Dark Matter Searches with CTA

Matthew Wood (SLAC)

on behalf of the CTA Consortium

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

Proposed US Contribution

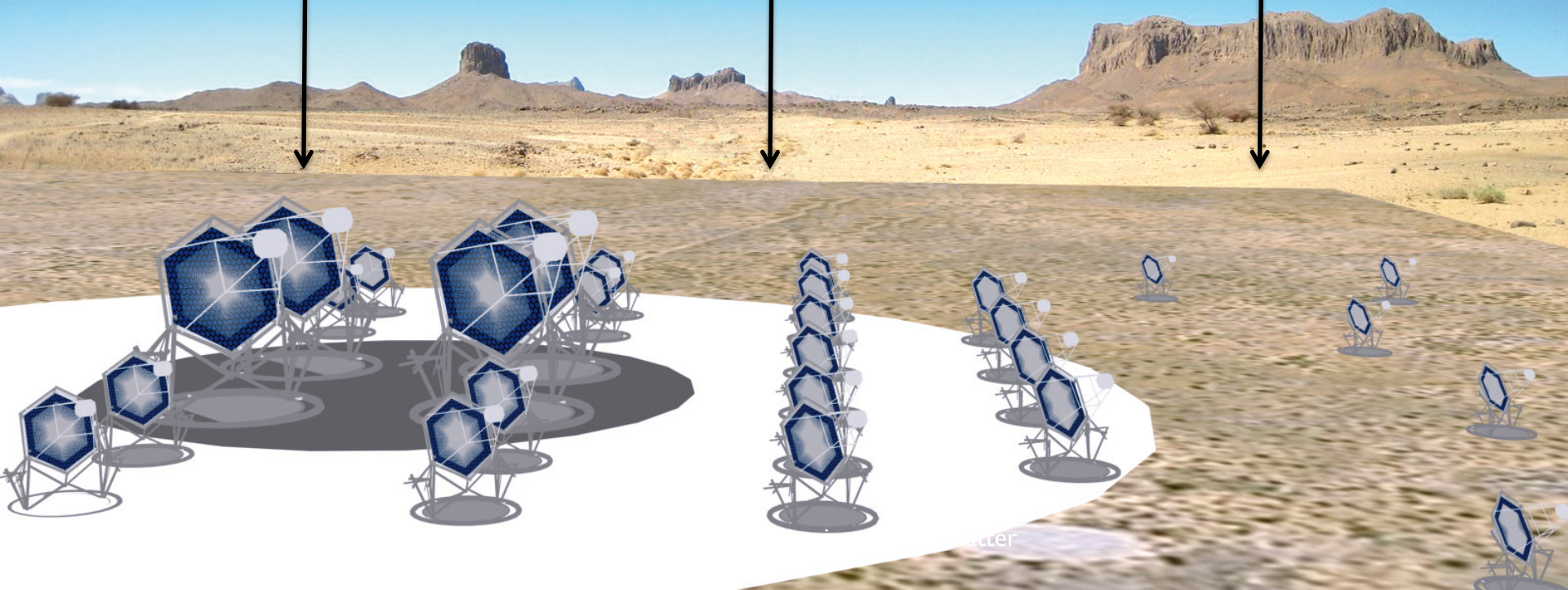
cta
cherenkov telescope array

Estimated cost ~200 M€ (+100 M$)

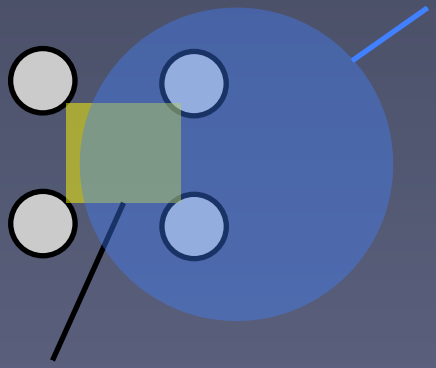
Low Energy
(<100 GeV)
LST 23 m (x4)

Medium Energy
(100 GeV – 10 TeV)
MST 10-12 m (x25 + 36)

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

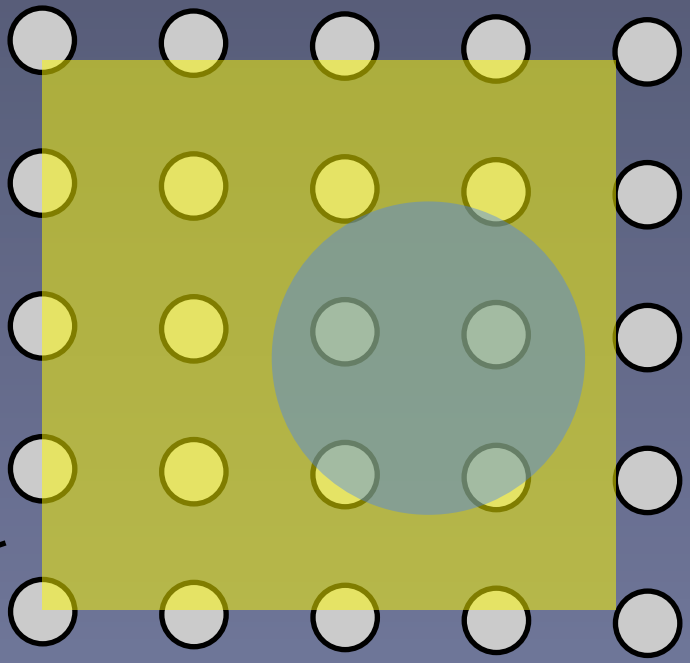


From current arrays to CTA



Light pool radius
R ≈100-150 m
≈ typical telescope spacing

Sweet spot for
best triggering
and reconstruction:
Most showers miss it!



Large detection area
More images per shower
Lower trigger threshold
Better angular resolution
and background rejection

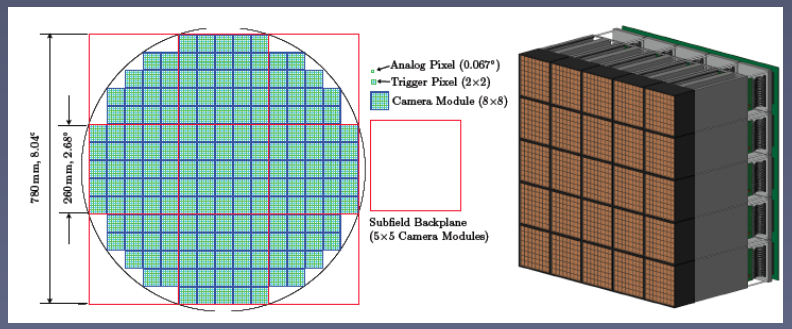
US Contribution

Enhancement of 36 additional MSTs utilizing Dual mirror (SC) design

Optics
Schwarzschild-Couder (SC)

Aperture: 9.7 m
Mirror Area: 50 m^2
Camera: 0.5 m^2
f/D: 0.58
Pixel Size: 0.067 deg
FoV: 8 deg

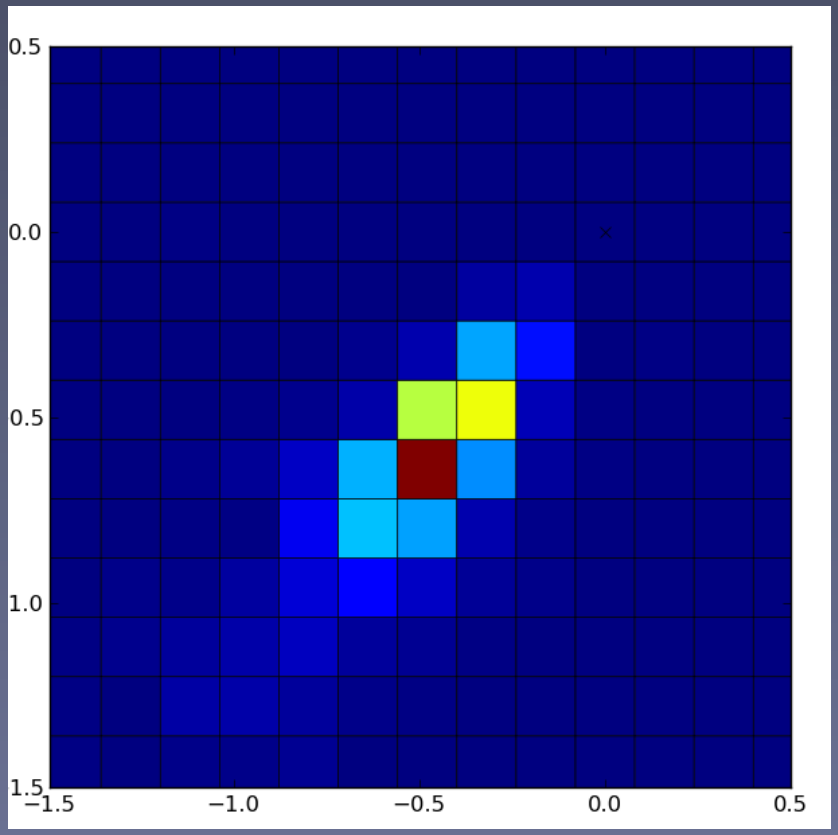
Camera



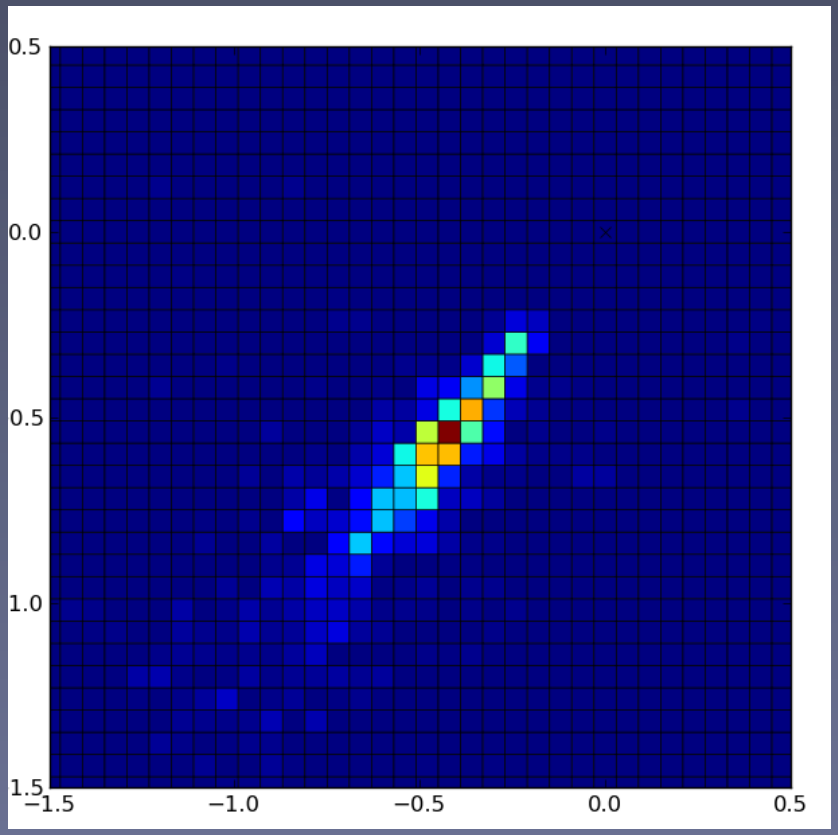
~10k pixels
Compact focal plane electronics
Low cost per channel
SiPM photosensors

Gamma-ray Shower Image (E = 1 TeV)

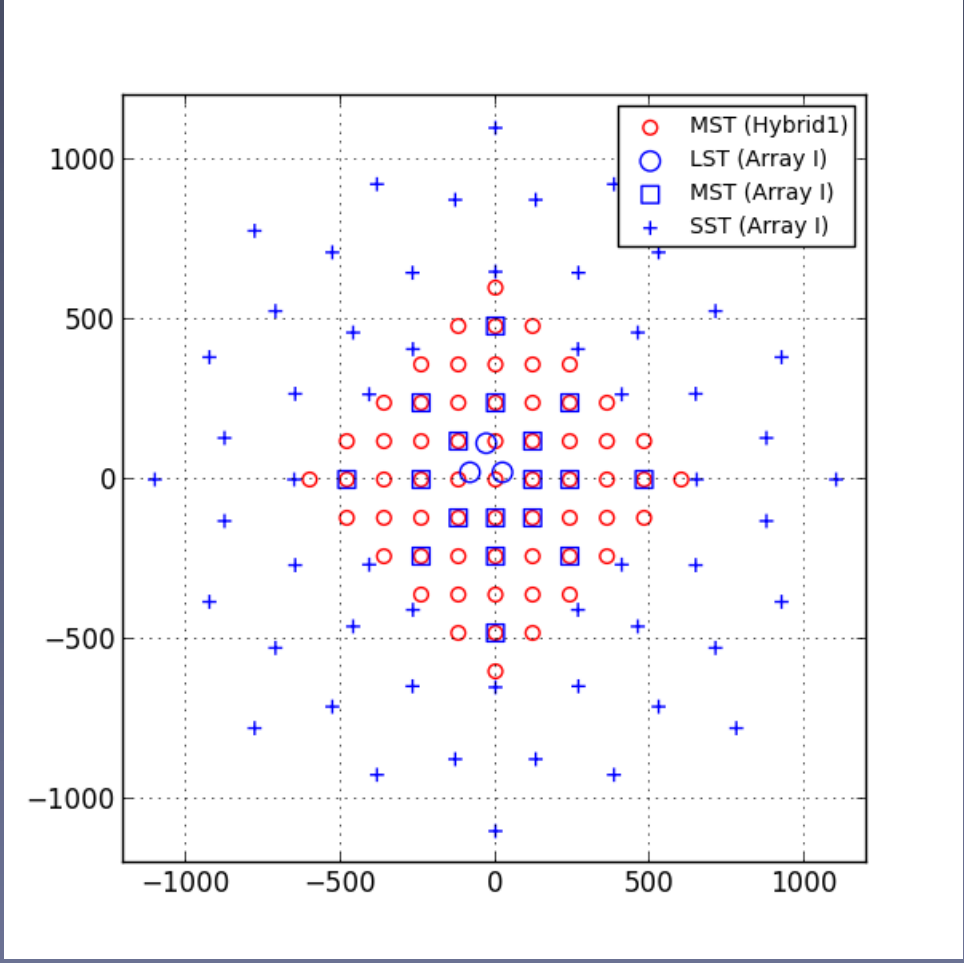
DC-MST (Single Mirror)



SC-MST (Dual Mirror)



Simulated Array Candidates

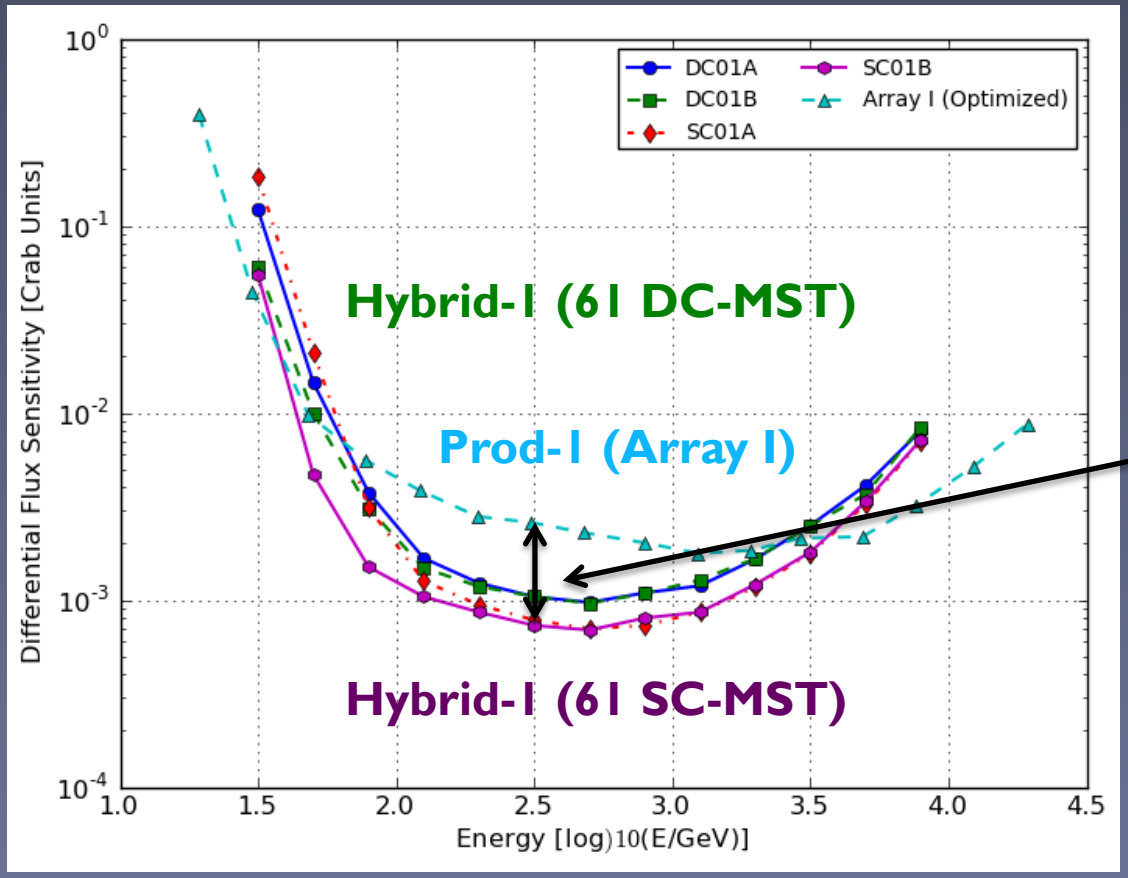


1 km

Prod-1 Array I
3 LSTs
18 MSTs
56 SSTs

Hybrid-1
61 MSTs

Projected Point-Source Sensitivity



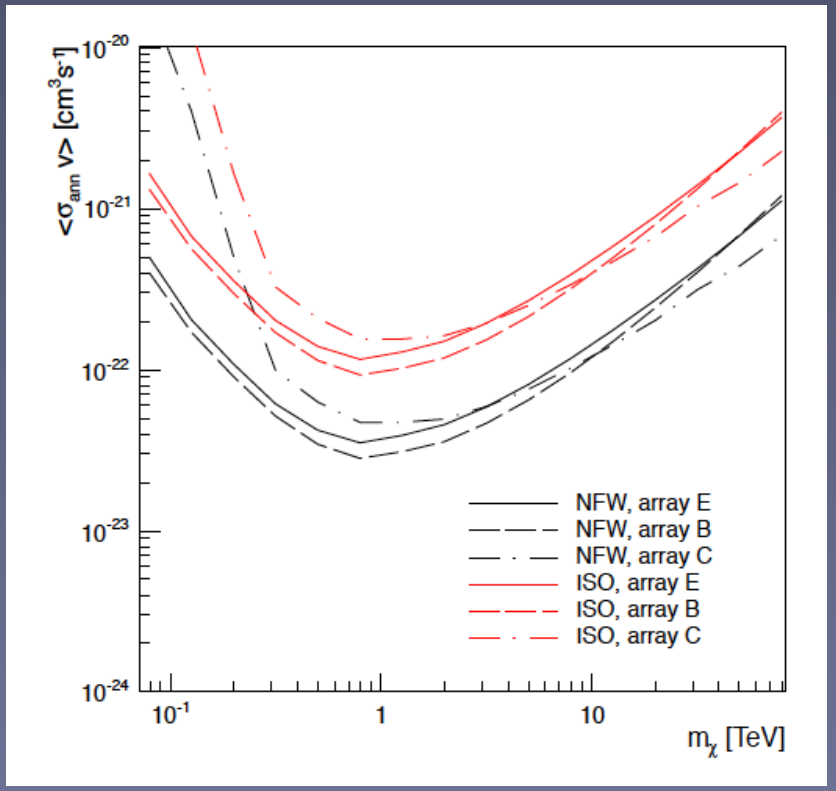
~2-3x improvement
In core energy range
From US contribution

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

Fundamental Physics with CTA

- Particle DM Searches
- Axion-like Particles
- Lorentz Invariance Violation
- For more details see Doro et al. 2012, arXiv:1208.5356

Projected CTA Sensitivity for 100 hour Observation of Sculptor



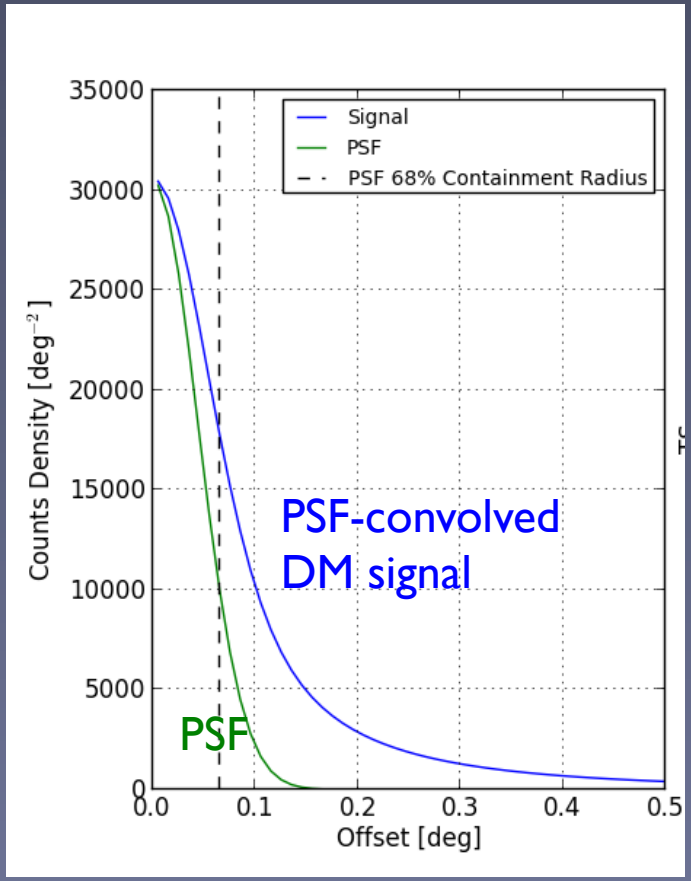
Doro et al. 2012

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
  - Automatic target as part of Galactic Plane Survey
  - 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)

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



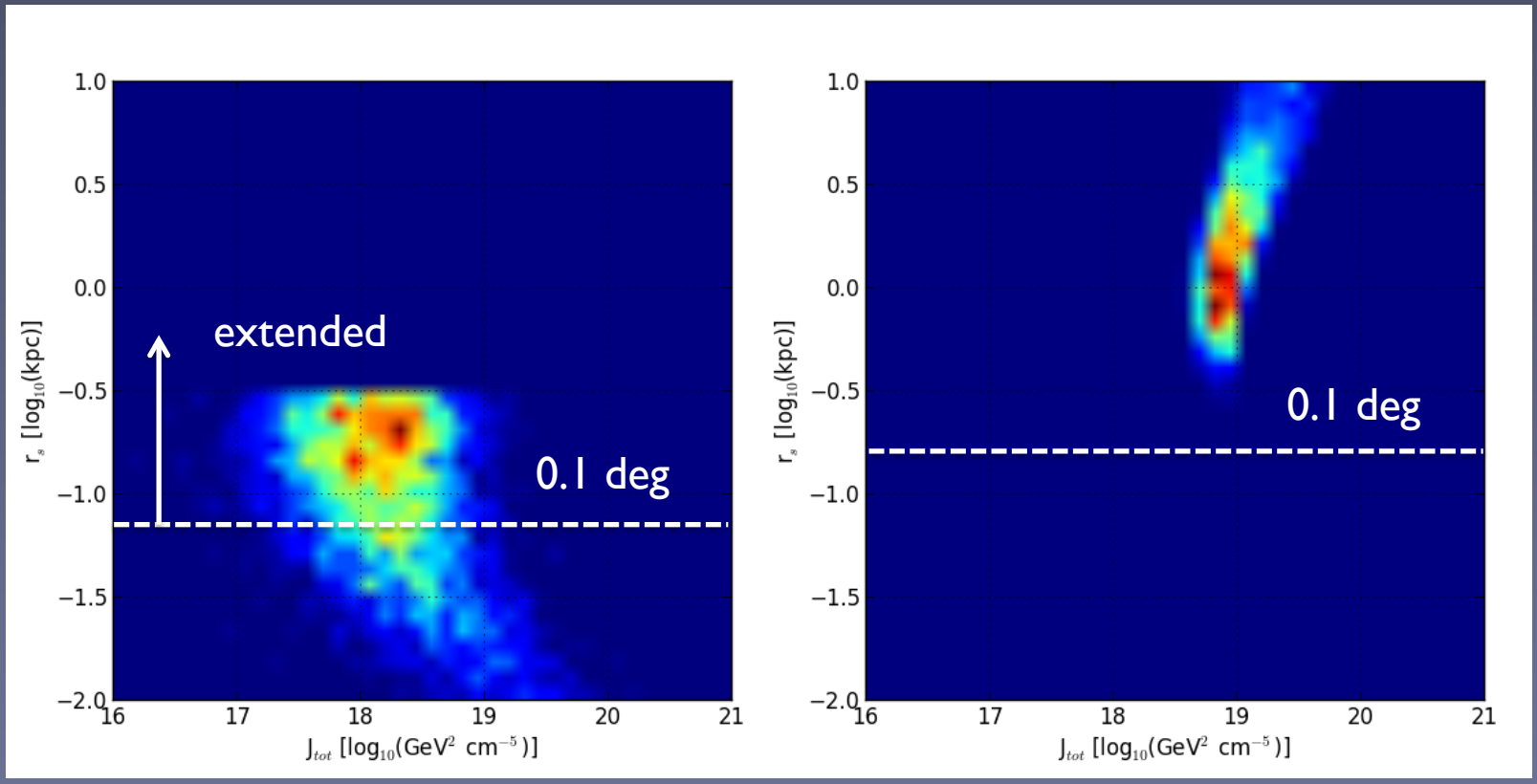
Source Offset

Dwarf Galaxies

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

Dwarf Galaxies: Astrophysical Modeling

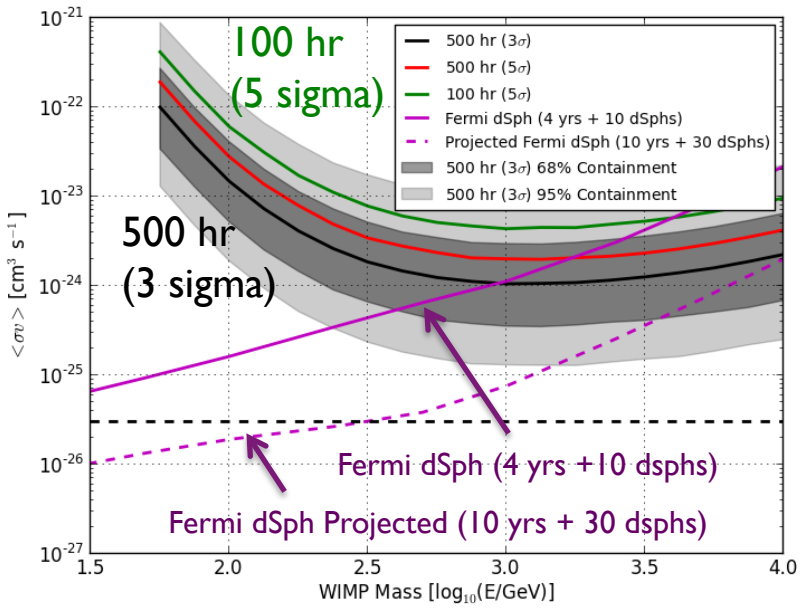
Coma Berenices **Sculptor**

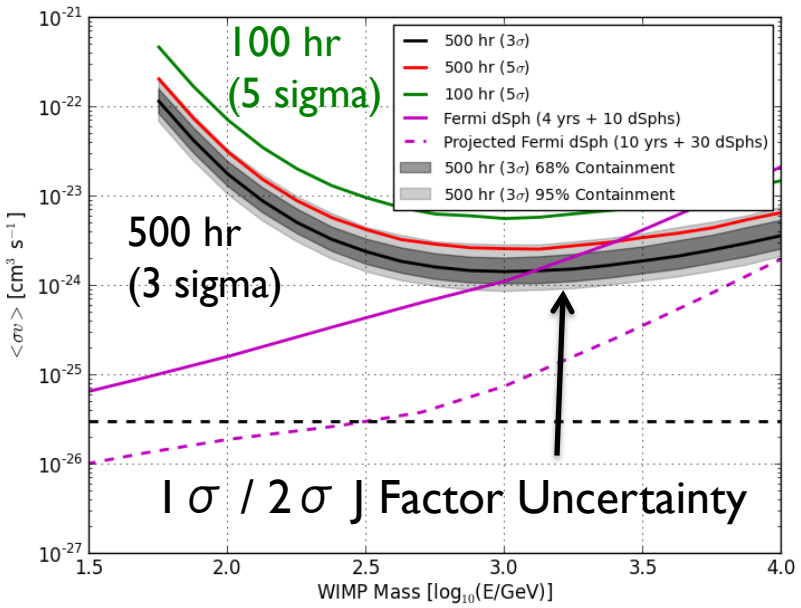


J Factor (Total Annihilation Flux)

Dwarf Galaxy Limits (bb)

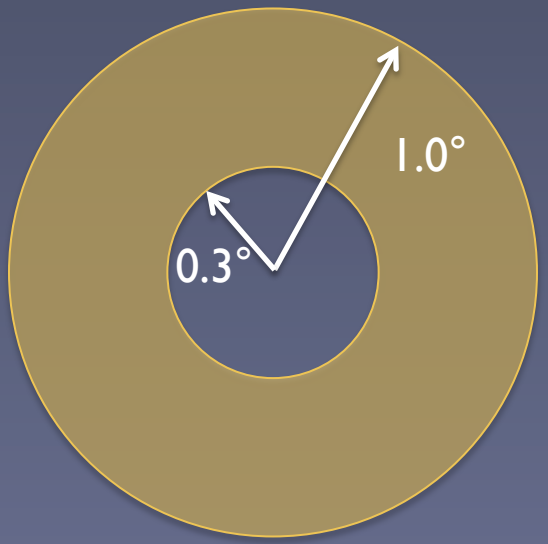
Coma Berenices **Sculptor**



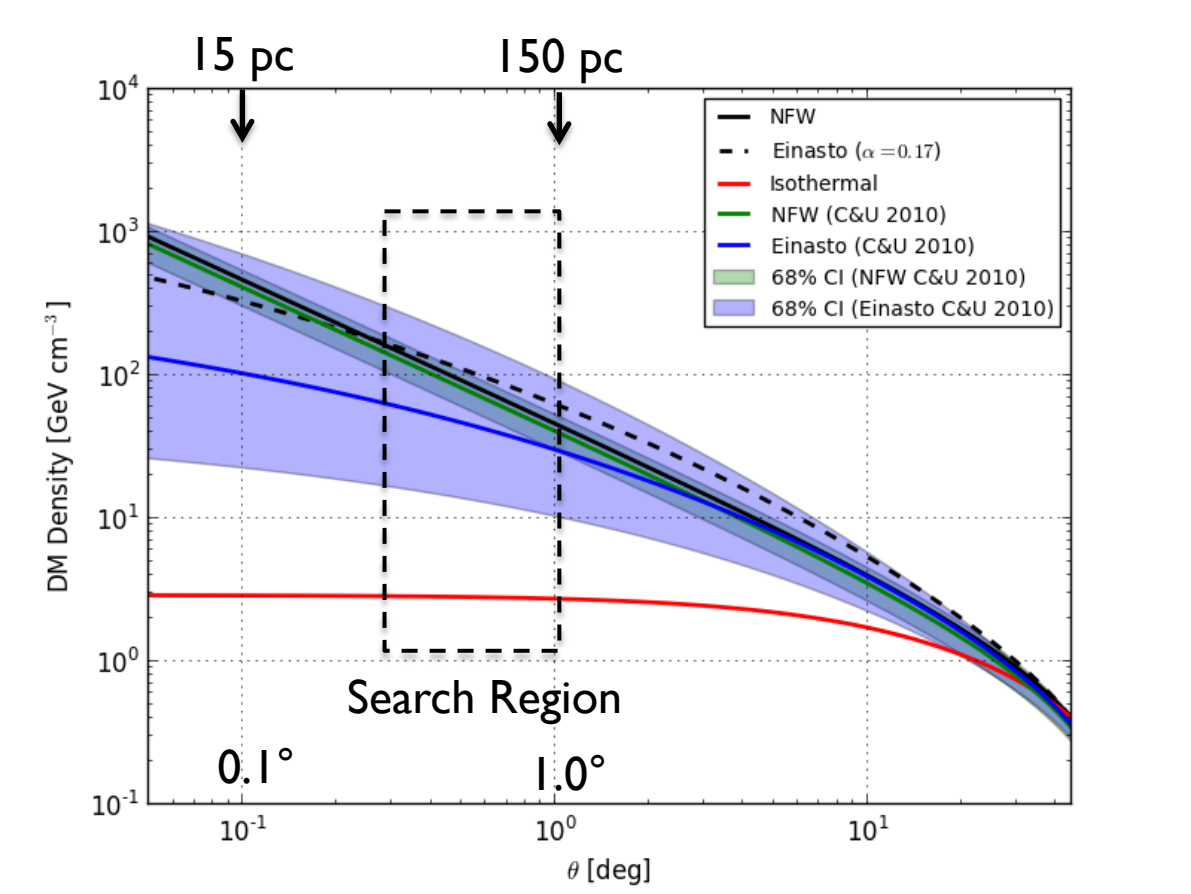


Galactic Center

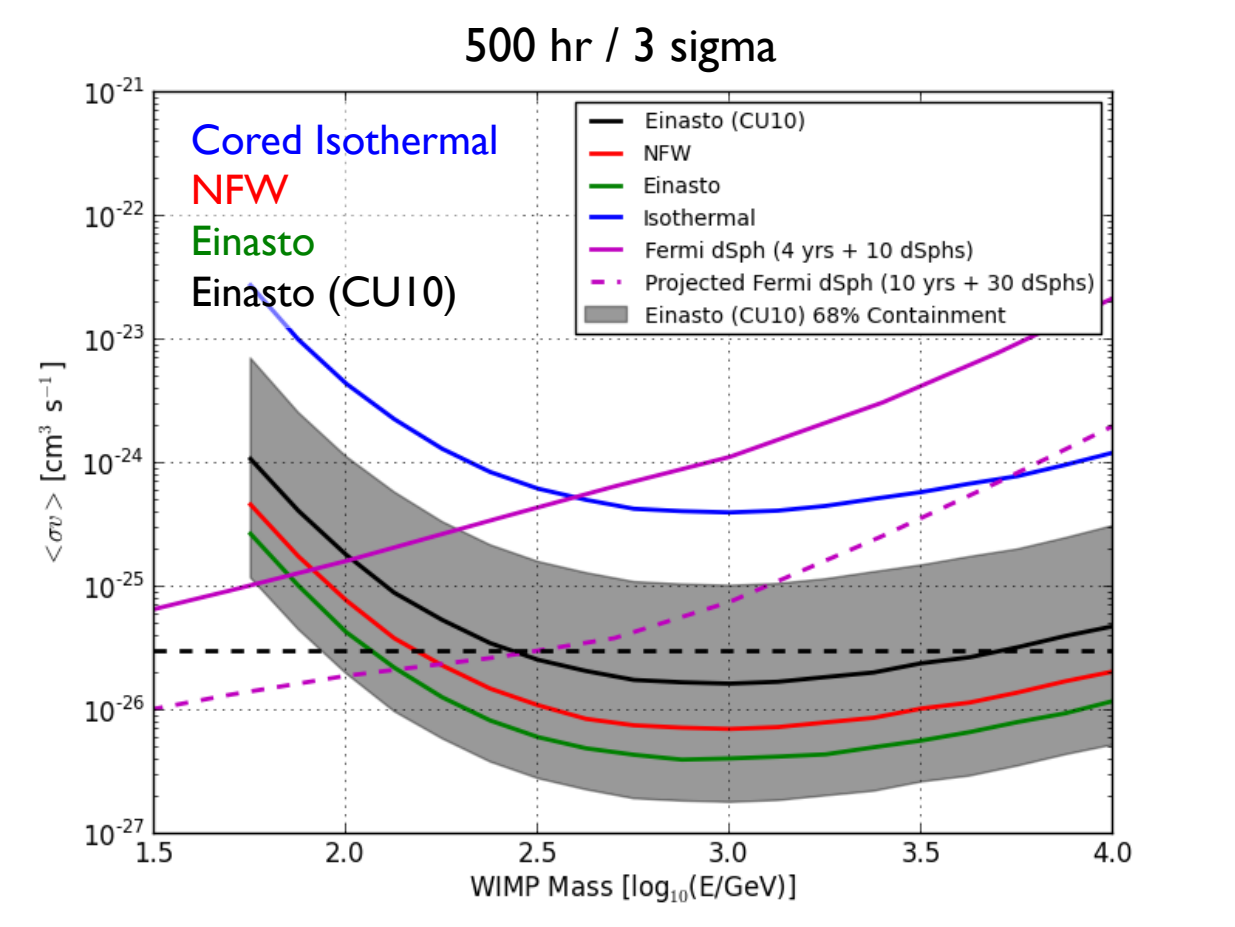
- Use an annular search region around the GC (R = 0.3 – 1.0 deg) to minimize astrophysical foregrounds (HESS-style analysis; see Abramowski et al. 2011)
- MW Halo Models
  - NFW, Isothermal, and Einasto profiles normalized to 0.4 GeV cm^{-3} at the solar radius
  - NFW and Einasto profiles with 68% uncertainties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



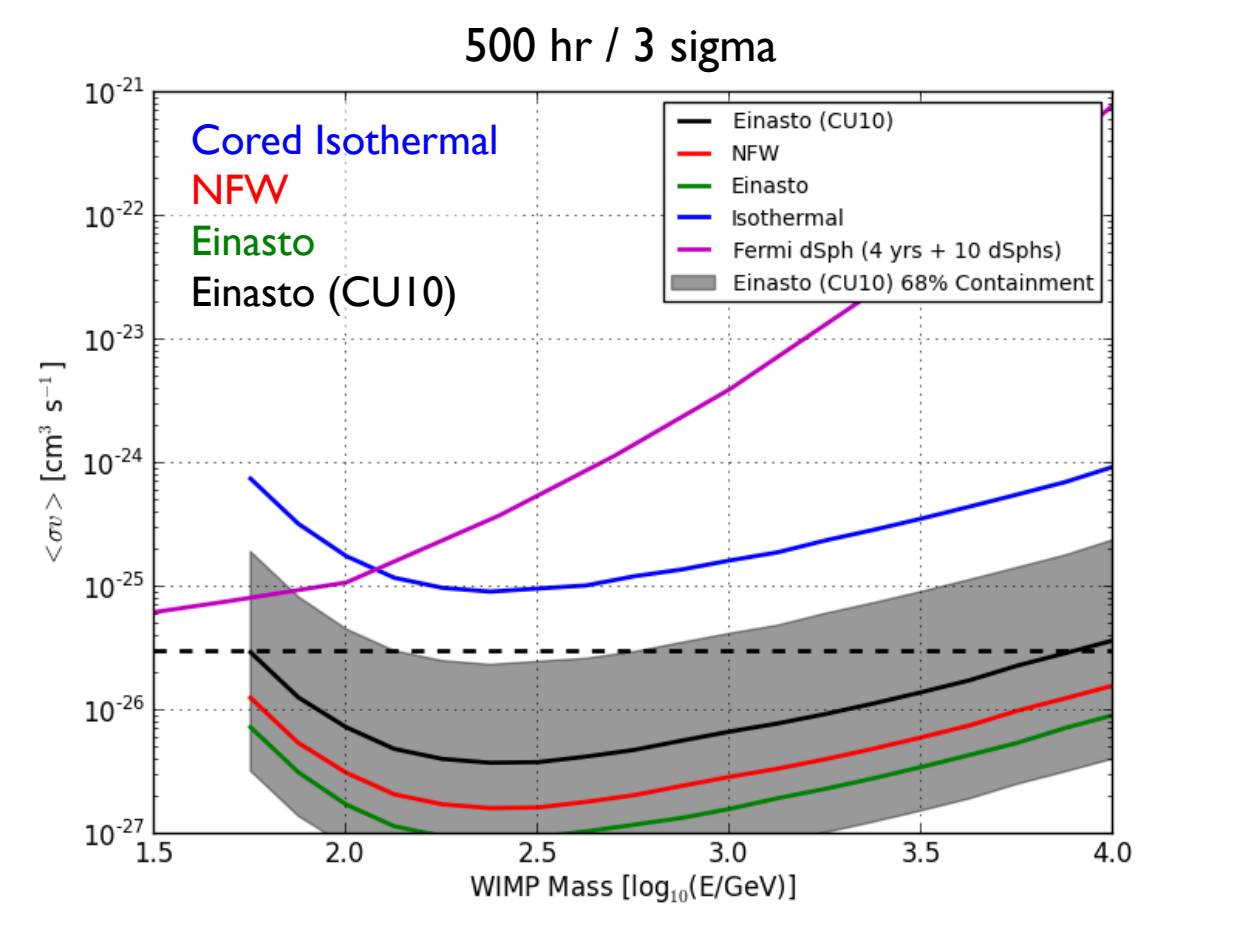
MW Density Profile



GC Limits (bb)


500 hr / 3 sigma
Cored Isothermal
NFW
Einasto
Einasto (CU10)
Einasto (CU10)
NFW
Einasto
Isothermal
Fermi dSph (4 yrs + 10 dSphs)
Projected Fermi dSph (10 yrs + 30 dSphs)
Einasto (CU10) 68% Containment
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
$<\sigma v>$ [cm^3 s^{-1}]
1.5
2.0
2.5
3.0
3.5
4.0
WIMP Mass [log$_{10}$(E/GeV)]

GC Limits (tau)

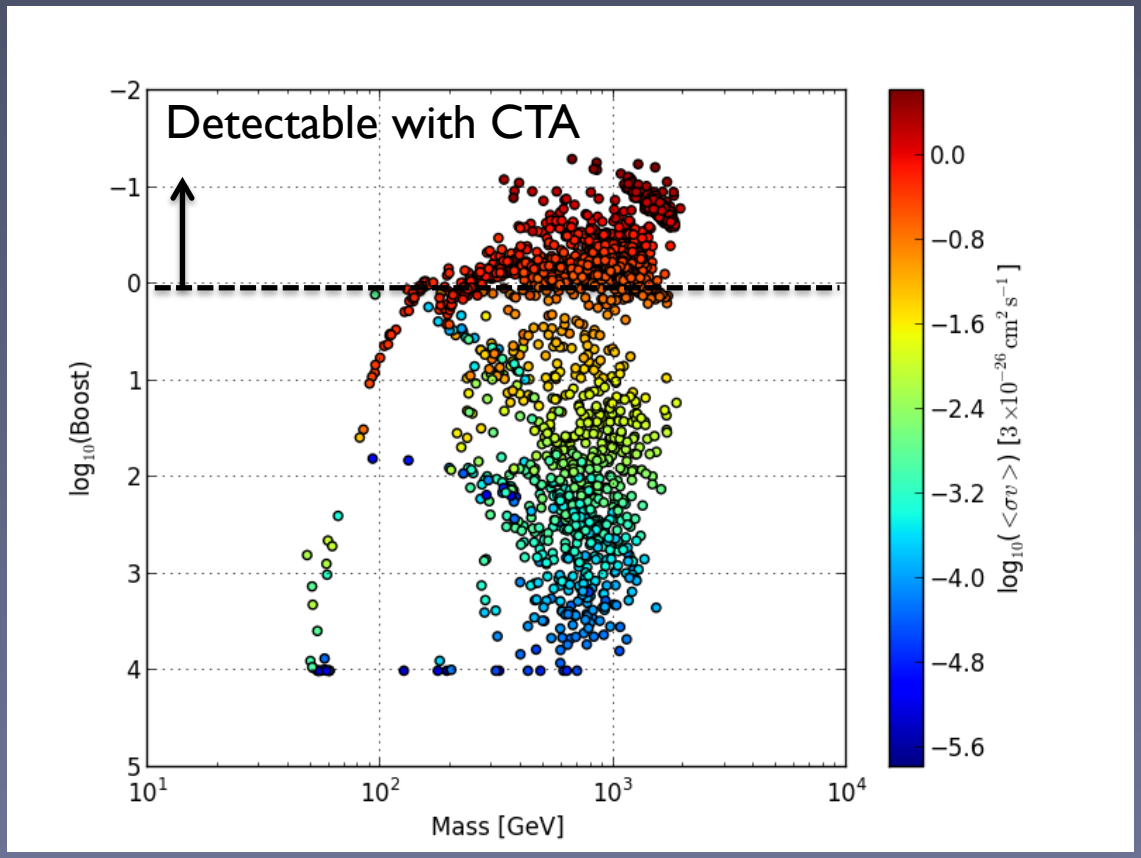


pMSSM Model Scan

- 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
  - Direct Detection WIMP-Nucleon Cross Section Limits (XENON100)
  - WIMP Relic Density (WMAP7): $\Omega_{DM}h^2 < 0.123$
- CTA sensitivity to each model calculated for 500 hr GC observation (NFW profile) and 3 sigma detection threshold

pMSSM Model Boosts

Boost

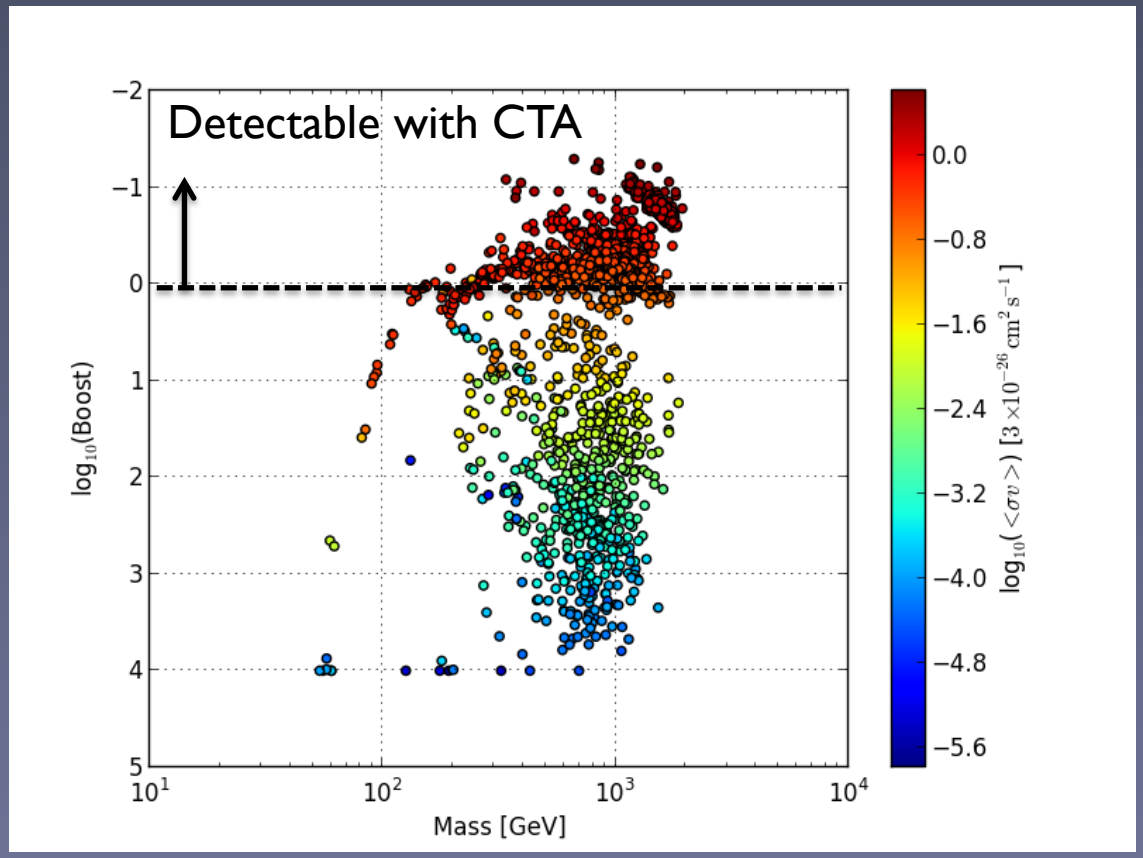


WIMP Mass [GeV]

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

Boost =
(Detectable Signal)/
(Model Signal)

pMSSM Model Boosts



Constraints

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

XENON100 (2011)

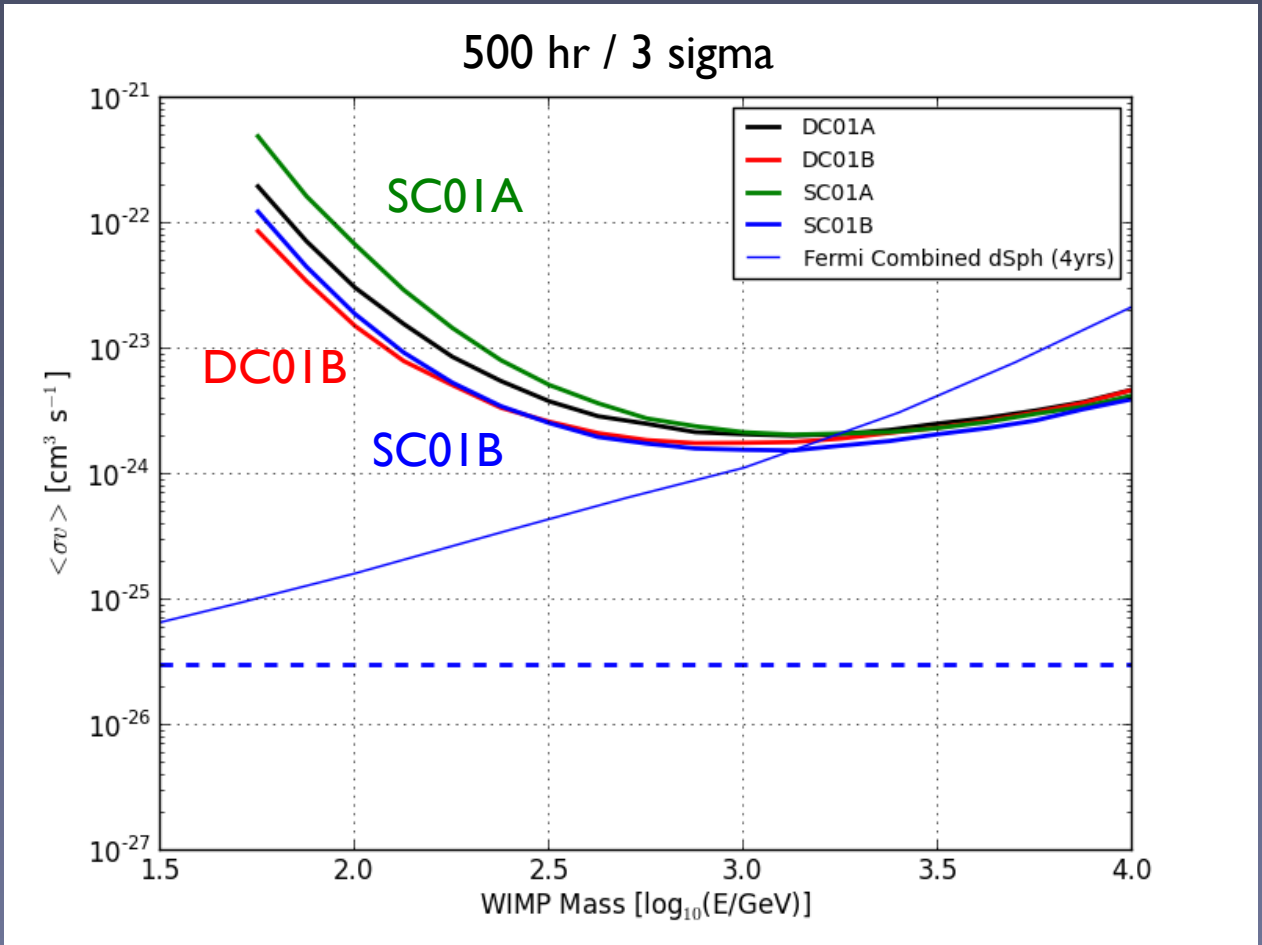
CMS+ATLAS (2012)

Boost = (Detectable Signal)/ (Model Signal)

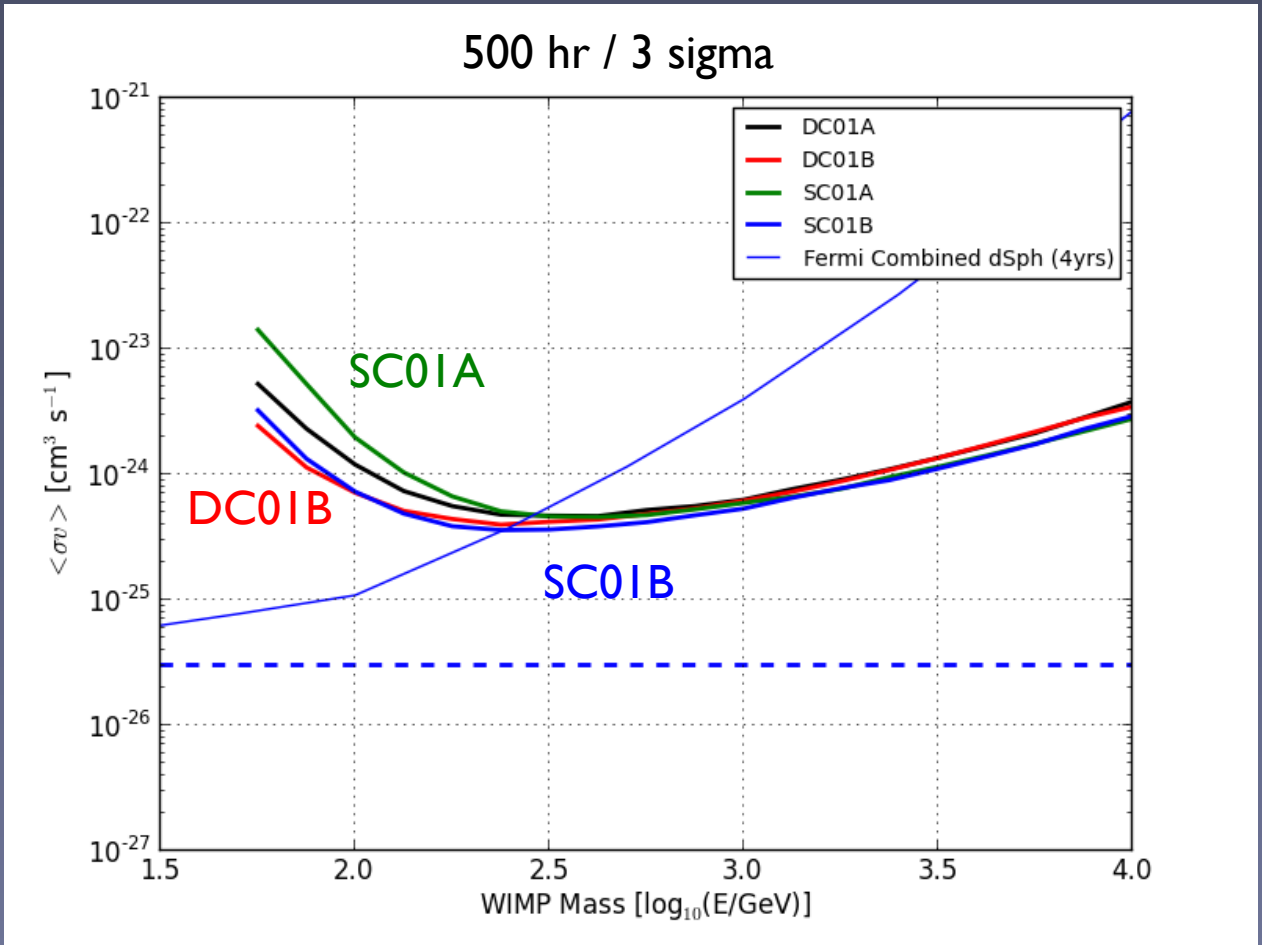
Conclusions

- CTA has good prospects for reaching WIMP models with thermal relic cross section and mass > 300 GeV
- **Dwarf Galaxies**: Need boosts of 10-100 to reach interesting parameter space
- **Galactic Center**: Models with thermal relic cross section should be detectable assuming an extrapolation of the 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)

Sculptor (bb)


500 hr / 3 sigma
DC01A
DC01B
SC01A
SC01B
Fermi Combined dSph (4yrs)
SC01A
DC01B
SC01B
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
10^{-27}
$<\sigma v>$ [cm^3 s^{-1}]
1.5
2.0
2.5
3.0
3.5
4.0
WIMP Mass [log$_{10}$(E/GeV)]

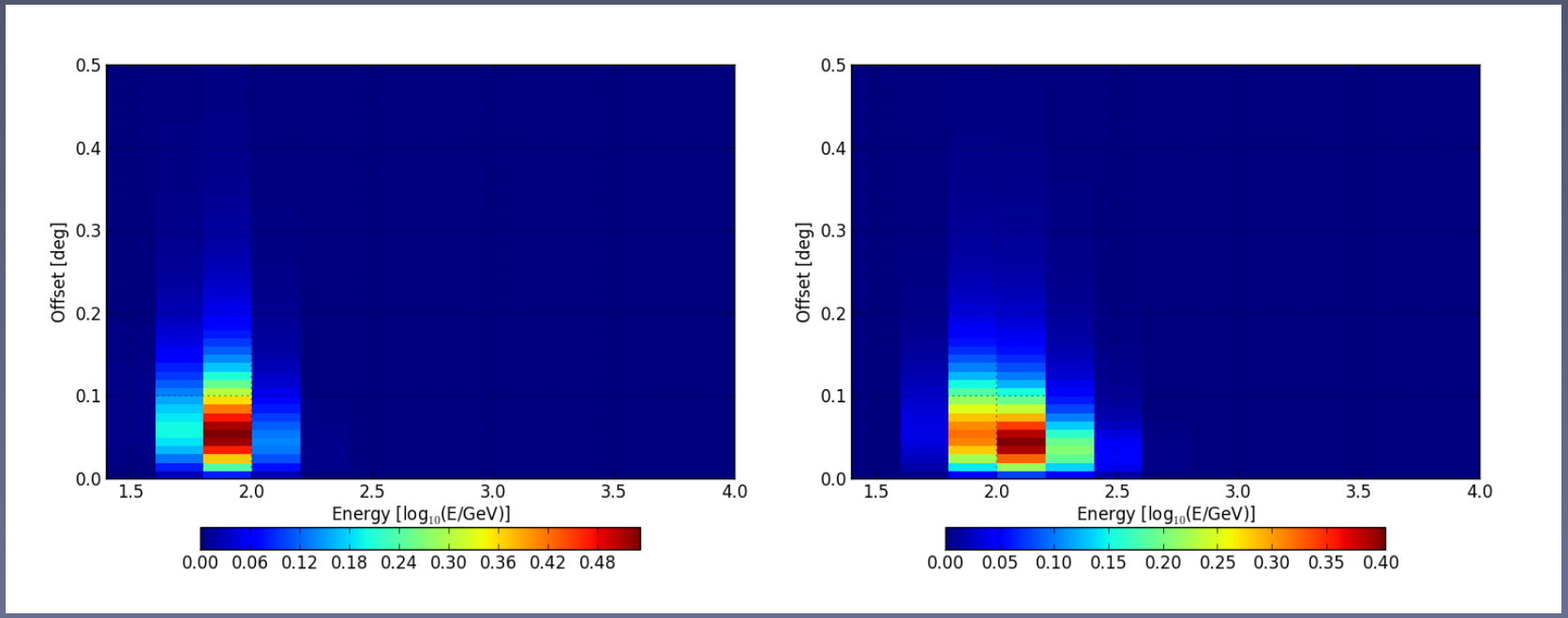
Sculptor (tau)



Log-Likelihood Intensity

M = 316 GeV **M = 1 TeV**

Offset



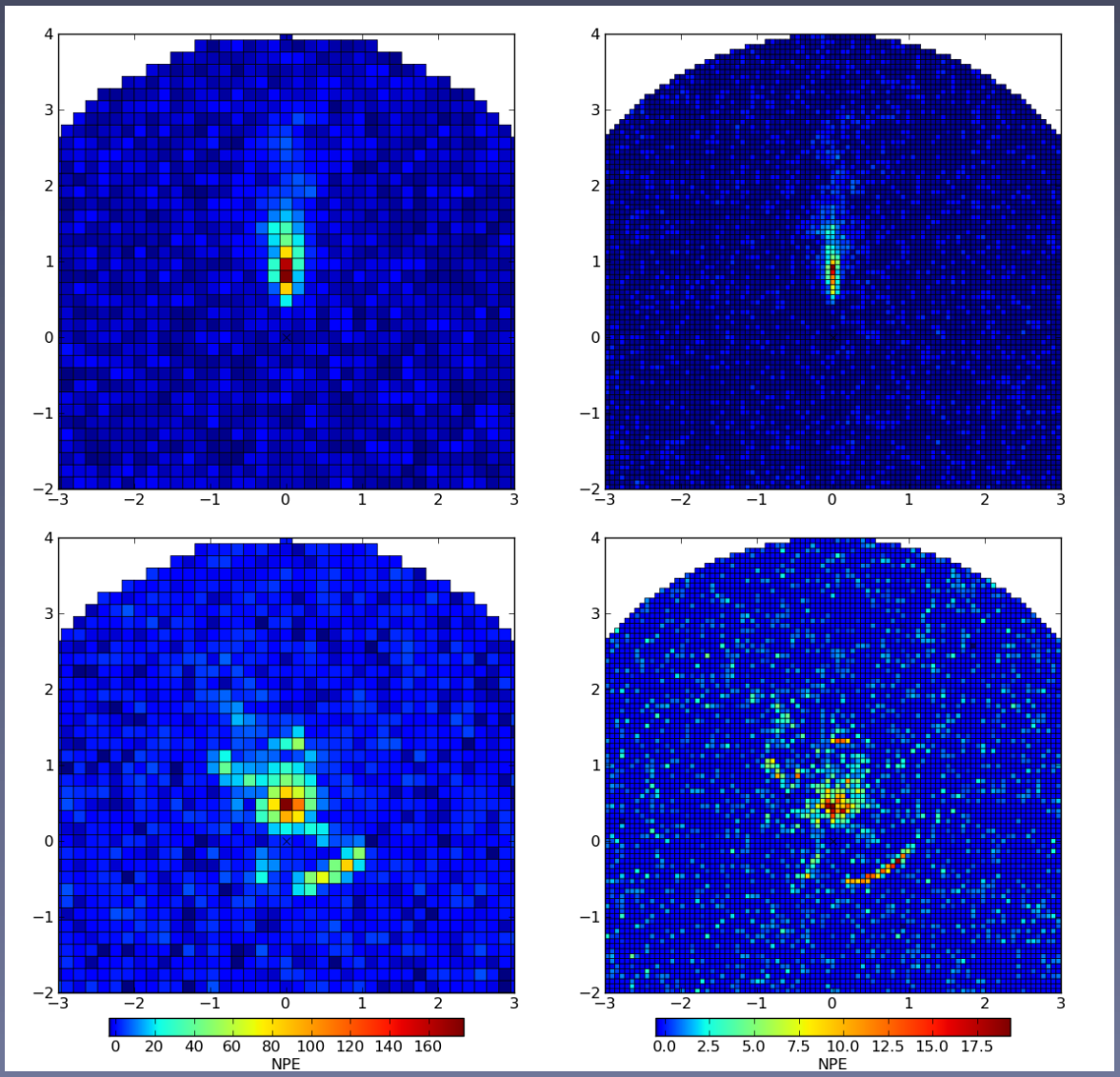
Gamma-ray Energy →

DC-MST

SC-MST

Gamma (E = 1 TeV)

Proton (E = 3.5 TeV)



GC Search Region