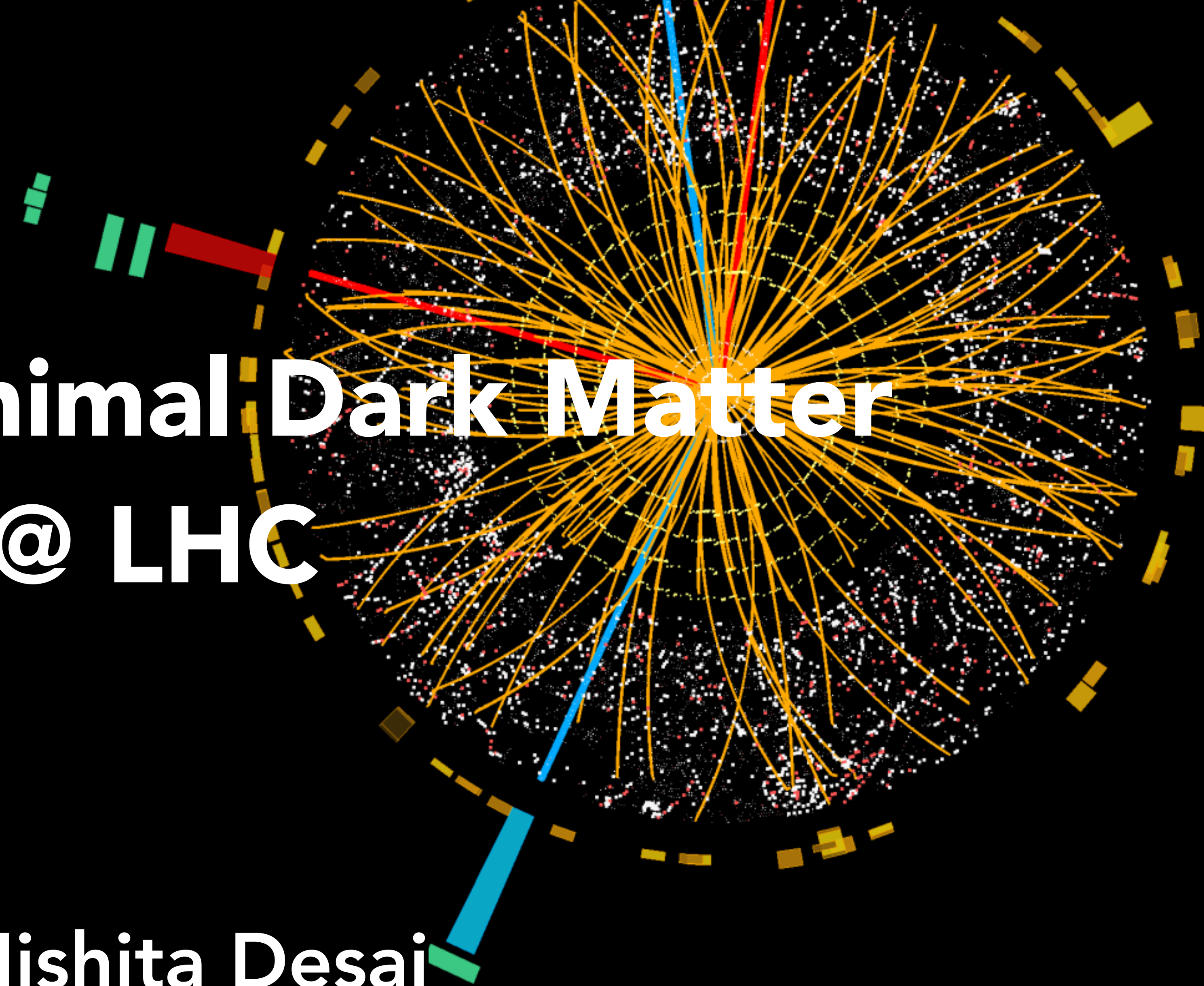


Next-to-minimal Dark Matter @ LHC

Nishita Desai

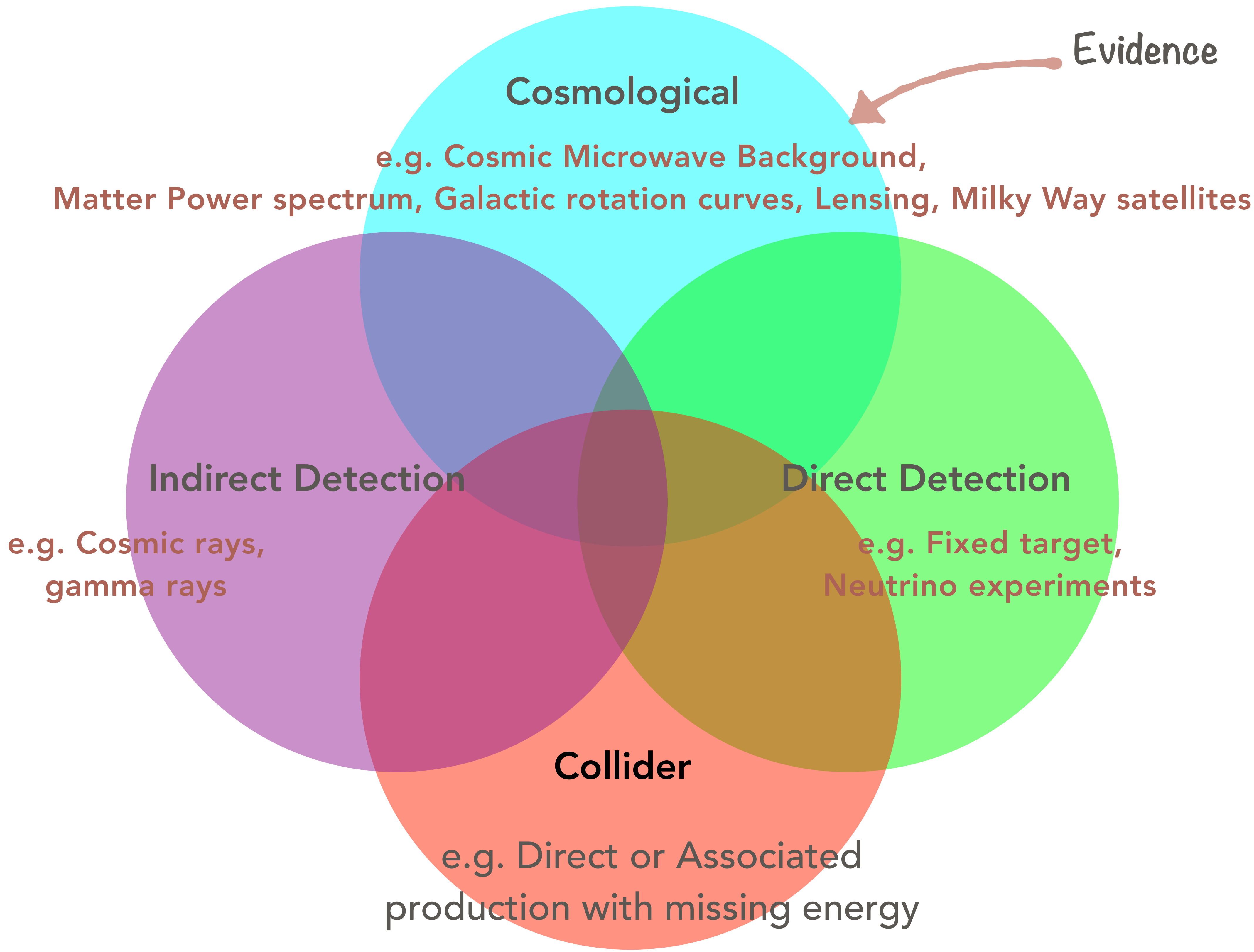
LUPM, Montpellier

Based on: arXiv:1804.0235 (with A. Bharucha and F. Brümmer)

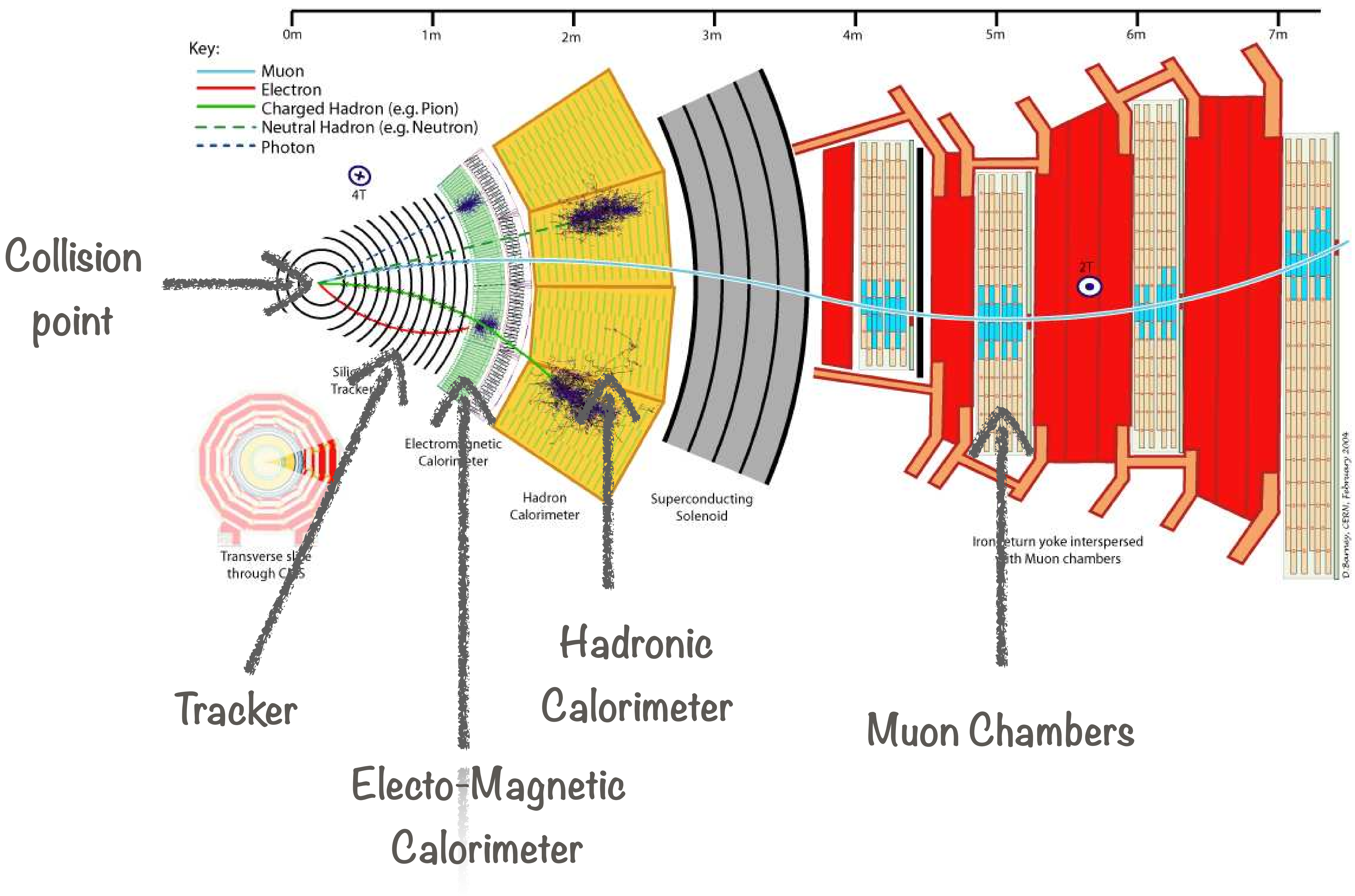
26 June 2018

Dark Side of the Universe 2018; Annecy

Complementarity of searches

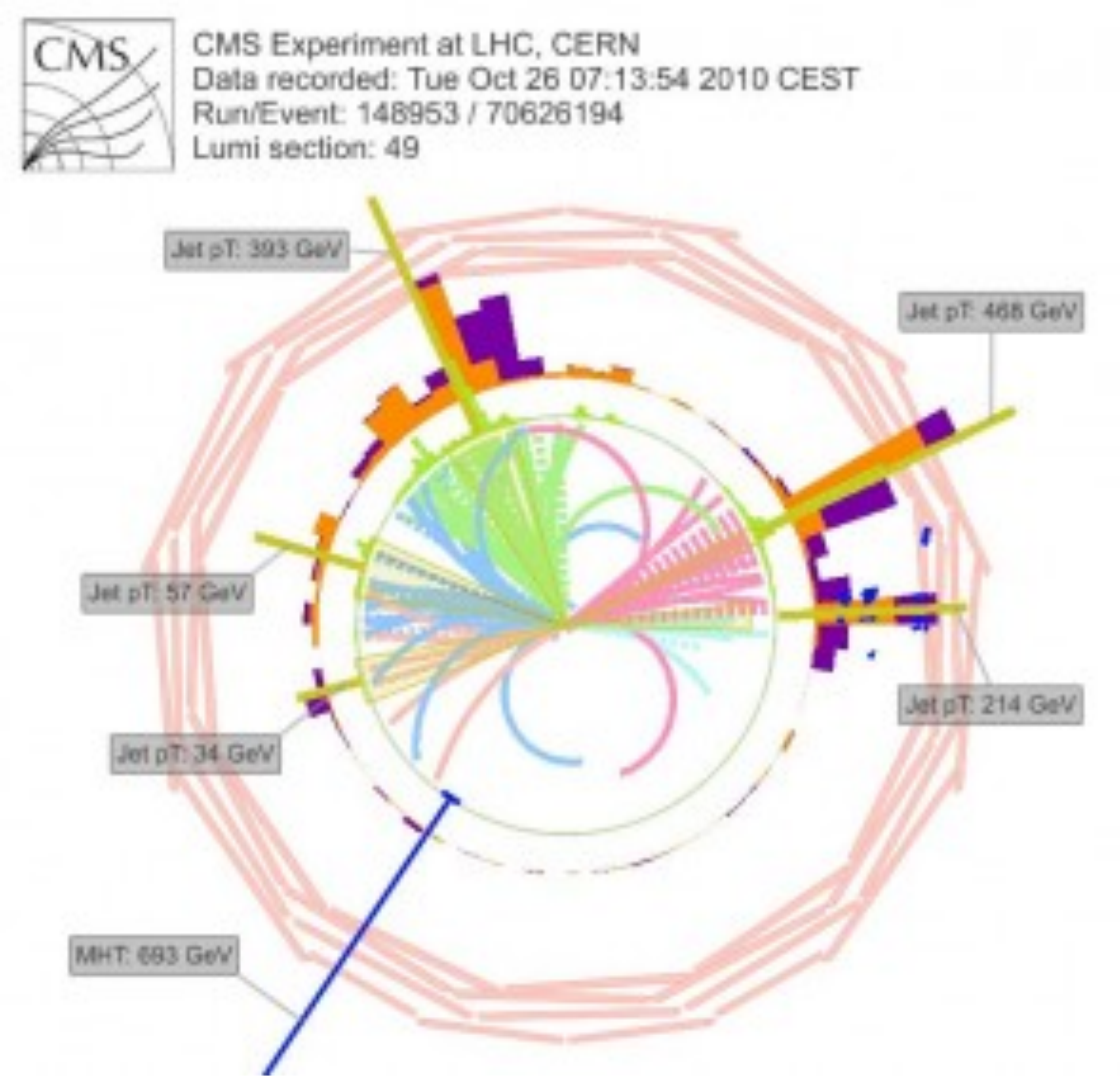


Anatomy of a typical detector @ LHC



What does a collision event look

- Detectable objects are **photons**, **electrons**, **muons**, hadrons (which form **jets**), and invisible neutrinos (in the form of **missing momentum or MET**)
- Most new particles will decay into SM particles
- We use **kinematic distributions** of detectable objects to define **signal** (i.e. new physics) and **background** (i.e. SM physics)

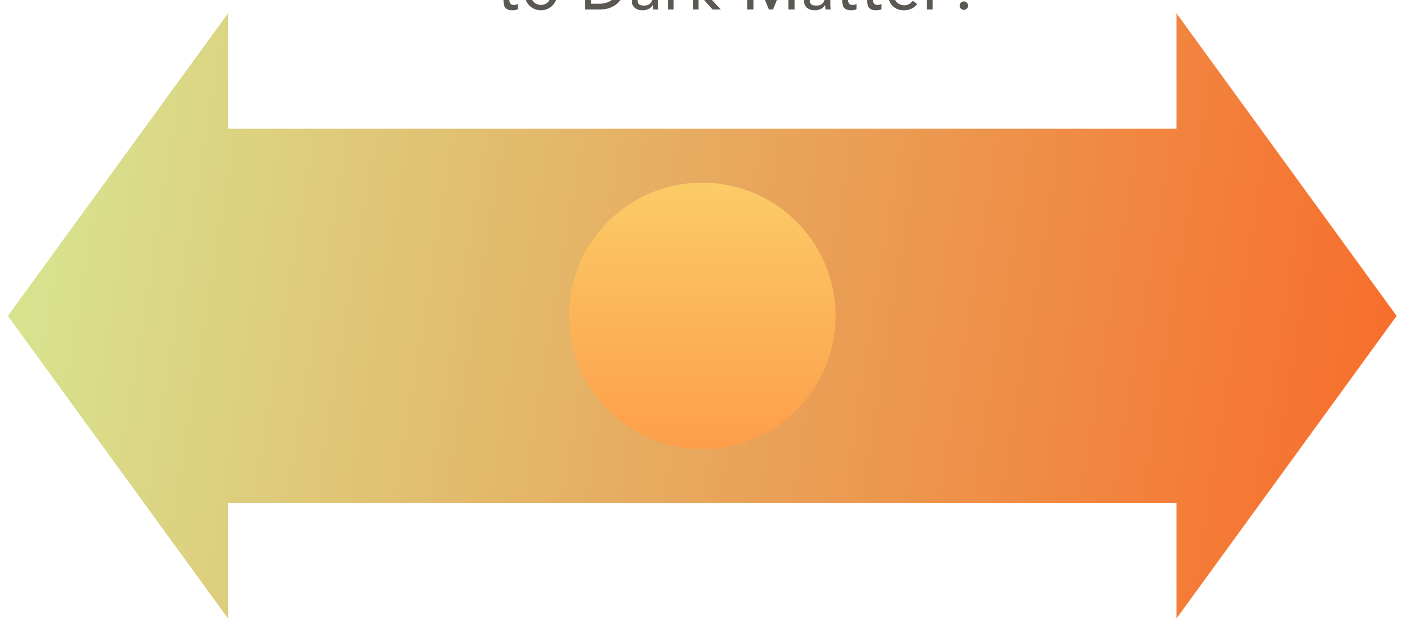


Writing down a model for DM

Is it a Scalar? Vector? Dirac or Majorana Fermion?

Does it couple directly to some SM particle (Z, h) ?
If there is a mediator, how does the mediator couple to SM?
to Dark Matter?

Effective Field Theory



Complete Models

eg. SUSY, Universal Extra Dim,
Little Higgs,…

PRO: Simple, Easy to relate observables

CON: bad high-energy behaviour

Simplified models

Trying to get the best of both worlds

IDEA: write down the simplest field content (often a DM field + one mediator)

PRO: Theoretically well motivated, fully calculable, extra particles

CON: Model Prejudices, complicated to understand

Bottom-up renormalisable DM models

New Symmetries / # Fields	0	Z_2	Z_2+
1	"Minimal DM"	Pure "Higgsino" or "Wino" Scalar singlet DM Inert doublet DM	...
2	??	Singlet-Doublet (N,N+1 plet) DM Higgs Portal DM s/t-channel scalar mediator	Dark Photon s-channel V/A mediators
3	??	SUSY neutralinos ...	Z′ mediator + higgs′ L-R models Hidden Valley models

Dark Matter from adding only 1 new field

Dark Matter makes up ~20% of our universe; an EW scale particle (a.k.a. WIMP) seems to be a good fit

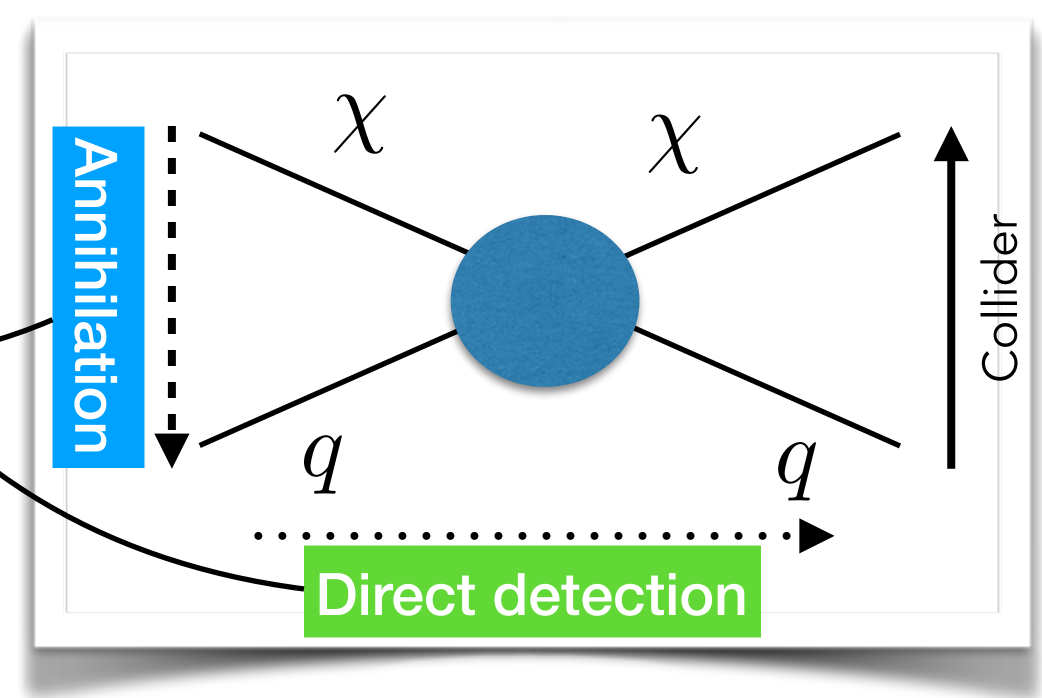
$$\Omega h^2 \sim 0.1 \Rightarrow \langle \sigma v \rangle \sim 1 \text{ pb} \cdot c$$

$$\Rightarrow m_\chi \sim O(10^2 - 10^3) \text{ GeV}; g \sim g_{\text{EW}}$$

What are minimal EW possibilities?

- SU(2) doublet fermion (a.k.a. Higgsino) ⇒ ~ 1.2 TeV
- SU(2) triplet fermion (a.k.a Wino) ⇒ 2.7 TeV
- SU(2) 5-plet fermion (MDM) ⇒ ~10 TeV
- SU(2) 7-plet scalar (MDM) ⇒ ~10 TeV

Cirelli et al; arXiv:hep-ph/0512090



100 TeV collider?

Idea for a "next-to-minimal" scenario

One SU(2) x U(1) singlet χ + one SU(2) N-plet ψ

$\mathbb{Z}_2$ stabilises the lightest state

$$\mathcal{L}_{\rm DM} = i\,\psi^\dagger\overline{\sigma}^\mu D_\mu\psi + i\,\chi^\dagger\overline{\sigma}^\mu\partial_\mu\chi - \left(\frac{1}{2}M\psi\psi + \frac{1}{2}m\chi\chi + \text{ h.c.}\right) + \mathcal{L}_{\rm quartic} + \mathcal{L}_{\rm mix}$$

$$\mathcal{L}_{\rm quartic} = \frac{1}{2}\frac{\kappa}{\Lambda}\phi^\dagger\phi\chi\chi + \frac{1}{2}\frac{\kappa'}{\Lambda}\phi^\dagger\phi\psi^A\psi^A$$

Strong limits from DD

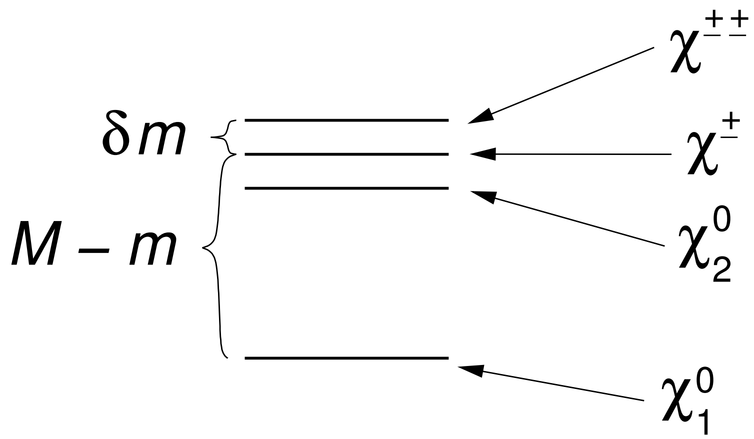
$$\mathcal{L}_{\rm mix} = \frac{\lambda}{\Lambda}\phi^\dagger\tau^a\phi\;\psi^a\chi + \text{ h.c.} \longrightarrow \theta \approx \frac{\sqrt{2}\lambda v^2}{\Lambda(M-m)}$$

N=3

$$\mathcal{L}_{\rm mix} = \frac{\lambda}{\Lambda^3}\,C^{j\ell}_{A\,ik}\,\phi^{\dagger i}\phi_j\phi^{\dagger k}\phi_\ell\psi^A\chi + \text{ h.c.} \longrightarrow \theta \approx \sqrt{\frac{2}{3}}\frac{\lambda v^4}{\Lambda^3(M-m)}\,.$$

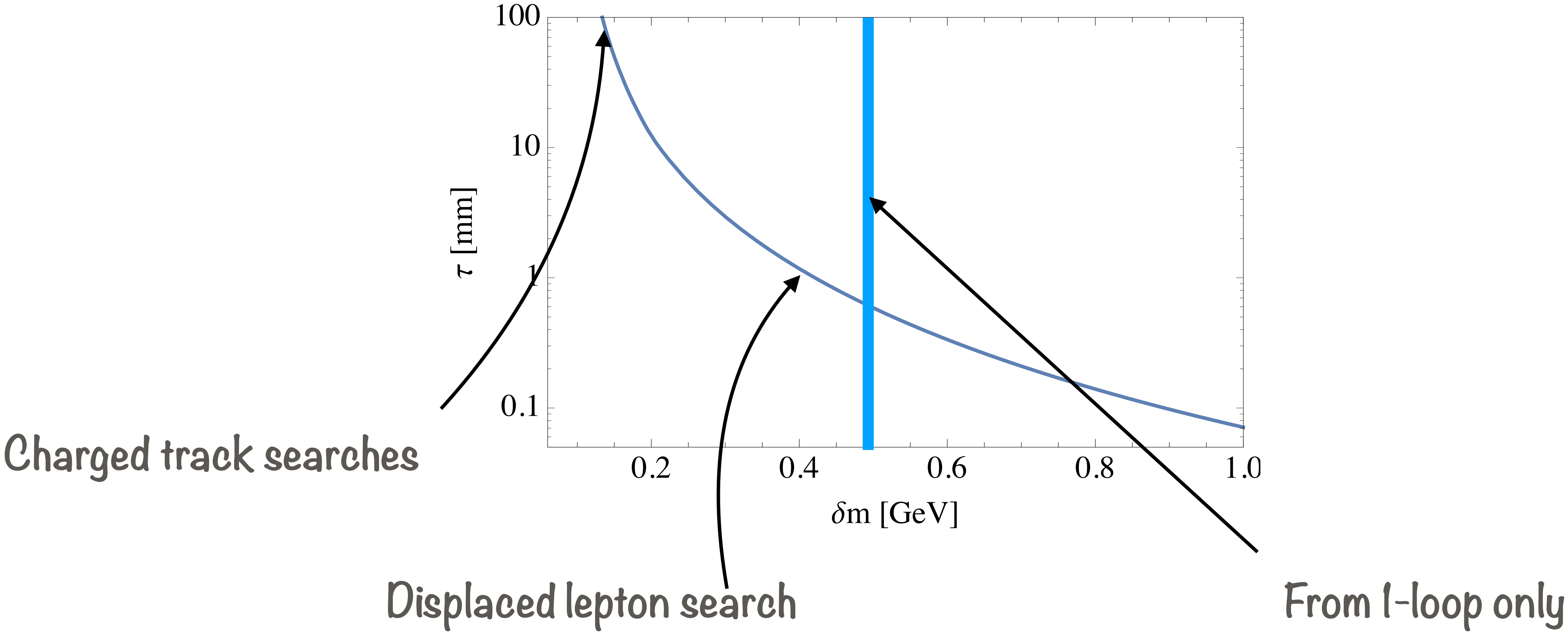
N=5

Collider searches: Quintuplet model

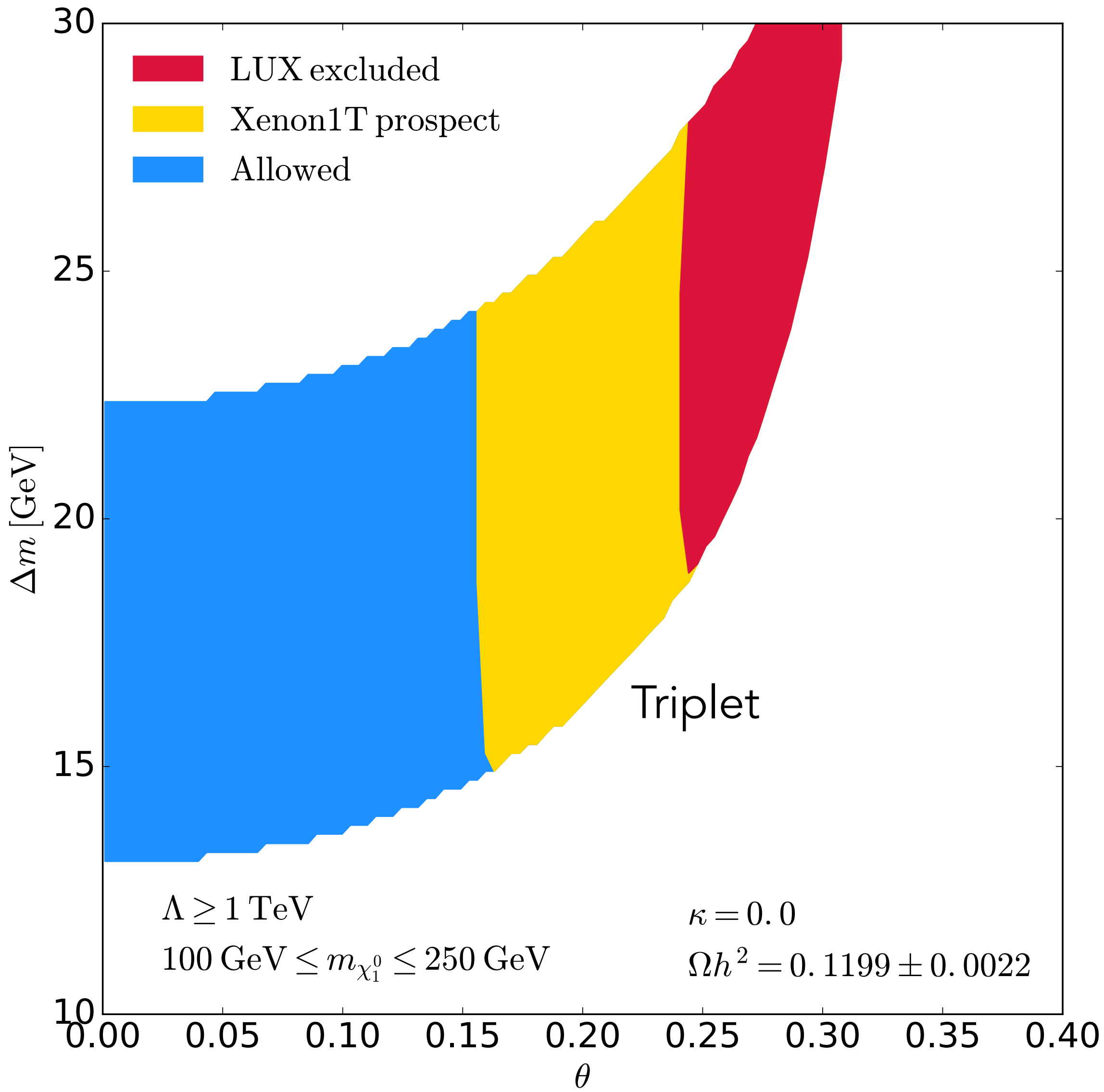


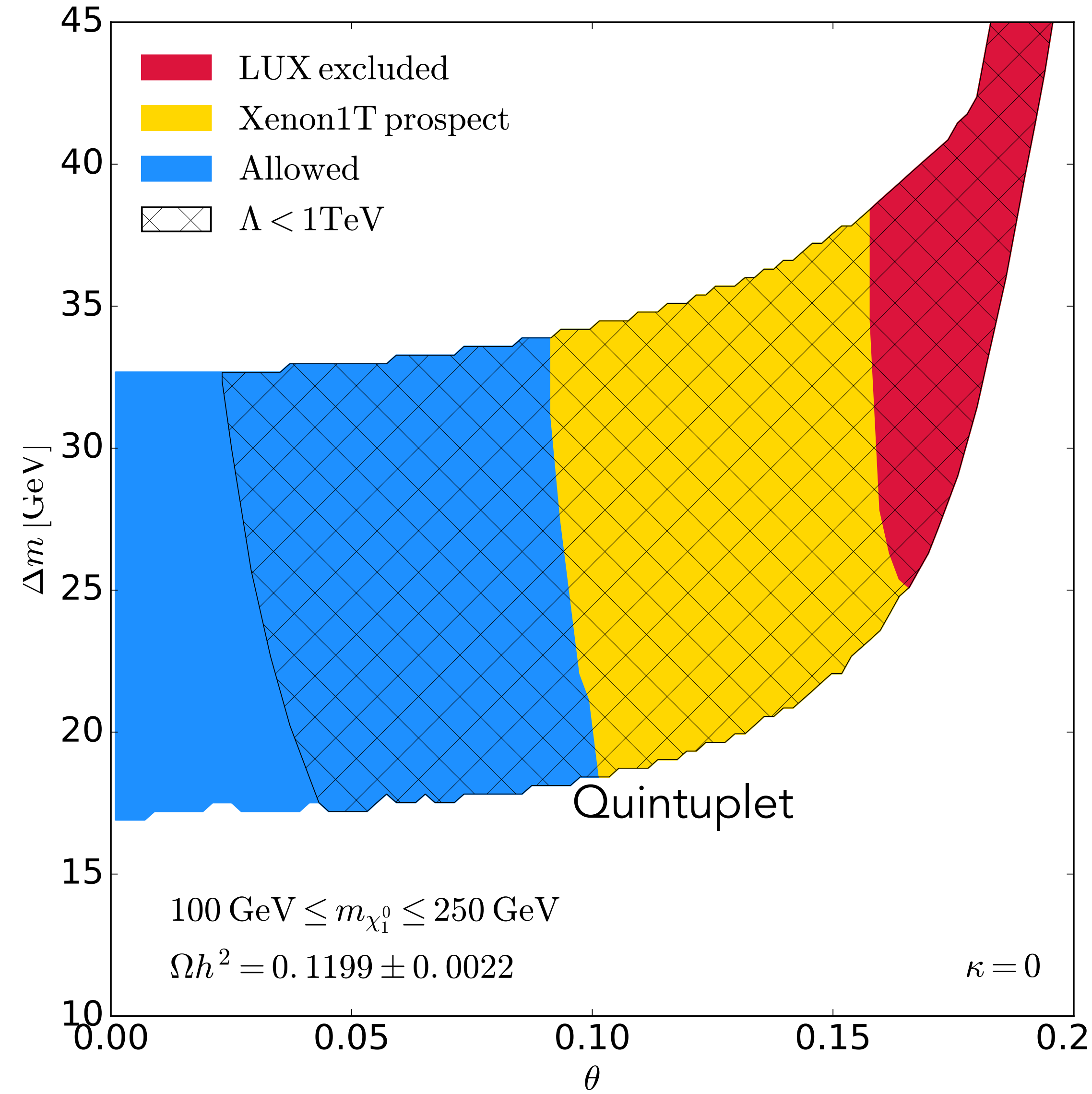
$$\chi^{++} \to \chi^{+}\pi^{+}$$
$$\chi^{+} \to \chi_1^0 W^* \to \ell\nu\chi_1^0$$
$$\chi_2^0 \to \chi_1^0 h^* \to b\bar{b}\chi_1^0$$

Large lifetime for the doubly charged partner



Direct Detection constraints

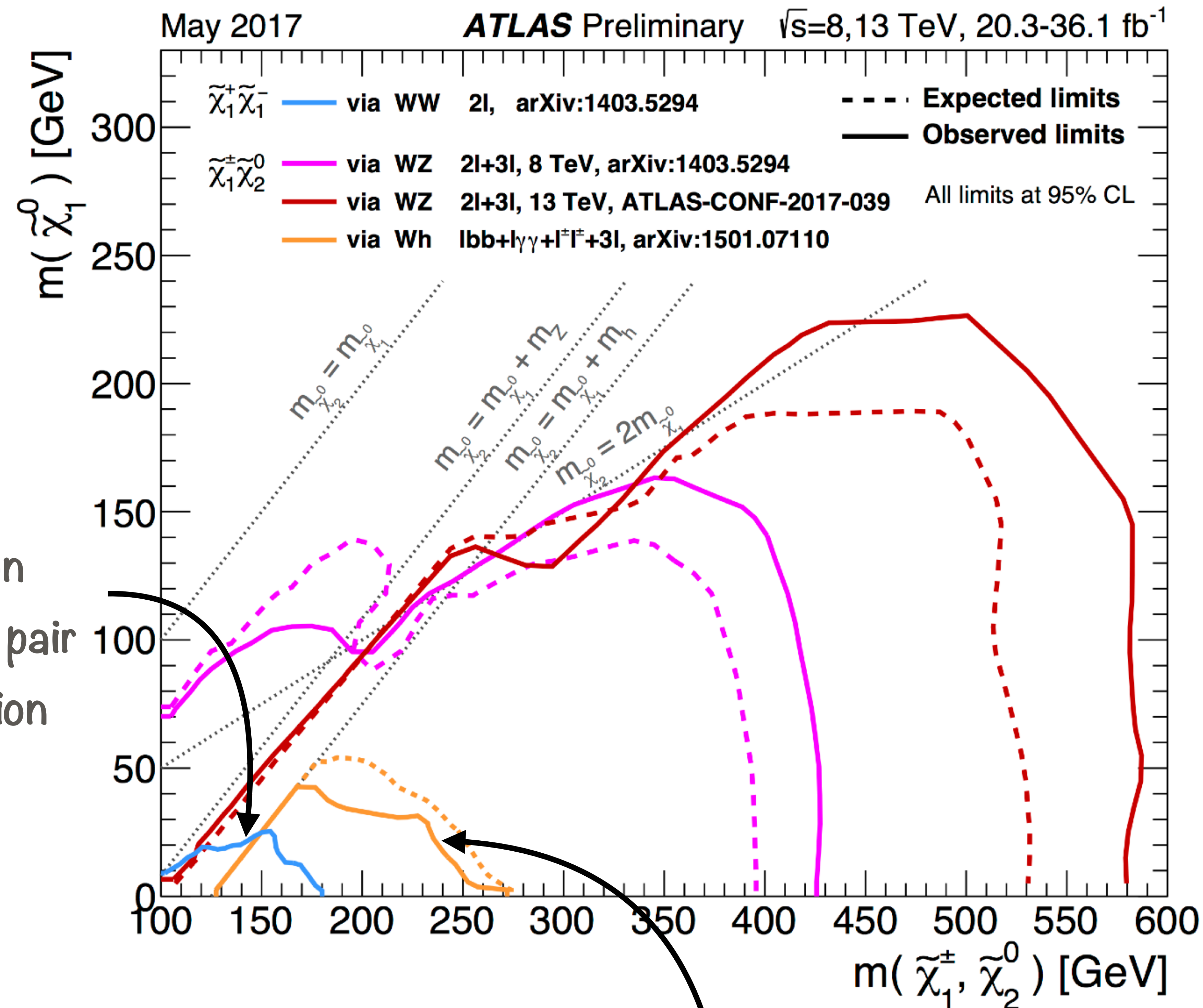




- Look at parameters that gives right relic density
- Low mixing angle gives low DD cross section; however, not a problem at the LHC because production is primarily Drell-Yan!

Brümmer et al; arXiv:1703.00370
Brümmer, Bharucha, Desai; arXiv:1804.02357

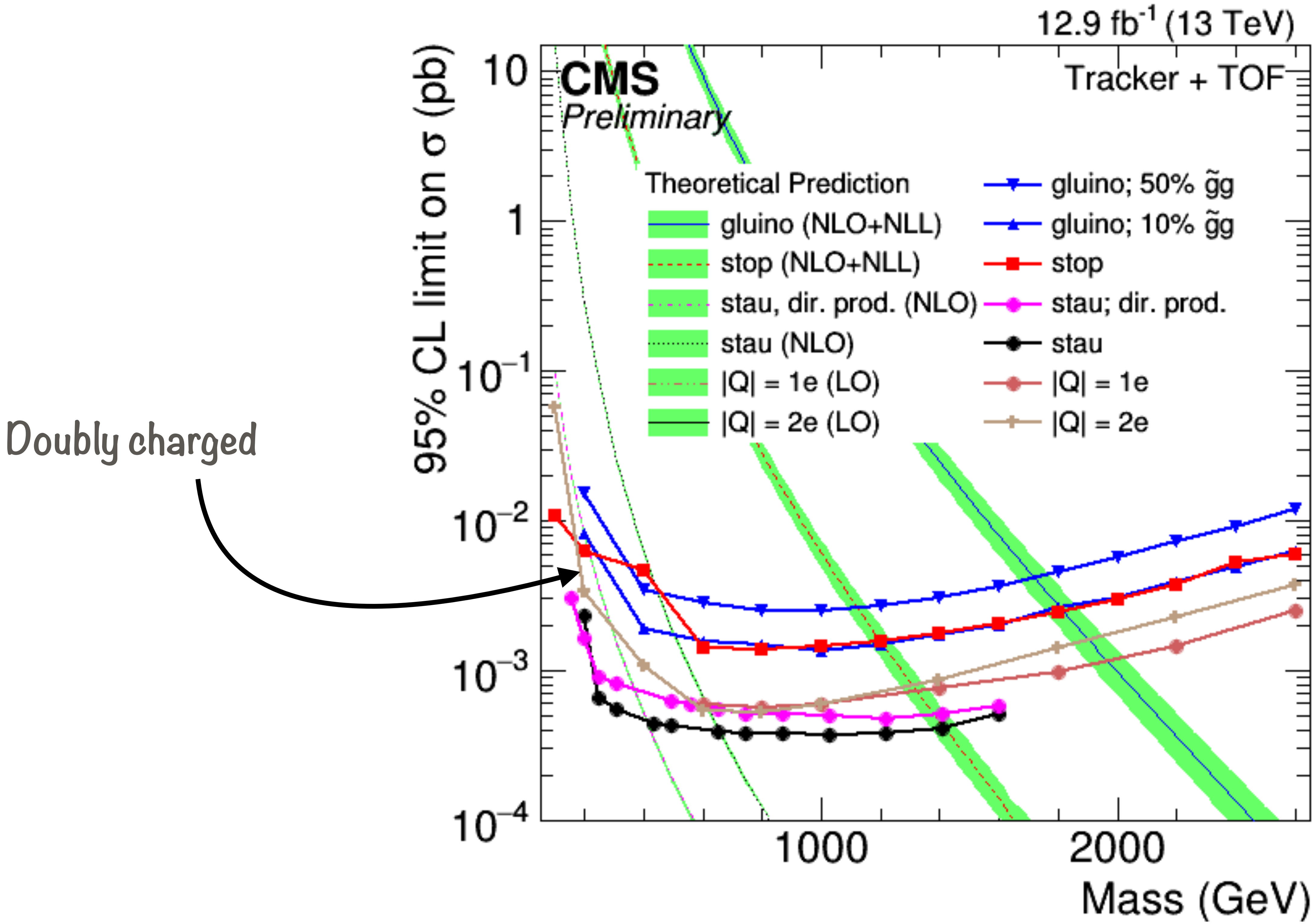
Prompt search limits: SUSY searches



Limit on Chargino pair production

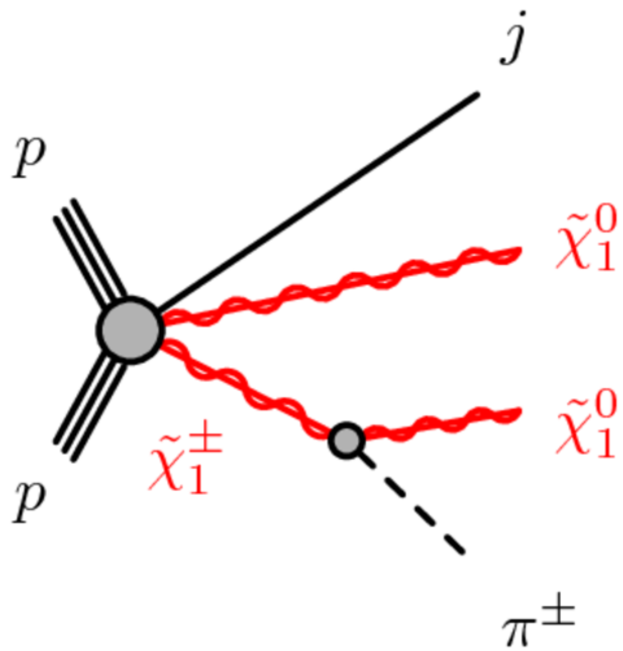
LHC limit on WH final state; not stronger than displaced leptons

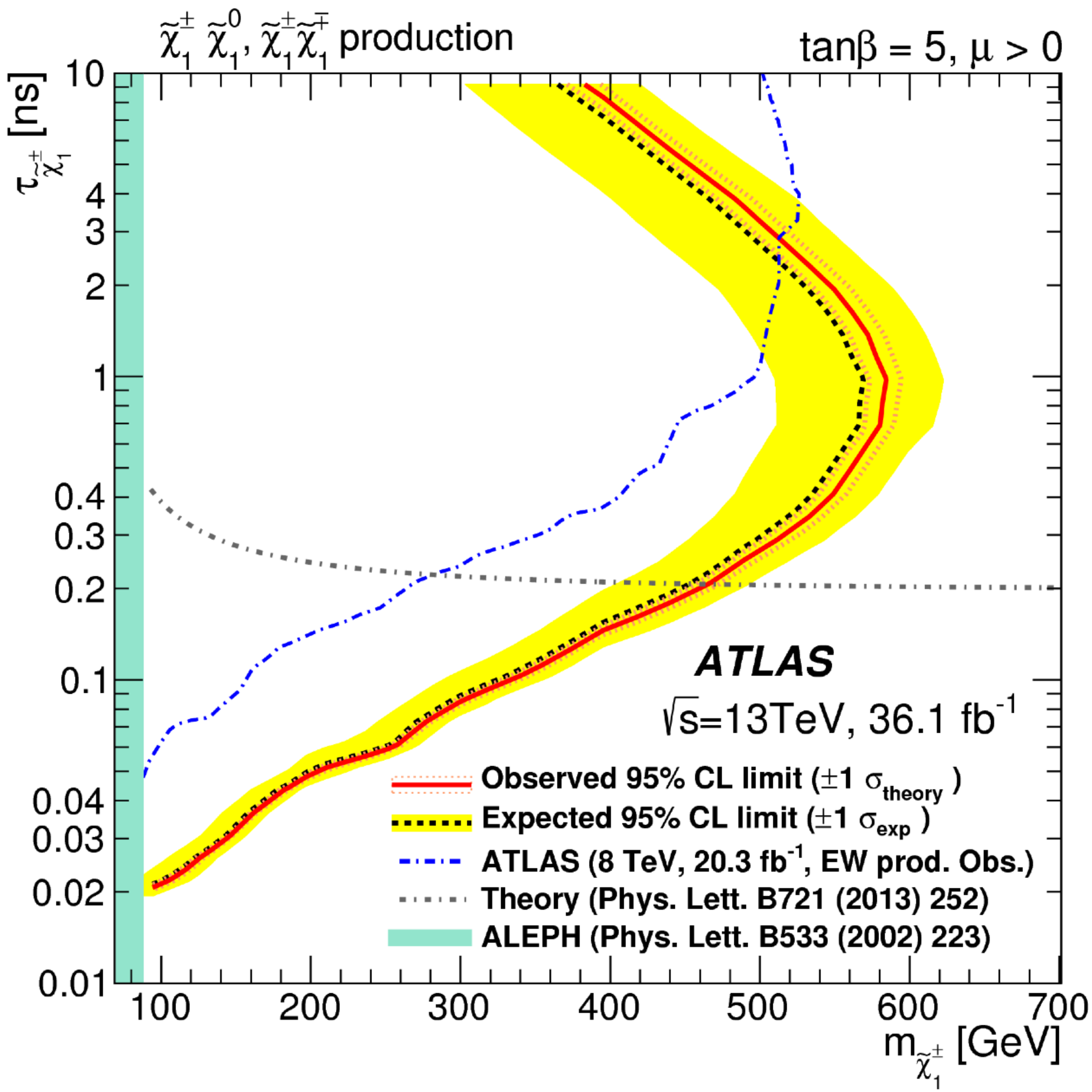
Other limits: charged track searches



Rule out long-lived region i.e. when mass difference is smaller than pion mass

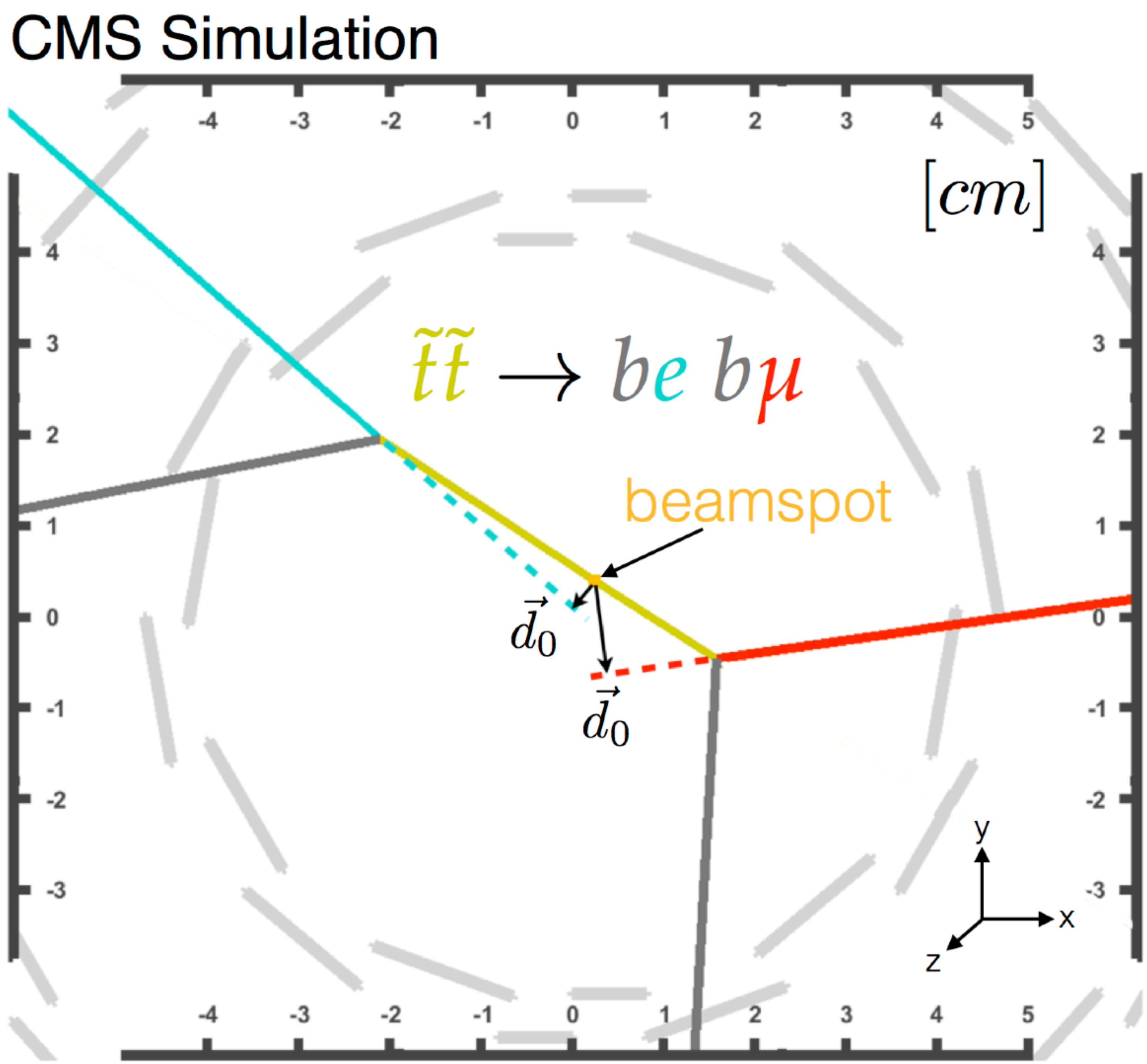
Disappearing track searches





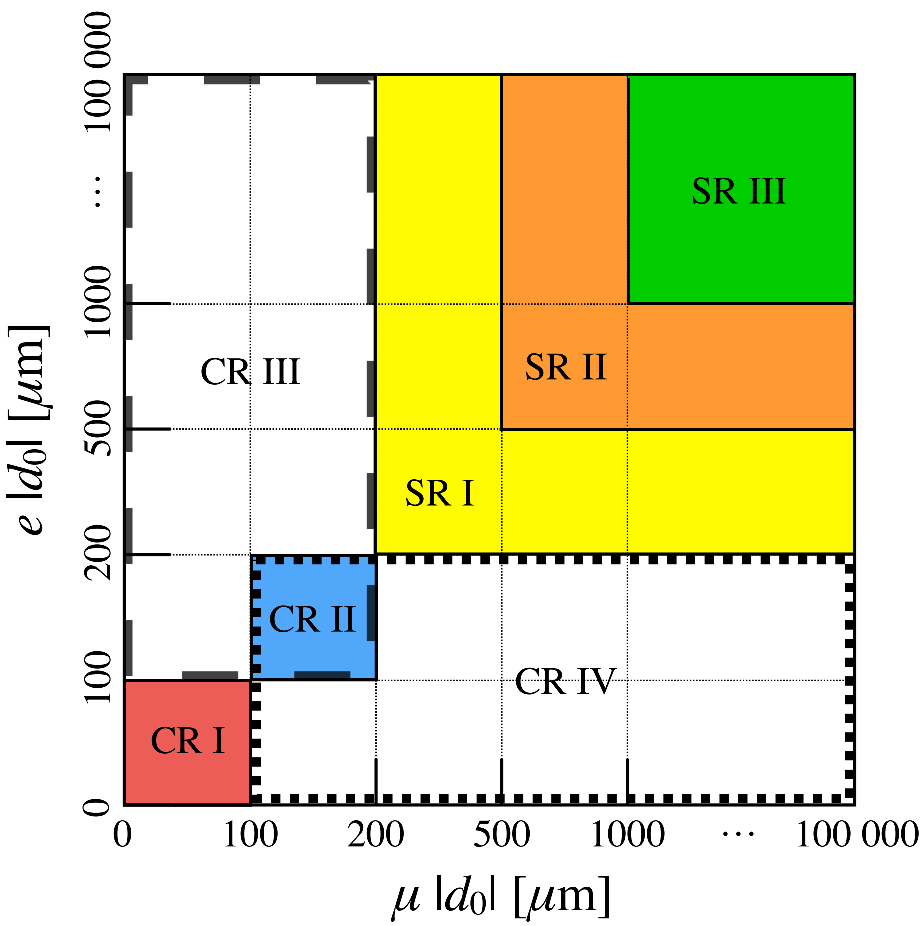
arXiv:1712.02118

Displaced Lepton Search



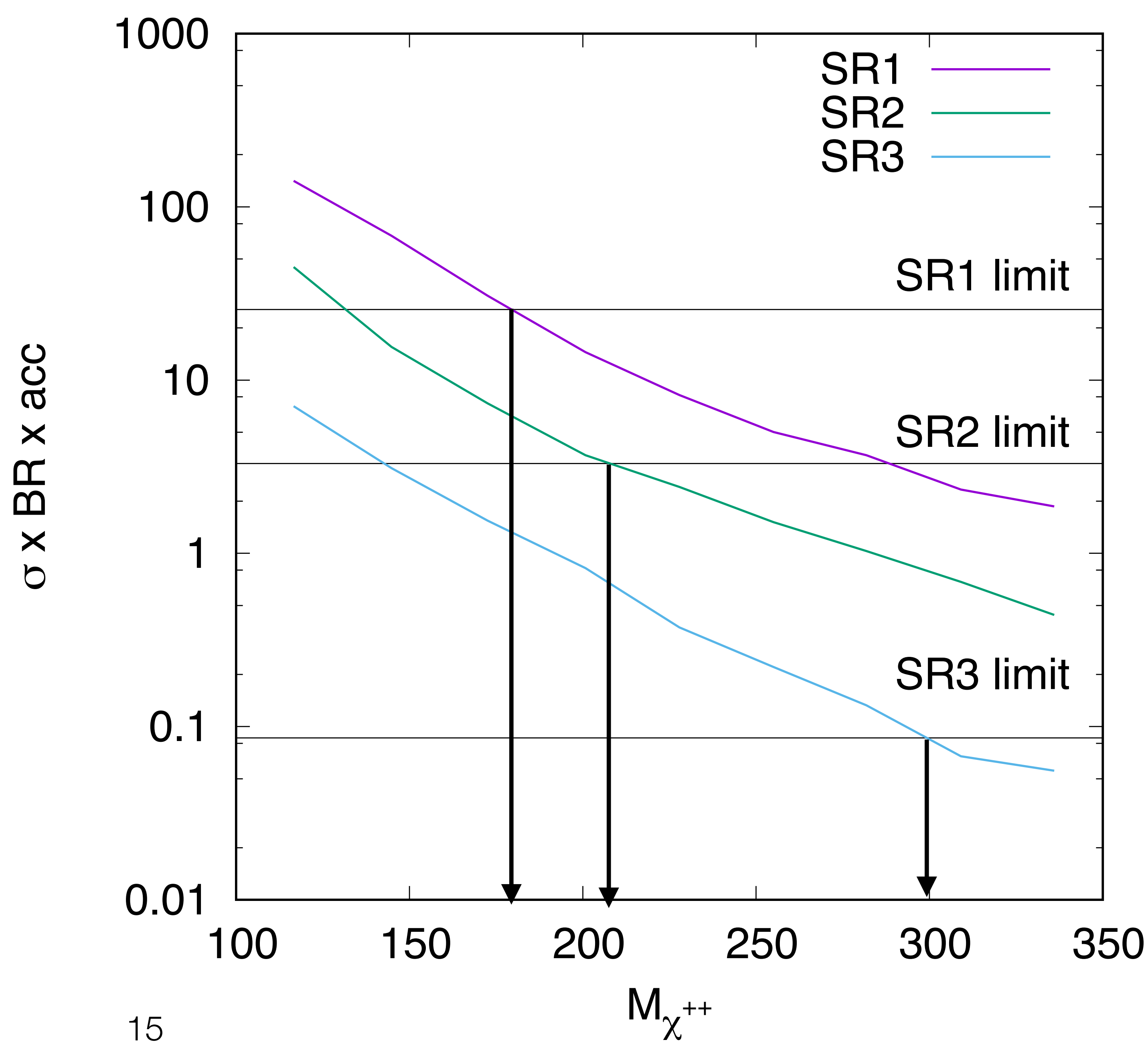
CERN-PH-EP/2013-037, CMS PAS EXO-16-022

The CMS displaced lepton search



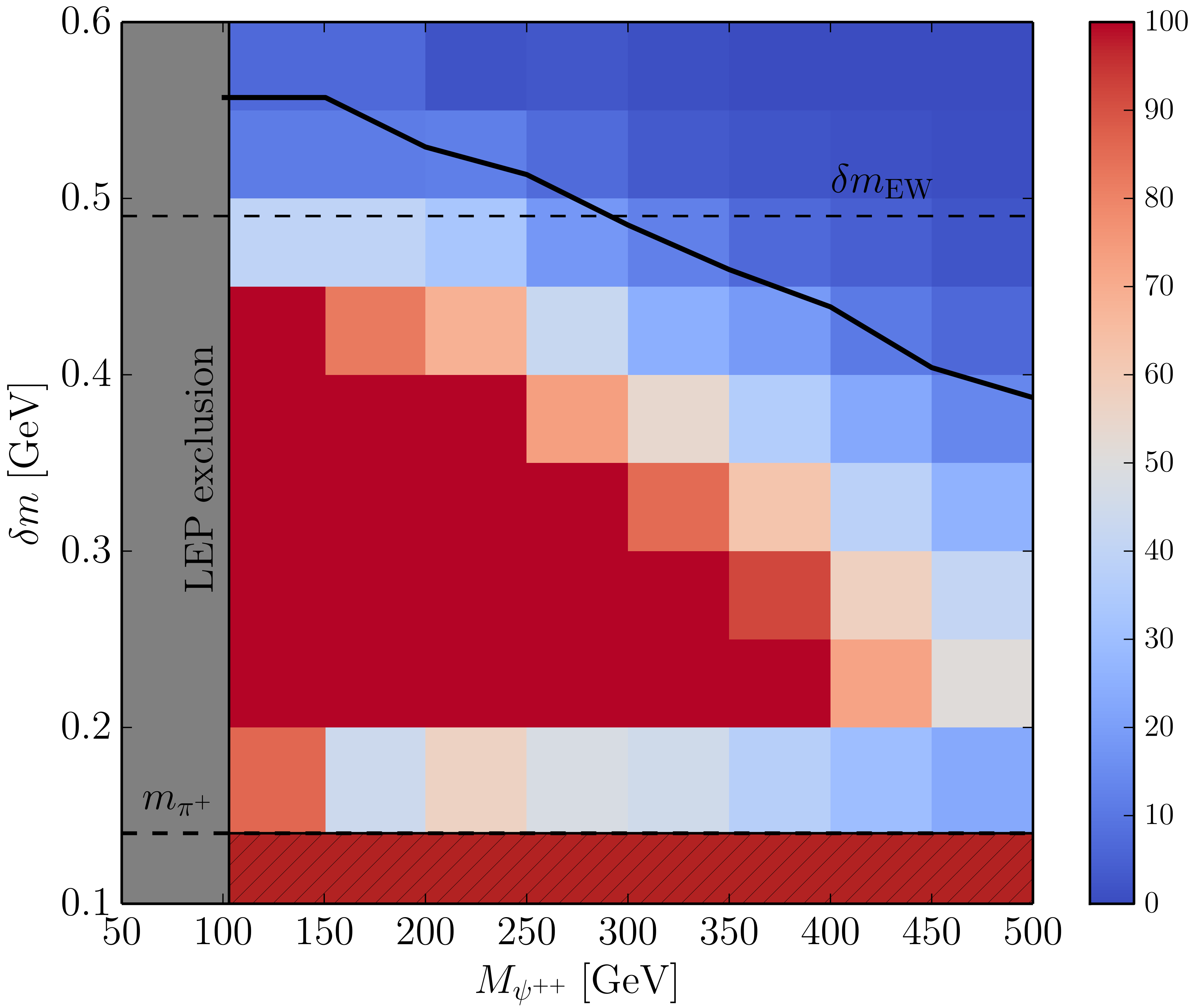
Validation

Lifetime	1 mm	10 mm	100 mm
SR1	34.4 (30 ± 5)	28.3 (35 ± 7)	4.83 (4 ± 1)
SR2	8.76 (6.5 ± 1)	24.6 (30 ± 5)	5.73 (5 ± 1)
SR3	1.69 (1.3 ± 0.3)	53.6 (51 ± 10)	24.6 (26 ± 5)

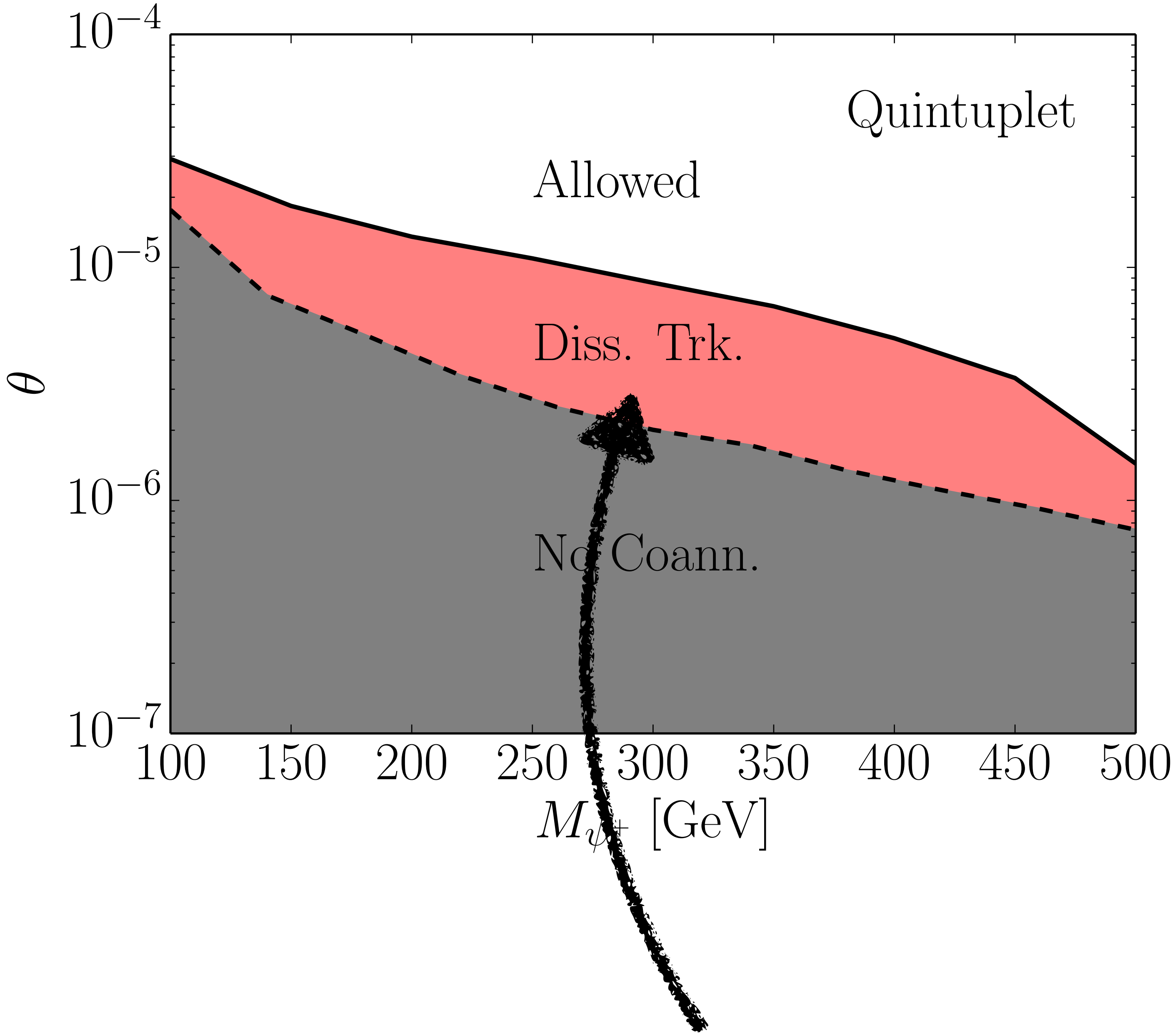


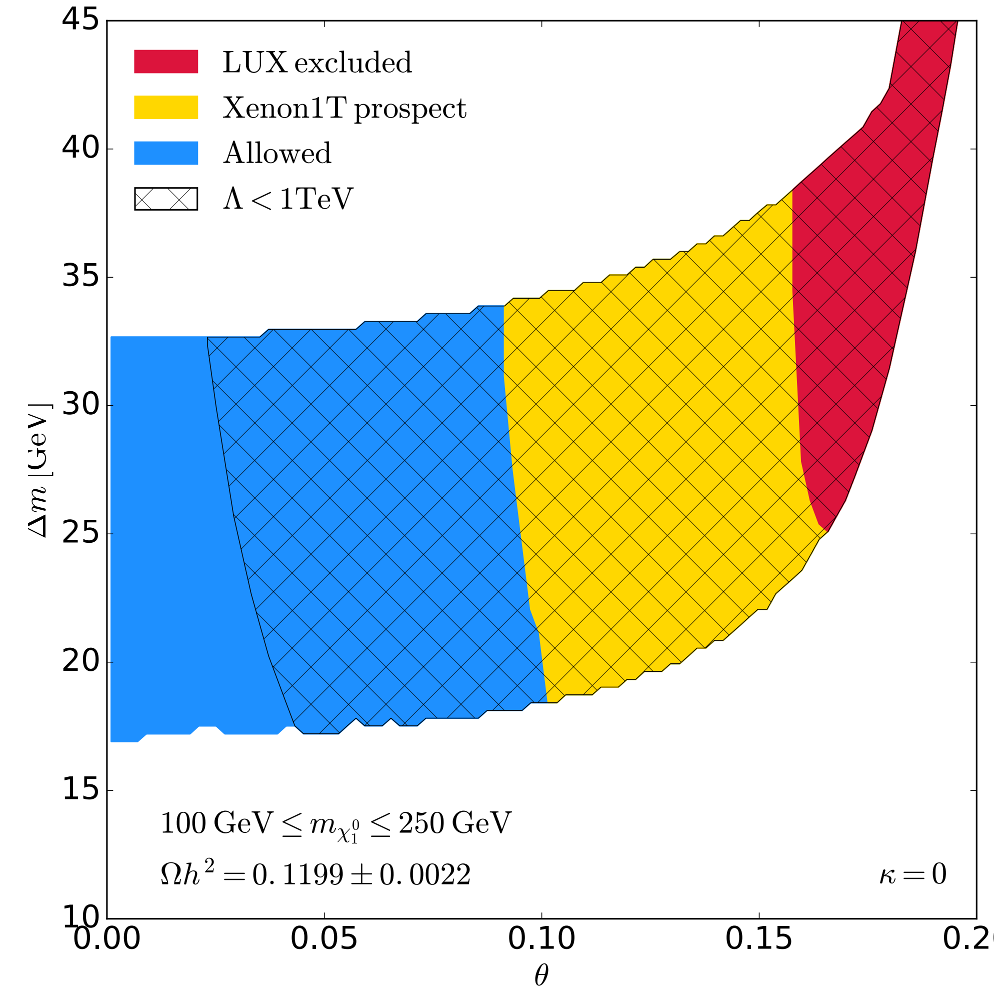
arXiv:1409.4789

Combination of displaced lepton and charged tracks



Limits on mixing angle



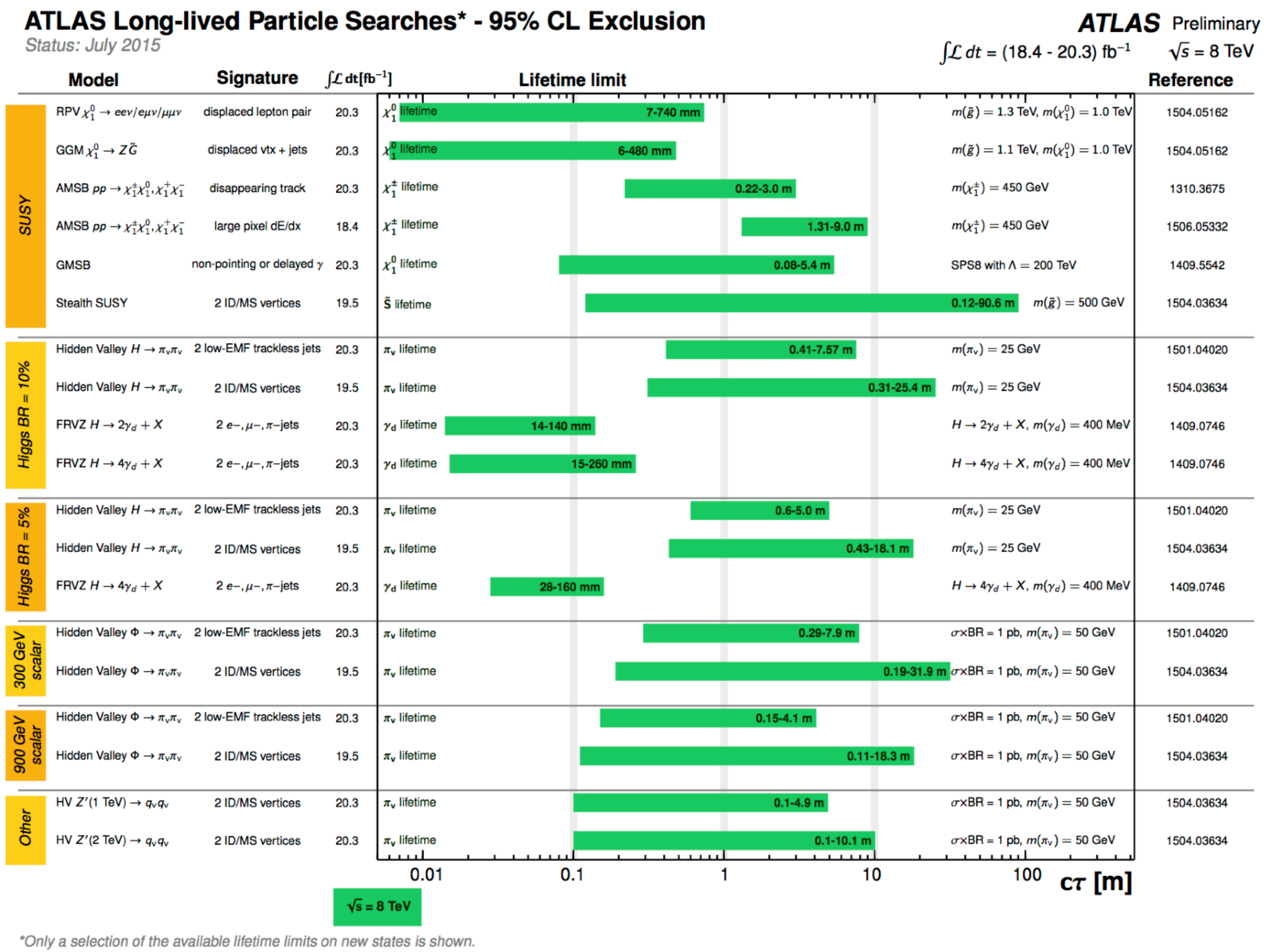


Provides a complementary lower limit on mixing

Filling the gaps in DM searches

DM + s-channel mediator	Dilepton, dijet, mono-jet, displaced vertices
DM + t-channel mediator	"squark" & "slepton" searches, (disappearing) charged tracks, displaced leptons
SU(2) n-plets	jets+MET, di-lepton+MET searches, mono-jet, mono-photon, (disappearing) charged tracks, displaced leptons
ALPs	Di-gamma, non-pointing photons
Sterile Neutrinos, Heavy Neutral leptons	leptons+MET, Z/higgs+MET displaced vertices, displaced leptons

Some LLP limits



ARE WE MISSING SOMETHING?

Summary

- Long-lived particles predicted by many theories as a natural consequence
- LLP searches often have nearly **zero background** and can provide a clean signature
- If a model predicts LLPs, these searches are **more sensitive** than traditional searches
- **Co-annihilation partners** in DM models are often long-lived and can provide the first indications of signal
- Important to look at LLPs to **cover full range of DM theory** possibilities.