



SEARCHING FOR DARK MATTER WITH ICECUBE



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Rencontres de Moriond
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AMUNDSEN-SCOTT STATION

Skiway

Station

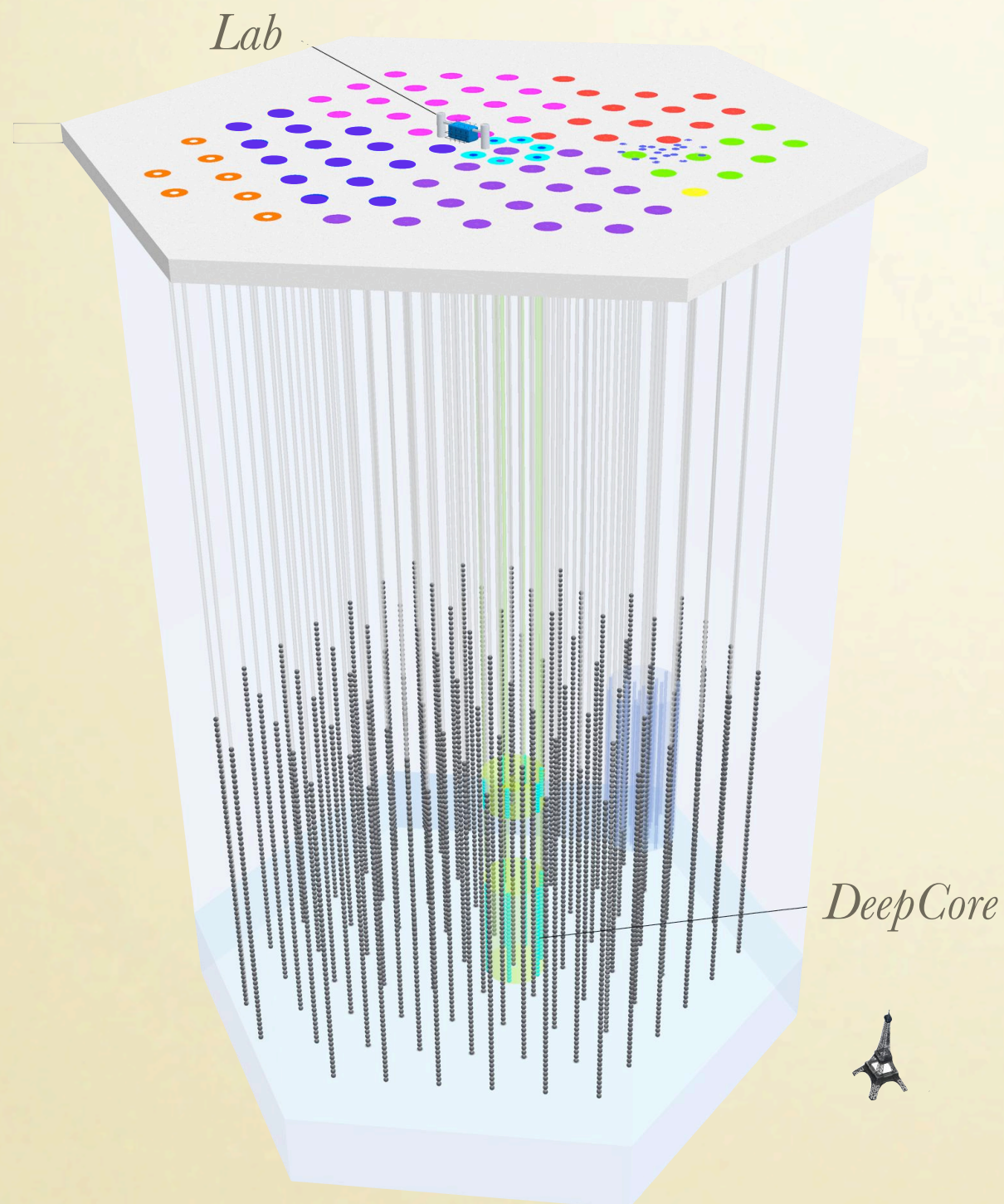
IceCube drill camp

South Pole

IceCube lab

(PHOTO: HENRY MALMGREN)

THE ICECUBE OBSERVATORY



IceCube

- Cubic km detector volume
- 1450–2450 m depth
- 125 m string spacing
- 17 m sensor spacing

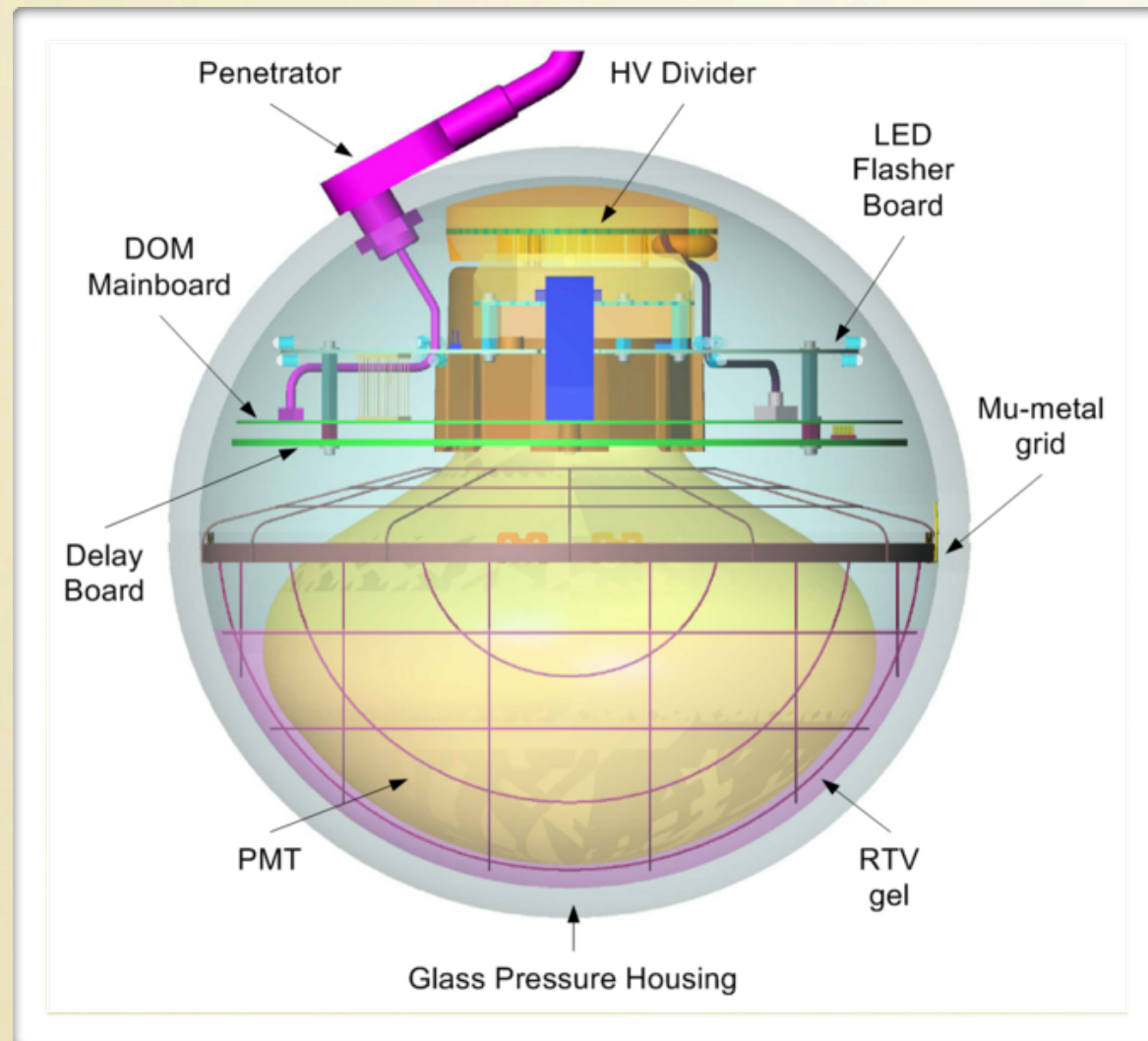
DeepCore

- 70 m string spacing
- 7 m sensor spacing

IceTop

- Surface cosmic ray detector

DIGITAL OPTICAL MODULE



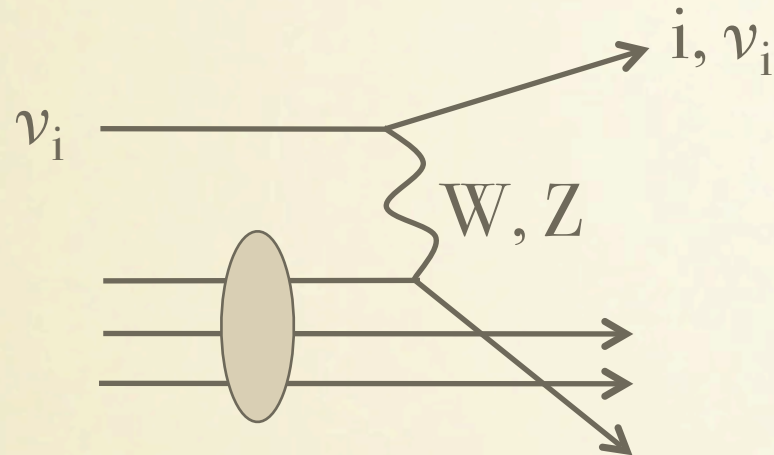
Photomultiplier

- 10" Hamamatsu
18% quantum eff. at 400 nm

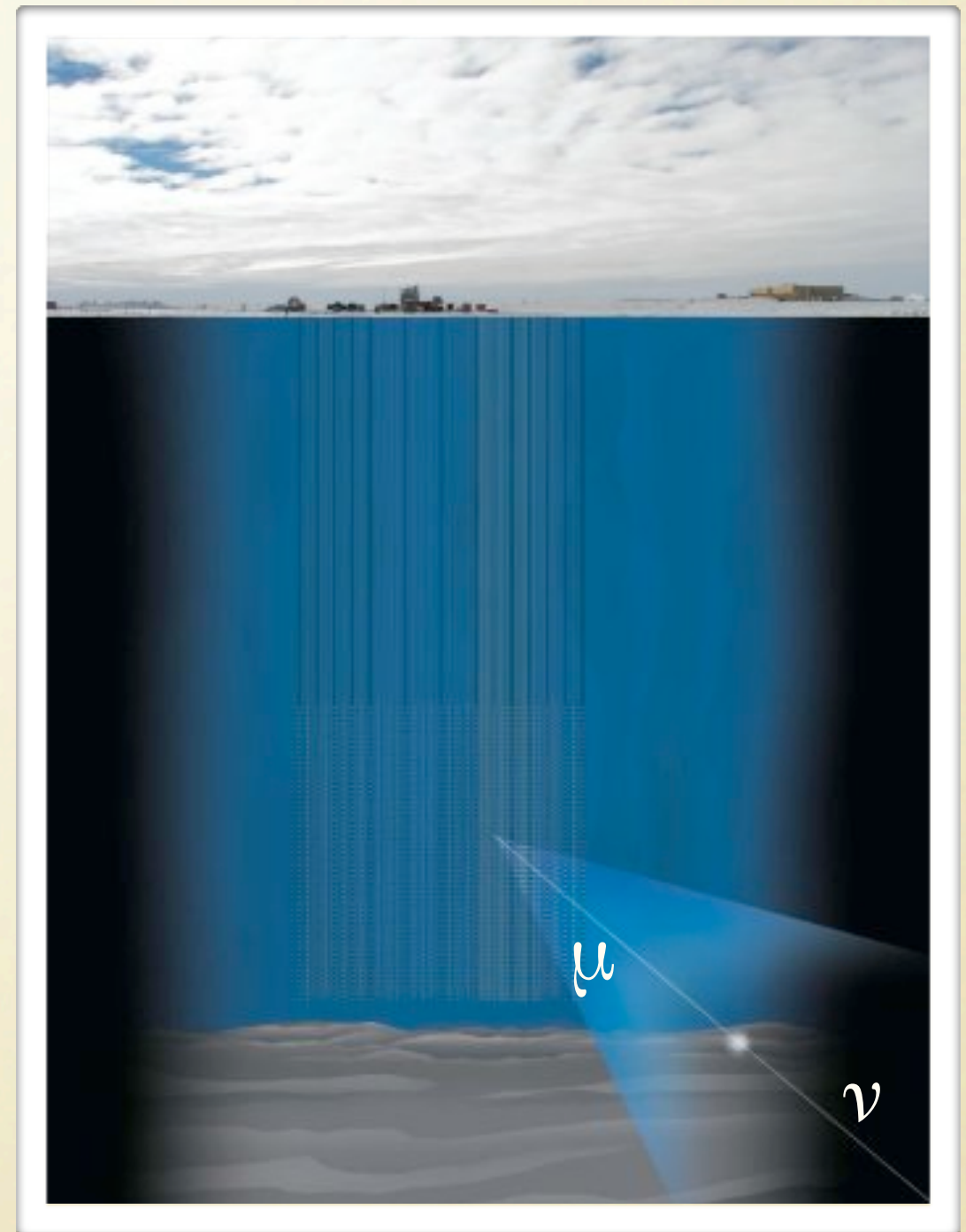
Digitizers

- ATWD
*3 gain channels
300 MHz sampling
400 ns recording time*
- ADC
*40 MHz sampling
6.4 ms recording time*

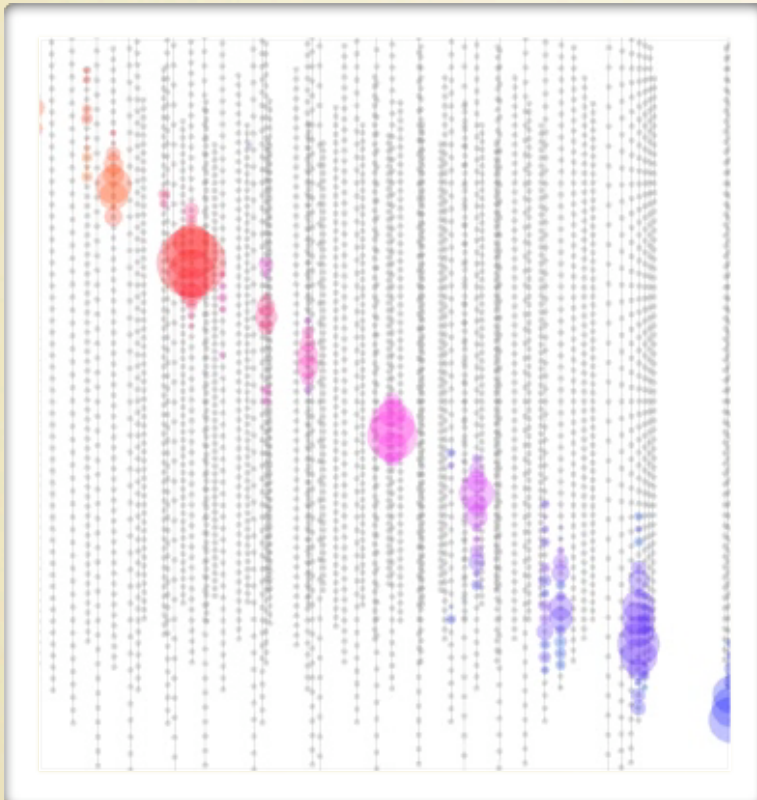
DETECTION PRINCIPLE



- Neutrinos interact in or near detector
- Tracks from charged-current ν_μ interactions: km scale
- Cascades from other interactions (neutral-current, ν_e , ν_τ): 10 m scale
- Detect Cherenkov radiation

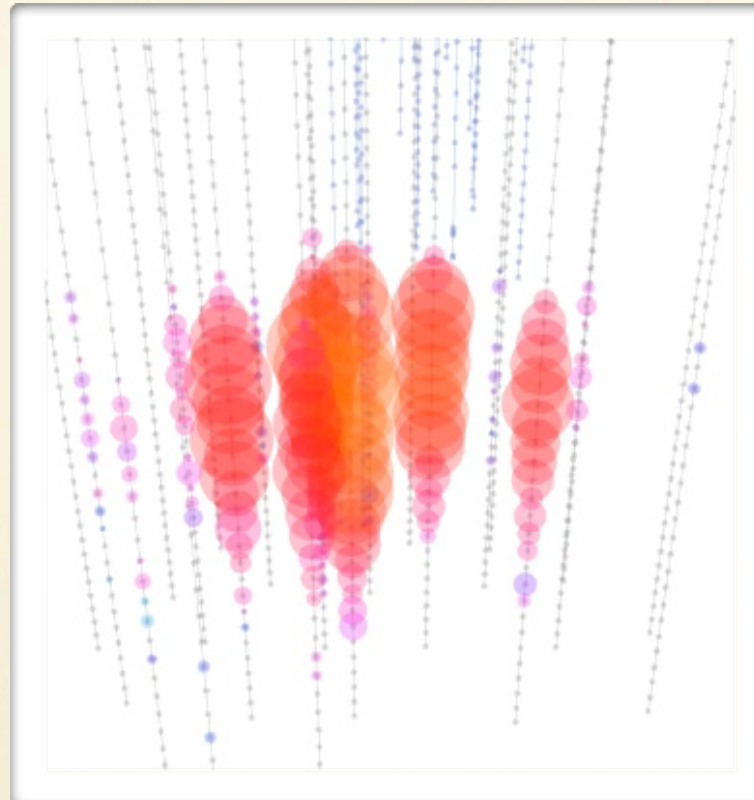


NEUTRINO SIGNATURES



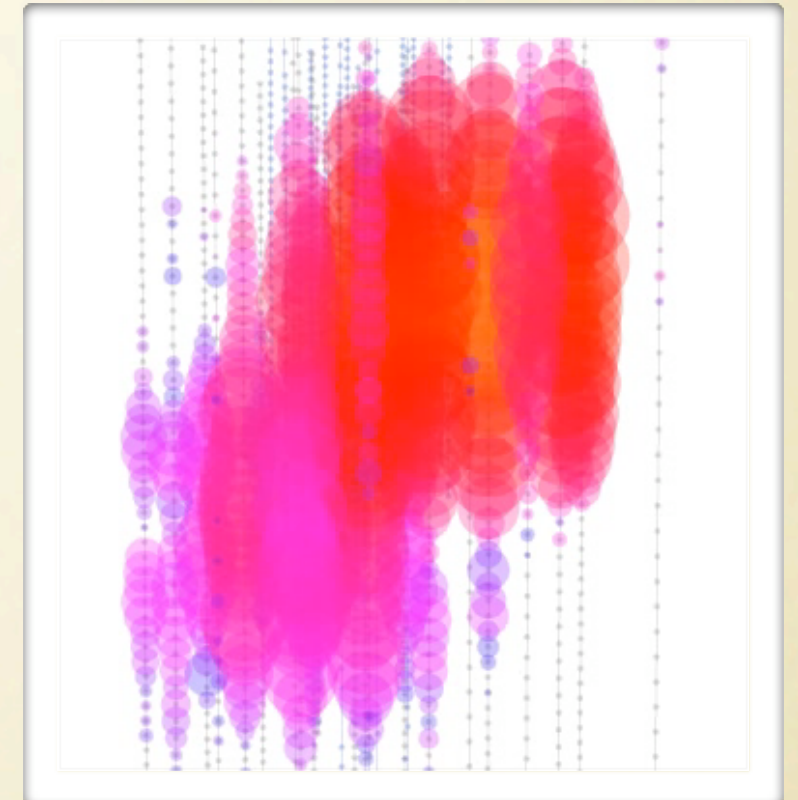
Tracks

- Through-going muons
- 1° pointing resolution



Cascades

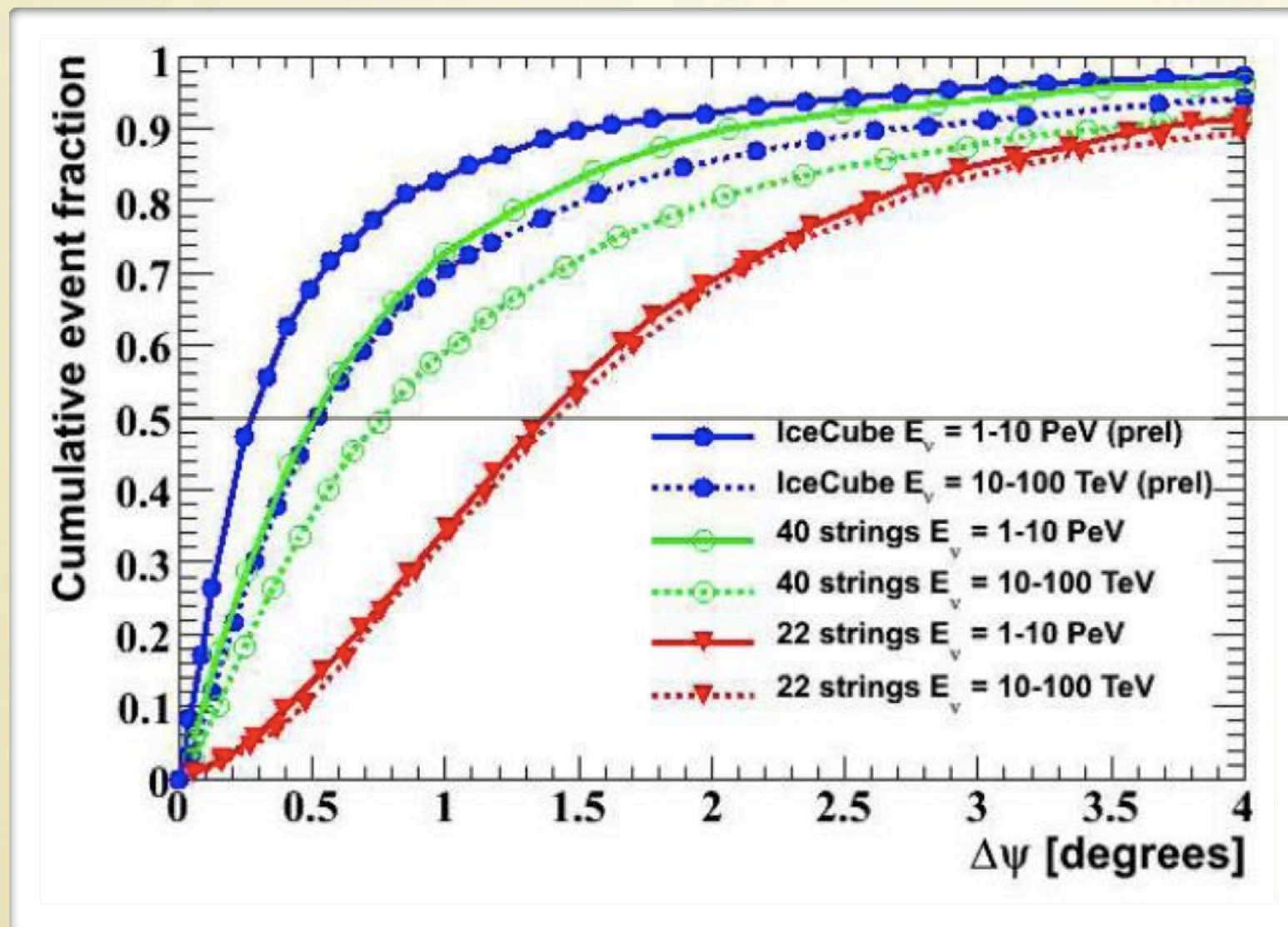
- Neutral current
- Charged current ν_e , ν_τ
- 10% resolution in $\log(\text{energy})$



Composites

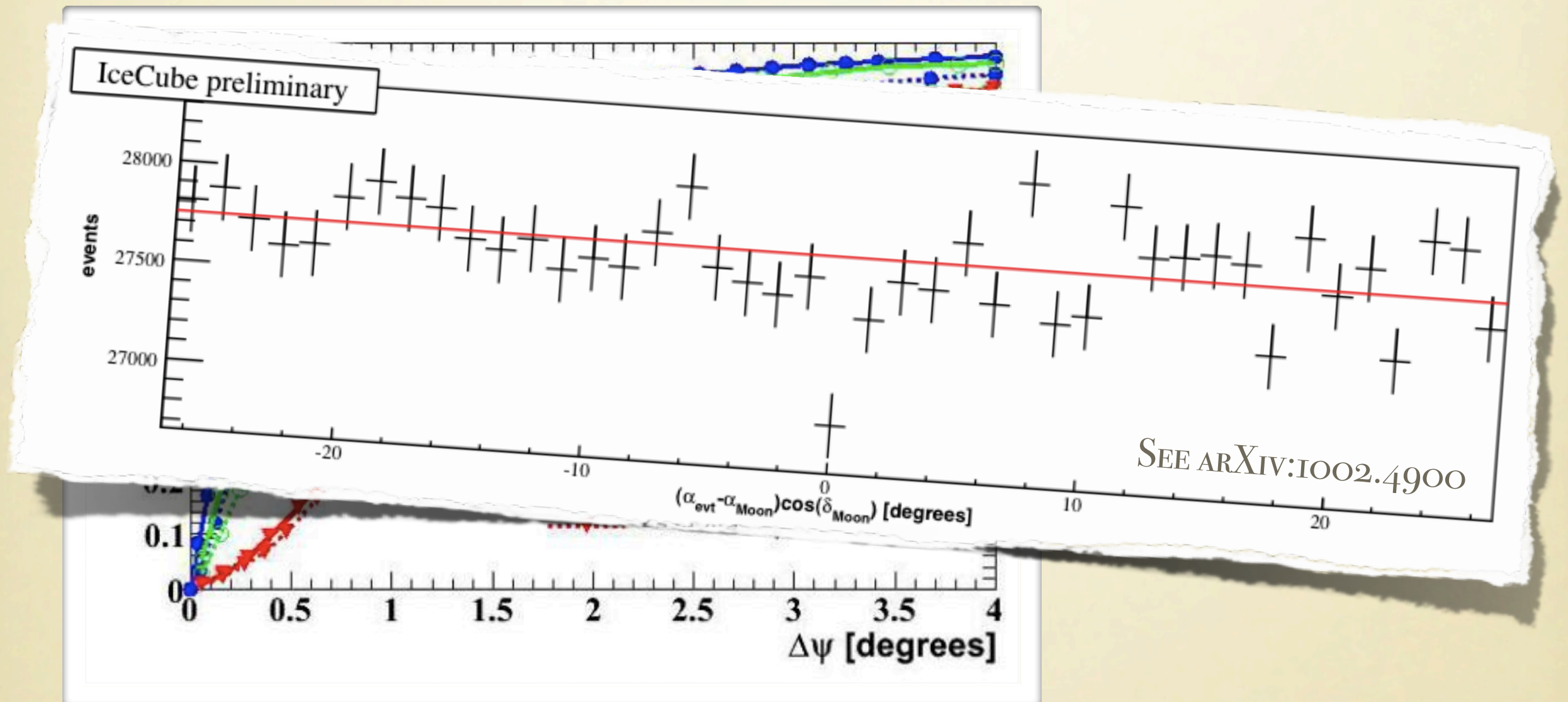
- Starting tracks, double bangs
- Good directional and energy resolution

POINTING RESOLUTION



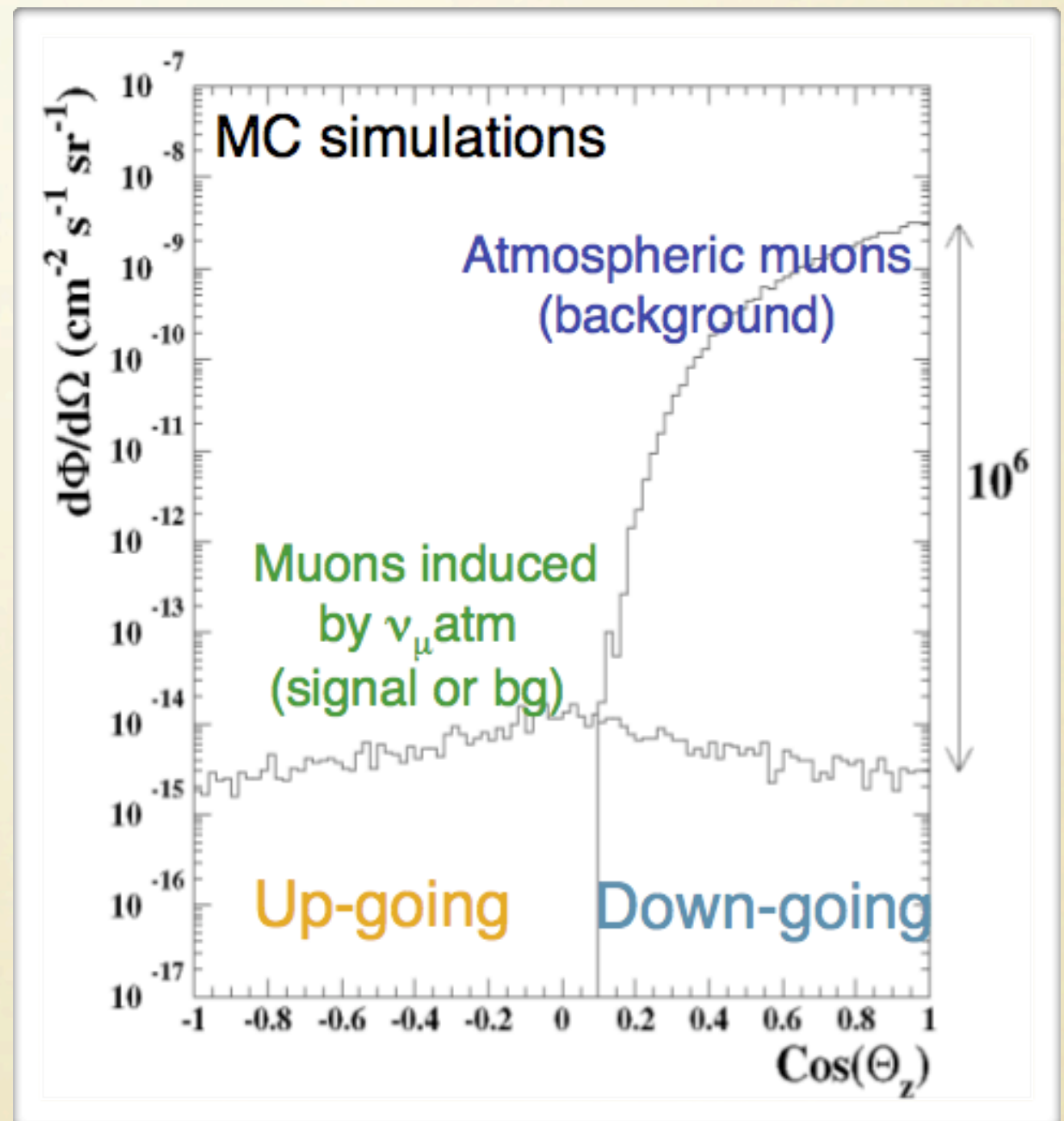
{ 22 strings: 1.5°
40 strings: $< 1.0^\circ$
80 strings: $< 0.5^\circ$

POINTING RESOLUTION



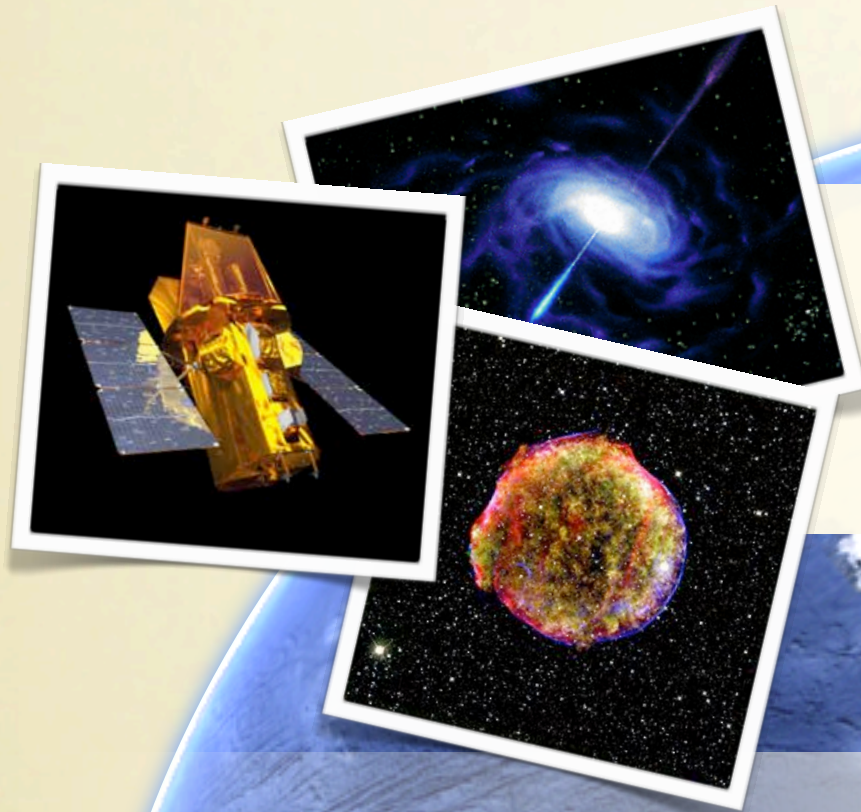
BACKGROUND & FILTERING

- Atmospheric muons from above
- Atmospheric neutrinos from all directions



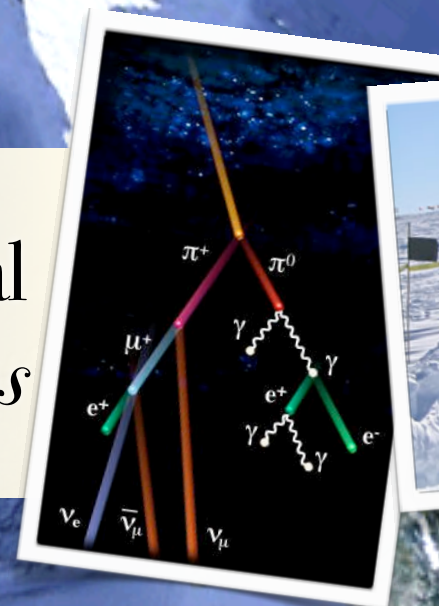
Simulated muon fluxes

SCIENCE OVERVIEW



Diffuse and point source searches
*active galactic nuclei, supernovae,
gamma ray bursts, dark matter*

Use 'background' as signal
cosmic rays & atmospheric neutrinos

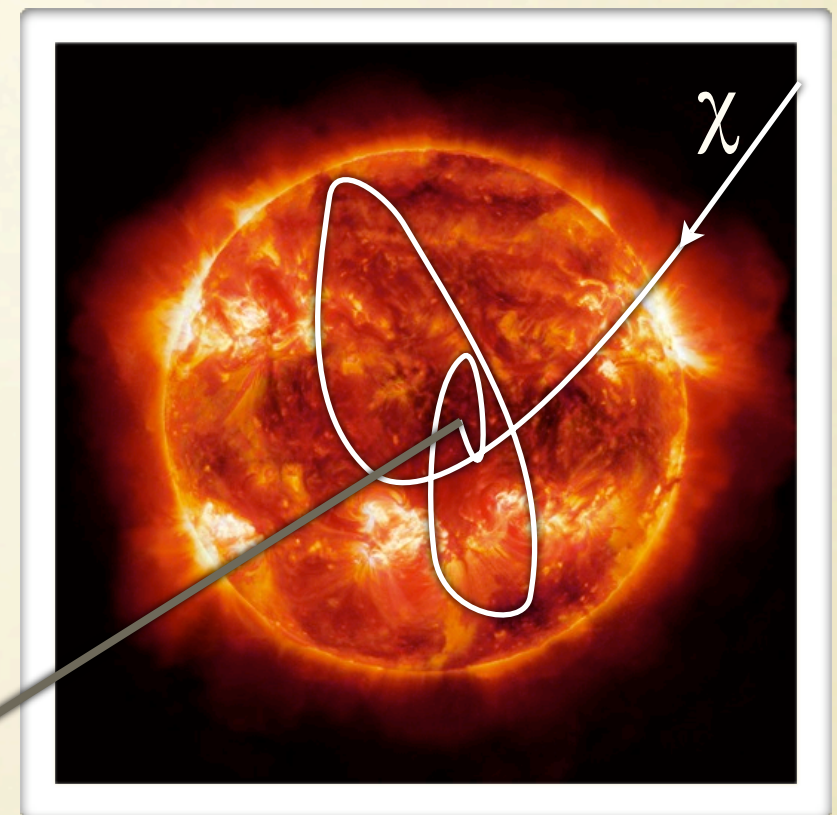


$$\nabla \cdot \mathbf{B} = \mu_0 \rho_m$$

Exotic and other phenomena
monopoles, supersymmetry & glaciology

HOW TO LOOK FOR DARK MATTER

- Dark matter amasses in heavy objects (Sun, Galactic Center)
- Look for neutrinos produced in self-annihilation (GeV–TeV scale)



$$\chi\chi \rightarrow \ell\bar{\ell} \rightarrow \nu_{\mu}$$

$$\chi\chi \rightarrow q\bar{q} \rightarrow \nu_{\mu}$$

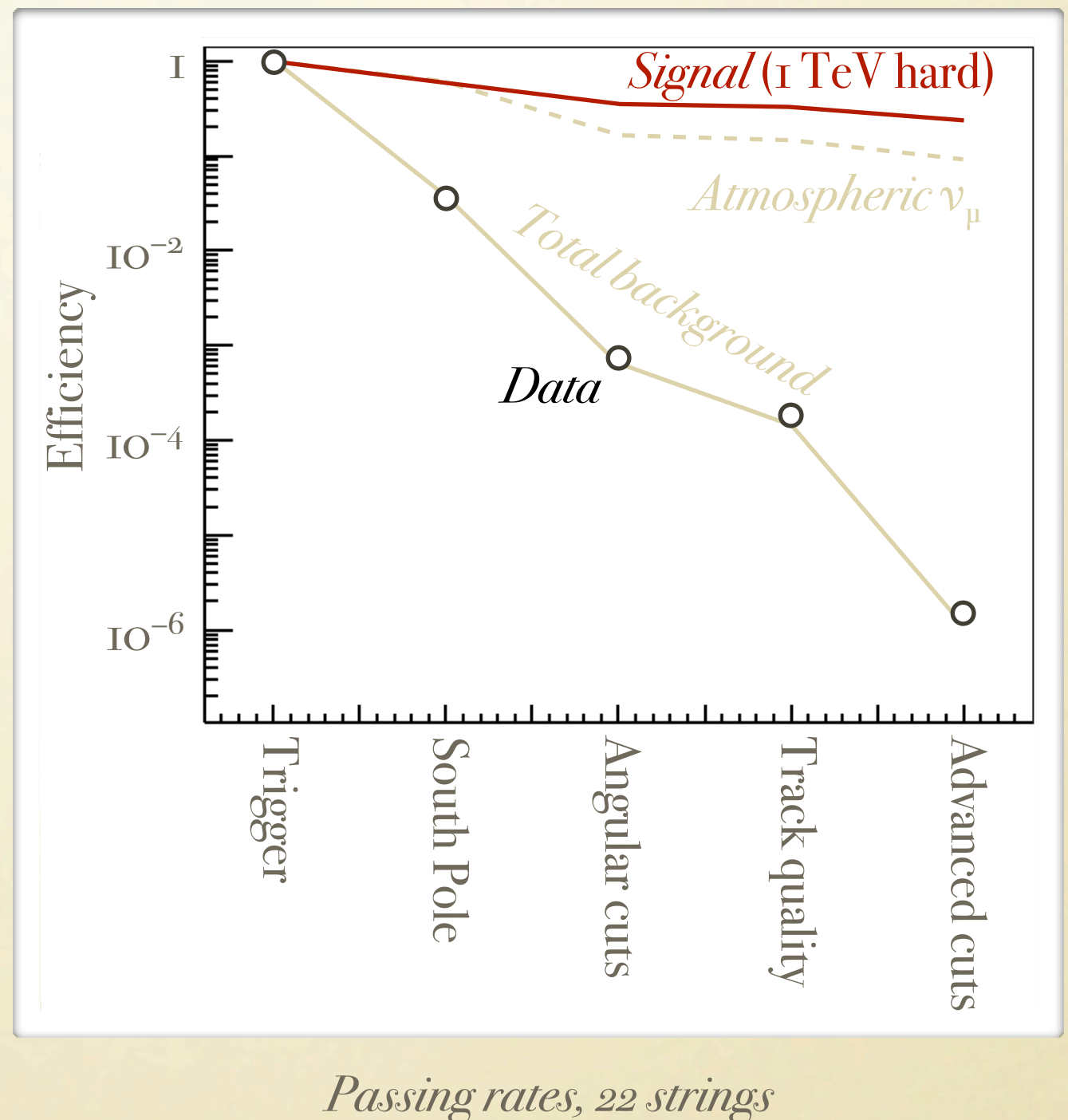
$$\chi\chi \rightarrow W^{\pm}, Z, H \rightarrow \nu_{\mu}$$

$$\chi\chi \longrightarrow \nu_{\mu}$$

WIMPS IN THE SUN

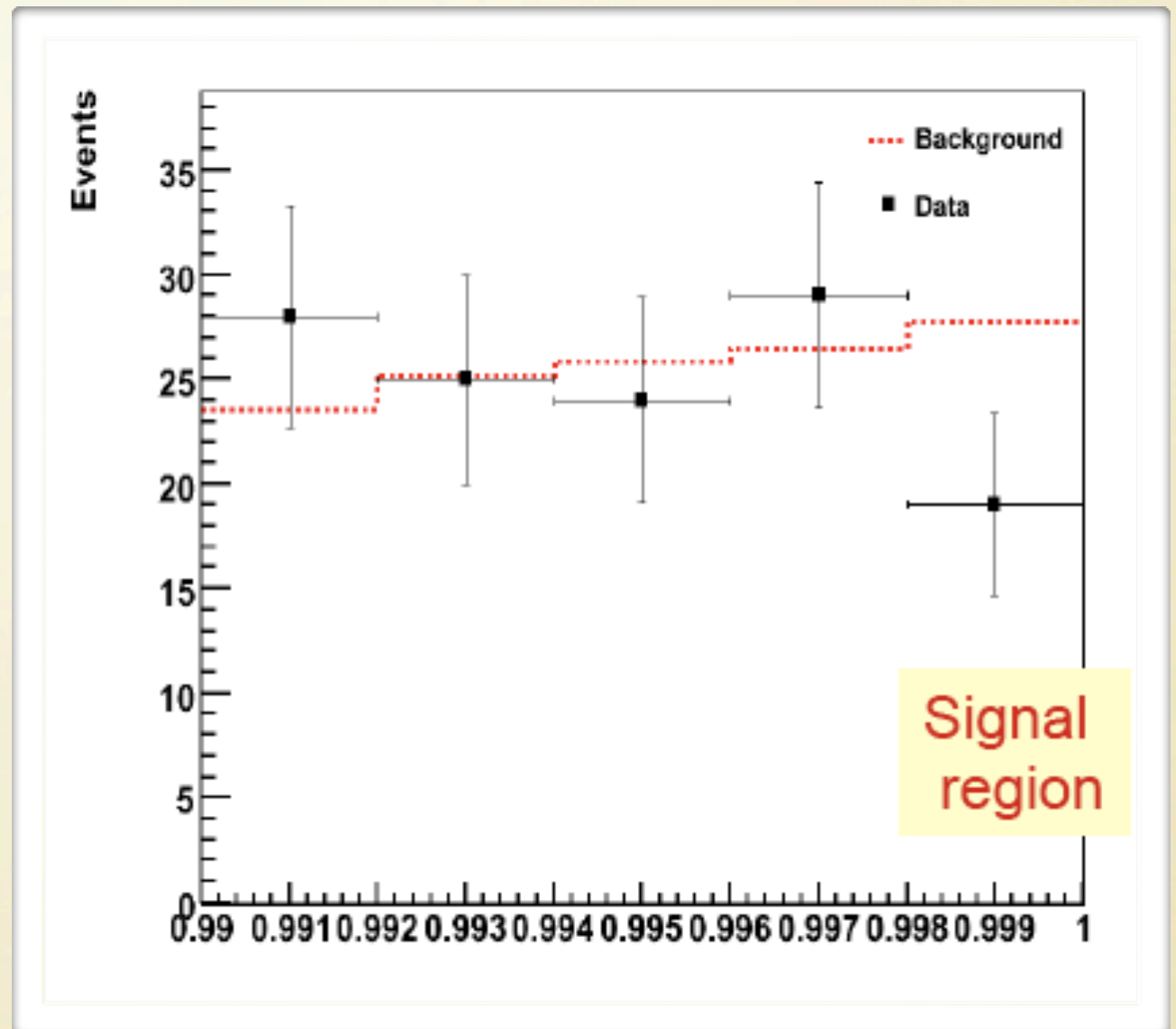
Filtering steps:

- Initial trigger
- Quality cut at South Pole
- Angular cuts
- Track reconstruction quality cut
- Advanced cuts:
log likelihood,
decision trees,
support vector machines



WIMPS IN THE SUN

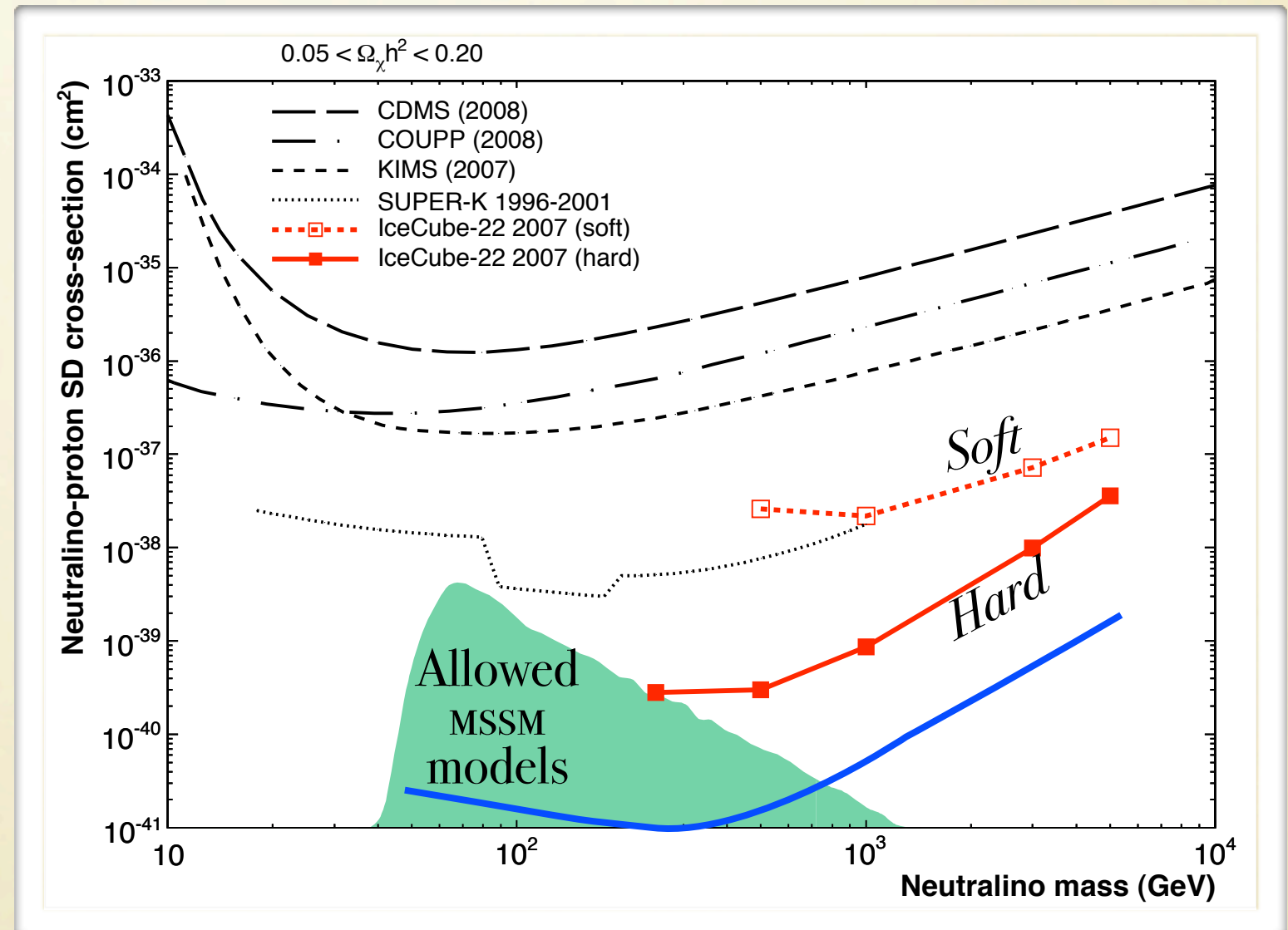
- IceCube 22: 104.3 days
AMANDA: 150.4 days
- Blind analysis
hide Sun azimuth
- Select zenith 90° – 120°
Sun below horizon
- Remove muon background
- 20% signal efficiency
- $\sim 4^\circ$ angular resolution



OBSERVED FLUX IS CONSISTENT WITH BACKGROUND EXPECTATIONS

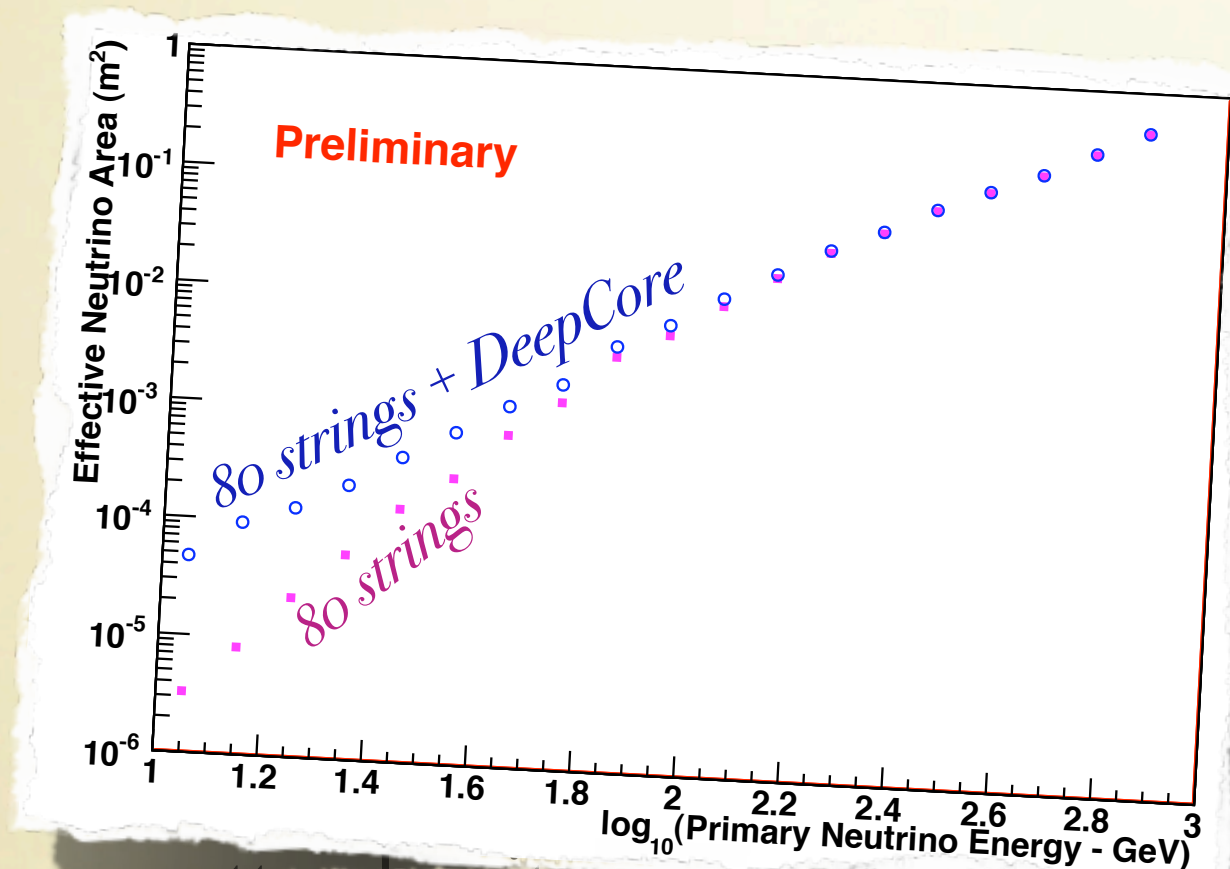
WIMPS IN THE SUN

- Muon flux limit probes spin-dependent neutralino-proton cross-section
- Dependent on models of dark matter density distribution and annihilation modes
- Hard: W^+W^-
Soft: $b\bar{b}$



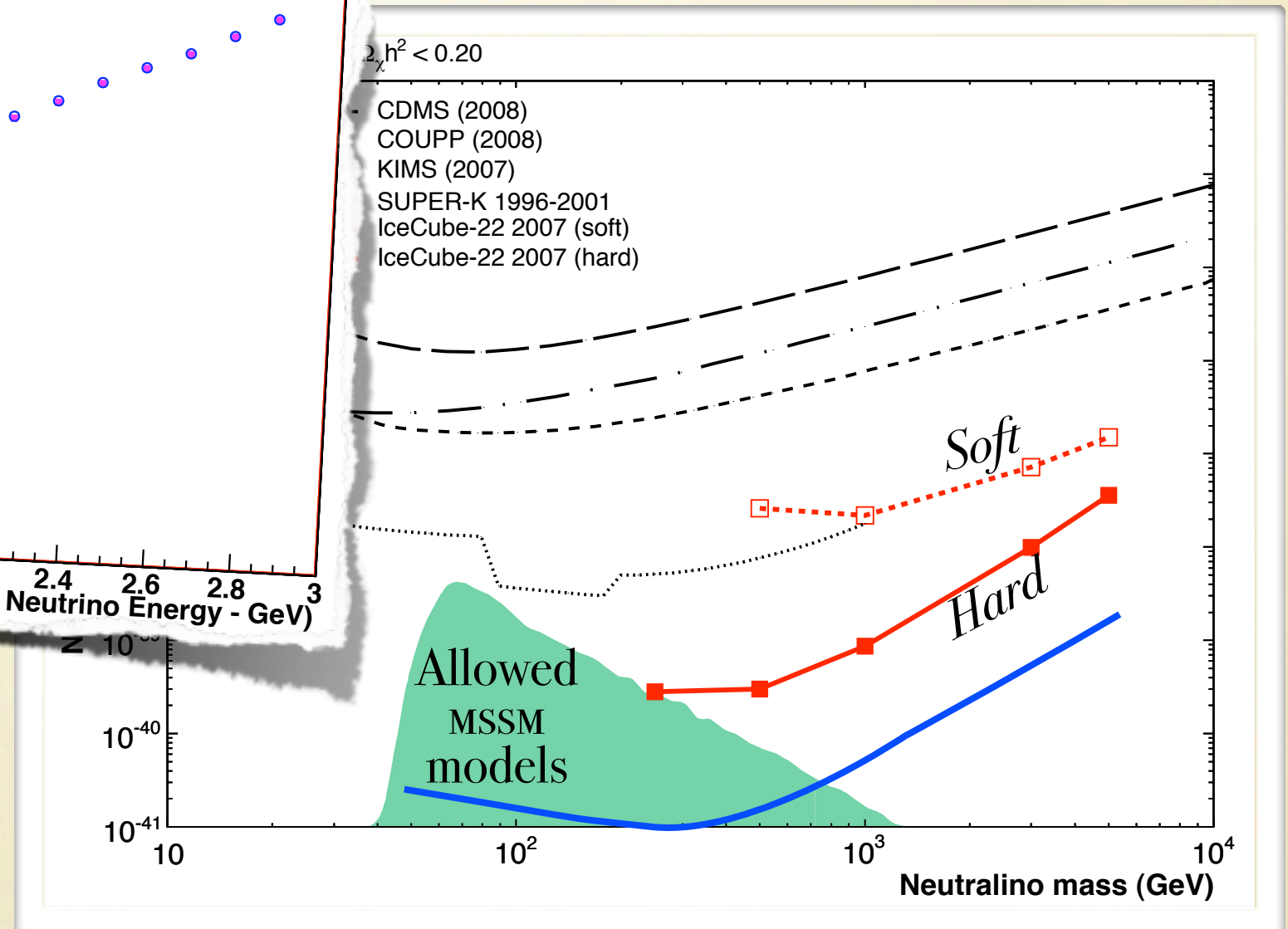
PRL IO2, 20I3O2 (2009)

WIMPS IN THE SUN



matter density
distribution and
annihilation modes

- Hard: W^+W^-
Soft: $b\bar{b}$

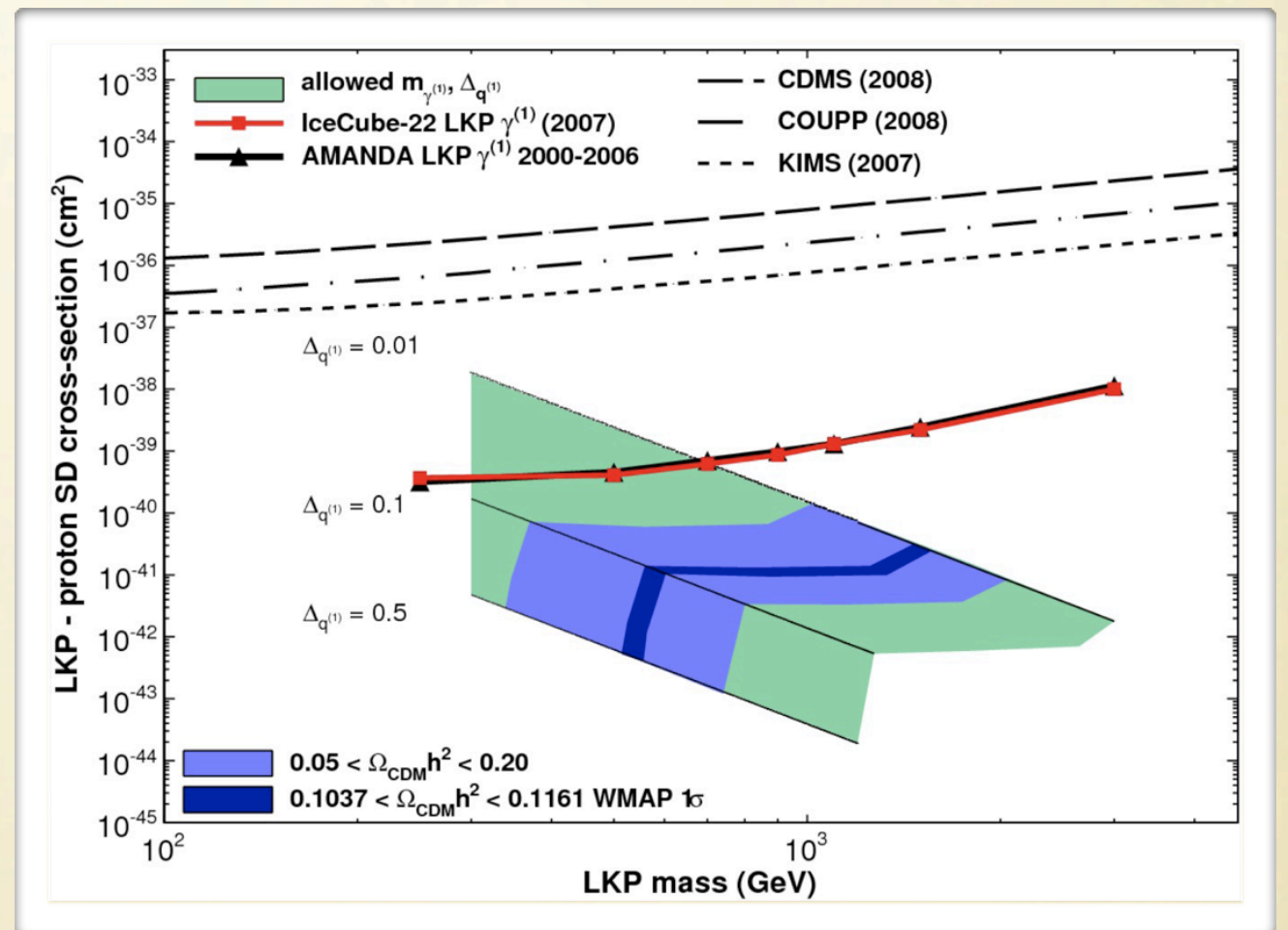


PRL IO2, 20I3O2 (2009)

WIMPS IN THE SUN

Kaluza-Klein dark matter

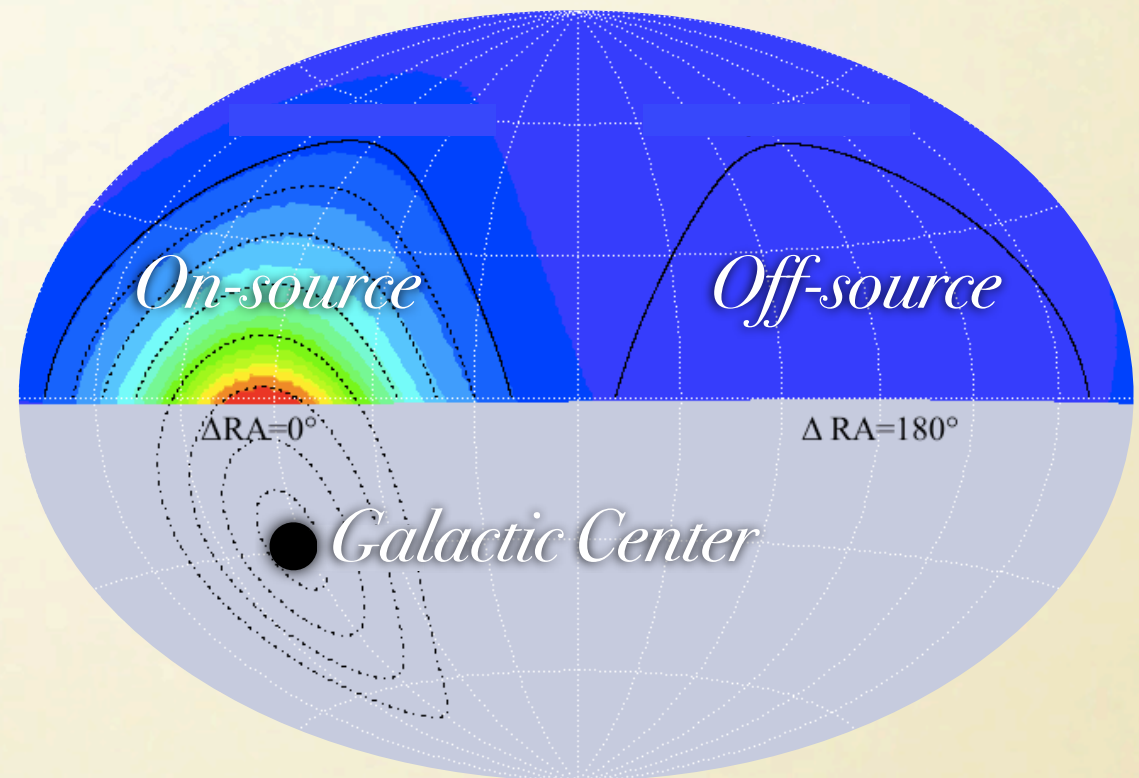
- 5 universal space-time dimensions
- Lightest KK particle (LKP) mass is 0.3–1.0 TeV
- In equilibrium in the Sun
- Annihilate to standard-model particles
- Result uses same dataset as ‘traditional’ WIMP search



SEE ARXIV:0910.4480, PRD ACCEPTED

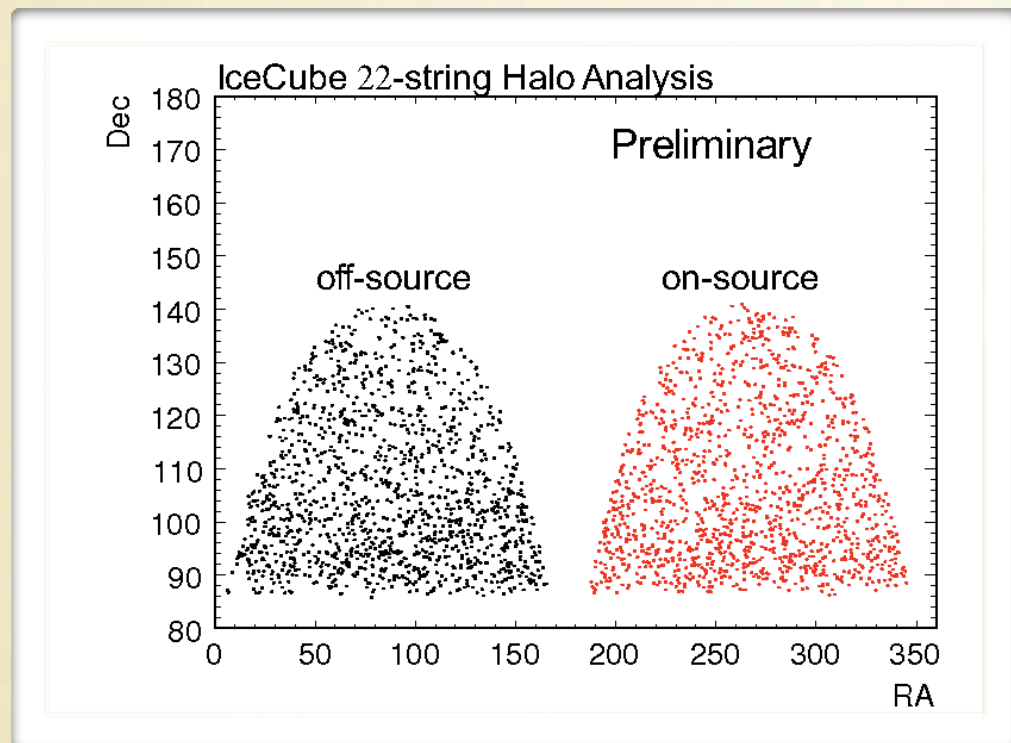
WIMPS IN THE GALAXY

- Galactic Halo extends below horizon
- Compare equal areas on-source and off-source
- Measure flux difference, pick models, and constrain self-annihilation cross-section

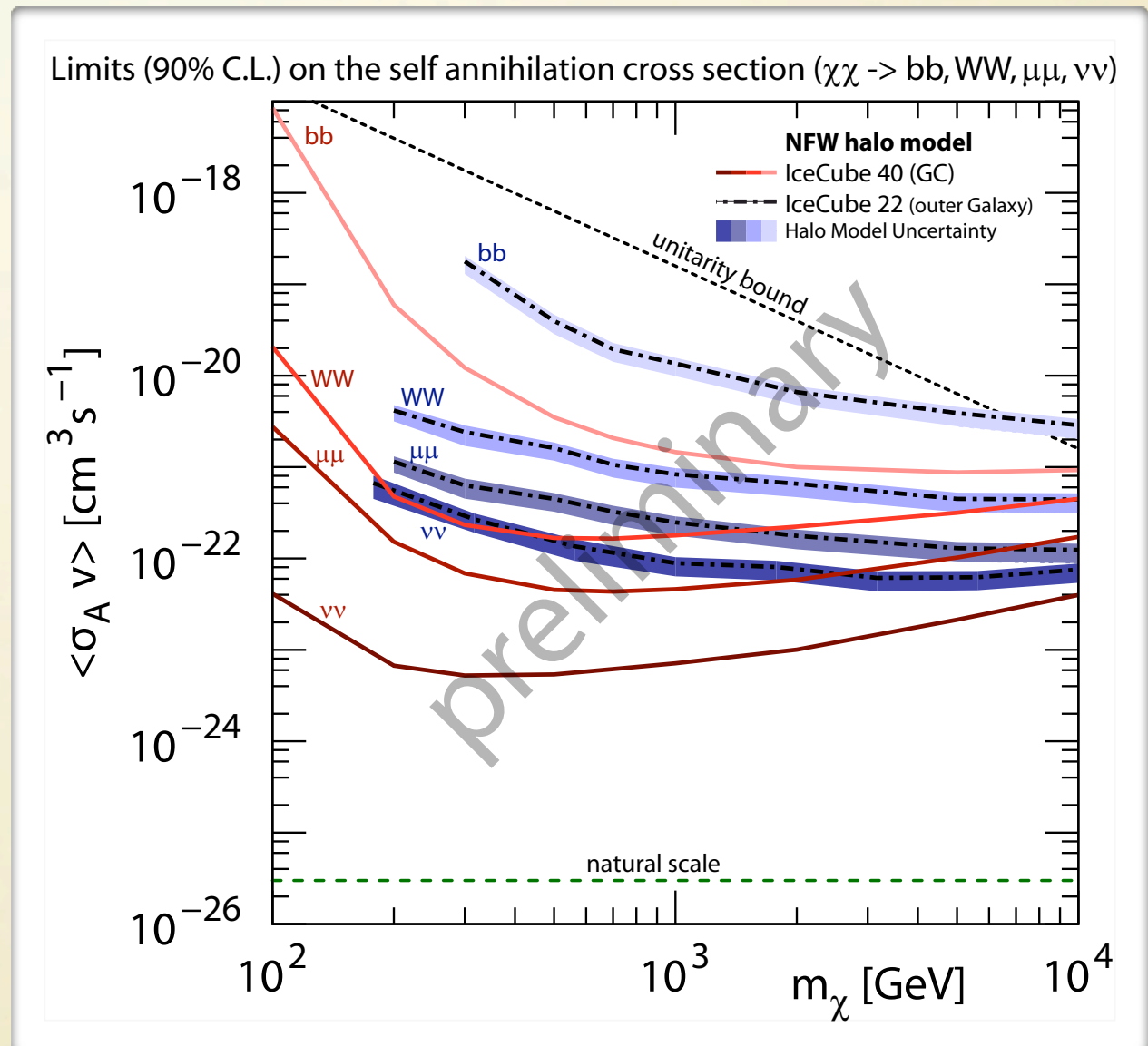


$$\frac{d\Phi}{dE} = \frac{1}{2} \langle \sigma_A v \rangle J(\psi) \frac{R_\odot \rho_\odot^2}{4\pi m_\chi^2} \frac{dN}{dE}$$

WIMPS IN THE GALAXY



- 90% confidence exclusion limit
- Width derives from various density models



SEE ARXIV:0912.5183

CONCLUSION

- Construction ends next year
- 79 strings in the ice; taking data starting April 1
- 22-string analyses limit spin-dependent cross-sections
- 40-string analyses are underway
- 59-string data available soon
- DeepCore boosts WIMP sensitivity below 100 GeV



THANK YOU



U. of Alberta



U. Alabama, Tuscaloosa
U. Alaska, Anchorage
U.C. Berkeley
Clark-Atlanta U.
U. Delaware/Bartol Inst.
Georgia Tech
U.C. Irvine
U. of Kansas
Lawrence Berkeley Nat. Lab
U. of Maryland
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Uppsala U.
U. Wuppertal



Chiba U.



U. of Canterbury, Christchurch

The IceCube Collaboration

36 INSTITUTIONS ✂ ~250 PHYSICISTS