Prospects for Detecting Dark Matter with CTA

Matthew Wood (SLAC)

on behalf of the CTA Consortium

SLAC NATIONAL ACCELERATOR LABORATORY

cta cherenkov telescope array

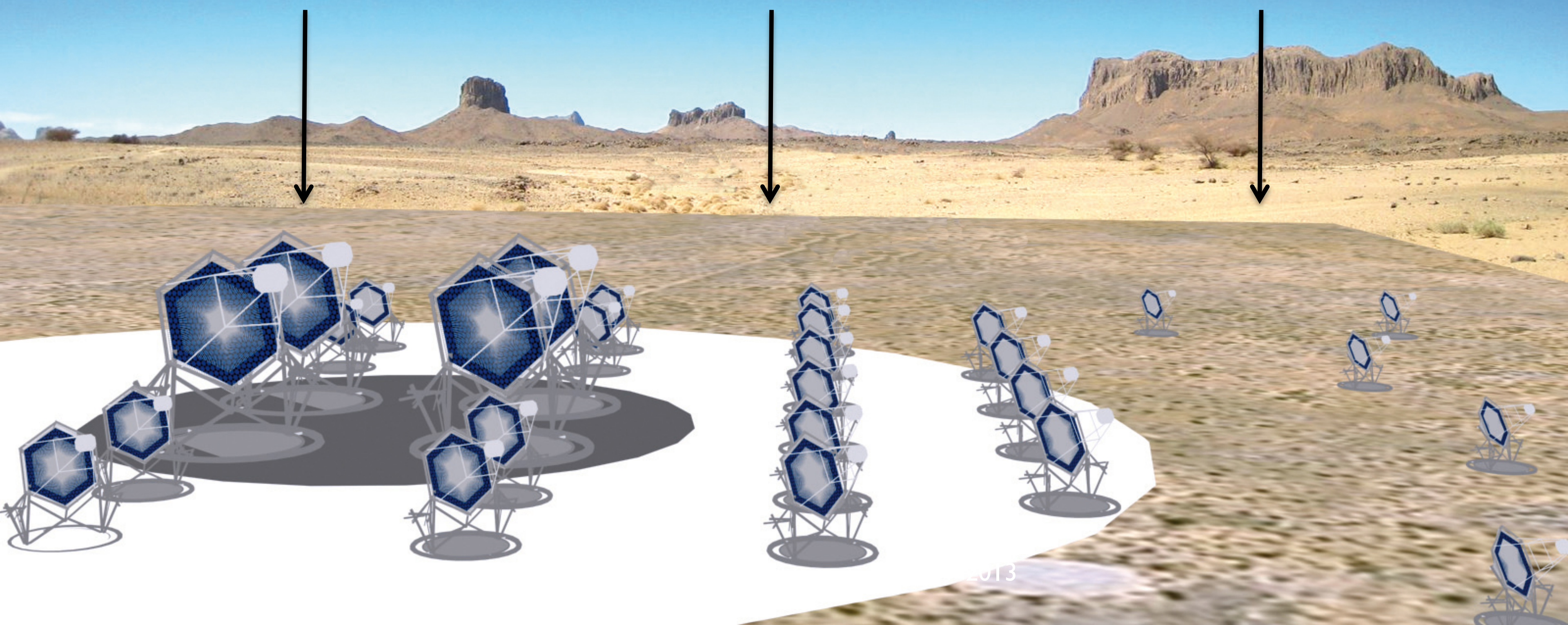
x10 fold sensitivity of current instruments
x10 fold energy range
improved angular resolution

cta
cherenkov telescope array

Low Energy
(<100 GeV)
LST 23 m (x4)

Medium Energy
(100 GeV – 10 TeV)
MST 10-12 m (x25)

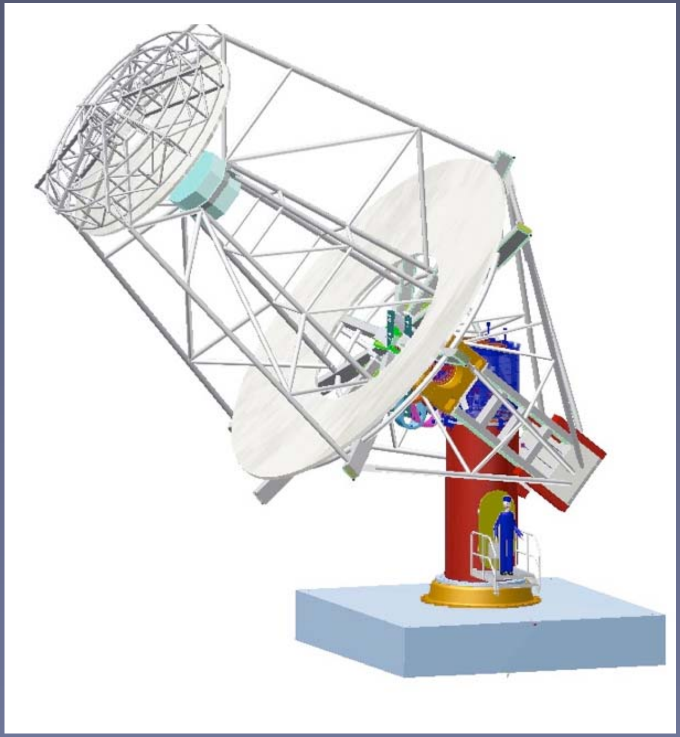
High Energy
(> 10 TeV)
SST 4-6 m (x30-50)



US Contribution

Enhancement of 25-36 additional Medium-Sized Telescopes (MSTs) with Dual mirror (SC) design

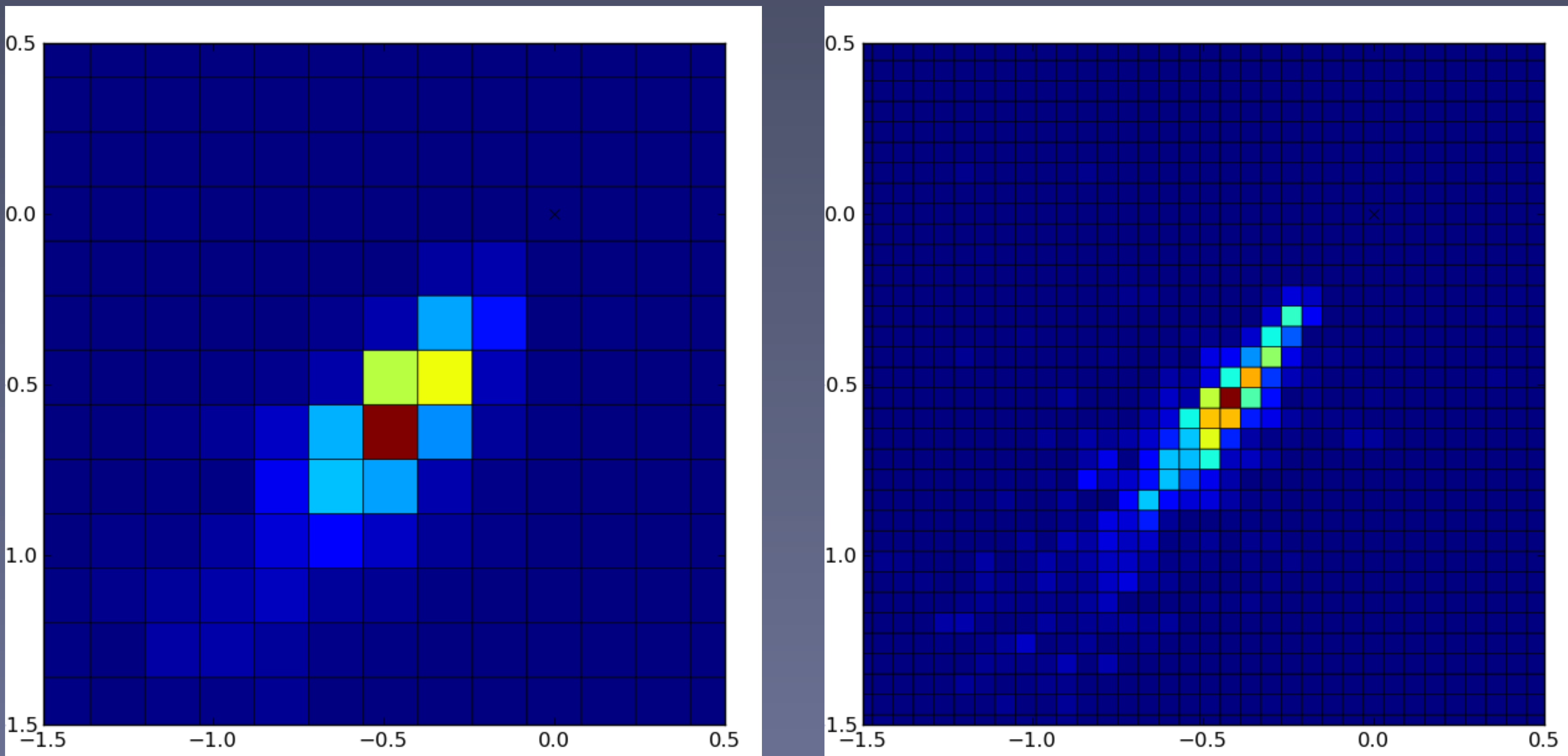
Schwarzschild-Couder (SC) Medium-Sized Telescope



- Dual-mirror optical design allows for good optical PSF over large FoV (8 deg)
- Small plate scale enables a compact and finely pixelated camera design employing low- power and cost-per-channel electronics

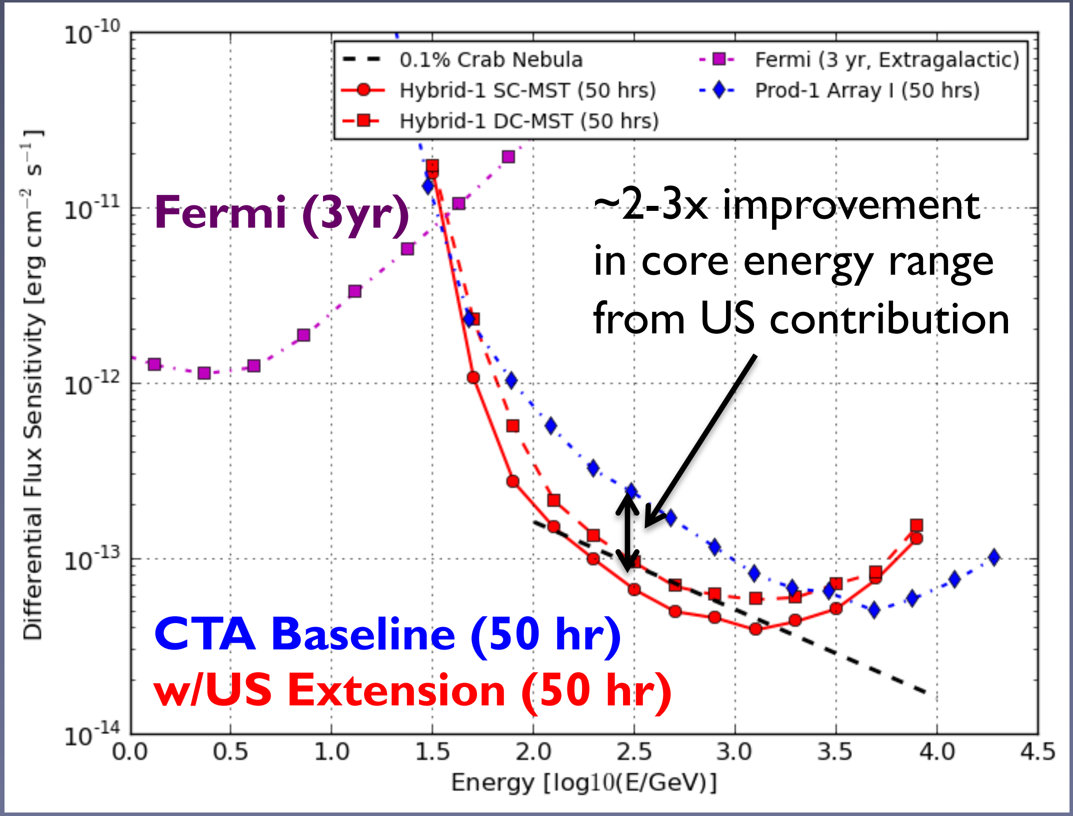
Gamma-ray Shower Image (E = 1 TeV)

DC-MST (Single Mirror) SC-MST (Dual Mirror)

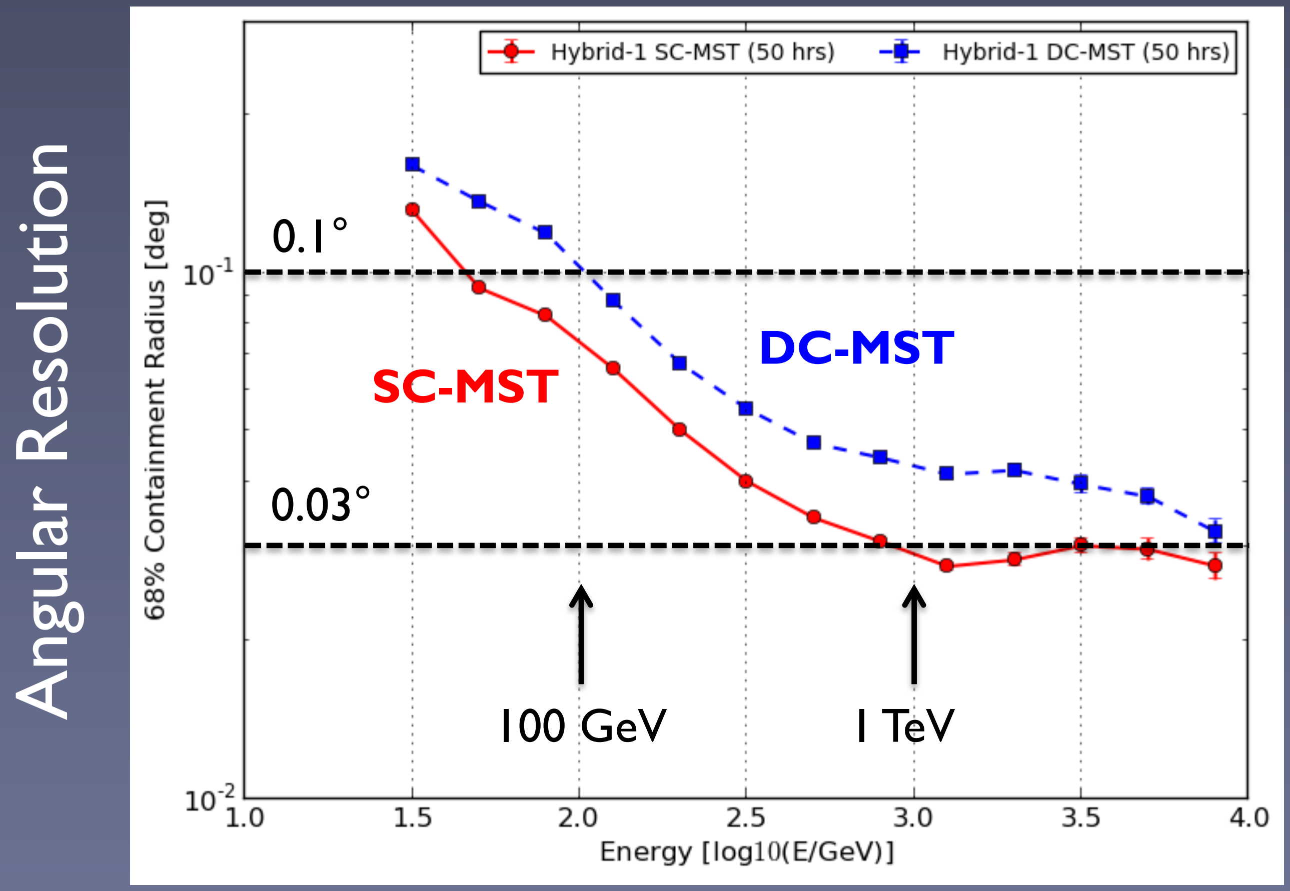


Point-Source Sensitivity

CTA Baseline: See K. Bernlohr et al. 2012, arXiv:1210.3503
Hybrid-1: See T. Jogler et al. 2012, arXiv: 1211.3181



CTA: Angular Resolution



DM Targets for CTA

- Dwarf Galaxies (dSphs)
  - Small theoretical uncertainty for massive dwarfs (Draco, Ursa Minor, Sculptor)
  - Need boost of at least 10-100 to reach models with relic cross section
- Galactic Center Region
  - Models with relic cross section could be detectable depending on astrophysical foregrounds
  - Large uncertainty on DM distribution in inner galaxy (< 100 pc)
- Galaxy Clusters
  - Total annihilation flux comparable with dSphs if substructure is included
  - Probably not competitive with dSphs given large angular extension
- MW Substructures (Fermi UnID Followup)

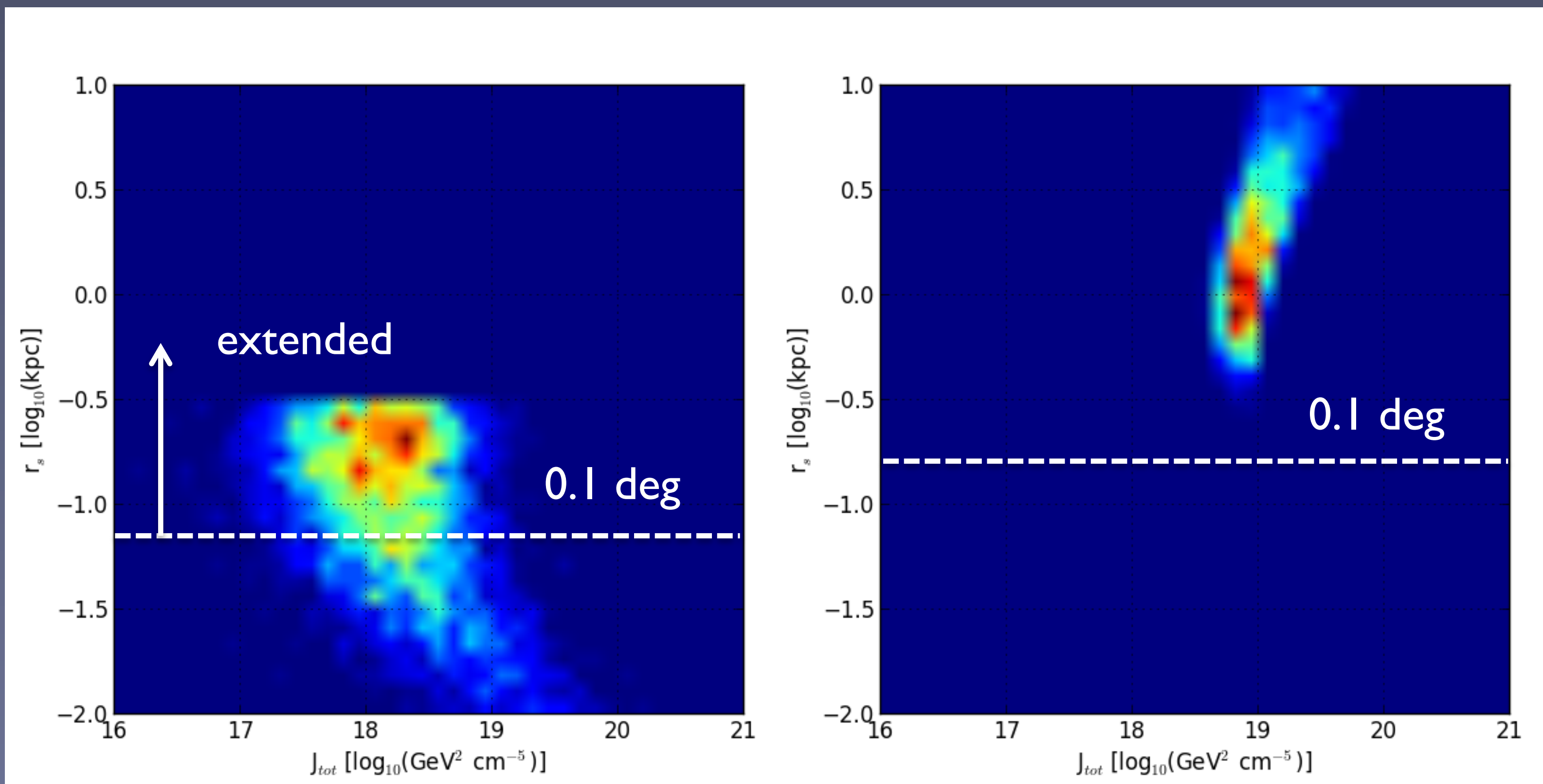
Dwarf Galaxies

- Choice of targets will be determined by CTA site
  - Southern Hemisphere: Sculptor, Fornax, Carina
  - Northern Hemisphere: Draco, Ursa Minor, Coma Berenices, Segue 1
- Most should be spatially resolved given CTA angular resolution (~0.1 deg at 100 GeV)
- Astrophysical Modeling
  - Assume NFW DM density profile
  - Determine parameters using Jean's analysis of stellar line of sight velocities (Strigari et al. 2008, Martinez et al. 2011)
  - Theoretical uncertainties on J factor estimated with Bayesian MCMC analysis

Dwarf Galaxies: Astrophysical Modeling

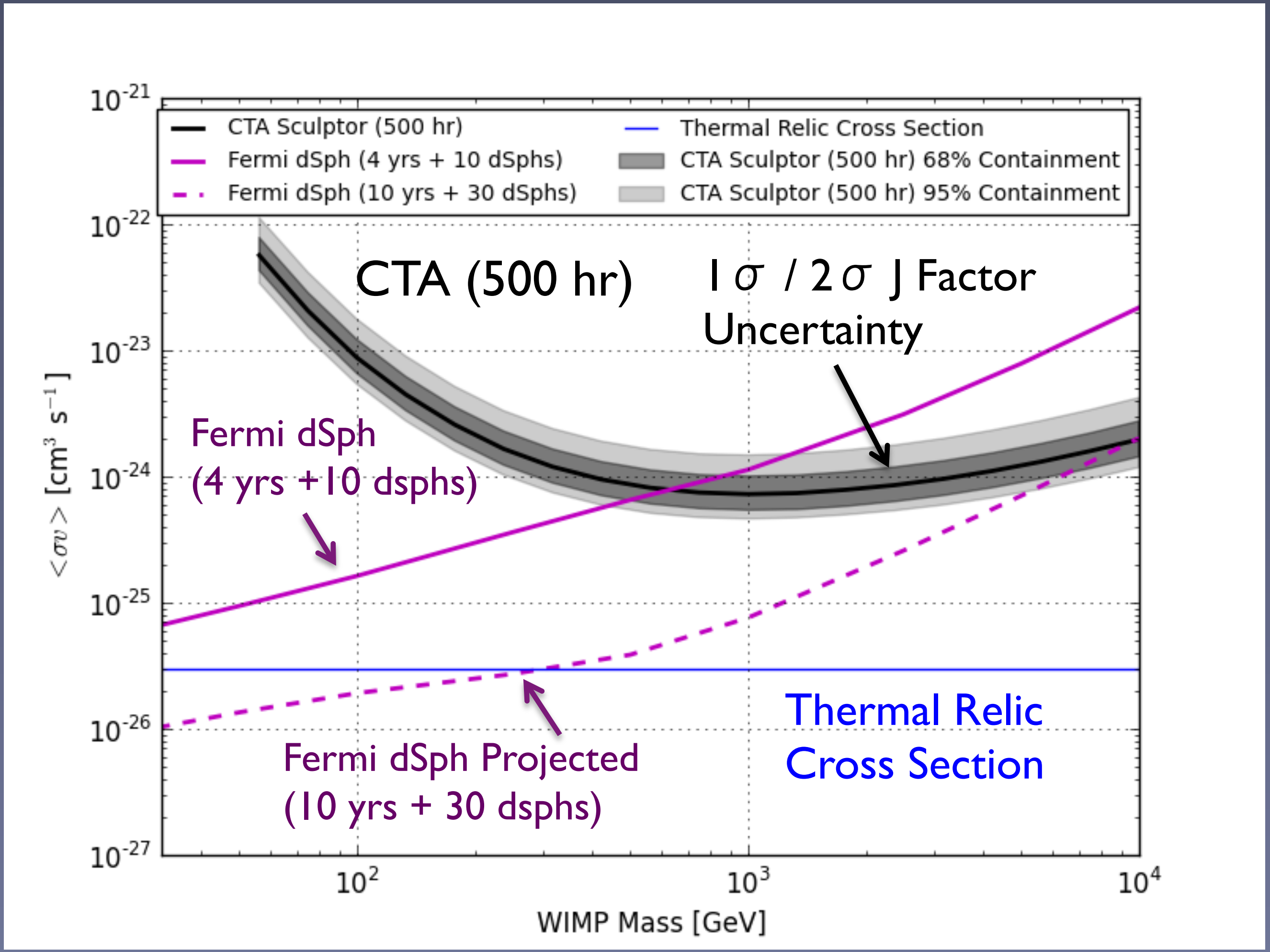
Coma Berenices **Sculptor**

Scale Radius

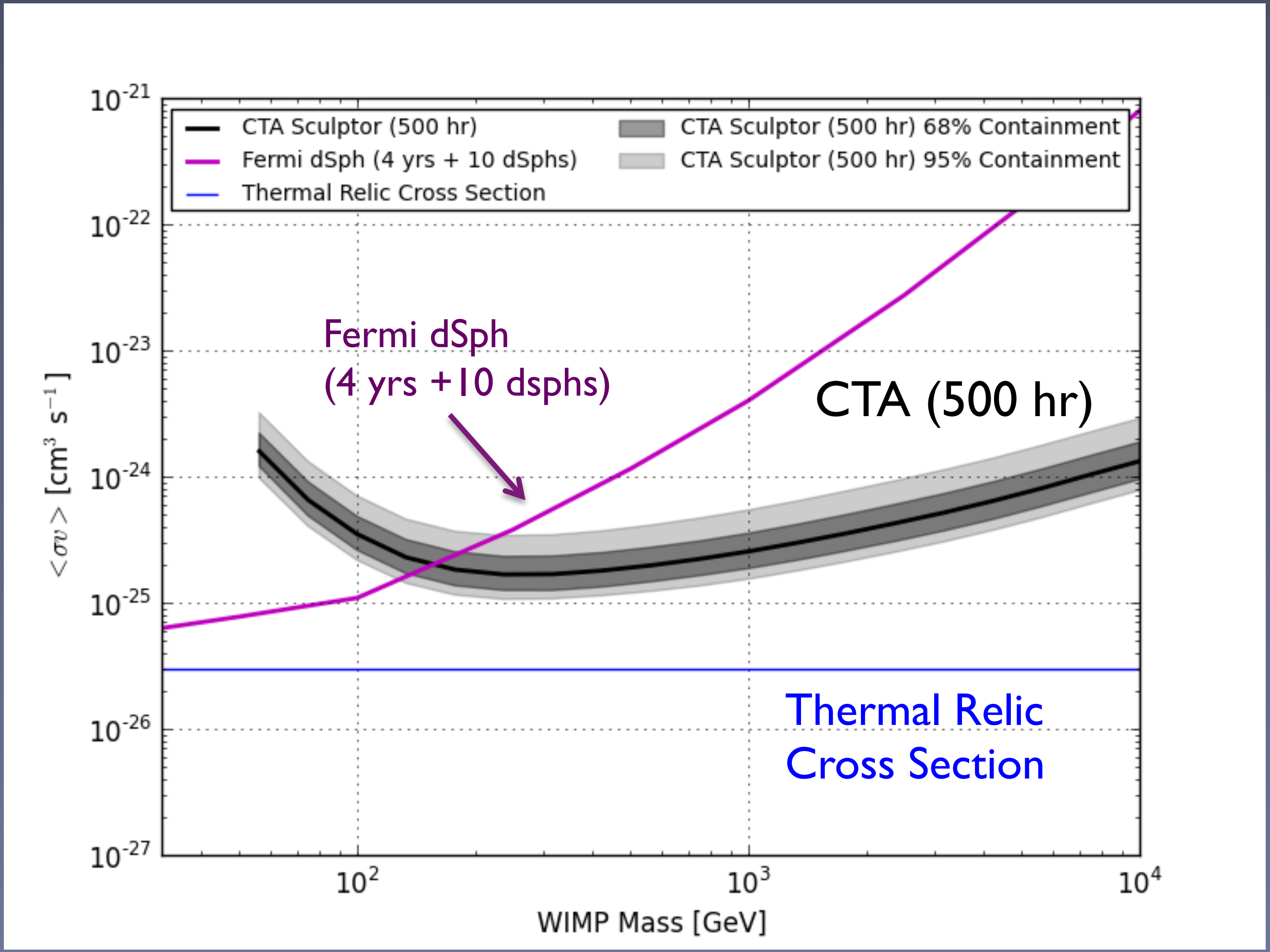


J Factor (Total Annihilation Flux)

Sculptor Limits (bb channel)

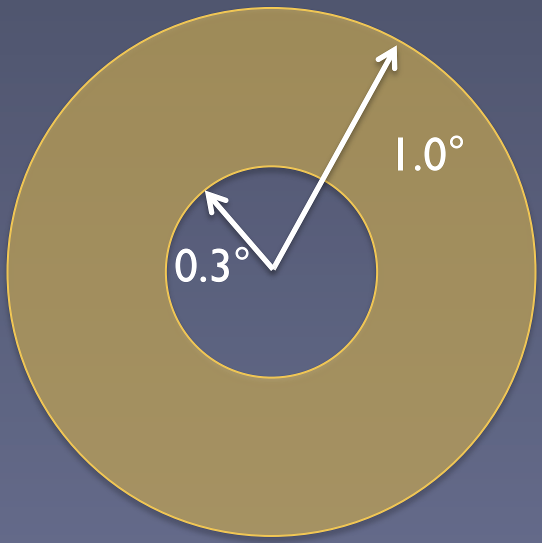


Sculptor Limits (tau channel)

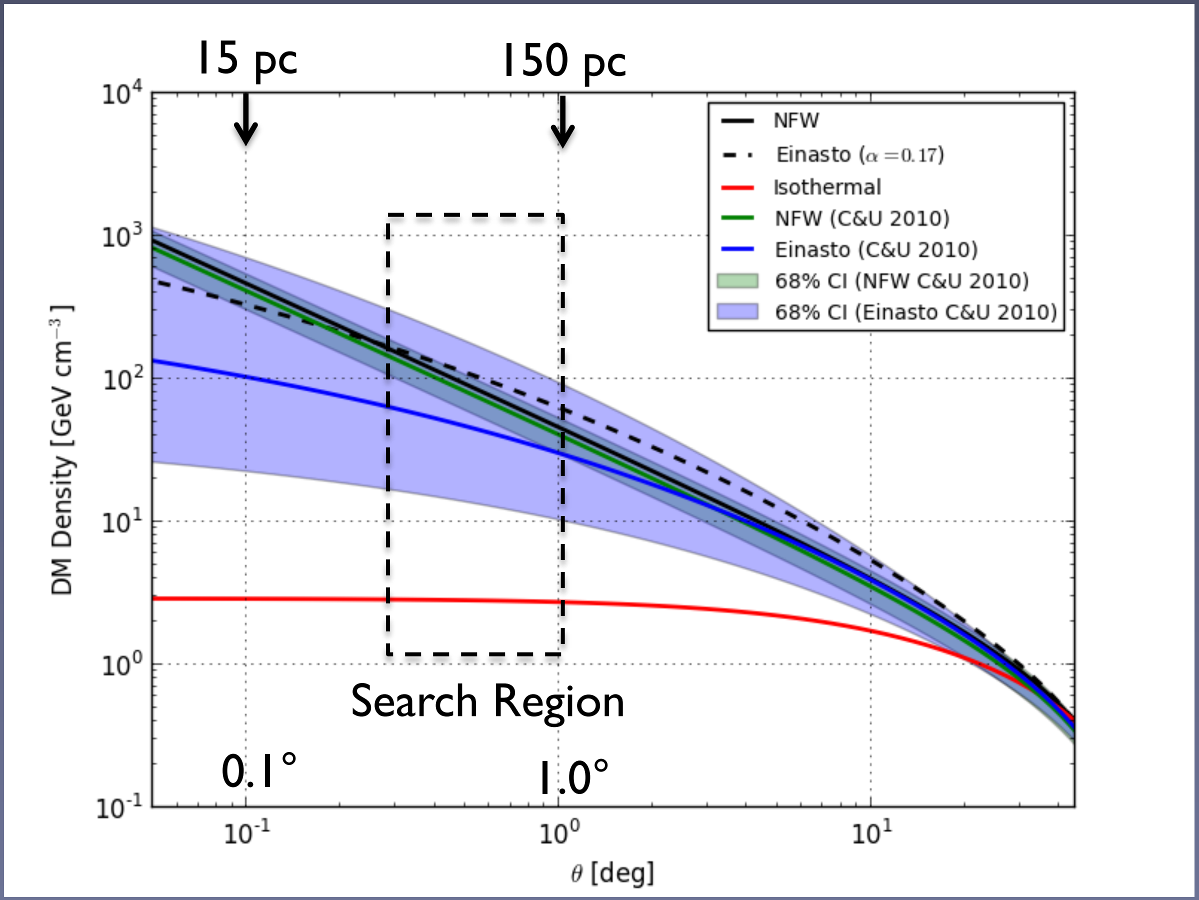


Galactic Halo

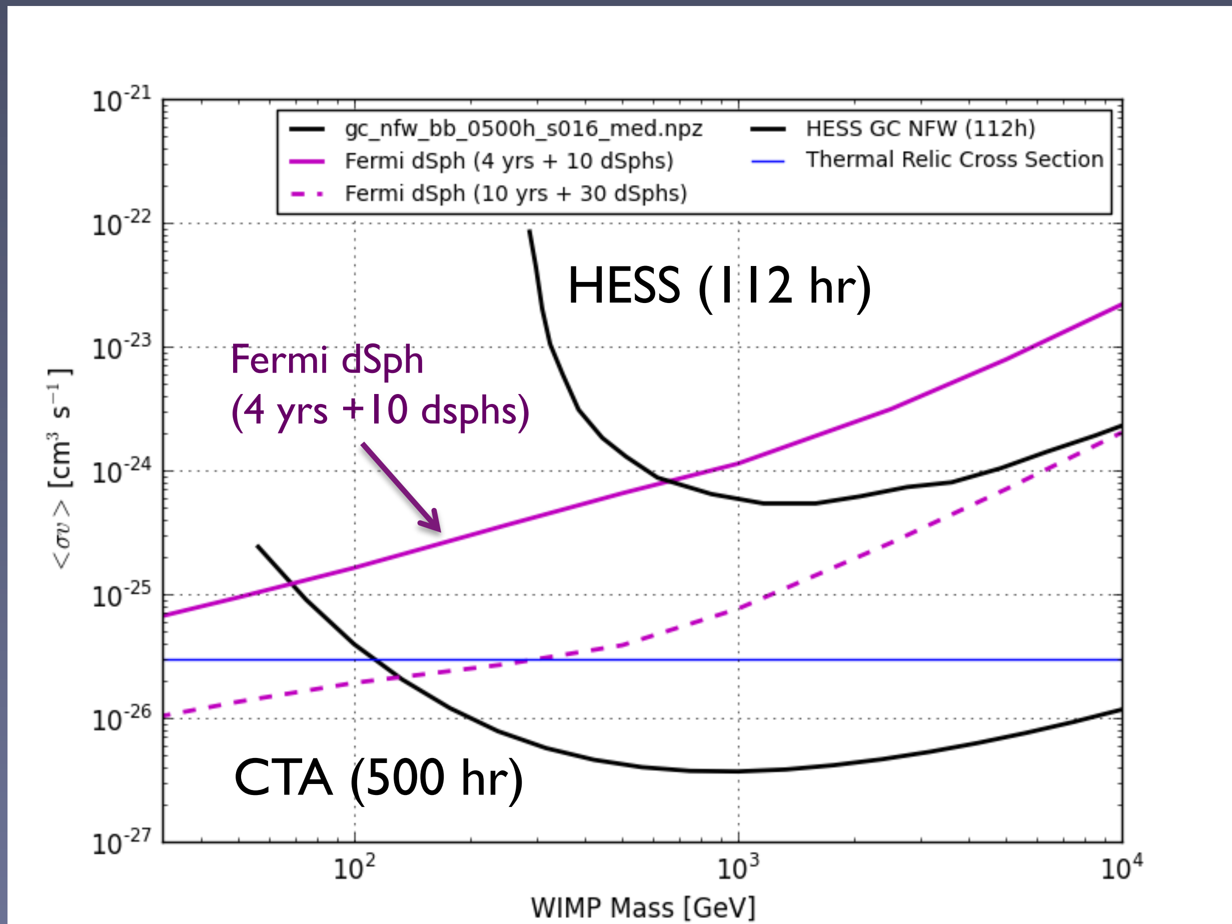
- Use an annular search region around the GC (R = 0.3 – 1.0 deg) to minimize astrophysical foregrounds (H.E.S.S.-style analysis; see Abramowski et al. 2011)
- MW Halo Models
  - NFW, Isothermal, and Einasto profiles normalized to 0.4 GeV cm^{-3} at the solar radius
  - NFW and Einasto profiles with 68% uncertainties taken from Catena and Ullio 2010 (recent meta-analysis of MW kinematic data)



MW Density Profile



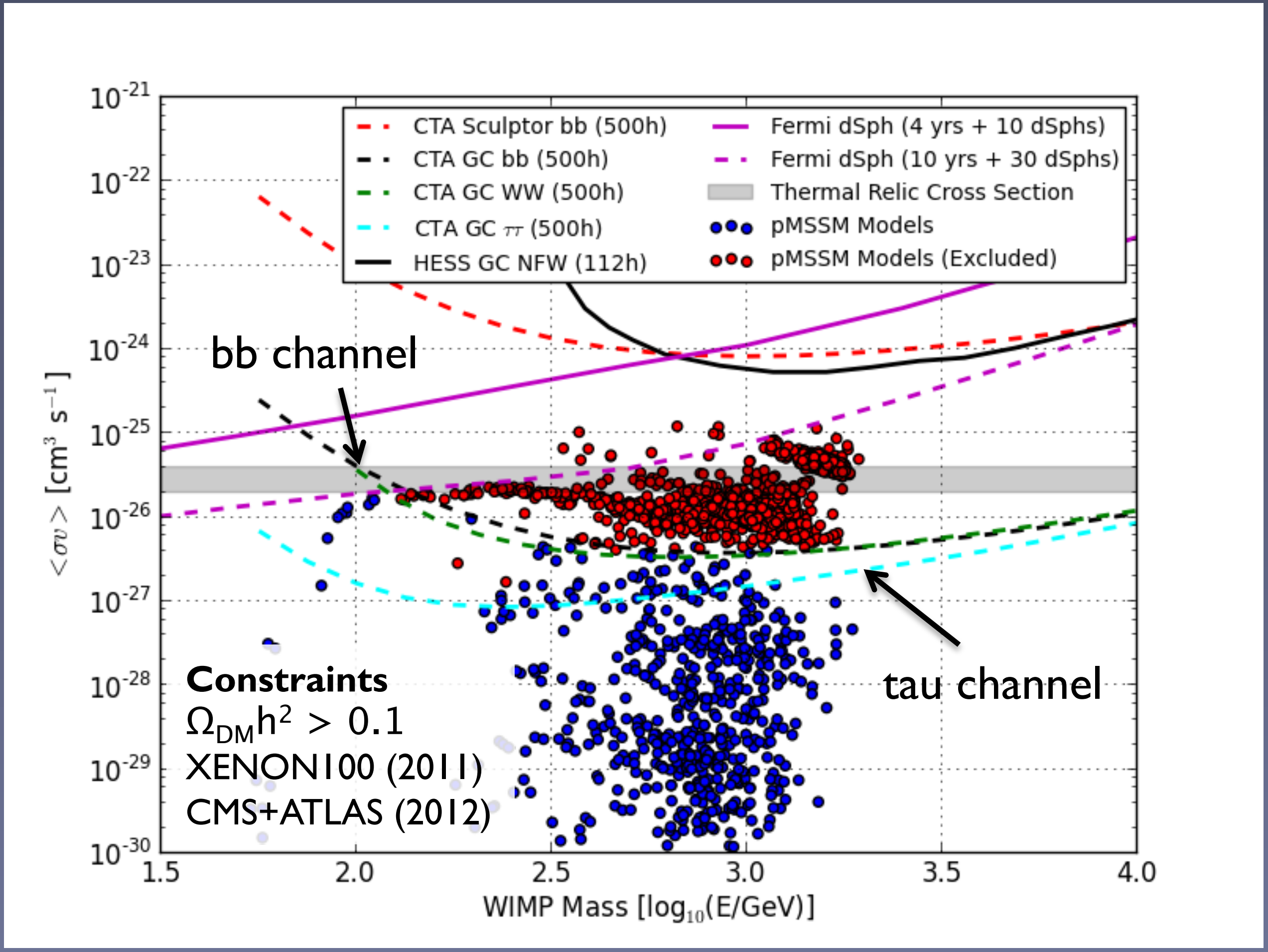
GC Halo Limits (bb channel)



pMSSM Model Scan

- Study of detectability of models in the Phenomenological MSSM (pMSSM; Berger et al. 2009) -- more flexible framework for studying MSSM models than cMSSM or mSUGRA
- Model set generated with numerical scans over the 19- dimensional parameter space of the pMSSM parameters (see Cotta et al. 2011, Cahill-Rowley et al. 2012)
- Model Constraints
  - CMS/ATLAS Searches (7 TeV)
  - Direct Detection WIMP-Nucleon Cross Section Limits (XENON100)
  - Upper bound on WIMP Relic Density (WMAP7): $\Omega_{DM}h^2 < 0.123$
- Input for CTA sensitivity projection
  - 500 hr GC observation
  - NFW MW Halo profile normalized to 0.4 GeV cm^{-3} at solar radius

pMSSM Model Exclusion

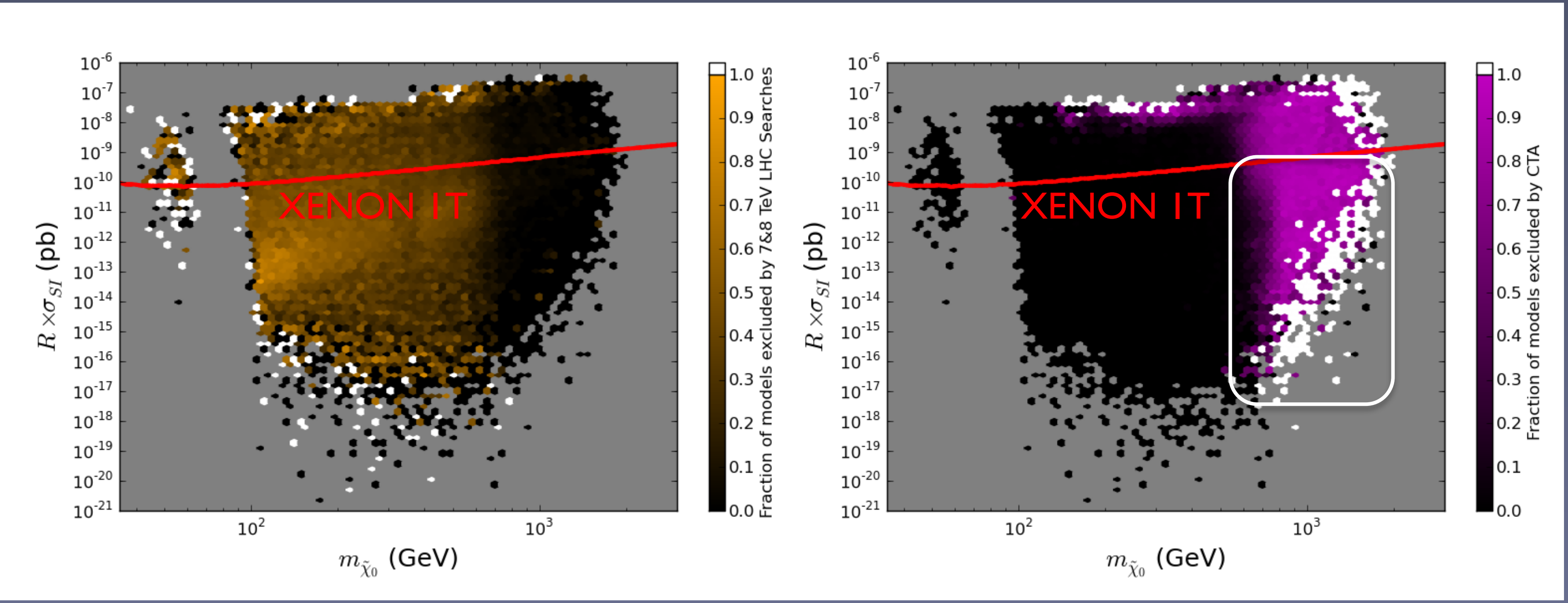


Wood et al. astro-ph/1305.0302

Complementarity with Direct Detection and Accelerators

Models Excluded by LHC

Models Excluded by CTA



Cahill-Rowley et al. hep-ph/1305.6921

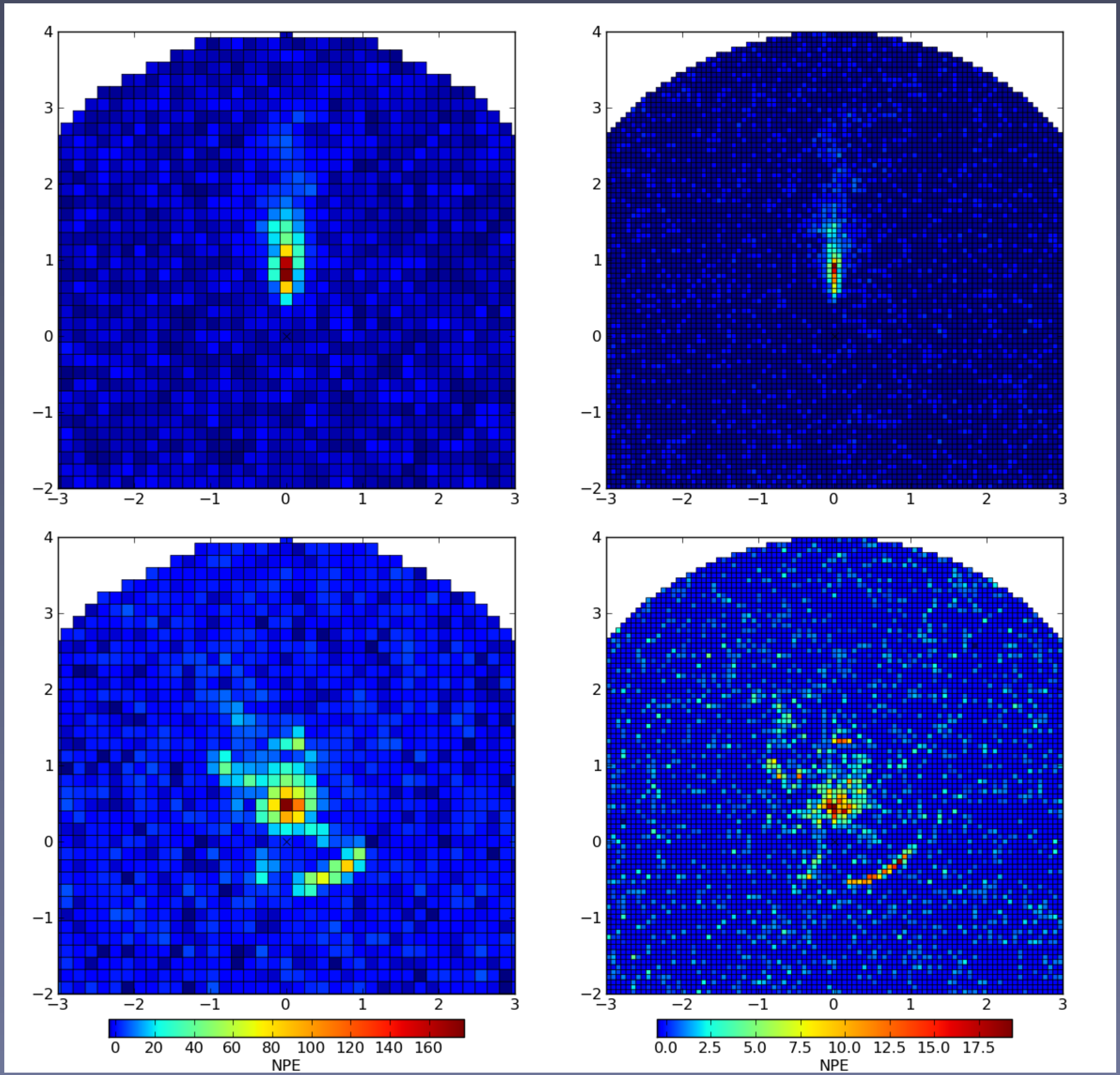
Conclusions

- CTA has good prospects for reaching WIMP models with thermal relic cross section and mass > 300 GeV
- **Dwarf Galaxies**: Thermal relic parameter space probed for boosts of 10-100 (e.g. Sommerfeld enhancement)
- **Galactic Center**: Models with thermal relic cross section should be detectable assuming an extrapolation of the MW DM density profile consistent with CDM simulations
  - Large fraction of pMSSM models satisfying current experimental constraints are detectable with CTA – particularly at high LSP masses (~1 TeV)
  - CTA will be highly complementary to LHC and direct detection searches in covering the full parameter space of WIMP DM models

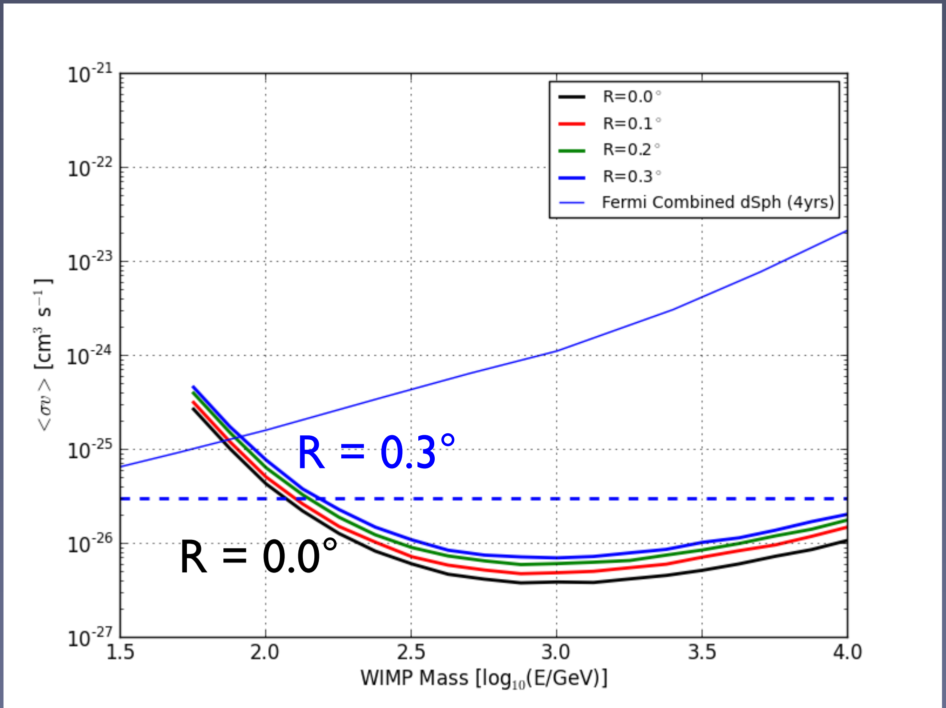
DC-MST SC-MST

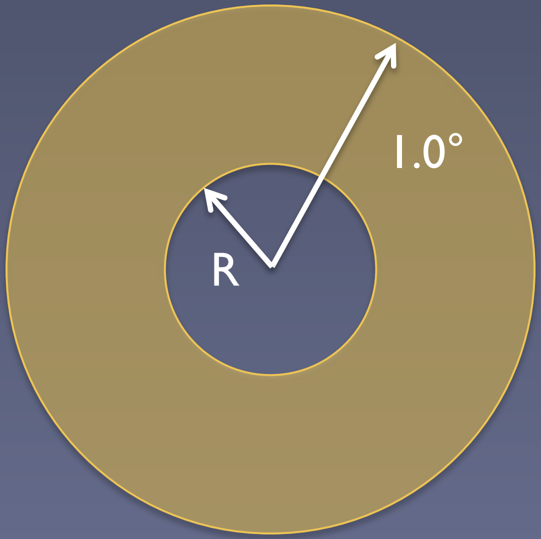
Gamma (E = 1 TeV)

Proton (E = 3.5 TeV)



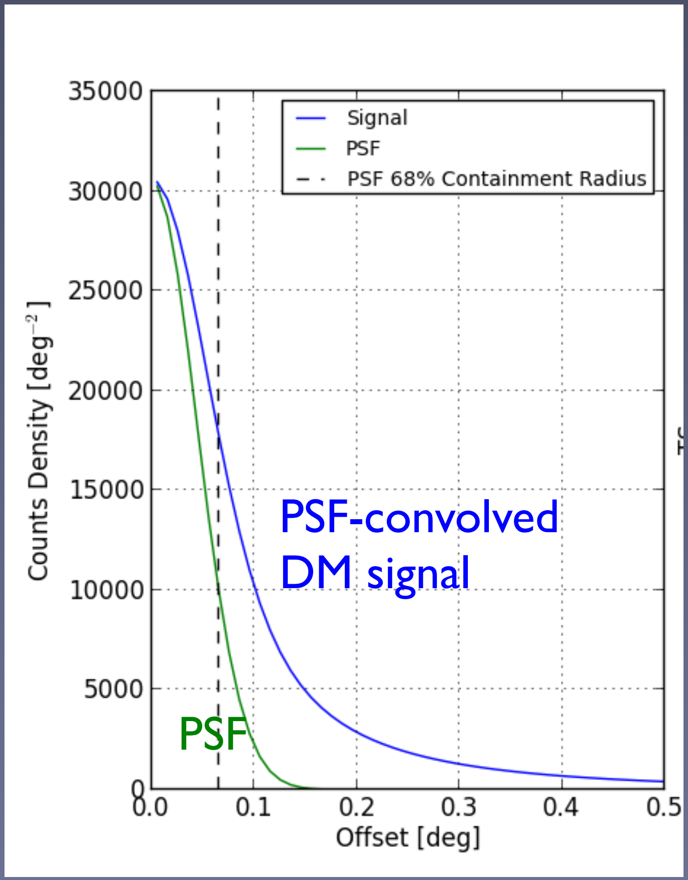
GC Search Region





Analysis Methodology

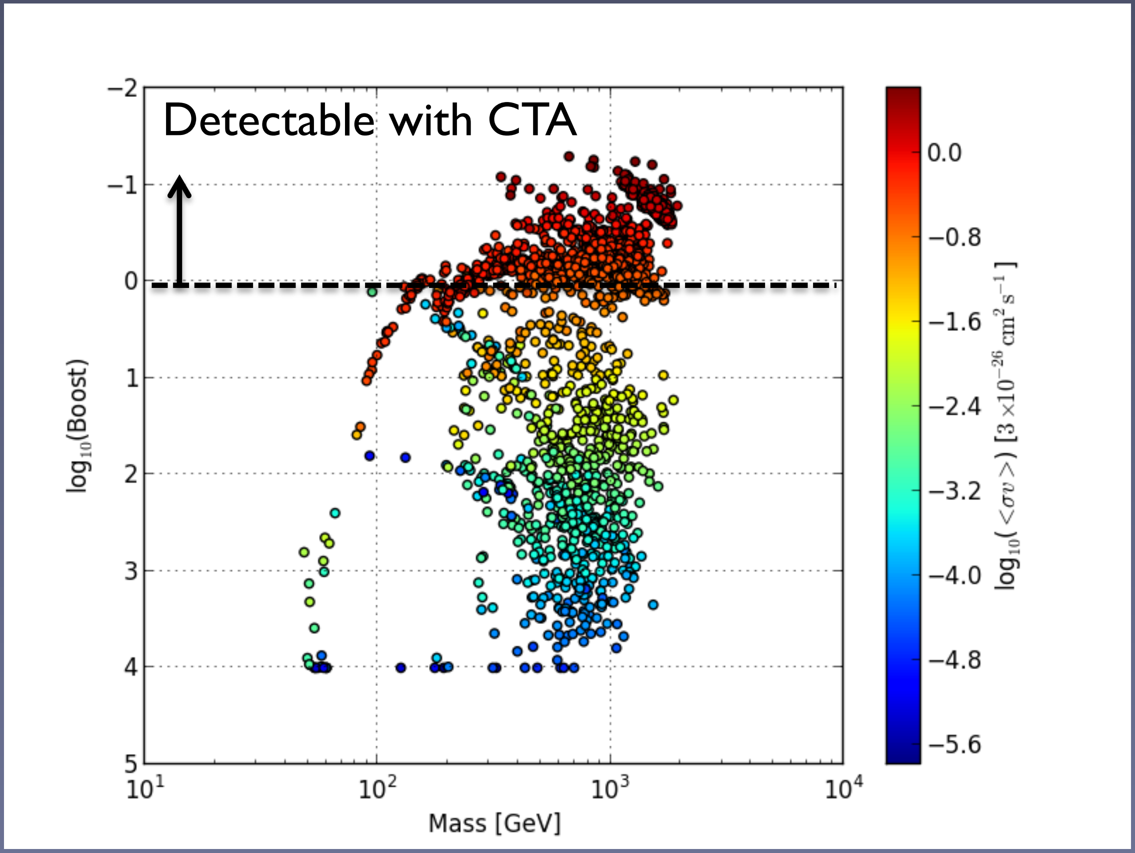
- 2D likelihood analysis
  - Reconstructed Energy (5 bins per decade)
  - Angular Offset
- Signal Model
  - Spatial profile of DM annihilation signal convolved with energy-dependent PSF
  - DM gamma-ray spectra taken from DarkSUSY (Gondolo et al. 2004)
- Background Model
  - Residual hadronic background (protons + electrons)
  - Assume flat distribution with normalization determined by control region with five times solid angle of signal region



Source Offset

pMSSM Model Boosts

Boost



WIMP Mass [GeV]

Constraints

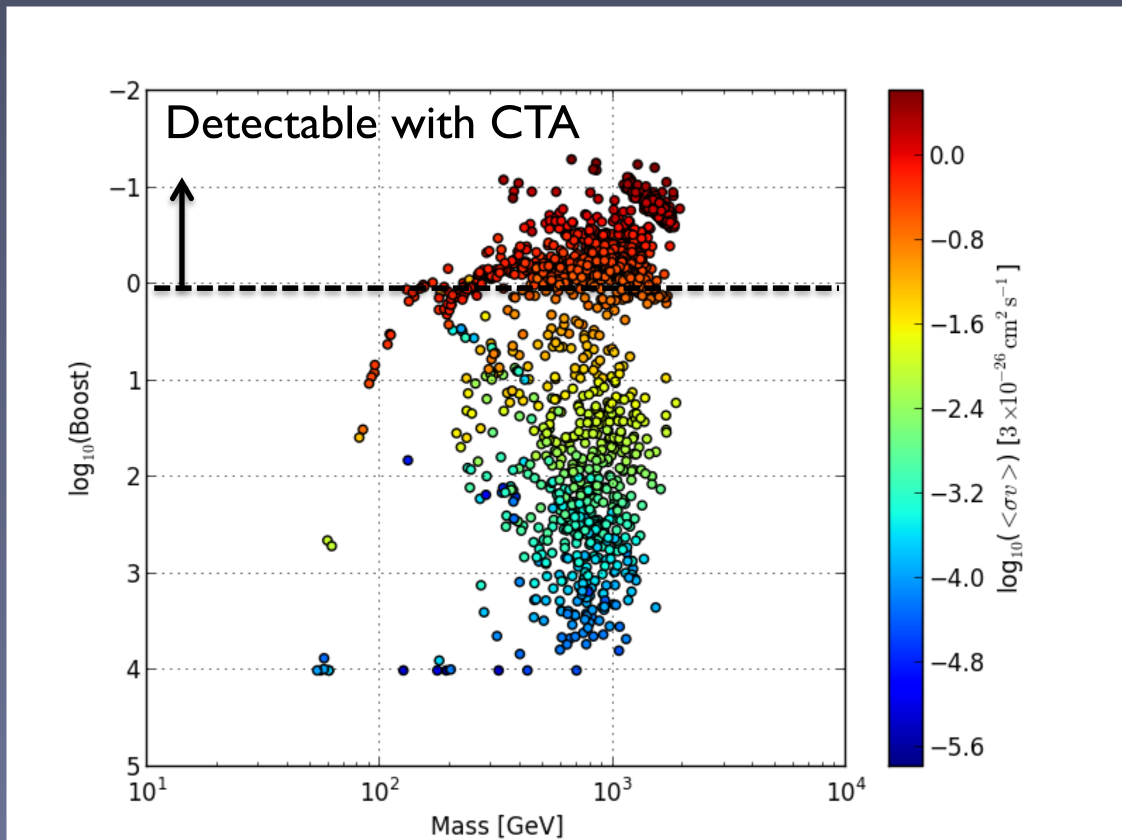
$\Omega_{DM}h^2 > 0.1$

XENON100 (2011)

Boost = (Detectable Signal)/(Model Signal)

pMSSM Model Boosts

Boost



WIMP Mass [GeV]

Constraints
$\Omega_{DM}h^2 > 0.1$
XENON100 (2011)
CMS+ATLAS (2012)

Boost =
(Detectable Signal)/
(Model Signal)