Overview of the Dark Matter Searches at the ATLAS Experiment

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IMPRS Young Scientists Workshop at Ringberg Castle
7 July 2015

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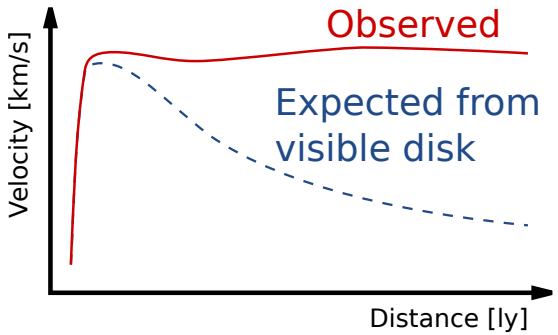
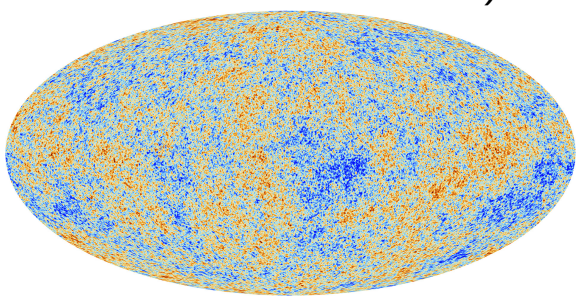
Motivation for Dark Matter (DM)

Presence of dark matter inferred from the observation of its gravitational interactions.

rotation curves of spiral galaxies



structure formation in the early universe ($\approx 25\%$ of the matter in our universe is DM)



gravitational lensing effect of galaxy clusters

Properties of Dark Matter

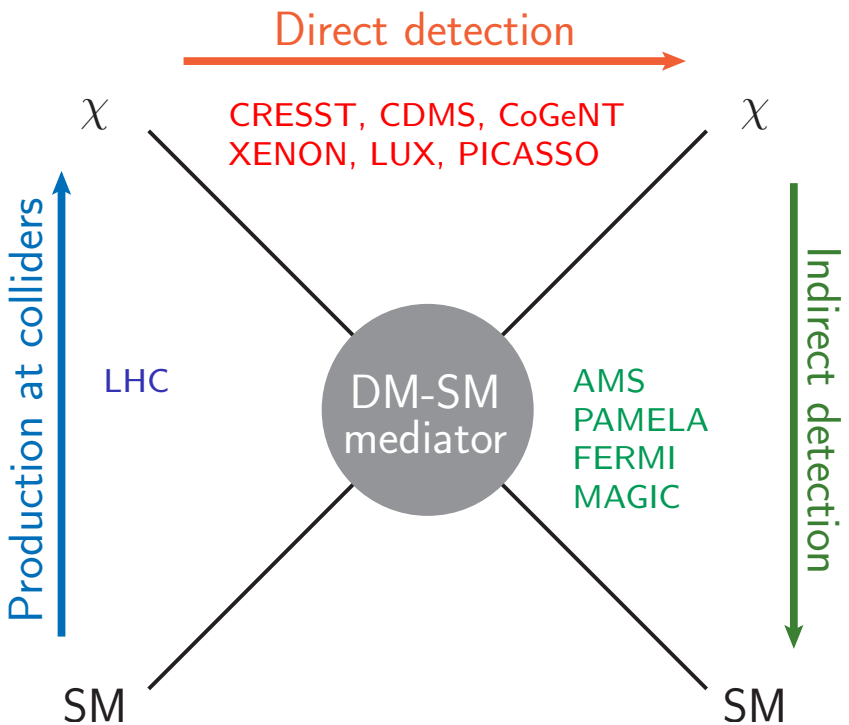
Requirements:

- massive
- stable
- electrically neutral
- weakly interacting

Candidates:

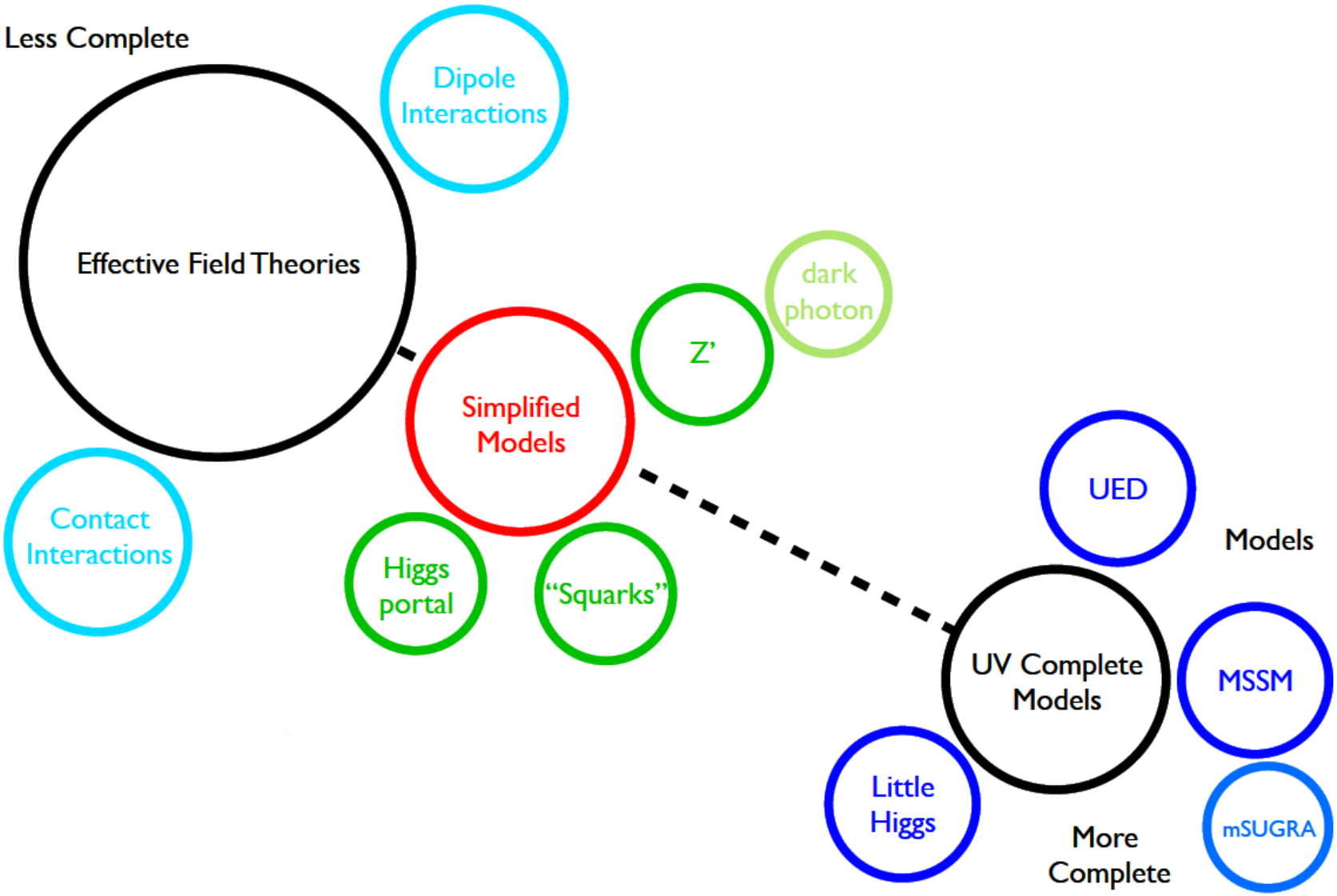
- WIMPs, Axions, sterile Neutrinos

Complementary dark matter experiments:

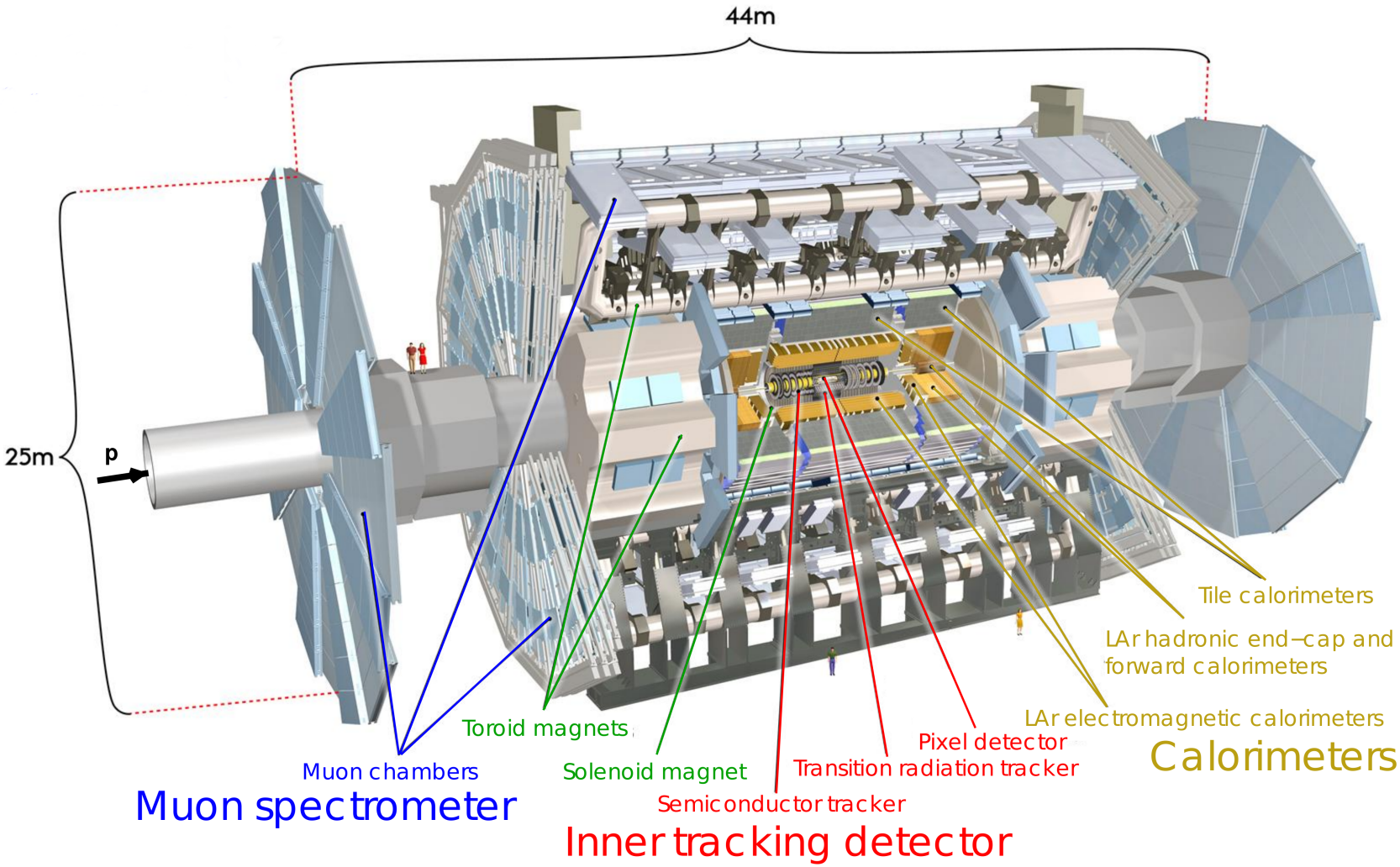


At colliders like the LHC, WIMPs are produced in pairs.

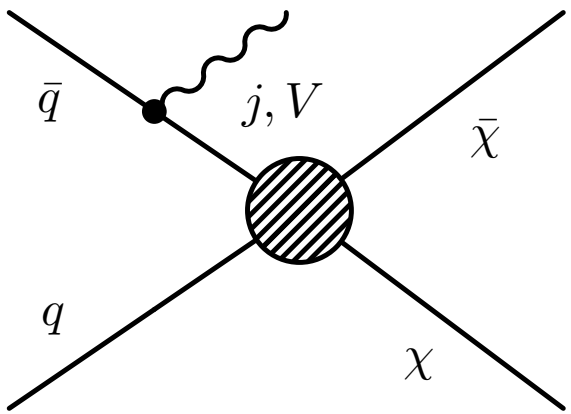
Spectrum of Theoretical Models



ATLAS Detector



- DM particles ($\chi\bar{\chi}$ pairs) escape undetected
- look for events with a large imbalance of energy in the transverse plane ($E_{\mathrm{T}}^{\mathrm{miss}}$)
- additional (triggerable) particles in the final state are needed:
  energetic jet, $V = \gamma, W, Z$ or a Higgs boson



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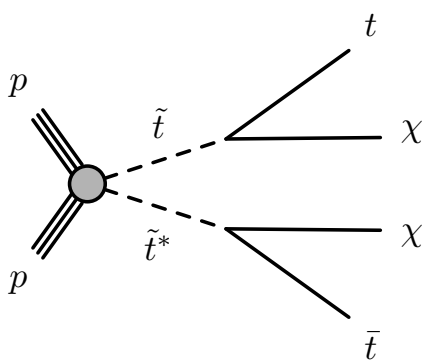
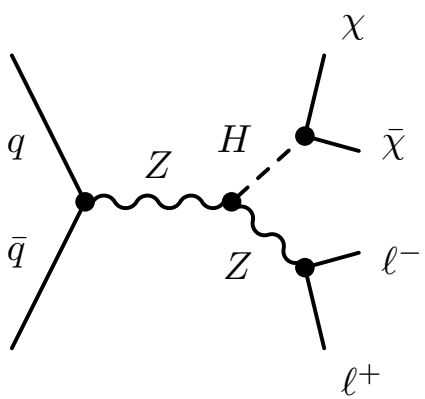
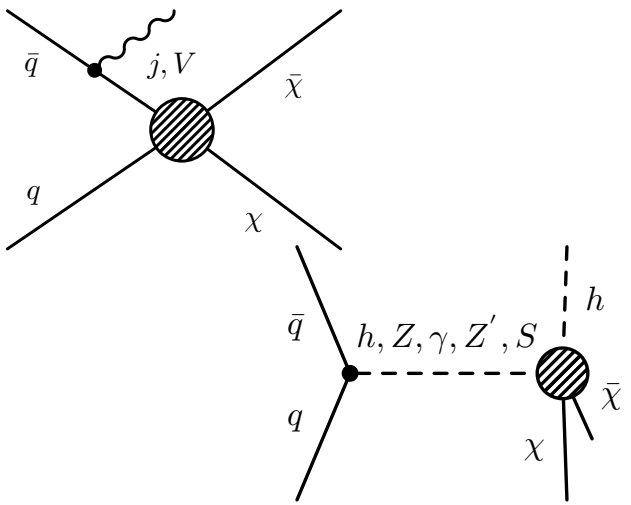


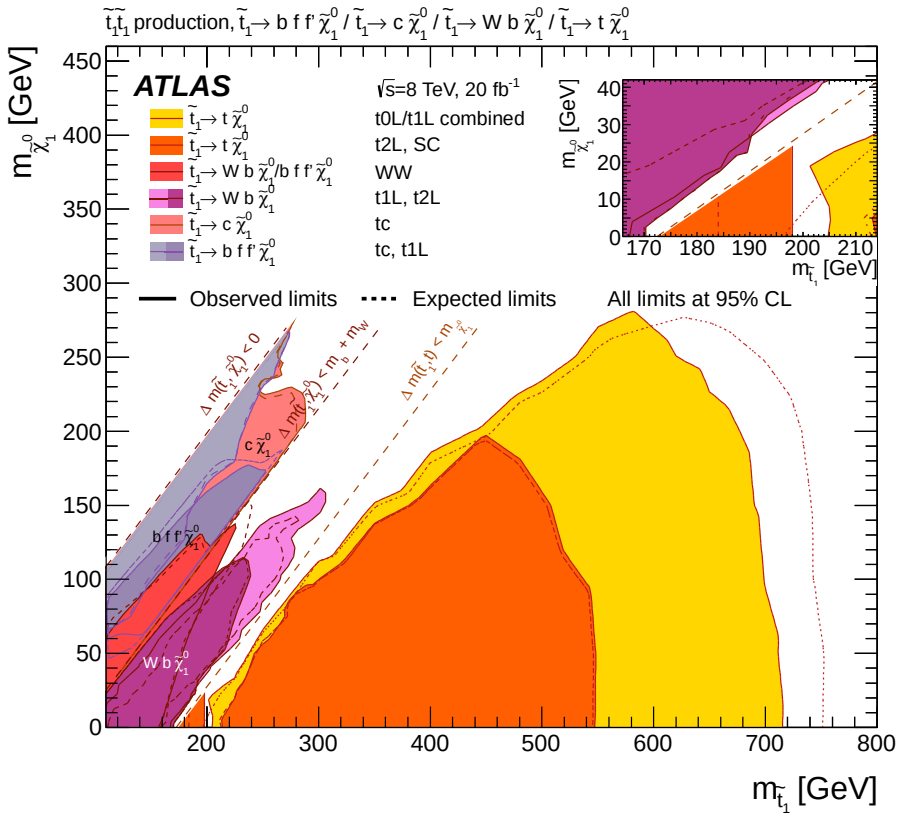




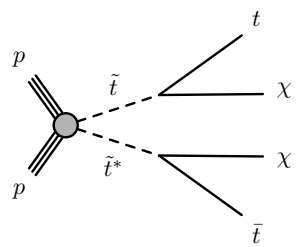
- R-parity conserving SUSY searches
- Higgs portal to dark matter
- mono-X searches, EFT or simplified models

RPC SUSY Searches - Direct stop Production

R-parity conserving SUSY models provide a perfect DM candidate.
SUSY particles are produced in pairs and decay in cascades to SM particles and two lightest SUSY particles (LSP) which escape undetected as WIMP candidates.



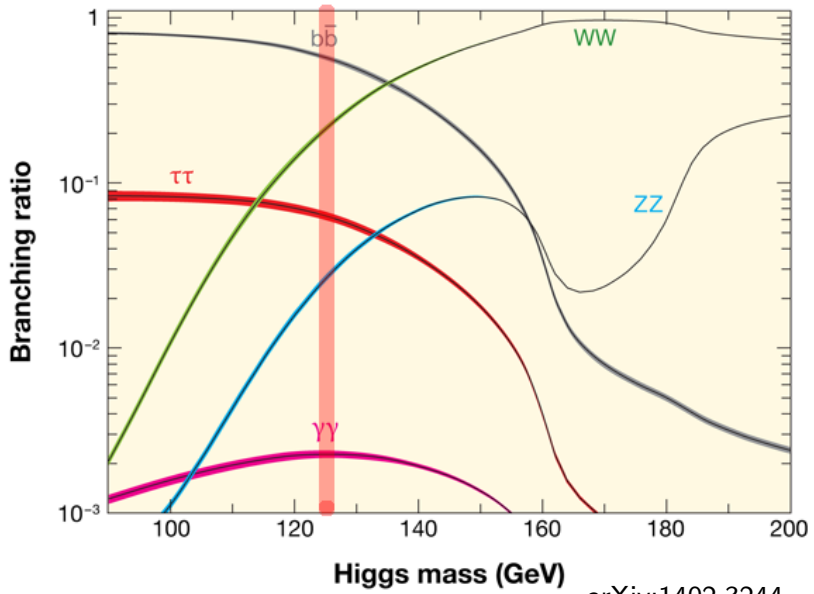
- signature: large $E_{\mathrm{T}}^{\mathrm{miss}}$
- SUSY searches are sensitive up to high LSP masses
- example: direct stop production



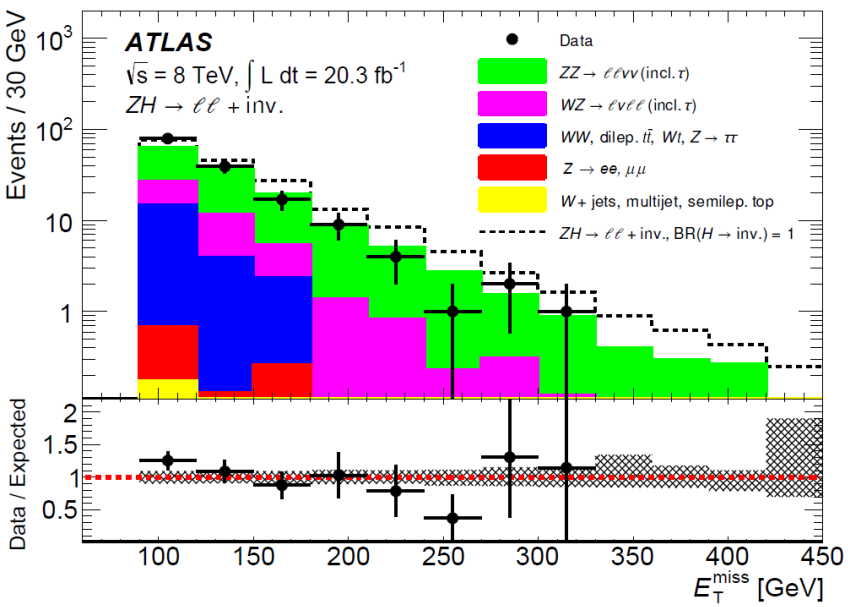
- in general many other RPC searches exist

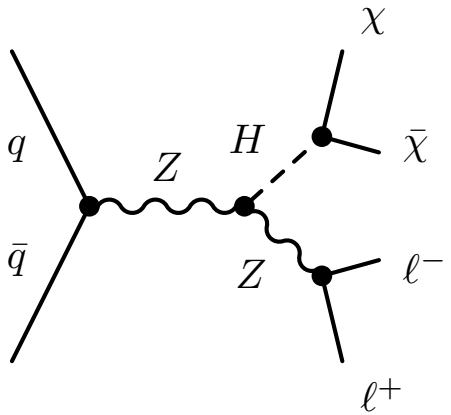
SUSY mass limits in the TeV range, new mass region accessible in LHC run 2.

Higgs Portal - Invisible Higgs Decay



arXiv:1402.3244

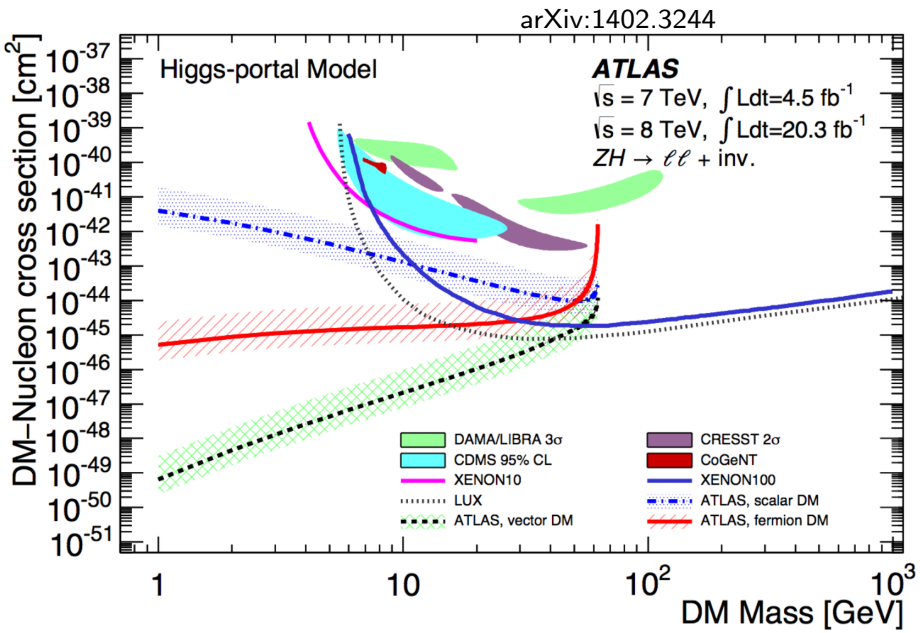


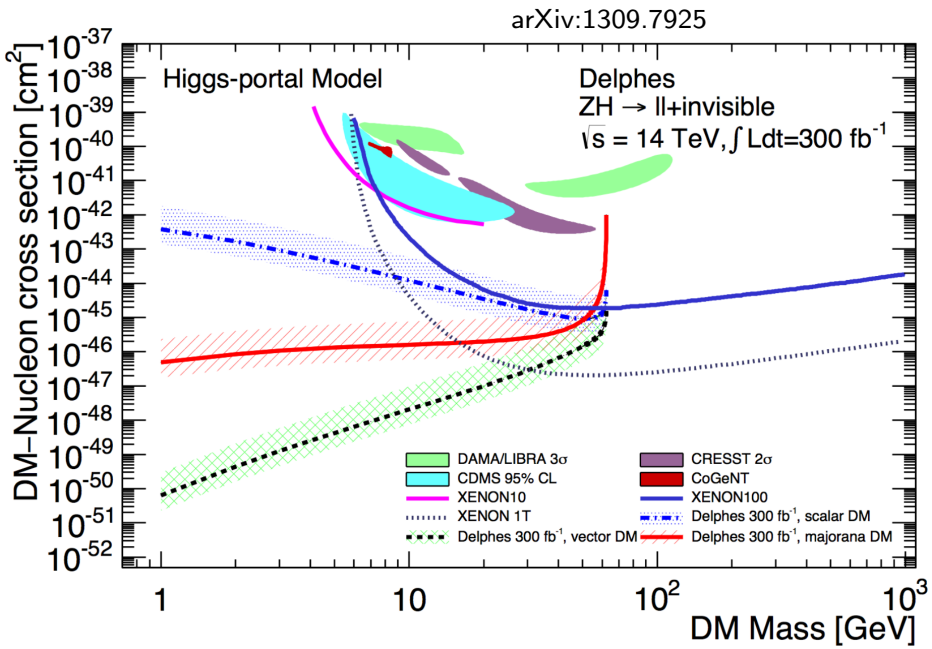


- assumption: DM particles couple directly to the Higgs boson
- DM particles relatively light ($m_\chi < m_h/2$)
- and contribute to the total Higgs decay width
- Constraints from measured Higgs decay BRs and from direct searches in associated Higgs production ZH with a vector boson as trigger particle

Upper limit of 75% (at 95% CL) on invisible Higgs decays BR from ATLAS run 1 data.

Higgs Portal - Current Results and Prospects

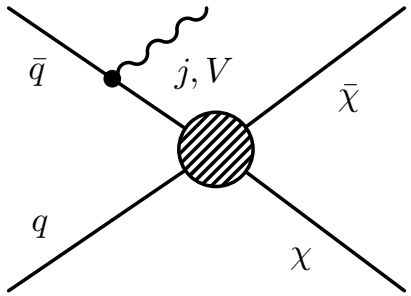




- ATLAS searches from run 1 translated into spin-independent DM-nucleon scattering cross section limits and compared to direct searches
  - assumptions of scalar, vector or Majorana fermion DM particles
  - strongest available limits for low-mass DM candidates
- ATLAS prospects for run 2, expected luminosity of 300 fb^{-1} at $\sqrt{s} = 14$ TeV

Dark Matter Mono-X Searches at ATLAS

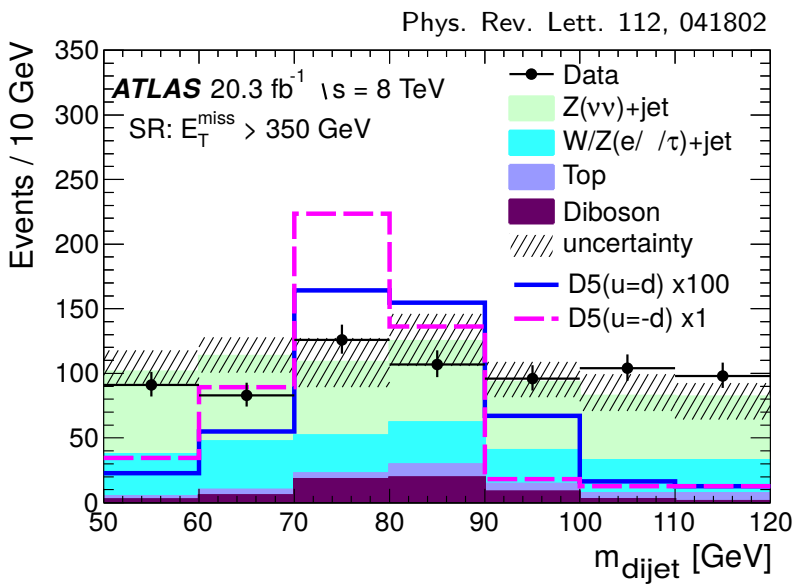
- in pp collisions, single jet/γ/W/Z's emitted in the initial state recoiling against pair produced WIMPs (missing transverse energy)



Example: Production of mono-W and Z decaying hadronically: jetjet+$\chi\bar{\chi}$

- EFT approach D5: dirac fermion, vector like opterator
- W can be emitted either from $\bar{q}$ or q

$\rightarrow$ destructive and constructive interference mode

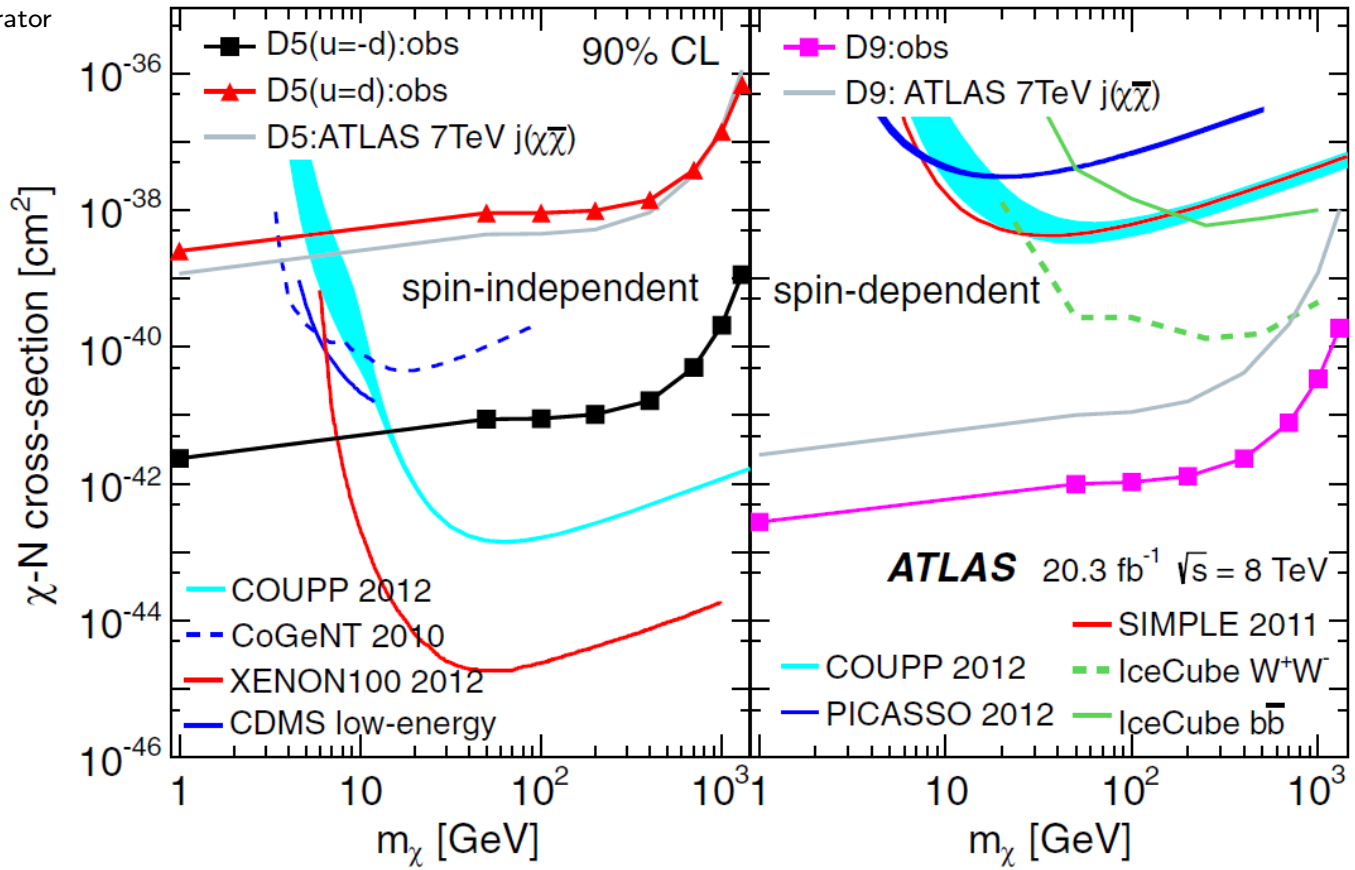


No excess above SM background seen in run 1.

Mono-X - Current Results

D5: vector like operator
D9: tensor like operator

Phys. Rev. Lett. 112, 041802

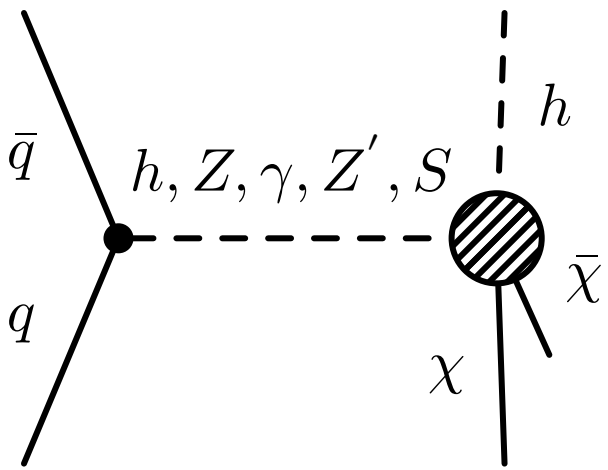


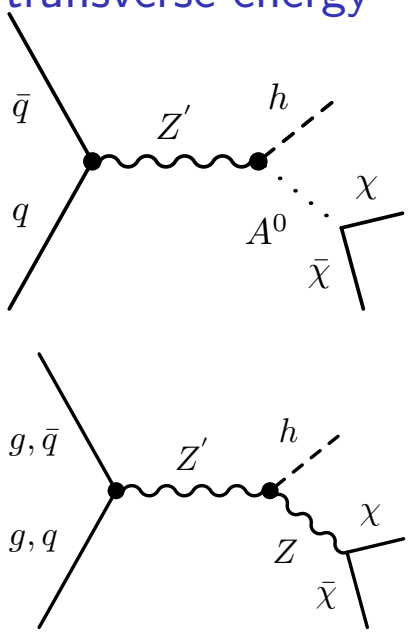
- WIMP pair production results interpreted as upper limits on the spin-dep. or spin-indep. DM-nucleon scattering cross section in comparison with direct searches
- mono-jet results are shown at $\sqrt{s} = 7$ TeV for comparison
- ATLAS allows to exclude cross sections also in the low mass region and in the spin-dep. case where direct searches are not very sensitive

The Mono-H Search

- new signal channel for WIMP searches
- SM Higgs ISR strongly suppressed due to the small couplings to light quarks
- Higgs boson produced in association with WIMP pair according to EFT or simplified models via intermediate particles
- $H \to b\bar{b}$ channel because of highest $BR(H \to b\bar{b}) \approx 0.577$

Final state with 2 b-jets and large missing transverse energy

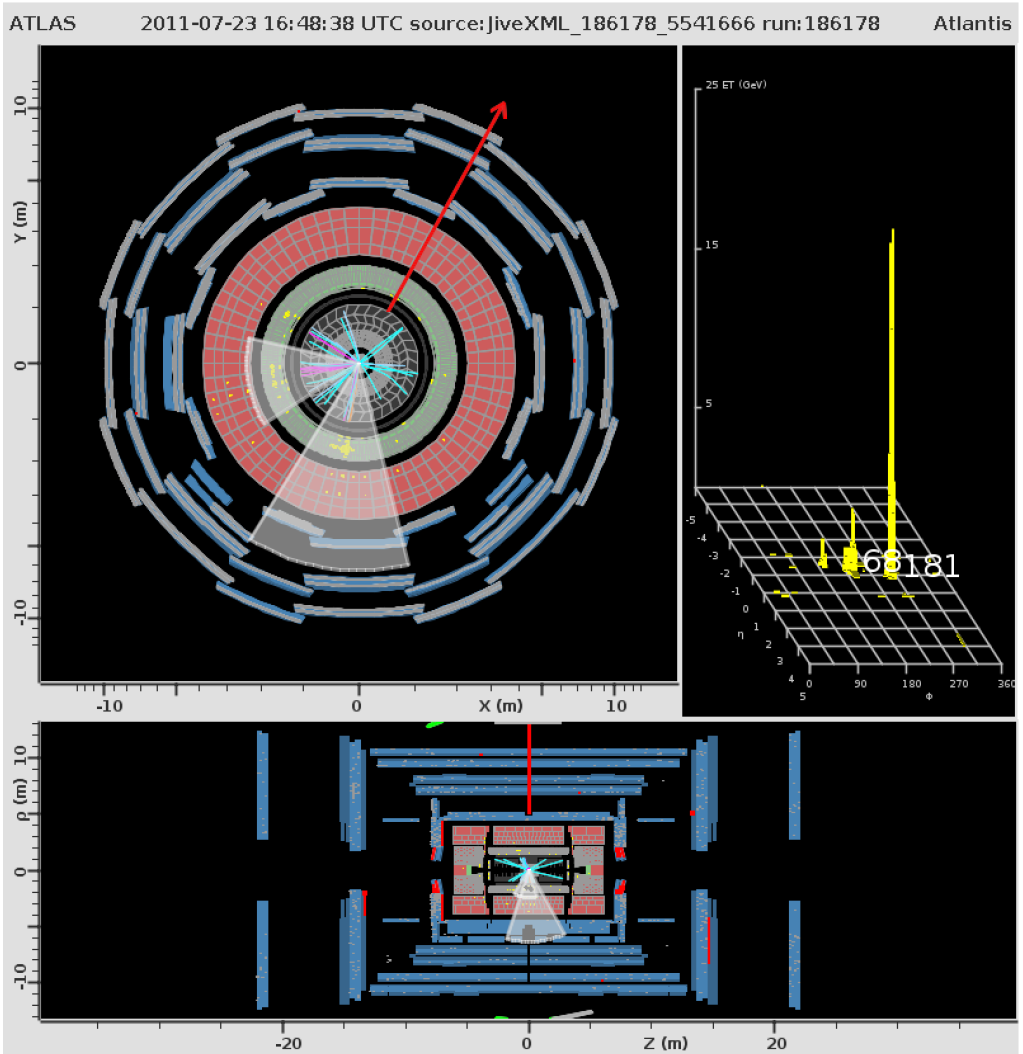




- Z' a heavy Z boson
- S a new scalar particle

- A^0 is a heavy pseudoscalar with a large BR to DM

Event Selection & Backgrounds



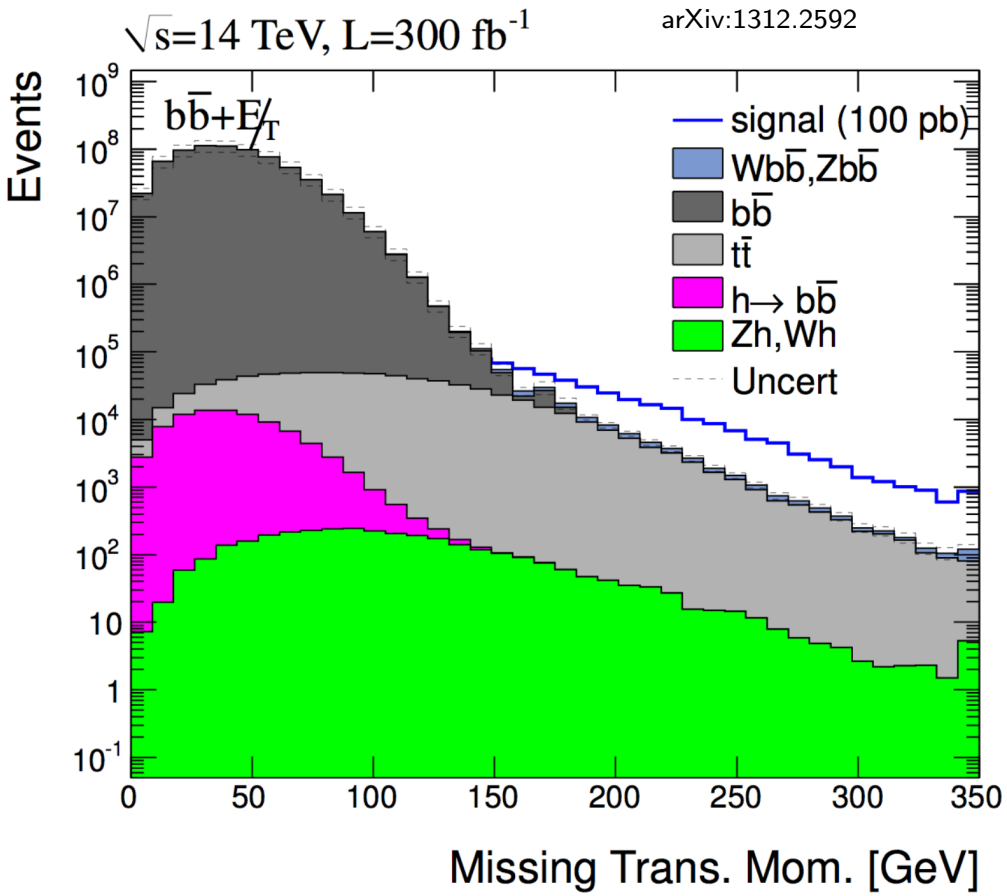
Resolved or boosted channel

- massive mediator particles can produce a highly boosted Higgs boson
- either 2 b-tagged jets or 1 fat-jet recoiling against a large E_T^{miss}
- no leptons
- $E_T^{\text{miss}} > 100$ or 300 GeV
- $\Delta\phi_{\text{min}}(E_T^{\text{miss}}, p_T^{\text{jet}}) > 1.0$
- 90 GeV $< m_{b\bar{b}} <$ 150 GeV

Backgrounds processes:

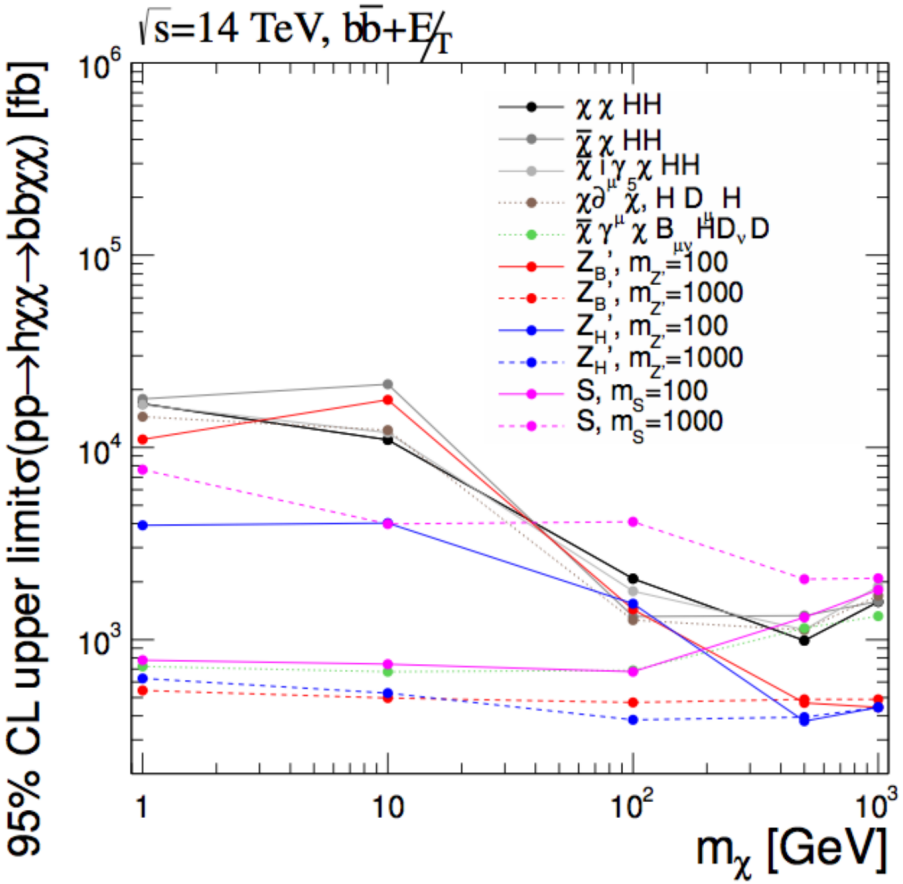
- irreducible background $Z \to \nu\bar{\nu} +$ jets
- reducible backgrounds: $W +$ jets, $Z +$ jets, diboson, single top and $t\bar{t}$ process

The Mono-H Search - Prospects



- generator level studies
- expected E_T^{miss} distribution for $m_\chi = 1$ GeV at $\sqrt{14}$ TeV
- signal distribution is dominant for $E_T^{\text{miss}} > 150$ GeV

The Mono-H Search - Prospects



arXiv:1312.2592

TABLE I: Summary of benchmark models for $h + \not{E}_T$ signals.

Effective operators	
$\lvert\chi\rvert^2\lvert H\rvert^2$	$\lambda = 0.01$
	$\lambda = 1$
$\bar{\chi}\chi\lvert H\rvert^2$	$\Lambda = 100$ GeV
	$\Lambda = 10$ TeV
$\bar{\chi} i\gamma_5\chi\lvert H\rvert^2$	$\Lambda = 100$ GeV
	$\Lambda = 10$ TeV
$\chi^\dagger\partial^\mu\chi H^\dagger D_\mu H$	$\Lambda = 300$ GeV
$\bar{\chi}\gamma^\mu\chi B_{\mu\nu} H^\dagger D_\nu H$	$\Lambda = 100$ GeV
Simplified models with s-channel mediator	
Z'_B	$m_{Z'} = 100$ GeV, $g_\chi = g_B = 1$, $g_{hZ'Z'}/m_{Z'} = 0.3$
	$m_{Z'} = 1000$ GeV, $g_\chi = g_B = 1$, $g_{hZ'Z'}/m_{Z'} = 0.3$
Z'_H	$m_{Z'} = 100$ GeV, $g_\chi = 1$, $\sin\theta = 0.1$
	$m_{Z'} = 1000$ GeV, $g_\chi = 1$, $\sin\theta = 0.1$
Scalar S	$m_S = 100$ GeV, $y_\chi = 1$, $\sin\theta = 0.3$, $b = 3$
	$m_S = 1000$ GeV, $y_\chi = 1$, $\sin\theta = 0.3$, $b = 3$

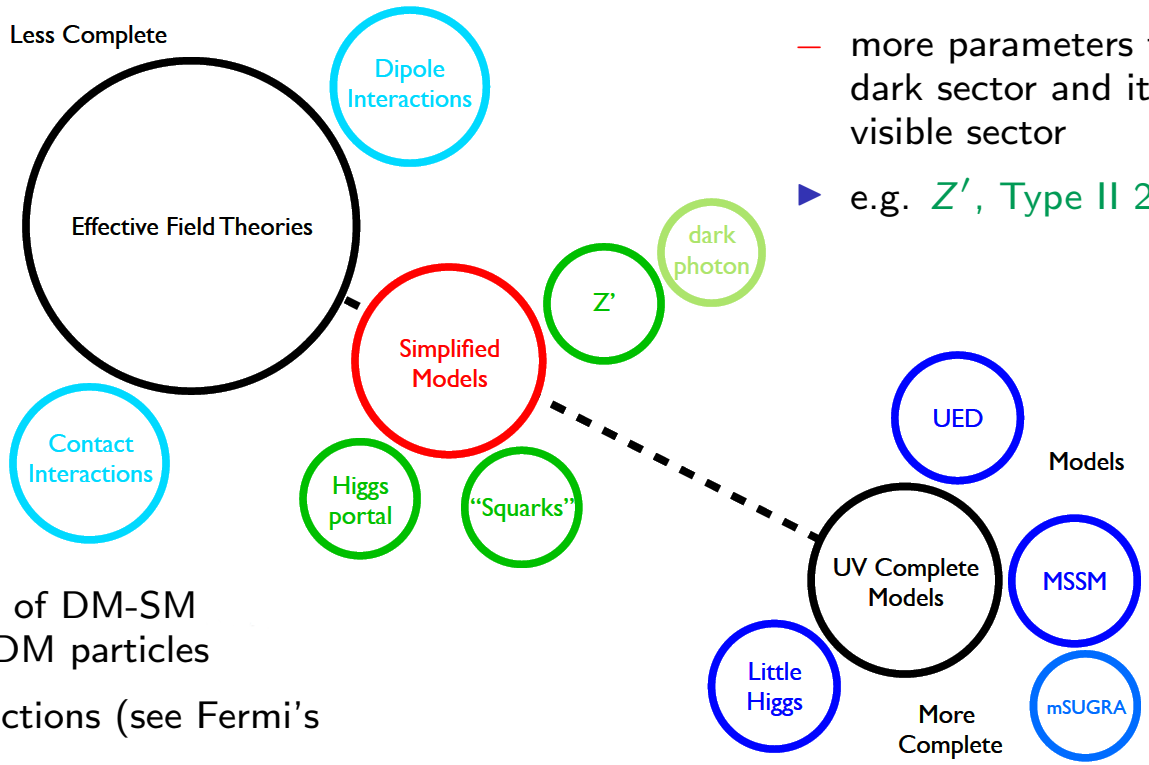
- expected cross section limits for $pp \to H\chi\chi \to b\bar{b}\chi\chi$
- EFT and simplified models are considered
- Z'_H couples to SM particles by mixing with the Z boson
- Z'_B leptophobic Z' that couples to both baryon number and DM
- S new scalar particle

Summary

- After the discovery of the Higgs boson in 2012, the search for DM is one of the most important topics of the LHC physics program.
- The LHC in particular is competitive at the low mass region and provides complementary DM results.
- New collision energy of 13 TeV gives access to higher energy scales, which is of special interest for SUSY and DM searches.
- Data taking at $\sqrt{s} = 13$ TeV has just started and dark matter discovery is hopefully around the corner.

Backup

Spectrum of Theory Space



Simplified Models

+ able to describe correctly the full kinematics of DM production
– more parameters that characterize the dark sector and its coupling to the visible sector
- e.g. Z', Type II 2HDM, Higgs Portal

EFT operators

- representing types of DM-SM interactions with DM particles
- like contact interactions (see Fermi's interaction)
+ minimal model dependence
+ limited number of d.o.f: scale of interaction ($M_\star$ or Λ) and m_χ
– only applicable at low momentum transfer (validity of the EFT?)

RPC SUSY Models

+ full descriptive theory with full kinematics of DM production
– a wealth of free parameters
- see for instance stop 0 lepton search