

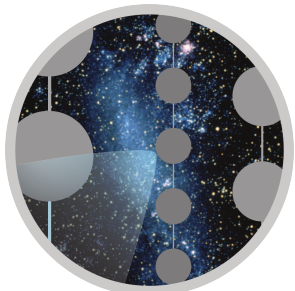
Latest Results on Searches for Dark Matter from IceCube

Matthias Danninger for the *IceCube Collaboration*

The Oskar Klein Centre for Cosmoparticle Physics, Stockholm University

The 2013 European Physical Society Conference on High Energy Physics

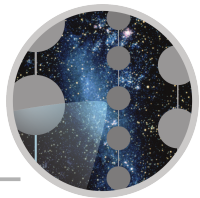
Stockholm, July 18-24, 2013



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Indirect Search with IceCube (Overview)



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

Dwarf spheroidal Galaxies:

→ IceCube-59 limits

Clusters of Galaxies:

→ IceCube-59 limits

(*arXiv:1210.3557 2012*)

Galactic Halo:

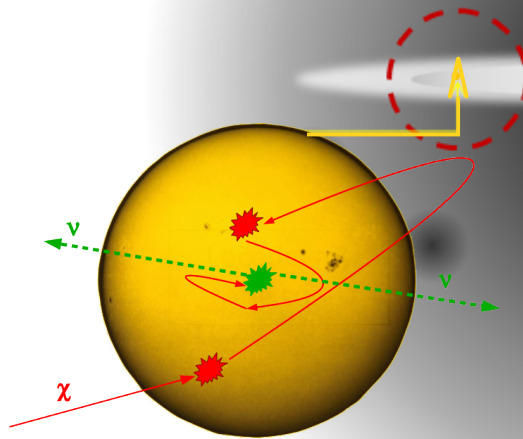
→ IceCube-22 limits
(*PRD 84 (2011) 022004*)

→ IceCube-79 limits.

Galactic Center

→ IceCube-40 limits
(*arXiv:1210.3557 2012*)

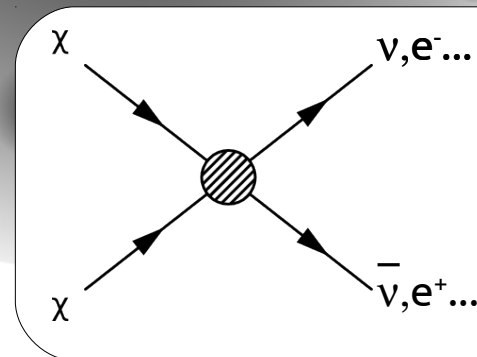
→ IceCube-79 sens.



Local sources (Sun & Earth):

→ IceCube-79 limits

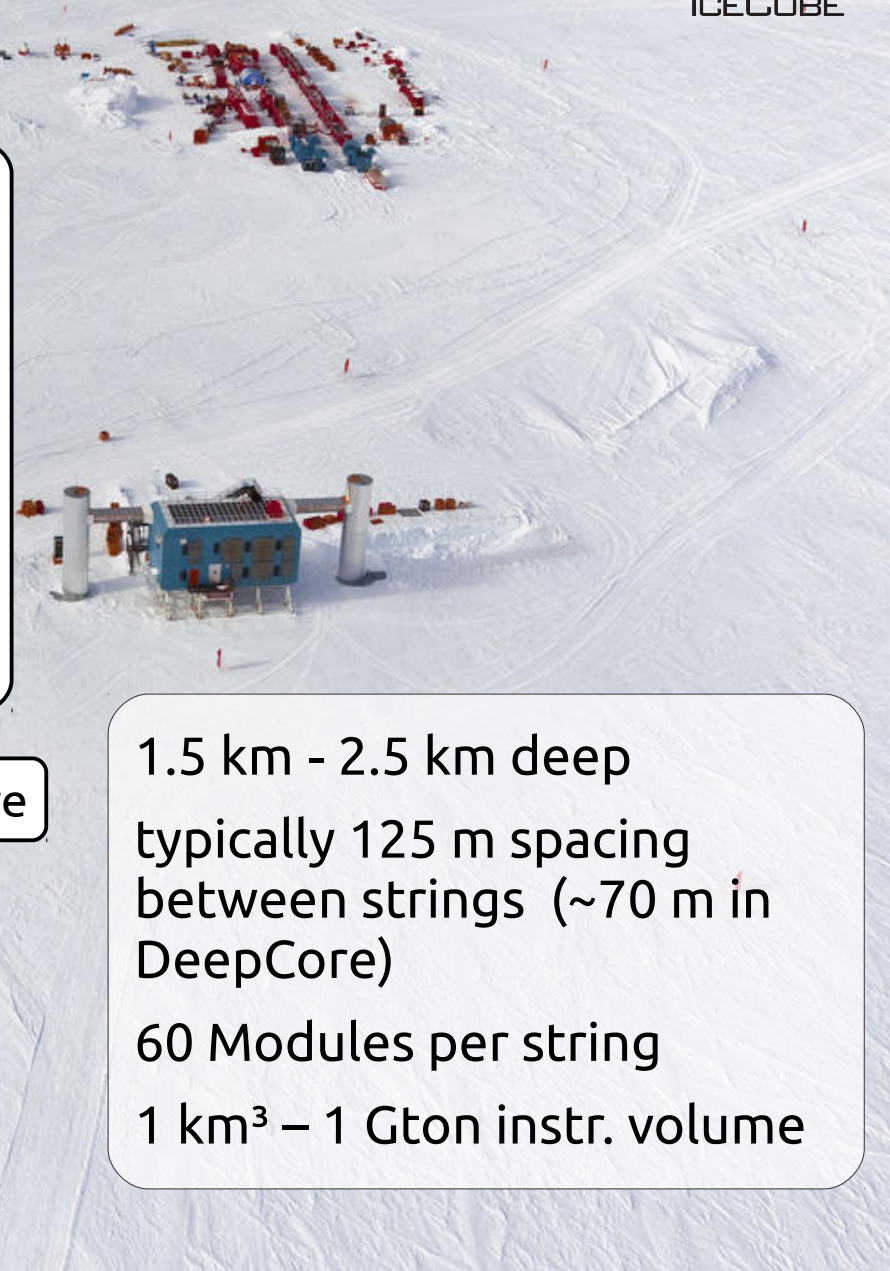
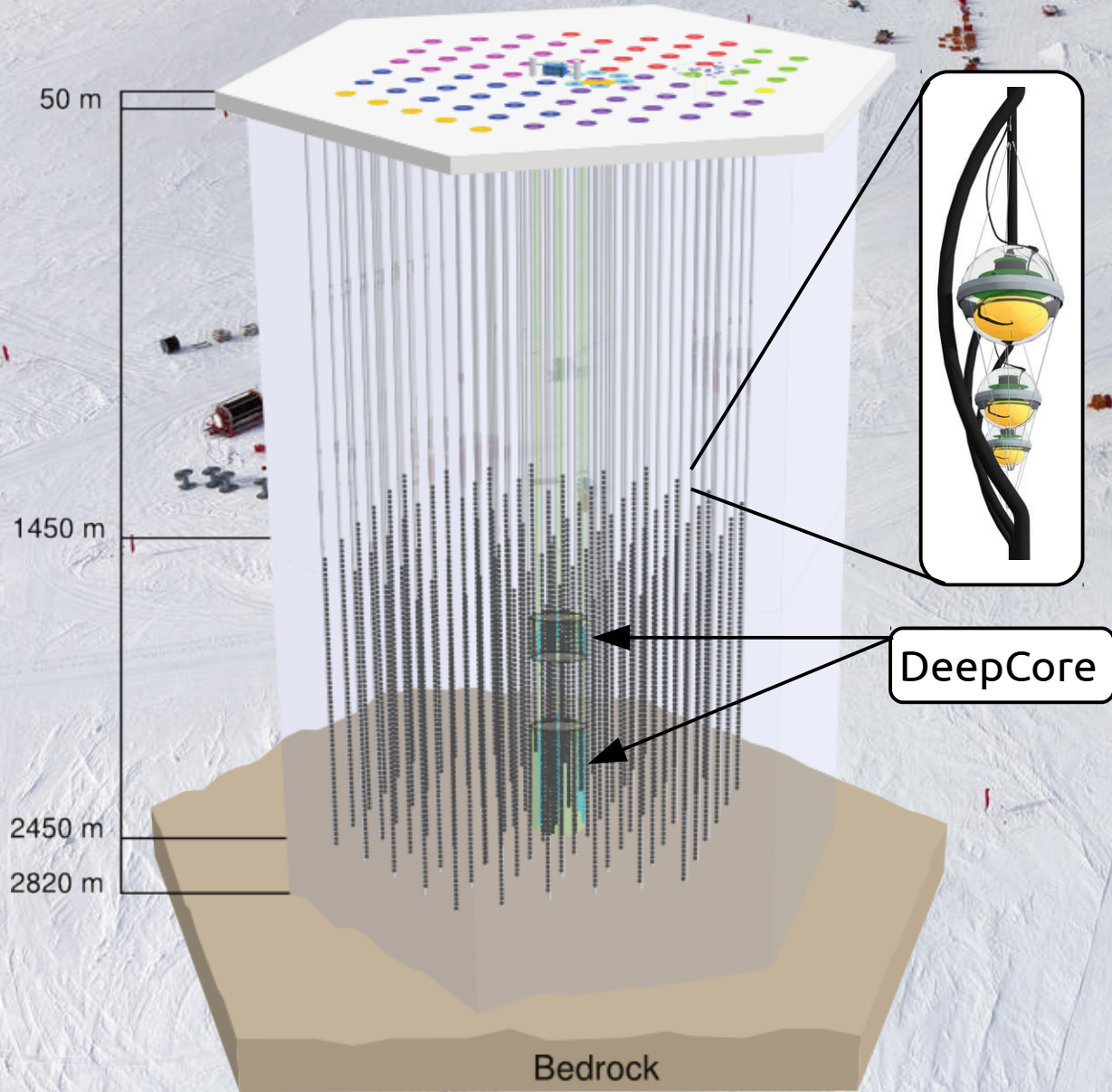
(*PRL 110 (2013) 131302*)



Searching for dark matter annihilations is in the low energy regime for IceCube. ~10 GeV-TeV

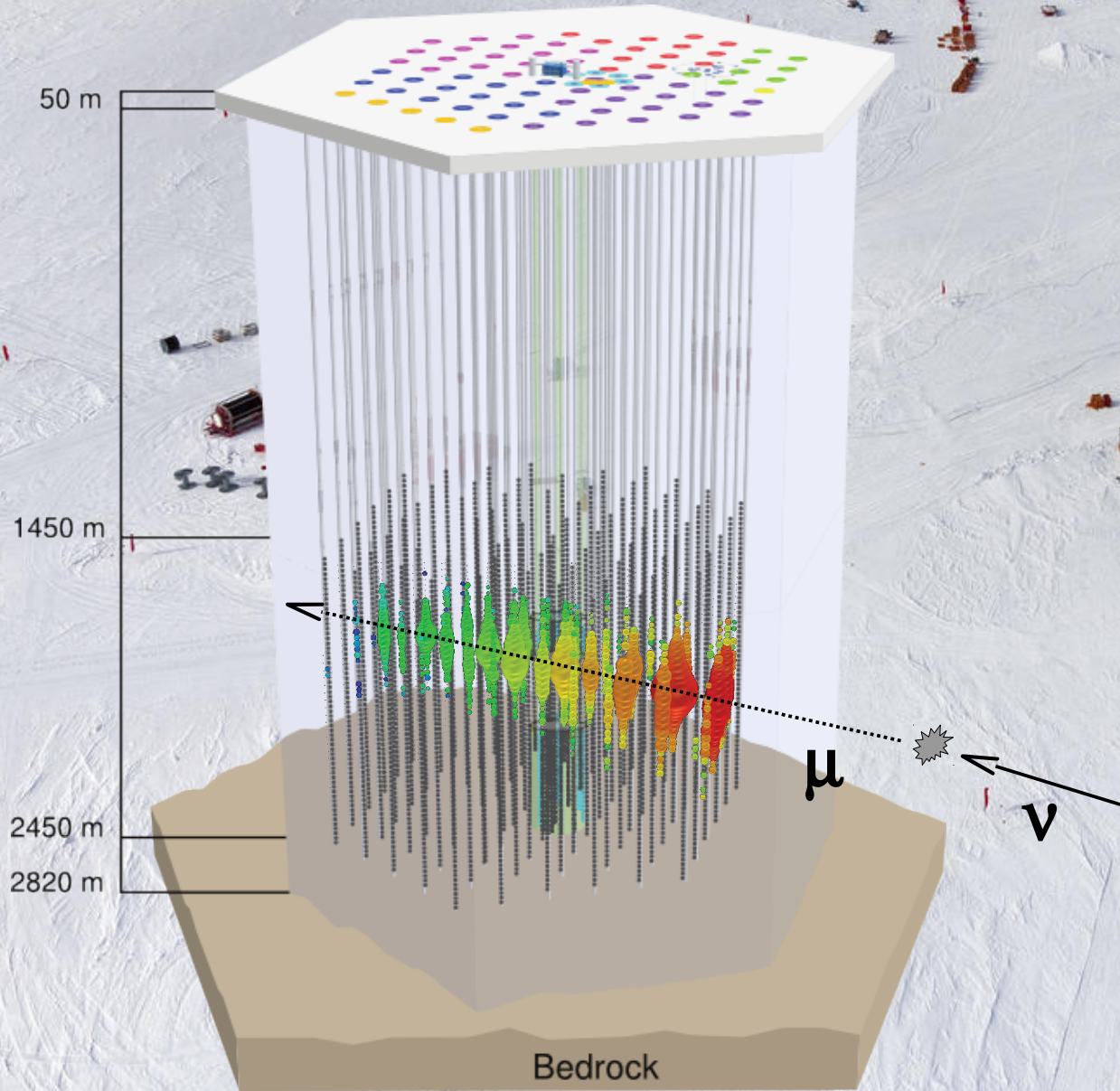
(Image: M.Strassler)

The IceCube detector

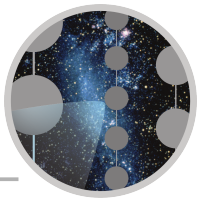


1.5 km - 2.5 km deep
typically 125 m spacing
between strings (~70 m in
DeepCore)
60 Modules per string
1 km³ - 1 Gton instr. volume

The IceCube detector



$O(\text{km}) \mu$ tracks from ν_{μ} CC
 $O(10\text{m})$ cascades from ν_e CC, low energy ν_{τ} CC, and ν_x NC
Cherenkov radiation detected by 3D array of optical sensors



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Solar Dark Matter Search with IceCube

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)

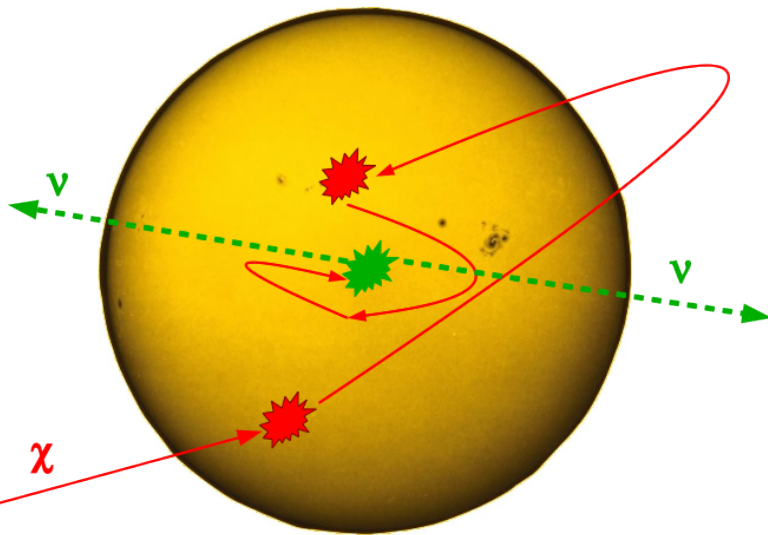
Details about Capture Process (e.g.):

Press & Spergel '85

Gould '88

Peter 2008

Sivertsson, Edsjö, PRD85 (2012) 123514



$$\frac{dN}{dt} = C_{capt.} - C_{ann.}$$

$$C_{ann.} = C_{capt.} \rightarrow \sigma_{total}$$

Proposed by:

Silk, Olive & Srednicki '85

Gaisser, Steigman & Tilav '86

Freese '86

Krauss, Srednicki & Wilzcek '86

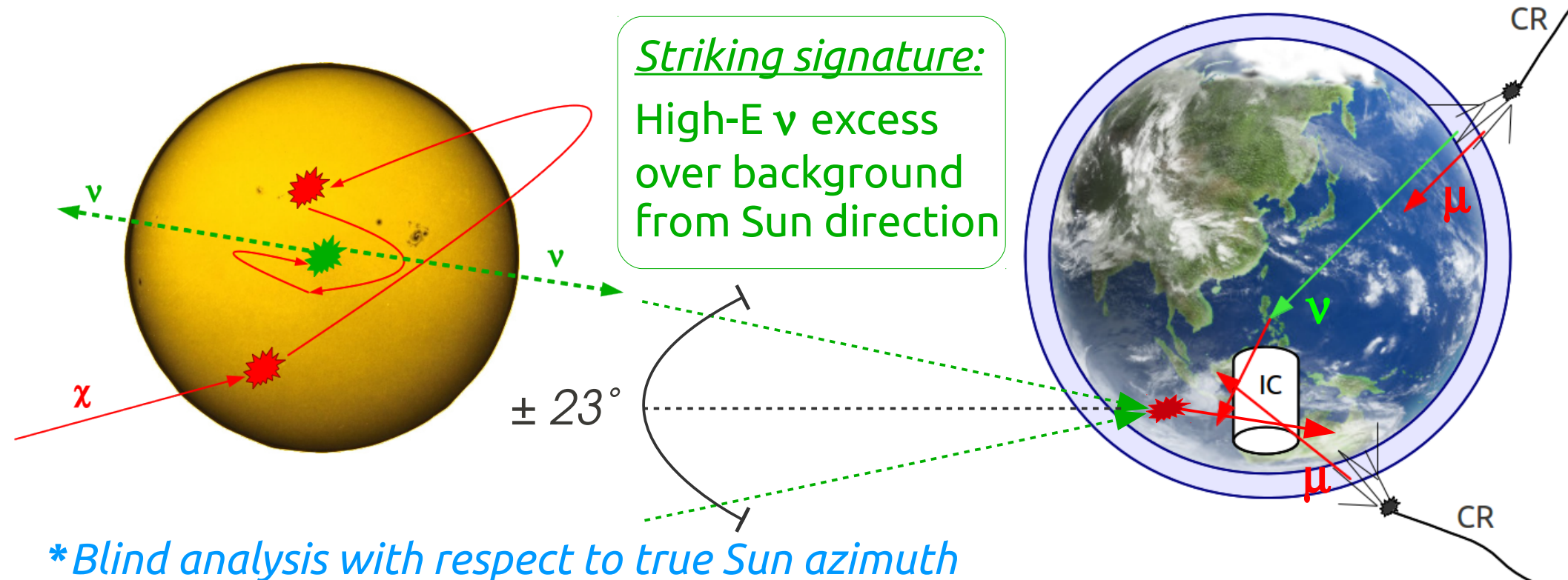
Solar Dark Matter Search with IceCube



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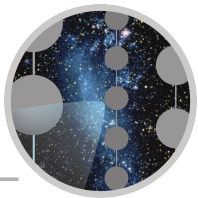
main analysis backgrounds:
atm. $\mu \sim O(10^8)$ triggering events/day
atm. $\nu \sim O(10^3)$ triggering events/day

Striking signature:
High-E ν excess
over background
from Sun direction



**Blind analysis with respect to true Sun azimuth*

IceCube-79 string analysis details

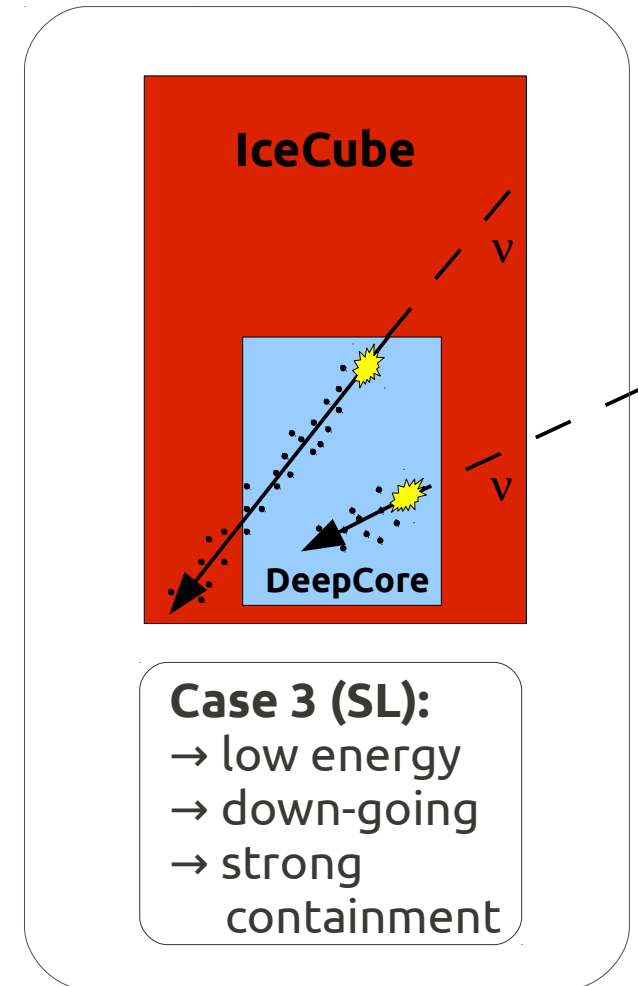
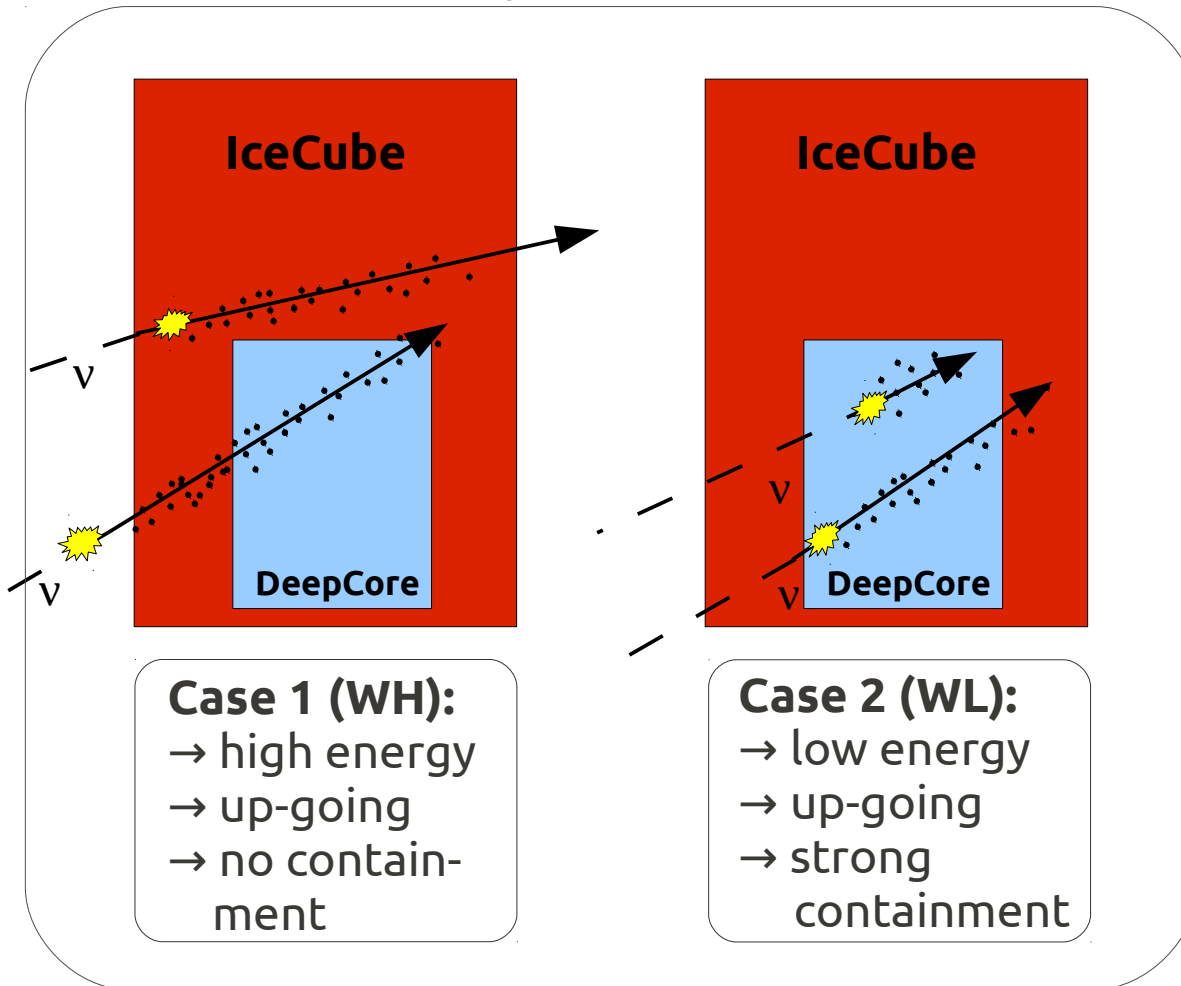


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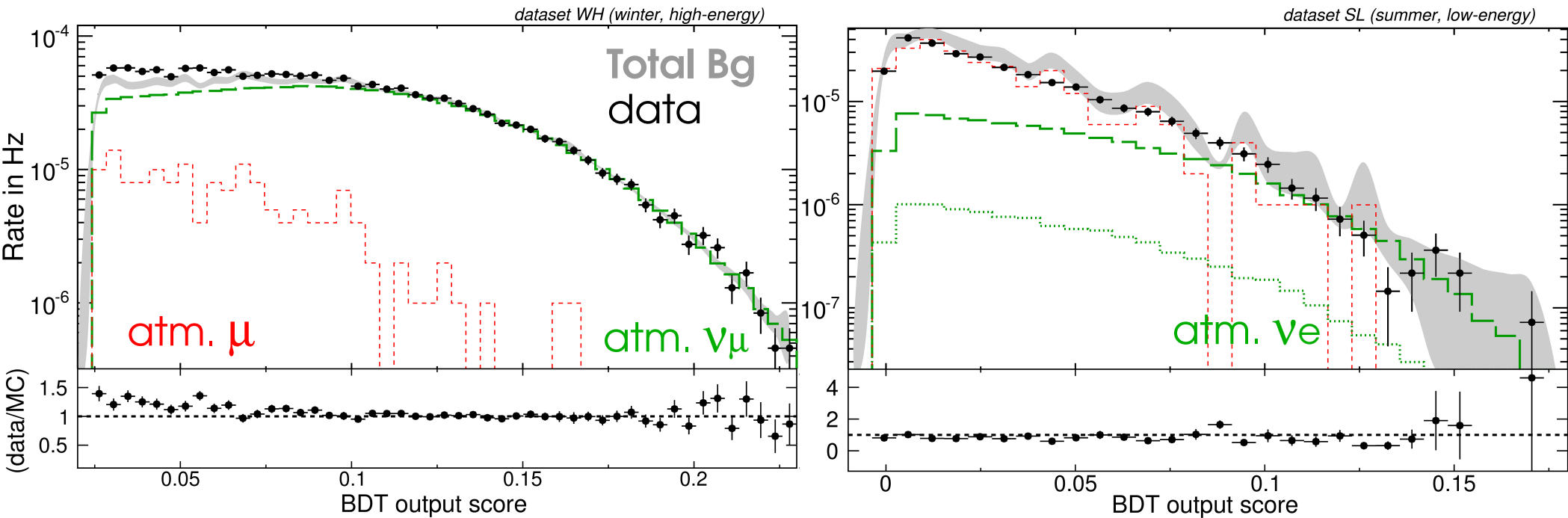
- Analysis for the whole year! Used 317 days livetime
- With DeepCore, analysis reaches neutrino energies of $10\text{-}20\text{GeV}$

151 days austral winter

166 days austral summer



Multivariate analysis step (final cut applied)

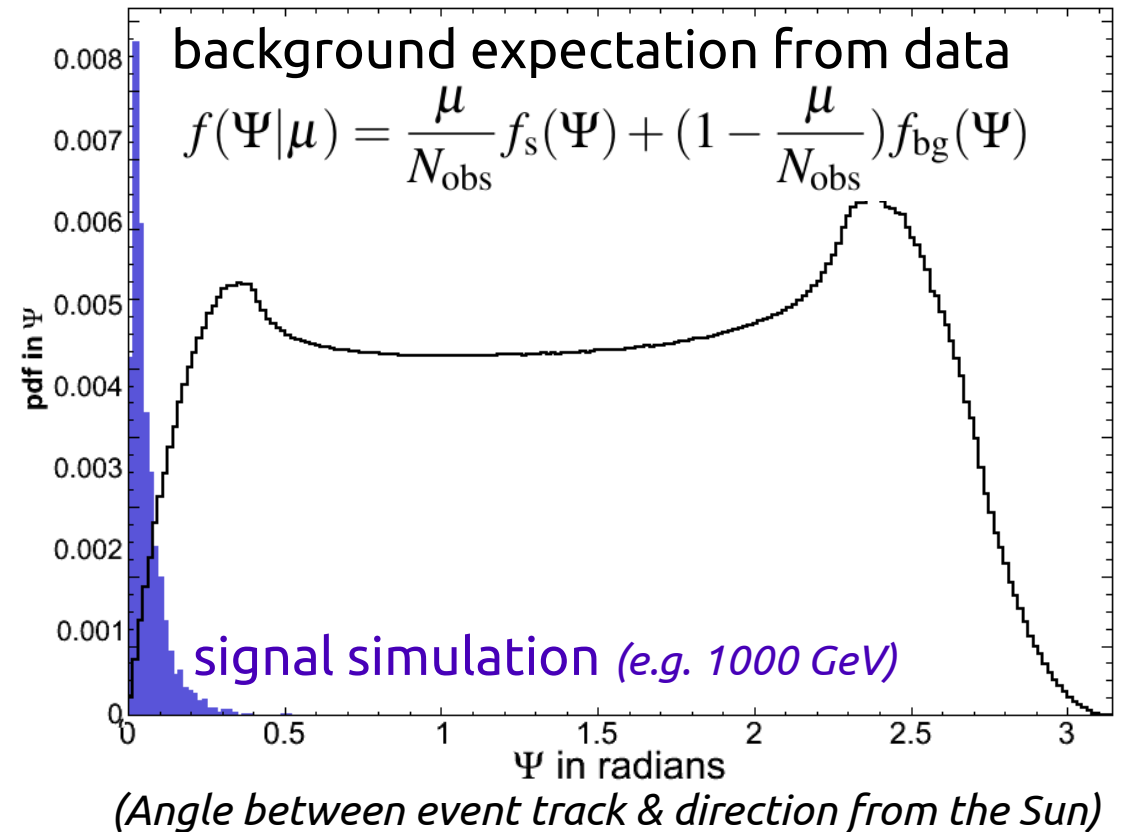


- **1 separate BDT** for each event selection
- training on **off-source exp. data** + separate signal simulation
- **Optimized final cut on BDT-output:** run llh-analysis for various BDT cuts; determine cut value with best sensitivity

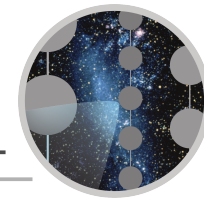
Maximum llh-analysis



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



Maximum llh-analysis



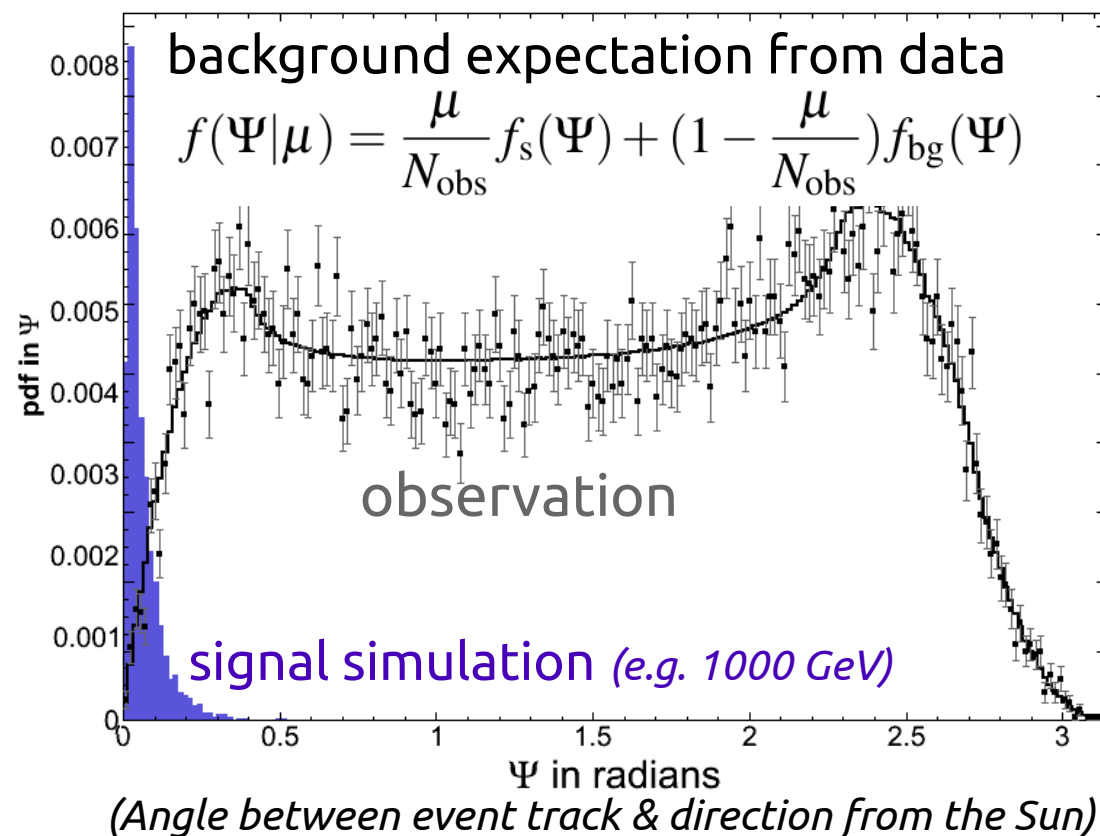
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The observed angle to the Sun is fitted with *signal* and *background* pdf:s

Evaluate shape fit with log-likelihood rank (FC) to construct CI for the number of signal events μ_s

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

$\mathcal{L}(\mu)$ is the pdf product over the final sample



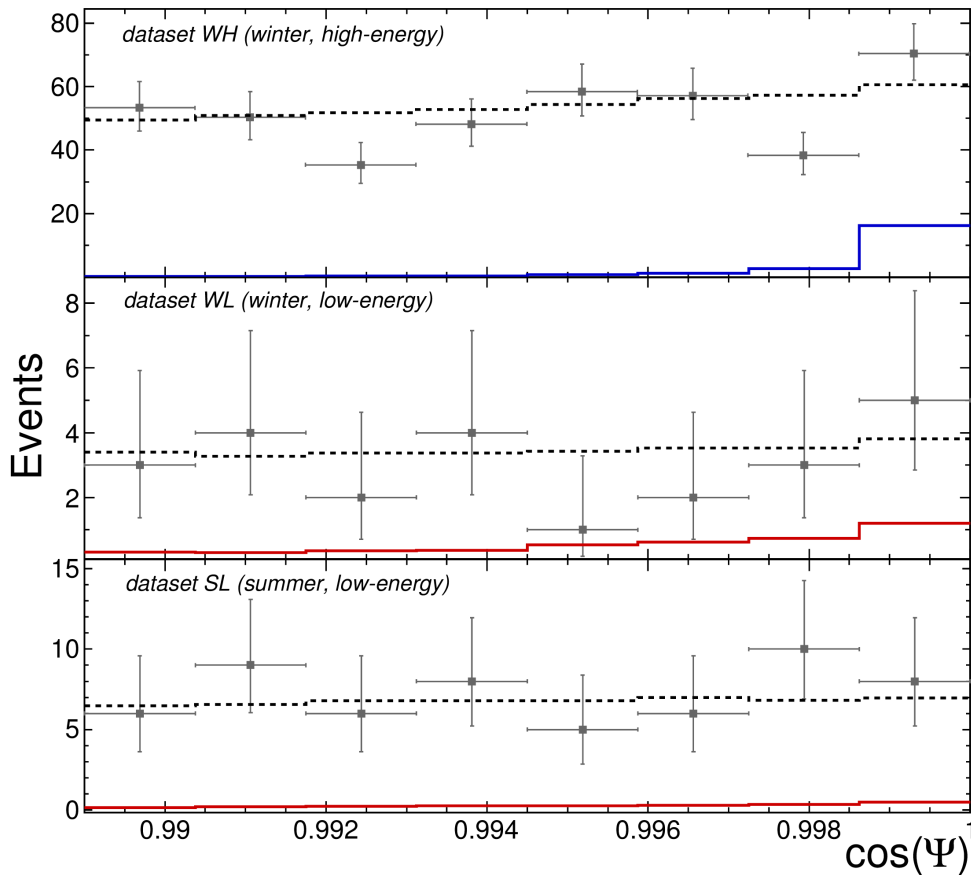
$$\mu_j = \mu \frac{T_{\text{live}}^j V_{\text{eff}}^j}{T_{\text{live}}^1 V_{\text{eff}}^1 + T_{\text{live}}^2 V_{\text{eff}}^2}$$

(scale to multiple datasets)

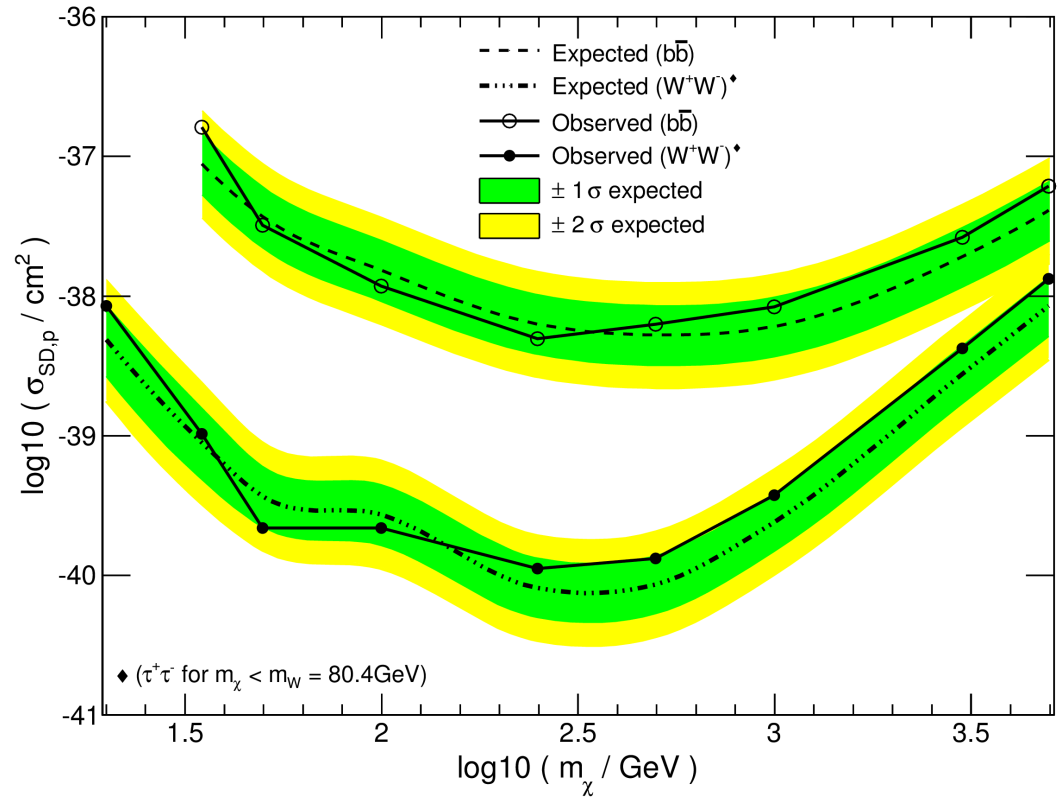
Unblinding results (observed results)



Unblinded events in different samples



Expected sens. vs. observed result

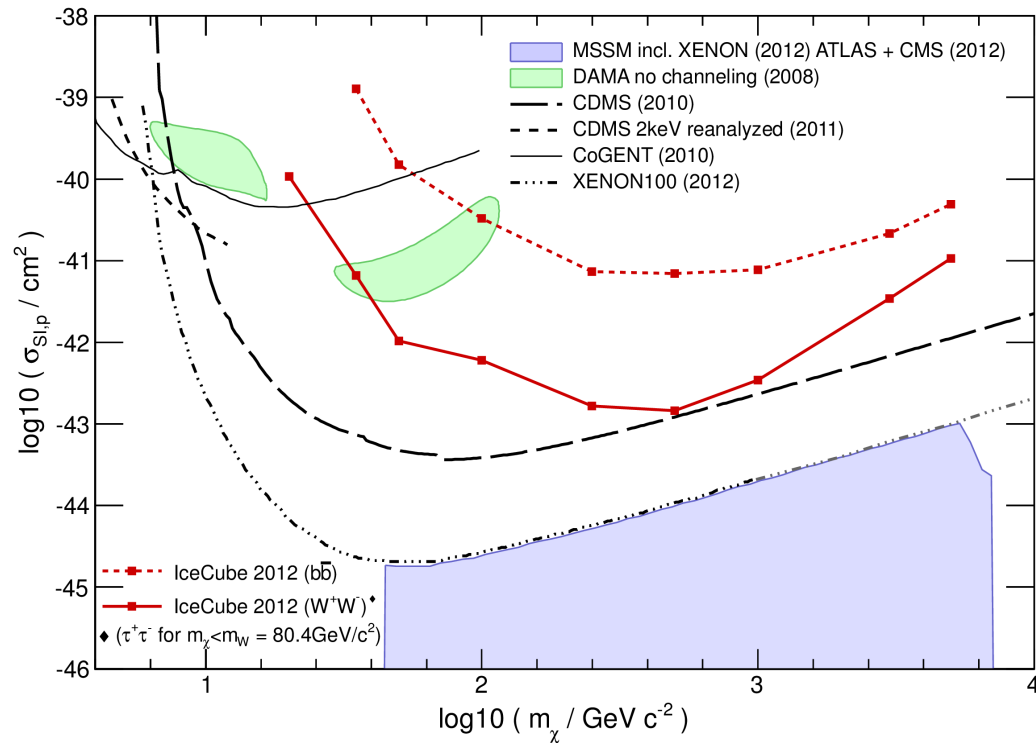


details on systematic uncertainties,
see *PRL* **110** (2013) 131302

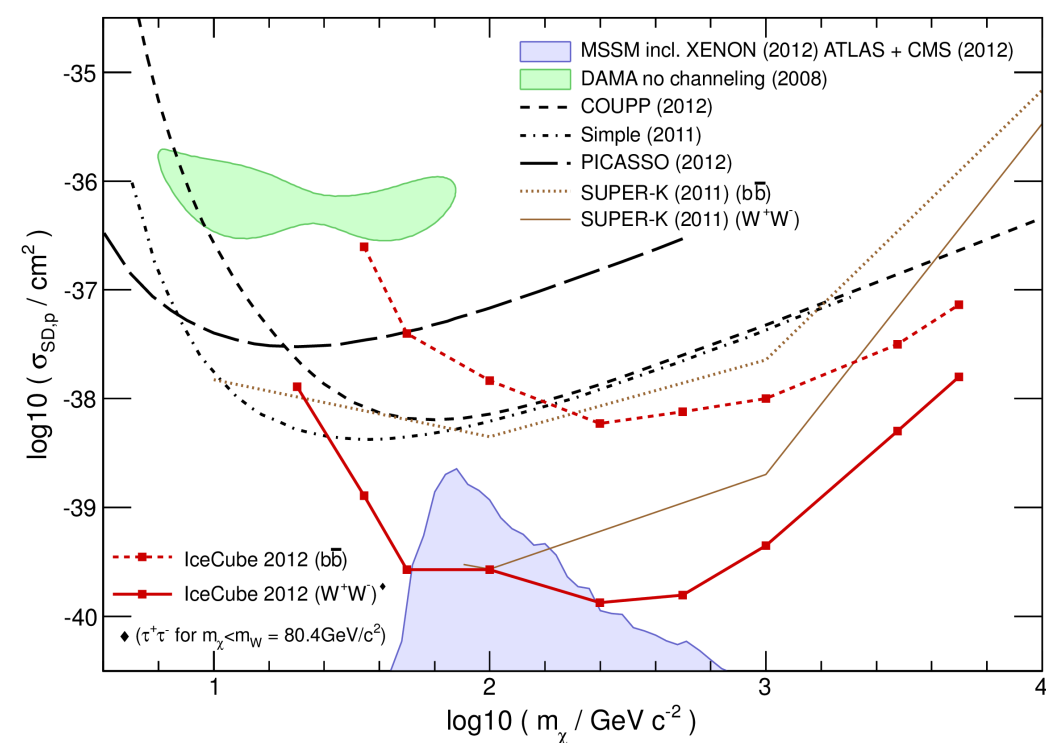
Solar WIMP search results (cross-section limit)



SI WIMP-proton cross-section limit



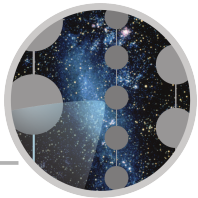
SD WIMP-proton cross-section limit



- 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

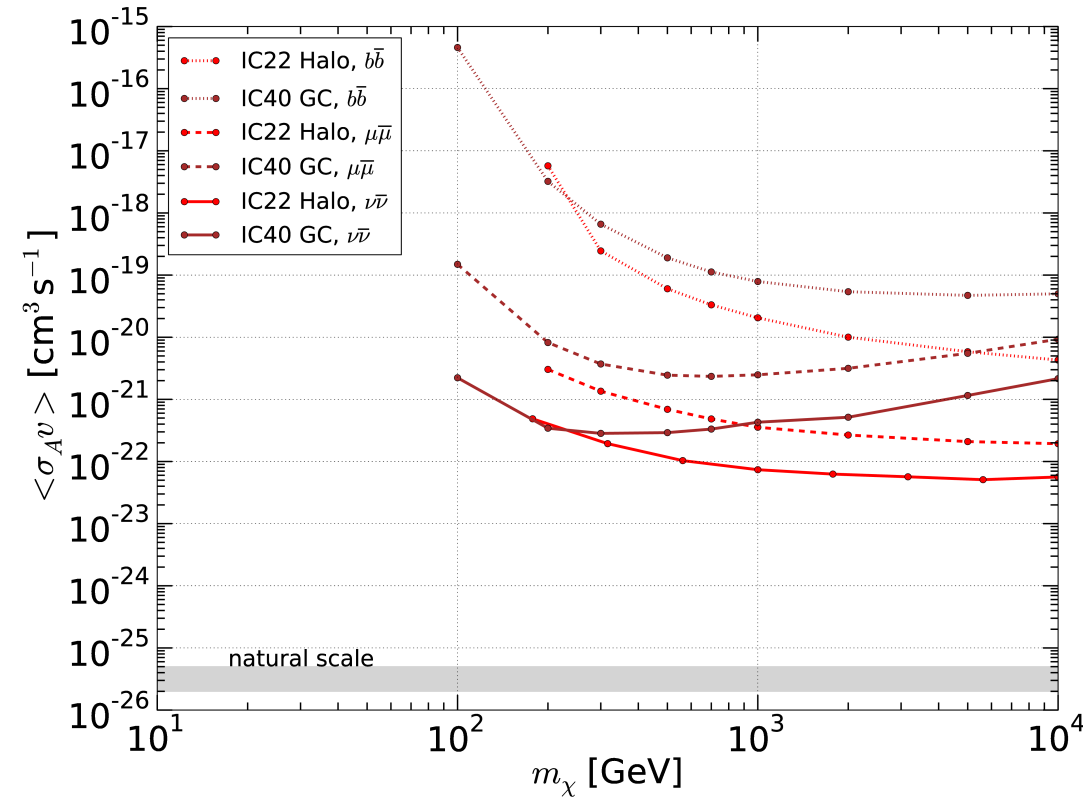
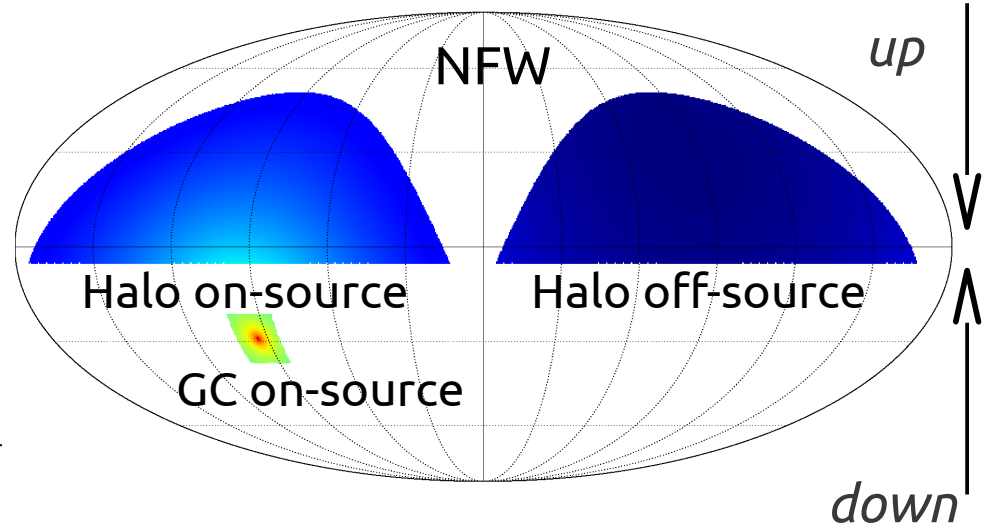
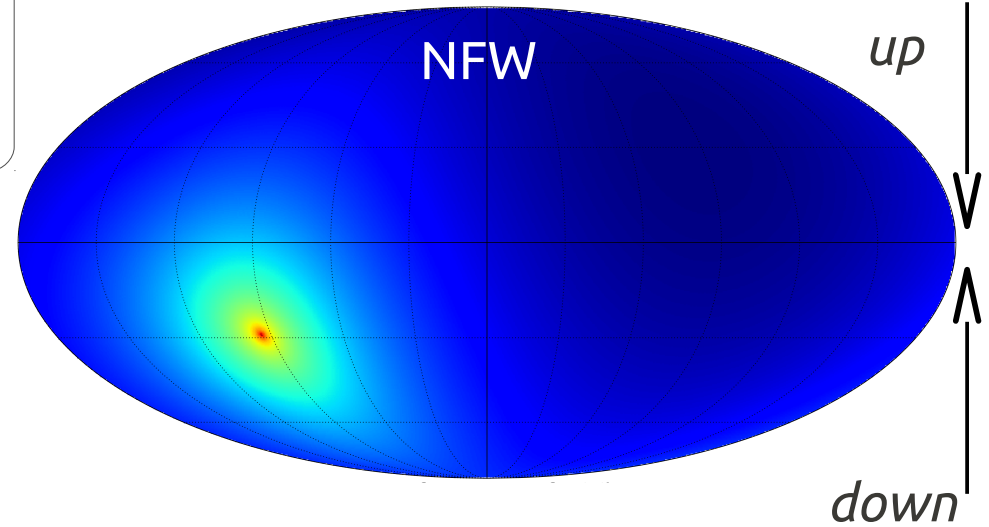
Galactic Dark Matter searches (first analyses)



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

(equatorial coordinates)





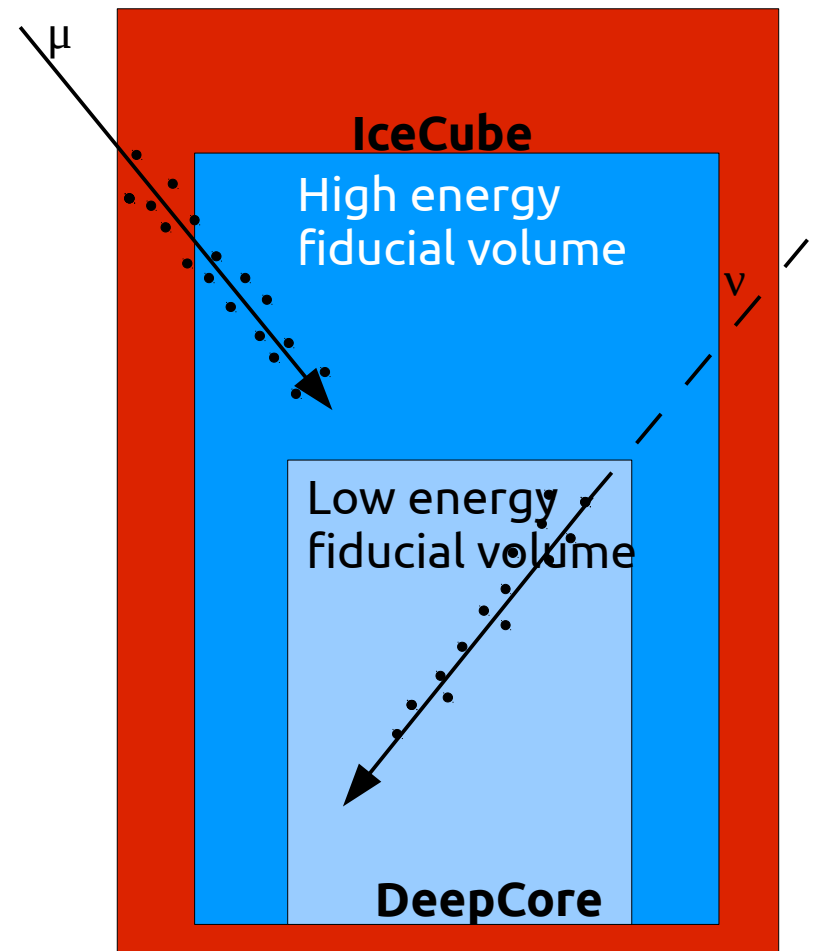
- Searching for neutrinos from self-annihilating *WIMPs in the GC*
- WIMP masses between *30 GeV* and *10 TeV*
- 79 string configuration of IceCube (*320 live days of 2010 - 2011*)

2 independent analyses:

Low-Energy ($m_\chi < 300 \text{ GeV}$)

High-Energy ($m_\chi > 300 \text{ GeV}$)

- Identifying starting events opens up the Southern Sky for IceCube.



Galactic Dark Matter searches (IceCube-79)



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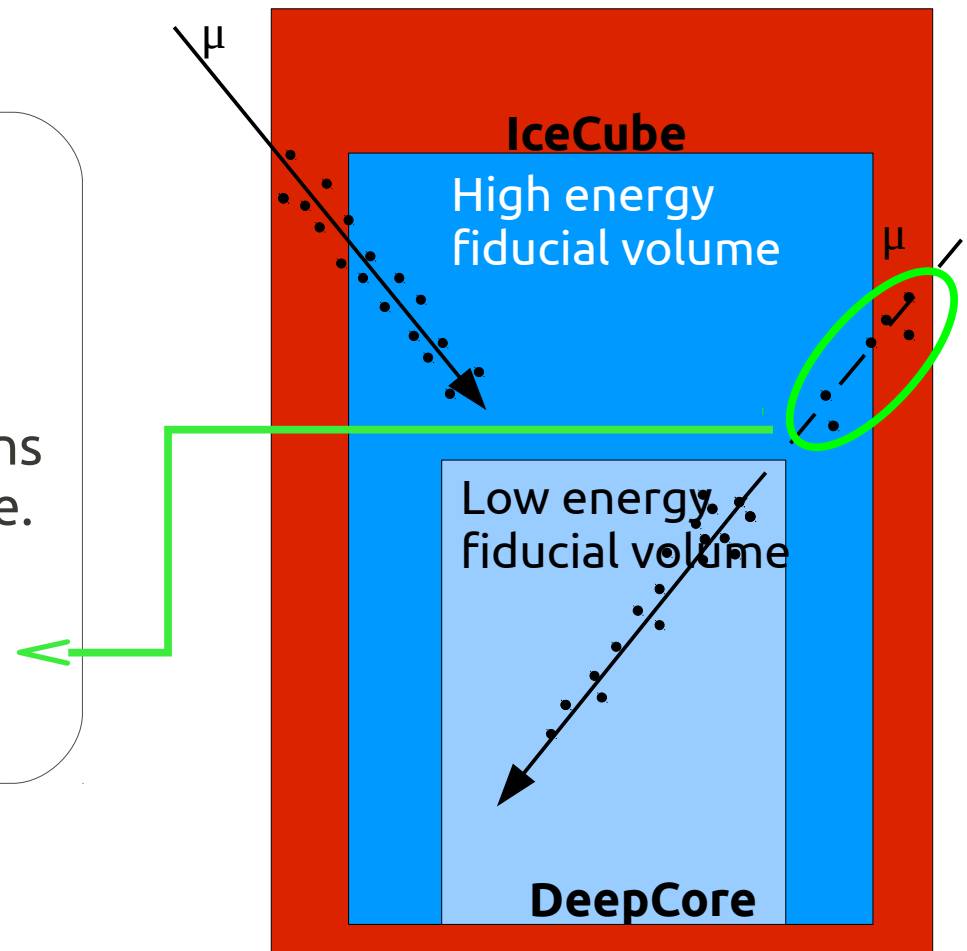
- Searching for neutrinos from self-annihilating *WIMPs in the GC*
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- 79 string configuration of IceCube (*320 live days of 2010 - 2011*)

2 independent analyses:

Low-Energy ($m_x < 300 \text{ GeV}$)

High-Energy ($m_x > 300 \text{ GeV}$)

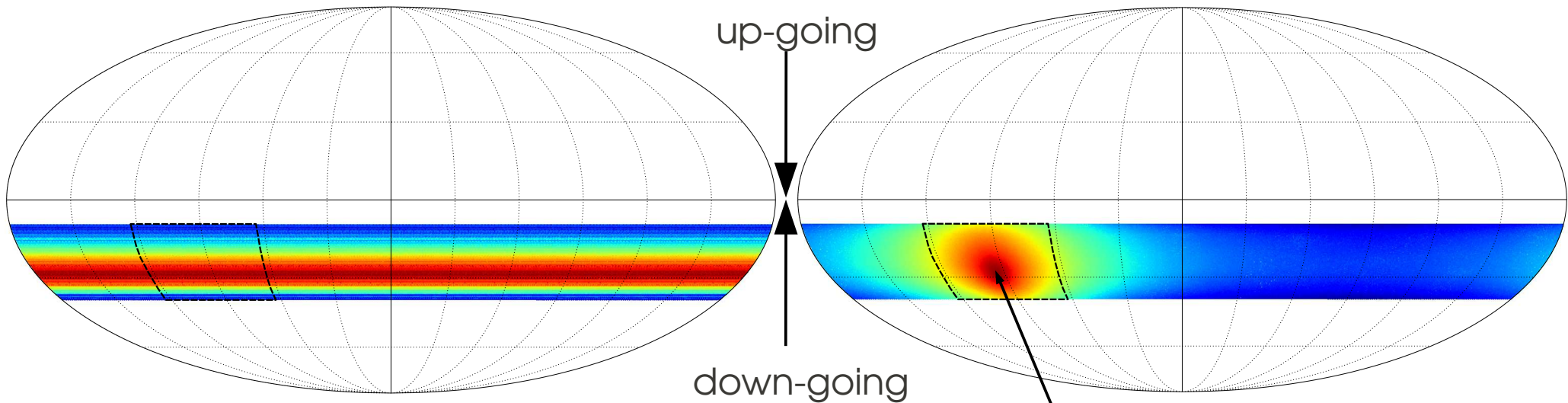
- Identifying starting events opens up the Southern Sky for IceCube.
- Both analyses rely on veto methods to reject incoming tracks.



2D skymap PDFs generated with healpix (equatorial coordinates)

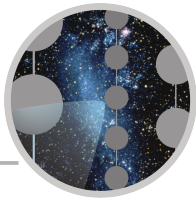
scrambled background

signal



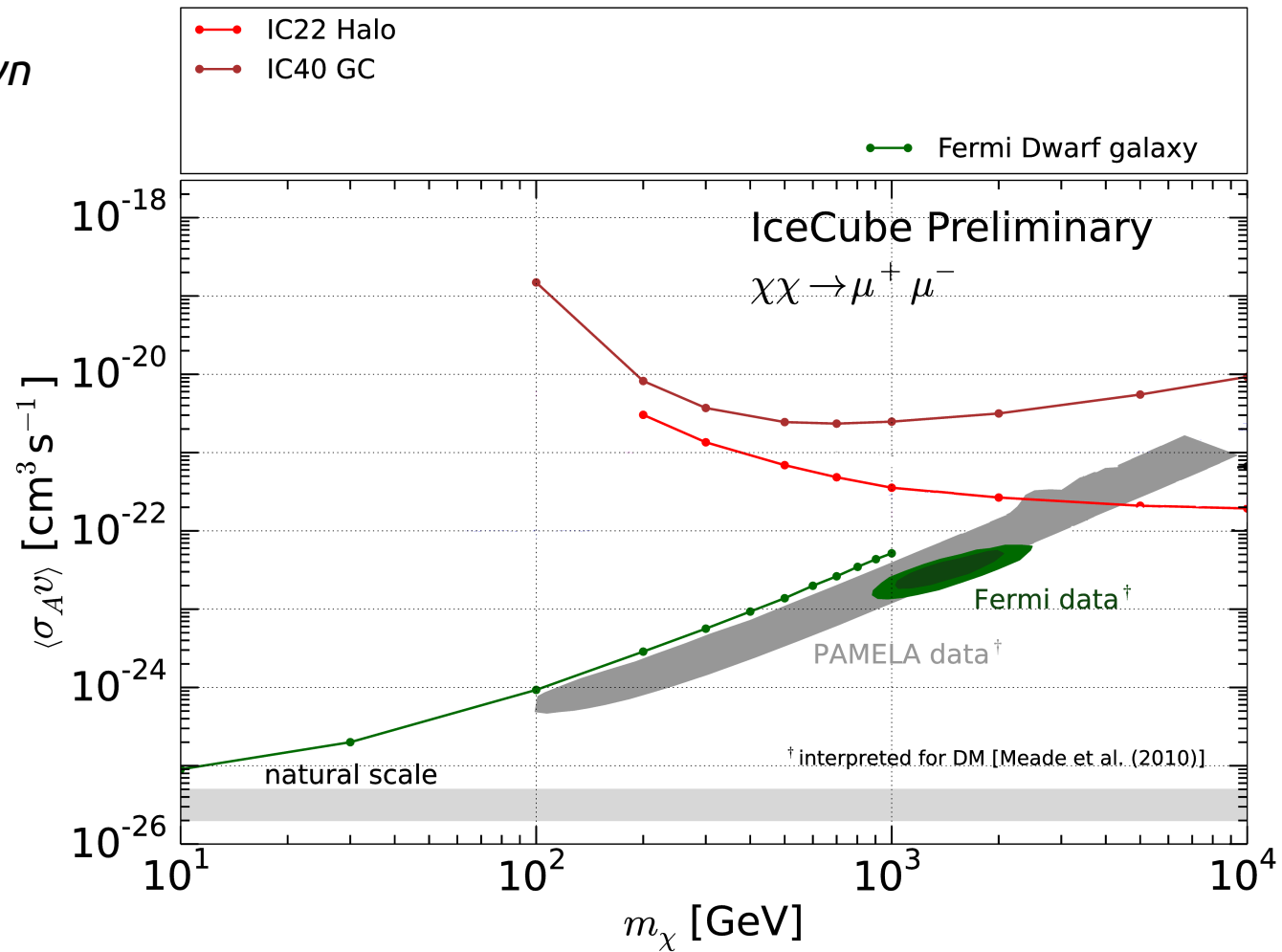
Galactic Center @ 266° RA; -29° Dec

Galactic Dark Matter searches (IceCube-79)



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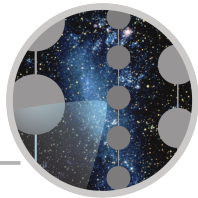
(IceCube results shown for NFW profile)



Search for many interesting potential annihilation channels:
 (Various DM-Halo models tested)

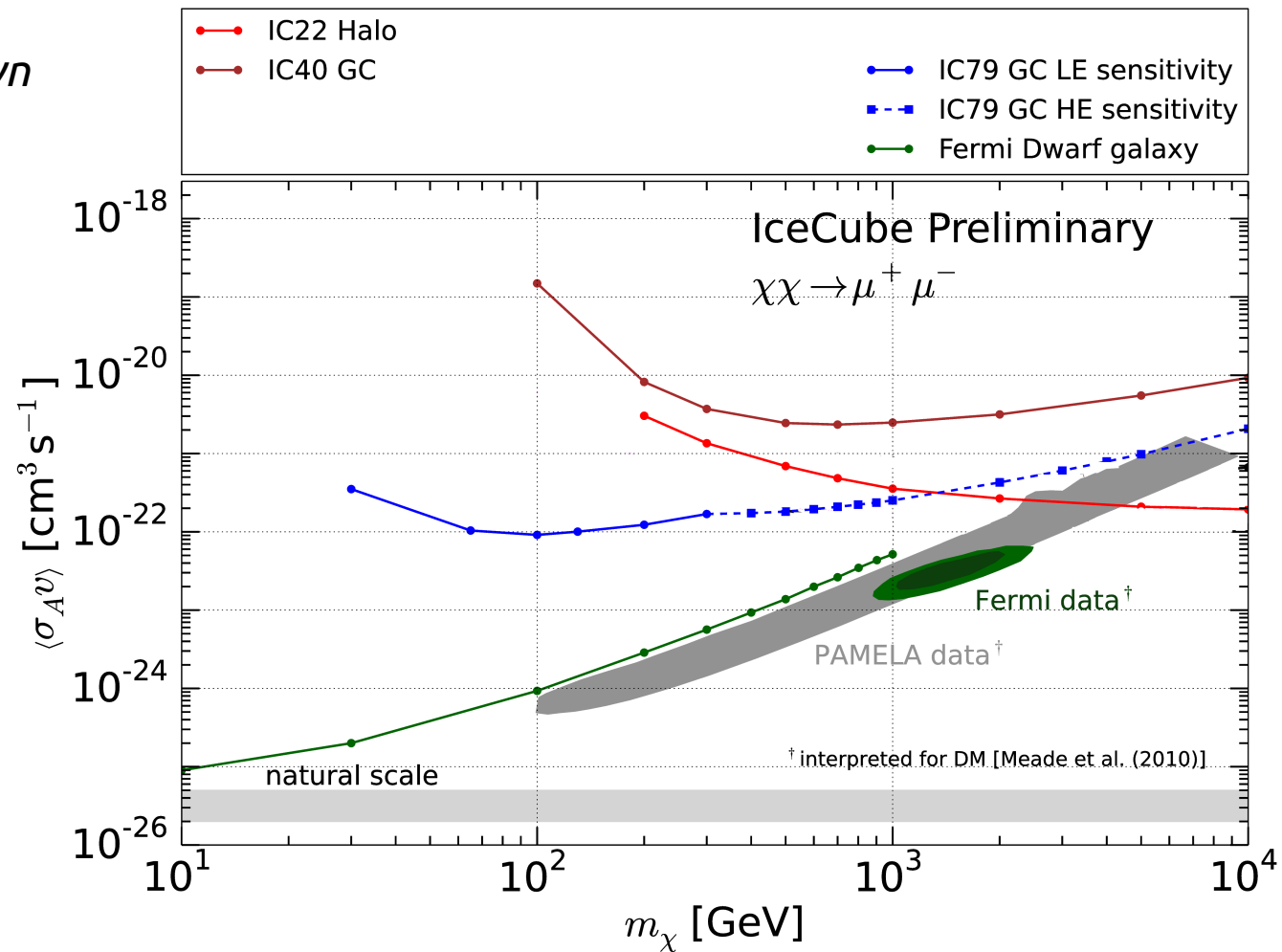
$$\chi\chi \begin{cases} \nu \bar{\nu}, \mu^+ \mu^-, \tau^+ \tau^-, W^+ W^-, b \bar{b} \\ Z^0 Z^0, Z^0 \gamma \end{cases}$$

Galactic Dark Matter searches (IceCube-79)



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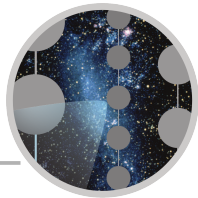
(IceCube results shown for NFW profile)



IceCube-79 Galactic Center analysis (sensitivity):

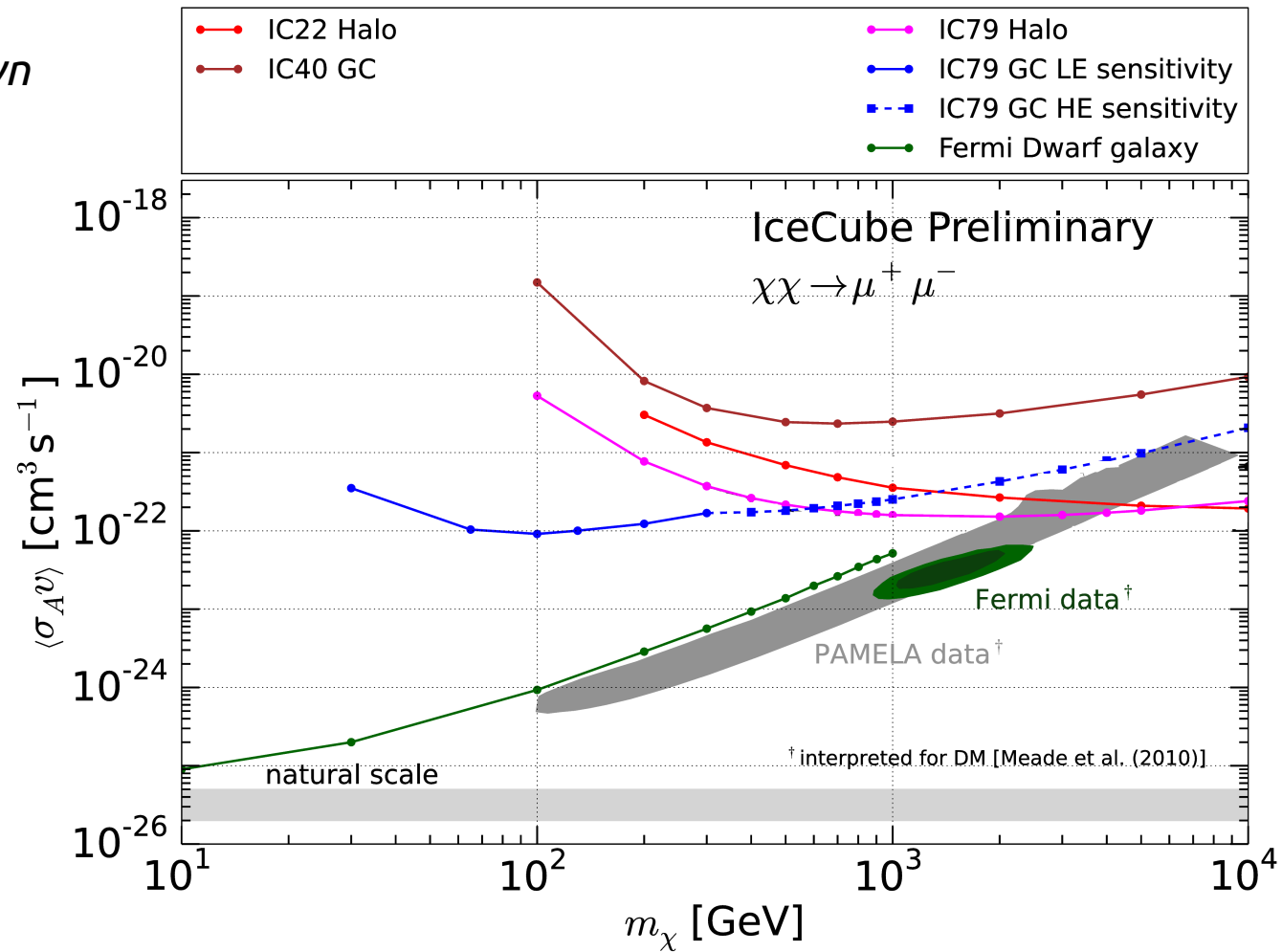
- First IceCube analysis looking at GC for low WIMP masses (< 100 GeV)
- 4 orders of magnitude improved sensitivity @ 100 GeV
- Unblinding is going on within the collaboration

Galactic Dark Matter searches (IceCube-79)



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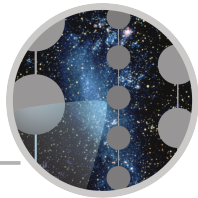
(IceCube results shown for NFW profile)



IceCube-79 Multipole analysis to search for Dark Matter in the Galactic Halo:

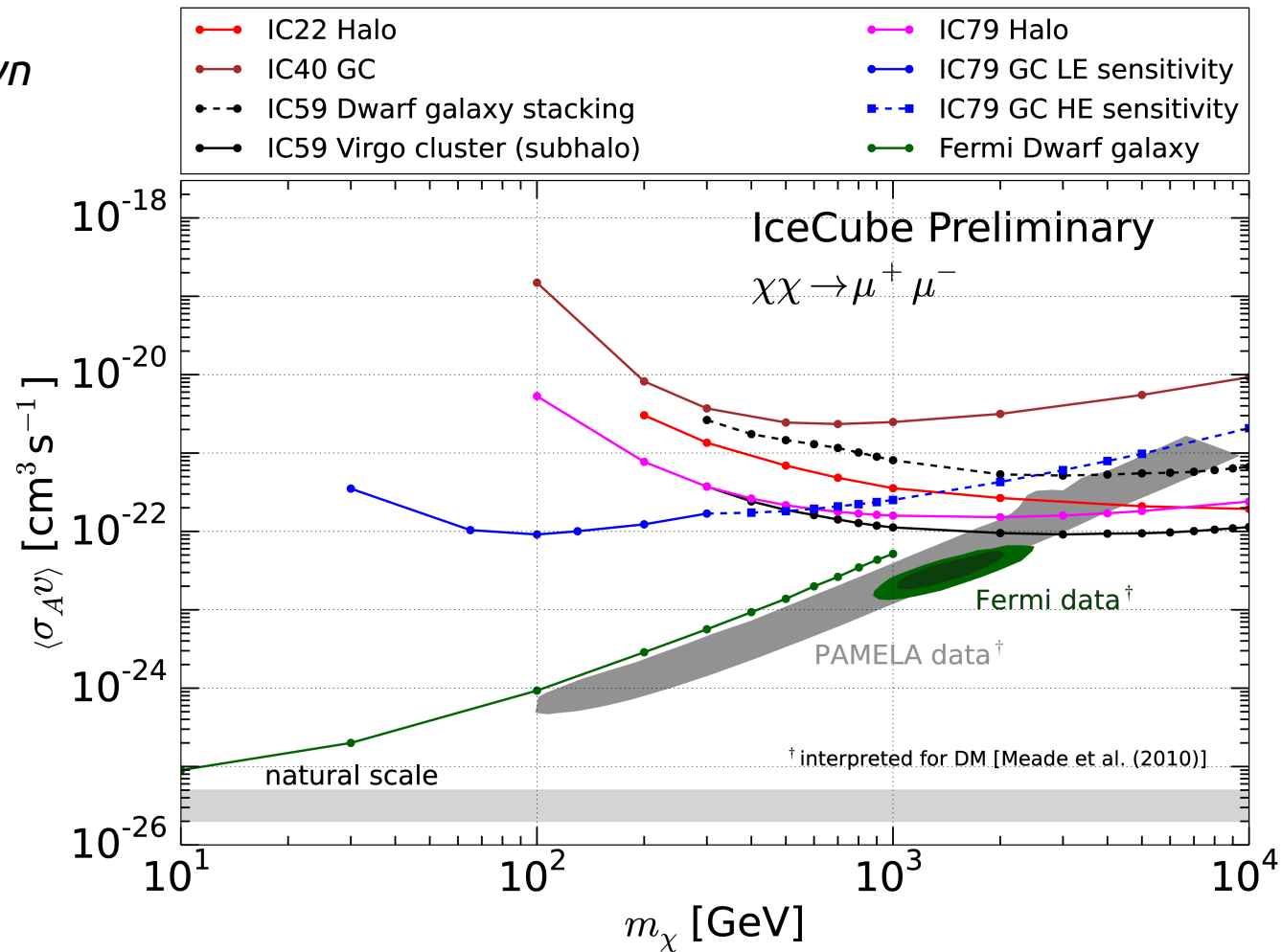
- focus on large scale anisotropies ($l < 100$)
- small Halo-model dependency
- results are compatible with the background-only hypothesis

Galactic Dark Matter searches (IceCube-79)



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(IceCube results shown for NFW profile)



IceCube-59 Dwarf galaxy searches:

- Source stacking analysis
- Optimized size of search window

IceCube-59 Galaxy cluster analysis:

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

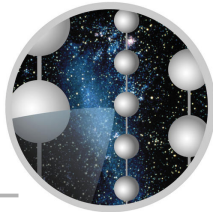
Summary



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- **Striking** WIMP signatures provide **high discovery potential** for indirect searches with neutrinos
- **DeepCore** plays crucial role in IceCube Dark Matter analyses
- 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,

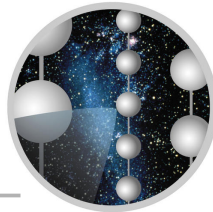




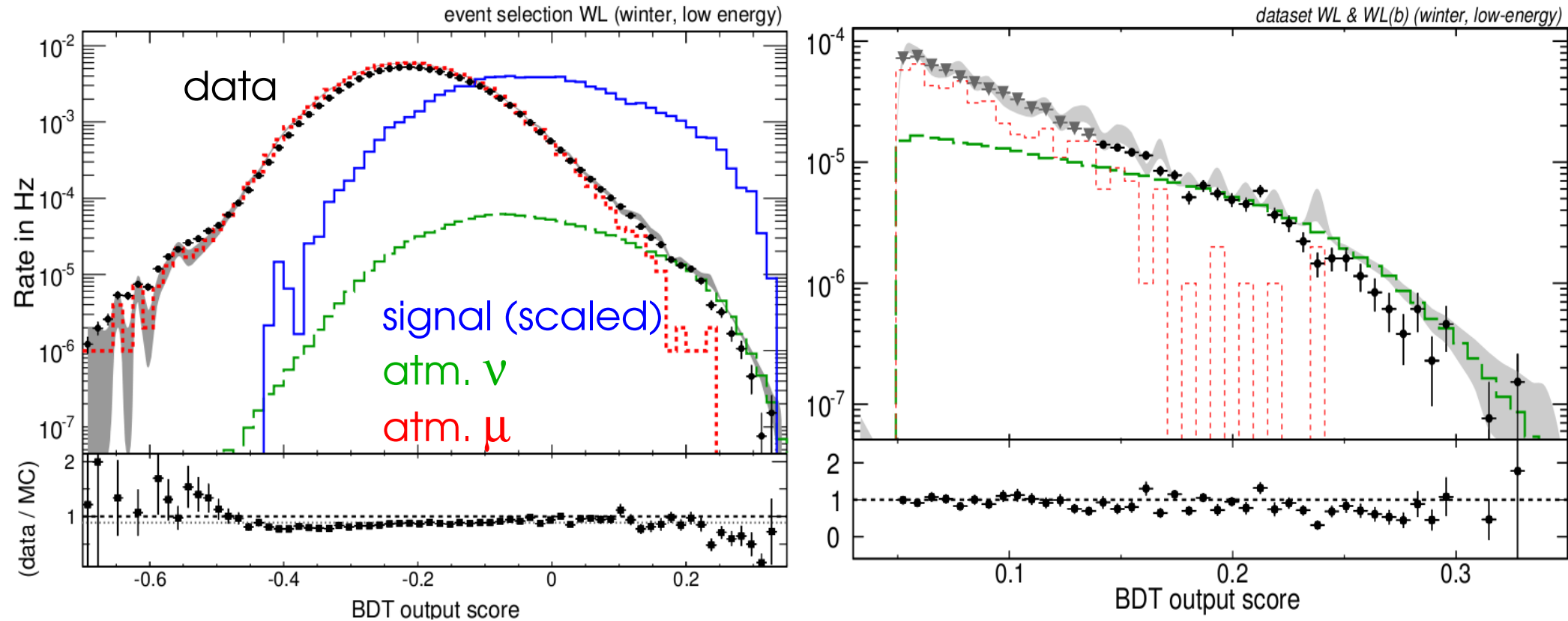
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Additional slides

Multivariate analysis step (BDT variable)

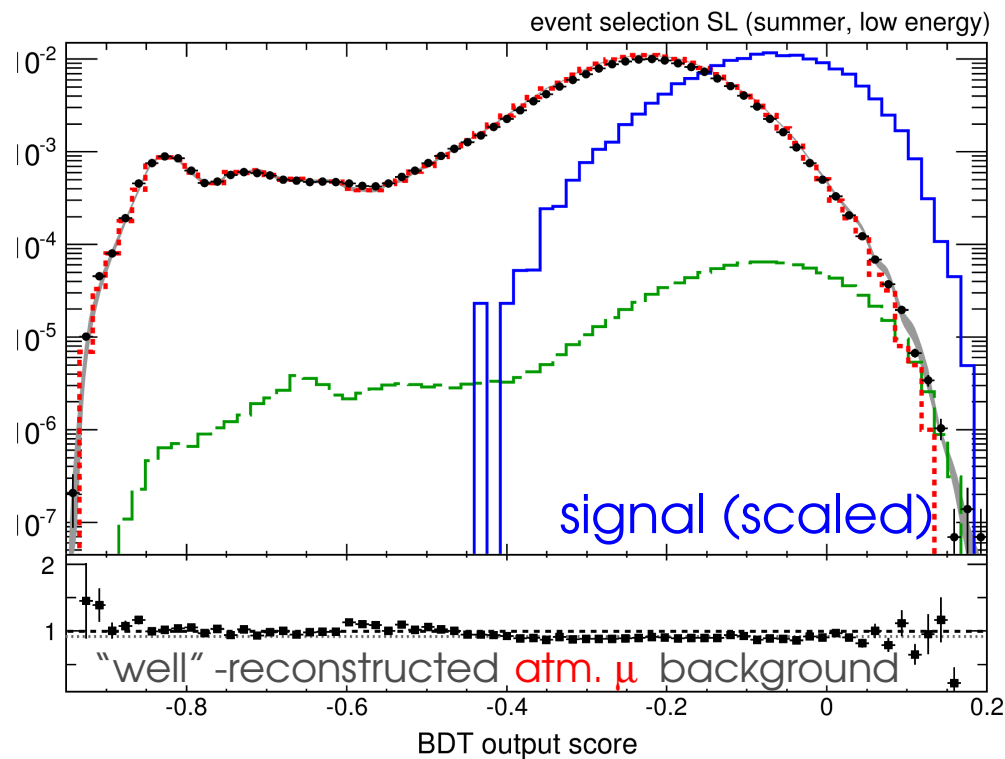
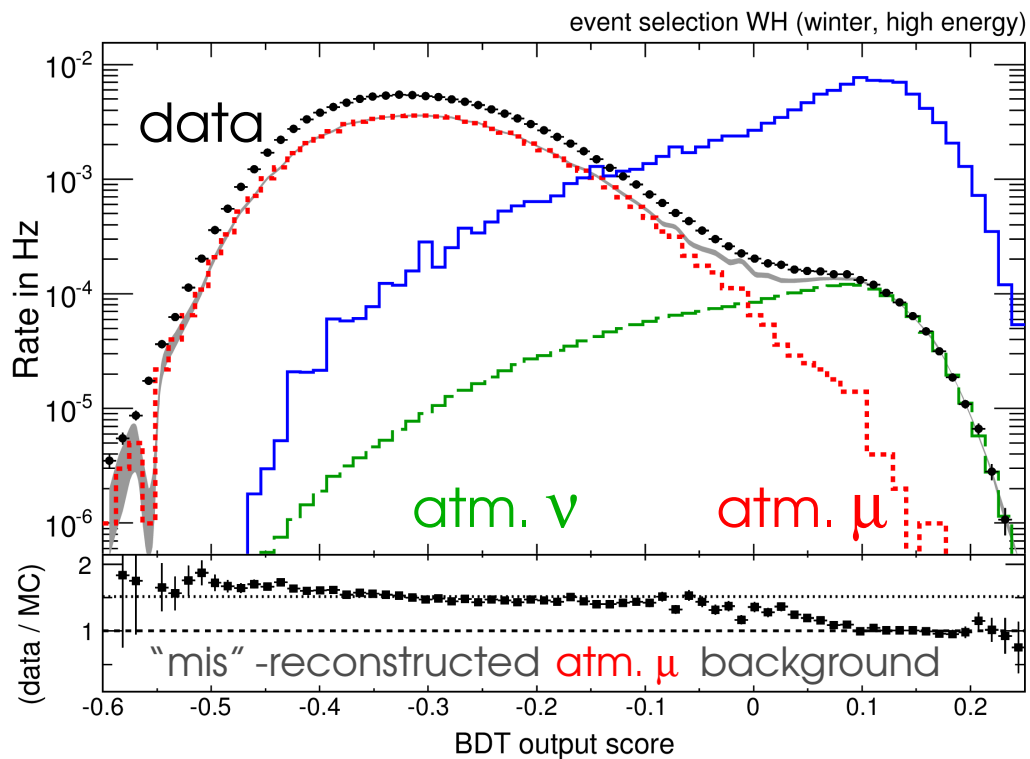


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- 1 separate BDT for each event selection
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Multivariate analysis step (BDT variable)



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