Testing dark matter with Cherenkov light – prospects of H.E.S.S. and CTA for exploring minimal supersymmetry

Krzysztof Jodłowski

Narodowe Centrum Badań Jądrowych
National Centre for Nuclear Research
ŚWIERK

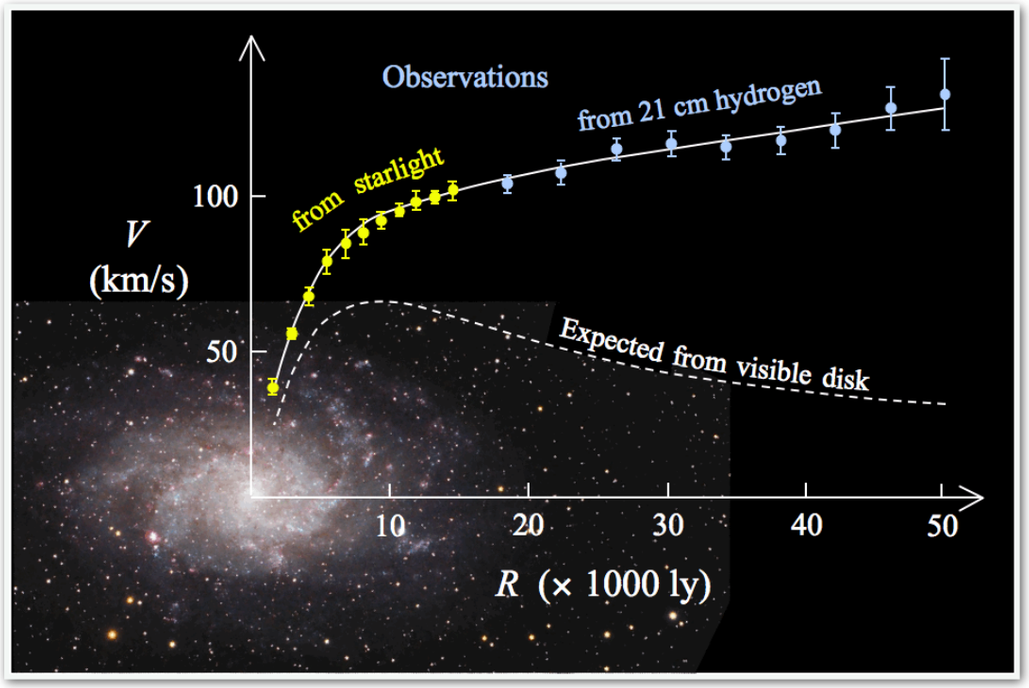
Particle Astrophysics in Poland
21/5/2019

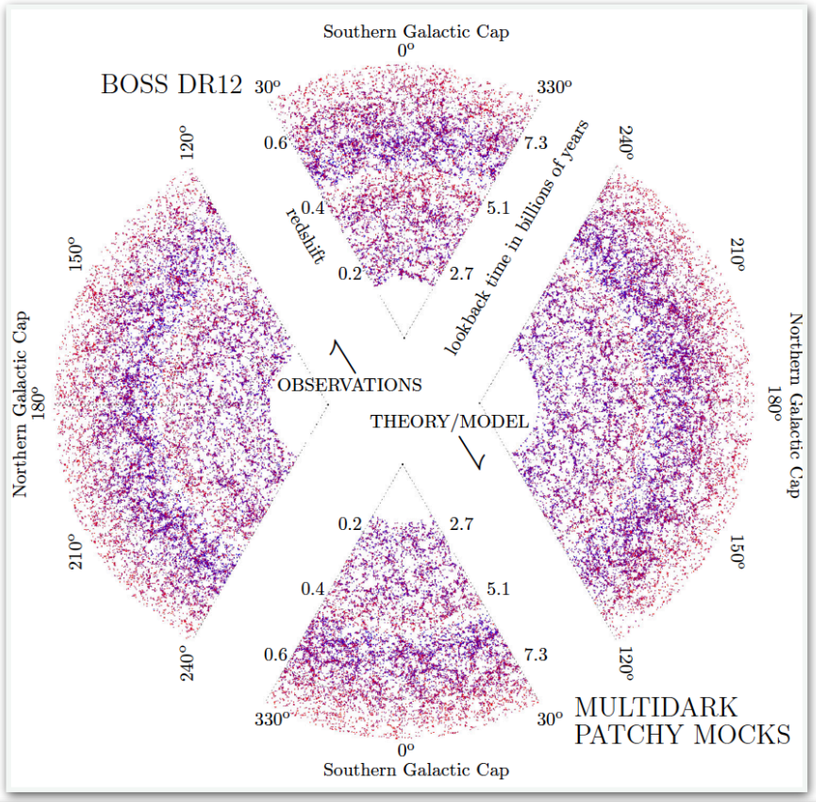
In collaboration with: A. Hryczuk, E. Moulin, L. Rinchiuso, L. Roszkowski, E. M. Sessolo and S. Trojanowski

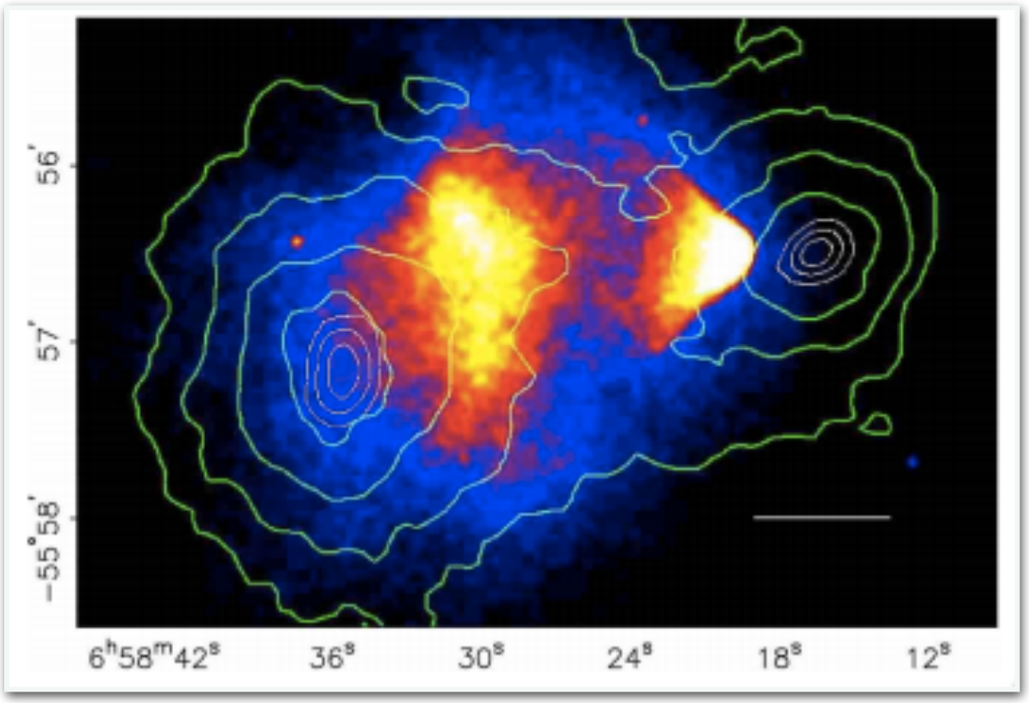
Based on: hep-ph/1905.00315

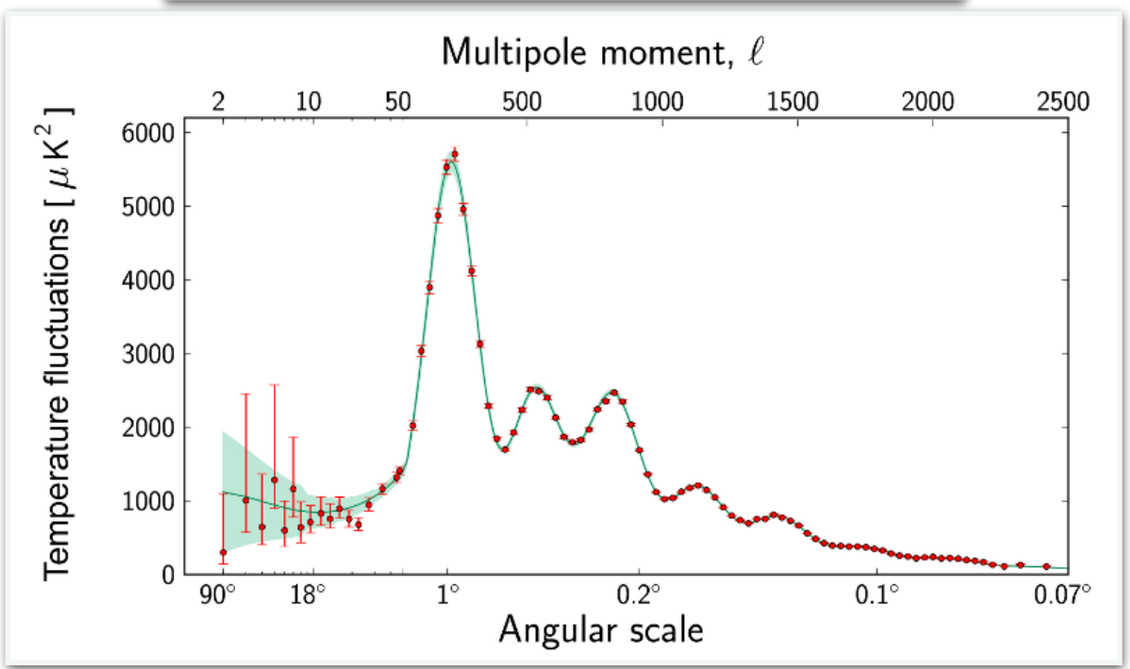
Dark Matter in the Universe

Evidence on multiple scales:









Particle DM

"WIMP miracle"

Since late 70's, its well known that particle with electroweak-scale mass and weak interaction with SM predicts observed relic density

$$\Omega_\chi h^2 \approx 0.1 \frac{3\times 10^{-26}\mathrm{cm}^3\mathrm{s}^{-1}}{\langle \sigma v\rangle}$$

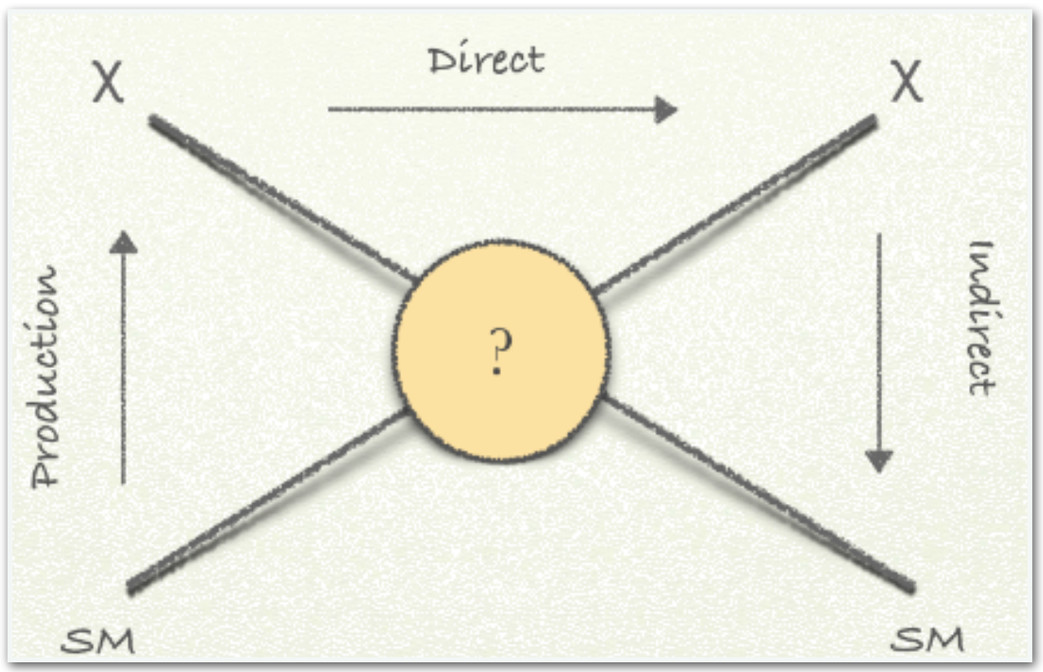
Lee, Weinberg '77; Others

Same energy scale is suggested by e.g. the hierarchy problem and currently being probed by LHC experiments

On dimensional grounds: $\sigma \propto \frac{g^4}{m_\chi^2}$

→ Plenty of possibilities!

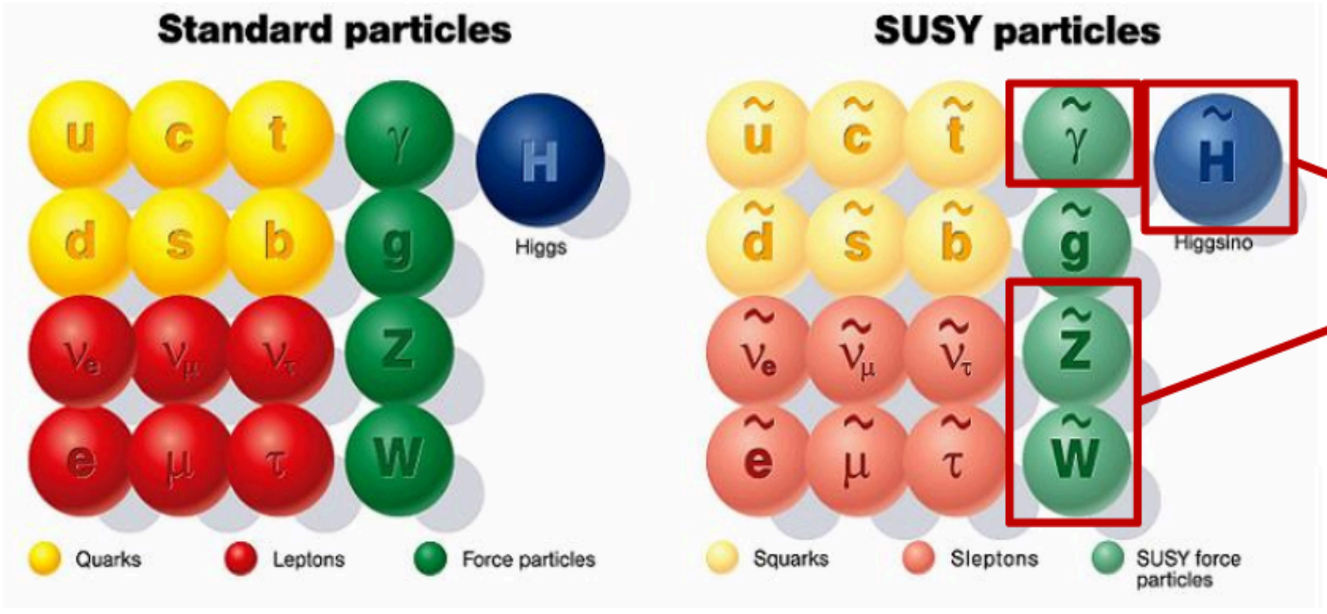
$\sim 1\mathrm{GeV} \lesssim m_\chi \lesssim 100\mathrm{TeV}$



Goal: indirect detection prospects of ~TeV neutralino DM

SUSY is arguably the most popular Beyond Standard Model framework which solves e.g. the gauge-hierarchy problem and provides several promising DM candidates

We consider the lightest **neutralino** as DM



It is mixture of gauge eigenstates:

- Higgsinos
- Wino
- Bino

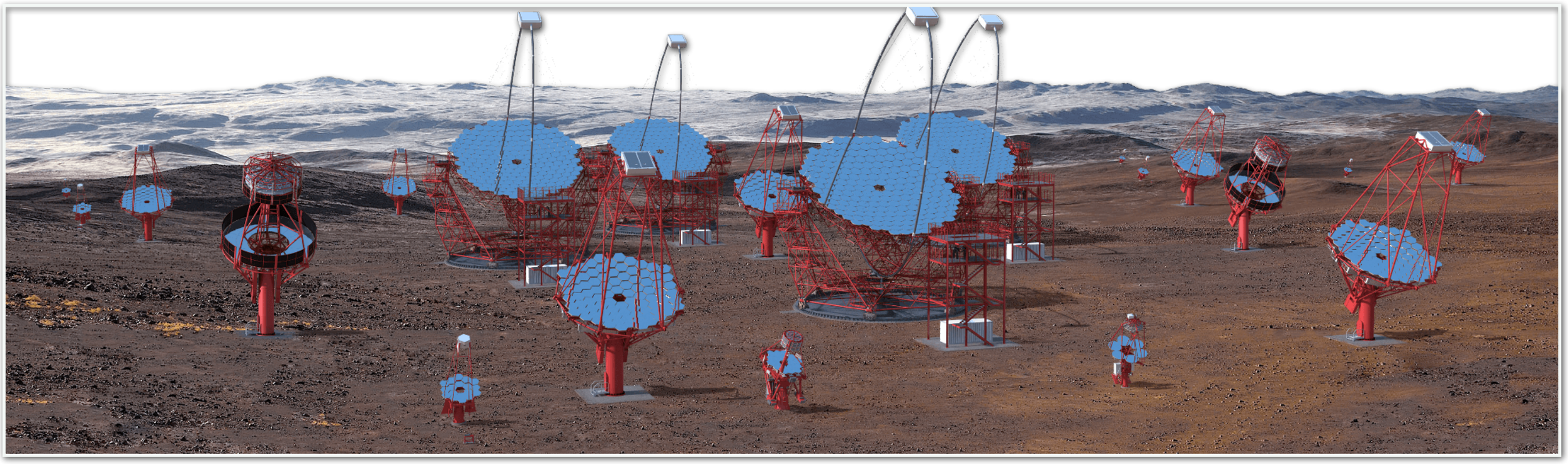
Global Z_2 symmetry ⟶ stable

Null collider searches have generally pushed SUSY scale into a multi-TeV regime ⟶ find ID prospects of 0.1 - 5 TeV neutralino in **pMSSM**

Cherenkov Telescope Array

- Major observatory for very high energy (**20 GeV to 300 TeV**) γ ray astronomy
- Telescopes located on both hemispheres - covers the whole sky
- In advanced stage of pre-construction - with production beginning in 2021
- Medium and small-sized telescopes already achieved ‘first light’
- Dedicated DM programme with 500 h of observations already planned
- Principal target is the Galactic halo within several degrees of the GC

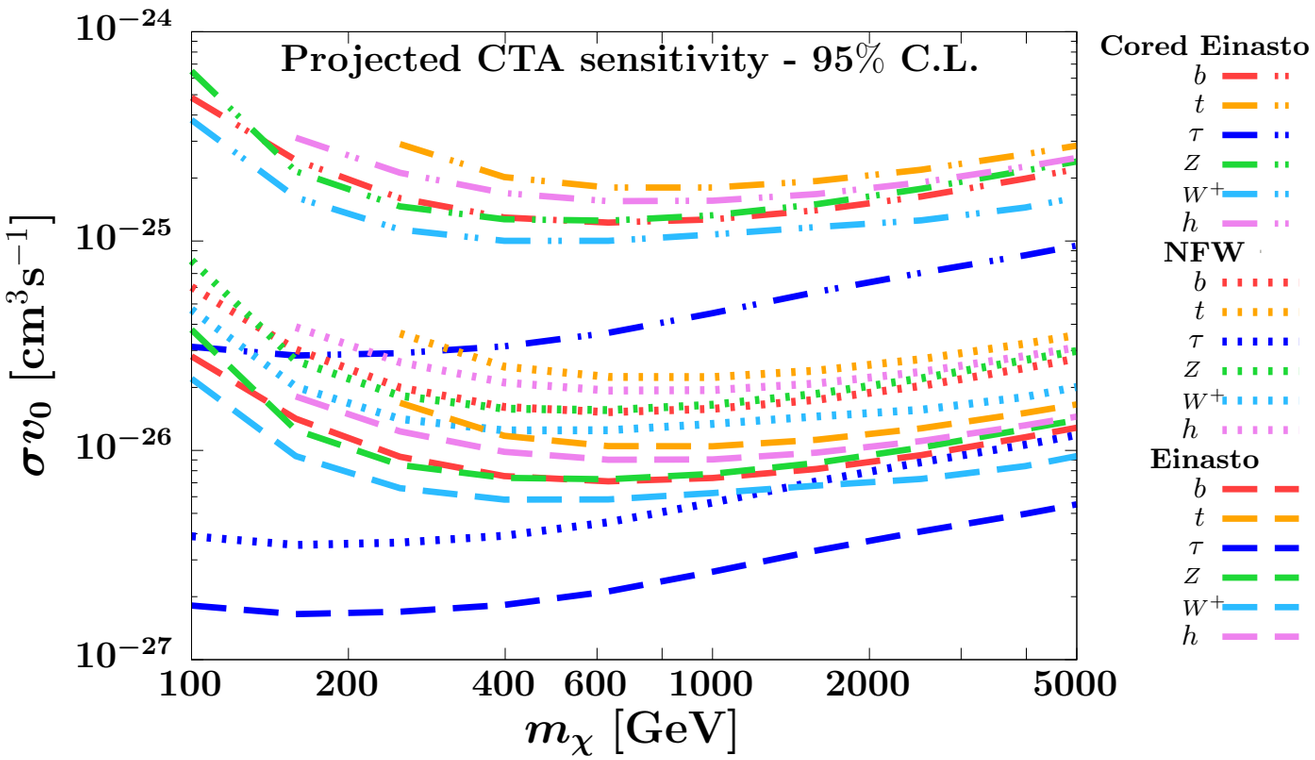
Cherenkov Telescope Array Consortium, 1709.07997

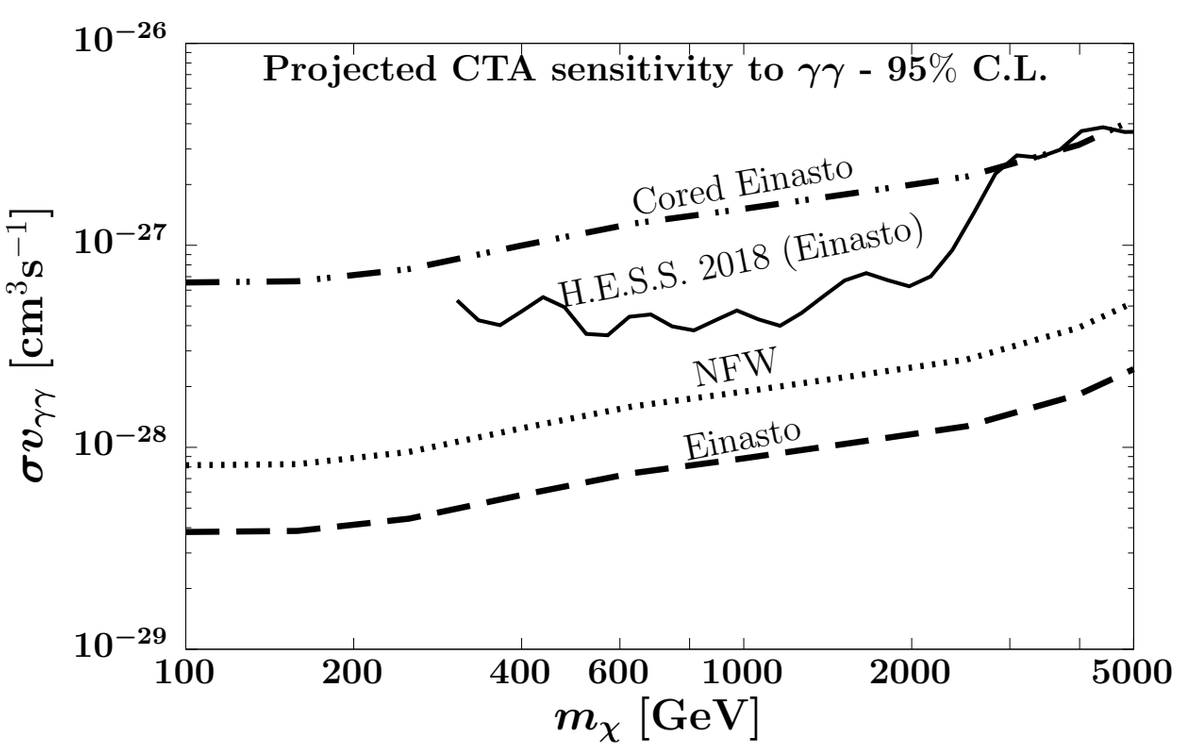


Projected CTA limits

- ROI extends up to $\pm 5^\circ$ from the GC both in longitude and latitude
- We derived CTA Southern array sensitivity using:
  - latest instrument response functions
  - 3-dim. log likelihood ratio test statistics
- Three different choices of the DM Galactic halo profile: **Einasto**, **NFW and Cored Einasto** (r_{core} = 3 kpc)

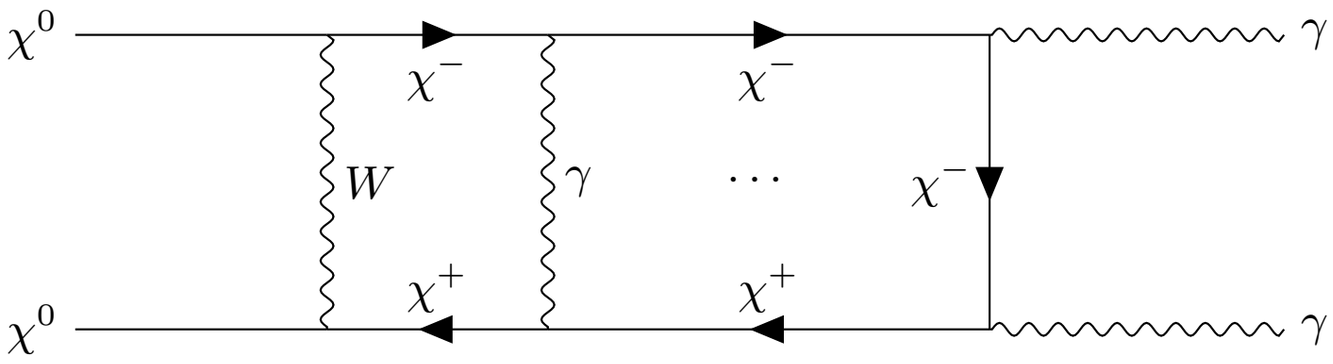
Based on: 1905.00315

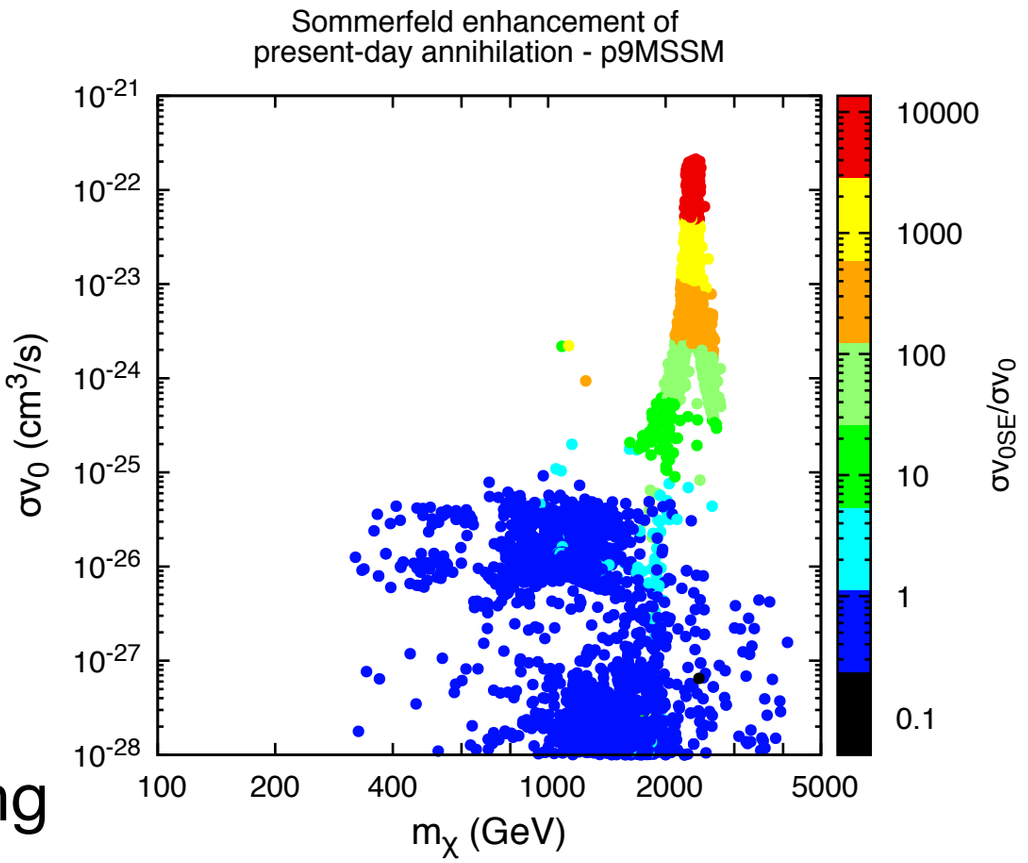




Sommerfeld enhancement

Sommerfeld, ’31
Hisano, 0610249





Non-relativistic, non-perturbative effect modifying the annihilation cross section due to long range force acting between slowly moving particles

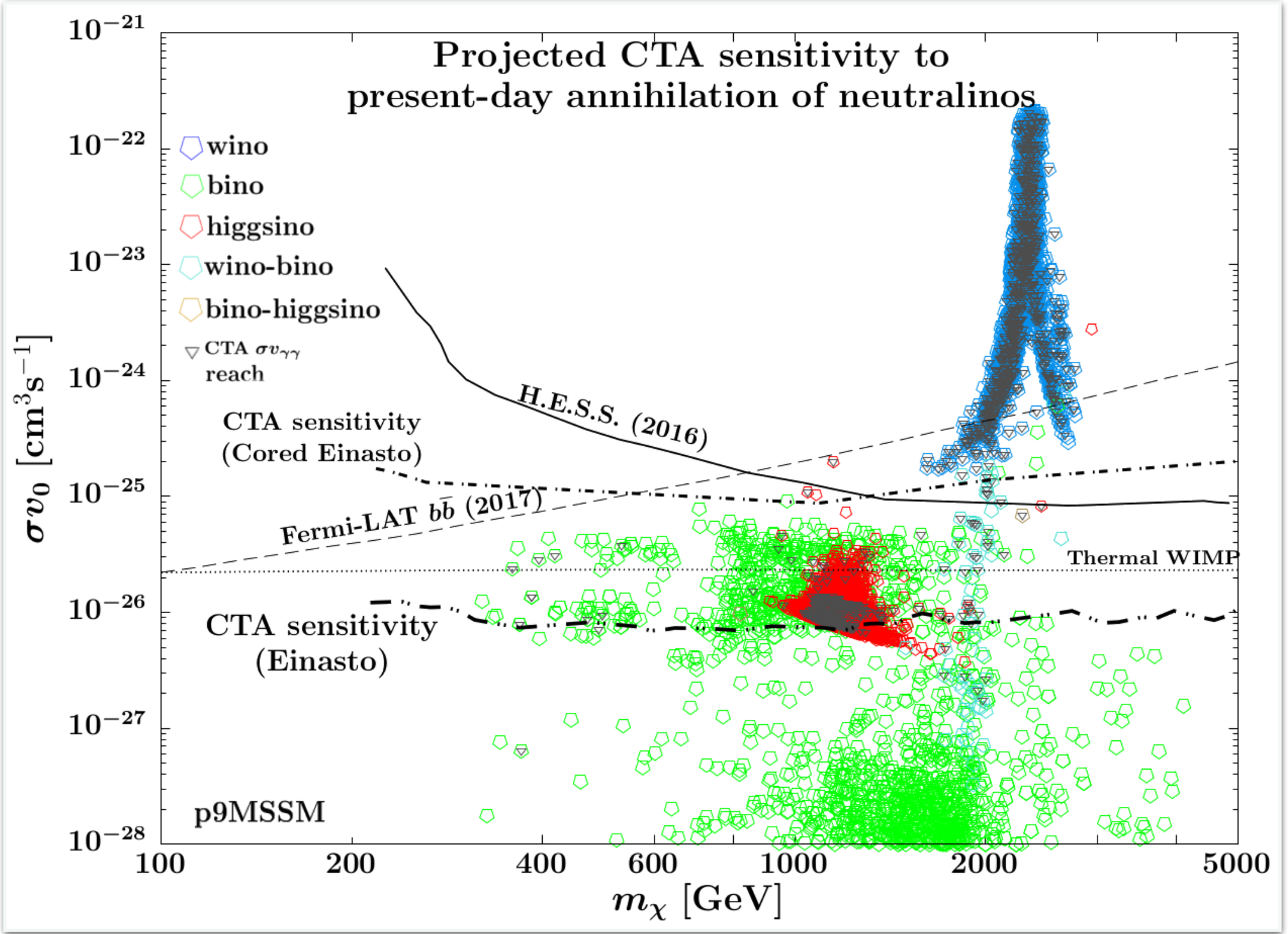
Based on **DarkSE** code
Hryczuk, 1102.4295

Important for **precise determination** of both relic density and present-day annihilation

SE crucial for **wino** DM - note **resonance at ~ 2.4 TeV**
Impact on relic density:

- Factor ~ 5 for mixed states with wino.
- ~10% for pure higgsino
- ~1% for pure bino

Results

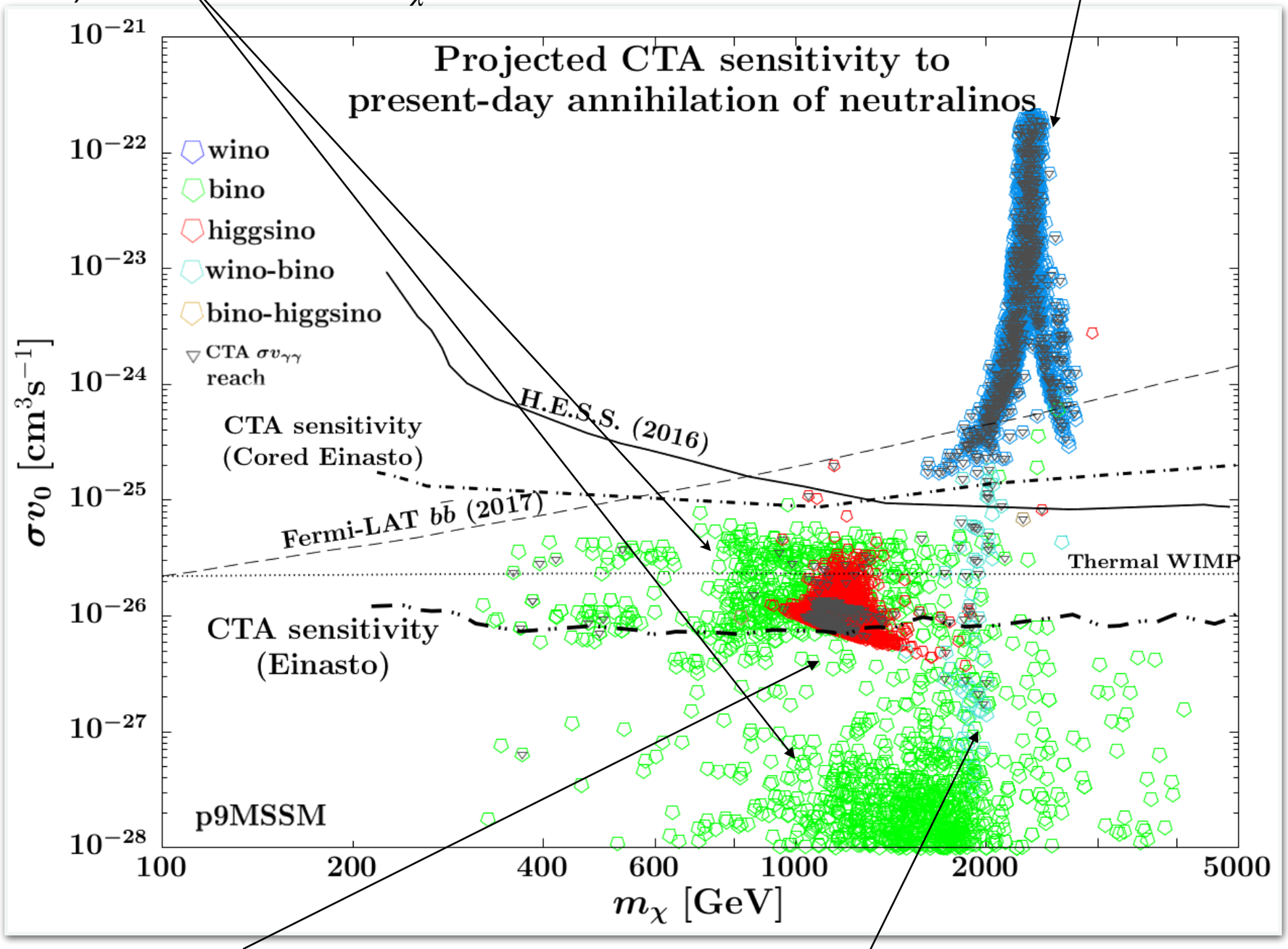

Projected CTA sensitivity to
present-day annihilation of neutralinos
wino
bino
higgsino
wino-bino
bino-higgsino
CTA $\sigma v_{\gamma\gamma}$ reach
CTA sensitivity (Cored Einasto)
H.E.S.S. (2016)
Fermi-LAT $b\bar{b}$ (2017)
Thermal WIMP
CTA sensitivity (Einasto)
p9MSSM
σv_0 [cm^{3}s^{-1}]
m_χ [GeV]
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
100
200
400
600
1000
2000
5000

Results

Bino

Require additional mechanism (e.g. coannihilation) to obtain correct $\Omega_\chi h^2$

Wino - already excluded



Higgsino

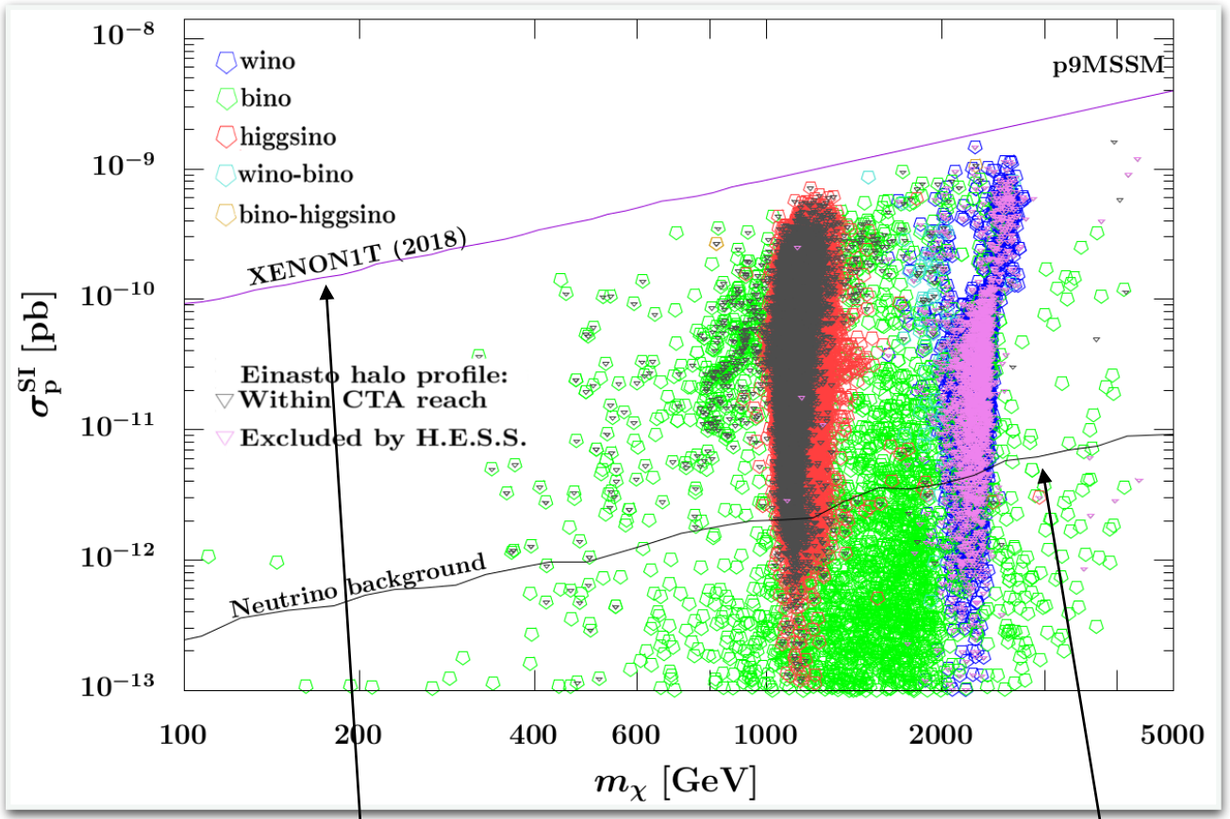
~ 1 TeV region

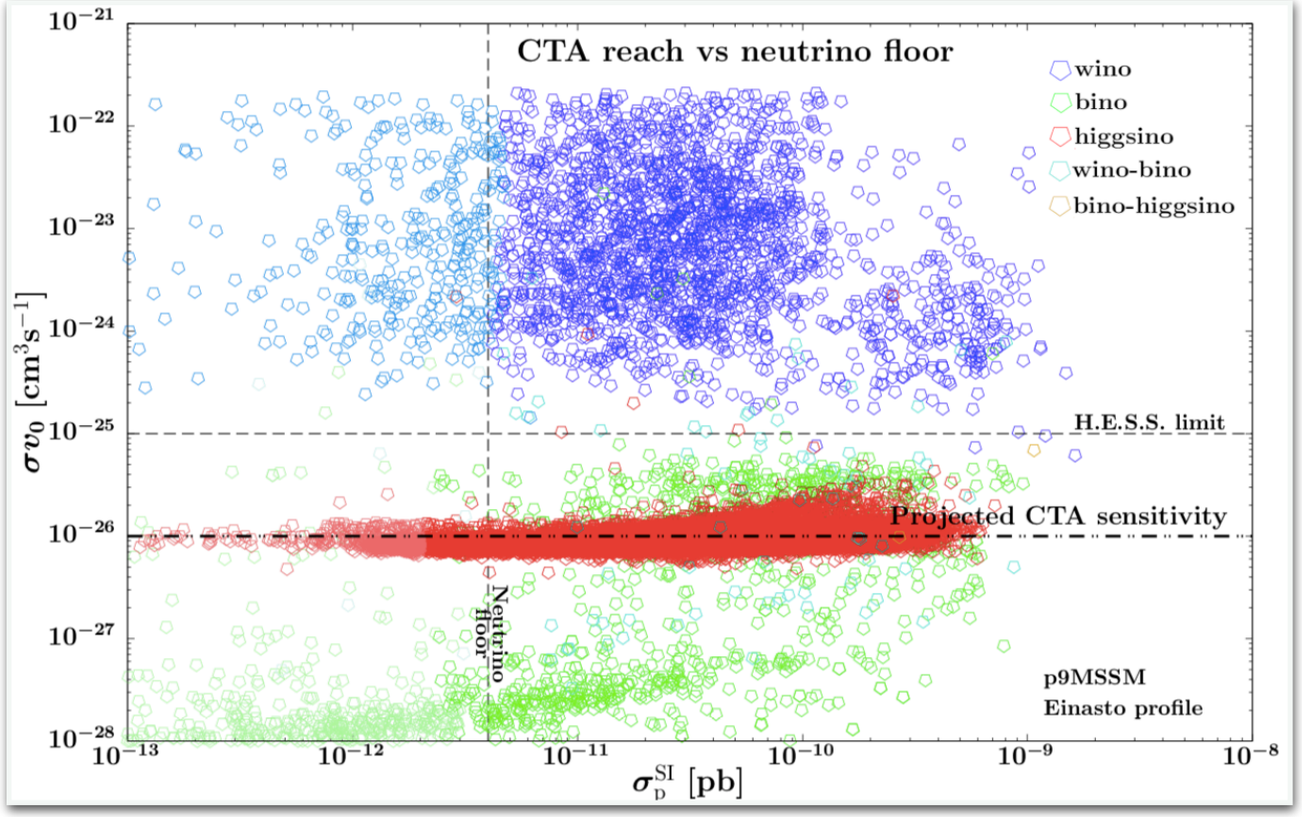
most promising candidate

Bino-wino

In reach of monochromatic γ line search

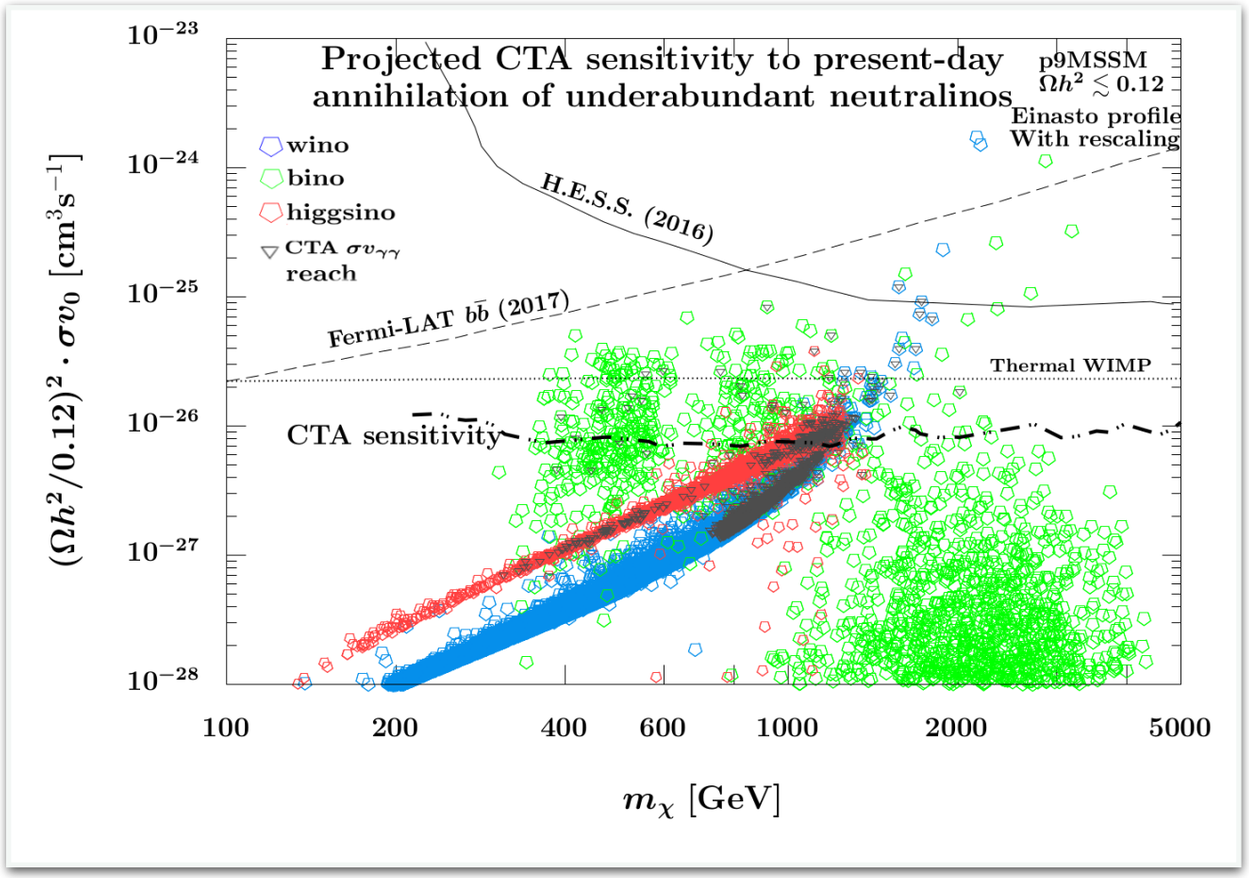
Complementarity with DD

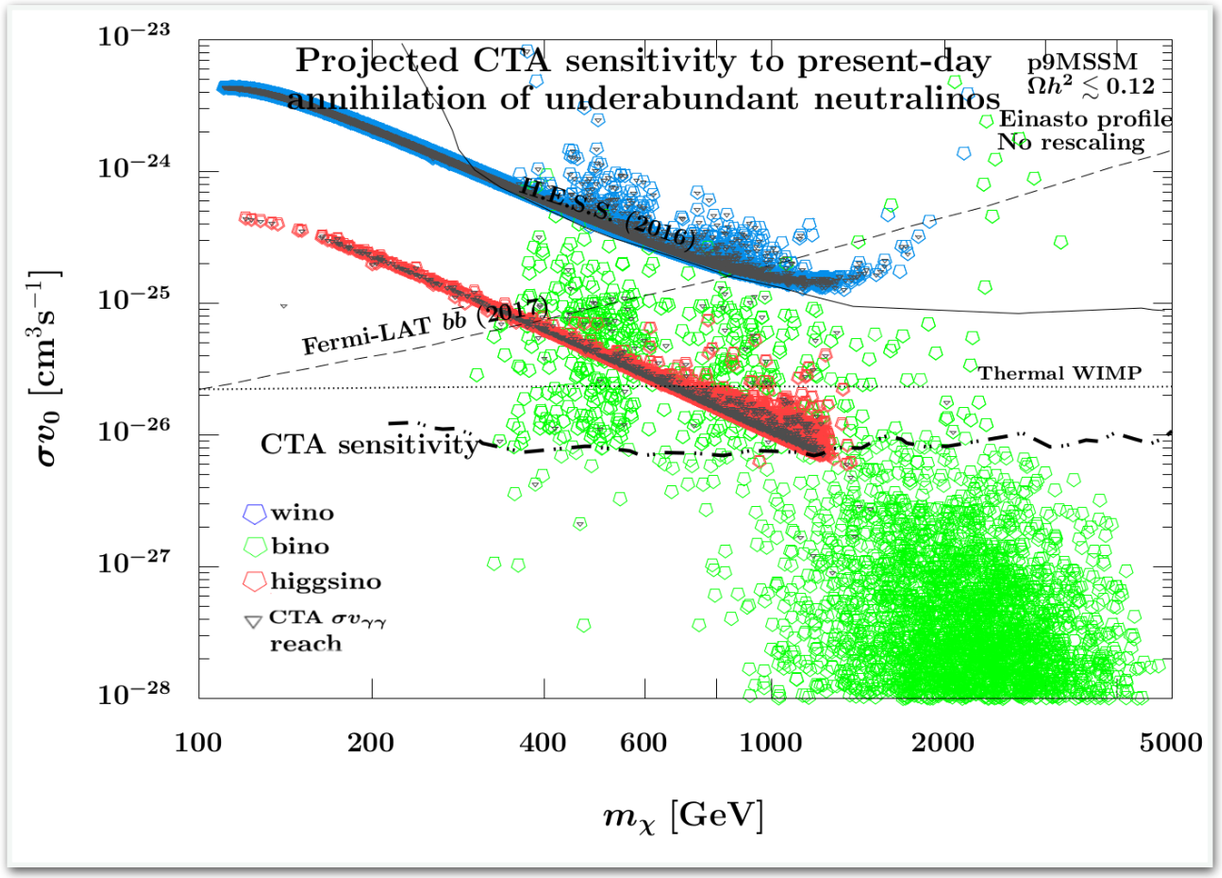




- **Wino and higgsino region will be probed in the majority of cases, corresponding to:**
  - **spin-independent scattering cross section below the reach of 1-tonne underground detector searches**
  - **even well below the irreducible neutrino background**
- **Higgsinos in the ~1 TeV region are good thermal DM candidates**
  - **Not directly constrained by collider and DD searches → complementarity**

Underabundant neutralinos - impact of γ line search





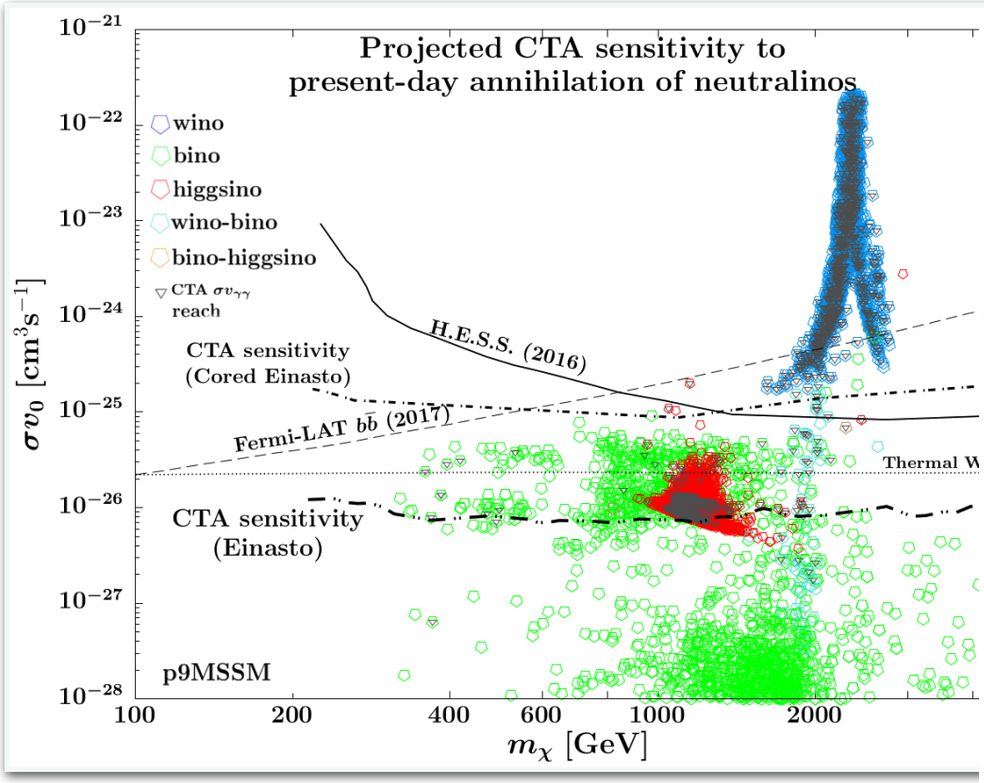
- The neutralino can be a good DM candidate even when its thermally produced relic abundance is different from the total DM relic density in the Universe
- It can then either be one of several DM components, or might even remain the only DM particle but in non-standard cosmological scenarios

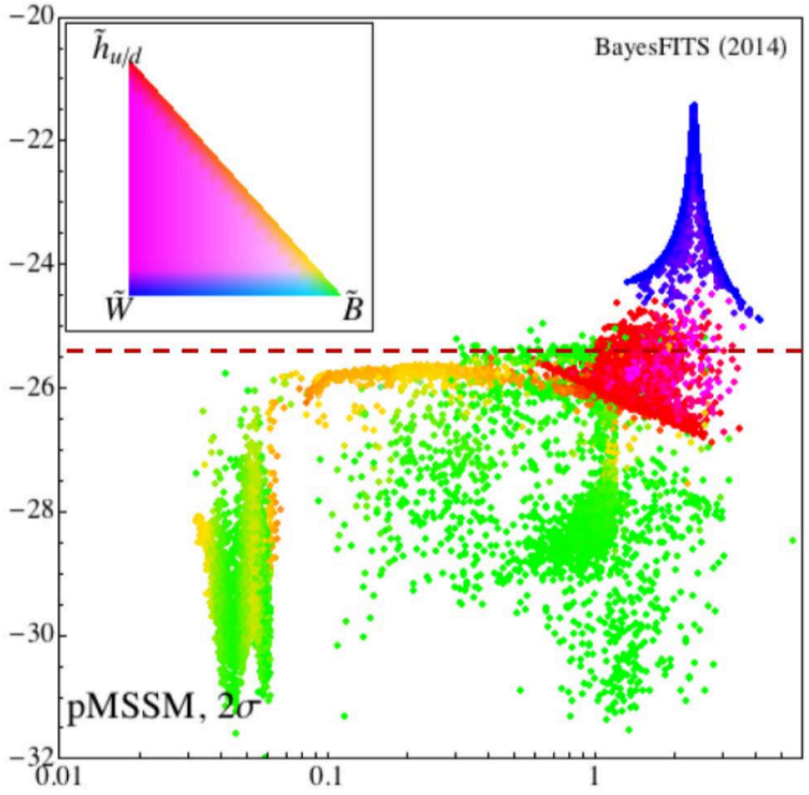
Conclusions

- We updated and improved study of the reach of CTA in testing neutralino DM in minimal supersymmetric scenarios
- Sfermion co-annihilations for the first time were considered with Sommerfeld effect included in a scanning framework
- Cored Einasto profile leads to substantially weaker current bounds and in this case, the H.E.S.S. limits do not completely exclude the region of the parameter space with wino-like neutralino DM. Instead, **CTA will be able to fully probe this important scenario**
- CTA will be sensitive to several cases for which direct detection cross section will be below the so-called neutrino floor, covering a large fraction of the **~ 1 TeV higgsino region**
- CTA sensitivity will be further improved in the monochromatic photon search mode for both single-component and underabundant DM

Backup

Previous studies



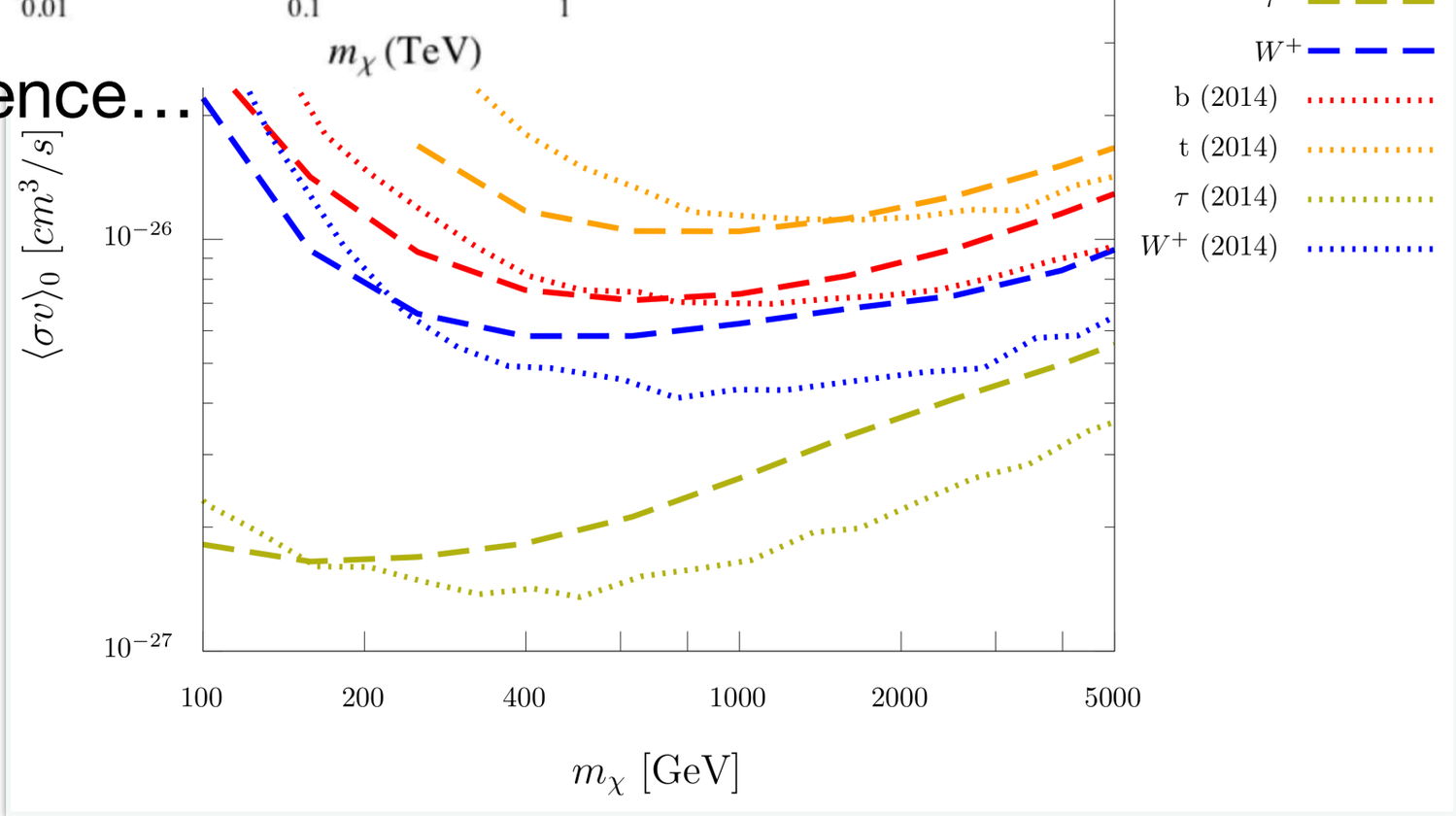


Roszkowski et al. 1411.5214
simplified treatment
of both SE and
CTA sensitivity limits

Globally, there is not much difference…

However:

- all channels considered, with slightly weaker limits than in 2014
- whole wino DM probed even with cored profile



Cabrera et al. 1503.00599