Latest Results on Searches for Dark Matter from IceCube

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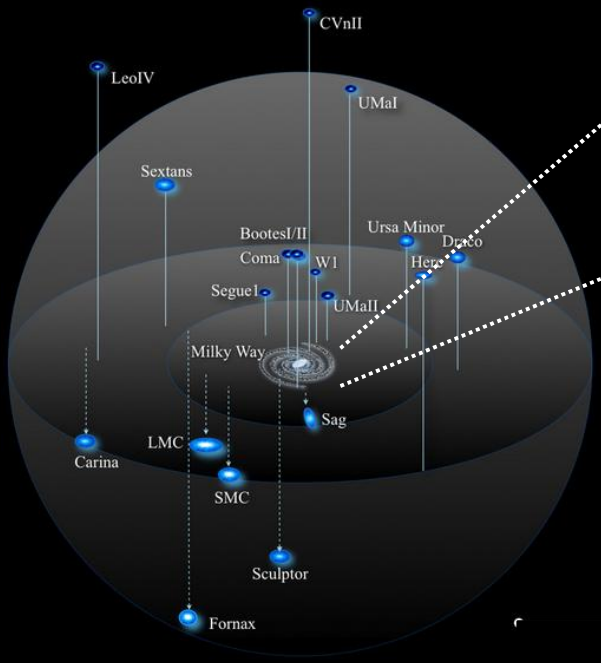
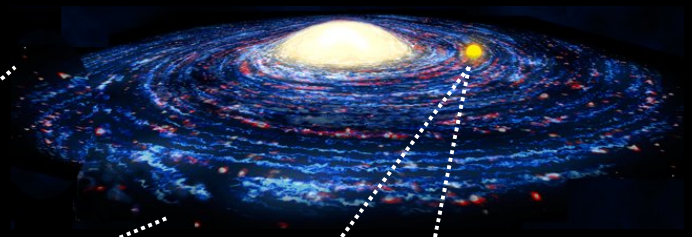
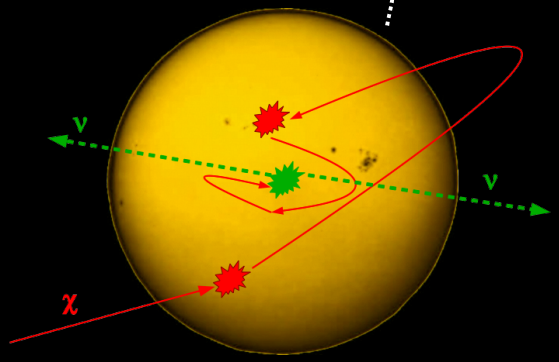
The Oskar Klein Centre for Cosmoparticle Physics, Stockholm University
The IceCube Particle Astrophysics Symposium
Madison, May 13-15, 2013

Indirect Search with IceCube (Overview)

Look for potential sources that are well defined and have low or understood astrophysical backgrounds



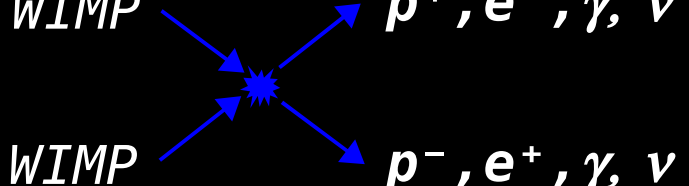




Galactic Halo:
→ IceCube-22 limits
(PRD 84 (2011) 022004)
Galactic Center
→ IceCube-40 limits
(arXiv:1210.3557 2012)
→ IceCube-79 sens.

Local sources (Sun & Earth):
→ IceCube-79 limits
(PRL 110 (2013) 131302)

Dwarf spheroidal Galaxies:
→ IceCube-59 limits
Clusters of Galaxies:
→ IceCube-59 limits



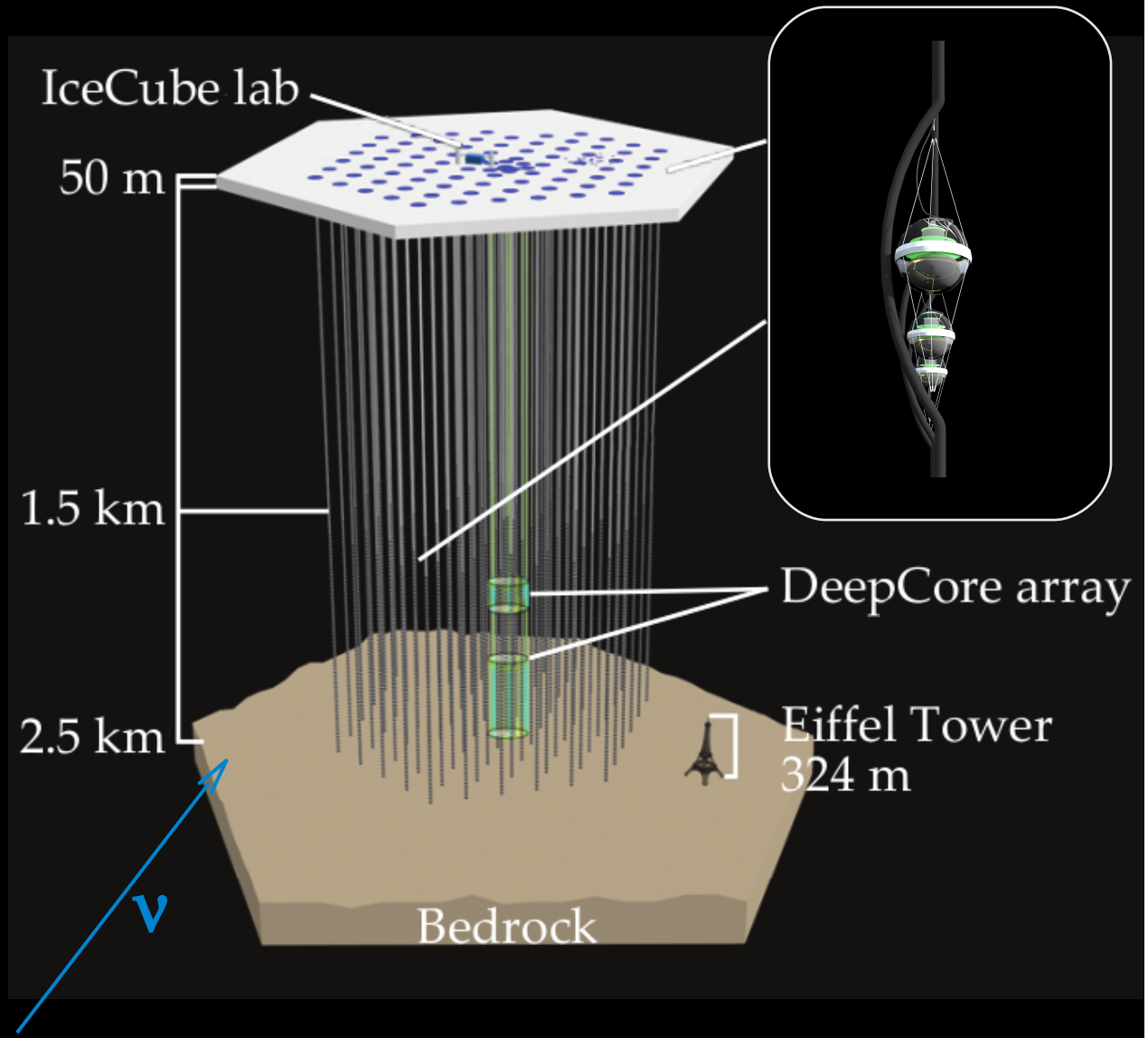
The IceCube detector

1.5 km - 2.5 km deep

typically 125 m spacing between strings (~70 m in DeepCore)

60 Modules per string

1 km -- 1 Gton instr. volume



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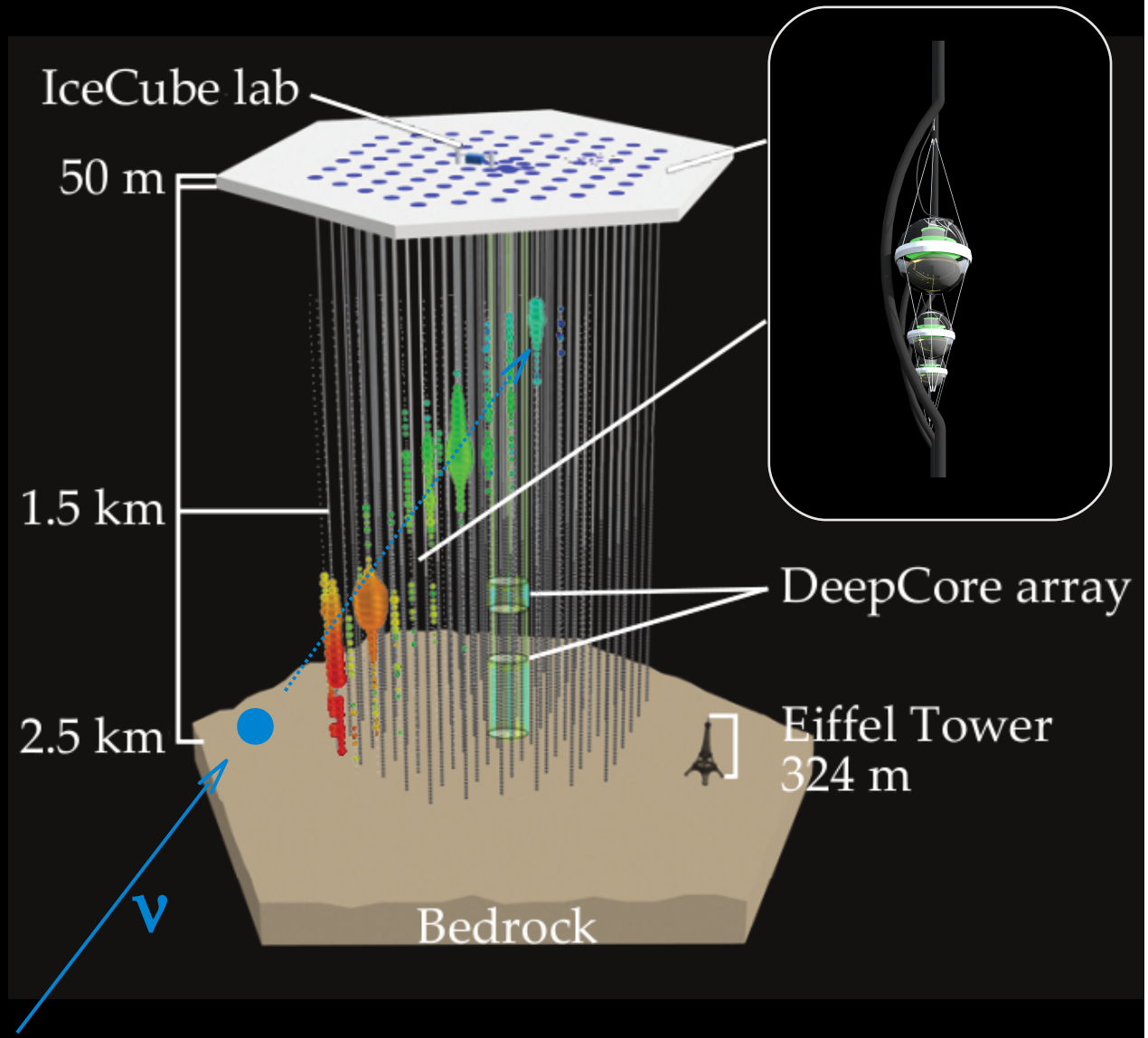
O(km) muon tracks from ν_μ CC

O(10m) cascades from ν_e CC, low energy ν_τ CC, and ν_x NC

Cherenkov radiation detected by 3D array of optical sensors (DOMs)



Solar Dark Matter Search with IceCube

- All processes depend on WIMP mass
- Annihilation channel (branching ratios)
- Annihilation cross-section
- Capture (scattering)
  → Scattering cross-sections (SI & SD)

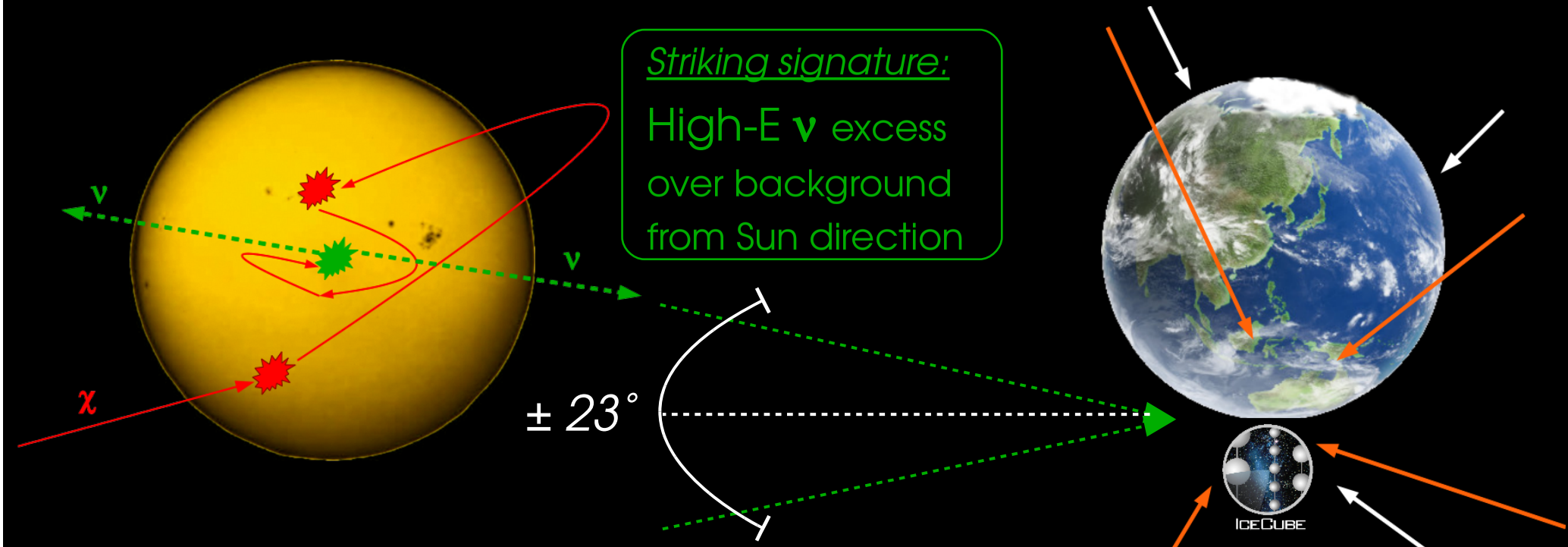
main analysis backgrounds:

atm. $\nu \sim O$ (10^3 triggering events/day)

atm. $\mu \sim O$ (10^8 triggering events/day)

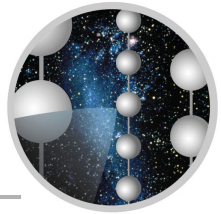
Striking signature:

High-E ν excess over background from Sun direction



**Blind analysis with respect to true Sun azimuth*

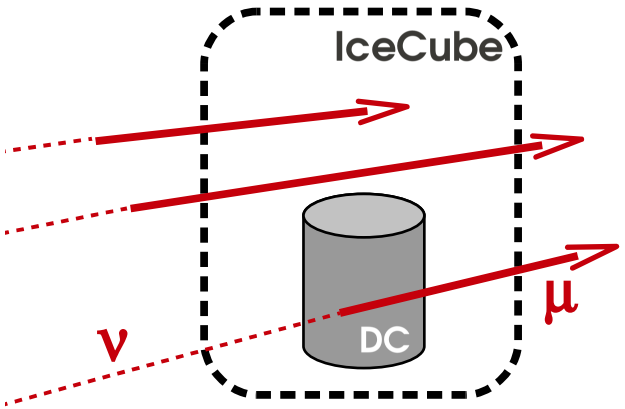
IceCube-79 string analysis details



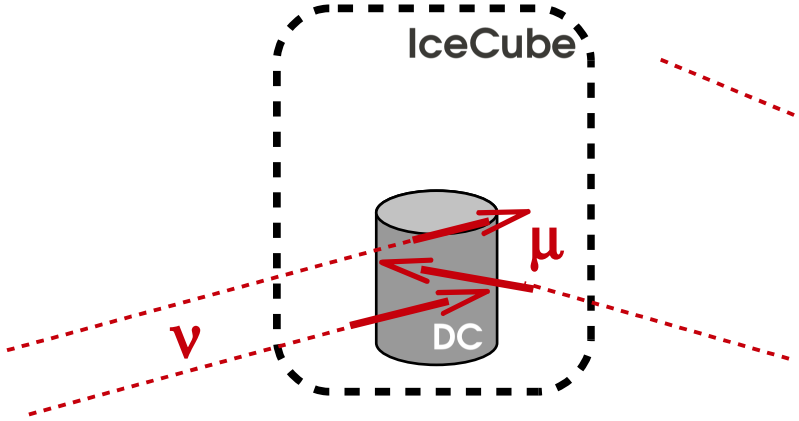
(PRL 110 (2013) 131302)

- Analysis for the whole year! Used 317 days livetime (151 days austral winter & 166 days austral summer)
- more than *60 billion* recorded events
- At final level *~25000* signal-like events in 3 independent samples
- With DeepCore, analysis reaches neutrino energies of *10-20GeV*

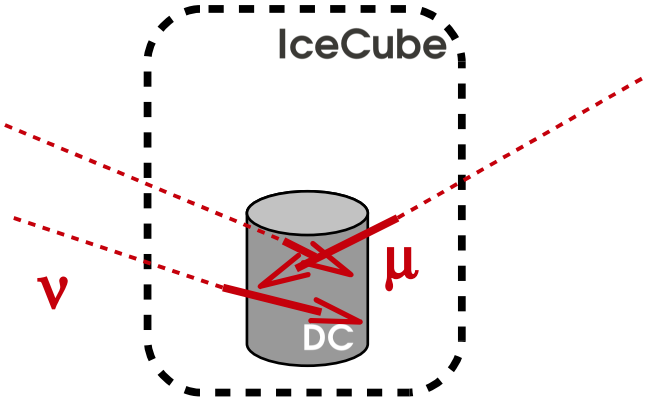
- ***Up-going*** ①
- No containment



- ***Up-going*** ②
- strong containment



- ***Down-going*** ③
- strong containment



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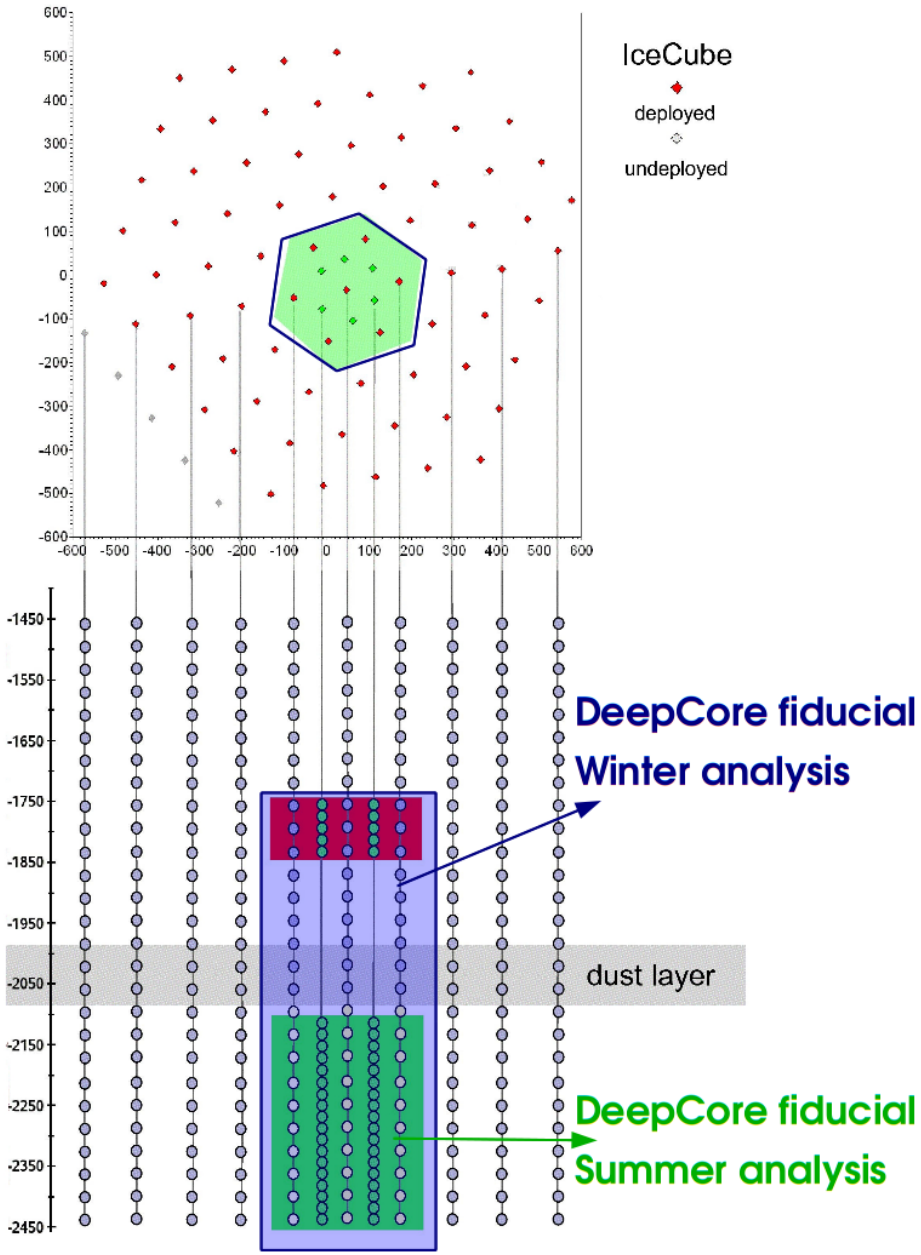

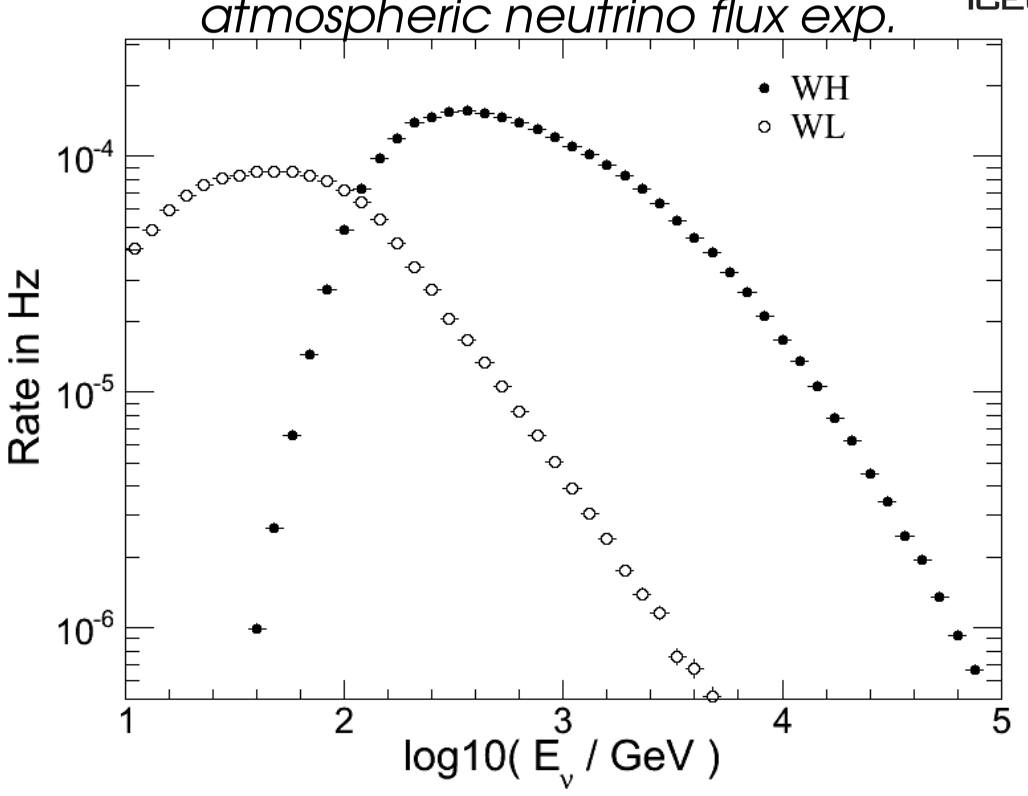

Signal event topology very different for low & high WIMP mass

→ find *geometrical cut* to split dataset into 2 non-overlaping datasets

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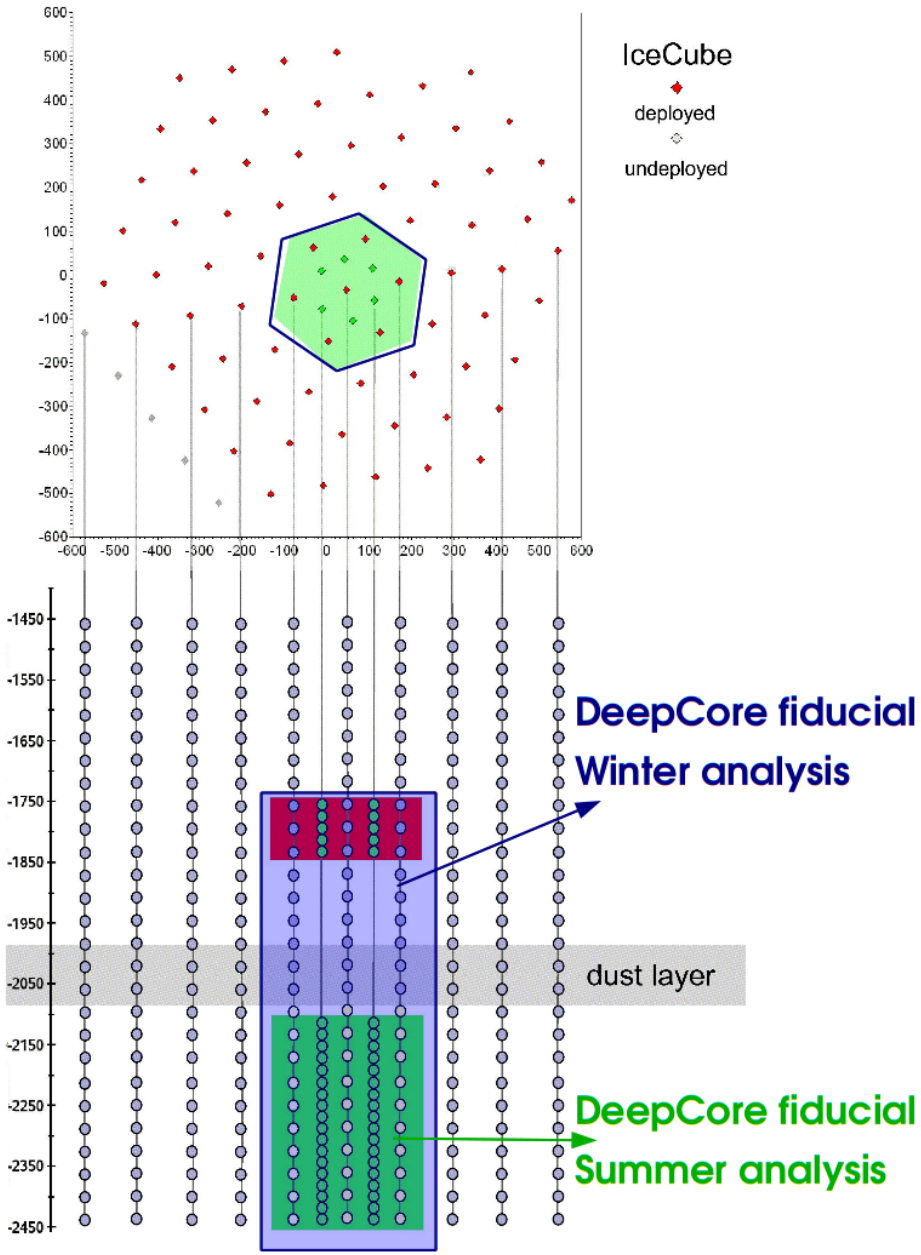
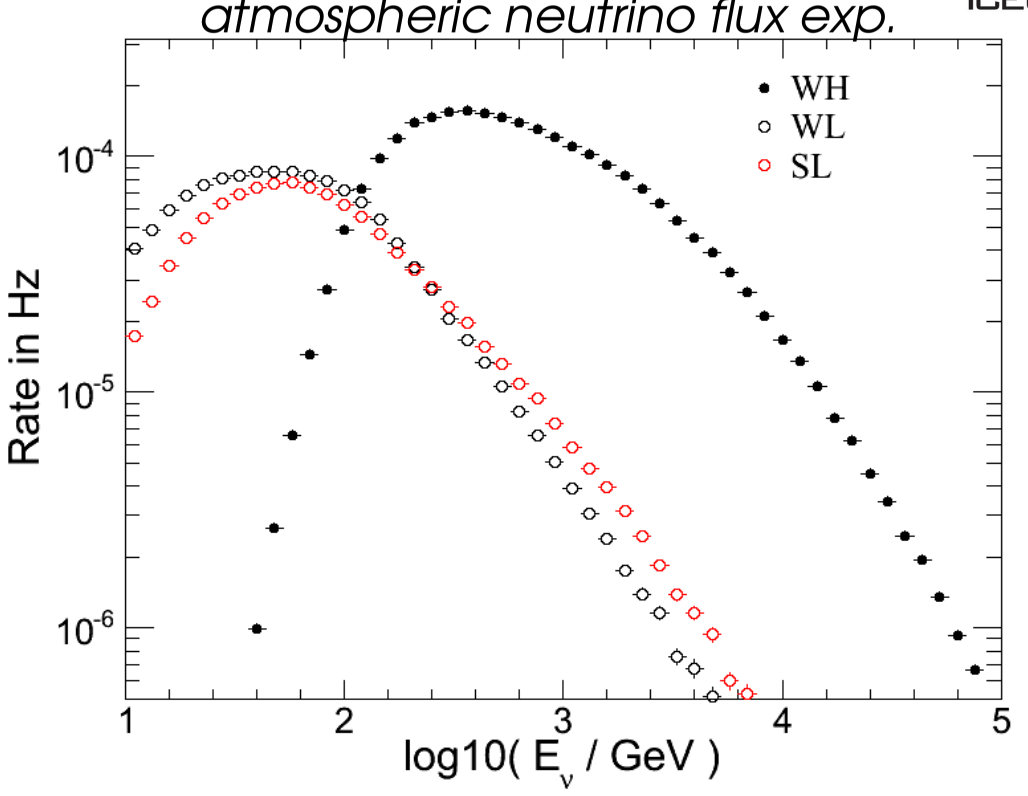
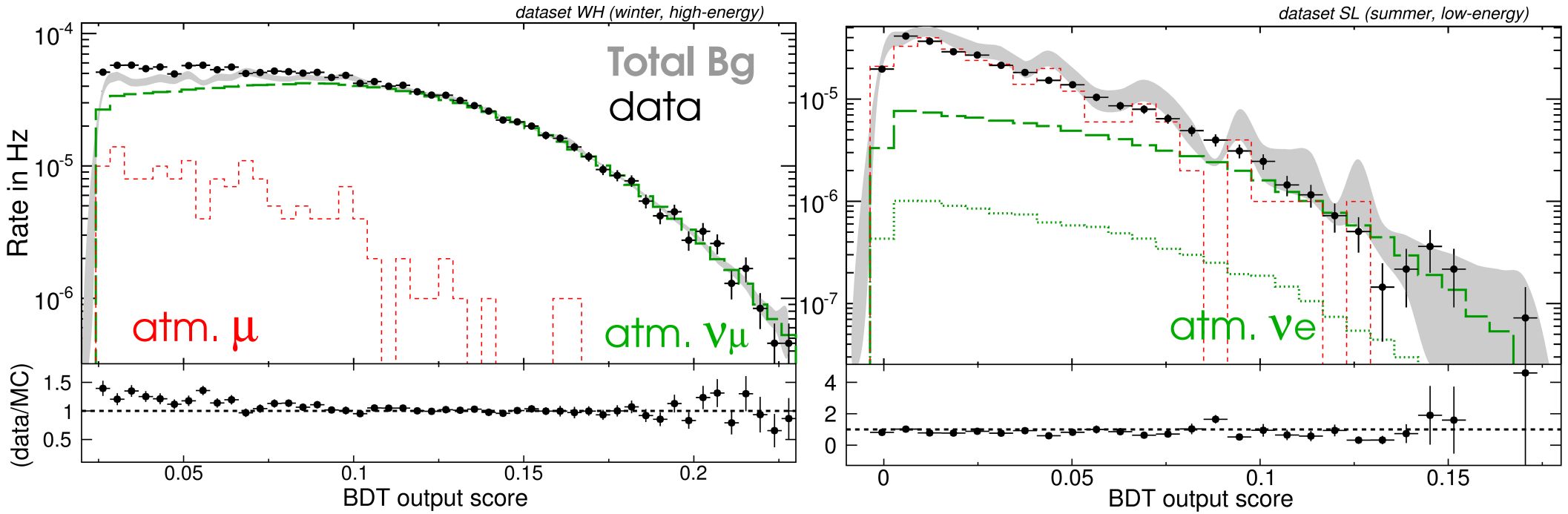




Signal event topology very different for low & high WIMP mass

→ find *geometrical cut* to split dataset into 2 non-overlaping datasets

Multivariate analysis step (final cut applied)



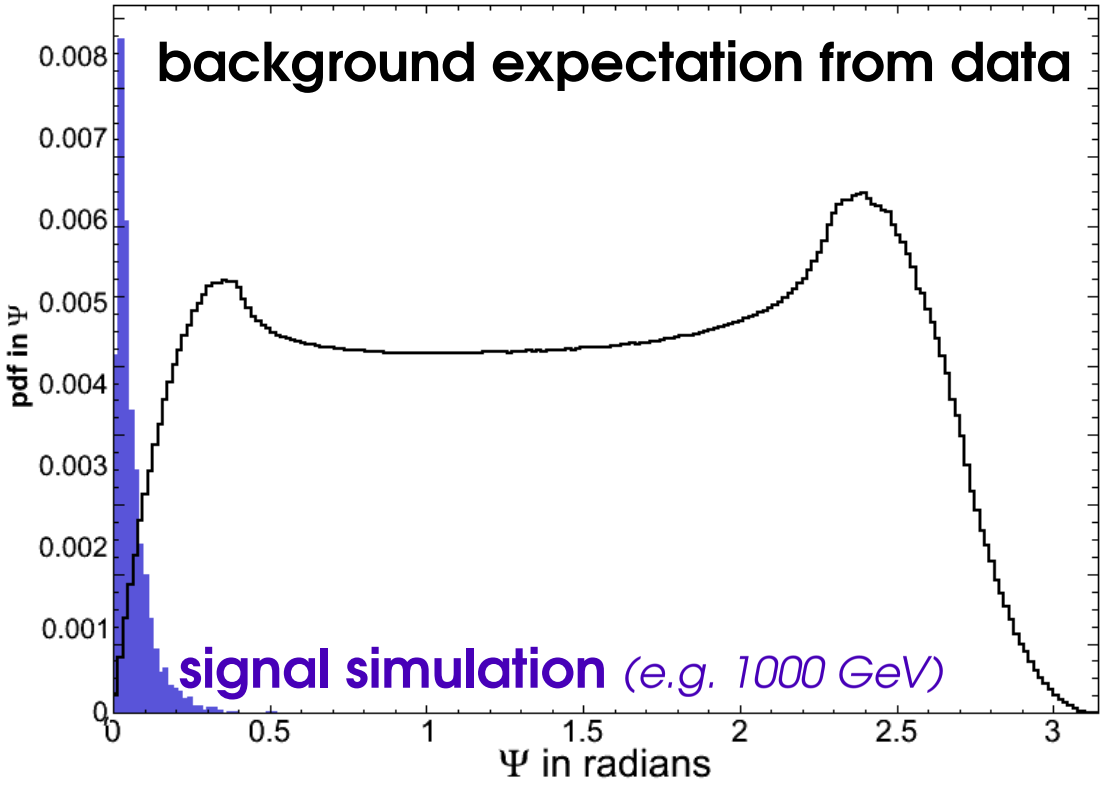
→ *1* separate BDT for each event selection

→ training on off-source exp. data + separate signal simulation

→ Optimized final cut on BDT-output: run llh-analysis for various BDT cuts; determine cut value with best sensitivity

Maximum llh-analysis

The observed angle to the Sun is fitted with *signal* and *background* pdf:s



(Angle between event track & direction from the Sun)

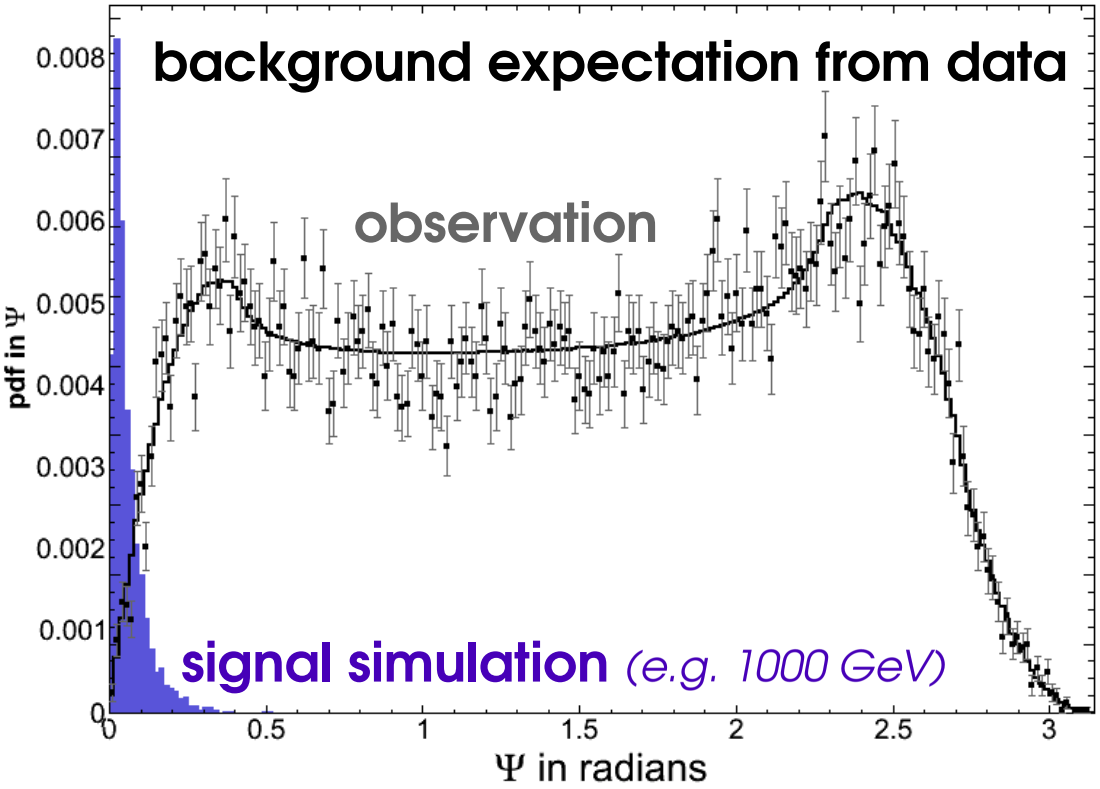
Maximum llh-analysis

The observed angle to the Sun is fitted with *signal* and *background* pdf:s

Evaluate shape fit with log–likelihood rank (Feldman-Cousins) to construct confidence regions for the number of signal events μs

$$R(\mu) = \frac{\mathcal{L}(\mu)}{\mathcal{L}(\hat{\mu})}$$

where ***L*** is the pdf product over the final sample



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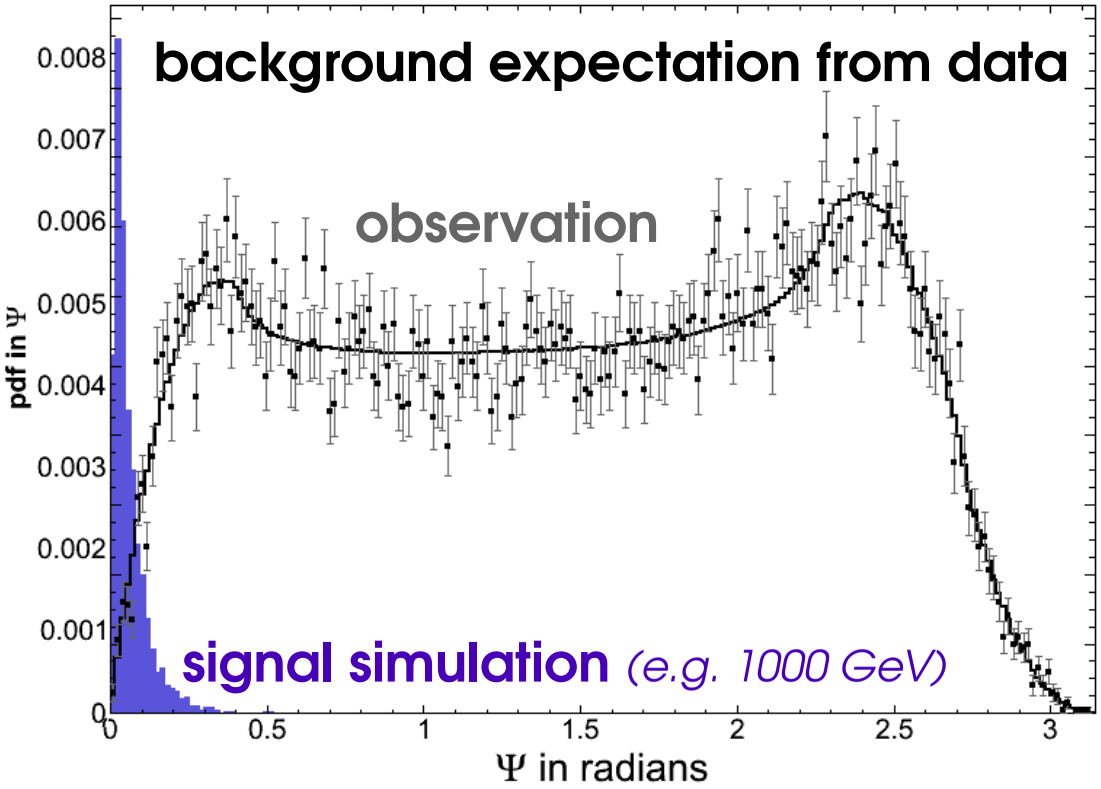
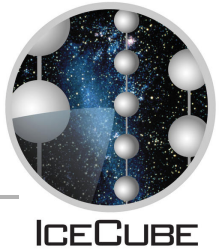


(Angle between event track & direction from the Sun)

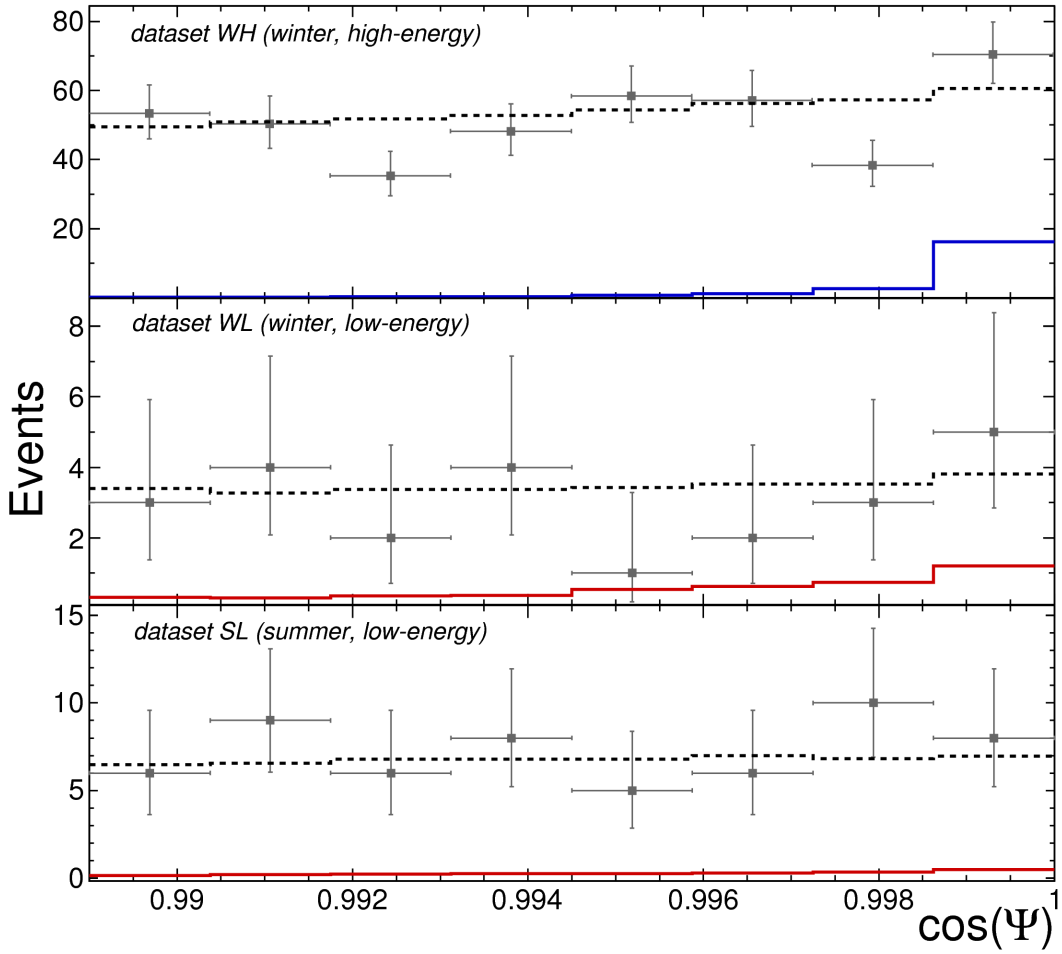
$$\mu_j = \mu \frac{T^j_{\text{live}} V^j_{\text{eff}}}{T^1_{\text{live}} V^1_{\text{eff}} + T^2_{\text{live}} V^2_{\text{eff}}}$$

Scale to multiple datasets

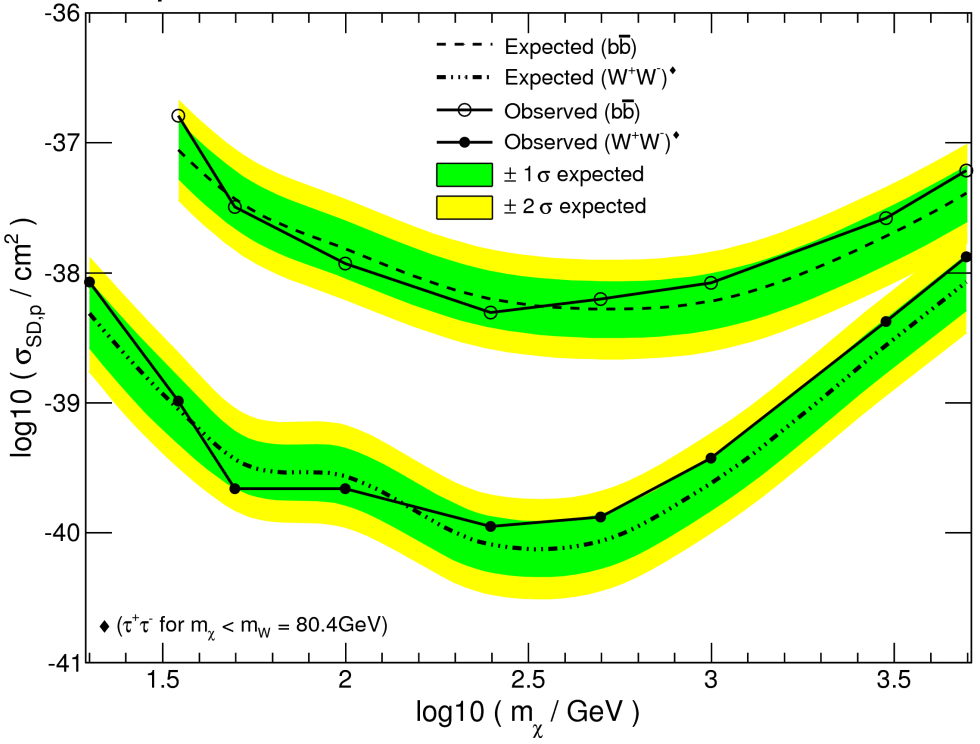
Solar WIMP search results (observed events)



Unblinded events in different samples

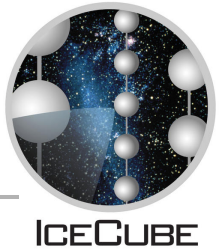


Expected sens. vs. observed result

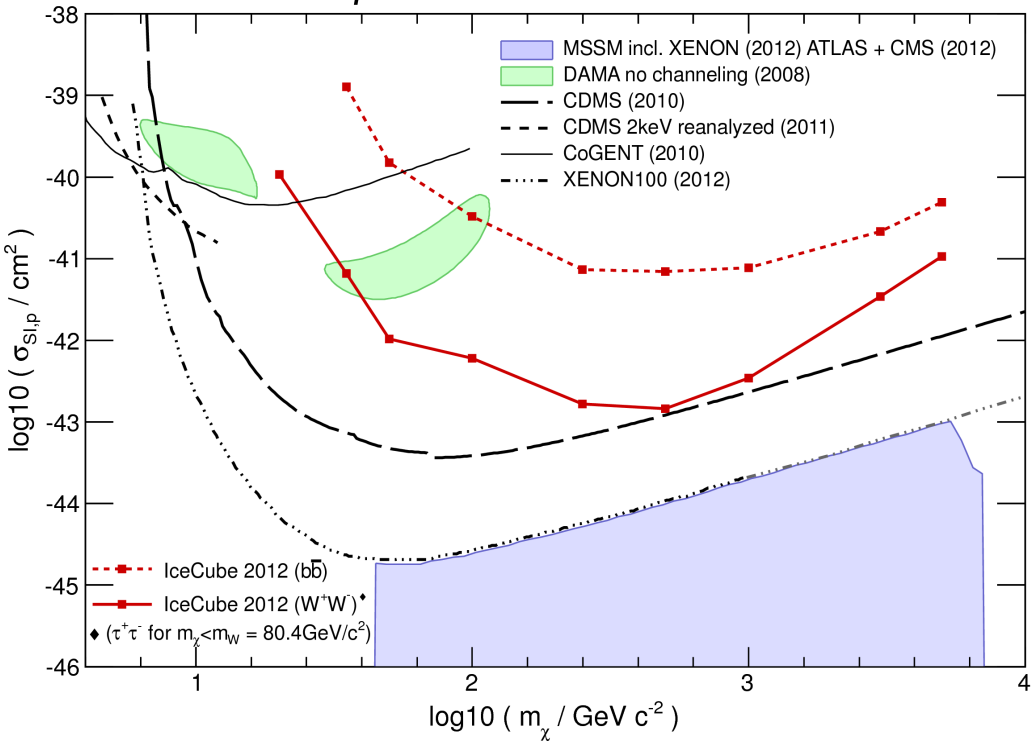


details on systematic uncertainties, see *PRL* **110** (2013) 131302

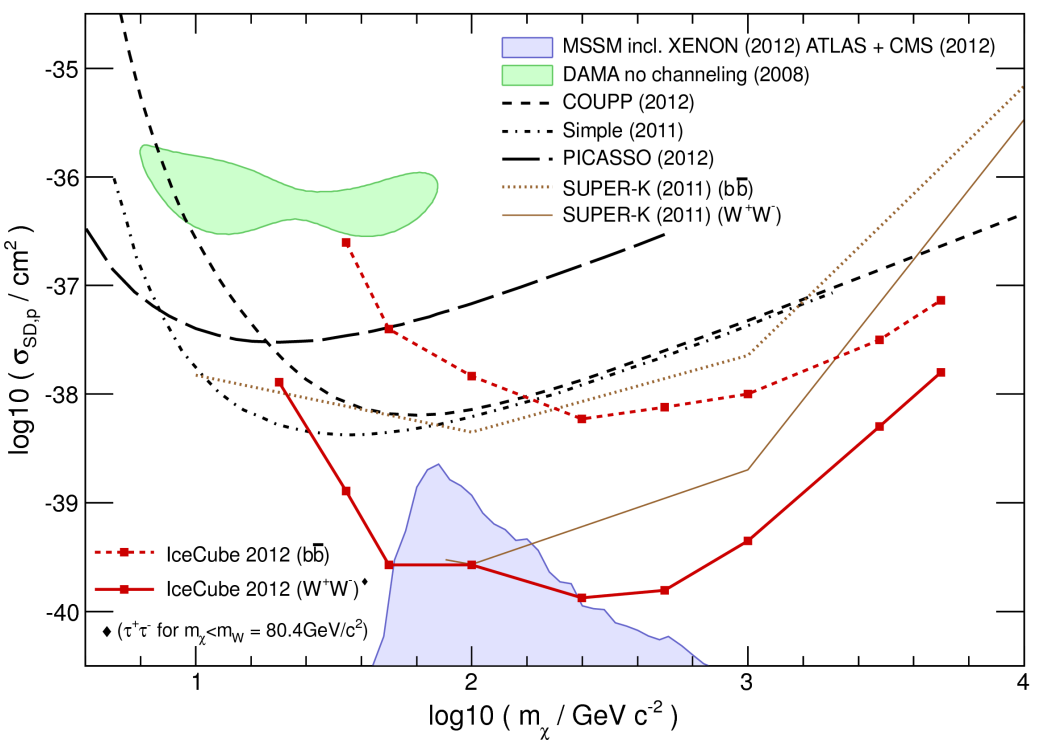
Solar WIMP search results (cross-section limit)



SI WIMP-proton cross-section limit



SD WIMP-proton cross-section limit



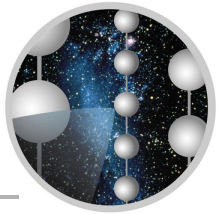
→ most stringent SD cross-section limit for most models

→ complementary to direct detection search efforts

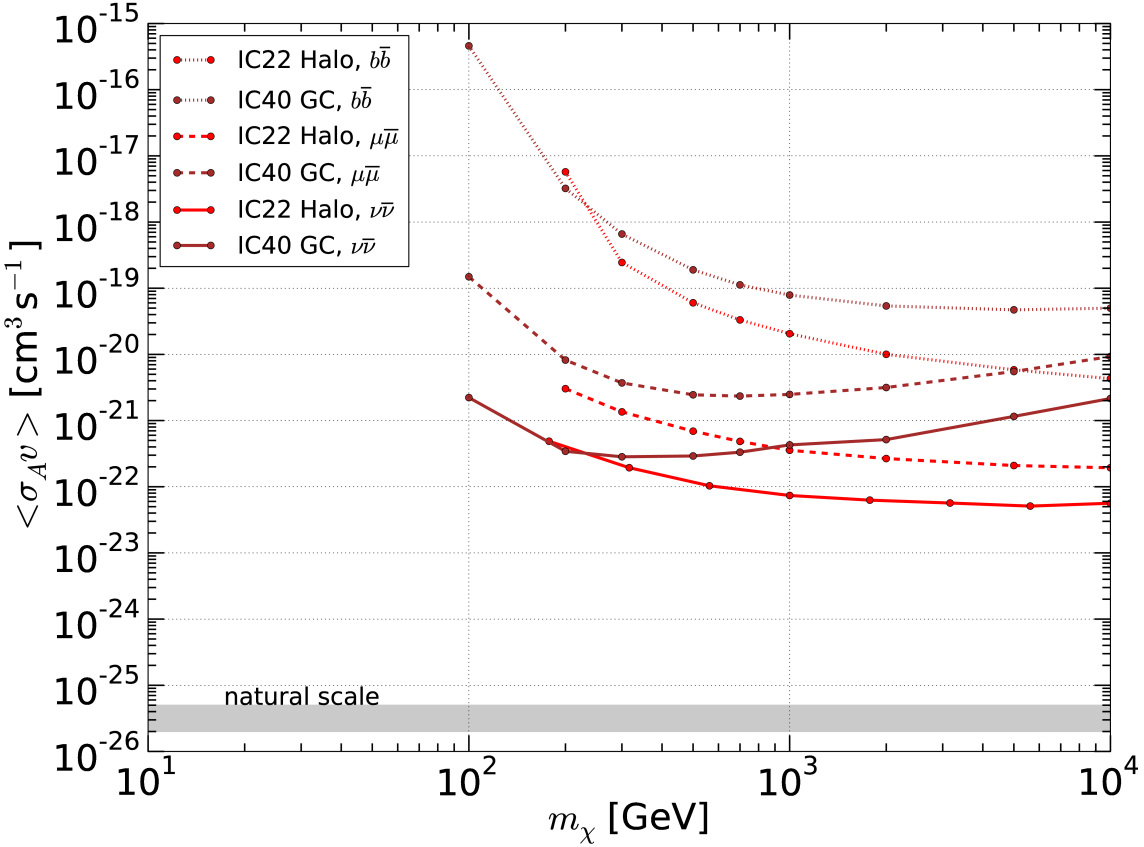
→ Different astrophysical & nuclear form-factor uncertainties

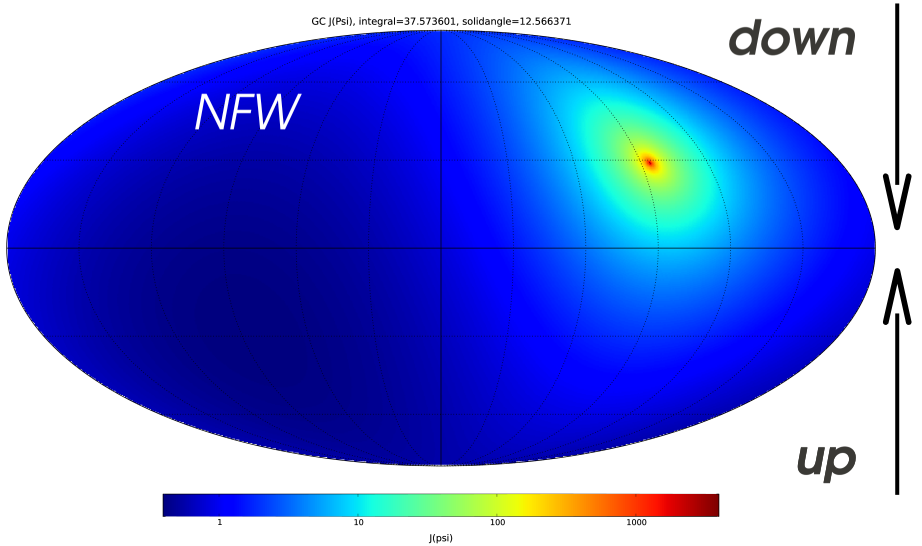
Galactic searches, dwarf spheroidal galaxies & nearby clusters of galaxies

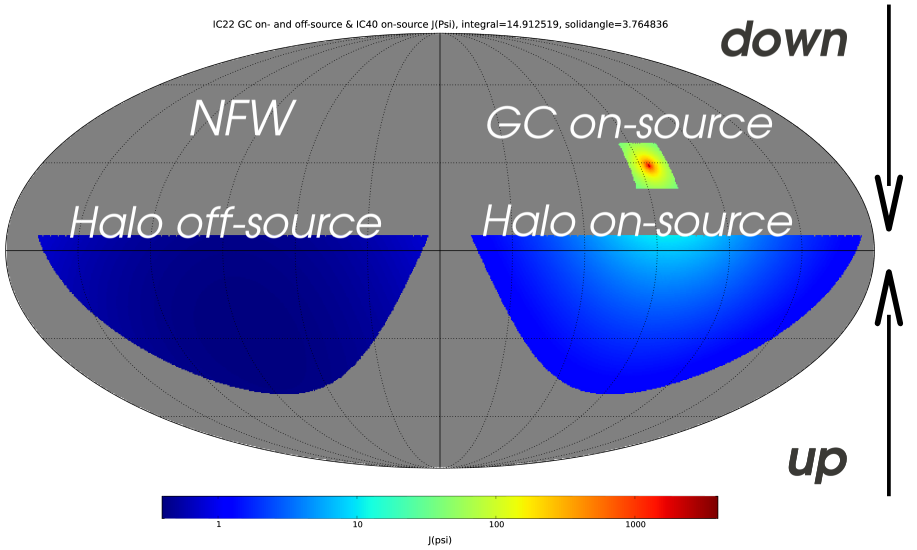
Galactic Dark Matter searches (first analyses)



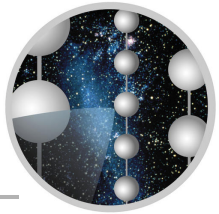
Limits computed at 90% C.L. as function of WIMP mass and for various ann. channels assuming branching fractions of 100%





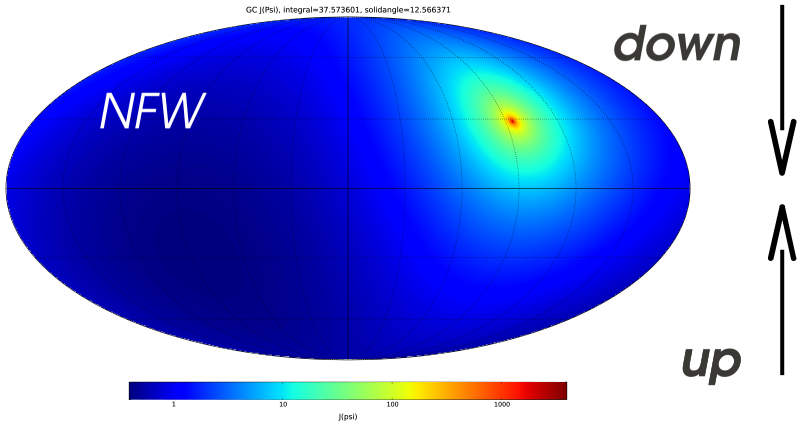


Galactic Dark Matter searches (IceCube-79)



New analysis using DeepCore:

- Improved muon-veto techniques
- Maximum likelihood analysis



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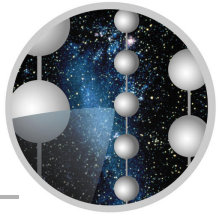

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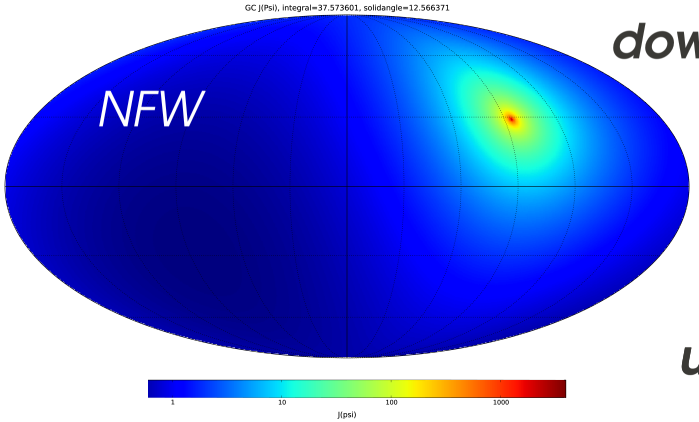

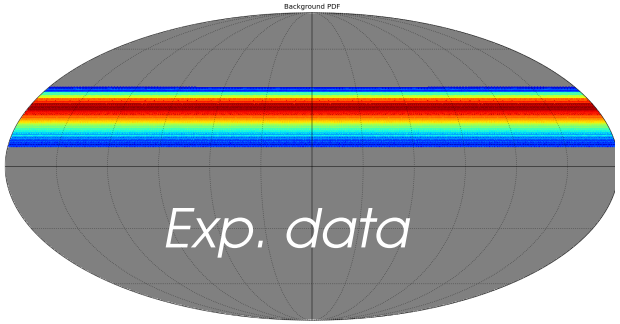

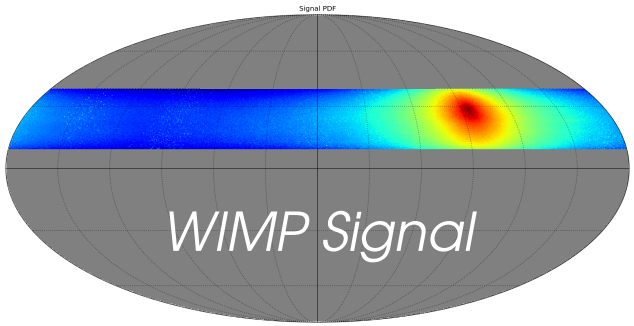

2D PDFs generated with healpix

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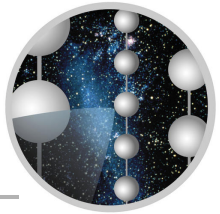

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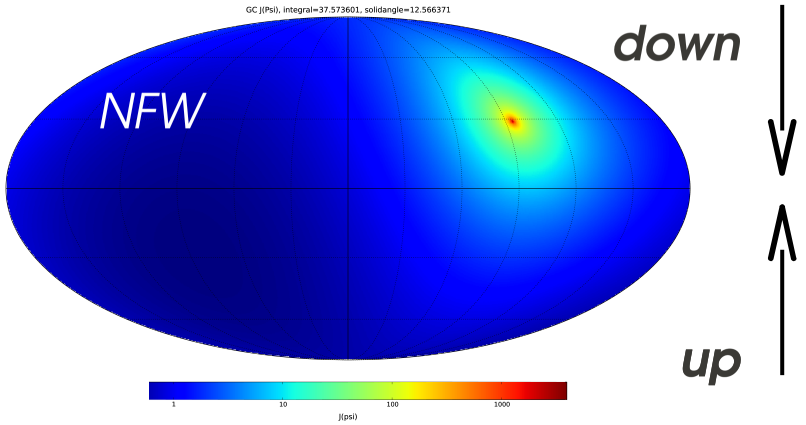

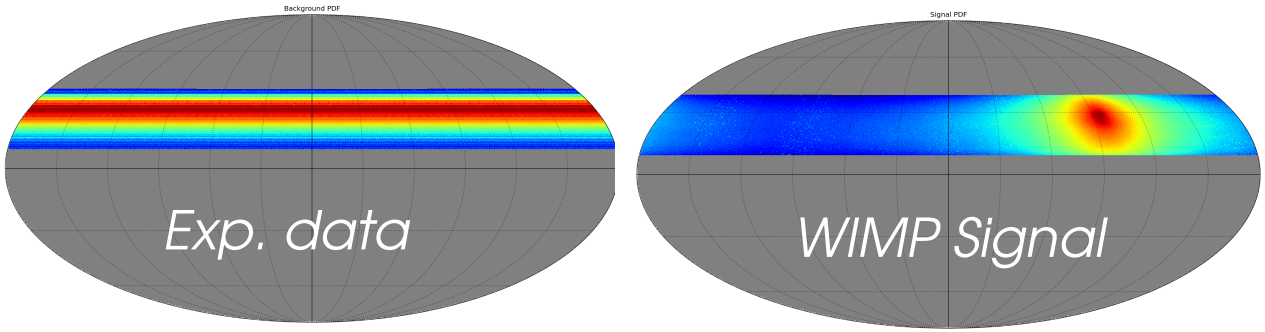

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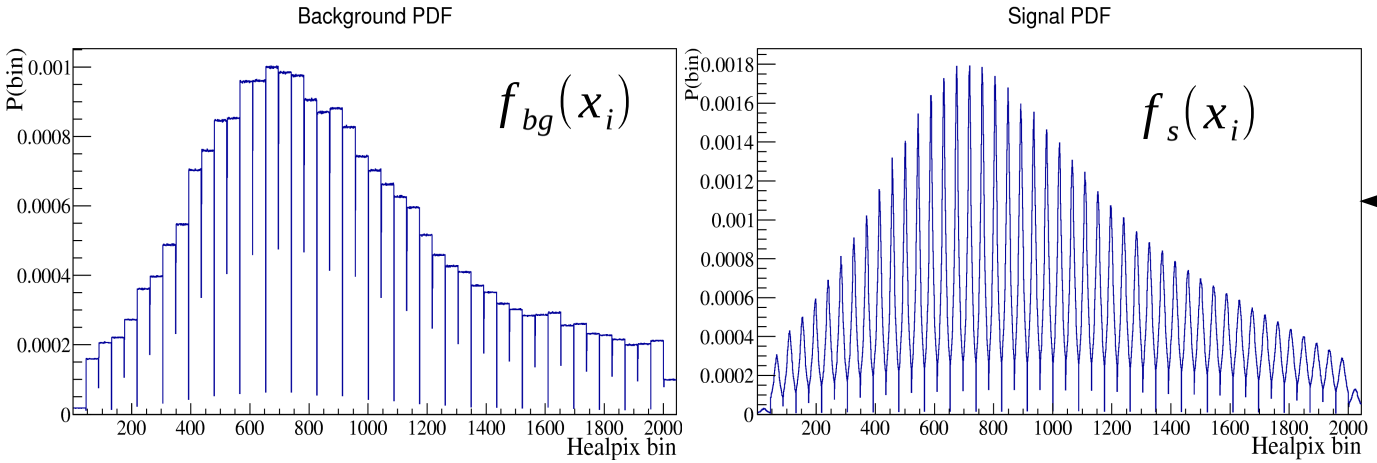
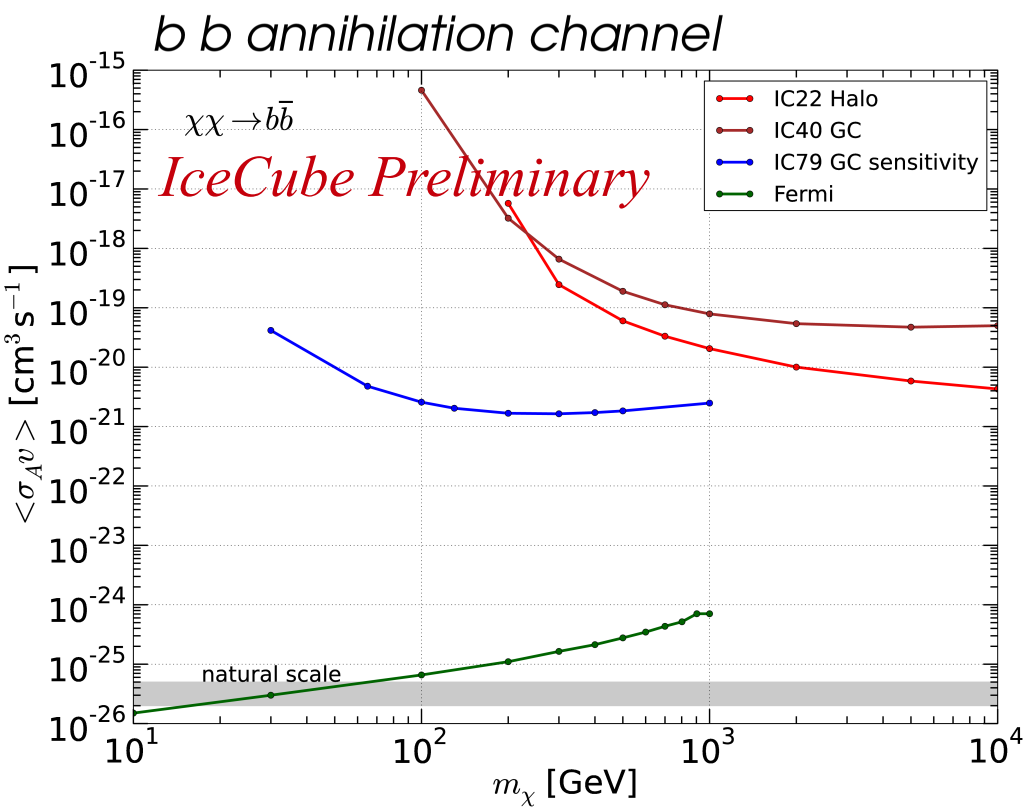
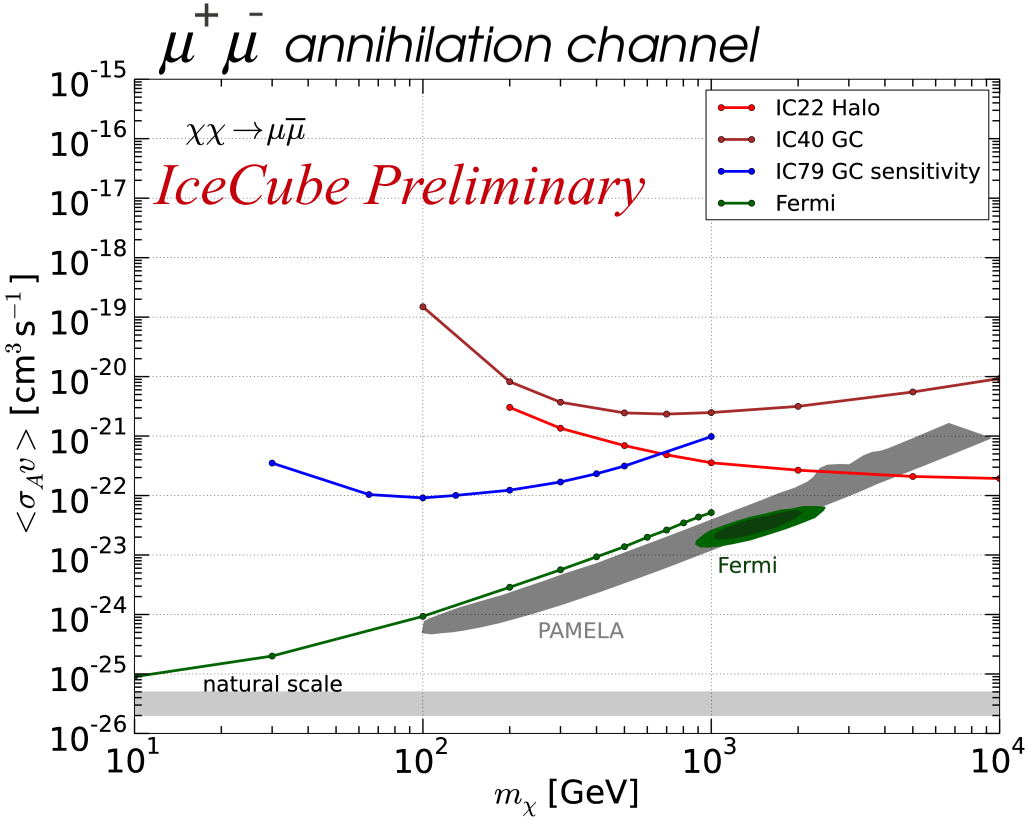


Healpix PDFs mapped to 1D

Galactic Dark Matter searches (IceCube-79)





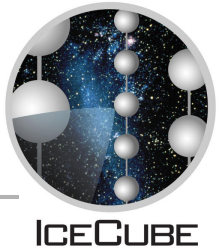
(IceCube results shown for NFW profile)

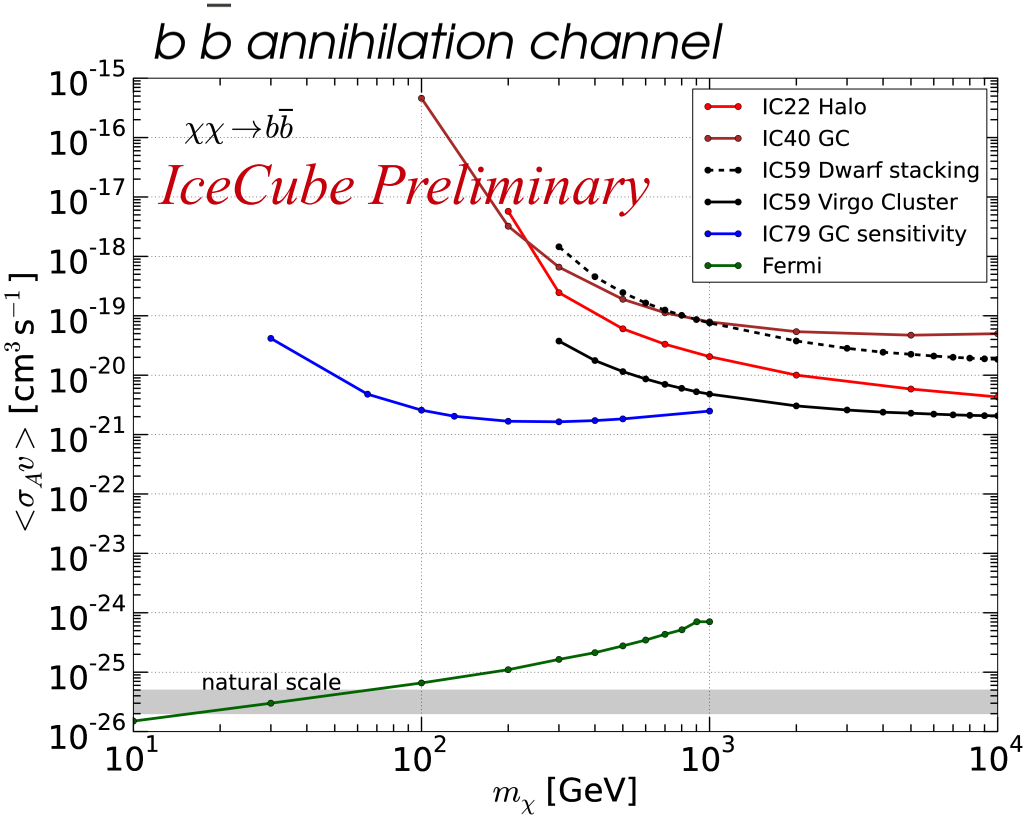
(Fit to Pamela/Fermi data by P. Meade et al (2011))

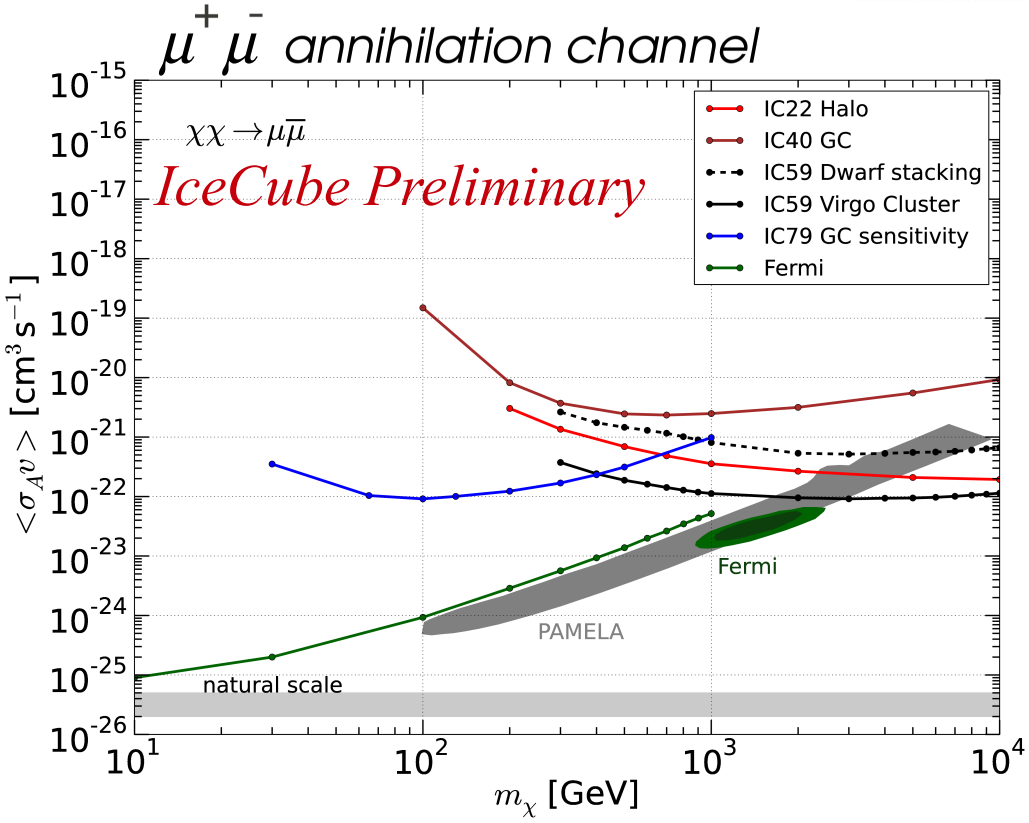
Search for many interesting potential annihilation channels:

$$\chi\chi \begin{cases} \nu\bar{\nu},\ \mu^+\mu^-,\ \tau^+\tau^-,\ W^+W^-,\ b\bar{b} \\ Z^0Z^0,\ Z^0\gamma \end{cases}$$

Galactic Dark Matter searches (summary)







(IceCube results shown for NFW profile)

(Fit to Pamela/Fermi data by P. Meade et al (2011))

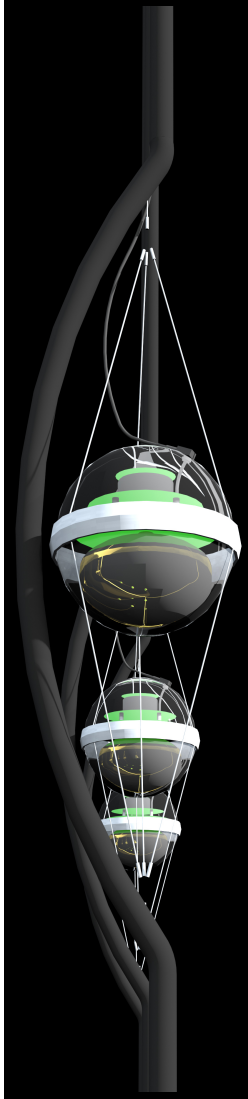
Dwarf galaxies:

- Source stacking analysis
- Optimized size of search window
- NFW profile assumed

Galaxy clusters:

- Extended point source search
- Optimized size of search window
- Substructures taken into account

Summary



- ***Striking*** WIMP signatures provide ***high discovery potential*** for indirect searches with neutrinos
- ***First*** DM analyses including ***DeepCore*** (***full year-round)***
- IceCube provides most stringent limits on the ***SD-WIMP-Proton scattering cross section*** for most WIMP models
- First experimental neutrino results on ***Clusters of Galaxies and Dwarfs Spheriodals***
- ***New analysis*** to probe DM self-annihilation cross section for ***low WIMP masses*** in the ***Galactic center***
- ***Additional on-going searches:***
  Earth WIMPs, secluded Dark Matter, ...