Results from a search for Dark Matter Captured in the Sun with IceCube

in the 79 -string configuration

Matthias Danninger,
The Oscar Klein Centre for Cosmoparticle Physics, Stockholm University

Partikeldagarna, Stockholm, November 2012

ICECUBE

Oscar Klein centre

? ? *Including the* ? ? ?

***N**on-**P**recision-**I**ceCube-**N**ext-**G**eneration_**U**pgrade*

(DeepCore)

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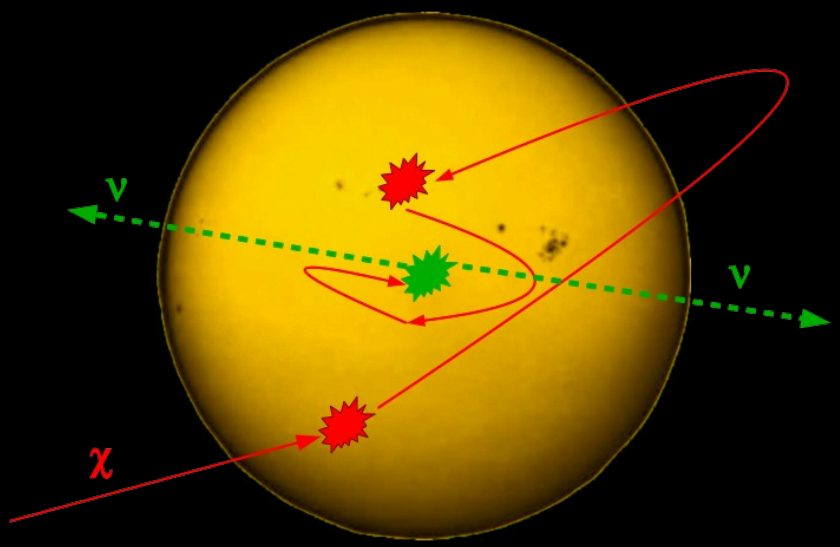
Solar Dark Matter Search with IceCube

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

Sofia Sivertsson's talk:
"WIMP diffusion in the Solar System and the neutrino signal from the Sun and the Earth"



Proposed by:

Silk, Olive & Srednicki '85
Gaisser, Steigman & Tilav '86
Freese '86
Krauss, Srednicki & Wilzcek '86

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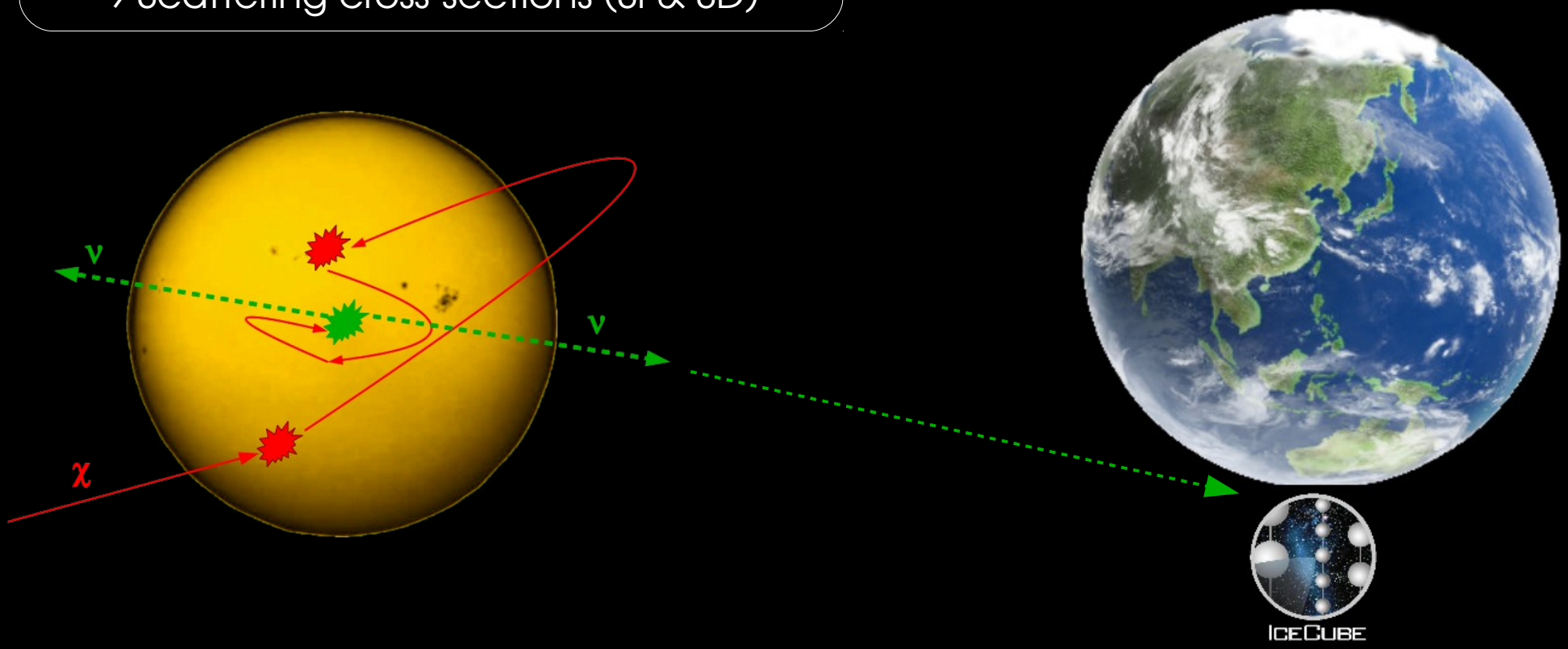

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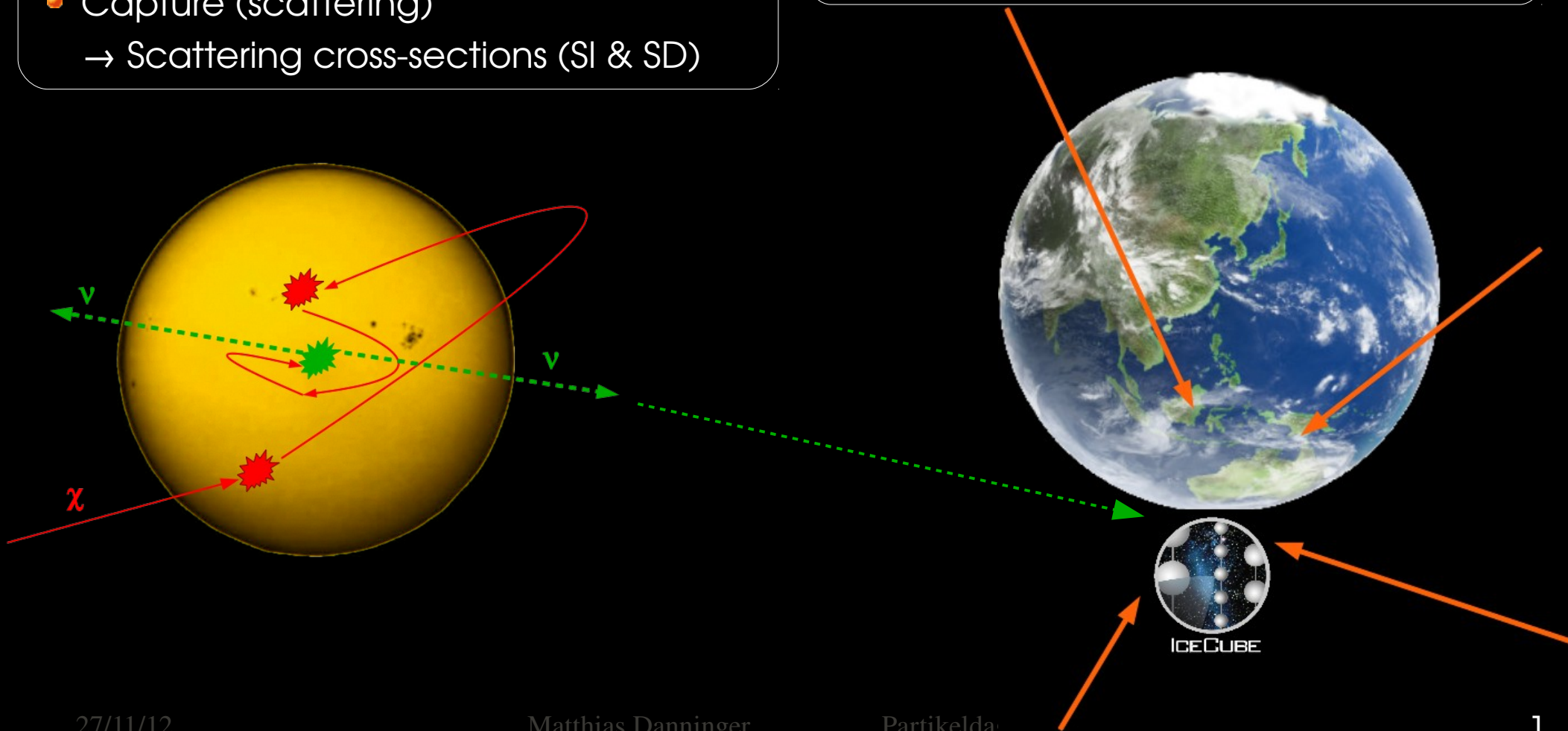
atm. $\nu \sim O$ (10^3 triggering events/day)



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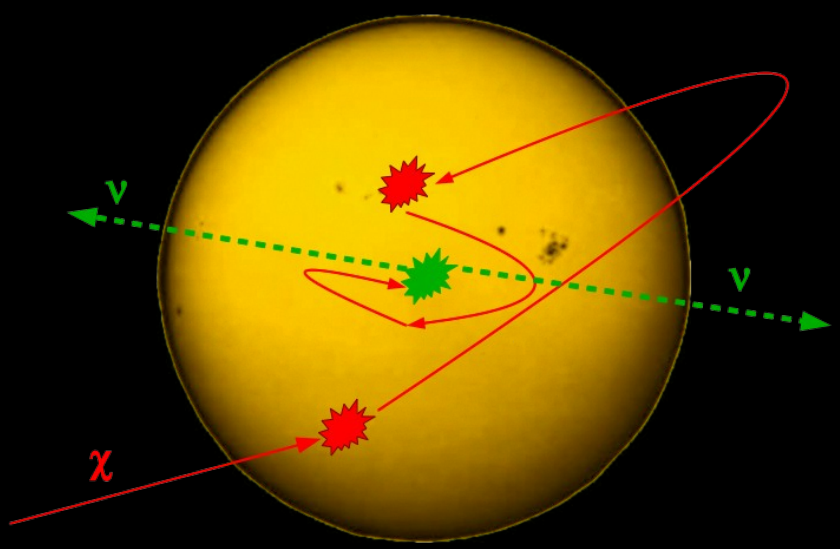

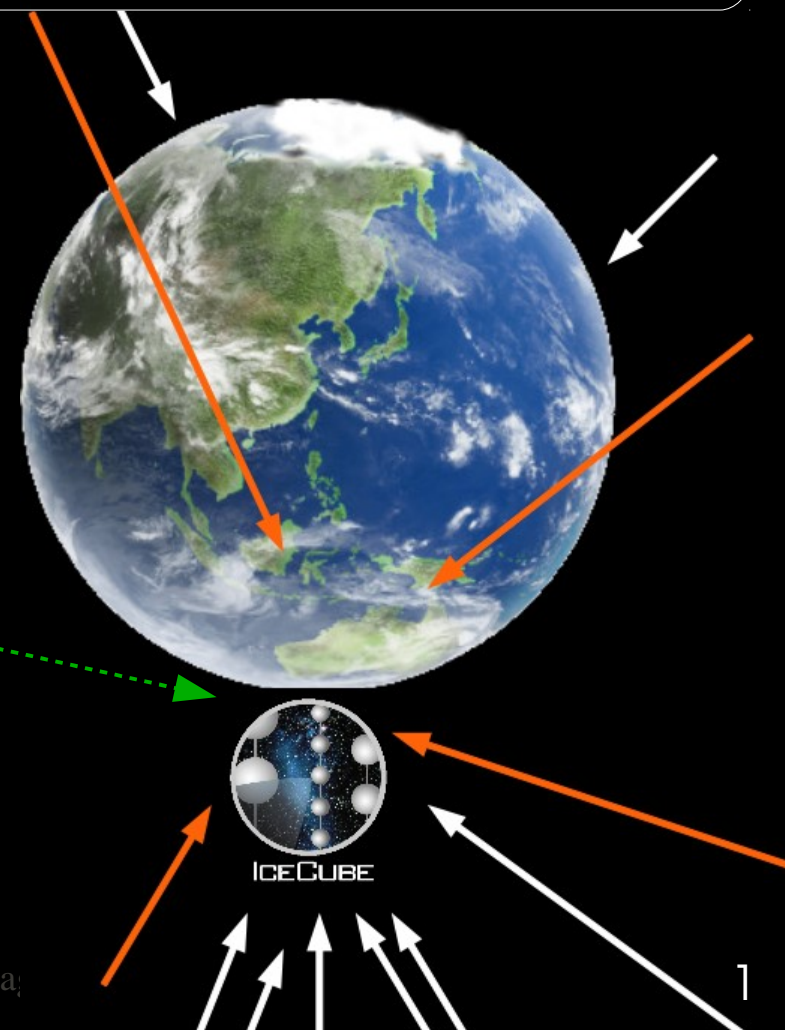

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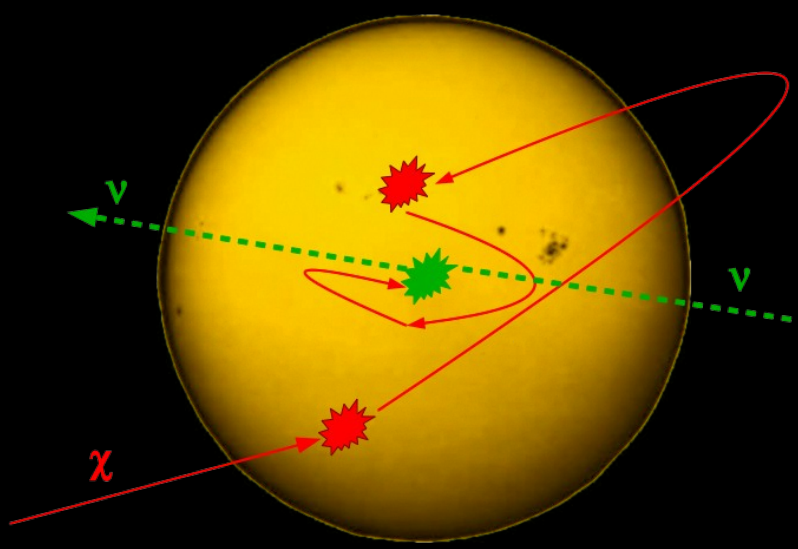
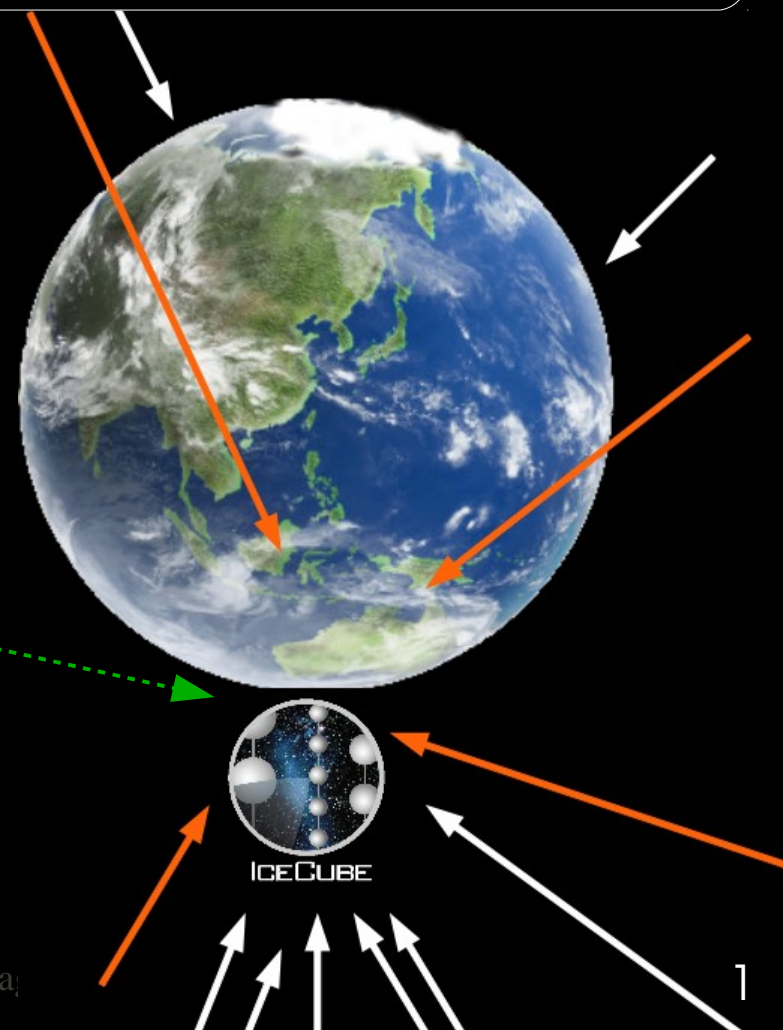
Striking signature:

High-E ν excess over background from Sun direction





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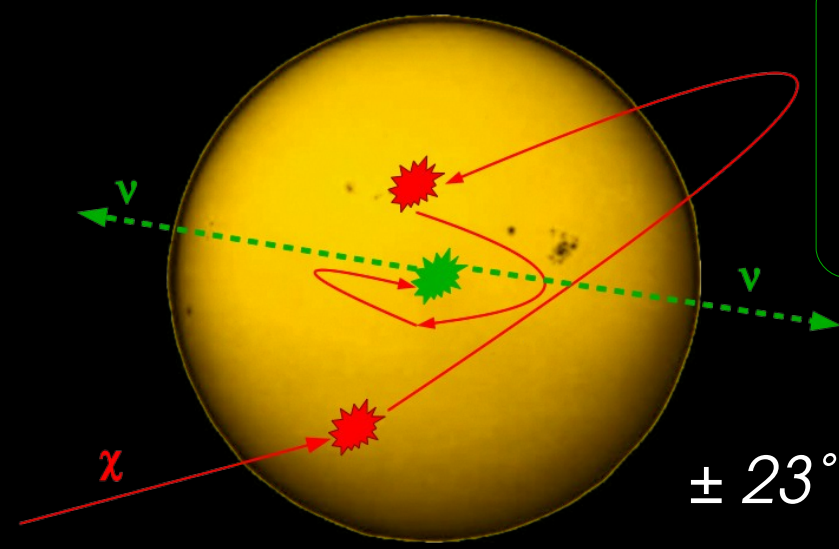
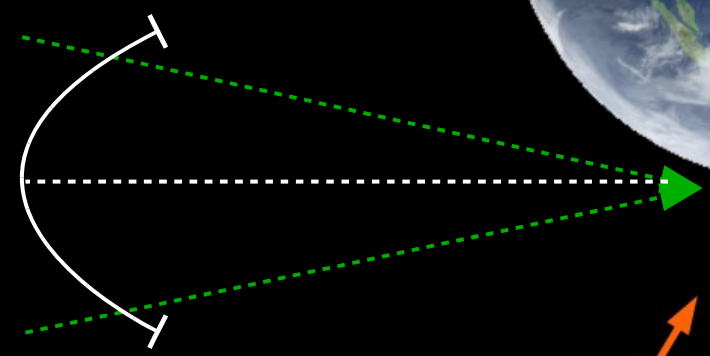
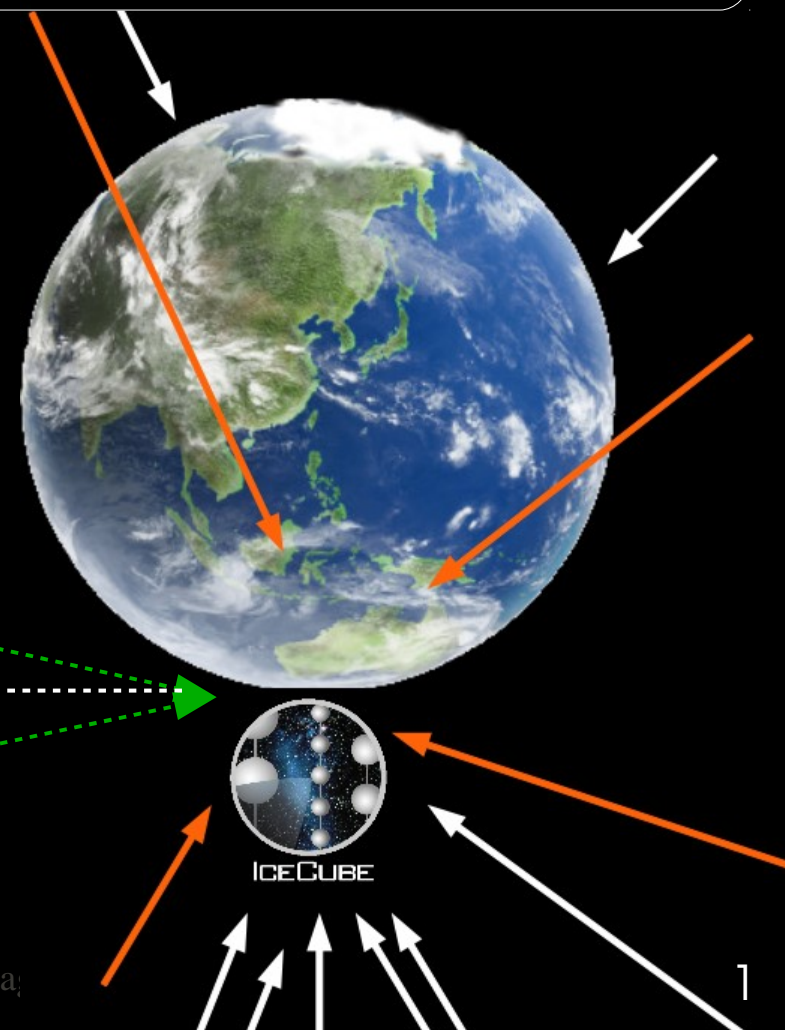




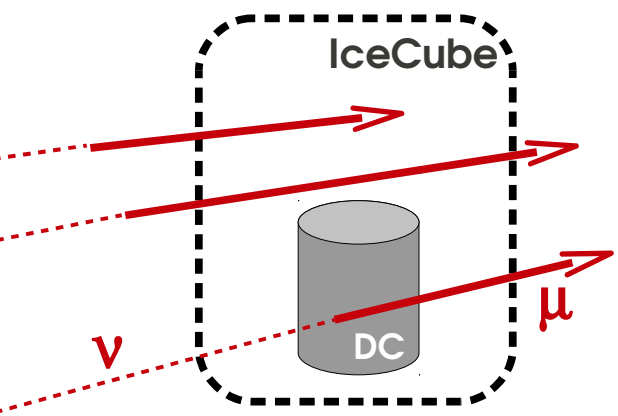


**Blind analysis with respect to true Sun azimuth*

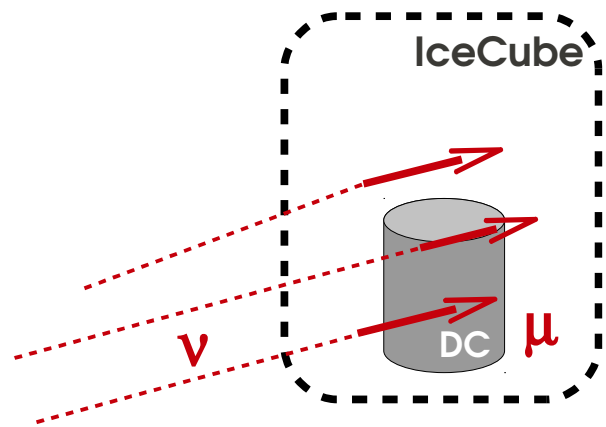
IceCube-79 string analysis details

- 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)
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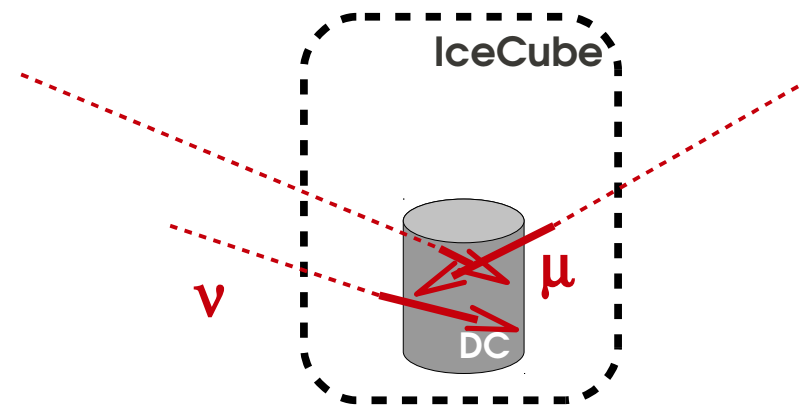

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Facts: *max pile-up (3 to 4) with an average pile-up ~1.201*

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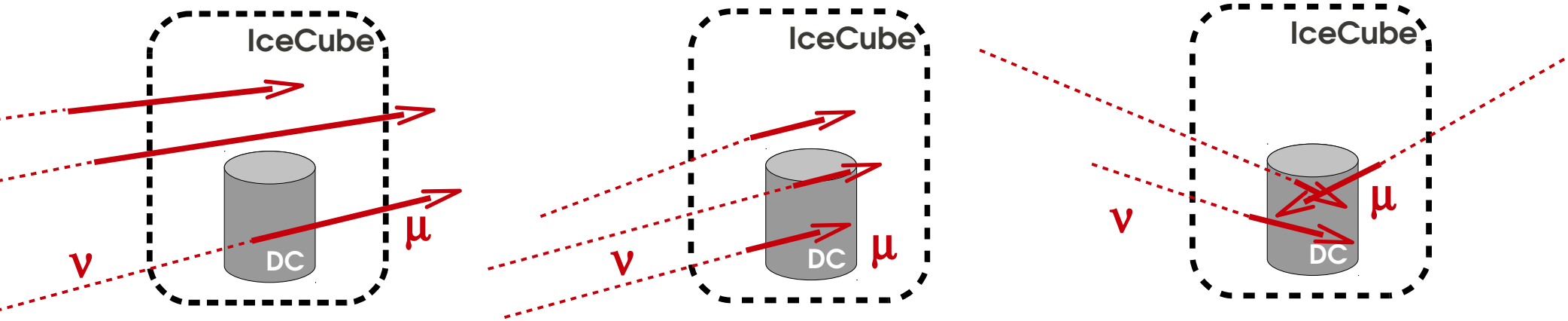

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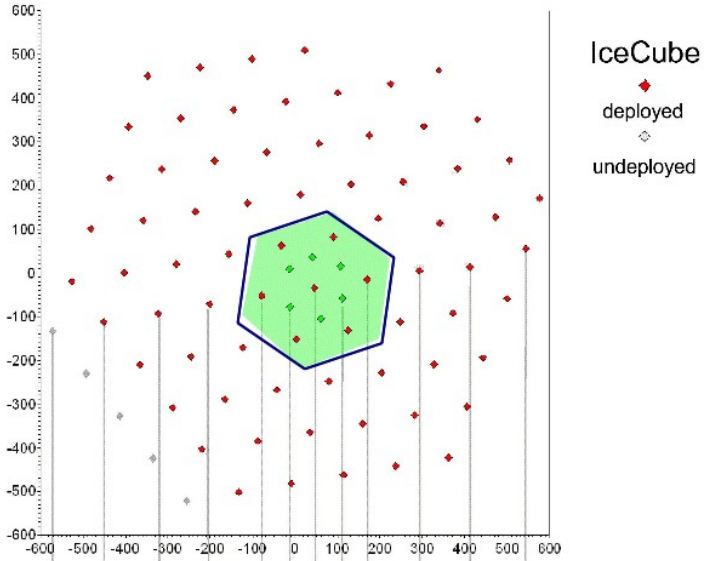

- By comparing signal simulation & data, cuts are placed that reduces the content of atmospheric muon events
- *Early analysis cuts:*
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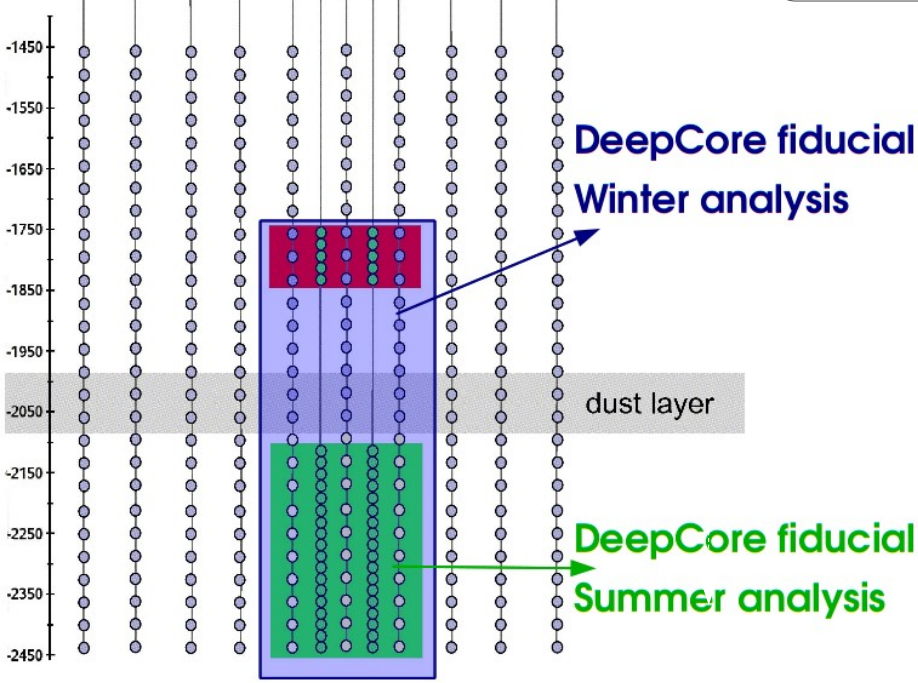
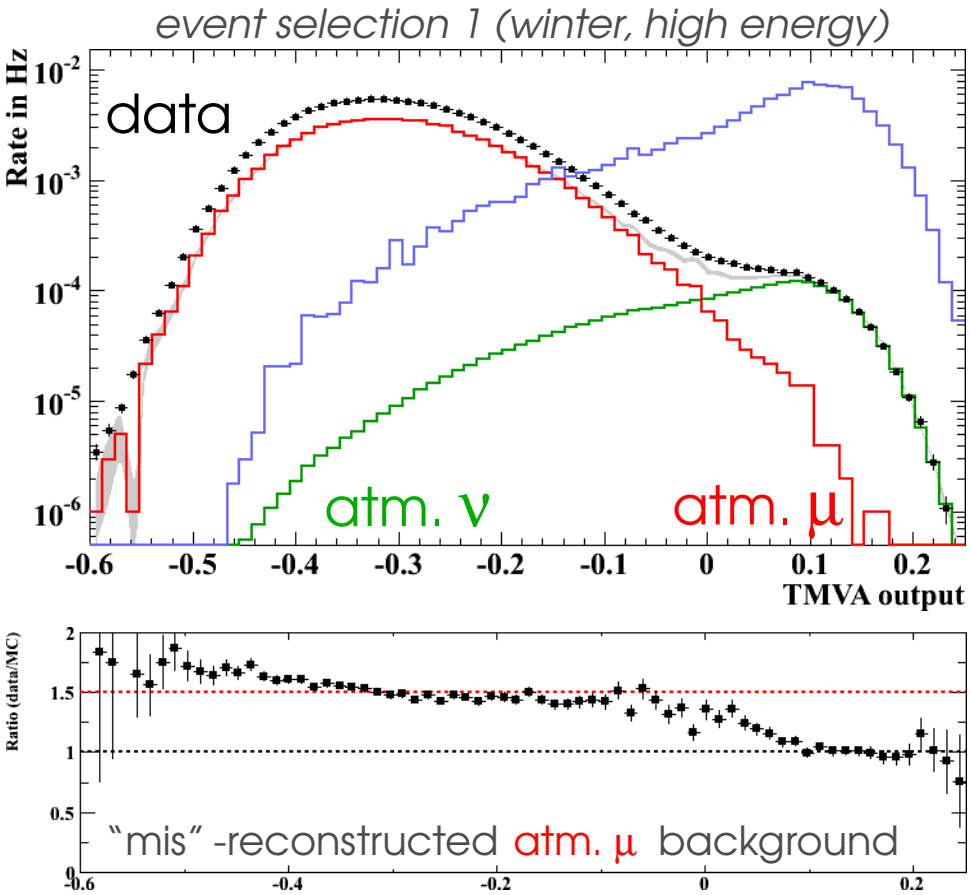
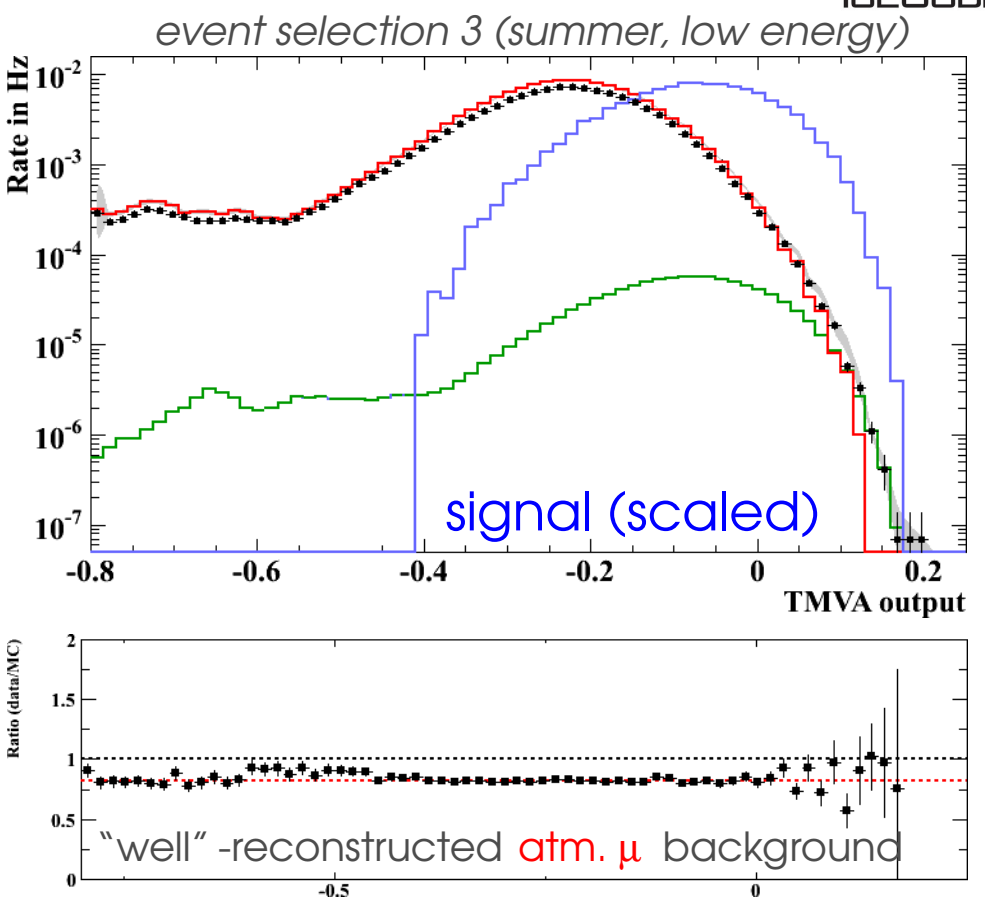


- Signal event topology very different for low & high WIMP mass
  → find *geometrical cut* to split dataset into 2 non-overlaping datasets

Multivariate analysis step (BDT variable)

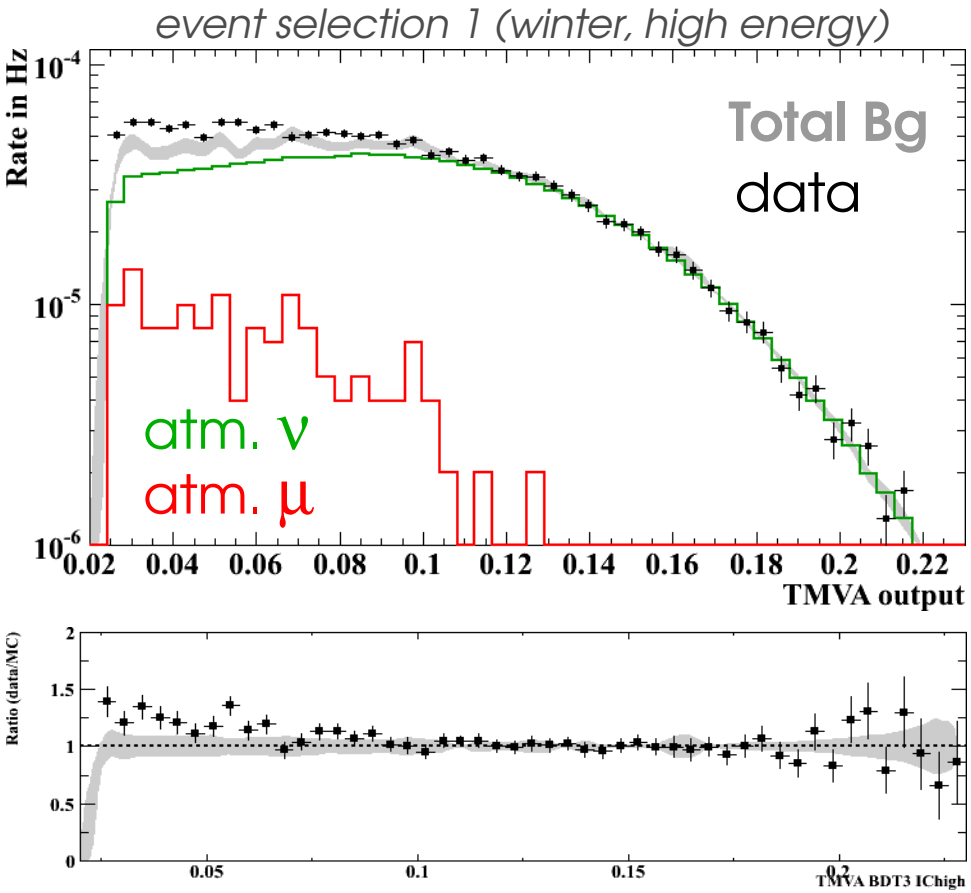


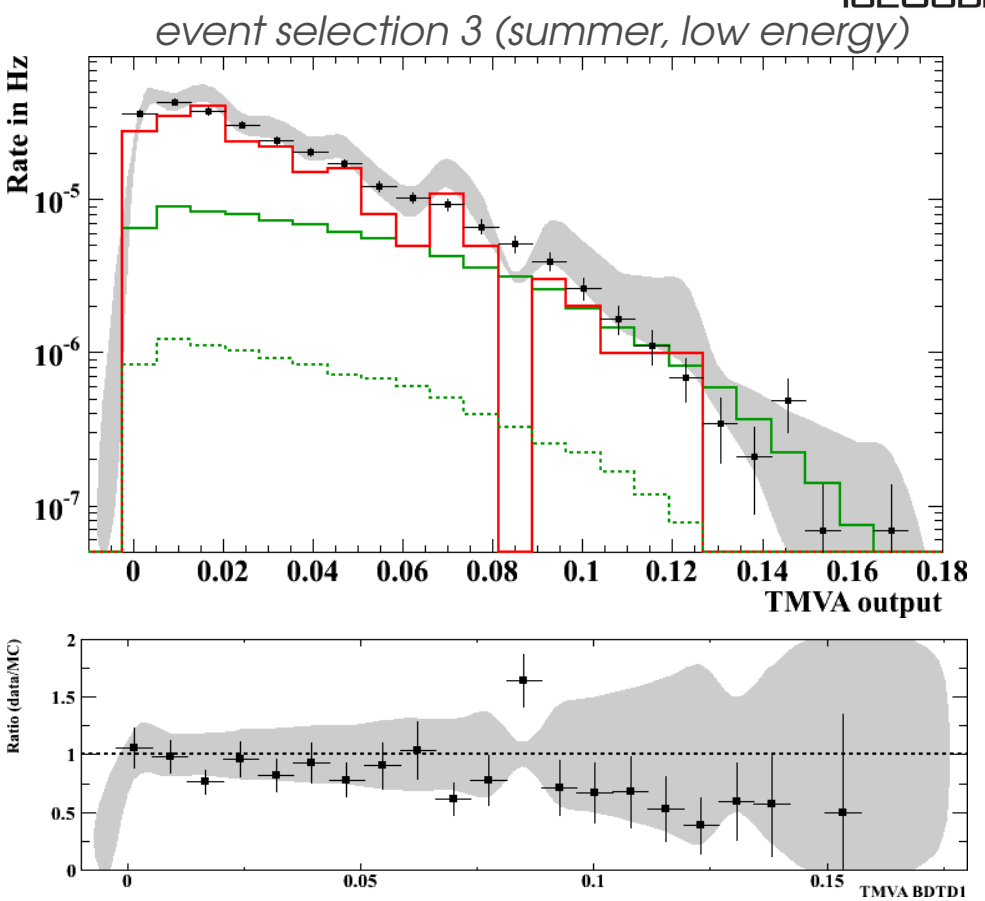


→ ***1*** separate BDT for each event selection

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

Multivariate analysis step (final cut applied)





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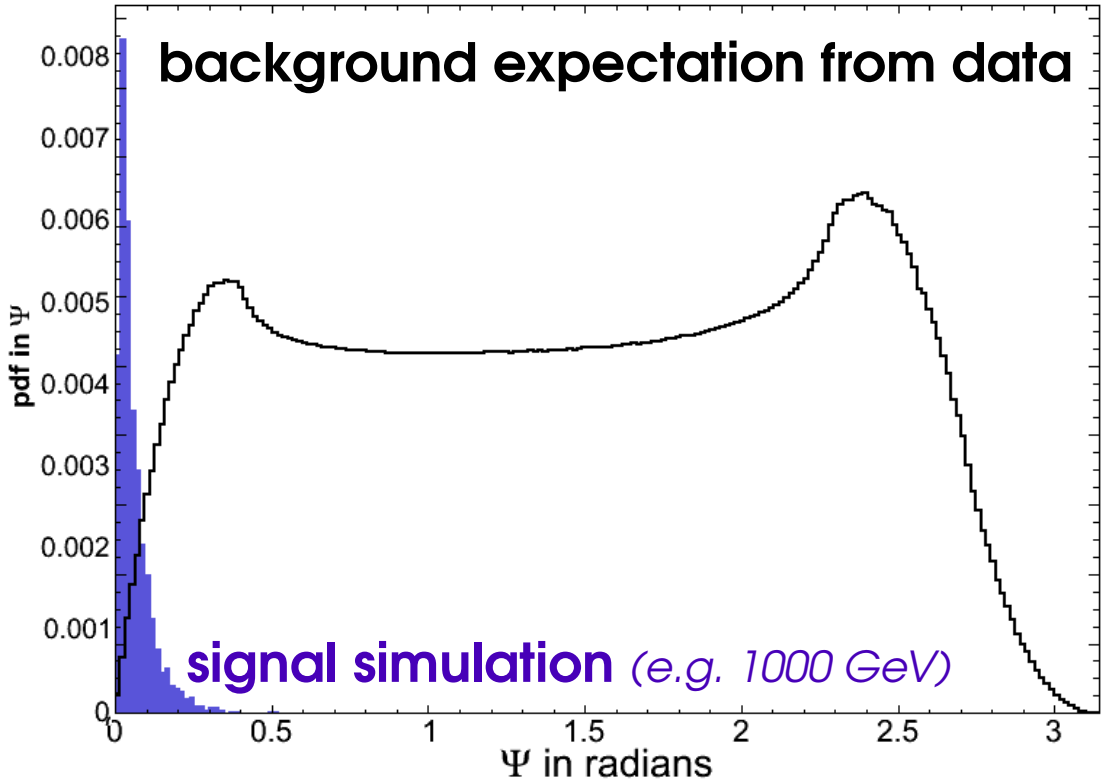
→ Optimized final cut on BDT-output: run llh-analysis for various BDT cuts, to determine cut value with best sensitivity (MRF & MDP)

Maximum llh-analysis

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



Angle between event track and direction from the Sun

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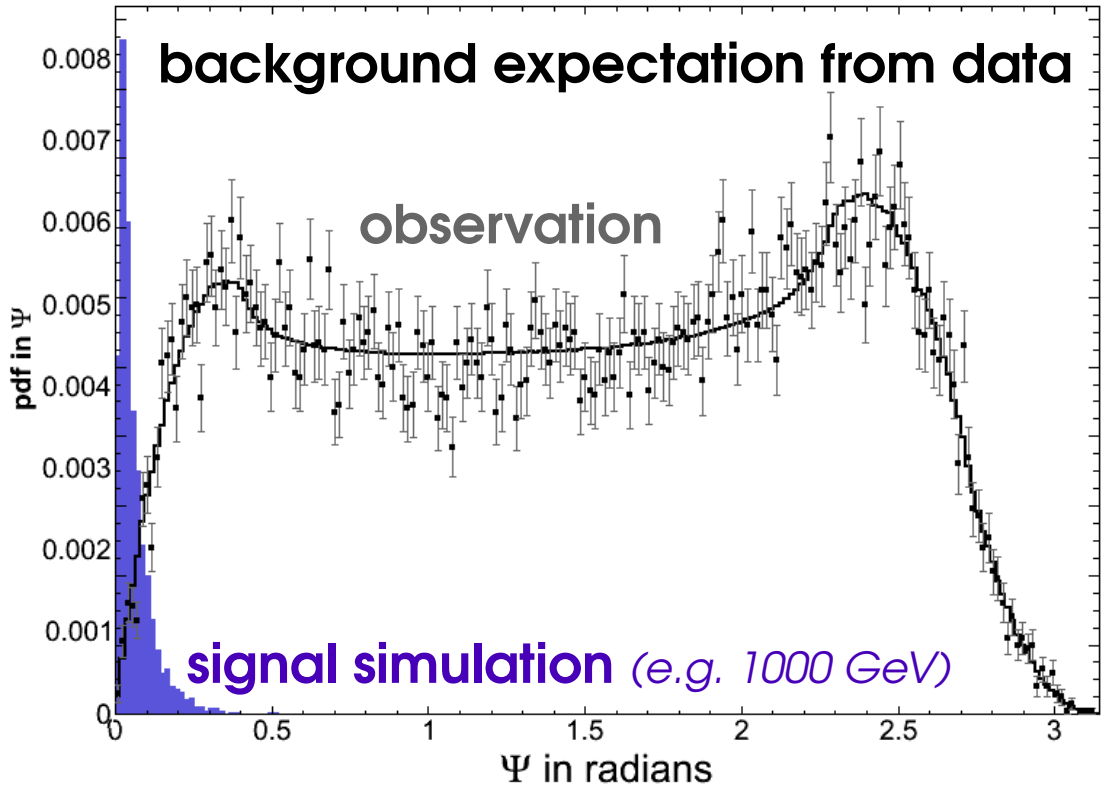
How many signal events can be consistent with the *observation*?

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

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

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



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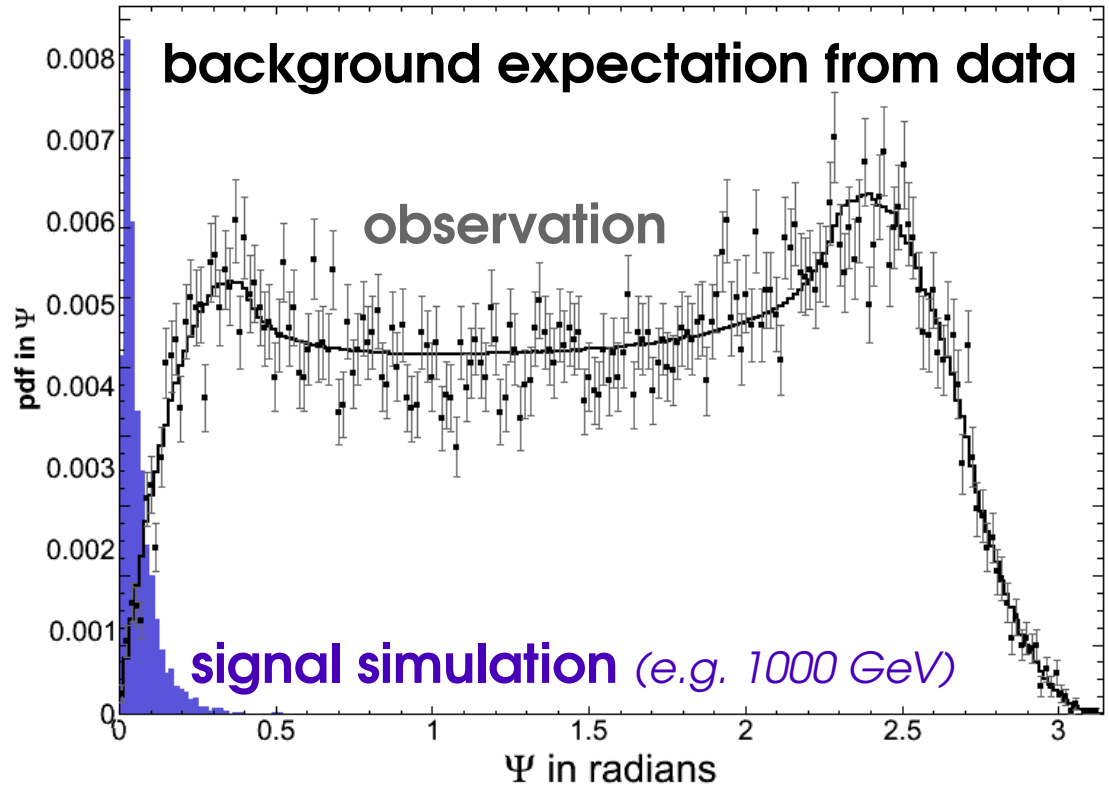

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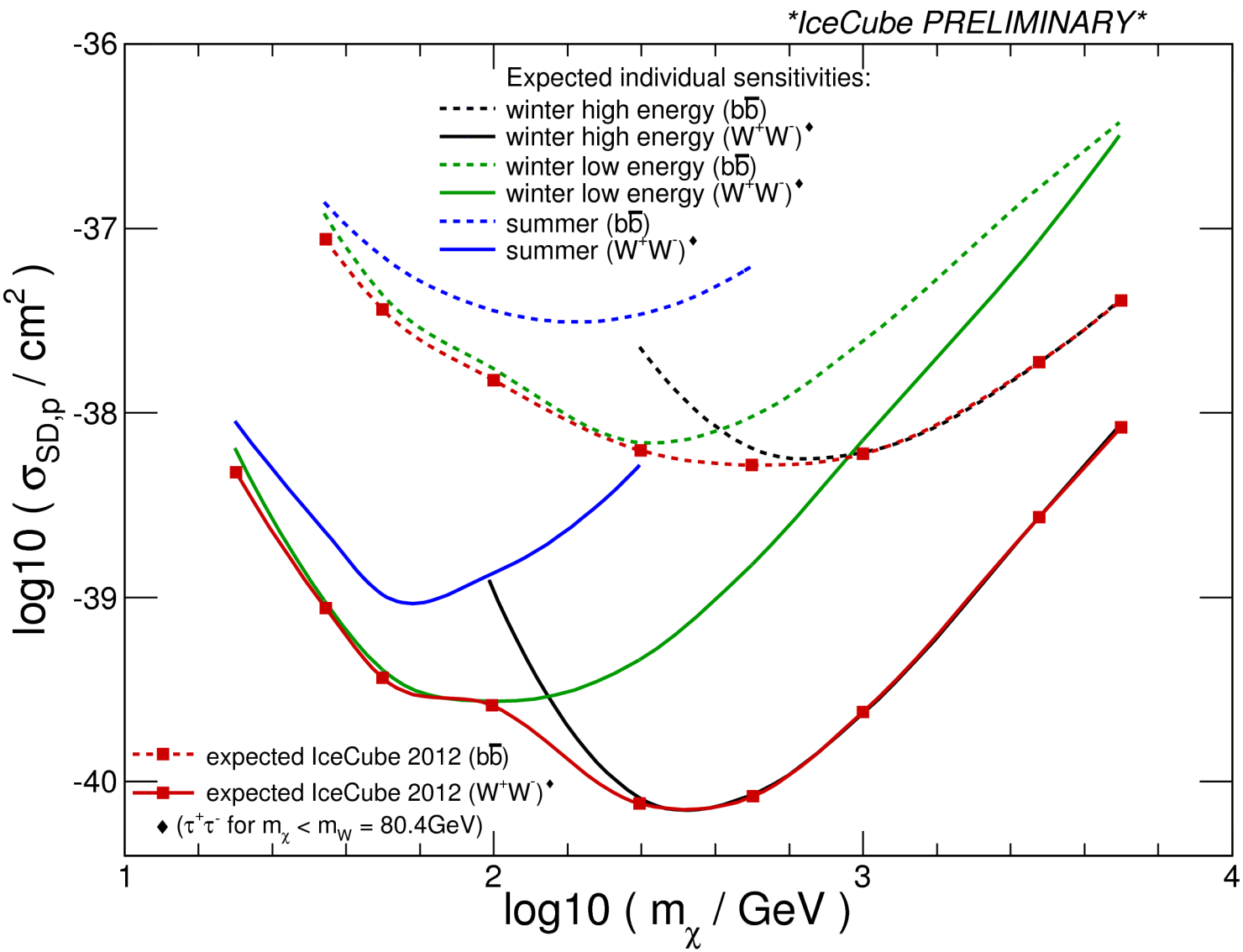
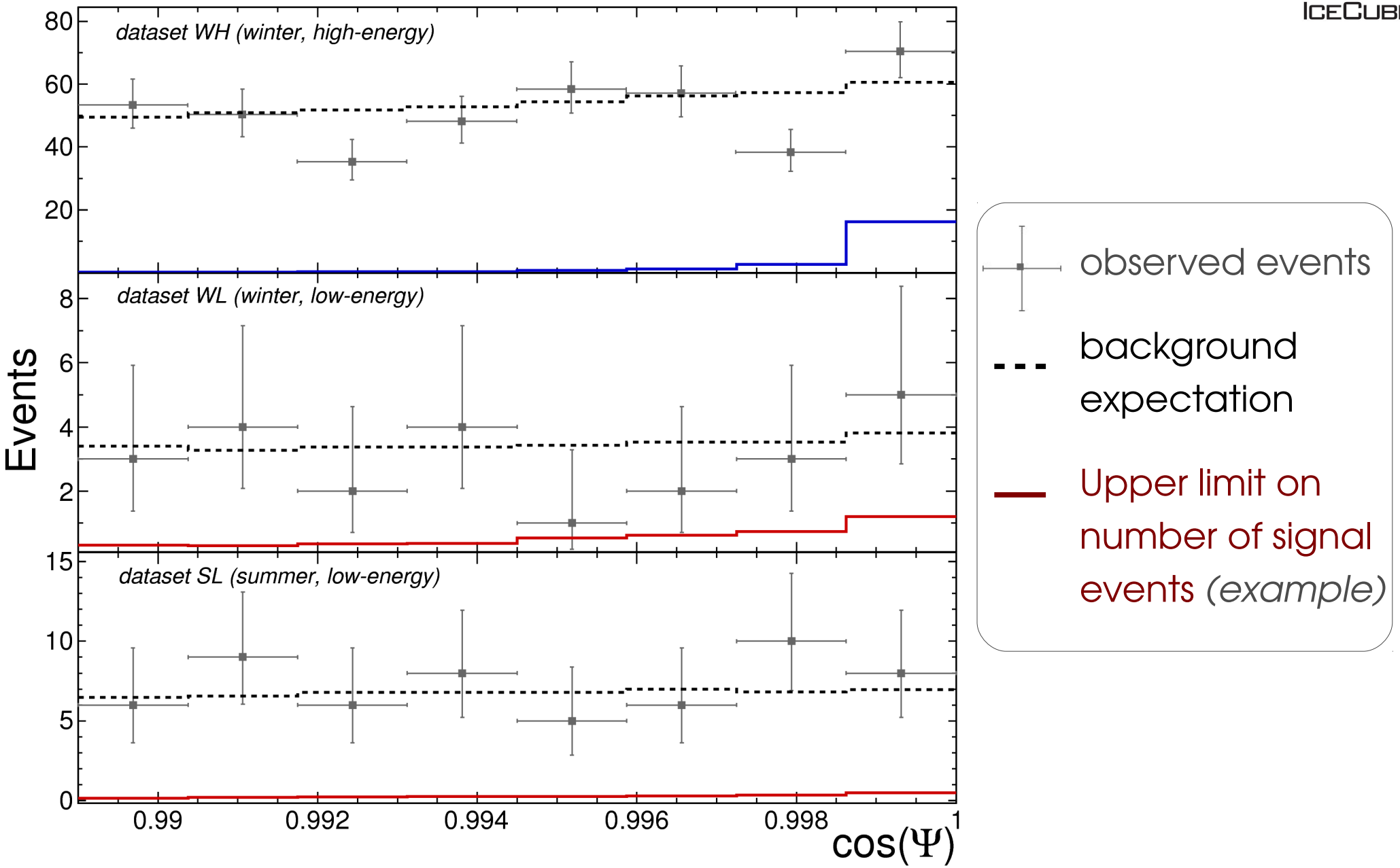
$$\mu_j = \mu \frac{T^j_{\text{live}} V^j_{\text{eff}}}{T^1_{\text{live}} V^1_{\text{eff}} + T^2_{\text{live}} V^2_{\text{eff}}}$$

Scale to multiple datasets

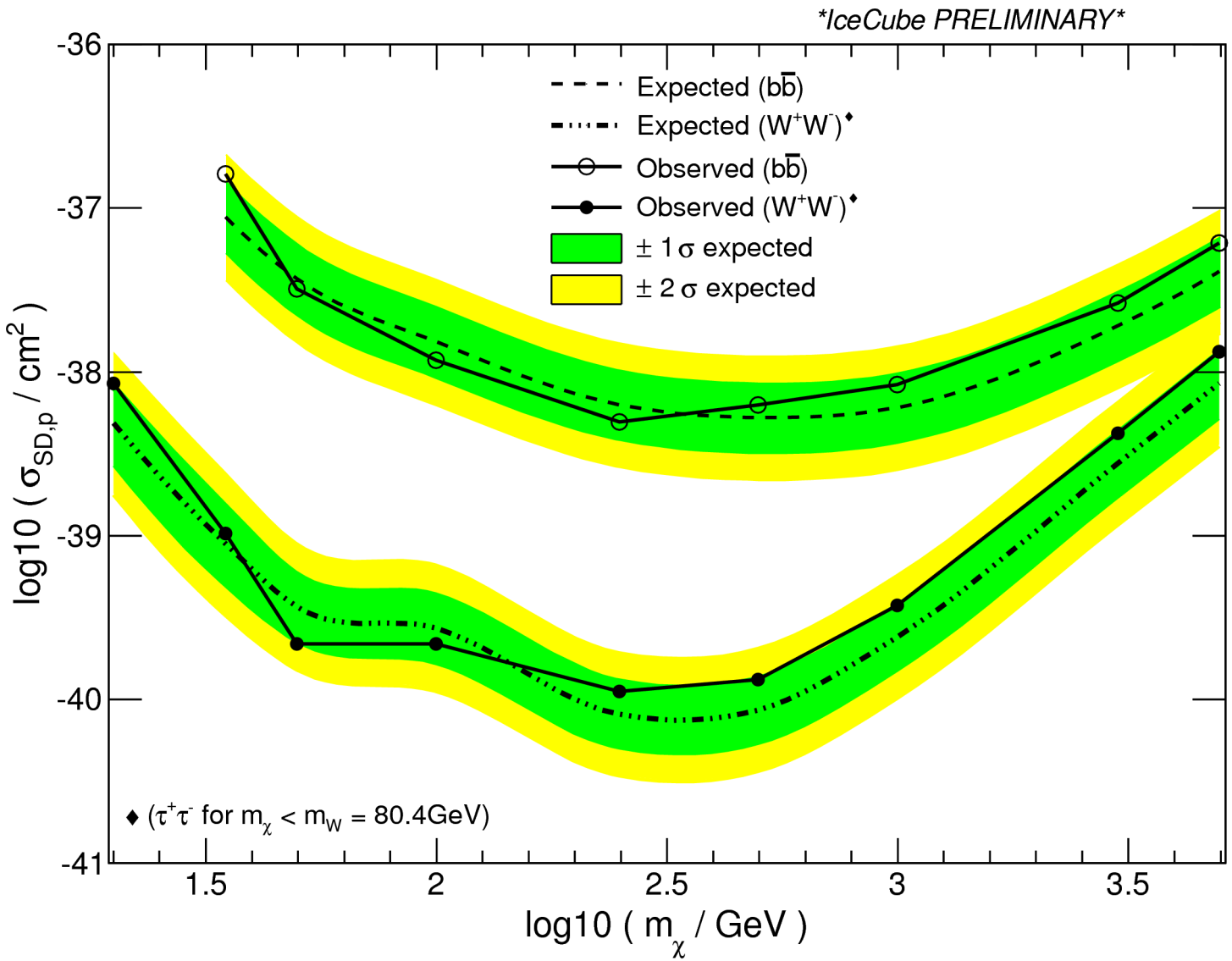
Unblinding results (expected sensitivity)



Unblinding results (events observed)



Unblinding results (observed results)



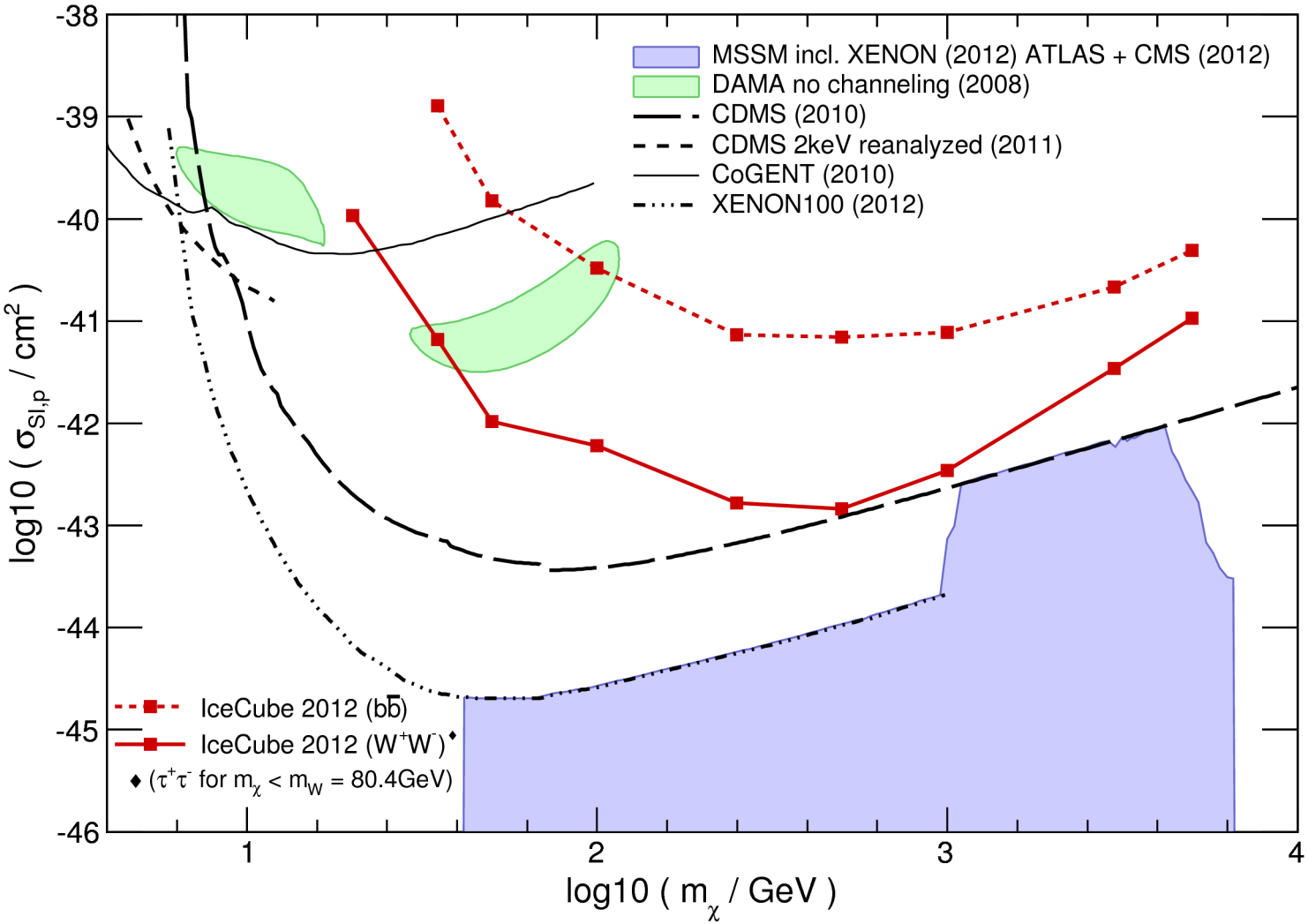
Systematic uncertainties

TABLE II. Systematic errors on signal flux expectations in percent. Class-II uncertainties marked *

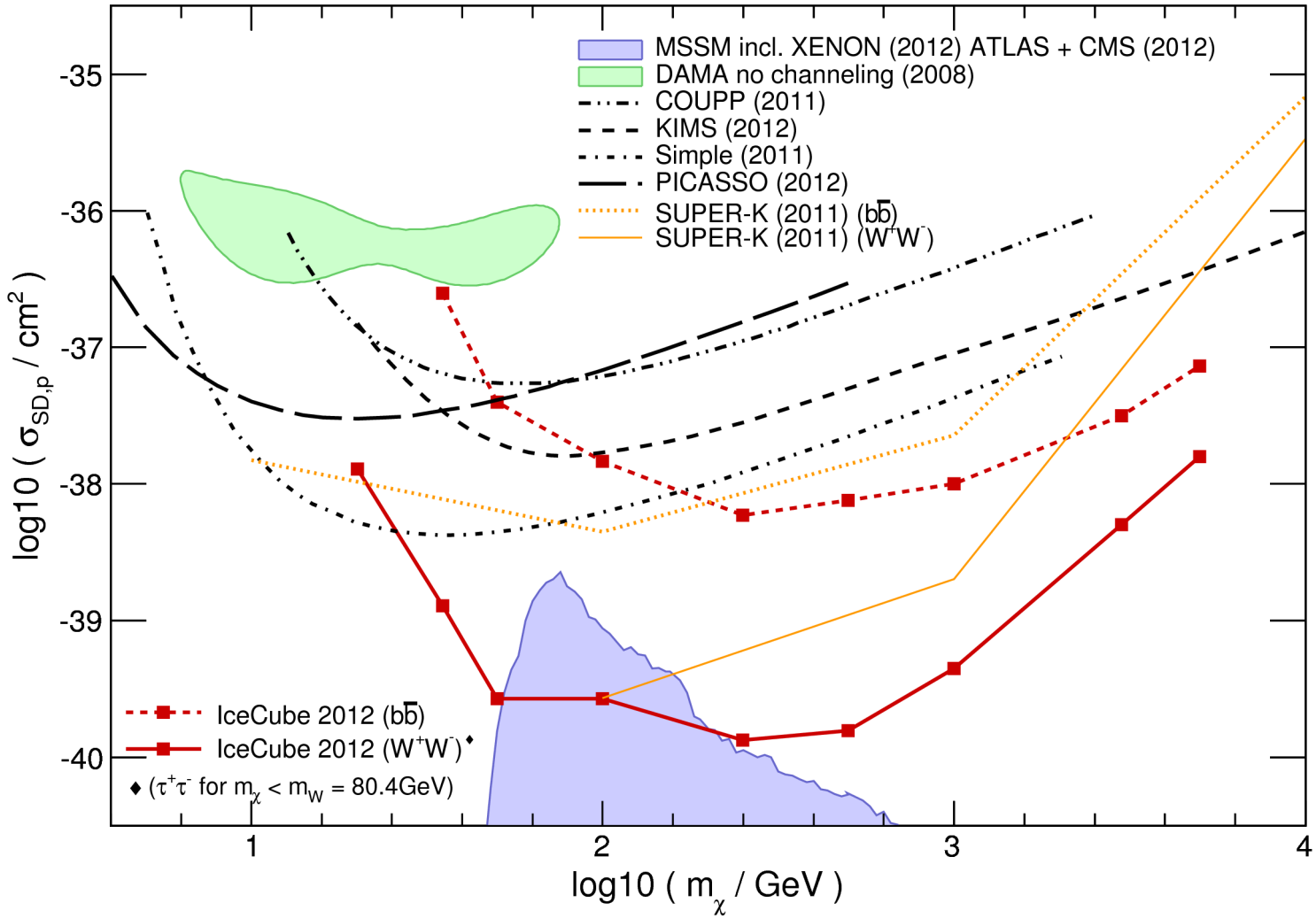
Source	mass ranges (GeV)		
	< 35	35 -100	> 100
ν oscillations	6	6	6
ν-nucleon cross-section	7	5.5	3.5
μ-propagation in ice	<1	<1	<1
Time, position calibration	5	5	5
DOM sensitivity spread*	6	3	10
Photon propagation in ice*	15	10	5
Absolute DOM efficiency*	50	20	15
Total uncertainty	54	25	21

* Full analysis performed with an alternative signal simulation, including maximum llh-analysis (change in acceptance + PSF)

Unblinding results (SI-cross-section limit)



Unblinding results (SD-cross-section limit)

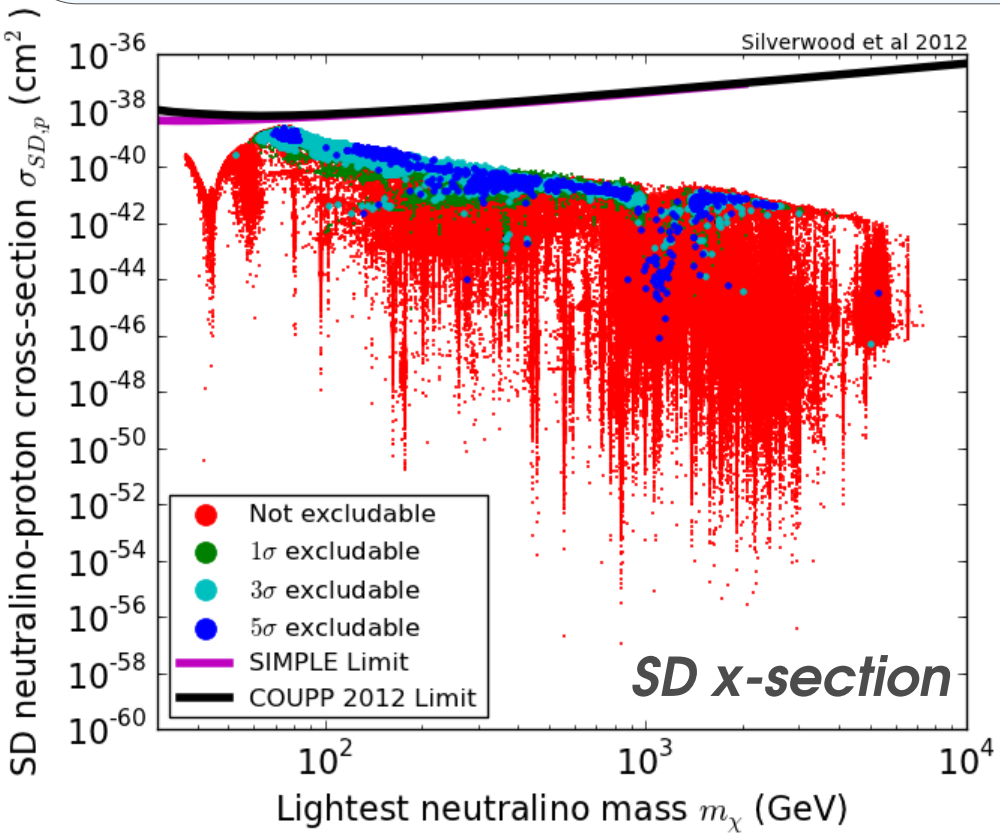


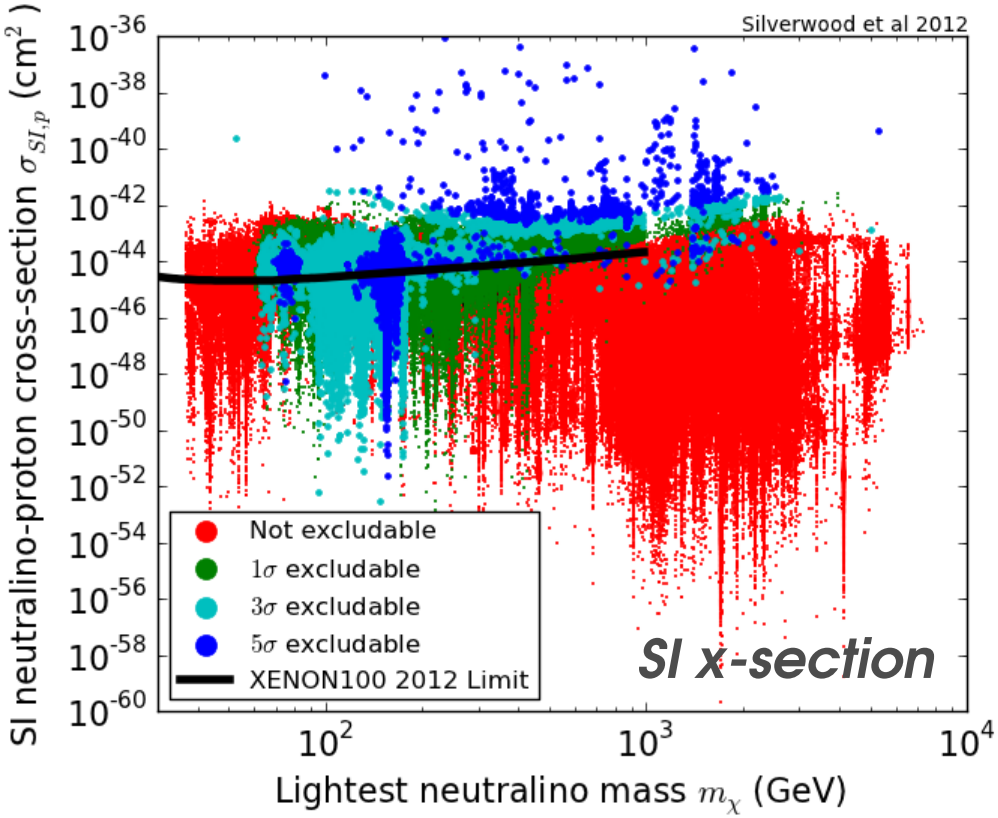
New SUSY analysis with IceCube

Ref: *P.Scott, C.Savage, J. Edsjö & the IceCube Coll., arXiv:1207.0810 & H.Silverwood et. al., arXiv:1210.0844*

Goal: Use as much of this information on **σSD , σSI , <σv> , mχ** and **BF (χ)** as possible to directly constrain specific points and regions in WIMP model parameter spaces

Details: 25-dim. parameter space (**MSSM-25)** using scanning based on importance sampling 6.02 million model points, DarkSUSY 5.0.6 used to calculate observables;





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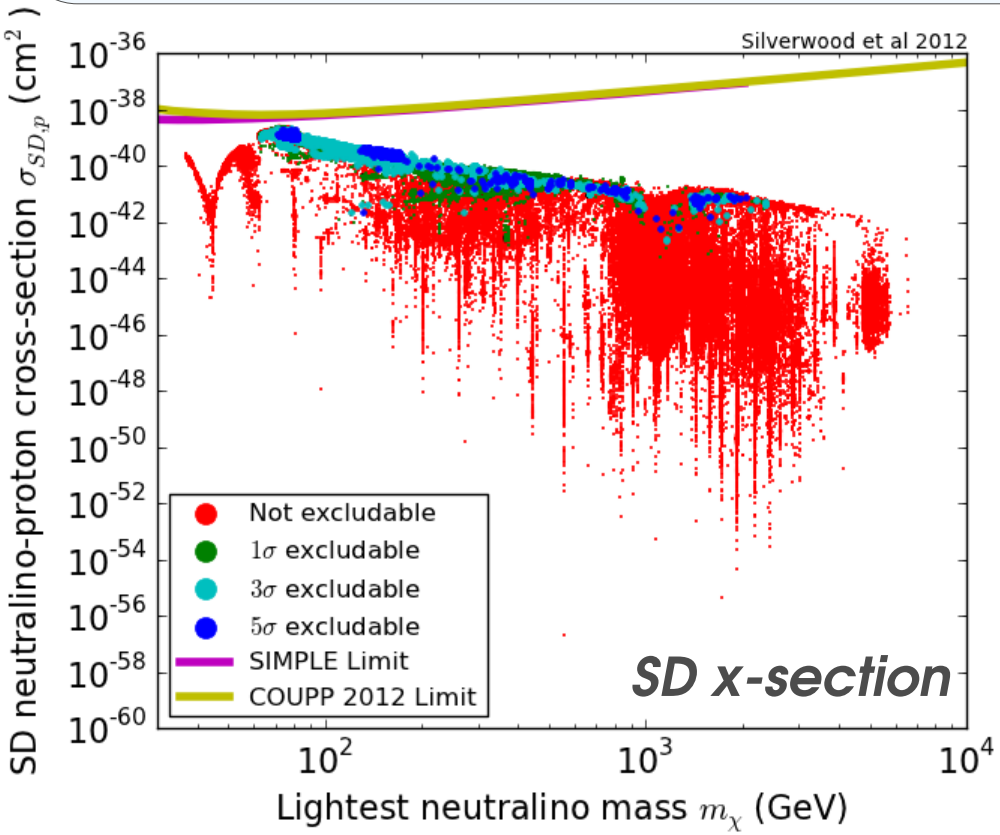
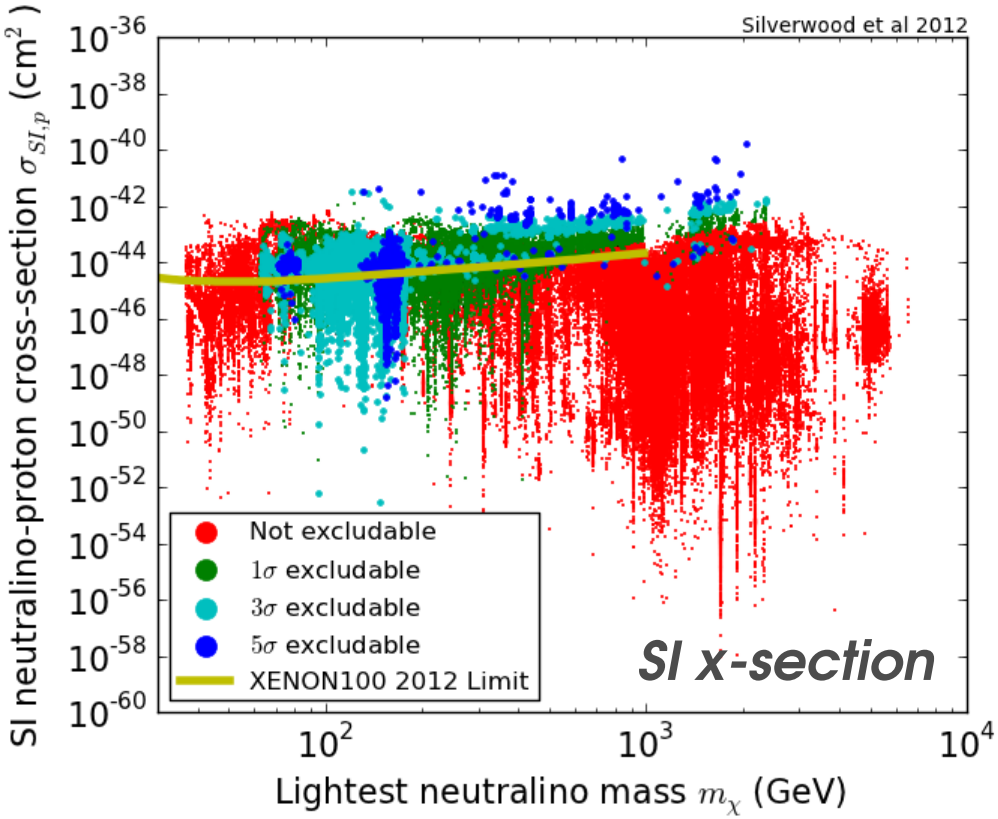
+neutral Higgs masses for any model between 124.4 - 126.8 GeV





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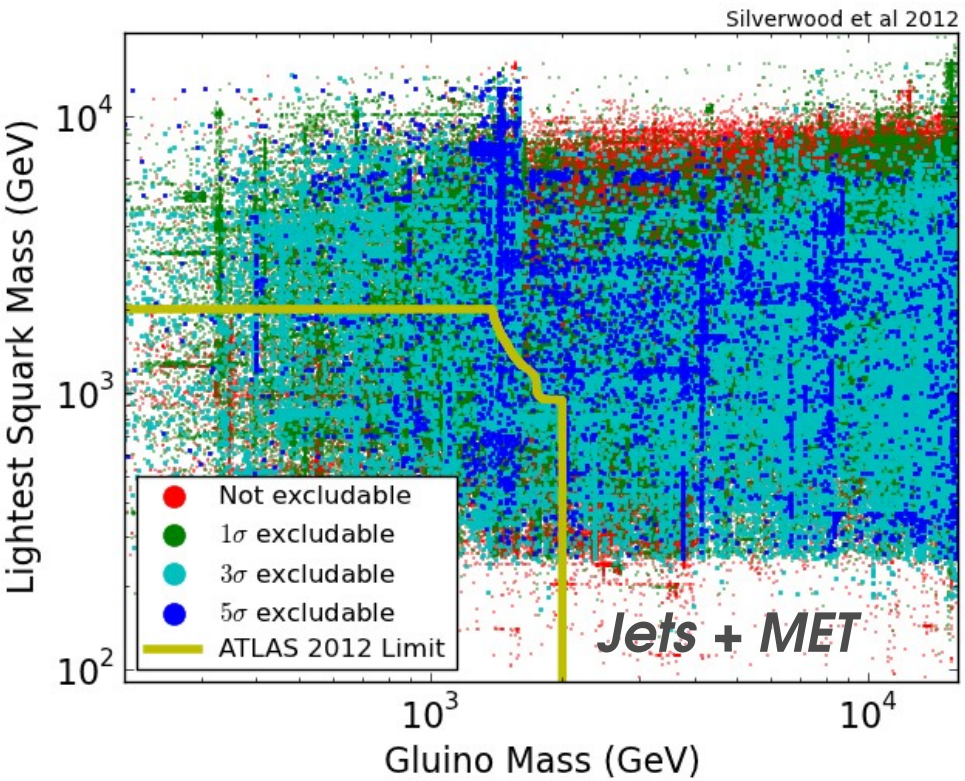
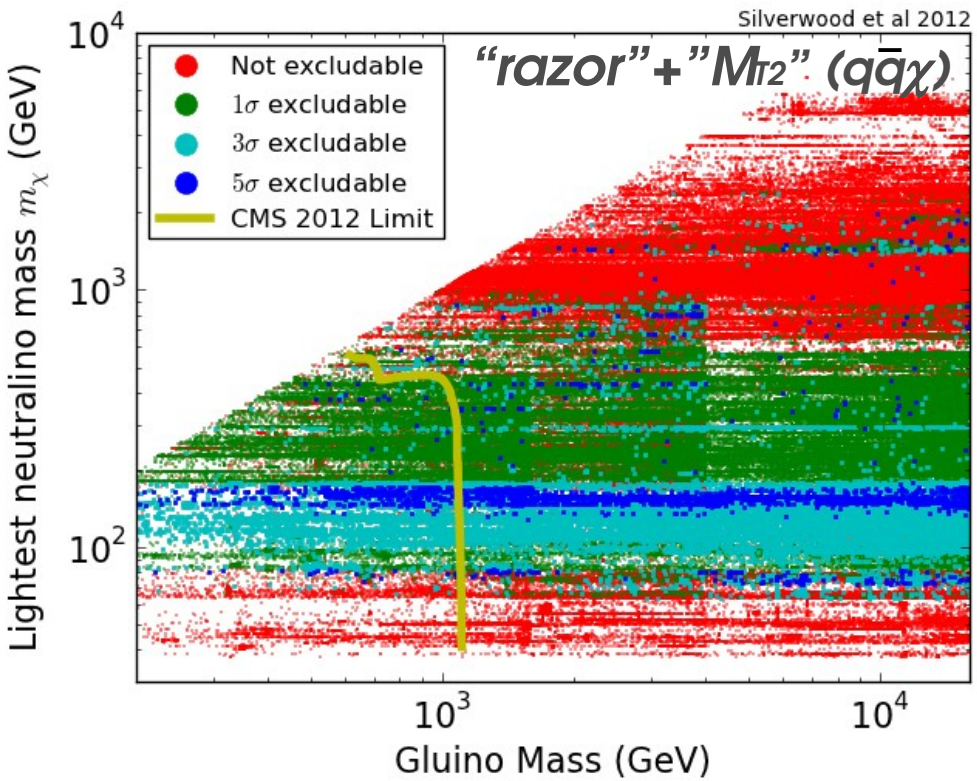
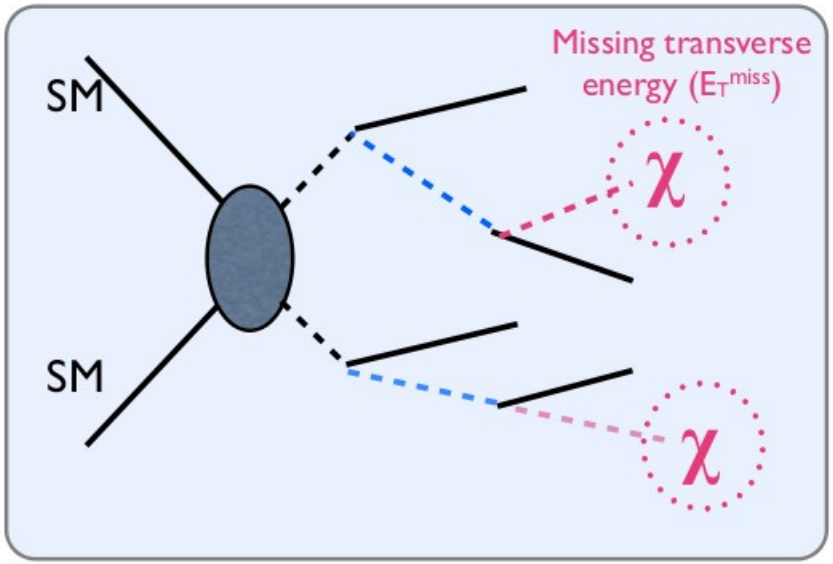
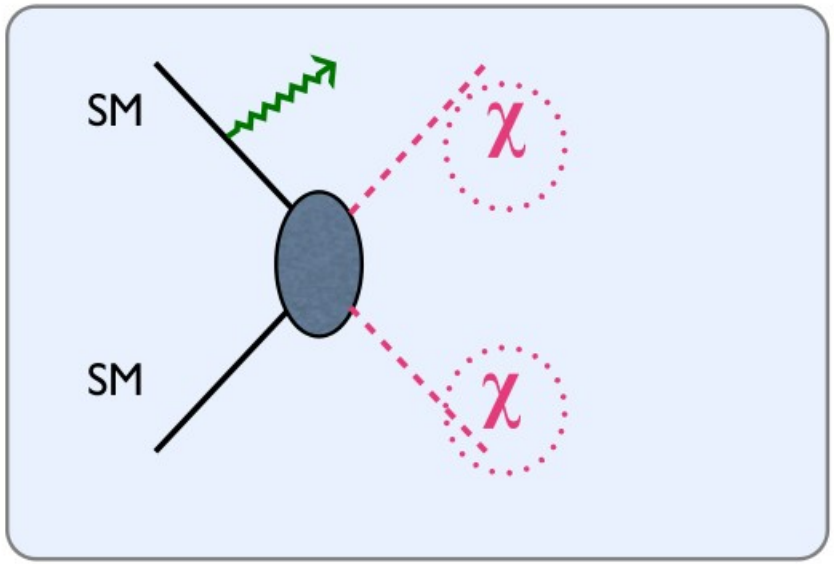




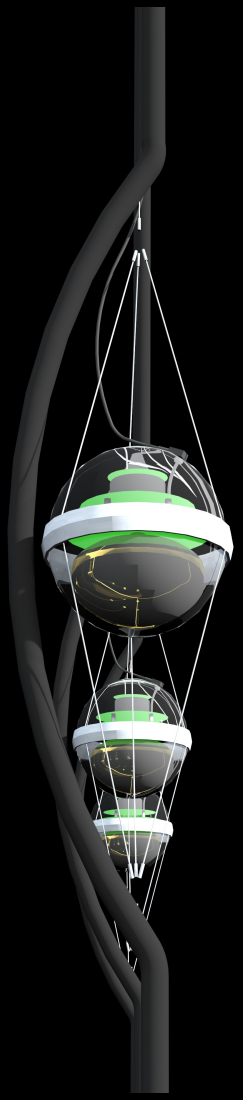
Mono-Jet & Mono-photon searches

- Very interesting & "*possibly*" competitive limits (especially in the SD x-section plane)
- depend strongly on the choice of the underlying effective theory and mediator masses
- Analyses performed for a large variety of mediators (unfortunately no complete set of results) → ***biased choices***





Summary



- ***First*** Dark Matter analysis including ***DeepCore***
- ***First full year-round*** IceCube solar Dark Matter search
- ***No excess*** of events from the Sun over expected backgrounds
- New very ***competitive SD-cross-section limits***
  → most stringent limits in large parts of WIMP mass range
  → ***new LKP limits*** with same search (not discussed in talk)
- ***This indirect search is a very complementary approach***
- ***The near future .....***
  Additional data in the full 86-string configuration (1.5 years)
  → 2 more DeepCore strings (even lower energy threshold)
  → *already new veto ideas → better low energy sensitivity*

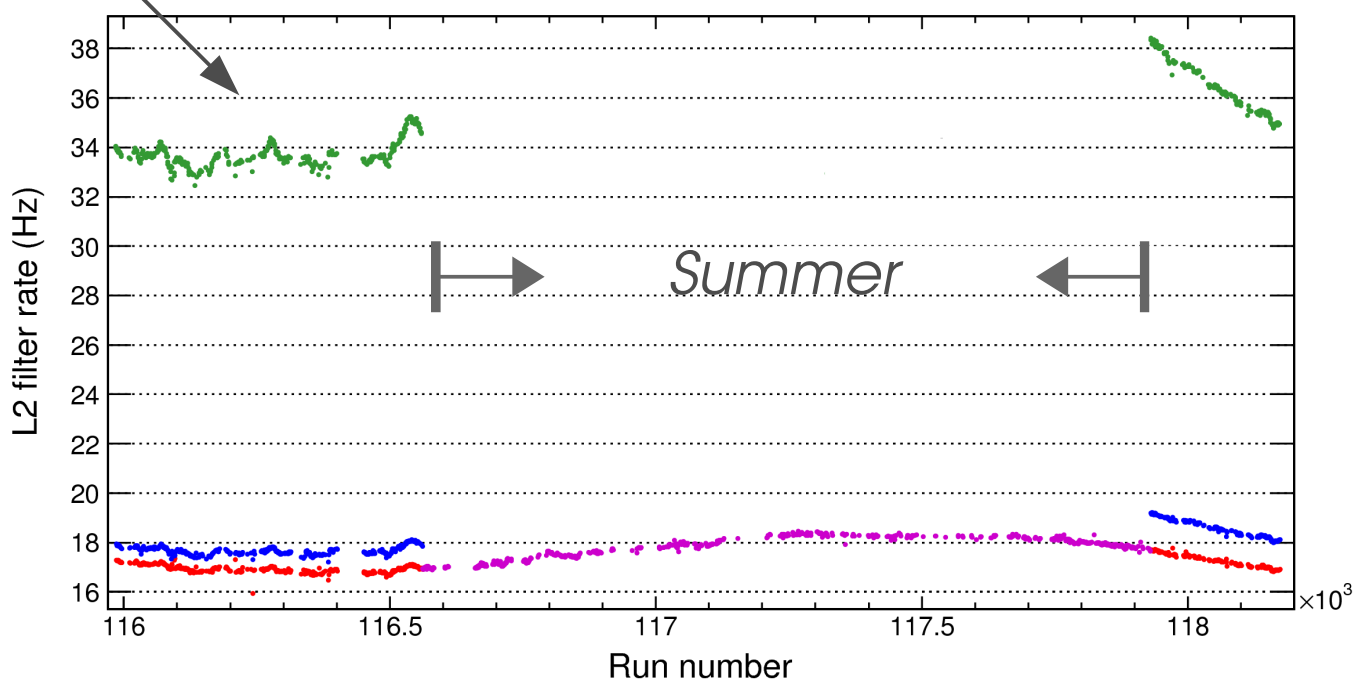
Additional slides

IceCube-79 string analysis details

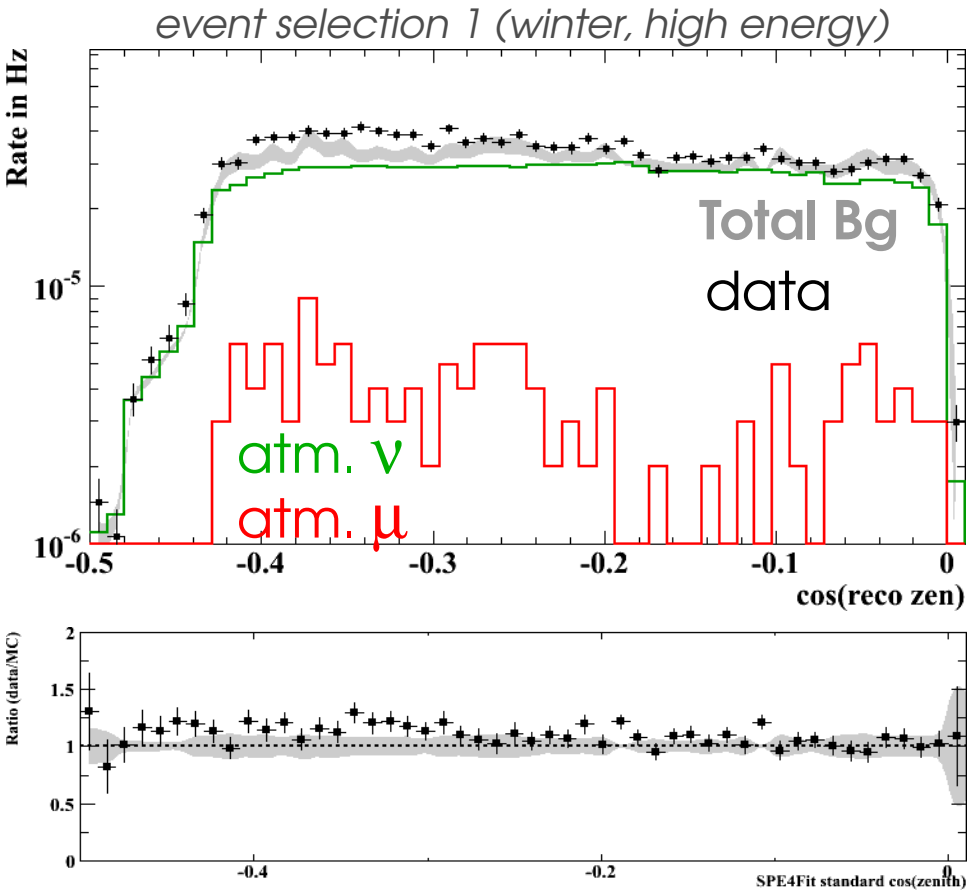
Dedicated online filters targeting:

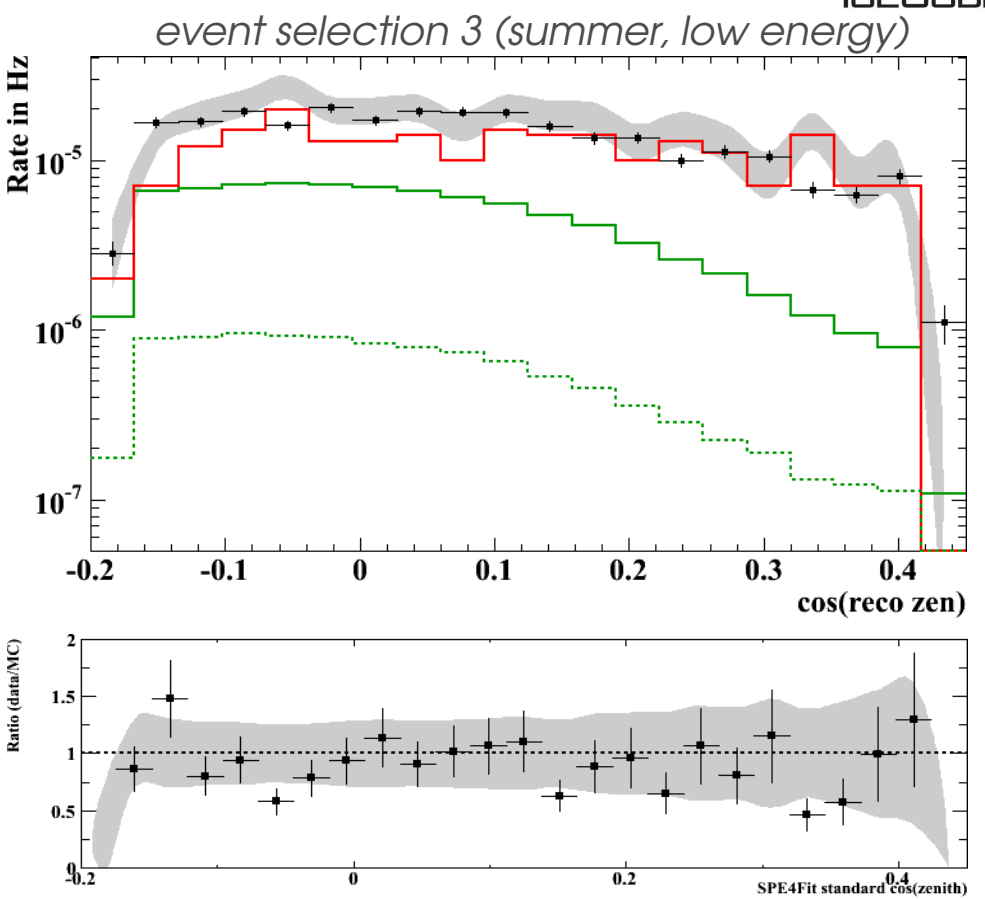
- muon events
- Low energy muon events (IceCube)
- DeepCore events
- DeepCore events (summer)

- By comparing signal simulation & data, cuts are placed that reduces the content of atmospheric muon events
- *Early analysis cuts:*
  dedicated online-filter → offline high-level reconstructions → first modest cuts (track quality/direction + containment)



Reconstructed zenith (final analysis level)





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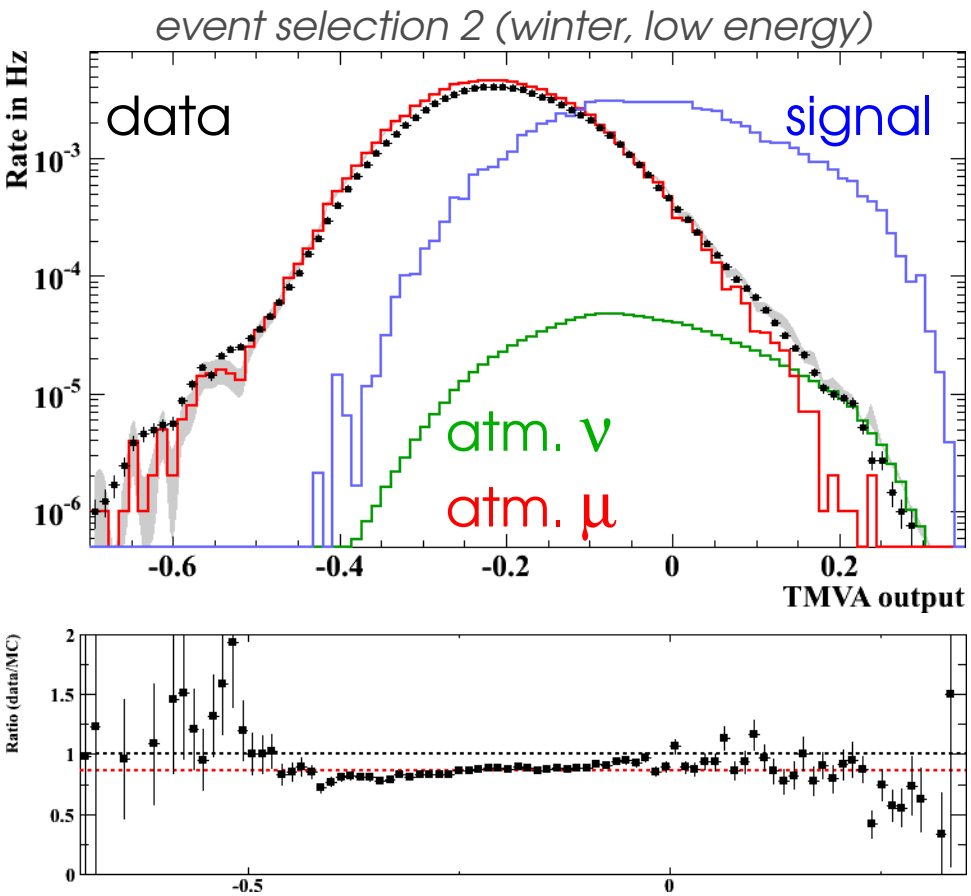

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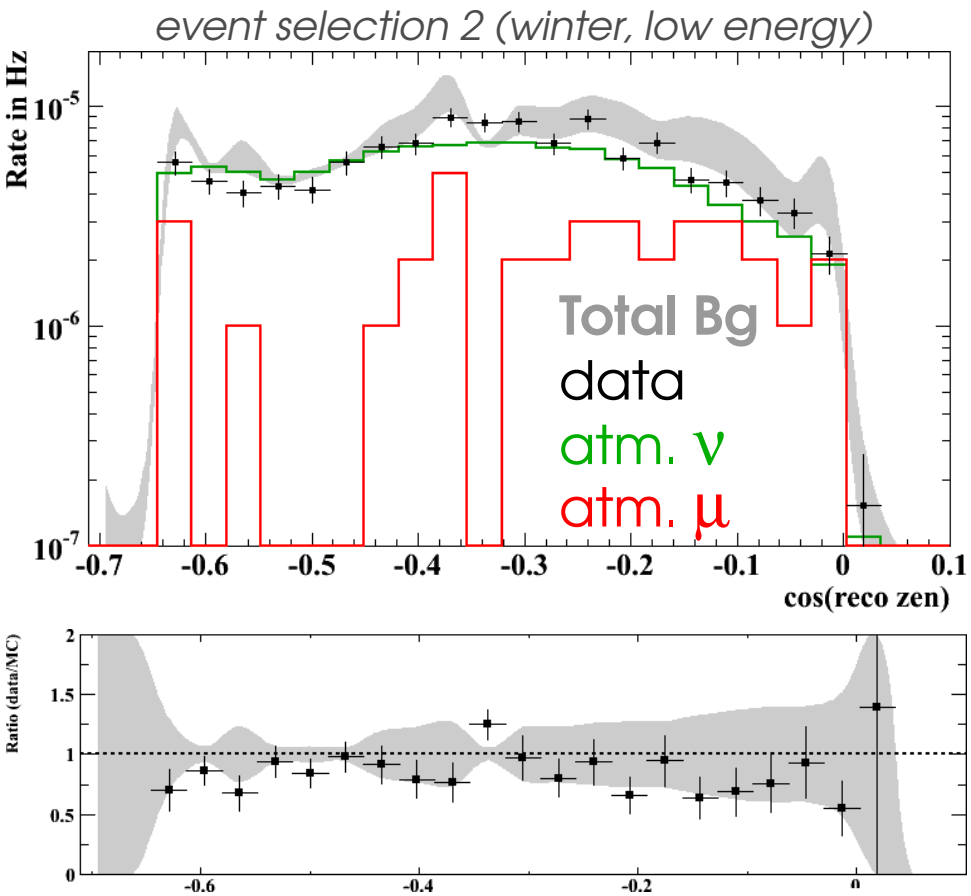
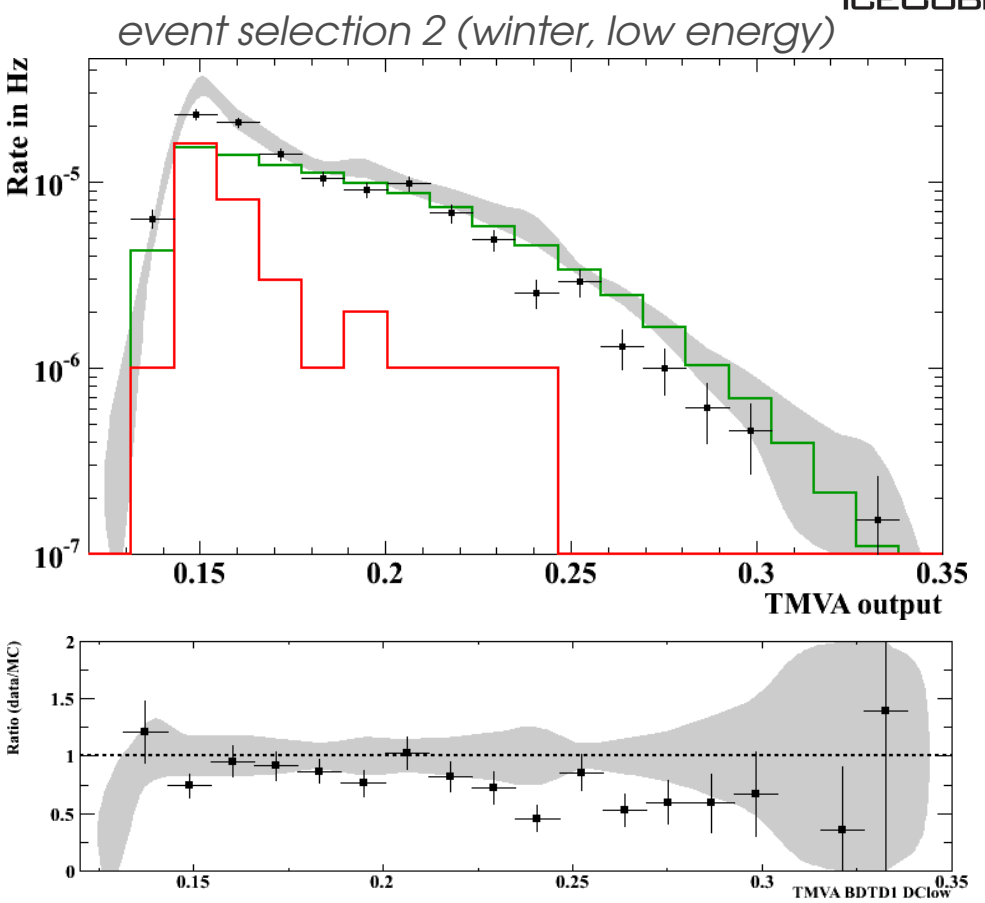
→ training on off-source exp. data + separate signal simulation

Reconstructed zenith & BDT output

(final analysis level)



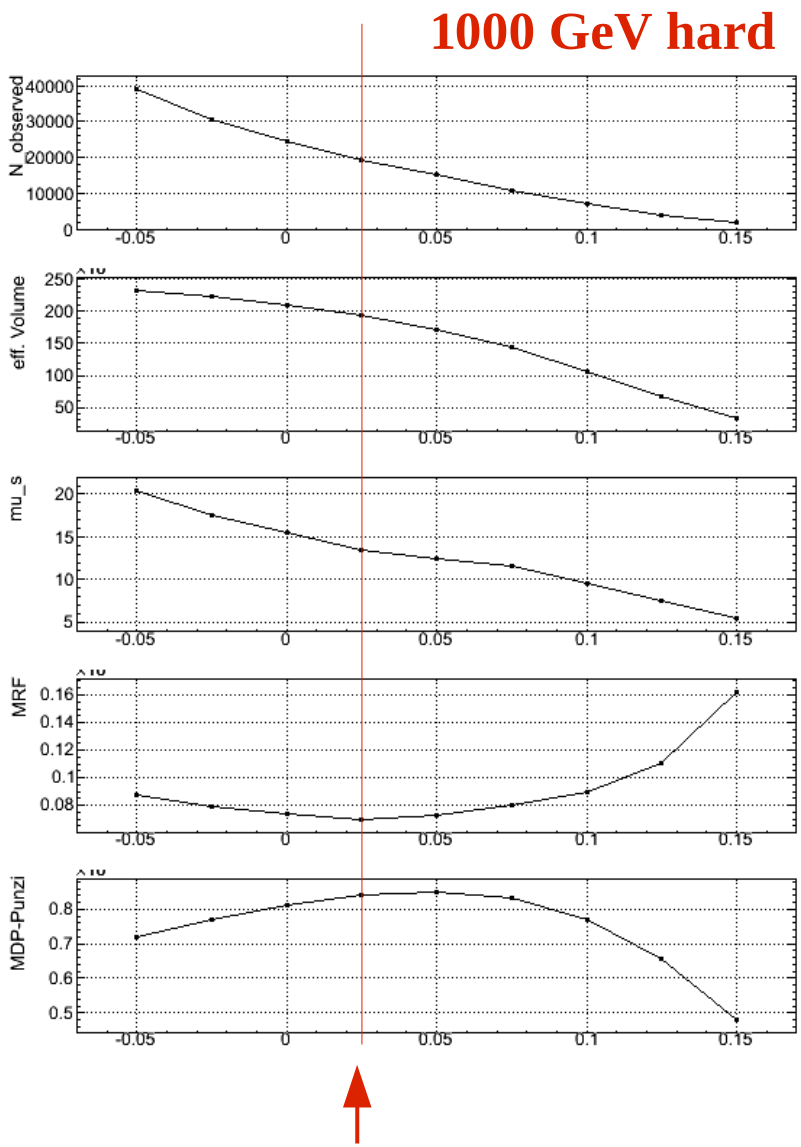


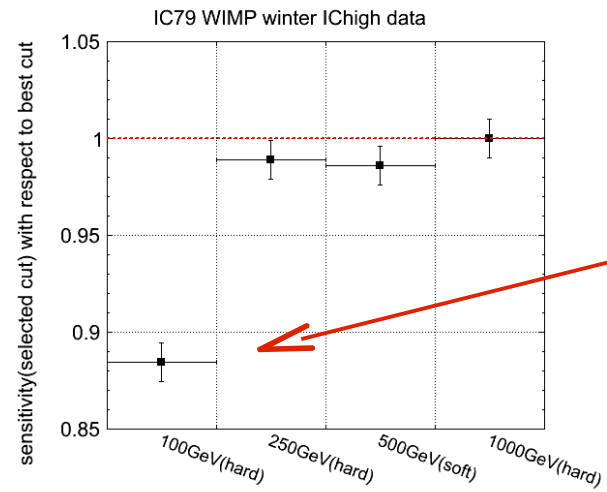
→ *1* separate BDT for each event selection

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

→ Optimized final cut on BDT-output: run llh-analysis for various BDT cuts, to determine cut value with best sensitivity (MRF & MDP)

Analysis: final cut on BDT-output





Still very efficient

Optimized final cut on BDT-output:

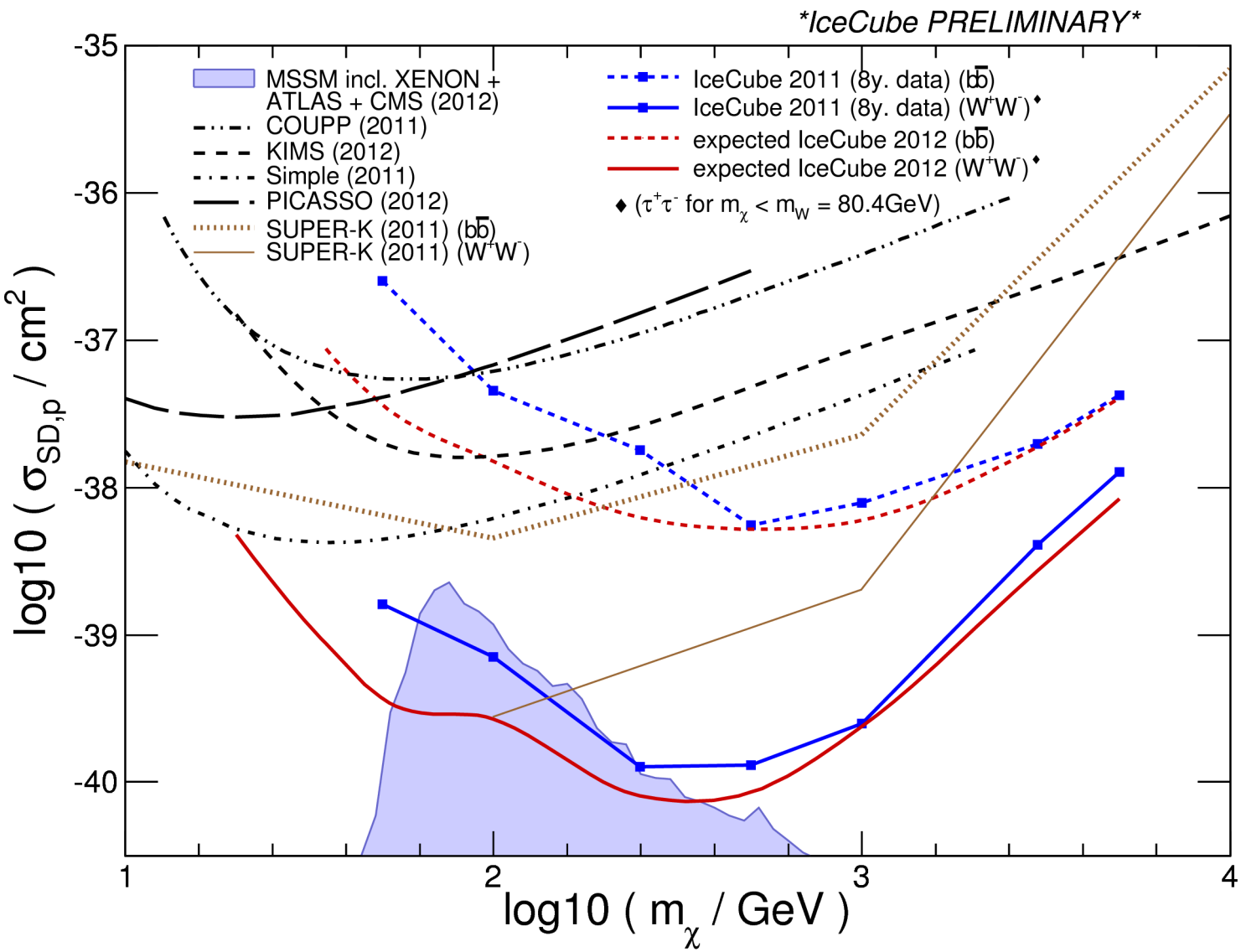
run full llh-analysis for various BDT cuts, to determine the cut value with the best sensitivity:

- each dataset individually
- calculate MRF
- calculate MDP (Punzi)
- check for many mass/channel combinations

Want to find 1 single cut per dataset

→ **(robustness rather than fine-tuning)**

IceCube 79 string sensitivity



Global SUSY analysis with IceCube

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

Include IceCube event level data in a global statistical fit.

→ *parameter estimation rather than model exclusion*

Composite likelihood made up of observations from all over:

- Dark matter relic density from WMAP
- Precision electroweak tests at LEP & LEP limits on sparticle masses
- B-factory data (rare decays, b → sγ)
- Muon anomalous magnetic moment
- LHC searches, direct detection *(not yet included in examples)*

$$\mathcal{L}_{\mathrm{IC}}(\Theta) = \mathcal{L}_{\mathrm{IC}}(n \mid \theta_s(\Theta) + \theta_b) \prod_{k=1}^{n} \mathcal{L}_{\mathrm{spec}}(E_k \mid \Theta)\, \mathcal{L}_{\mathrm{ang}}(\cos\phi_k \mid \Theta)$$

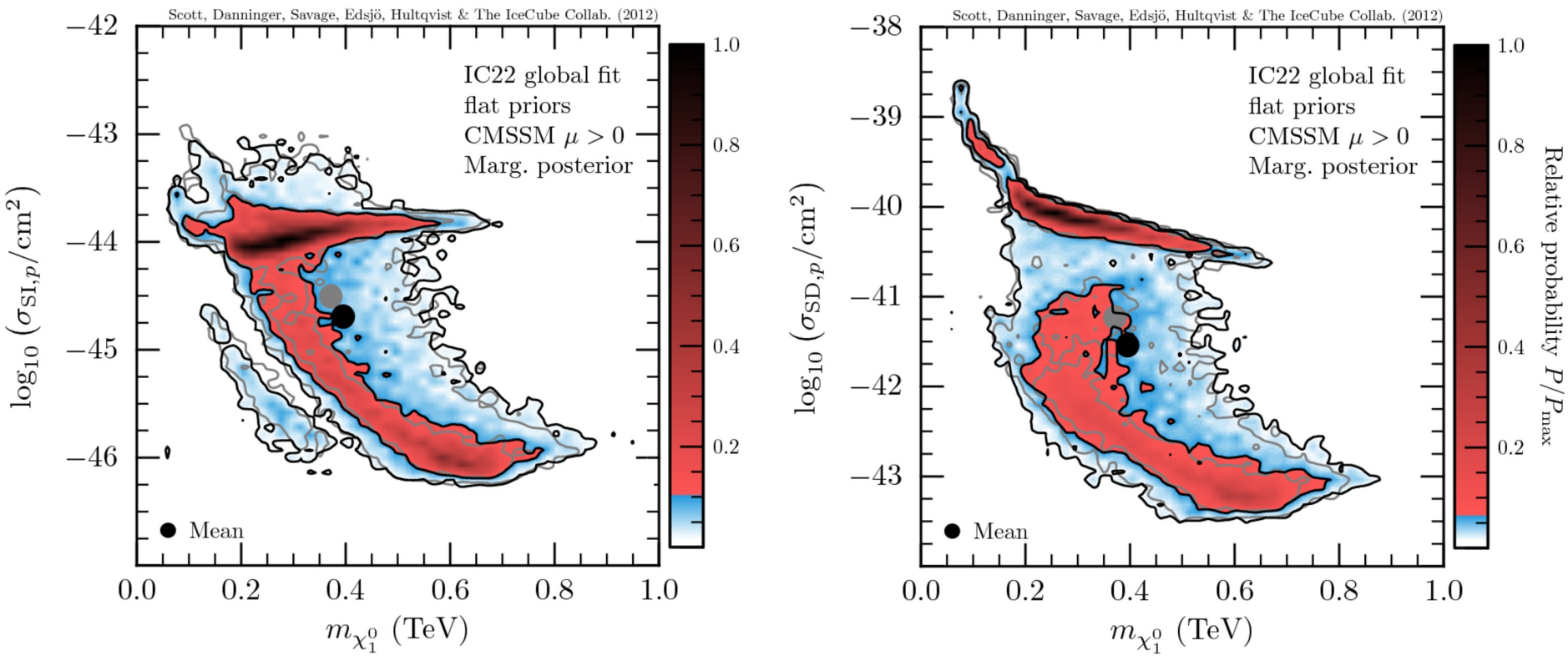
+ IceCube unbinned likelihood

- Θ: WIMP or SUSY parameters
- n: **Number** of muon events
- E_k: Muon **energy**
- $\cos\phi_k$: Muon **angle** from Sun

Global SUSY analysis with IceCube

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

CMSSM, IceCube-22



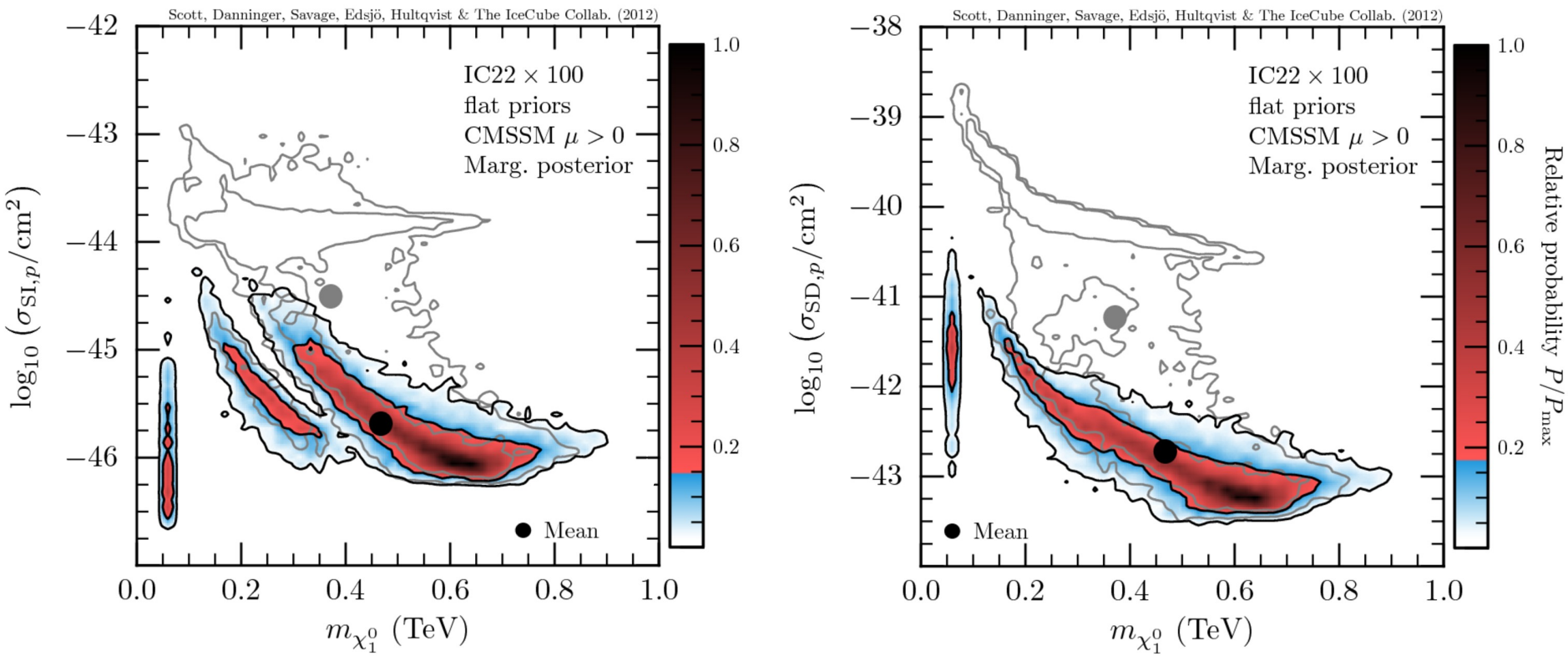
- ✗ Contours indicate 1σ and 2σ credible regions
- ✗ Grey contours correspond to fit *without* IceCube data
- ✗ Shading+contours indicate *relative* probability only, not overall goodness of fit

Global SUSY analysis with IceCube

More details: P.Scott, C.Savage, J. Edsjö & the IceCube Collaboration, arXiv:1207.0810

CMSSM, IceCube-22 with 100x boosted effective area

(indication for IceCube-79 and 86-string prospects)



- ✗ Contours indicate 1σ and 2σ credible regions
- ✗ Grey contours correspond to fit *without* IceCube data
- ✗ Shading+contours indicate *relative* probability only, not overall goodness of fit