Collider search for minimal dark matter 1703.09675, in preparation

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Dark Matter Properties

- What characterize the dark matter?
  - Abundance: $\Omega h^2 \sim 0.1$
  - Stability
  - Small interaction b/w SM particles
- The “minimal” candidate $\rightarrow$ minimal DM

Cirelli *et al.* 05

Minimal Dark Matter

- Particle with SU(2) and U(1) charge
- Abundance: WIMP miracle
- Automatically stable for higher SU(2) repr.
- Neutral one is weakly interacting

DM Charge and Mass

SU(2)	U(1)	mass
2	$\frac{1}{2}$	1.1 TeV
3	0	2.9 TeV
...		
5	0	9.4 TeV

Cirelli *et al.* 15

- We focus on the Fermionic 5-plet in this talk

Detection Methods

- Now we know the interaction and the (upper bound of) mass.
- Then, how do we detect it?
    - Indirect detection
    - Direct detection
    - **Collider experiments**

Search Strategy

- $\not{E}_T + j$: ~ 3TeV for 100 TeV collider Ismail *et al.* 16
- **Disappearing tracks** from the decay of **charged partners**

Charged Partner in the SU(2) Multiplet

- After EWSB, the 5-plet χ becomes

$$\chi = (\chi^{2+}\ \chi^{+}\ \chi^{0}\ \chi^{-}\ \chi^{2-})$$

- We have charged Dirac Fermions as the dark matter partner

Mass Difference

- The radiative correction makes charged partners heavier
- Without EWSB, there's no mass difference
  - **Higgs VEV** v is the typical scale
- $\Delta M \simeq Q^2 \alpha_2 M_W \sin^2 \frac{\theta_W}{2} \simeq Q^2 166\,\text{MeV} \ll M_\chi$

Decay Mode and the Lifetime

- The Main decay mode is $\chi^{Q+1} \to \chi^{Q}\pi^{+}$
  - Width: $\Gamma \sim {G_F}^2 {f_\pi}^2 \Delta m^3$
- The lifetimes are macroscopic!
  - $\tau(\chi^{2+}) \sim 1\,\text{mm}$
  - $\tau(\chi^{+}) \sim 1.7\,\text{cm}$

χ^+ Track in the Collider

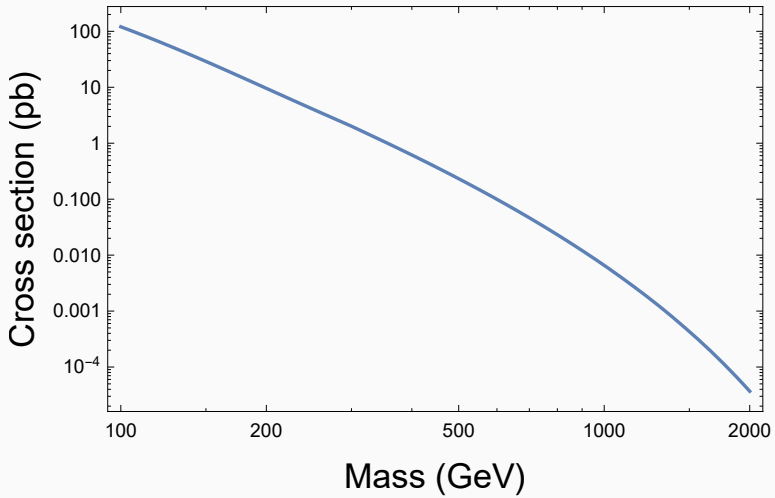
- In ATLAS, the pixel detector begins at 3 cm.
  - χ^+ may leave the disappearing track!
  - The p_T of $\pi^\pm$ is not large enough to reconstruct its track
  - χ^{2+} lifetime is too short for the tracker
    - Due to the small Δm, it doesn't look as a displaced vertex

Setup for Disappearing Track Search

- χ^{2+} decay is almost instantaneously
- $c\tau(\chi^{+} \to \chi^{0}\pi^{+}) \sim 2\,\text{cm}$
    - Count how many disappearing tracks appear

Number of Signals

- Production cross section for 13 TeV:



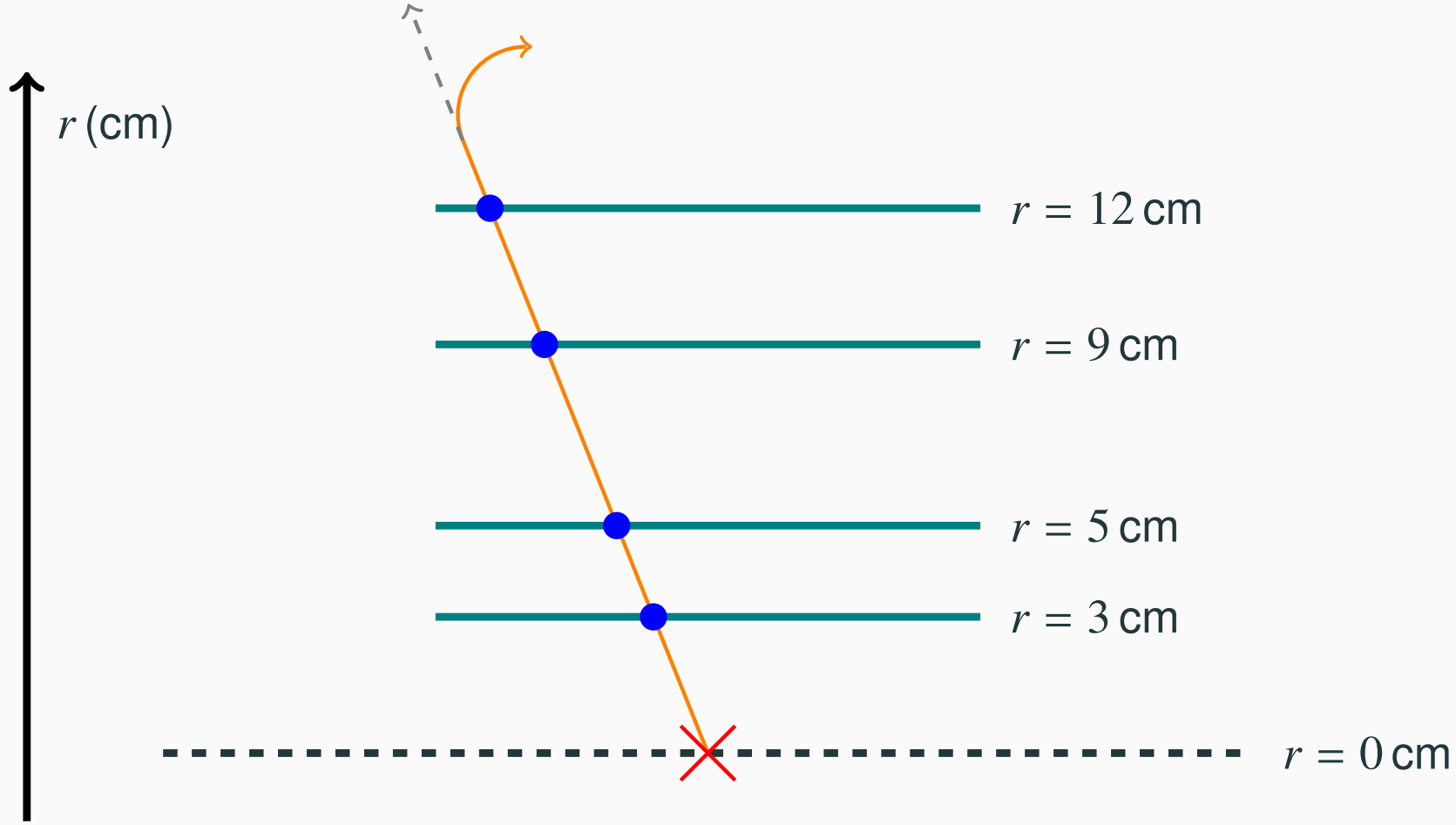
- Not so small
- Acceptance rate?

Cut and Acceptance Rate

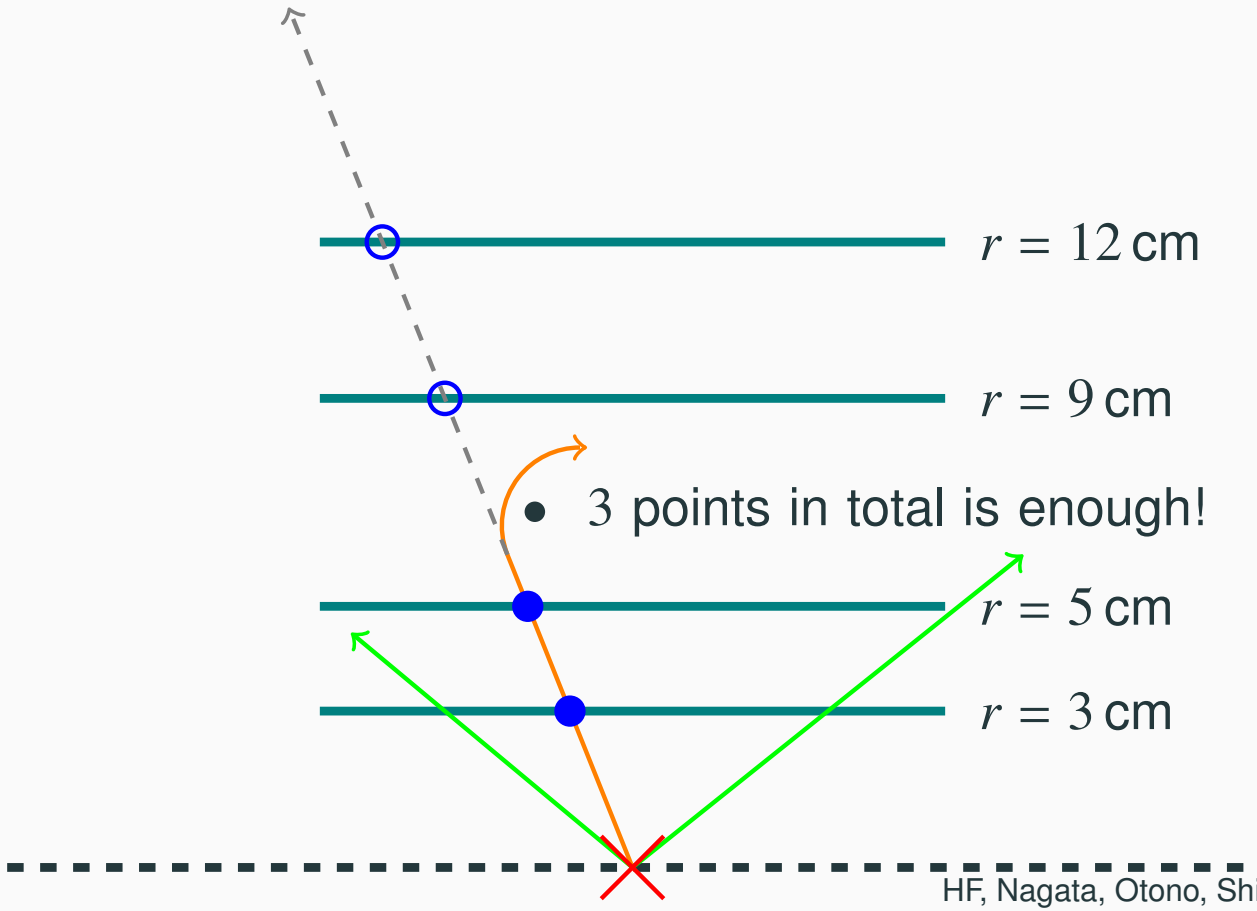
- MET cut
- Jet PT cut
- Geometrical cut on η
- Isolation
  - Acceptance: $\mathcal{O}(\%)$
- **Disappearing condition**
  - $\exp(-L/c\tau\gamma\beta_T)$

ATLAS Collaboration, arXiv:1712.02118

Look Inside the Tracker



Improvement to 2-point Search



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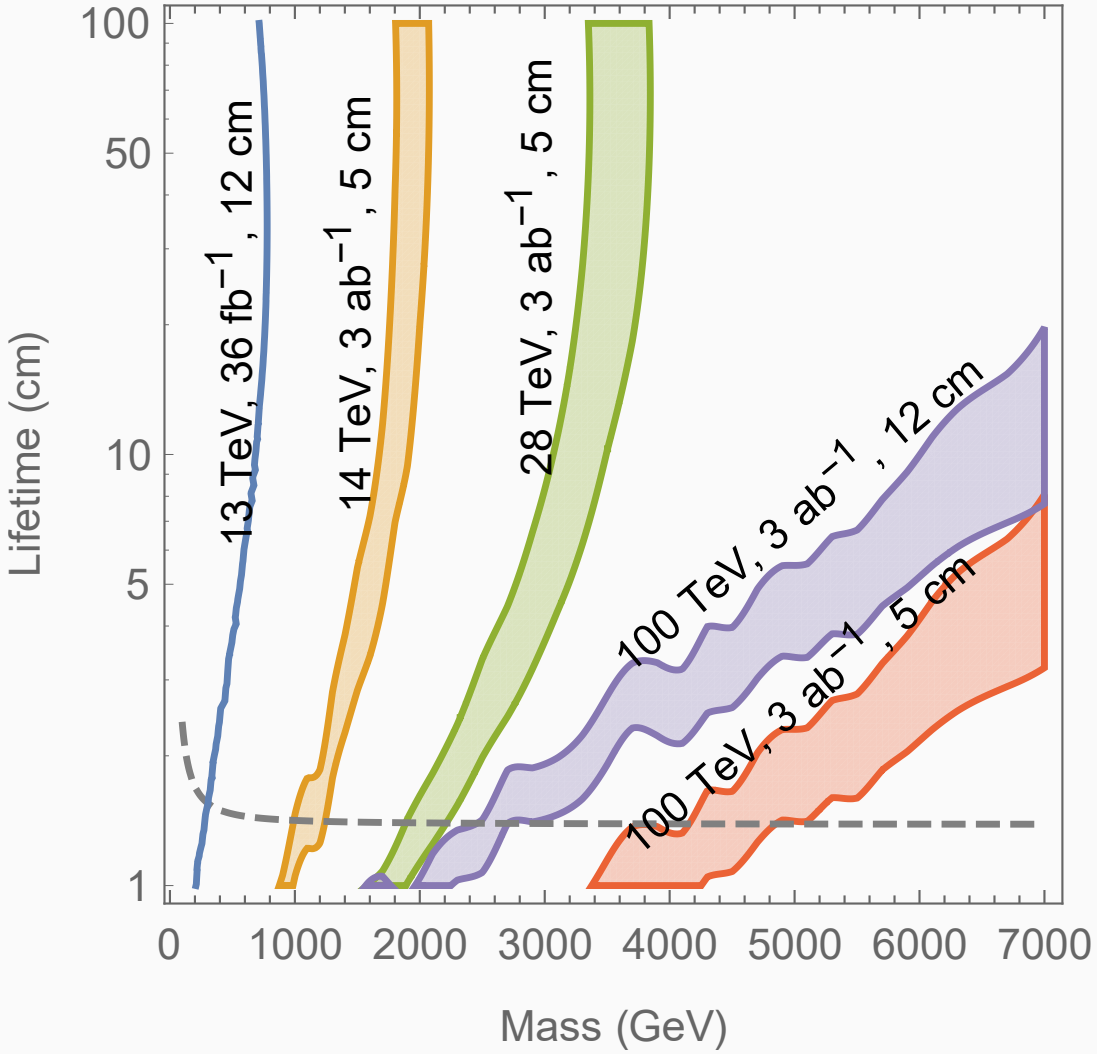
- Interacting point is determined by the other jet activities

Result


100
50
10
5
1
Lifetime (cm)
0
1000
2000
3000
4000
5000
6000
7000
Mass (GeV)
13 TeV, 36 fb^{-1}, 12 cm
14 TeV, 3 ab^{-1}, 5 cm
28 TeV, 3 ab^{-1}, 5 cm
100 TeV, 3 ab^{-1}, 12 cm
100 TeV, 3 ab^{-1}, 5 cm

Conclusions

- Disappearing track is important for minimal DM search
  - Including SUSY LSP like pure wino or higgsino
- We need to not only increase the energy but also **improve trackers and analysis**
- BG estimation & reduction is needed

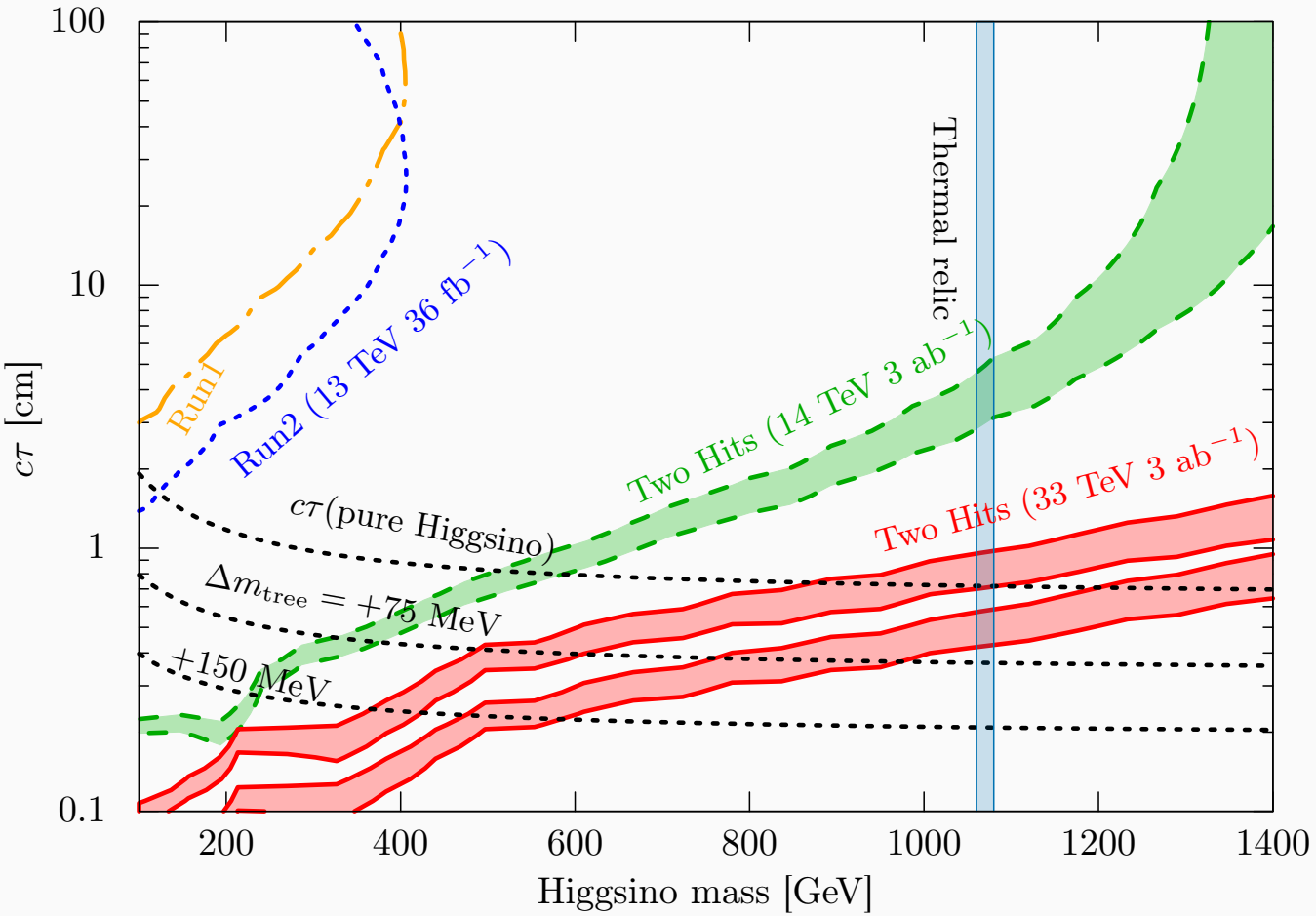
Backup

What is the Background?

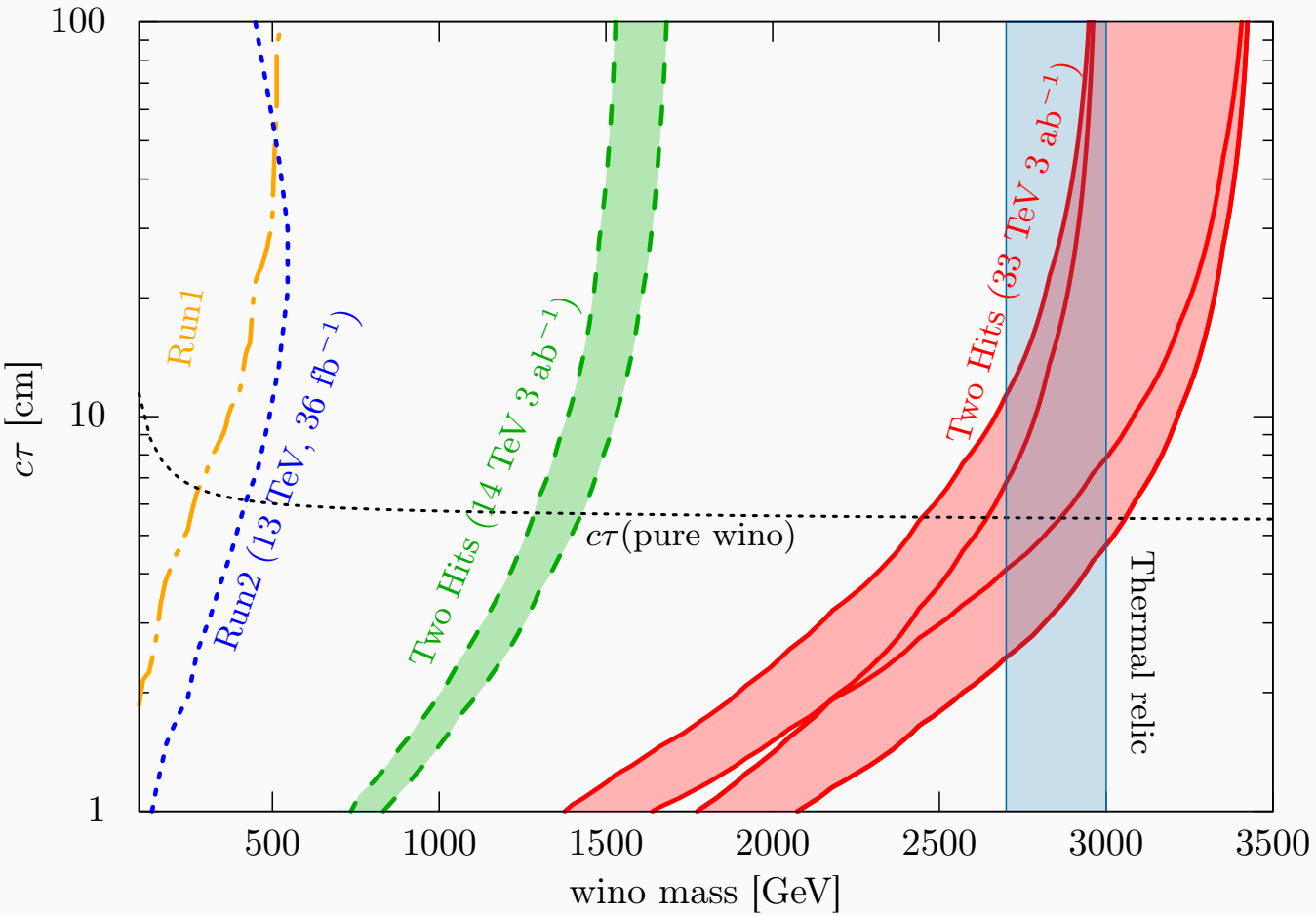
- Misidentification of kink tracks
  - Does not change much for 2-pt strategy
  - Also, the displaced vertex analysis can be used
- **Fake disappearing tracks**

ATLAS Collaboration, arXiv:1712.02118

Higgsino


100
10
1
0.1
$c\tau$ [cm]
200
400
600
800
1000
1200
1400
Higgsino mass [GeV]
Run1
Run2 (13 TeV 36 fb^{-1})
Two Hits (14 TeV 3 ab^{-1})
Two Hits (33 TeV 3 ab^{-1})
Thermal relic
$c\tau$(pure Higgsino)
$\Delta m_{\rm tree} = +75$ MeV
$+150$ MeV

Wino


100
10
1
$c\tau$ [cm]
500
1000
1500
2000
2500
3000
3500
wino mass [GeV]
Run1
Run2 (13 TeV, 36 fb^{-1})
Two Hits (14 TeV 3 ab^{-1})
$c\tau$(pure wino)
Two Hits (33 TeV 3 ab^{-1})
Thermal relic