Dark Matter at a future hadron collider

personal summary

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Dark Matter at a future hadron collider
FERMILAB
12/6/15

Fox

Axions

Primordial Black Holes

?

?

MACHOs

Sterile neutrinos

WIMPs

Q-balls

pathological Models

what do we call these?

What is the simplest DM model?

- SM particle as mediator [simplest models]

  ‣ Higgs portal

  ‣ Minimal DM (Wino, Higgsino, etc.)

  ‣ ?? (neutrino, axion, other?)

- BSM Mediator [simplified models]

  ‣ vector, axial, scalar, pseudo…

  ‣ s/t channel, boson/fermion DM,…

- Full models

  ‣ MSSM (cMSSM, pMSSM, MSSM+X…)

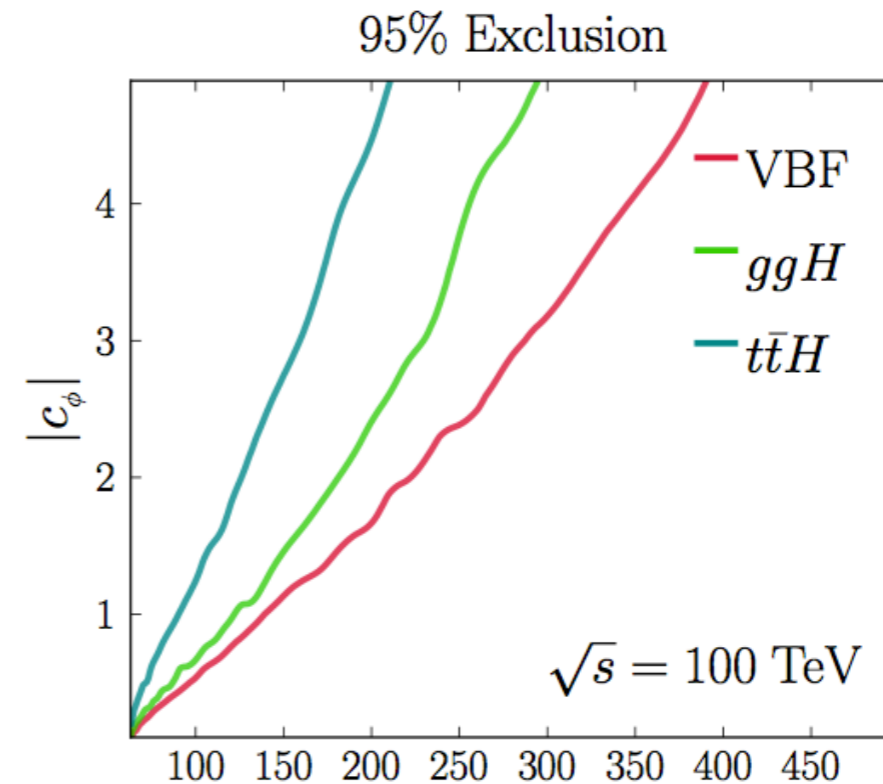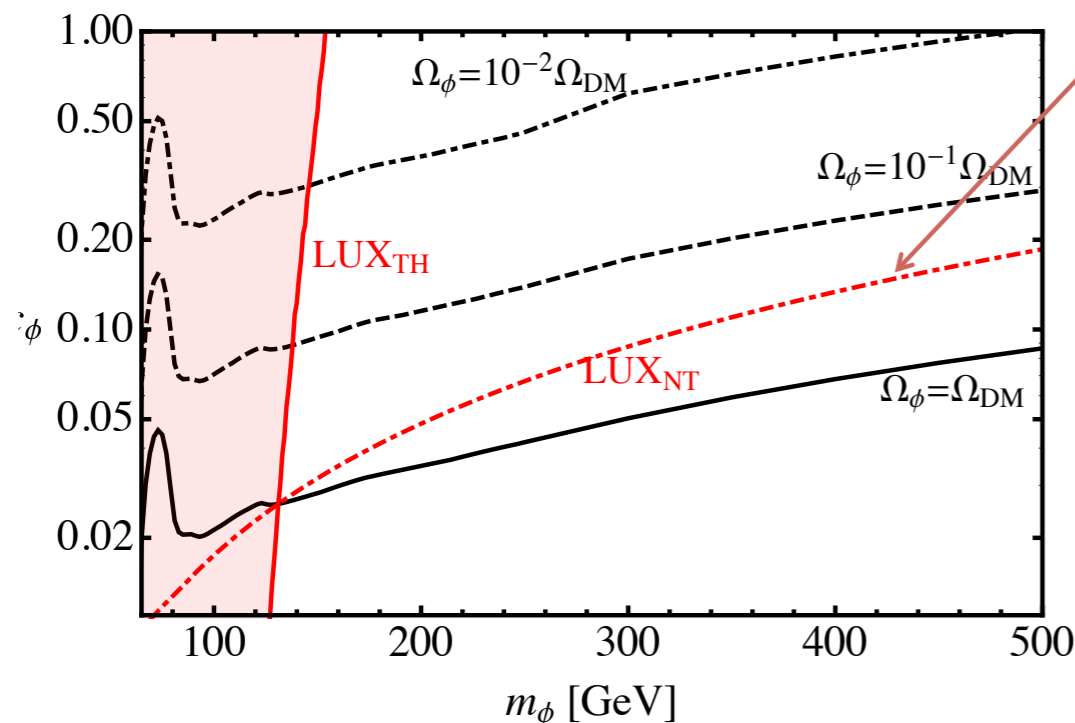 ‣ Little Higgs, Universal extra dimensions, …

Higgs portal

A "classic" extended Higgs sector:
- Higgs Portal (HP)

Mccullough

$$\mathcal{L} = \mathcal{L}_{SM} - \frac{1}{2}\partial_\mu\phi\partial^\mu\phi - \frac{1}{2}M^2\phi^2 - c_\phi|H|^2\phi^2$$

$$+ A_H\phi|H|^2 + \mu_\phi\phi + A_\phi\phi^3$$

$\rho \propto$

σ_{DD}

Direct detection should cover it!
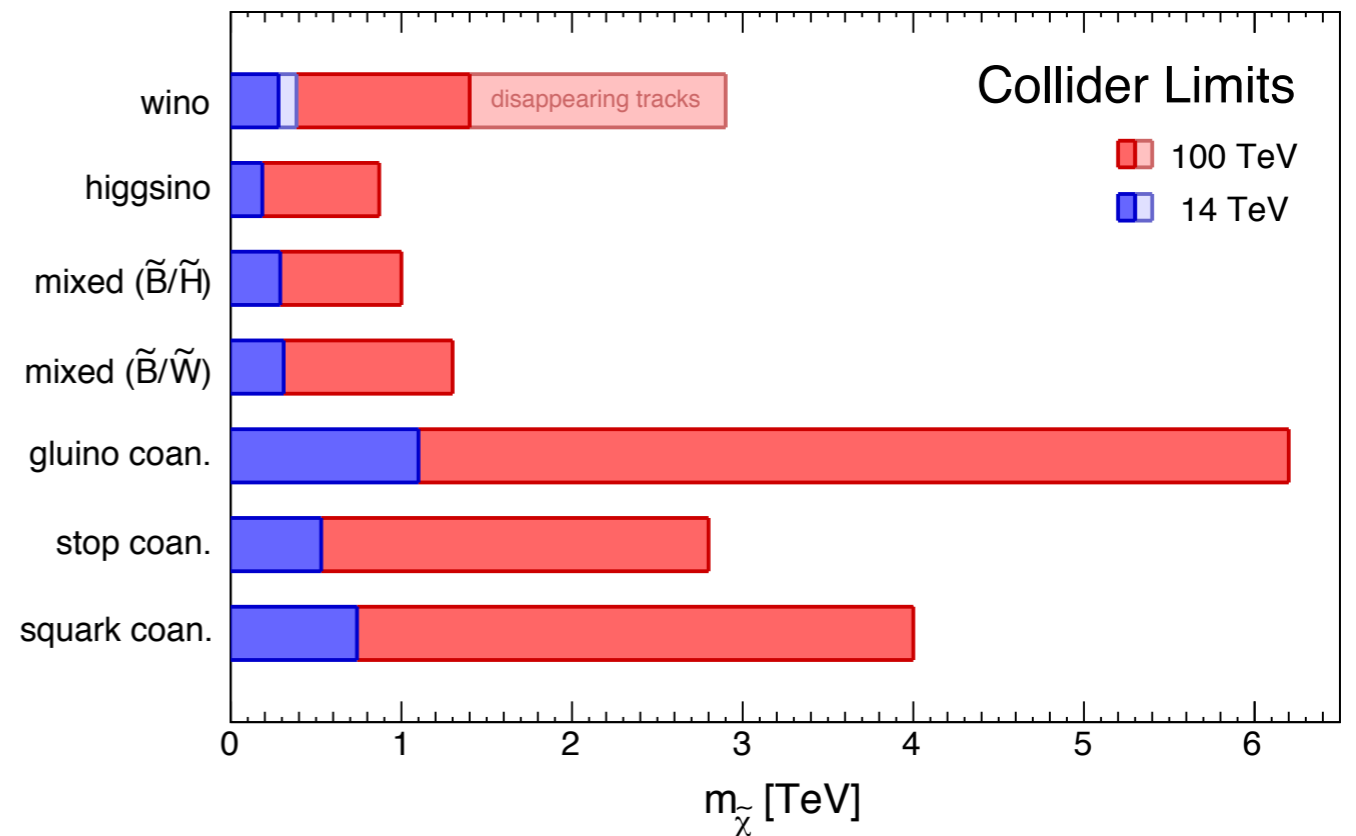Can we improve the 100 TeV reach?
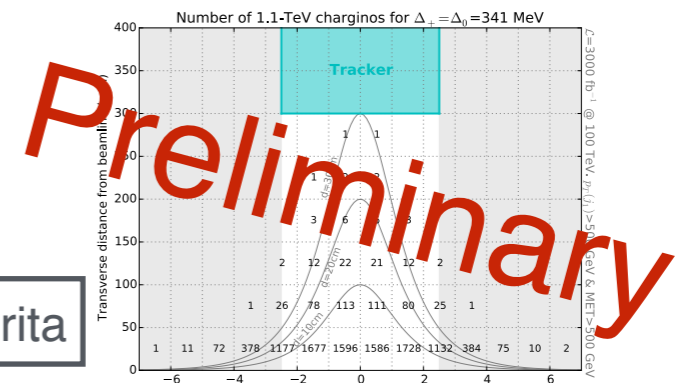What if we find something in DD? Linear Collider?

Neutralinos

- SU(2) multiplet. Coupling fixed by gauge invariance. Only ONE parameter!

- Pure Wino in reach of 100 TeV disappearing tracks essential!!!

- Higgsino needs more work - seems possible with enough tracking within 10cm of IP
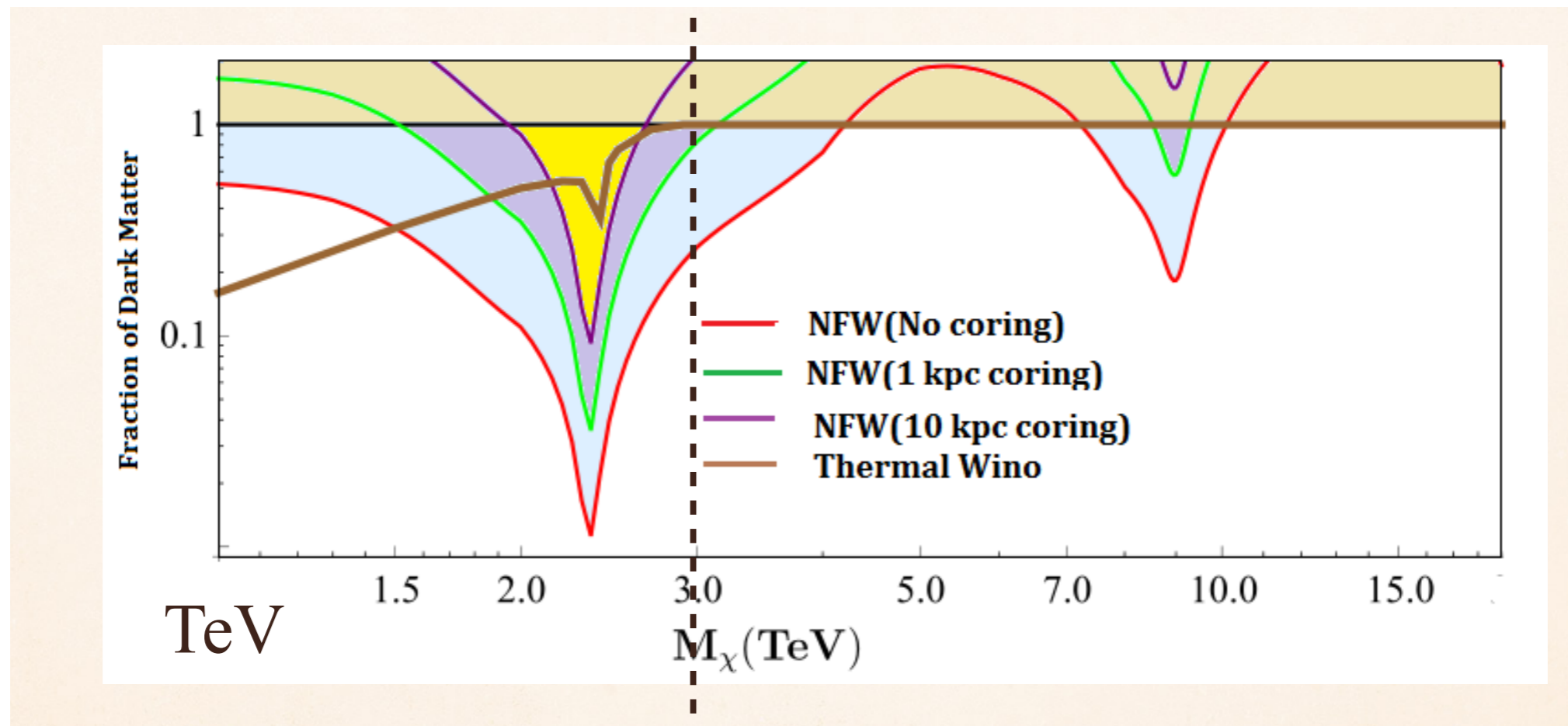
Pixel dE/dx?

Mahbubani, PS, Zurita

Neutralinos

- Indirect
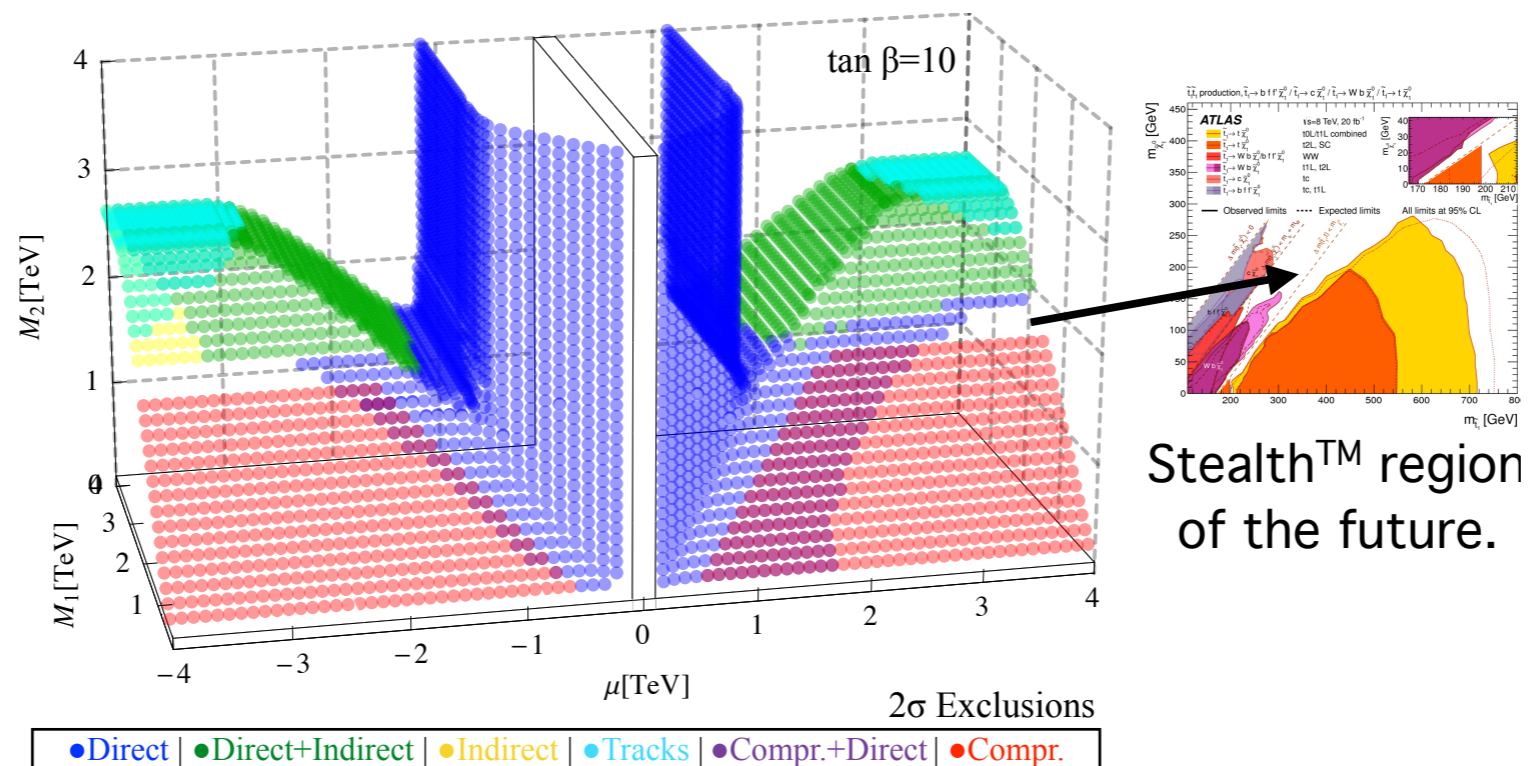

- Strong probe of Wino case. Higgsinos again difficult. Also: How to verify a discovery/excess?

Neutralinos

- Direct + Indirect + Collider
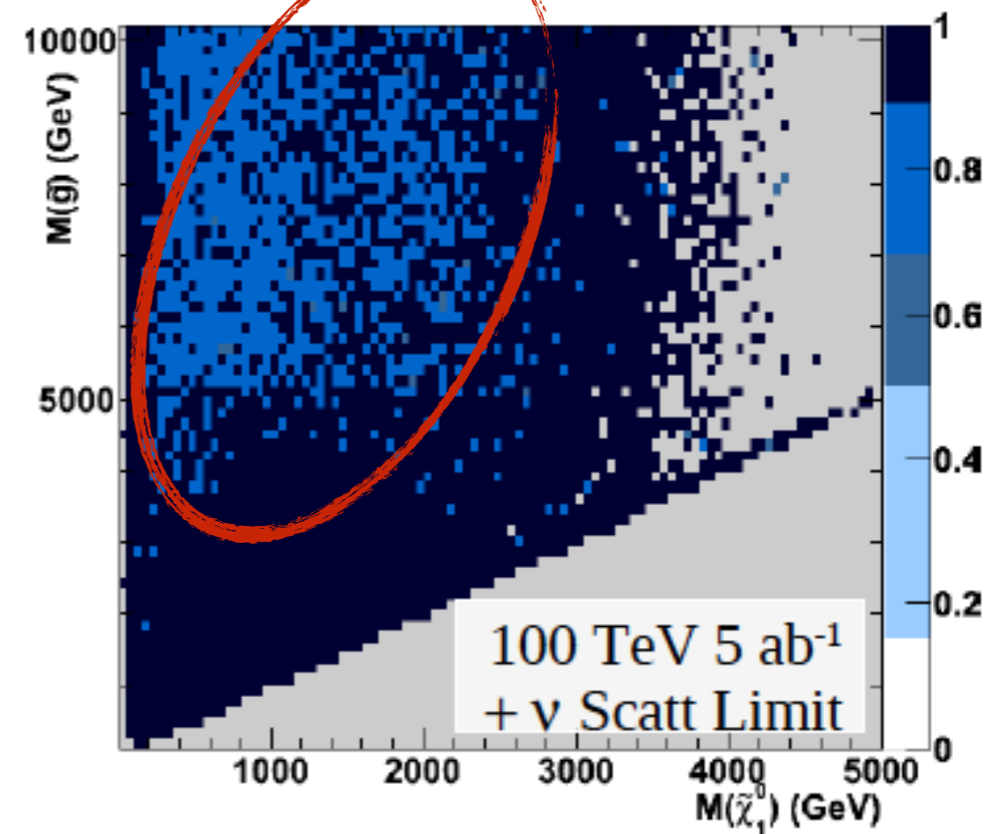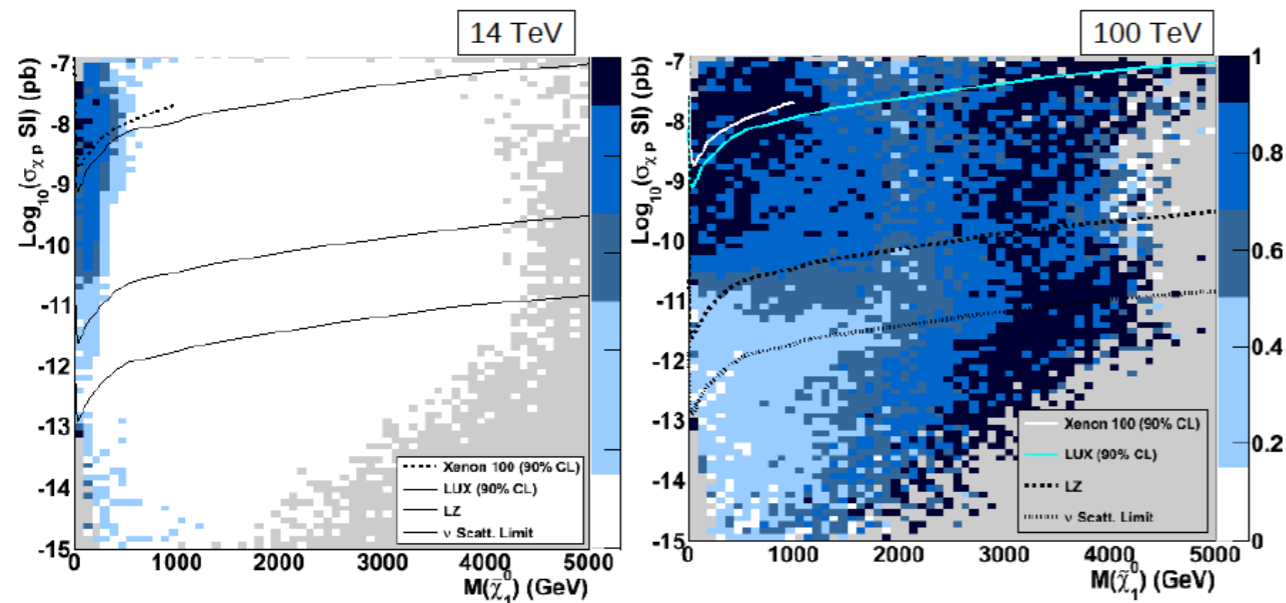
100 TeV future coverage

Stealth™ region
of the future.

2σ Exclusions

•Direct | •Direct+Indirect | •Indirect | •Tracks | •Compr.+Direct | •Compr.

- Some cracks - double coverage of most regions would be better!

™ Fan, Reece, Ruderman

Neutralin

$\sqrt{s}$ (TeV)	L (ab^{-1})	Collider (MET)	+LUX DM	+LX DM	+3rd Gen. DM
100	1.0	0.63	0.65	0.73	0.90
100	3.0	0.67	0.69	0.75	0.91
100	5.0	0.69	0.72	0.76	0.92

100 TeV 5 ab^{-1} + LUX

100 TeV 5 ab^{-1} + LZ

100 TeV 5 ab^{-1} + ν Scatt Limit

- Disappearing tracks needed here? Can we get NLSP lifetime in these plots to connect with simplified studies?

Simplified Models

Buchmuller
Dent
Harris

- EFT very fruitful - has inspired many searches for "hadronic recoil + X"

  ‣ Validity at LHC questionable - need better framework to present expt. limits, compare with direct/indirect detection

- Simplified models

  - As way to communicate results, not as final theories of DM

  - Are often still EFTs - SU(2) breaking, unitarity etc can limit validity

  - Fast learning process - mistakes happen, can be fixed!
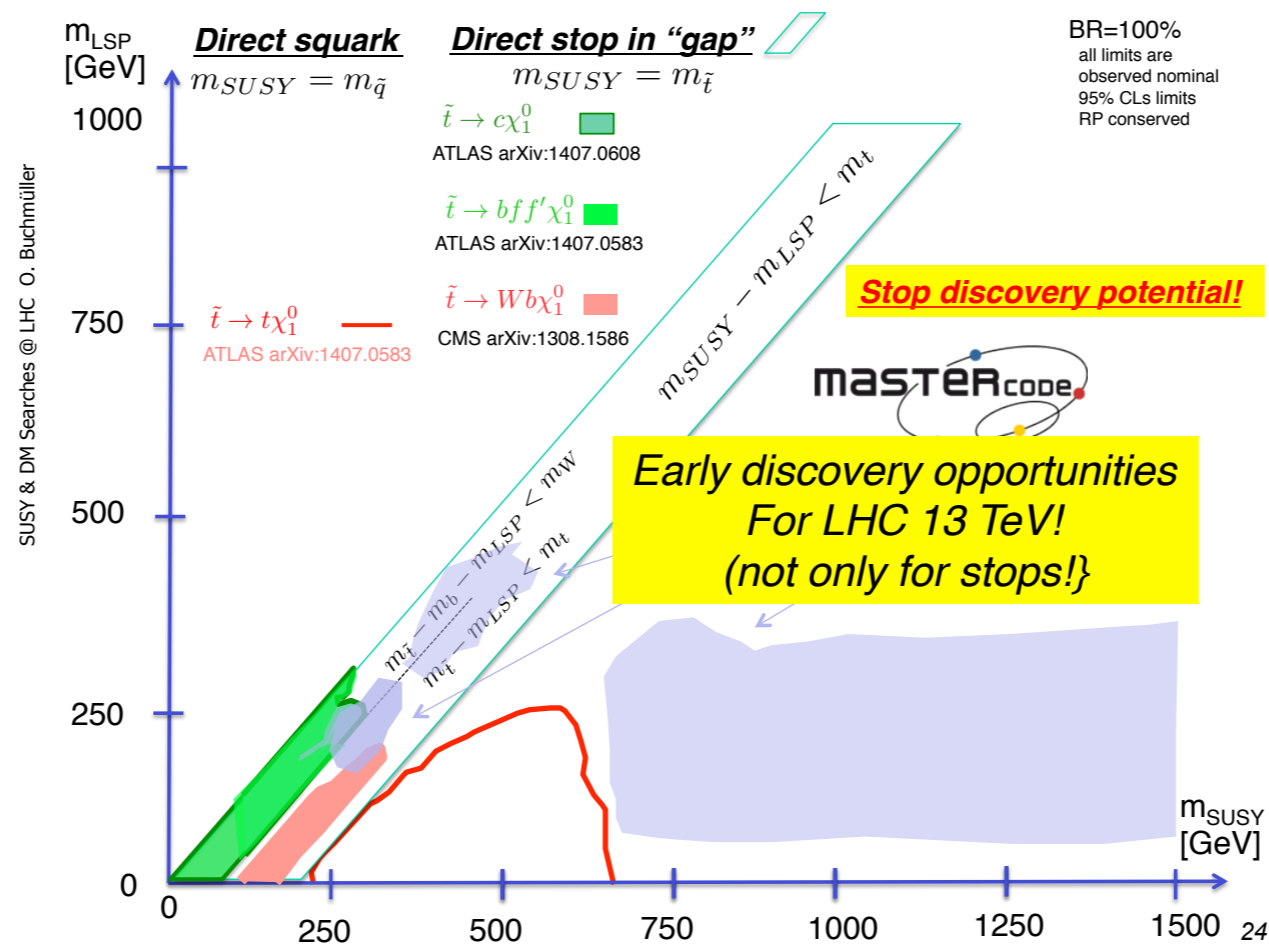
Simplified Models

Buchmuller
Dent
Harris
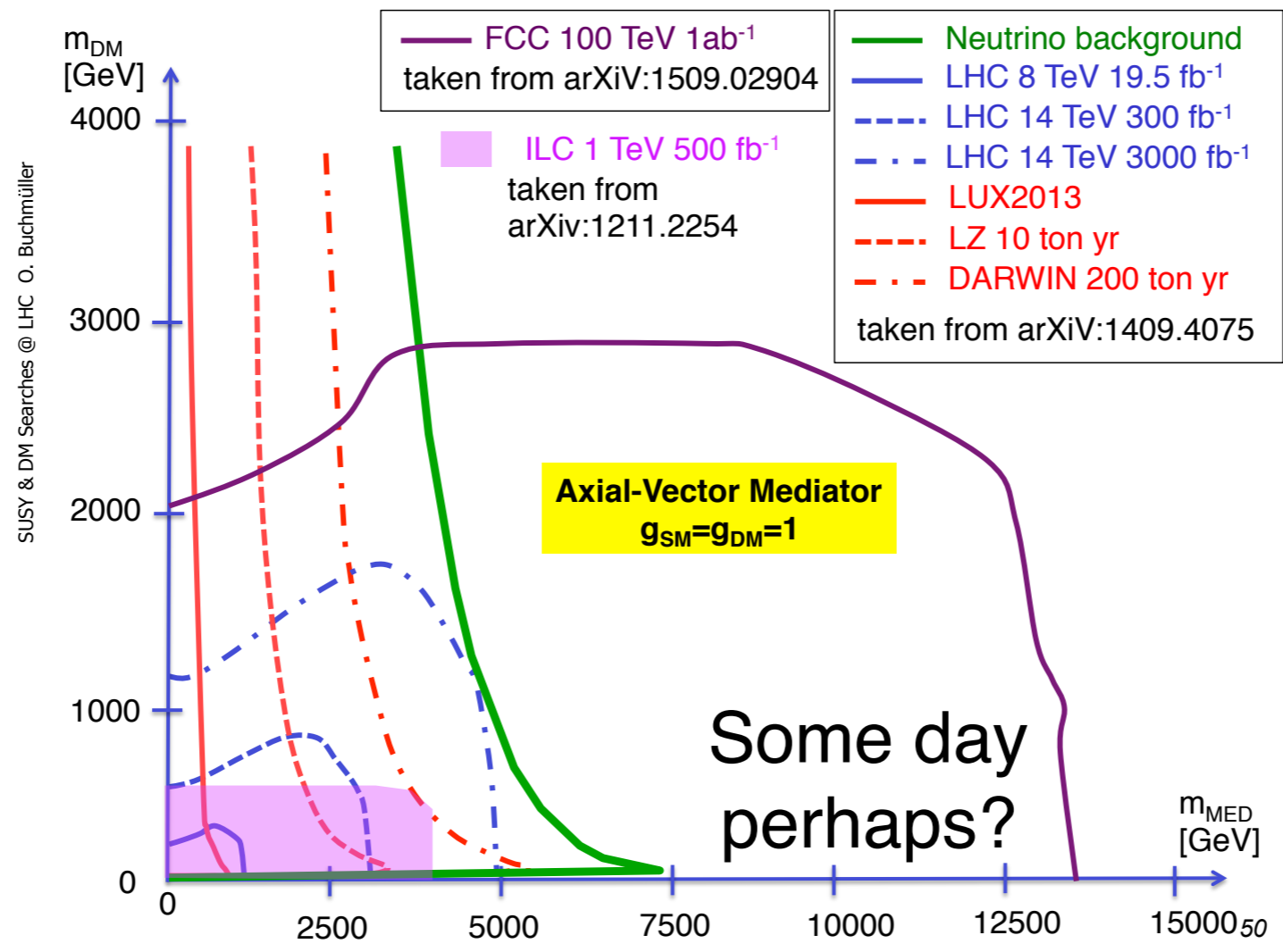
- ~ 3 TeV reach. e+e- machines typically probe $\sqrt{s}/2$, include e.g. leptophilic DM etc…. ?

Full Models/MSSM

Buchmuller
Battaglia

- Don't forget: Every SUSY search is a DM search

- Simpl. models approach very successful here - lessons?

Full models

- Do current DM - simplified models match onto MSSM DM scenarios? I don't think so

  ‣ Combination of new mediators (A0)

  ‣ and SM mediators (Wino/Bino/Higgsino make the DM)

- Scalar simpl. model -> Higgs portal

  ‣ Seems to work, but I would keep Higgs mediated DM as separate category

- Are we covering little Higgs, UED, other DM scenarios using these simplified models? Or should they just serve as basis for recasts?

30 Years from Now

Direct detection

- Getting close to the neutrino floor! Not necessarily the end (see Dent's talk)

- Difficult to determine mass

- Can collider lift the degeneracy?
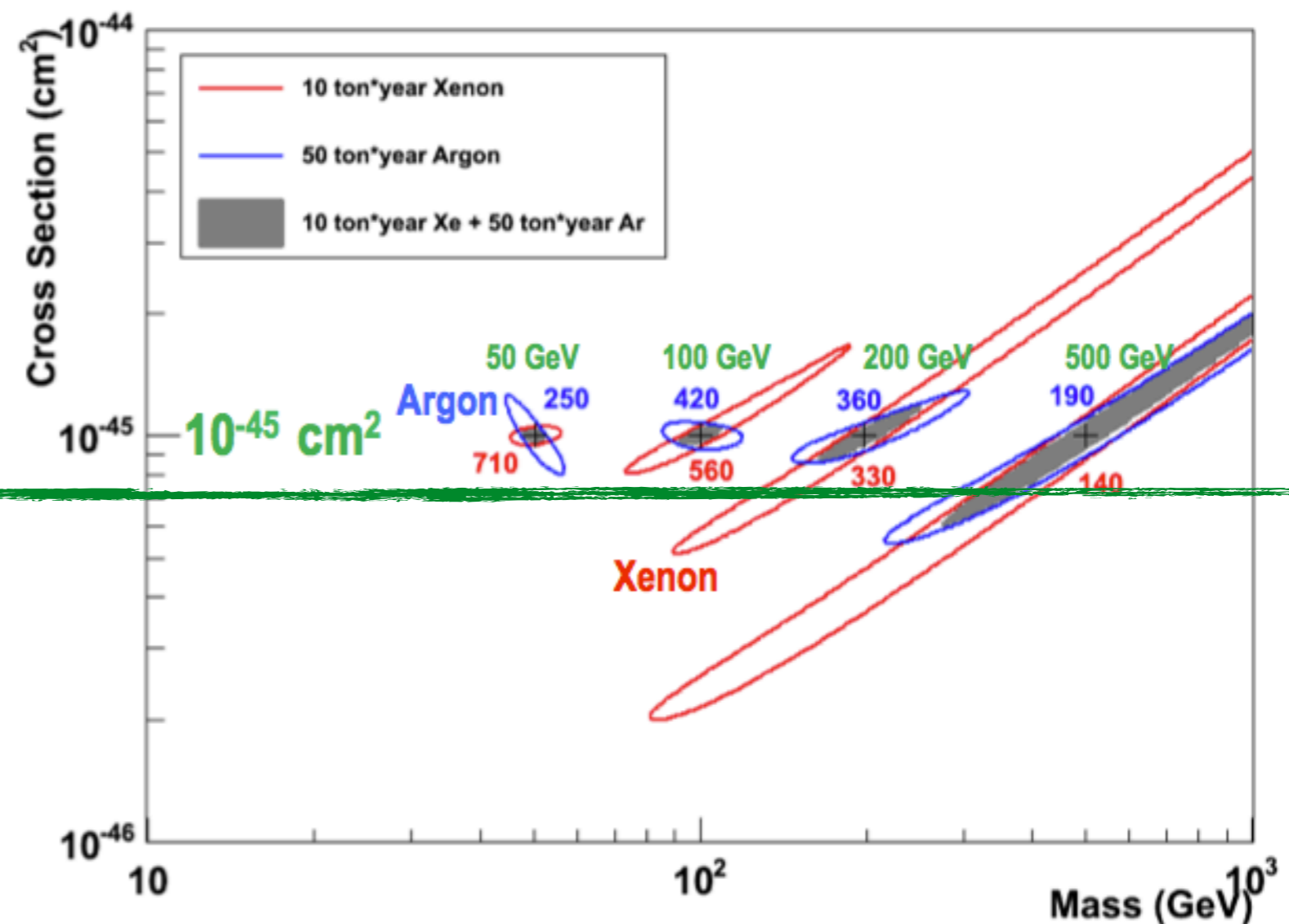
Indirect detection

Drlica-Wagner

Fermilab

- Needed to verify that what we see is actually the stuff making up the halo

- Line search offers access to DM mass

- Access to difficult models (e.g. leptophilic)
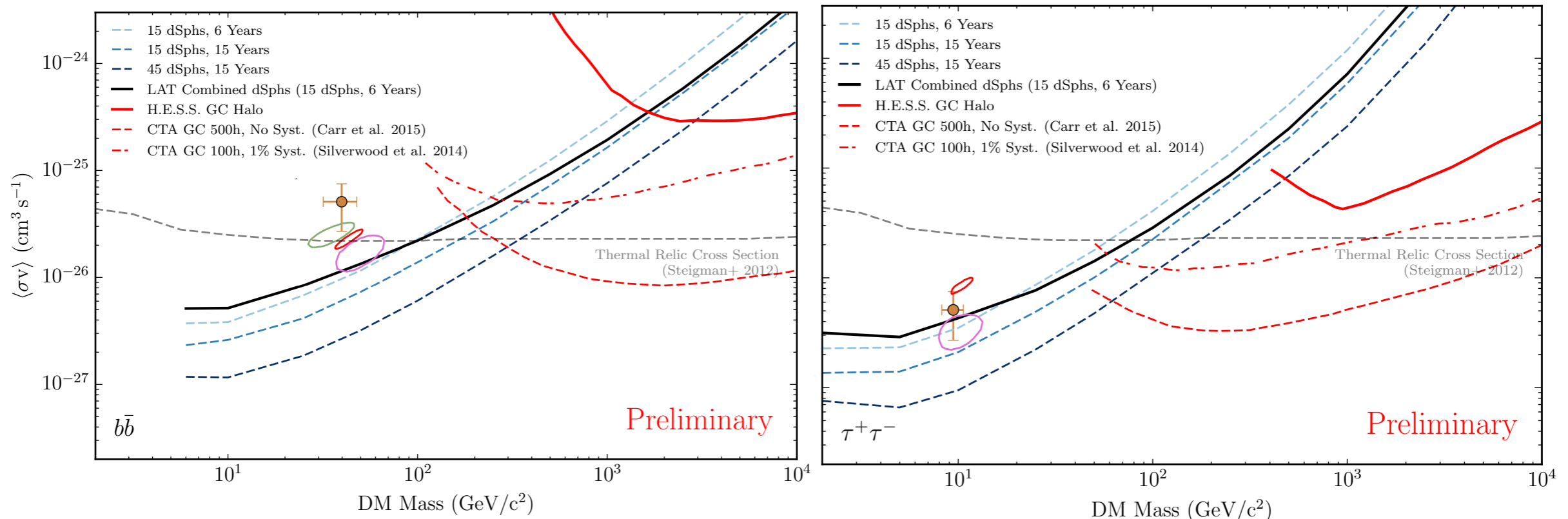
DM properties

- Mass?

- Couplings?

  ‣ Go to Dijets, distinguish operators/simp. models

  ‣ Quark/Gluon tagging?

  ‣ Add mono-X for discrimination?

- And of course we study the mediator

Detector Design?

- Multi-purpose detector

  ‣ dynamic range limited — offset by future technologies?

  ‣ triggering?

  ‣ will some aspects be worse than ATLAS/CMS (e.g. tracking?)

- Dedicated detector

  ‣ What could it be? Pure tracker (no calo?)

  ‣ Focus on soft stuff, but how do we trigger? Tracking-triggers?

The pathological models/signatures

Are actually quite generic

- Disappearing tracks essential for Wino/Higgsino models

- Simplest extension of Higgs portal model has rich displaced phenomenology

- Asymmetric DM models motivate GeV scale hidden sectors - with TeV scale mediator displaced signatures are generic

- RPV SUSY, Baryogengesis models, etc all have parameter ranges with displaced signatures

Typically easier to distinguish from SM backgrounds
Don't throw away this opportunity

Flavoured DM

Agrawal

- Objects coupled to SM better don't screw up flavour observables

- Nice framework for DM model building

  ‣ Explain astro-physical excesses

  ‣ Alleviate tension in WIMP 'miracle'

- Collider: Flavour correlations to identify flavour symmetries of DM - a study would be interesting

Mili-charged particles

Yavin

- Well constrained by astro-physics

  ‣ Gap in GeV-TeV region: Collider!

- Put simple detector behind ~20m of rock behind the main detector

  ‣ Simple and affordable addition to existing collider experiments ($1million)

  ‣ Needs a bit planning ahead (space, infrastructure)

- Note: This is also a displaced signature!

Light mediators

- DM annihilates to BSM mediators directly

  ‣ half the parameter space of simplified models!

- Difficult to directly probe full param space

- Exotic Higgs decays complementary probe

a, s
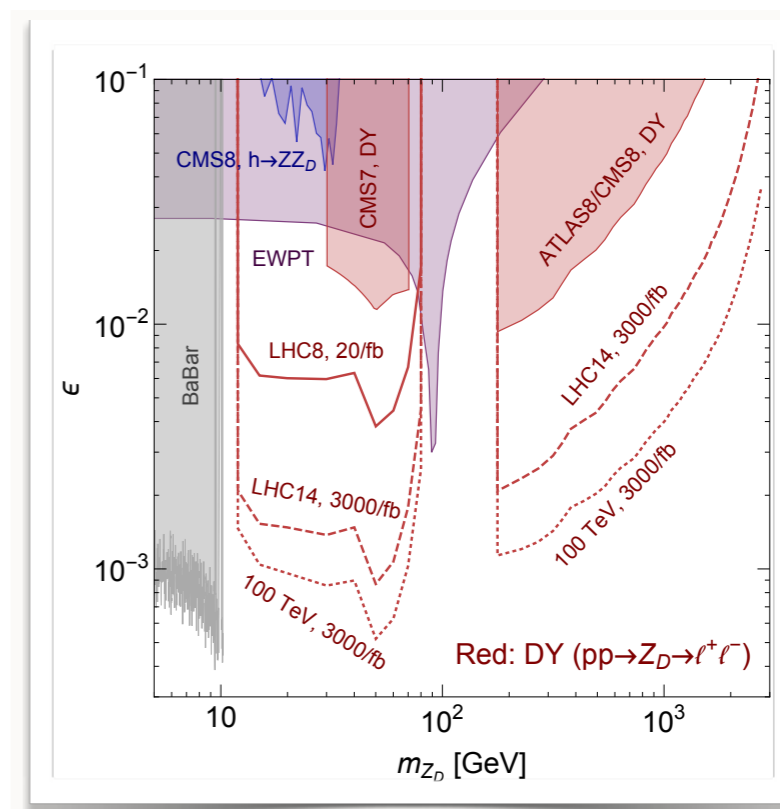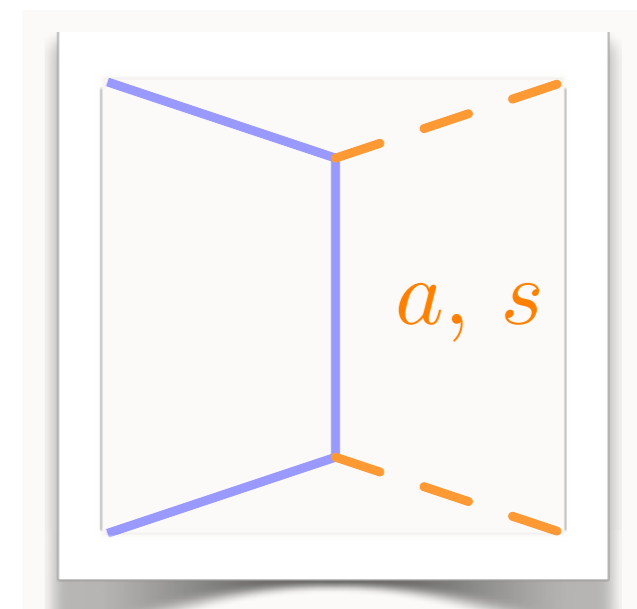
Dynamical DM

Thomas Dienes

- Multi-component DM

- Many possible realisations, e.g. extra dimensions, confined dark sectors, etc.

- Kinematic shapes as discrimination tool

Others?

- Models

  ‣ Asymmetric DM

  ‣ Composite DM

  ‣ Atomic DM

  ‣ …

- Signatures to think about

  - Lepton jets, photon jets

  - MET aligned with jets (hadronic recoil?)

  - Boosted displaced objects

  - Rare meson searches

Summary of the summary

- Can we probe the thermal WIMP scenario at a future hadron collider?

- What could we say about a discovery? How do we know 'hadronic recoil = DM'

- Which other scenarios (beyond WIMP) can be probed - what are good benchmarks?

Summary of the summary

- Can we probe the thermal WIMP scenario at a future hadron collider?

  ‣ Collider + DD + ID gives good coverage

  ‣ Not 100% in e.g. MSSM and limiting cases (simplified Neutralino models) - but maybe with improvements

  ‣ Simplified models: 100 TeV probes the mediator, still need to understand if model space is well covered

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Summary of the summary

- Can we probe the thermal WIMP scenario at a future hadron collider?

- What could we say about a discovery? How do we know 'hadronic recoil = DM'

  ‣ Complementarity of DD/ID/Collider - better if a point is covered by two searches!

  ‣ DM coupling characterisation possible? Mono-X, Di-X?

- Which other scenarios (beyond WIMP) can be probed - what are good benchmarks?

Benchmarks

- Higgs portal

- pure Wino, pure Higgsino

- Co-annihilation scenario? Reach up to 6 TeV!

- Any/all of the simplified models as benchmarks? Or pick pMSSM, little Higgs, UED benchmark points instead?

- Beyond WIMP models - suggestions?

Other thoughts

- DD/ID/Collider complementary by construction

- ILC, FCC-ee, CLIC, etc

  ‣ 1 TeV ILC reach for Higgs portal?

  ‣ Higgs, triple gauge coupling, EWPT sensitive in some cases - anyways part of the program!

- Energy, Luminosity goals from DM side?

  ‣ 150 TeV (LianTao, for Higgsinos!)

  ‣ ?

Blank

Document - DM part

Phil Harris, PS editors for DM

1   Introduction: the goals of this Chapter of the FCC-hh physics report[1]

2   Supersymmetry searches and studies[2]

3   Dark Matter searches and studies[3]

3.1   Introduction

3.2   Status and Prospects of DM Searches

3.2.1   Direct Detection

3.2.2   Indirect Detection

3.2.3   Relic Density Bounds

3.2.4   Colliders

3.3   WIMP, SM Mediator

3.3.1   Weak Gauge Bosons

3.3.2   Higgs Portal

3.3.3   Mixed Scenarios

3.4   WIMP, BSM Mediator

3.4.1   Simplified Models

3.4.2   Mediator vs. Direct Search

3.4.3   Light Mediators

3.5   WIMP, non-minimal models

3.5.1   Co-Annihilation

3.5.2   Resonant Annihilation

3.5.3   MSSM Dark Matter

3.6   Beyond WIMP DM

3.6.1   Asymmetric DM

3.6.2   Dark QCD/Hidden Valley DM

3.6.3   ... anything we are forgetting? WIMPy Baryogenesis?

3.7   Detector Design and Requirements

3.8   DM Summary

Suggestions,
Comments
are
welcome!!!