기초과학연구원
Institute for Basic Science

Thursday, 22nd February, UCLA Dark Matter 2018

Searches at CLIC for Electroweak Dark Matter

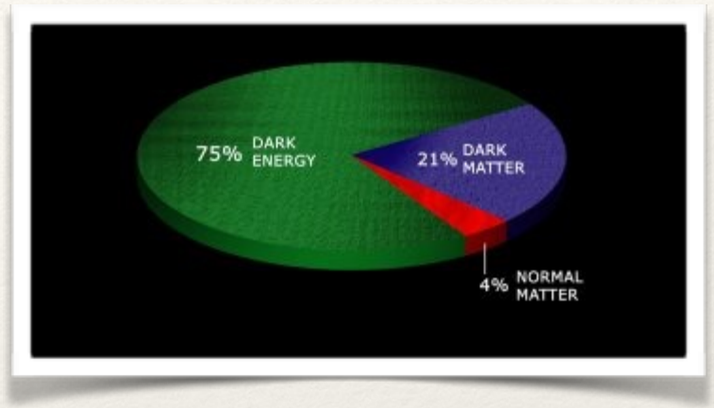
A. Spray, K. Kadota,
M. Cirelli, F. Sala
arXiv: 1802.xxxxx

Table of Contents

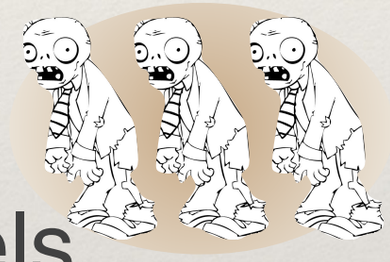
1. Motivation
   a) Electroweak Multiplets as simple Dark Matter
   b) Lepton colliders with large √s
2. Search Strategies
   a) Standard searches
   b) Mono-leptons + soft tracks
3. (Preliminary) Results
4. Conclusion

Motivation & Theory

Electroweak Multiplets

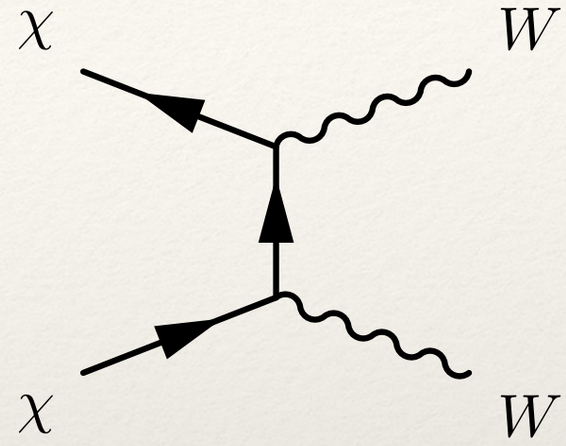


- Classical example of dark matter
  - The weak in WIMP
- Can be considered a low-energy limit of several models
  - e.g. Supersymmetric Higgsino & Wino

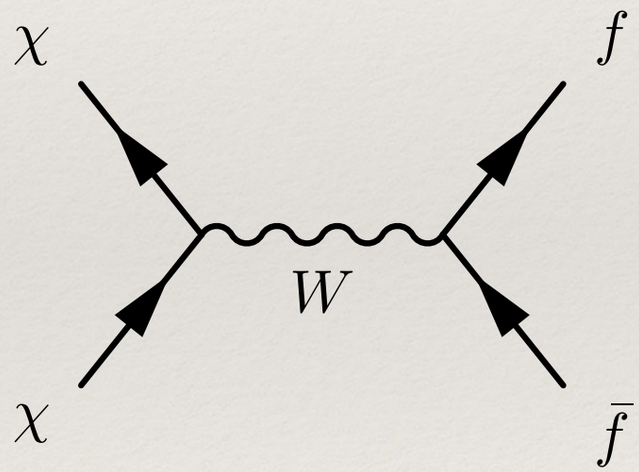


- Or a simple extension of Standard Models
  - Fermion quintet (Minimal Dark Matter), accidentally long-lived
  - Other multiplets with ad hoc stabilising symmetries
- Simplicity is attractive

- Pure multiplet ⇨ only $\mathrm{SU}(2)\times\mathrm{U}(1)$ gauge interactions
  - Single parameter: dark matter mass
  - Components of multiplet radiatively split (charged components heavier)

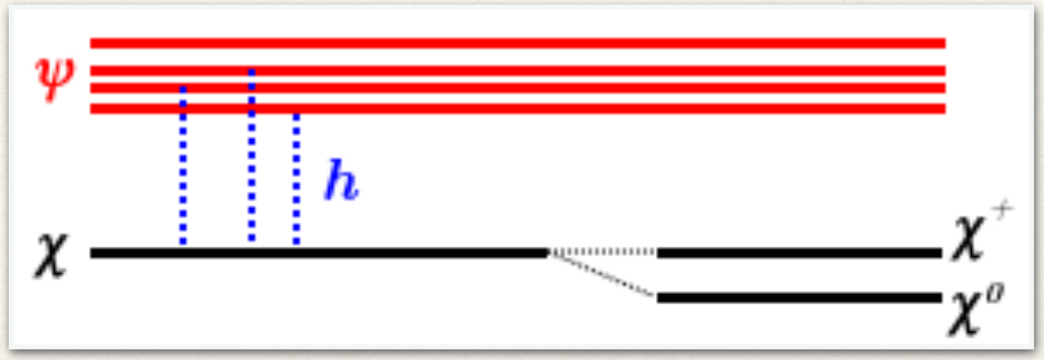


  - Relic density determined by SM processes
    - Higgsino 1 TeV
    - Wino 2.4 TeV (Sommerfeld effect)
    - Fermion 5plet 10 TeV (Bound state formation)



- Lighter states allowed; just don't saturate relic density

- Additional dark sector states:
  - Mass mixing: different mass splitting
    - Focus on $\delta m < 10$ GeV



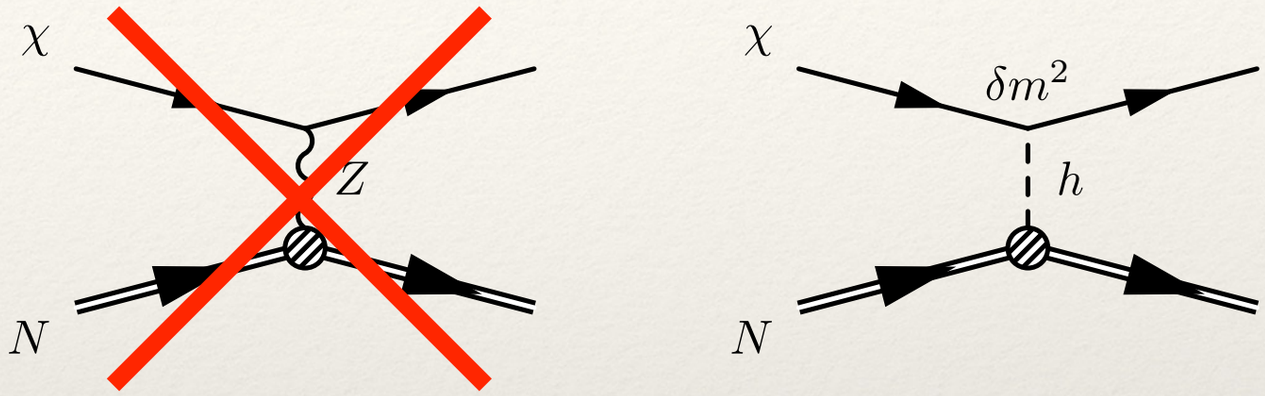
  - Modifies couplings to gauge bosons

$$g = g_w \cos\theta \qquad \frac{\delta g}{g_w} \sim \frac{\delta m^2}{(m_X - m_{DM})^2} \lesssim 1\%$$

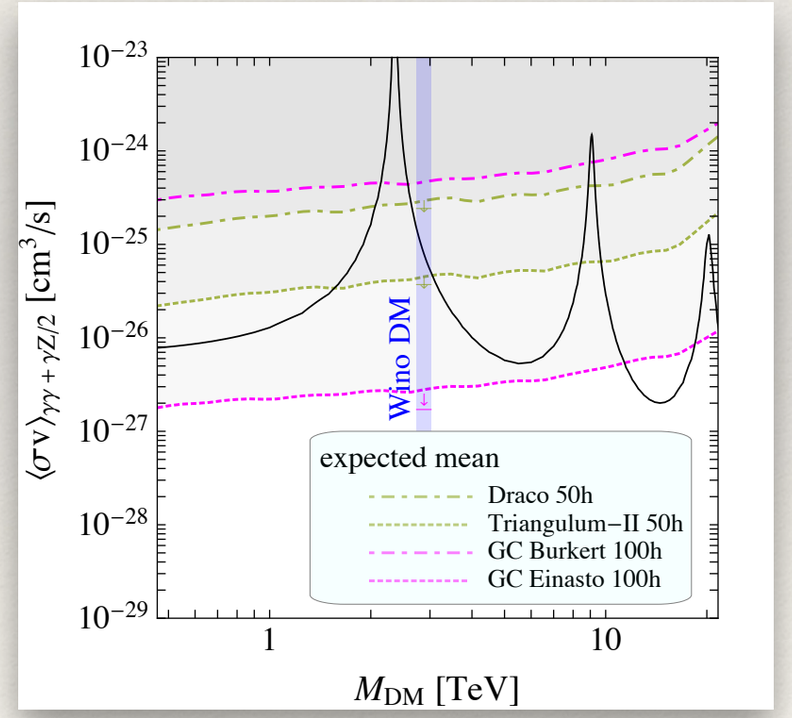
  - Coannihilations/interference: different relic density
- Treat mass & mixing as separate free parameters
- Will not impose a relic density constraint

Searches for Simple Multiplets

- Direct searches weak
  - No/inelastic Z coupling
  - Higgs coupling suppressed



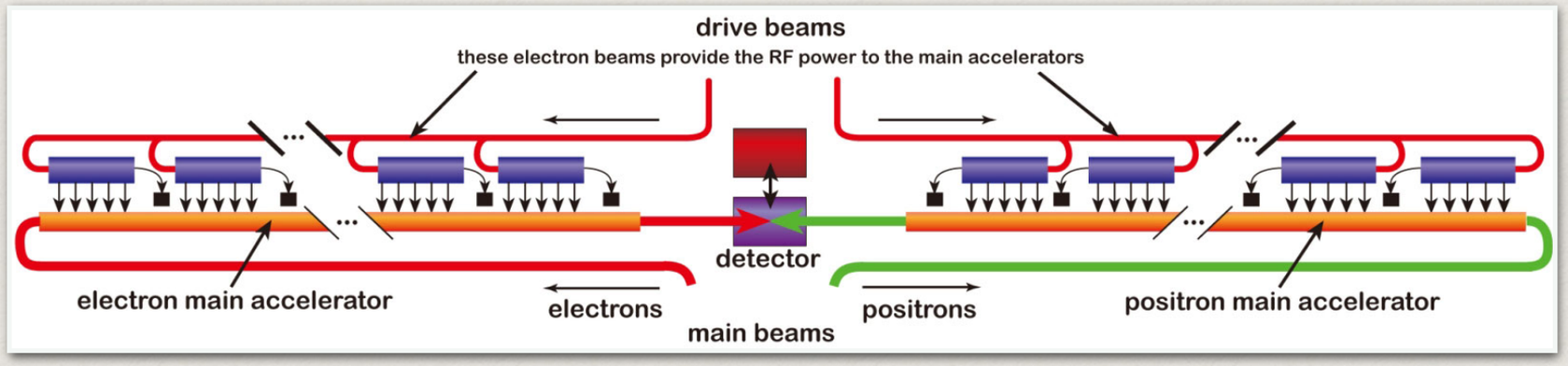
- Also tricky at LHC
  - Depends on lifetime (see later discussion)
  - LEP still wins in parts of theory space
- Cosmic ray (indirect) searches often best
  - Galactic uncertainties; terrestrial confirmation?
- Future lepton colliders



Sala, Silk *et. al,* 1608.00786

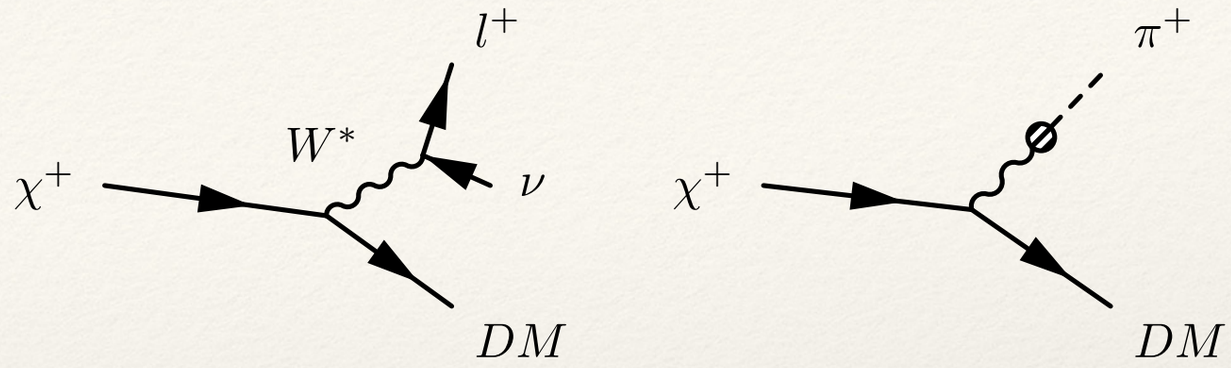
Lepton Colliders & CLIC

- Lepton colliders couple efficiently to EW gauge bosons
- No QCD obfuscation
- Multiple proposals, e.g. ILC, but largest √s at CLIC

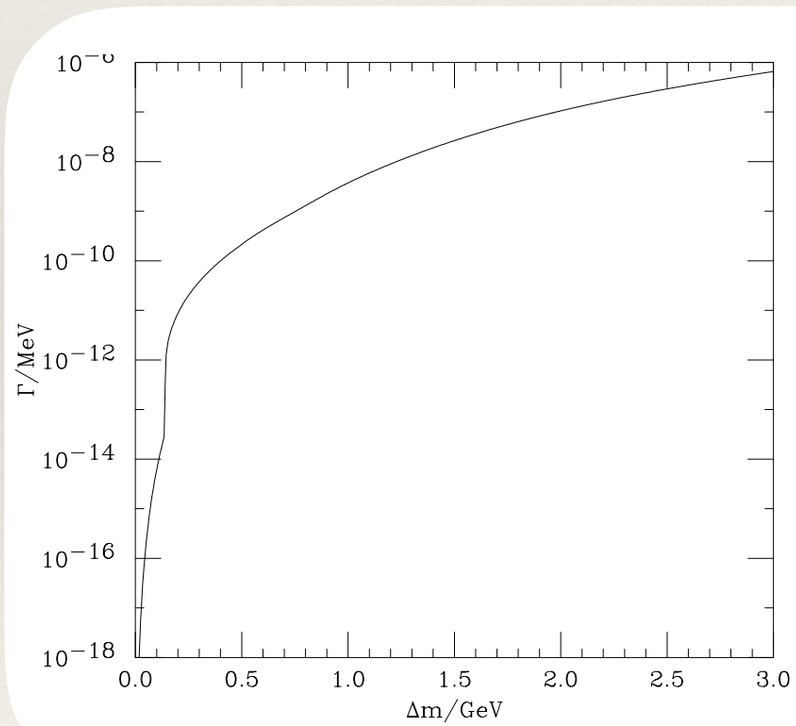


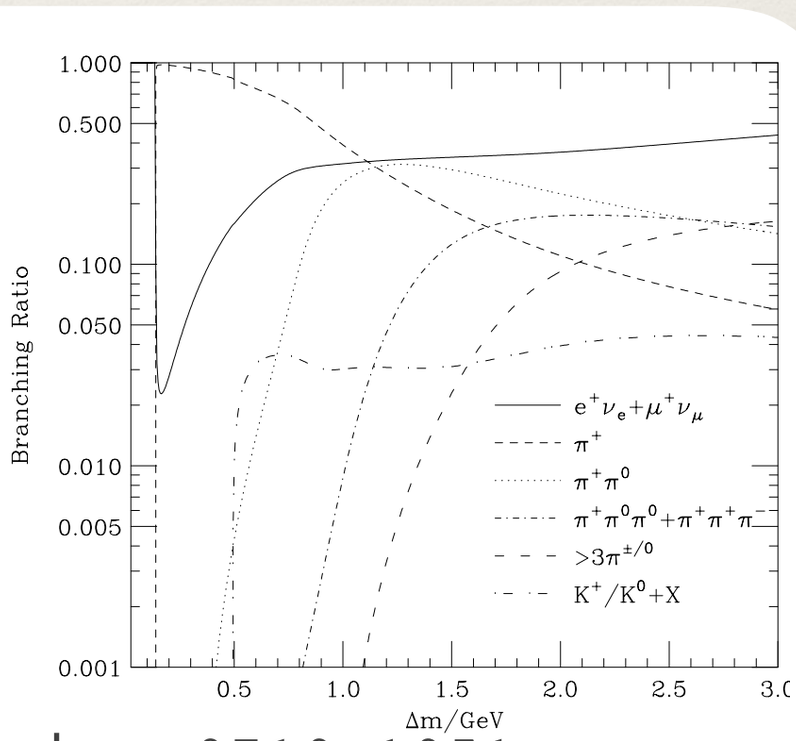
- 3 TeV, 2 ab^{-1} design goals
- Large $\gamma\gamma \to$ hadrons background at $p_T < 10$ GeV
- ISR & Beamstrahlung important; simulate with Whizard 2.4

- Charged states in multiplet dominate production
- Decay through virtual W



- Lifetime & decay modes sensitively depend on δm





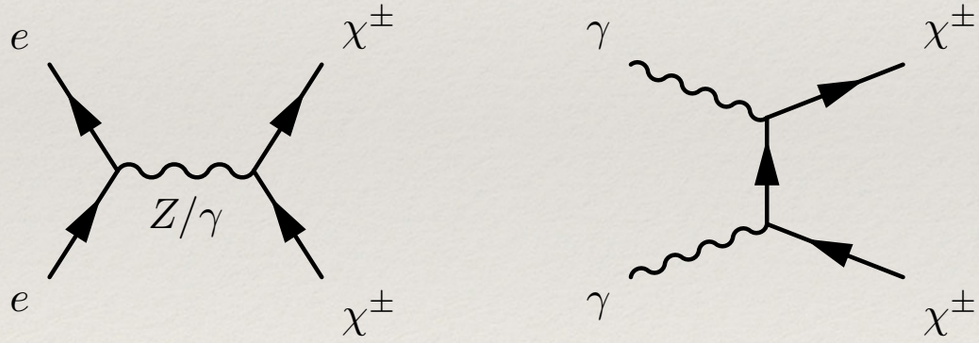
Grellscheid & Richardson, 0710.1951

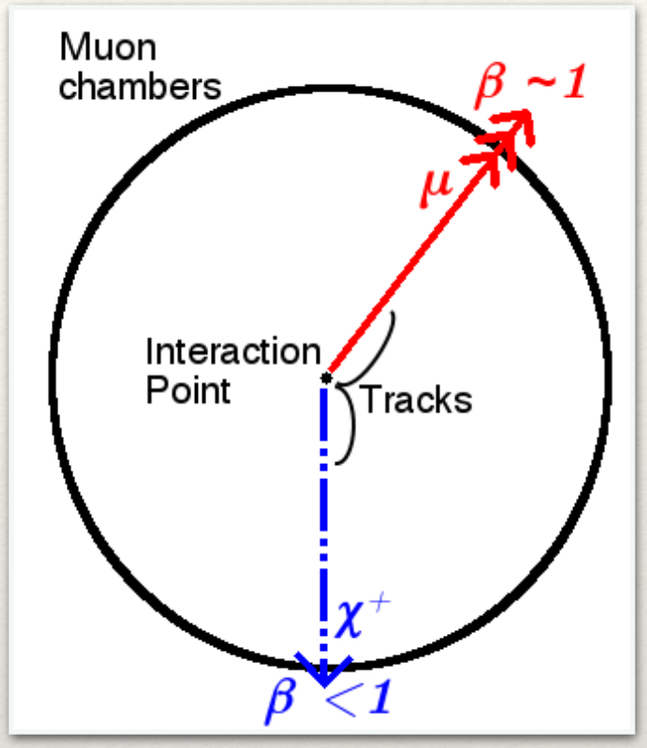
- Searches depend on lifetime & hence mass splitting

Collider Search Details

Long Lived Charged Particles

- Collider-stable charged states
  - Look like slow muons
- Use LHC searches as guide 1411.6795
- Search for two LLCPs (one + γ worse)



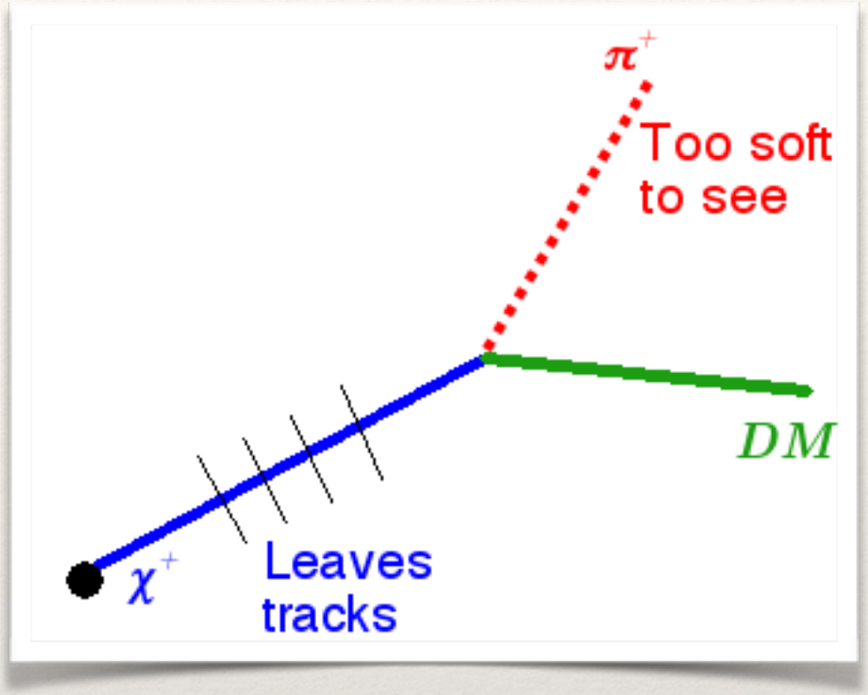


p_T	> 70 GeV
$\lvert\eta\rvert$	< 2.4
β	< 0.85

- Background dominantly mis-measured μ
- Difficult to estimate; LHC fractional rate ~ 10^{-4}
- O(10) background events in total data sample

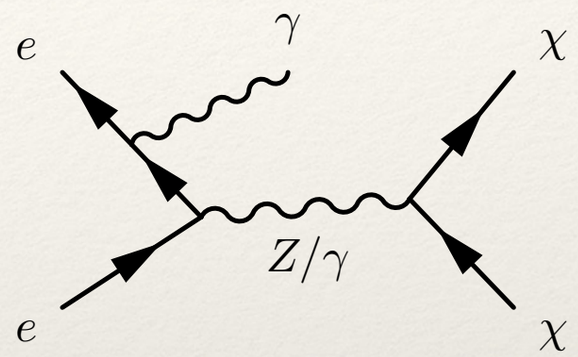
Disappearing Tracks

- Standard search for $c\tau \sim 10$ cm
  - χ^+ decay before muon chambers
  - Decay products too soft to see
- Applies to radiative $\delta m = 165$ MeV
- Difficult as a theorist to model:
  - Unknown reconstruction efficiency; vary from 10% to 100%
  - Background dominated by fakes, hard to simulate
    - Suppress with hard photon $p_T > 100$ GeV

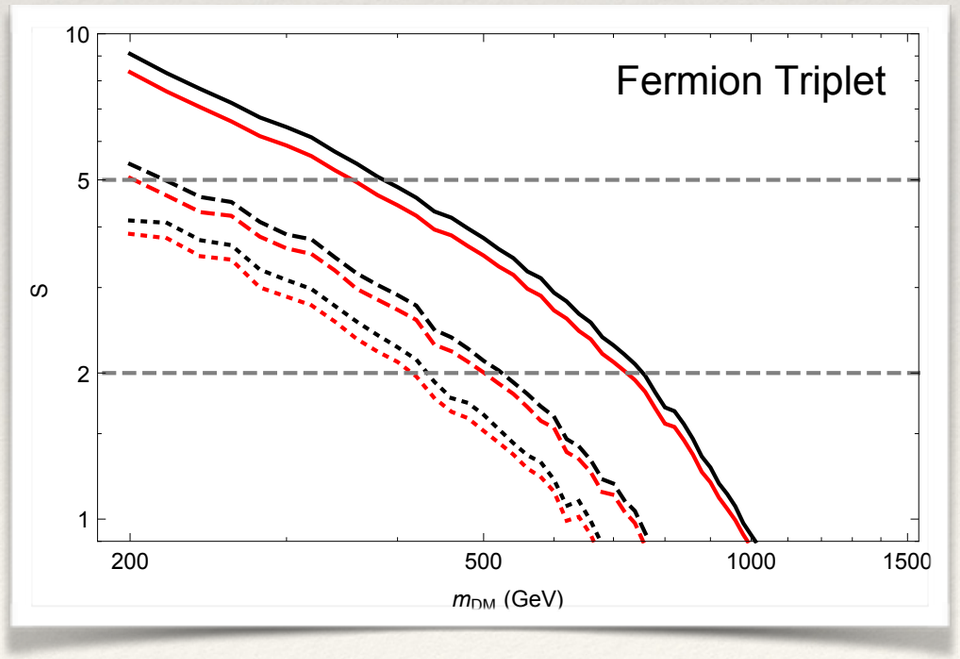


Monophotons

- Relevant for moderate $\delta m \sim$ GeV
  - Soft decay products not tagged
  - Prompt decay (not disappearing track)

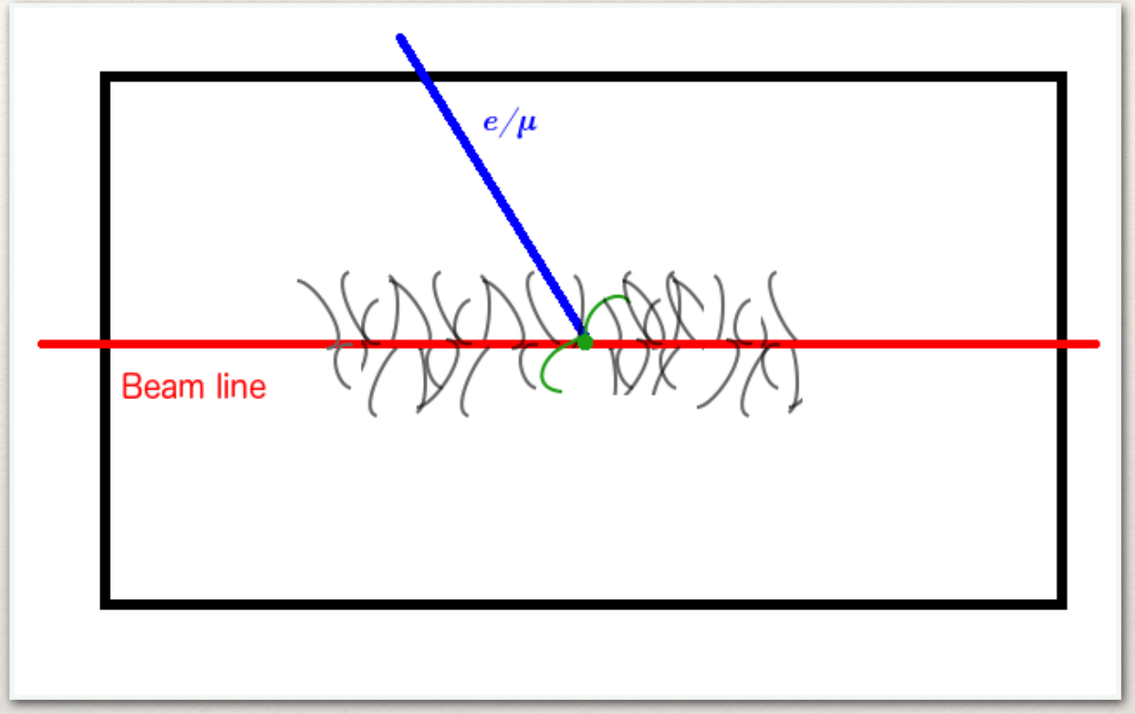


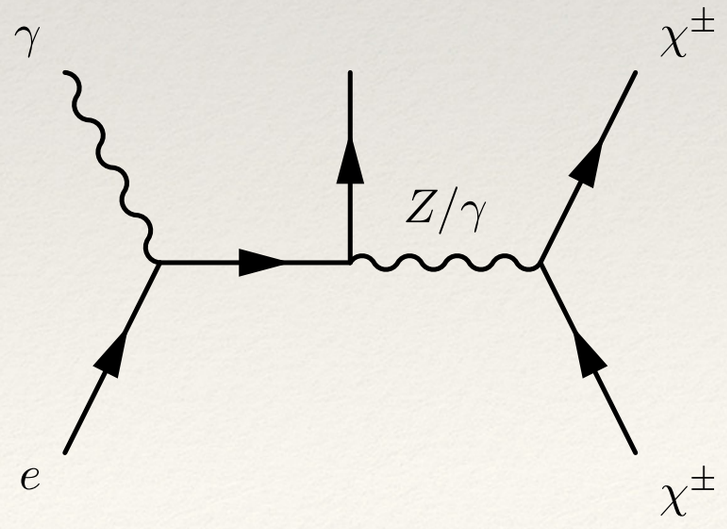
- Simple final state: single hard photon
  - Optimise cuts with respect to p_T, E^γ, η
  - Assume 0% to 1% systematic uncertainty
- Background dominantly $e^+e^- \to \nu\bar{\nu}\gamma$
  - Same scaling as signal with polarisation
  - Result is that these searches are very weak



Lepton + Prompt Soft Tracks

- Still WIP, results preliminary
- Relevant for δm ~ 1 to 10 GeV
- Soft decay products invisible against $\gamma\gamma \to$ hadrons
  - Reconstruct primary vertex with track from hard lepton
  - CLIC goal 10 μm resolution
  - Dominant production relies on beamstrahlung

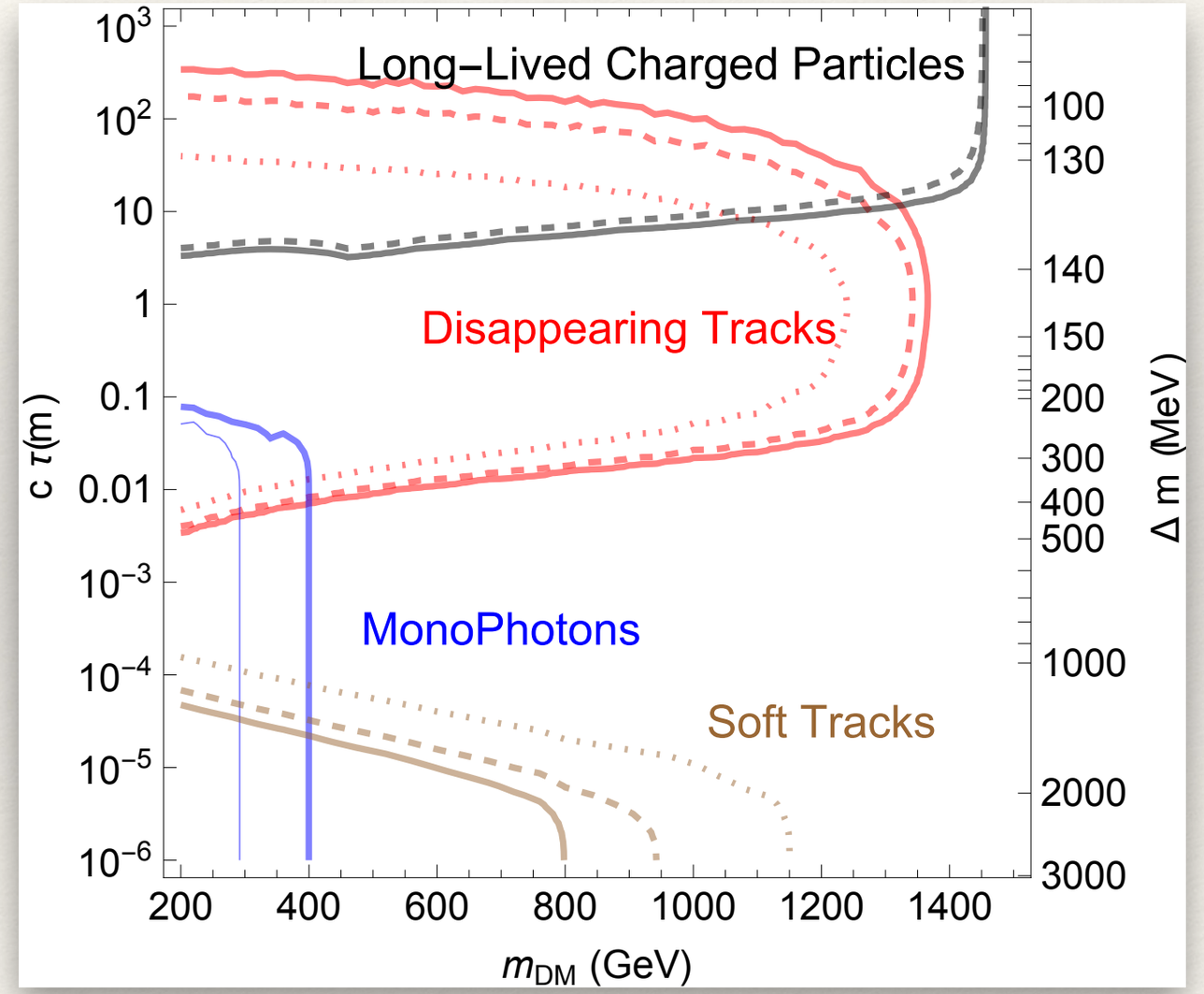




Results

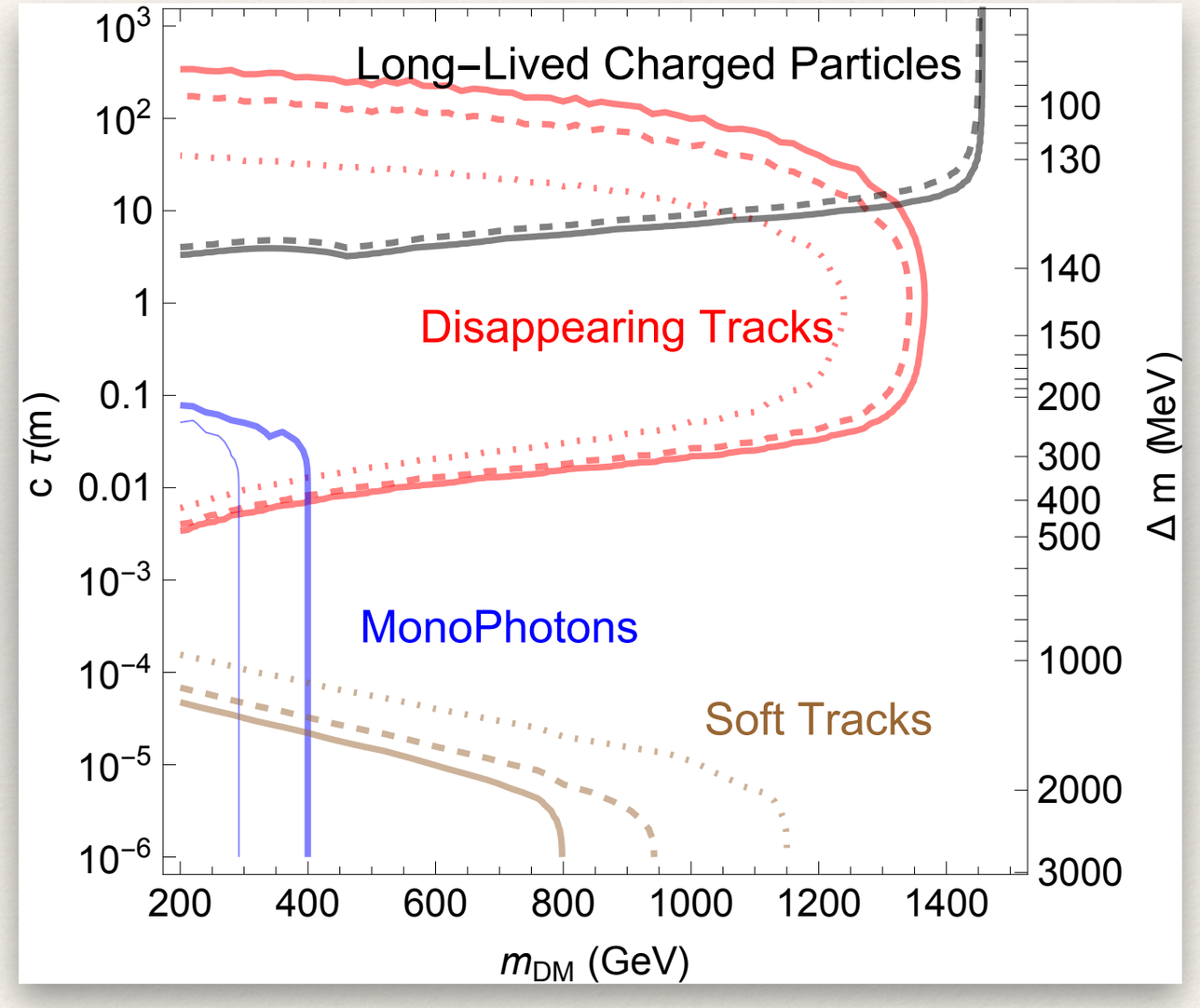
Fermion Doublet (Higgsino)

- **LLCP** prospects reach to kinematic limit **1.5 TeV**
  - Solid (dashed) lines show exclusion/ discovery contours



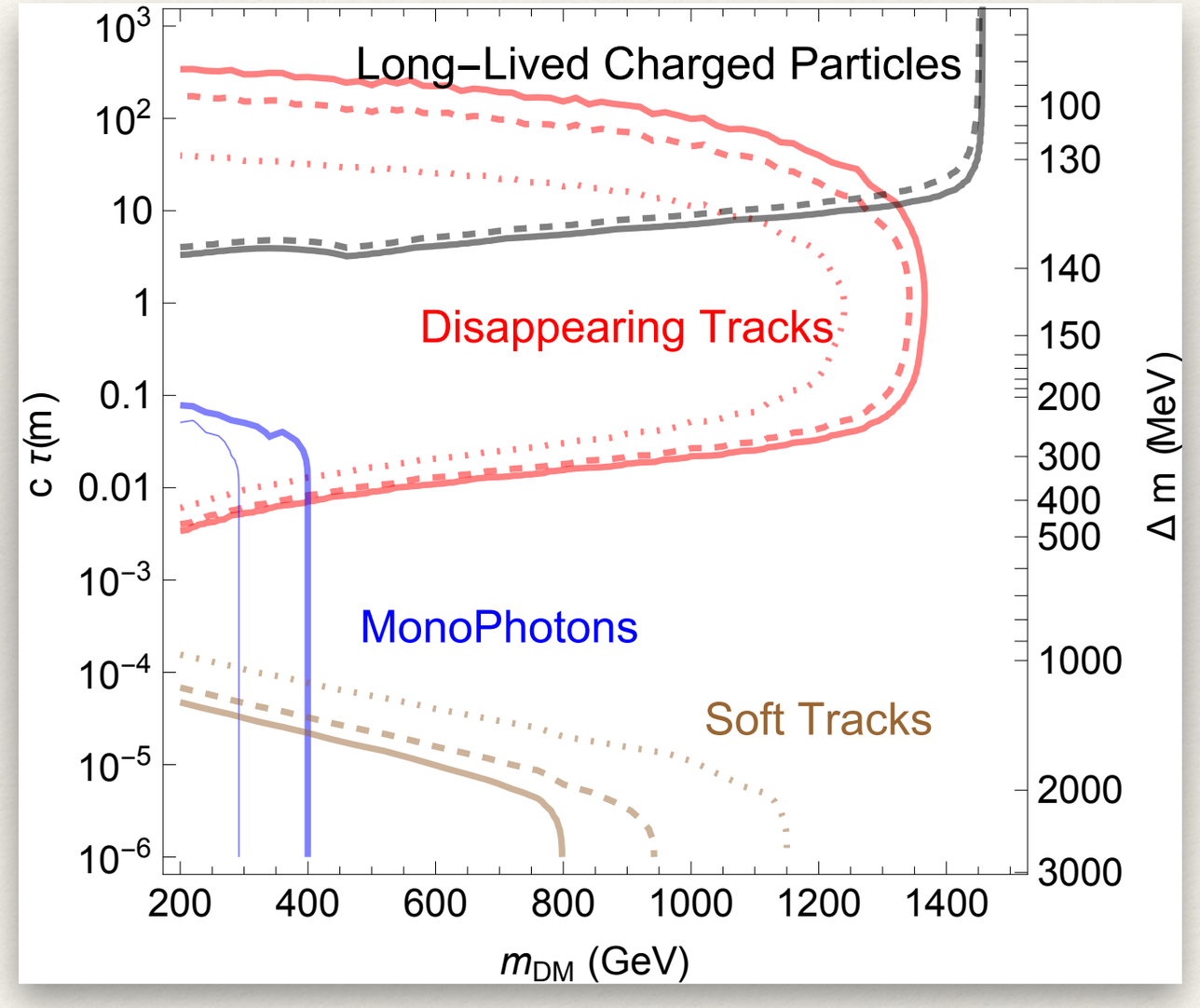
Fermion Doublet (Higgsino)

- **LLCP** prospects reach to kinematic limit **1.5 TeV**
- Disappearing tracks effective, but hard photon weakens
  - Solid/dashed/dotted lines show 10 expected events for 100% (50%, 10%) track reconstruction efficiency



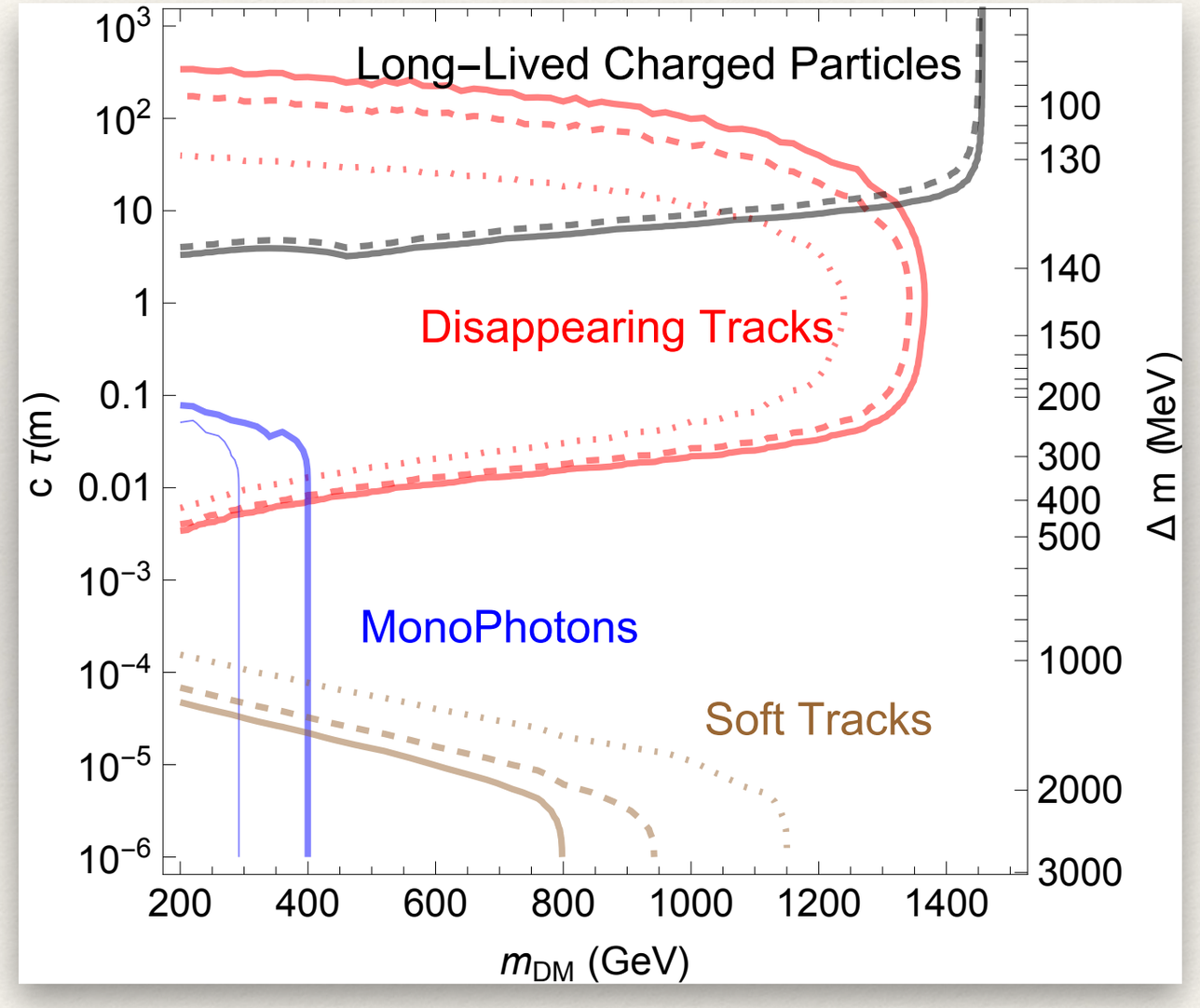
Fermion Doublet (Higgsino)

- **LLCP** prospects reach to kinematic limit **1.5 TeV**
- Disappearing tracks effective, but hard photon weakens
- Monophotons best for $\delta m \sim 0.4—1$ GeV, but
  - No discovery potential
  - Solid/feint lines exclusion only, for 0.5%/1% systematic uncertainties
  - Little improvement on LHC

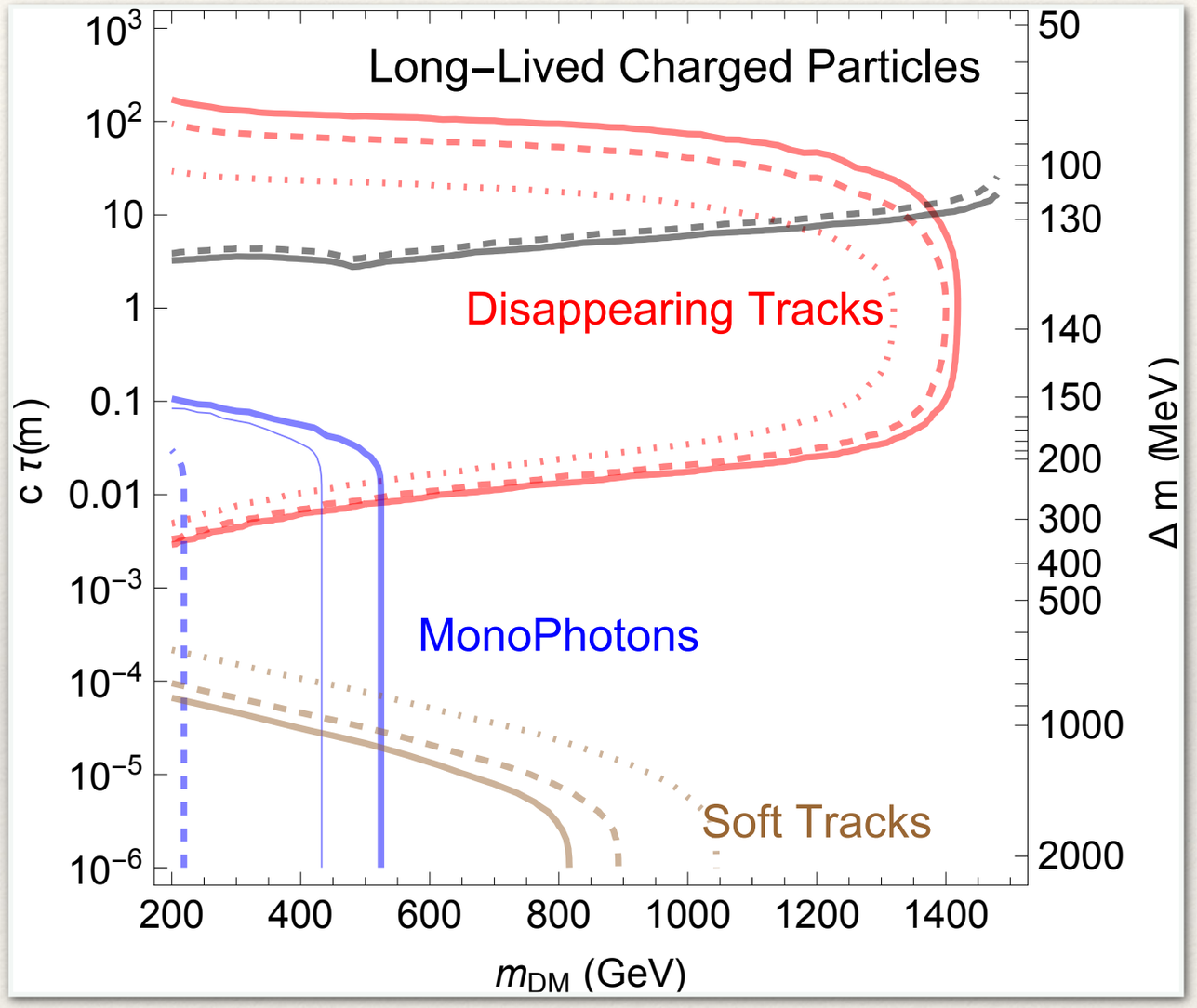


Fermion Doublet (Higgsino)

- **LLCP** prospects reach to kinematic limit **1.5 TeV**
- Disappearing tracks effective, but hard photon weakens
- Monophotons best for $\delta m \sim 0.4—1$ GeV, but
  - No discovery potential
  - Little improvement on LHC
- Lepton + tracks need hard lepton plus ISR/beamstrahlung
  - Solid/Dashed/Dotted lines for 100/50/10 events, incomplete decay simulation

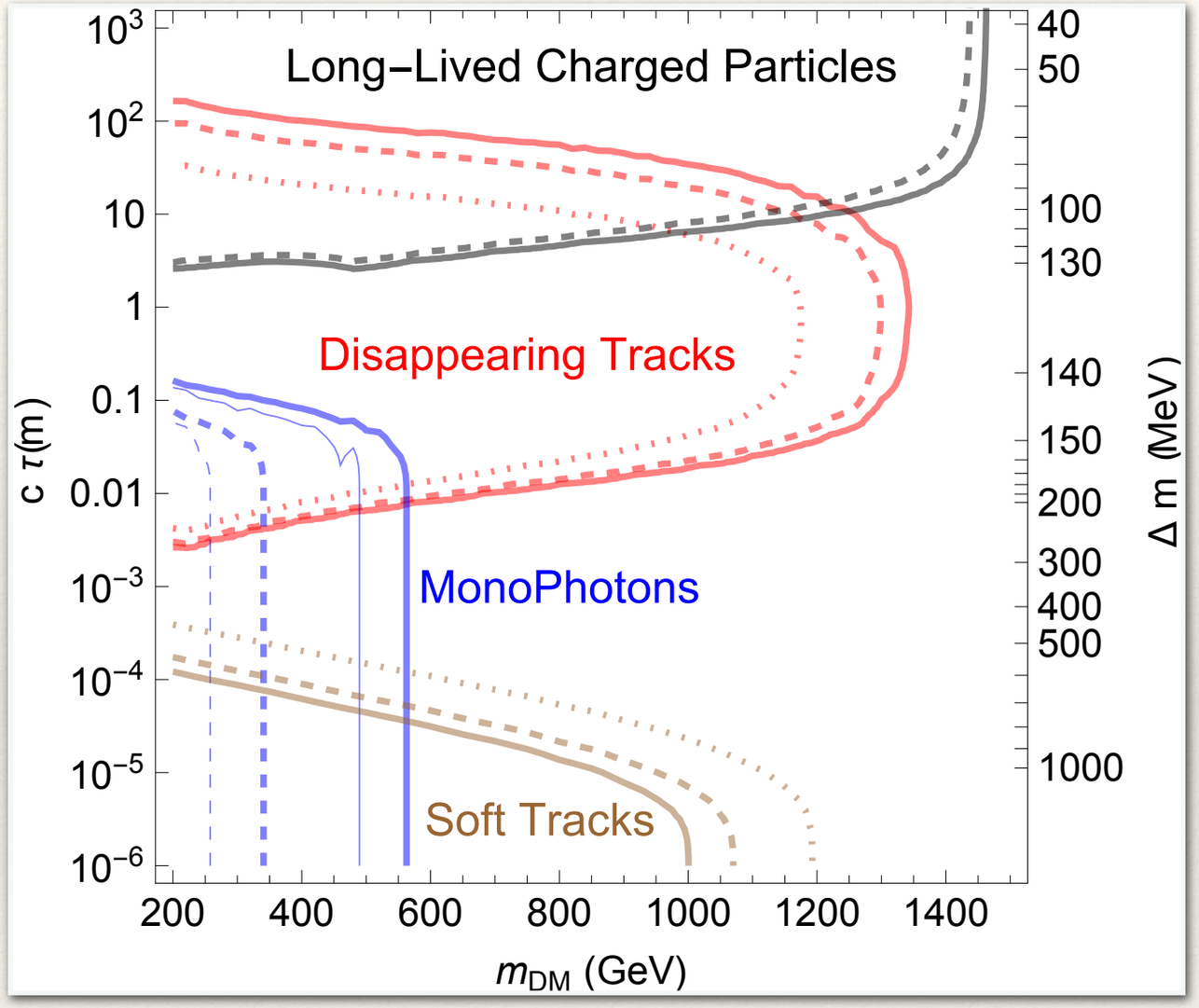


Fermion Triplet (Wino)



- Reach stronger due to larger production cross sections

Scalar Quintet



- Stronger mono-photons but weaker disappearing tracks

Conclusions

- EW multiplets are a simple yet interesting DM candidate
- CLIC could effectively probe thanks to large √s
- Searches are very sensitive to charged state lifetimes
- Hard lepton plus soft tracks an under-explored signal
- Have shown prospective limits on several models

- EW multiplets are a simple yet interesting DM candidate
- CLIC could effectively probe thanks to large √s
- Searches are very sensitive to charged state lifetimes
- Hard lepton plus soft tracks an under-explored signal
- Have shown prospective limits on several models

THANK YOU!