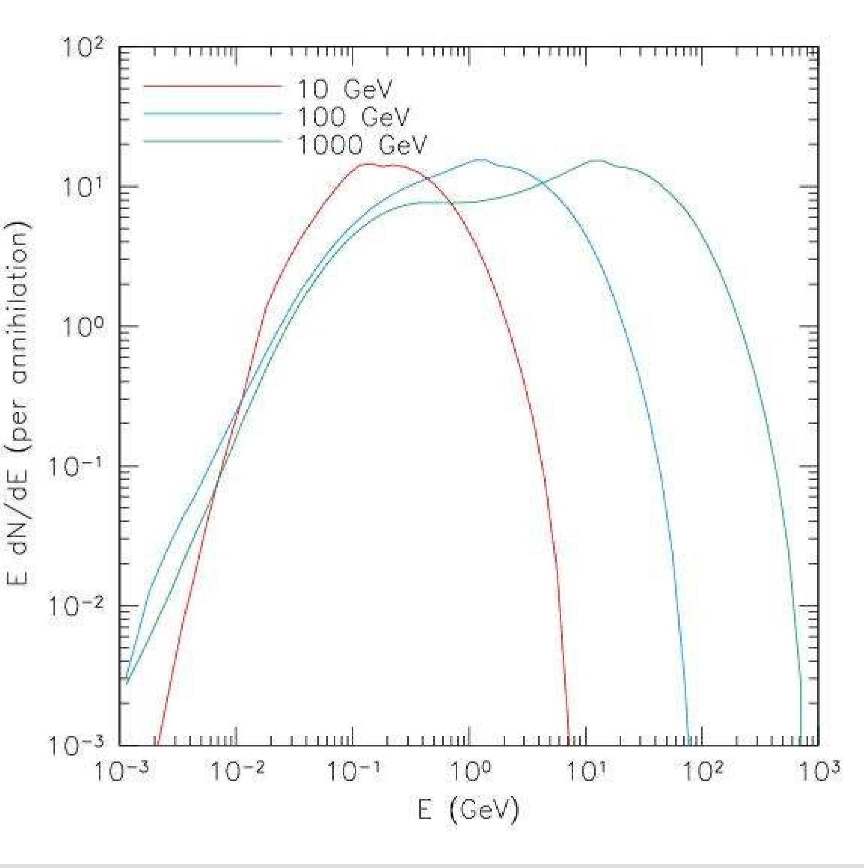
Dark Matter and Data

(2007 will be here in no time)

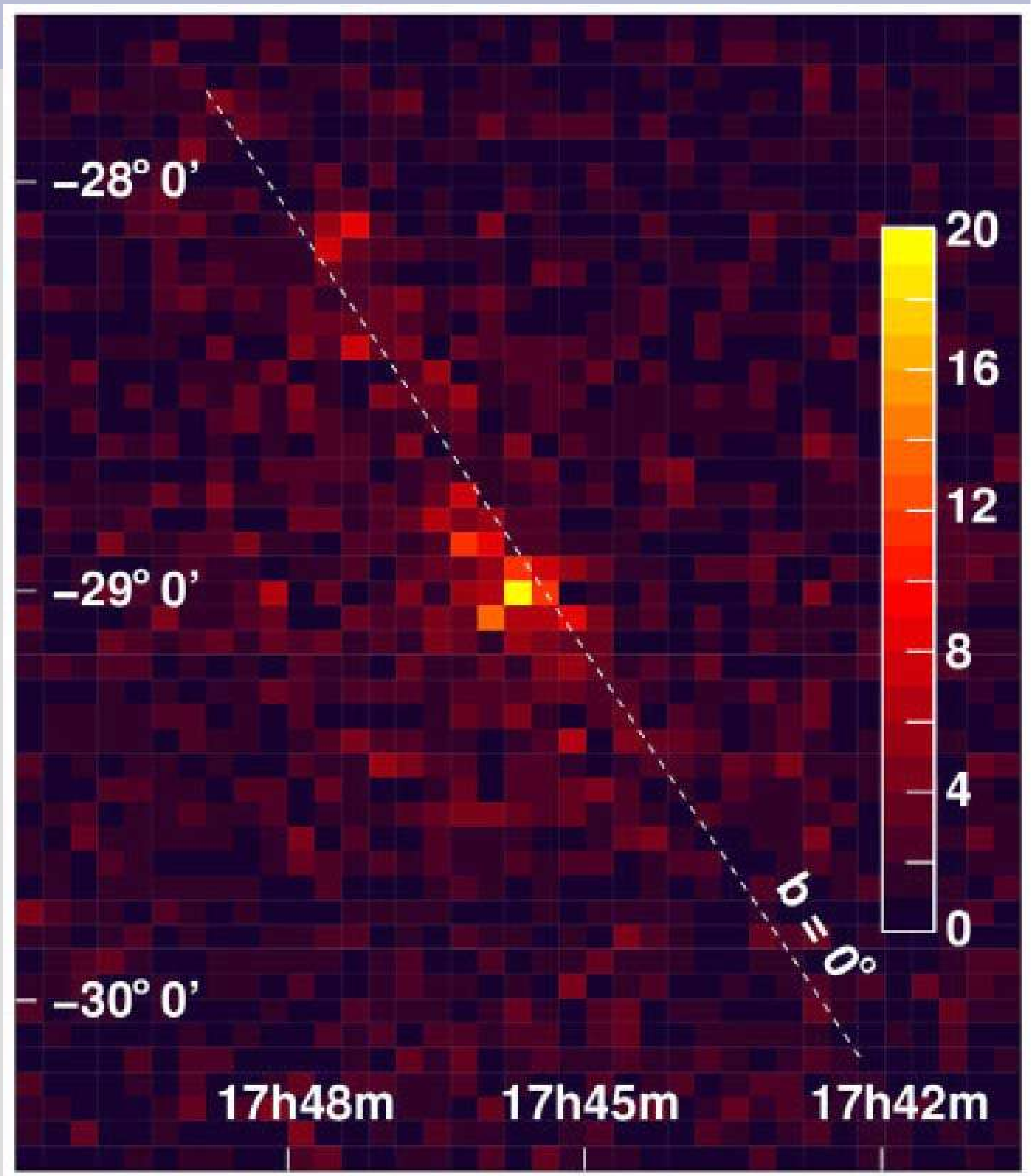
Dark Matter Annihilations

- WIMP models predict annihilation rates that may be observable
- Clearest signature is gamma ray lines ($\gamma\gamma$, γZ): universally loop-suppressed
  - In SUSY, BR as large as 0.001
- Hadronic channels usually dominate
  - pions decay into photons, leptons
  - baryons are a relatively small fraction
- Neutral pion decays expected dominate the gamma continuum
- Spectrum is hard at ~ 1 GeV
  - this may allow discrimination from astrophysical backgrounds



The Galactic Center

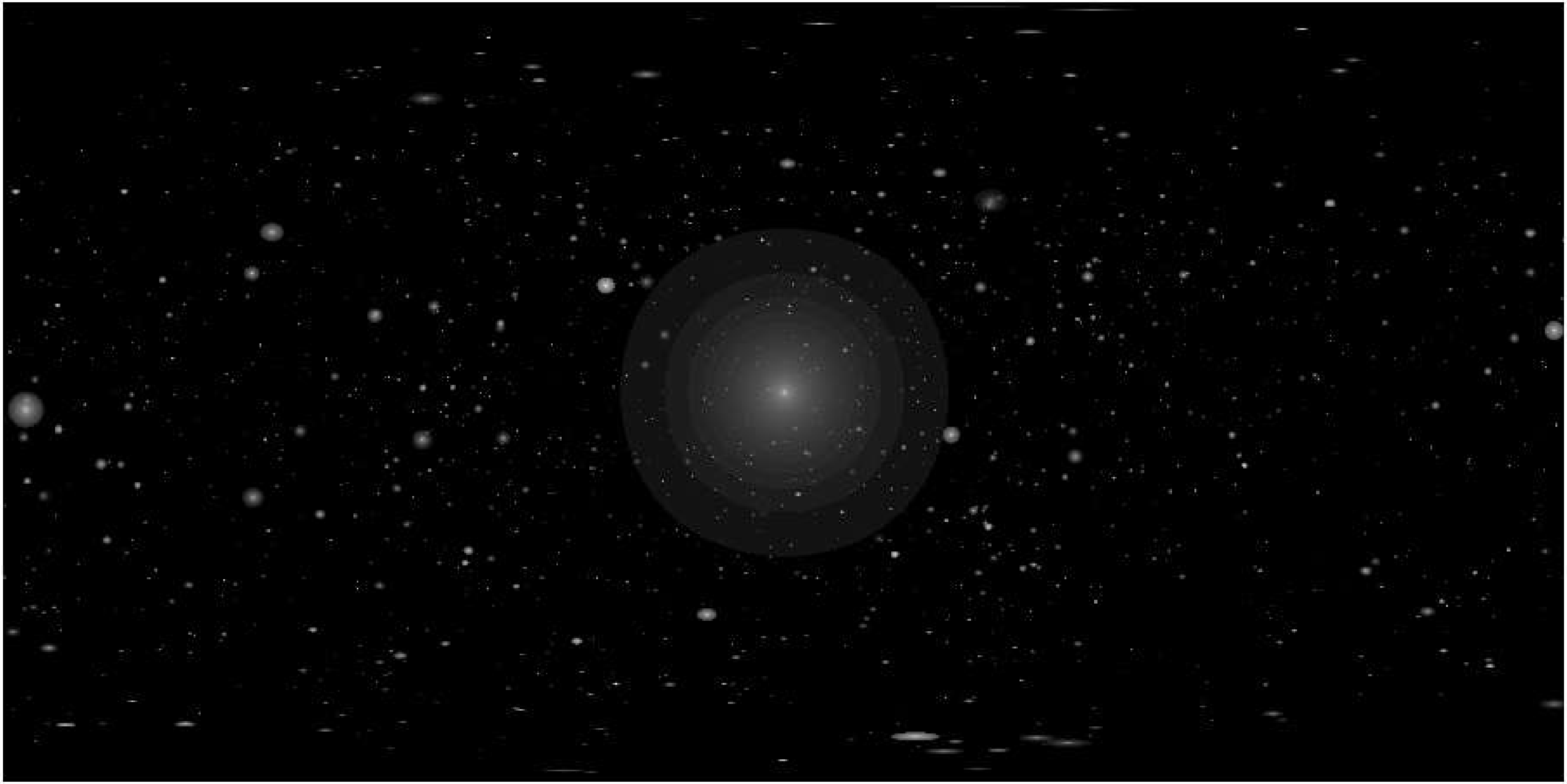
- EGRET observed a power-law point source
- HESS sees emission at energies > 10 TeV
- Black hole may confuse any dark matter signal
  - lines are always clear, but may not be bright enough
- Large astrophysical uncertainties
  - density profile?
  - adiabatic contraction?
  - “spike” around black hole?
  - disruption of cusp/spike?



Substructure in the Milky Way Halo

- CDM models predict a significant amount of substructure
  - "why don't galaxies look like clusters?"
- Satellites away from the galactic plane may be easier to see in annihilations – only extragalactic background
- Are they bright enough?
  - N-body simulations
  - semi-analytic models
- We use method of Taylor & Babul 04 (semi-analytic) to simulate Milky Way size halos (EAB, E. Bloom, J. Taylor, L. Wai, J. Chiang, in progress)
  - bulk halo (NFW)
  - satellites down to 1e6 solar masses

Mock Milky Way Halo



Visibility of Gamma Continuum

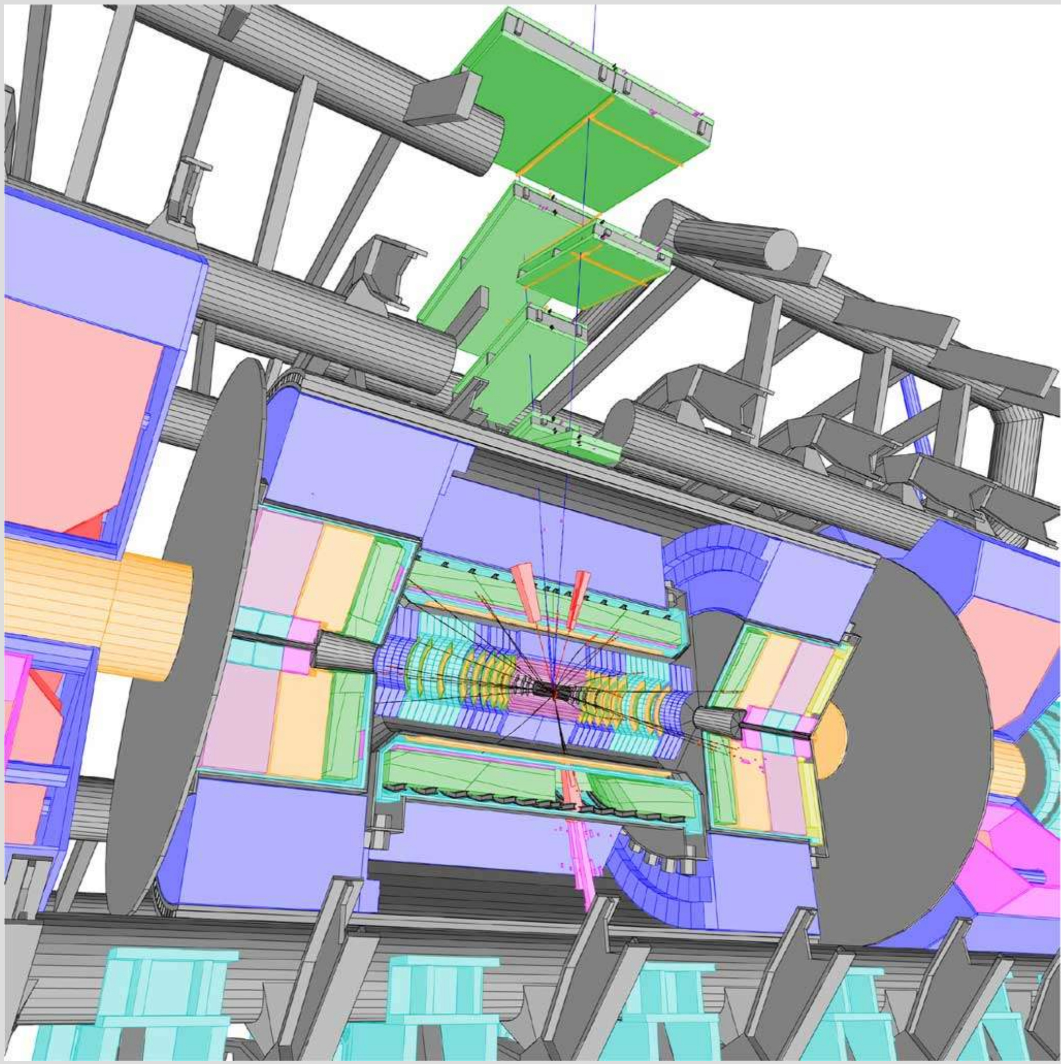
- Astrophysical input is the squared density

$$J=\int \rho^2 \, dl / [(0.3\,\mathrm{GeV\,cm^{-3}})^2 (8.5\,\mathrm{kpc})]$$

- J >~ 1000 is interesting
  - 100 GeV, 3e-26 cm^2 s^-1
  - 50 N / m^2 yr deg^-2
- Most models of the halo have J this large or larger
  - NFW easily makes this
  - isothermal with 1 kpc core
  - many satellites exceed this
- Distinguish satellites from point sources?
- Possible (probable?) scenario: GLAST survey finds candidate satellites, lines not observed
  - follow-up with ACTs
  - huge effective area, tiny FOV
  - energy resolution worse
- To do:
  - simulate detections of diffuse sources
  - simulate sub-GeV spectrum
  - can we pull this all together?

Studying Dark Matter at the LHC

- **LHC dark matter search is very promising**
  - **properties measured well**
  - **ILC is a huge improvement**
  - **BUT, lifetime limit is ~ μs**
- **Can a candidate found at LHC be identified with a candidate found with GLAST, CDMS, etc? (and vice-versa?)**
- **Build a consistent picture**
  - **accelerator measurements, relic density, direct and indirect detection**



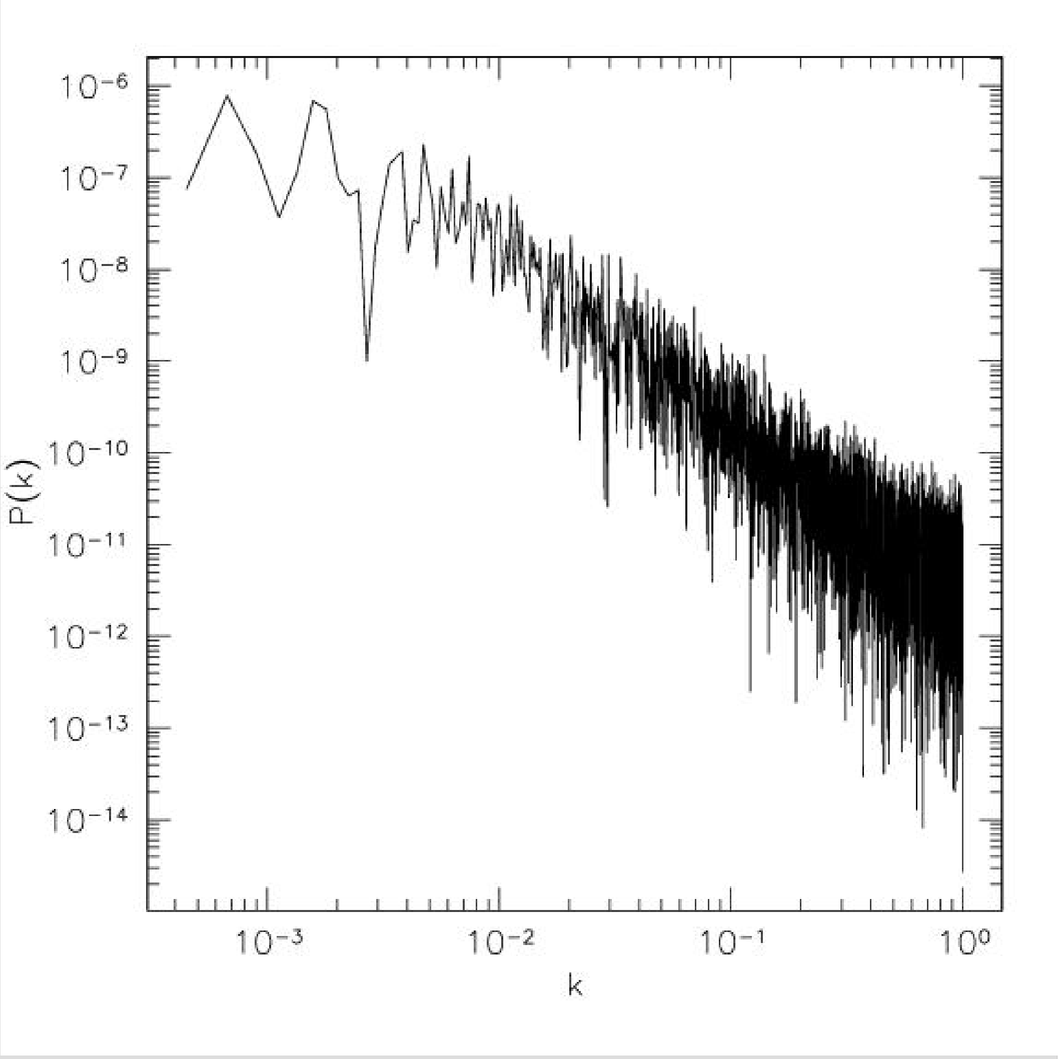
Dark Matter Observables at the LHC

- Strategy (work done with M. Battaglia, M. Peskin):
  - Benchmark SUSY models
    - ILC cosmology points
  - What does LHC measure at each point, with what error?
  - Explore likelihood surface for nearby models
    - calculate relevant quantities like relic density, direct detection rate, annihilation cross section
  - Find measurement accuracy for these astrophysically interesting quantities

- SUSY scans: benchmark points are mSUGRA
- Scan is more free: MSSM with 24 parameters at the electroweak scale
  - gaugino masses (3)
  - mu, m_A, tan beta (3)
  - A parameters (3^{rd} gen) (3)
  - squark masses (3L, 6R)
  - slepton masses (3L, 3R)
- Use MCMC to explore likelihood surface
  - adaptive covariance matrix

Markov Chain Monte Carlo

- Efficient technique to sample large-dimensional parameter spaces
  - linear in D
- Use covariance matrix of current samples to propose new samples
  - this is just the local shape of the likelihood surfaces
- Chains of models have statistics according to true distribution
  - check convergence with power spectrum of chains



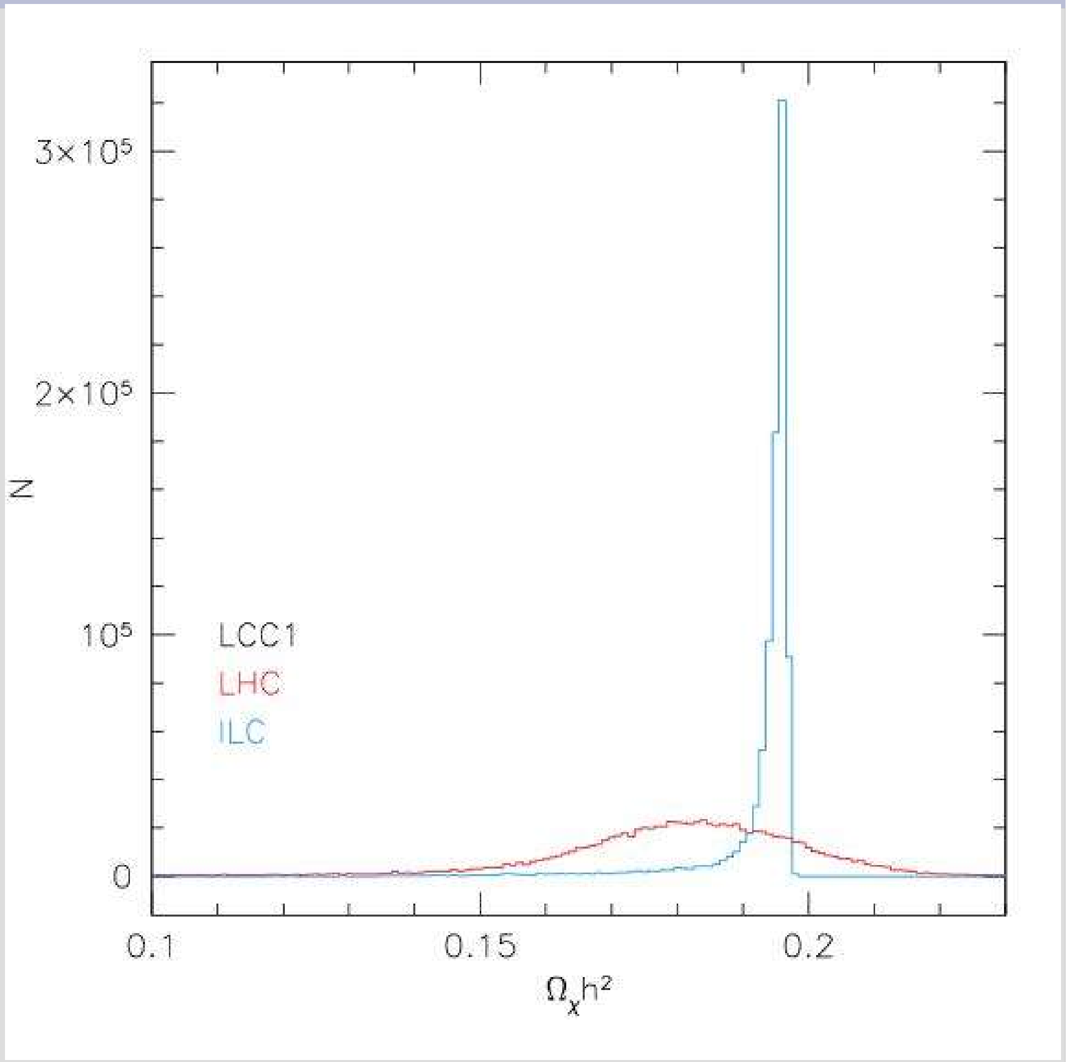
ILC Cosmology Benchmark Points

- LCC1: bulk region
- LCC2: focus point
- LCC3: stau coannihilations
- LCC4: Higgs resonance
- Low mass spectra
  - squarks heavy for LCC2
- Results for LCC1 and LCC2
  - relic density
  - direct detection rate
  - annihilation cross section

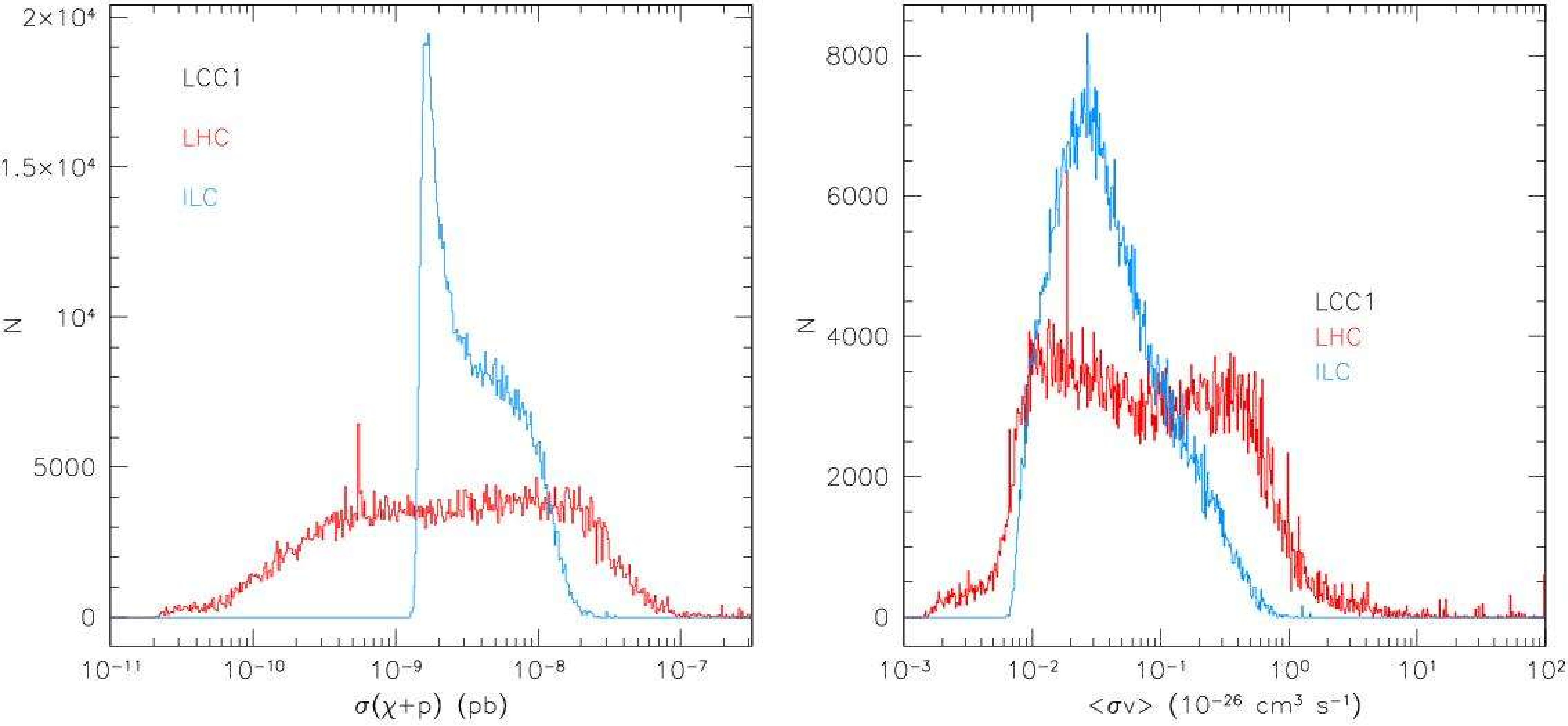
- What are the measurements?
  - neutralino masses, splittings
  - chargino masses (ILC only)
  - squark/gluino masses (< 2 TeV)
    - ILC improves measurement through better neutralino masses
    - stops only at ILC
  - slepton masses if < 300 GeV
  - production cross sections (ILC only, polarized beams)
    - neutralino, chargino, selectron pairs
    - 3rd generation sfermions (L-R mixing)
  - Higgs masses (light, A)
  - BR($b \to s\gamma$)

LCC1: Bulk Region

- Neutralino is B-ino, 95 GeV
- W-inos at 180 GeV
- Higgsinos at 375 GeV
- Squarks at 550 GeV
- Sleptons at 140, 200 GeV
- Gluino at 600 GeV
- Light Higgs at 113 GeV
- Heavy Higgses at 395 GeV

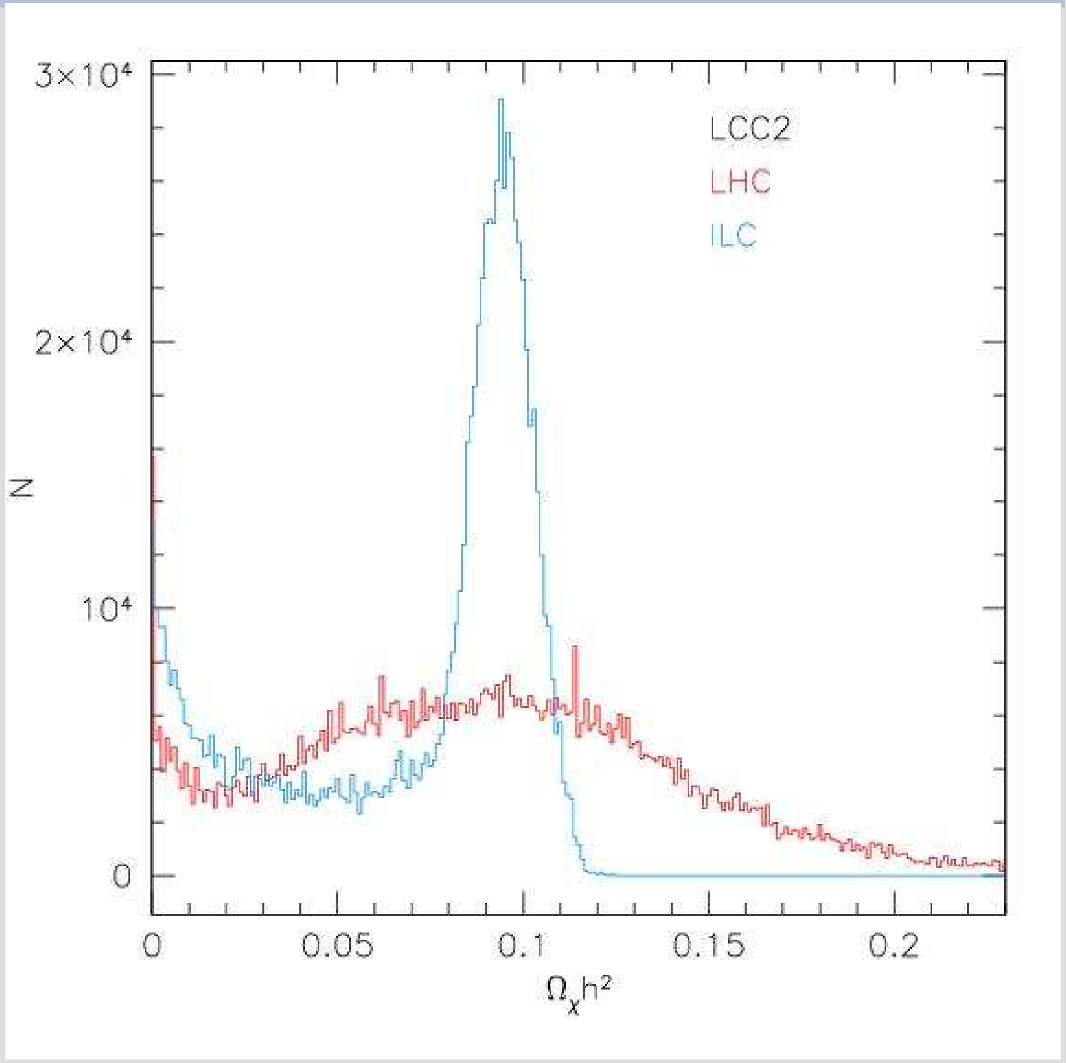


LCC1: Bulk Region

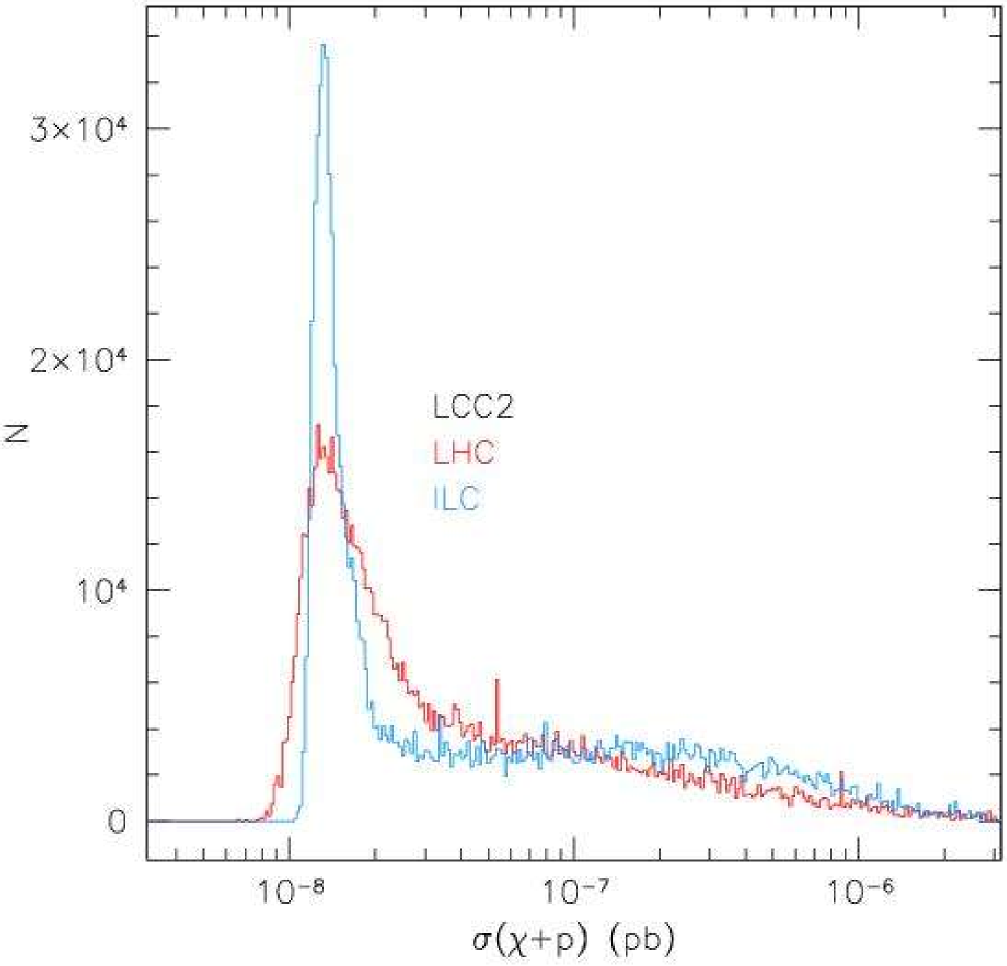


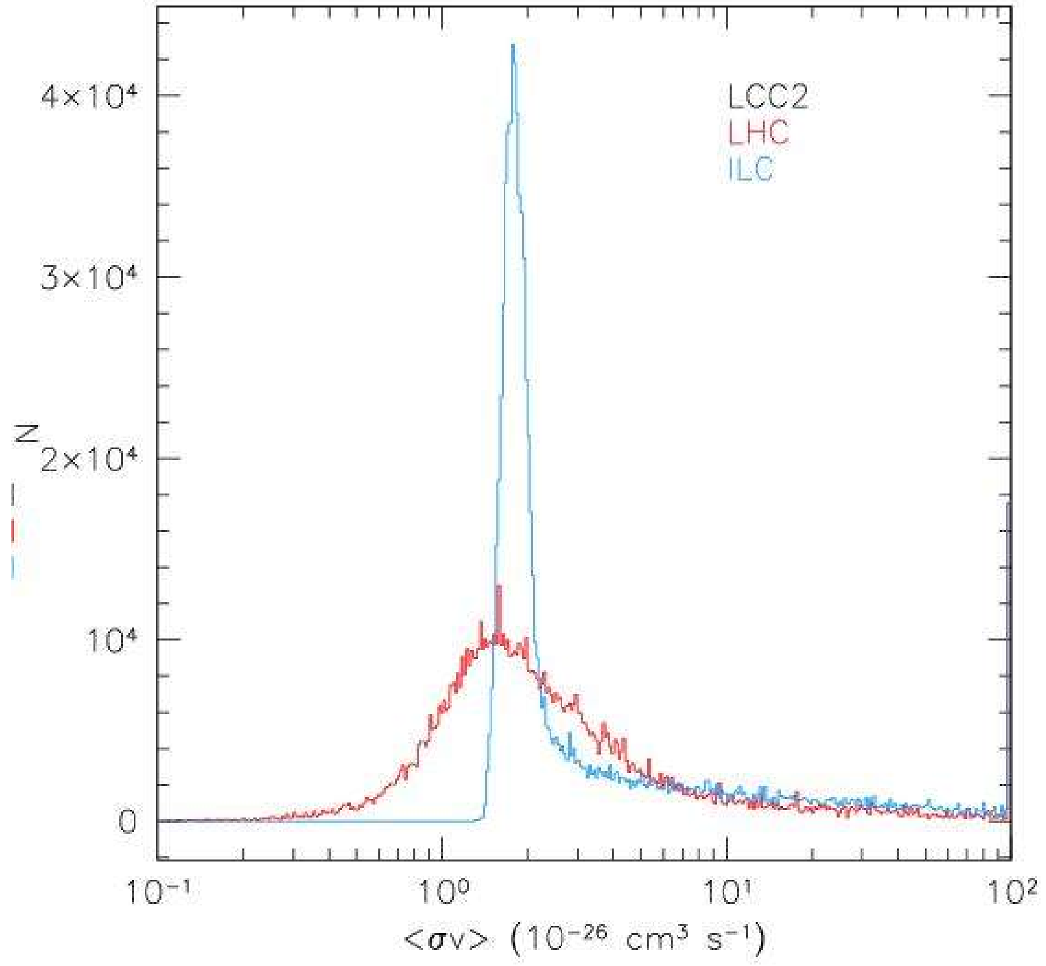
LCC2: Focus Point Region

- Neutralinos are mixed: 107, 166, 190, 295 GeV
- Squarks, sleptons at 3.3 TeV, unobserved at LHC
- Gluino at 850 GeV
- Light Higgs at 119 GeV
- Heavy Higgses at 330 GeV



LCC2: Focus Point Region





Summary

- 2007 will be a big year for dark matter
- GLAST all sky survey may find WIMP annihilations in the Milky Way substructure (resolved, flat spectrum sources)
  - follow-up with ACTs: hunt for the lines
- LHC may find a candidate dark matter particle, other states
  - measure properties relevant to dark matter
  - improve measurements by direct detection, relic density
  - ILC much more accurate
- Accelerators -> annihilation cross section -> density profile -> galaxy formation!
- Hopefully we can form a consistent picture