higgs couplings are explored
- Supersymmetry scenarios with R_P-conservation can have a natural DM candidate. Discovery of supersymmetry will have important impact for DM
- Generic searches for DM in analyses dealing with missing E_T: typically mono-object searches
- So far exclusion limits only, but maybe soon with the collisions at 13 TeV :

The Future?



SUSY & DM Searches @ LHC O. Buchmüller
m_{DM} [GeV]
4000
3000
2000
1000
0
FCC 100 TeV 1ab^{-1}
taken from arXiV:1509.02904
ILC 1 TeV 500 fb^{-1}
taken from arXiv:1211.2254
Neutrino background
LHC 8 TeV 19.5 fb^{-1}
LHC 14 TeV 300 fb^{-1}
LHC 14 TeV 3000 fb^{-1}
LUX2013
LZ 10 ton yr
DARWIN 200 ton yr
taken from arXiV:1409.4075
Very preliminary
Needs more checking!
Motivated from discussions at
DESY HH seminar.
Axial-Vector Mediator
$g_{SM}=g_{DM}=1$
Some day perhaps?
m_{MED} [GeV]
0
2500
5000
7500
10000
12500
15000