Search for Spin-Independently coupling WIMP using high E solar neutrino in Hyper-K

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ICRC
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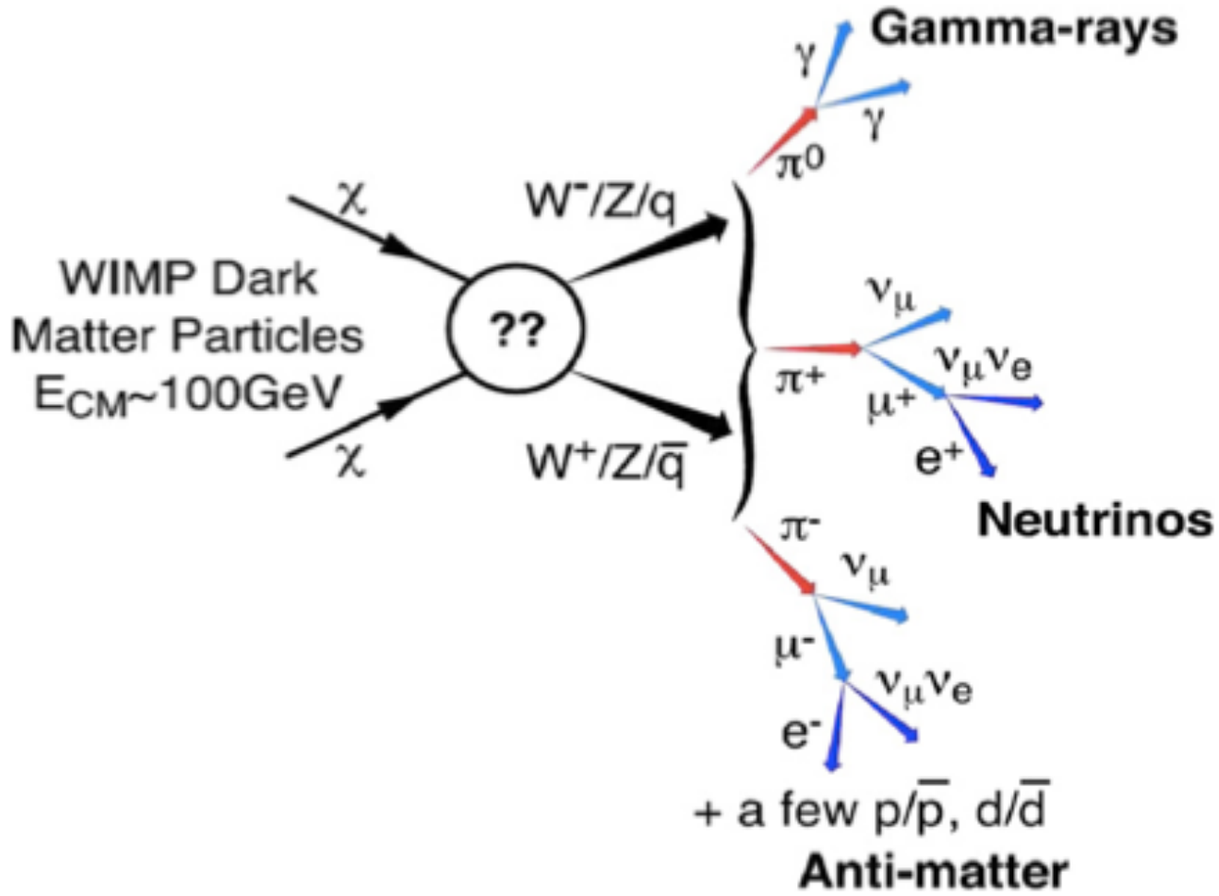
Outline

- Introduction
- Uncertainties in solar WIMP neutrino analysis
- Light WIMP search - motivation & strategy
- Light WIMP search - current limits & Hyper-K sensitivity
- Light WIMP search - Hyper-K target models
- Conclusion

indirect WIMP search

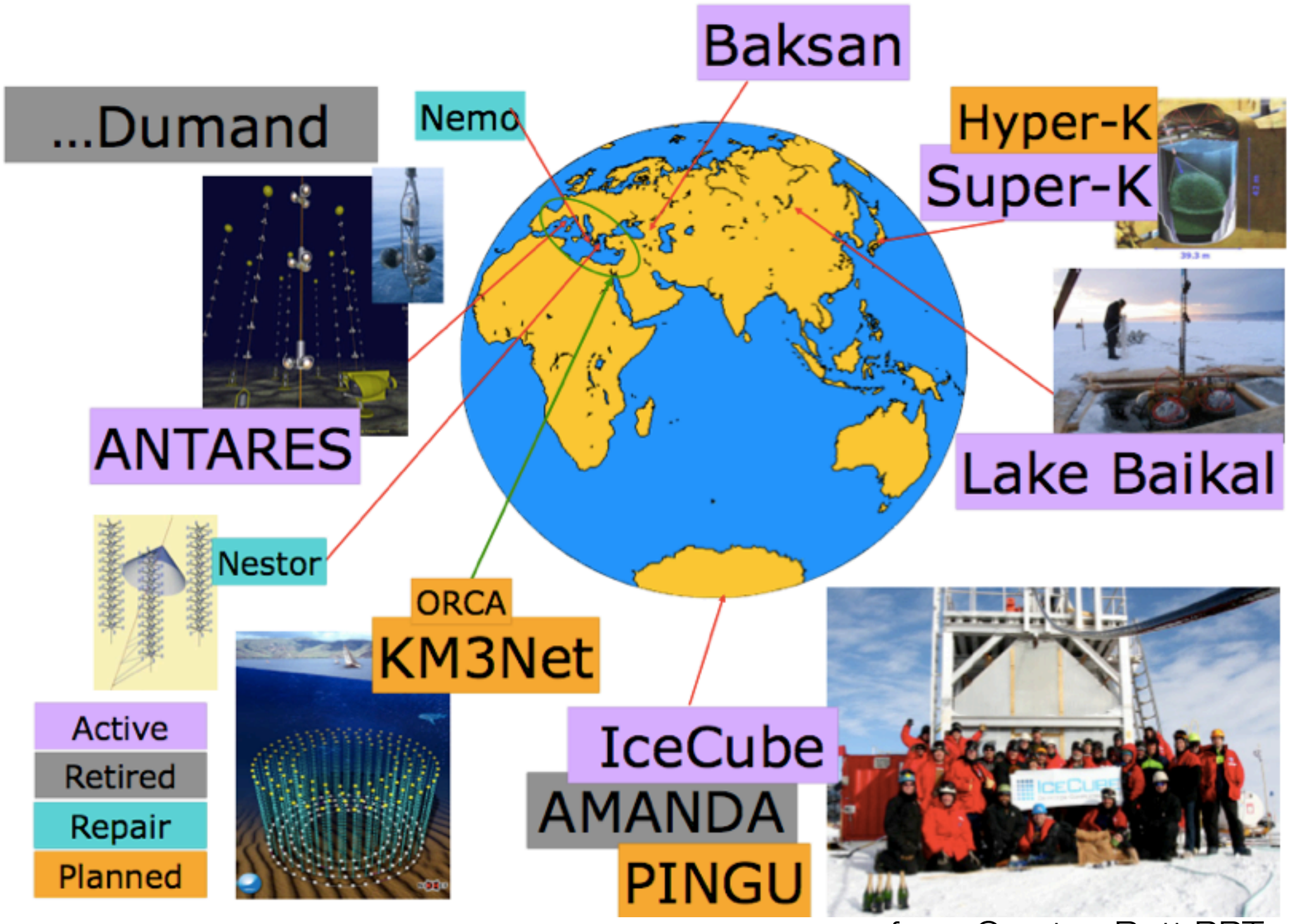


Up-to now only neutrino WIMP search couldn't make any claim on excess of events,
from any target source(the Sun, Earth, Galactic center, halo, dwarf galaxy, etc...)

-> does it mean our way of detection is so trusty?

indirect WIMP neutrino search

Solar WIMP searches - Past, Present, Future



from Carsten Rott PPT

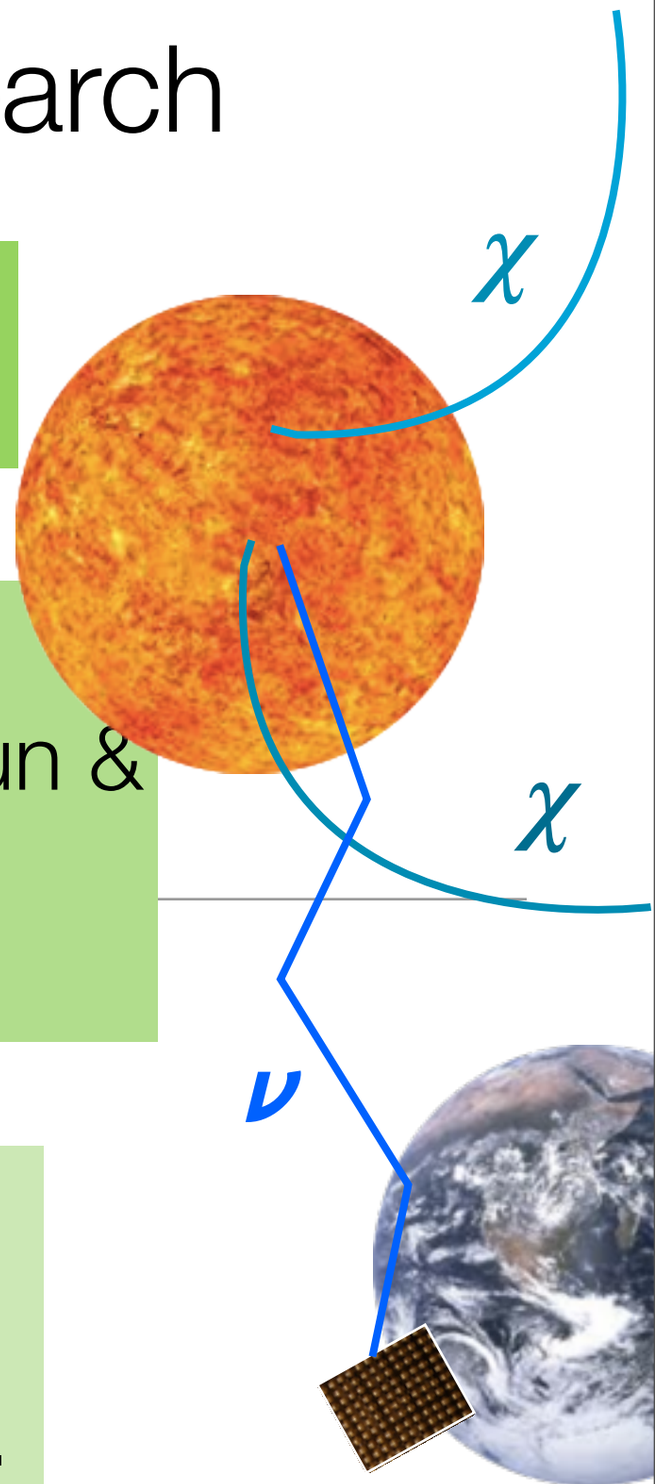
indirect solar WIMP neutrino search

As the Sun passes through Galactic plane, WIMPs can scatter off a nucleus inside the Sun.

After transferring recoil energy to nucleus, WIMP becomes gravitationally bound to the Sun & undergoes additional scatters from elements and settles to the core.

WIMPs pair annihilates to the various channels of which b, tau channels can produce energetic neutrino before stop.

neutrinos can pass through the Sun and be detected in neutrino detector.



It is good strategy in terms of sensitivity

- Since suggested in early 80's, it has been most powerful analysis in spin-dependent(SD)ly coupling WIMP search, & functioned as good independent/ multiple attempt in spin-independent(SI) coupling WIMP search.

Is it good strategy in terms of reliability?

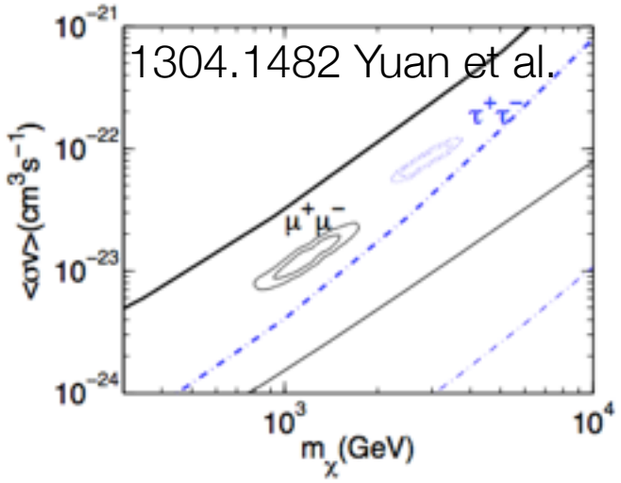


FIG. 8: 1σ and 2σ parameter regions on the $m_\chi - \langle\sigma v\rangle$ plane for the DM annihilation scenario. The lines show the 95% upper limit of Fermi γ-ray observations of the Galactic center (thin lines, with different normalization of the local density corrected, [50]) and dwarf galaxies (thick lines, [51]) for $\mu^+\mu^-$ (black solid) and $\tau^+\tau^-$ (blue dashed-dotted) channels respectively.

I found a comment about AMS interpretation...

> The Galactic center γ-rays exclude the parameter space to explain the $e^{\pm}$ excesses. However it may suffer from the uncertainties of the density profile of DM in the halo center.

I'm afraid if this is general impression of people about any cosmic ray WIMP search?
but...

- Using neutrino as a target, the Sun/Earth as sources is relatively reliable than other cosmic rays - uncertainties are better understood / controlled, & there shouldn't be pulsar or something big between them & us.

- we can't clear out astrophysical uncertainties, but can quantify the size of how much the errors affect.

- Assumptions shared with direct detections

- a particle which can explain WMP miracle alone.

- Local WIMP phase space(ρ=0.3GeV/cm^3, Vsun=220km/s, Vd=270km/s)

- elastic scattering off nuclei
  axial vector(SD) and/or scalar(SI) coupling
  isospin-invariant interaction

Assumptions for WIMP neutrino analysis

- pair annihilation to fermions or etc & mono annihilation channel

- Equilibrium between capture and annihilation

- S-wave annihilation mode to be dominant(not velocity suppressed)

- Uncertainties in solar WIMP neutrino analysis

Uncertainties in capture process : foam factor

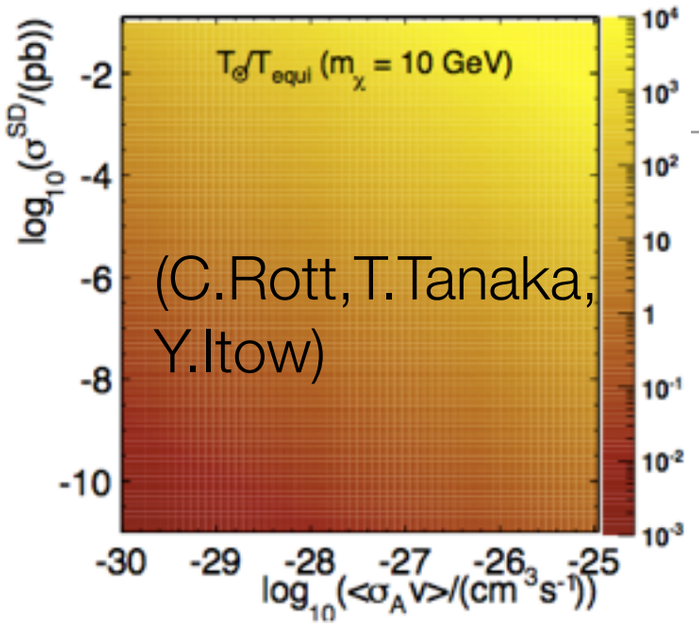
relevant only for scattering off heavy nuclei -> relevant to SI scattering,

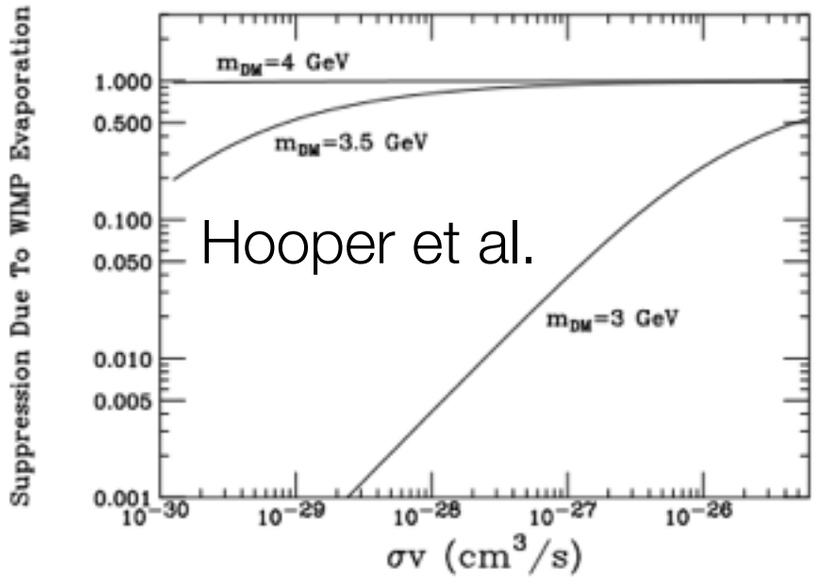
SD coupling only WIMP -
pure Hydrogen detector is free from this discussion
while others are affected as much as similar in amplitude to that of astrophysical uncertainties
(D. G. Cerdeno et al, 1208.6426)
SI coupling WIMP - foam factor is expected to affect the solar analysis result max ~ 20% for heavy WIMP candidate

Uncertainties in capture process : solar system

* solar diffusion : bounded WIMPs escape by solar system effects, negligible for low mass WIMP
- calculated by darksusy
* solar model : nuclei & electron distribution compared bs05op & bs05_agsop models using darksusy
* capture - annihilation Equilibrium
- argue it is achieved in most models of MSSM
* solar evaporation
- no impact above 4GeV

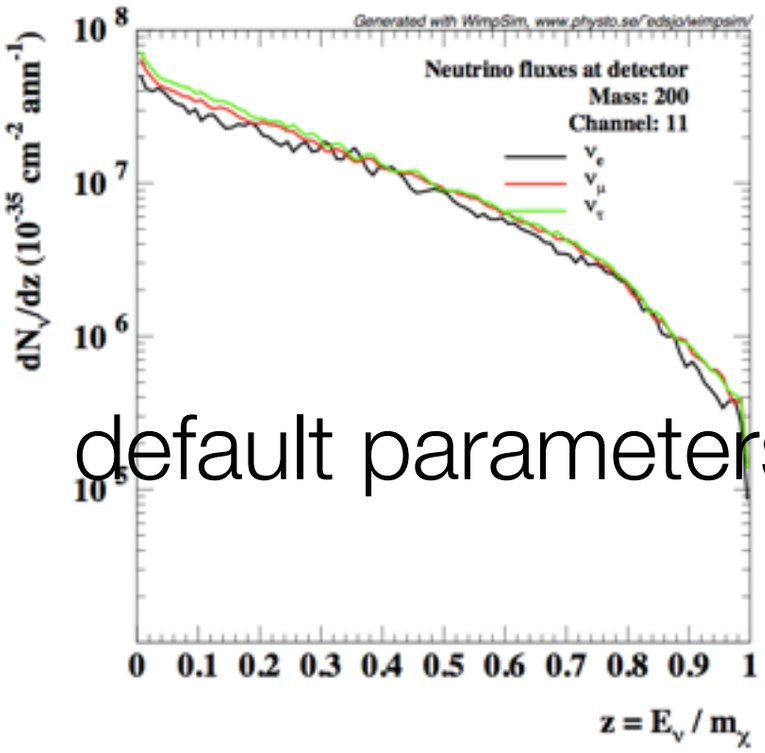
		form factor	solar model	solar evapo	solar diffusi
4~ 20GeV	SD	1%	3%	1%	0%
	SI	20%	15%	1%	0%
50~ 100GeV	SD	1%	4%	1%	0%
	SI	20%	20%	1%	0%
200GeV	SD	1%	6%	1%	2.8%
	SI	20%	25%	1%	2.8%





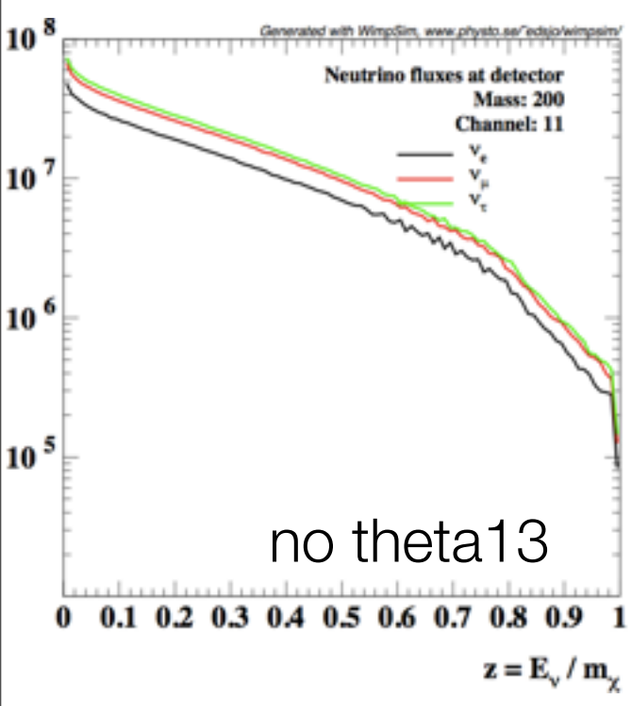
In conclusion : combining all errors affect the solar analysis result < 25%

Uncertainties in neutrino propagation

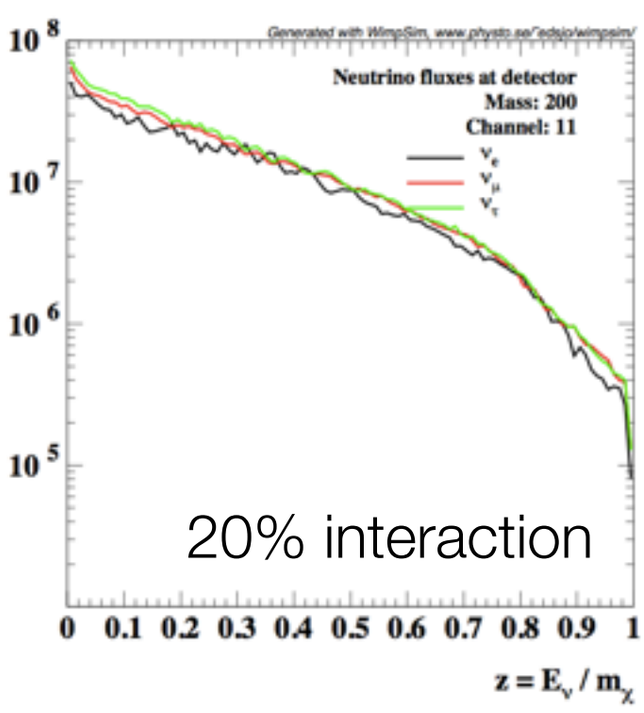


default parameters

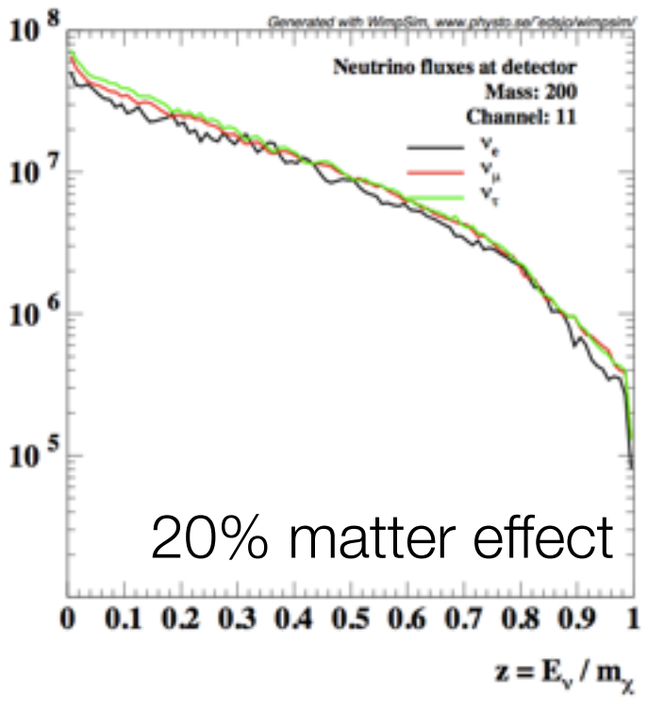
- 1sigma of 5 oscillation parameters
- matter effect in the Sun/Earth(10/8% of electron density)
- Interaction inside the Sun : 20% of cross section



no theta13



20% interaction



20% matter effect

plots are with increased size of error to be visible

simulated for SK using DarkSUSY(JCAP 07 (2004) 008 P. Gondolo et al), WIMPSIM(J. Edsjö et al)

"while uncertainties can result in significantly different annihilation rate in the Sun, impacts in the analysis tend to be on the conservative side."(C.Rott talk HK 1st open meeting)

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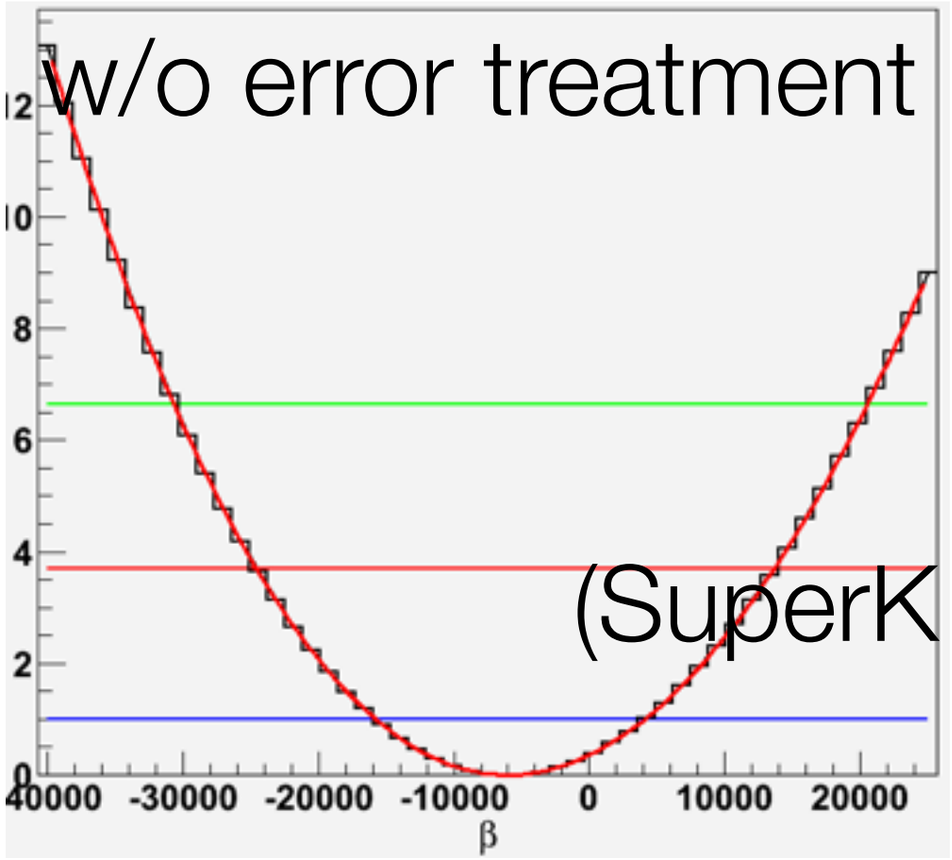
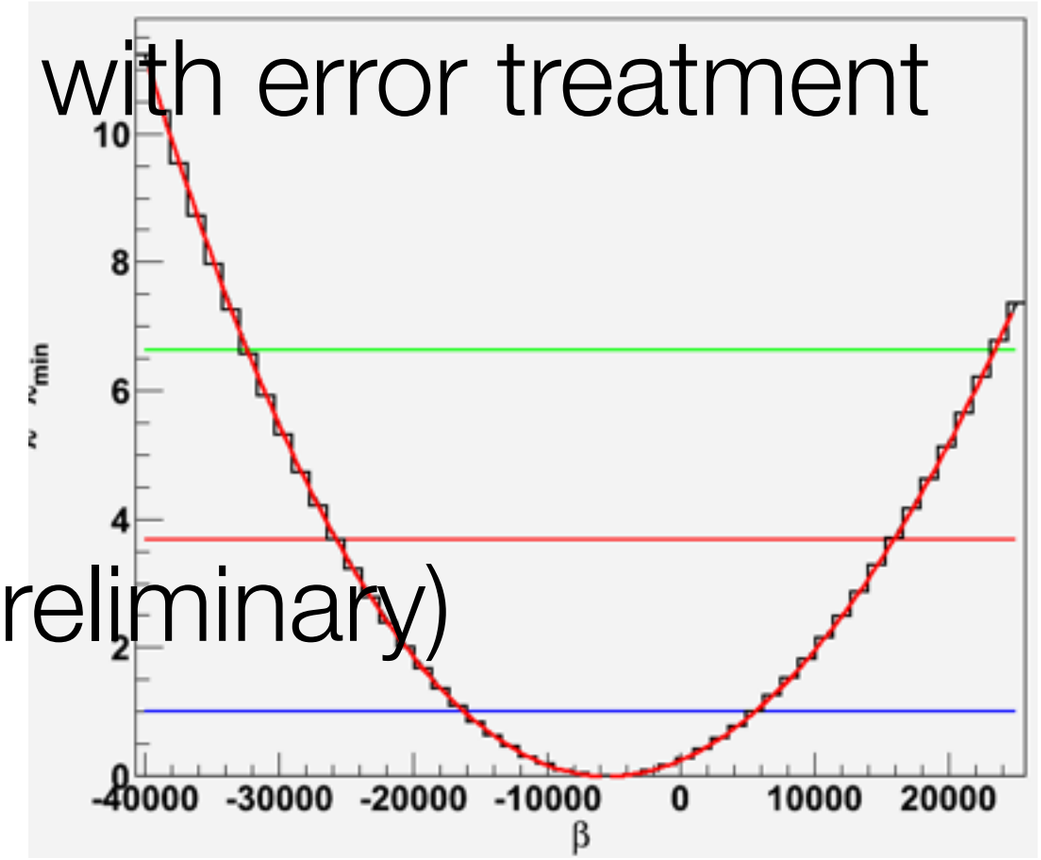
good treatment of uncertainties doesn't affect the result much

w/o error treatment



with error treatment



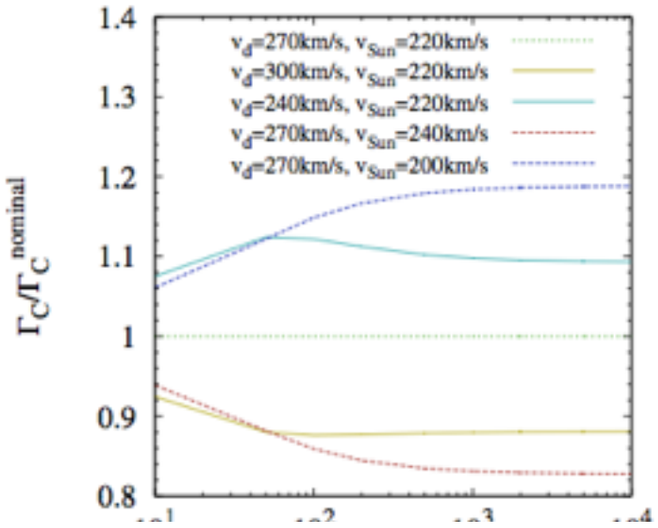
(SuperK preliminary)

Most severe uncertainties come from phase space of dark matter... (and we share these with direct detections)

➢ **Local halo density**

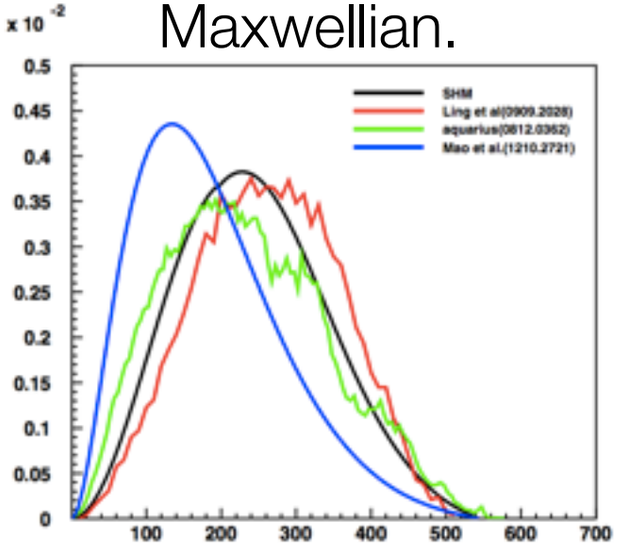
: deviation from standard assumption ρ0 = 0.3GeV/cm³ boosts the signal for 1 ~ 2.8 times for 0.25 GeV/cm³ ~ 0.70 GeV/cm³ (C.rott,T.Tanaka,Y.Itow)

➢ **Local halo velocity distribution(VDF)**
: deviations from standard assumption

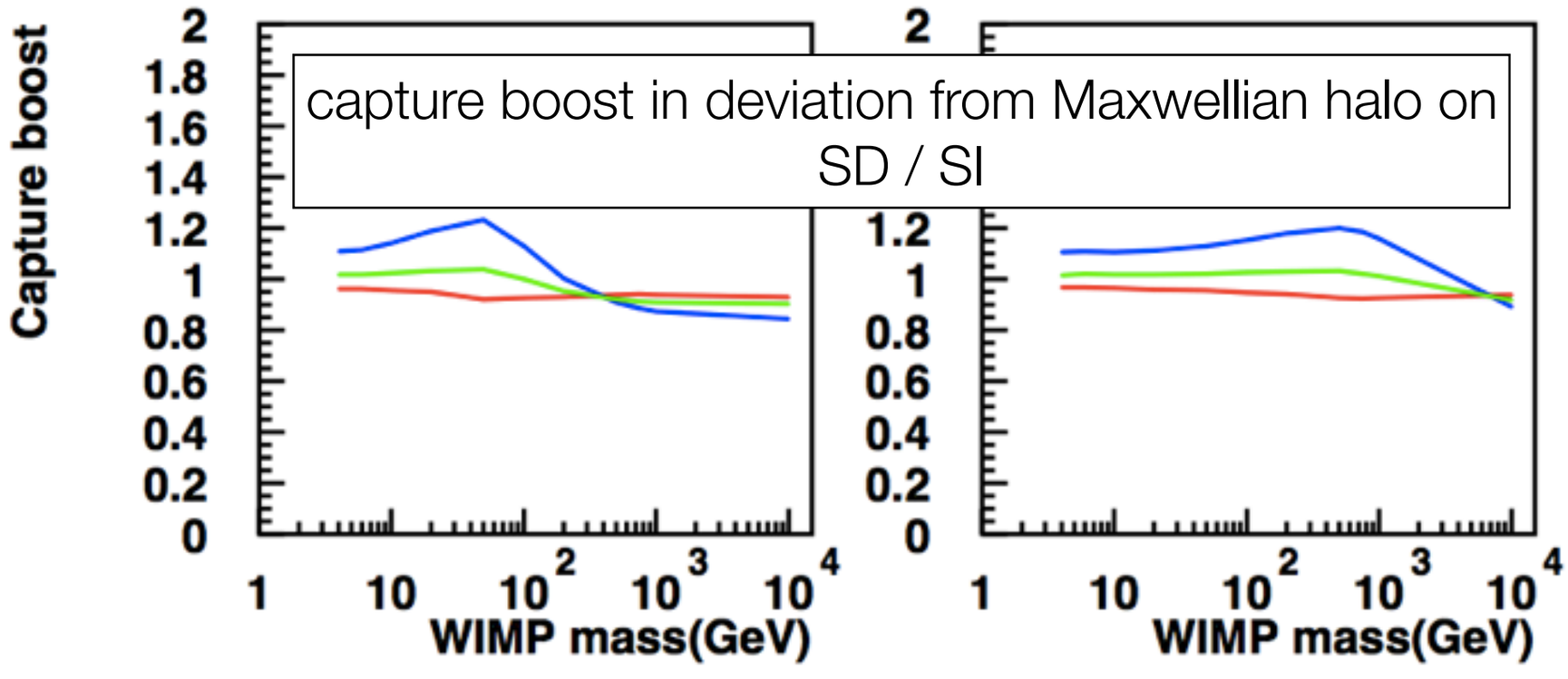


1) solar circular velocity, velocity dispersion
: affects small for low mass WIMP (C.Rott, T.Tanaka, Y.Itow)

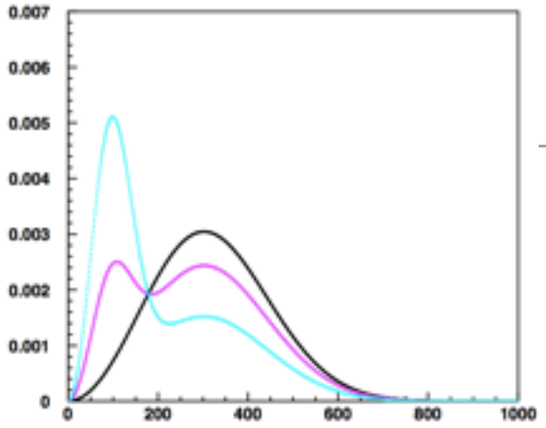
2) simulated halo VDFs show deviations from Maxwellian.



capture boost in deviation from Maxwellian halo on SD / SI



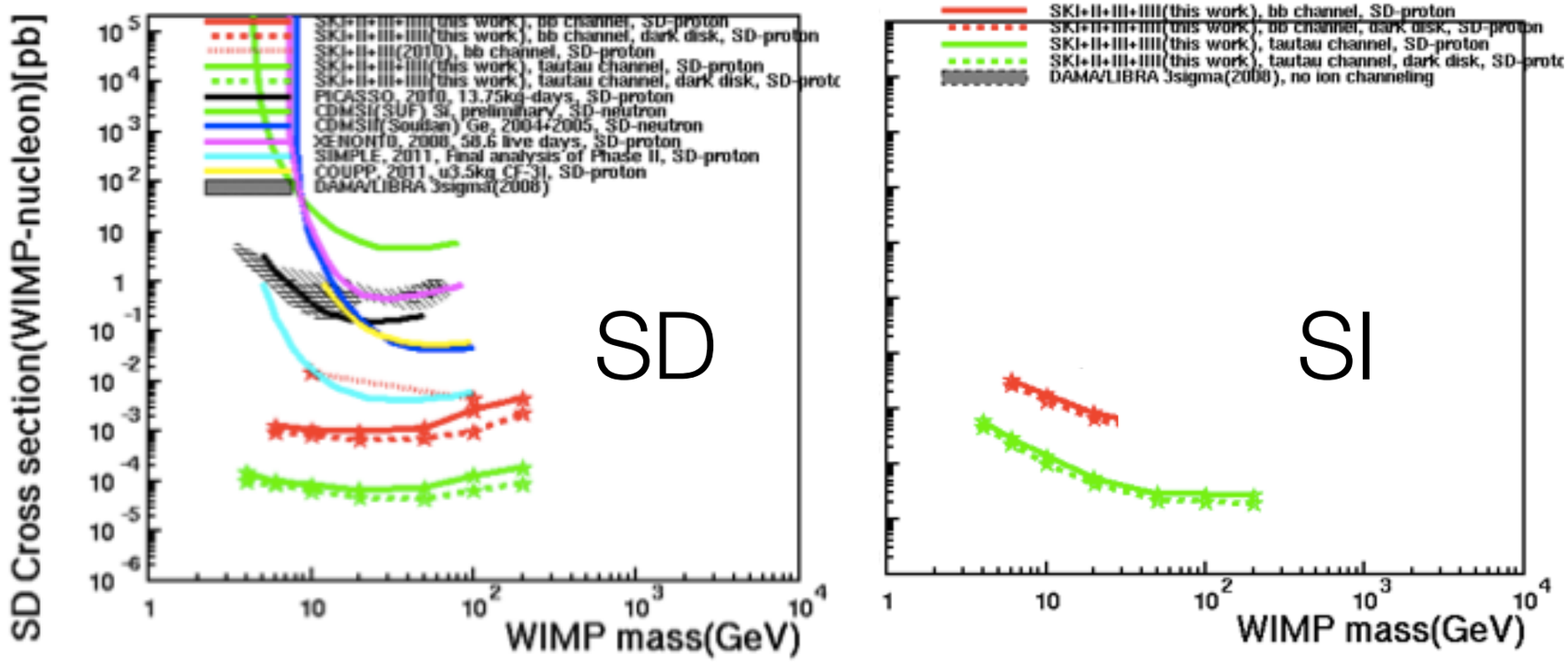
➢ Extra structure of WIMPs - dark disk, debris, caustics, etc.



VDF of strong dark disc(blue, 50% of halo density), 25% (pink)

-> abundance in low velocity can boost neutrino detection!

Existence of co-rotating invisible structure, dark disc in the solar neighbor, claimed to be robust by cosmological simulations

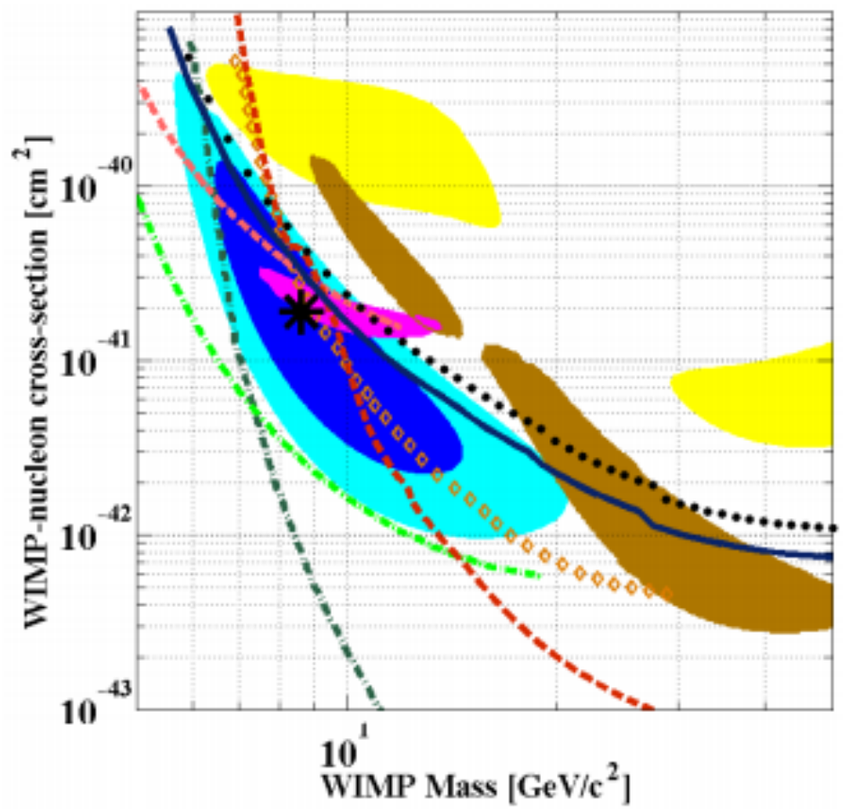


SD : In low mass(below 10GeV), maximally factor 2 affected in most extreme modified velocity distributions currently being discussed

SI : relation between neutrino detector / DD results can hold in either case of strongest or with mildest(no dark disc) assumptions of dark disc.

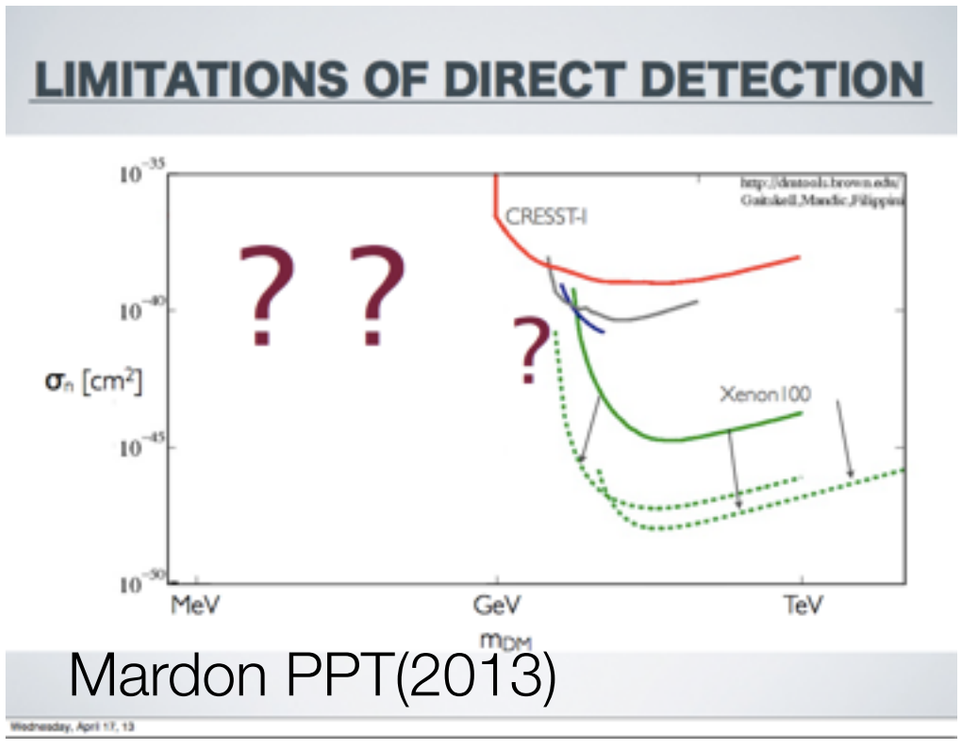
- Light WIMP search - motivation & strategy

Search for the light WIMPs in Hyper-K



Accumulated claimed signal from direct detection(DAMA,CoGeNT,CRESST,CDMS si) for 5~20GeV WIMP

CDMS Ge / XENON10/100 conflict



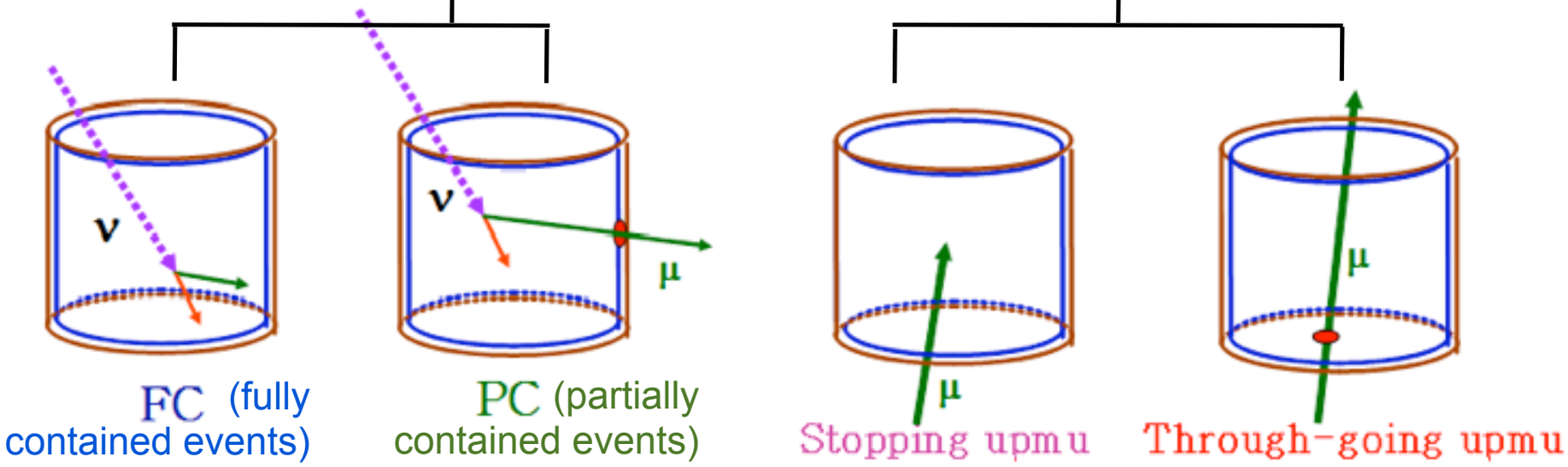
Xenon10, Xenon100 has come close to demonstrating sensitivity to a ~8GeV WIMP, but Will be nice to have another independent experiment here!

Super-K is the current most sensitive detector for few GeV neutrino, so will Hyper-K.

Search for the WIMPs using contained events in Super-K

Events categories in Super-K

contained events **up-going muons(upmu)**



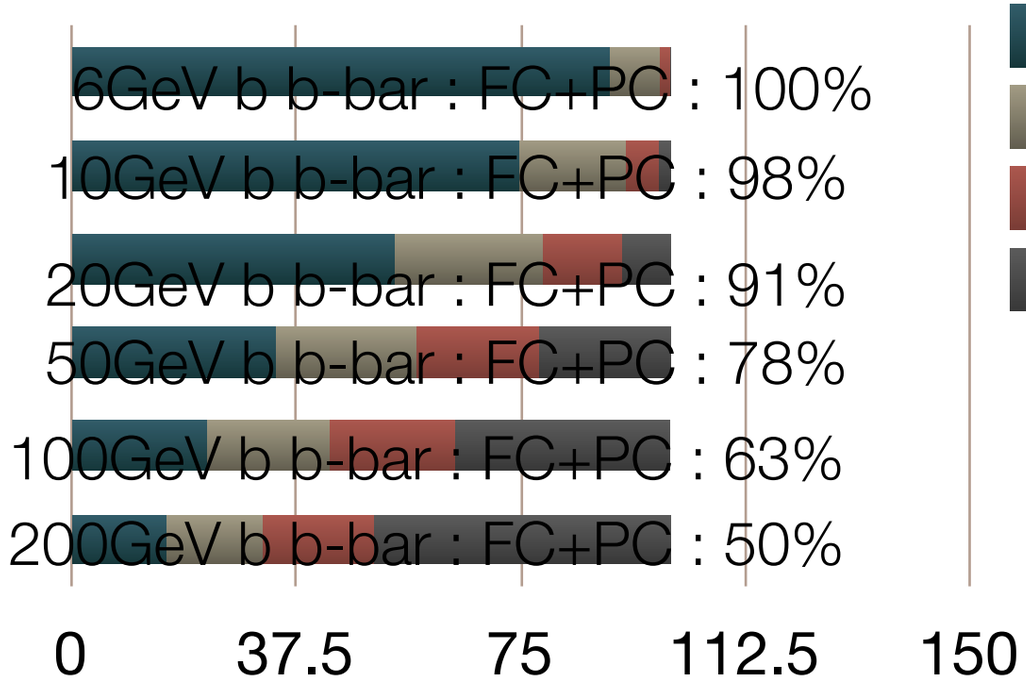
FC (fully contained events)

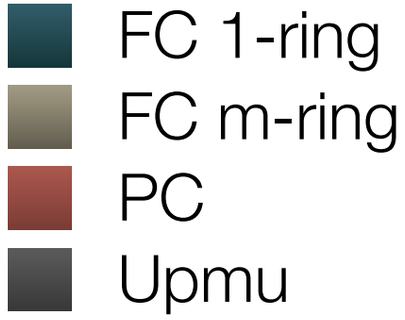
PC (partially contained events)

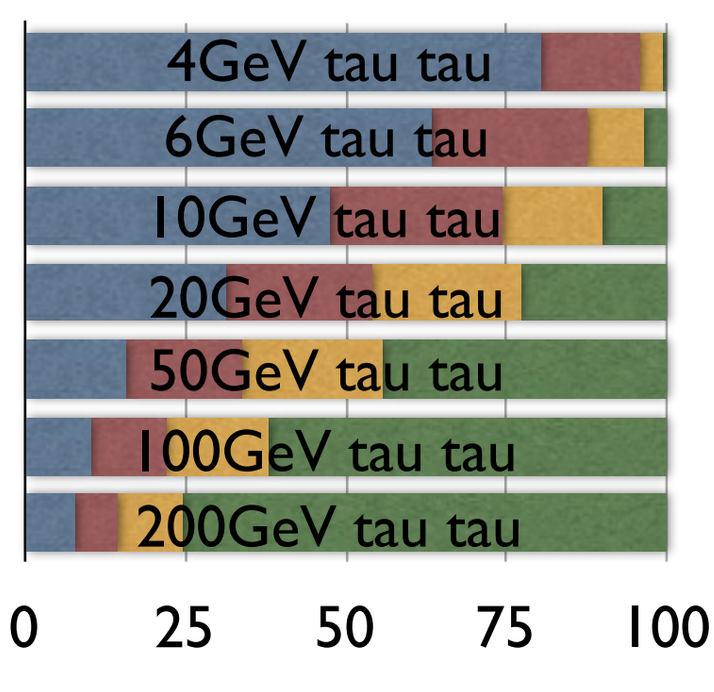
Stopping upmu

Through-going upmu

For low mass WIMP below 10GeV, most of the signal goes to contained(FC+PC) categories.



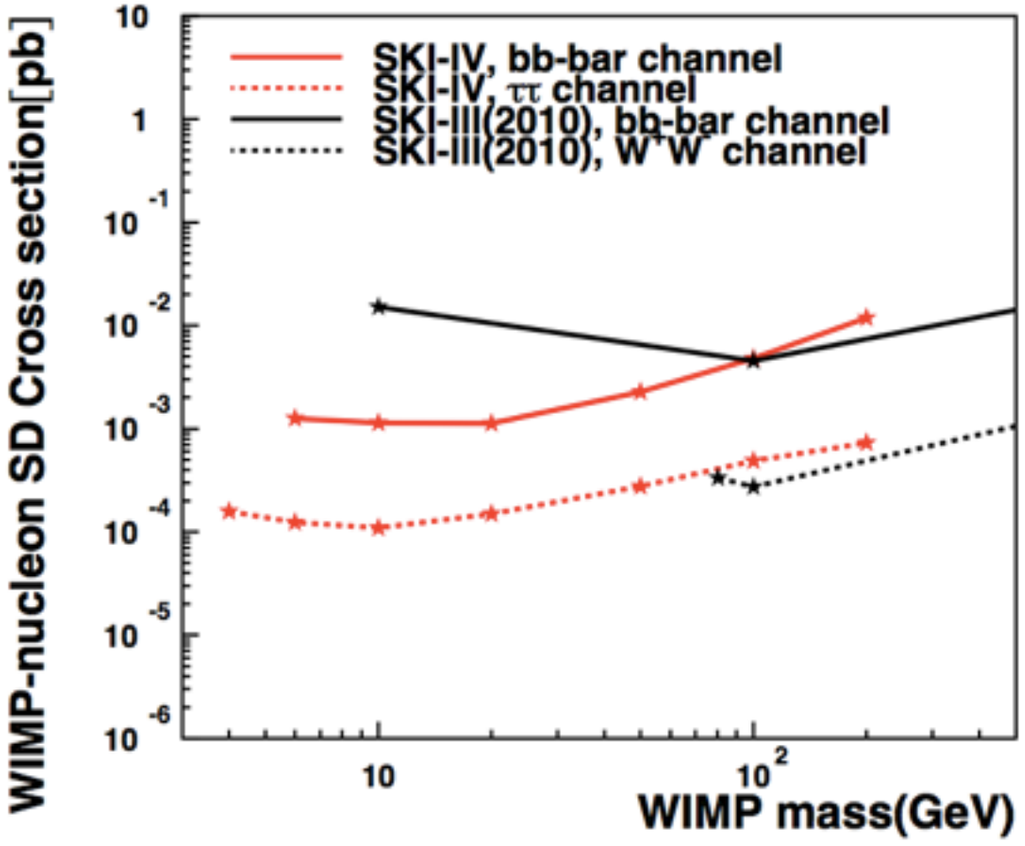




limit on SD WIMP-proton scattering cross section : Super-K solar analysis

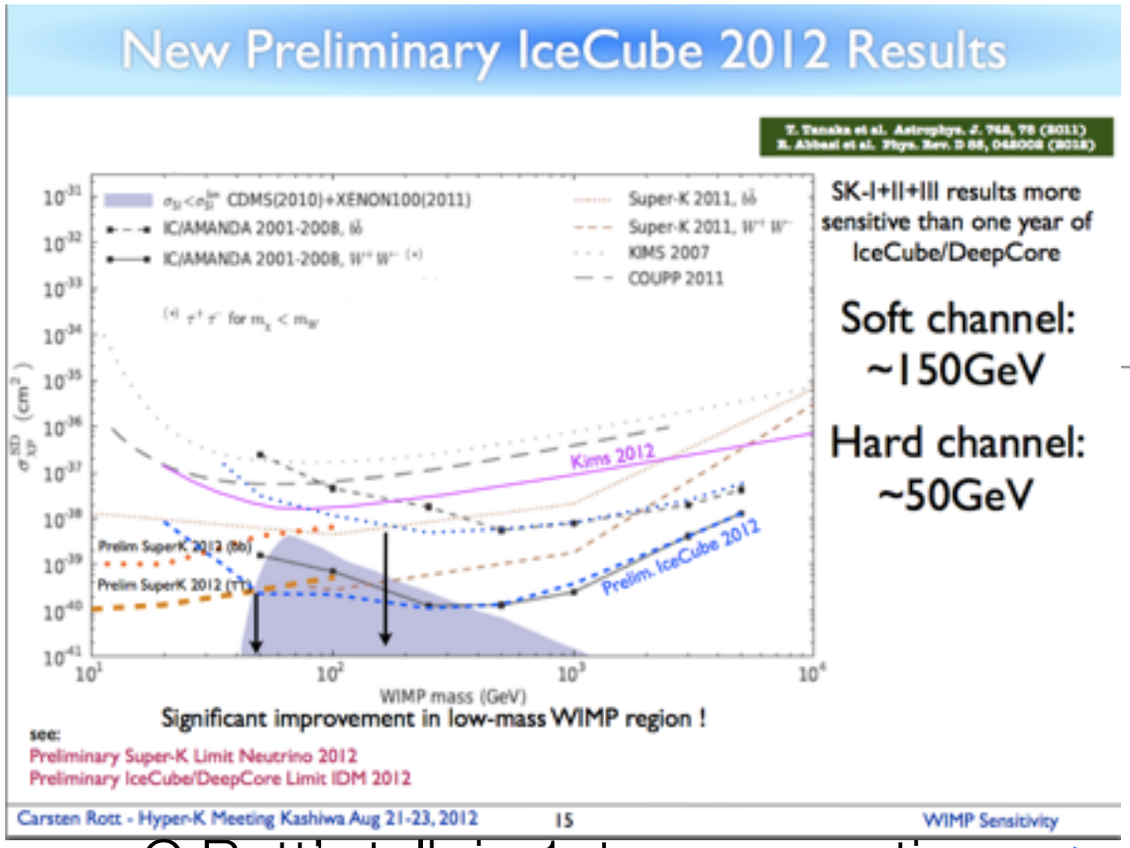
Search for access neutrino flux in the direction towards the Sun compared to expected background of atmospheric neutrinos.

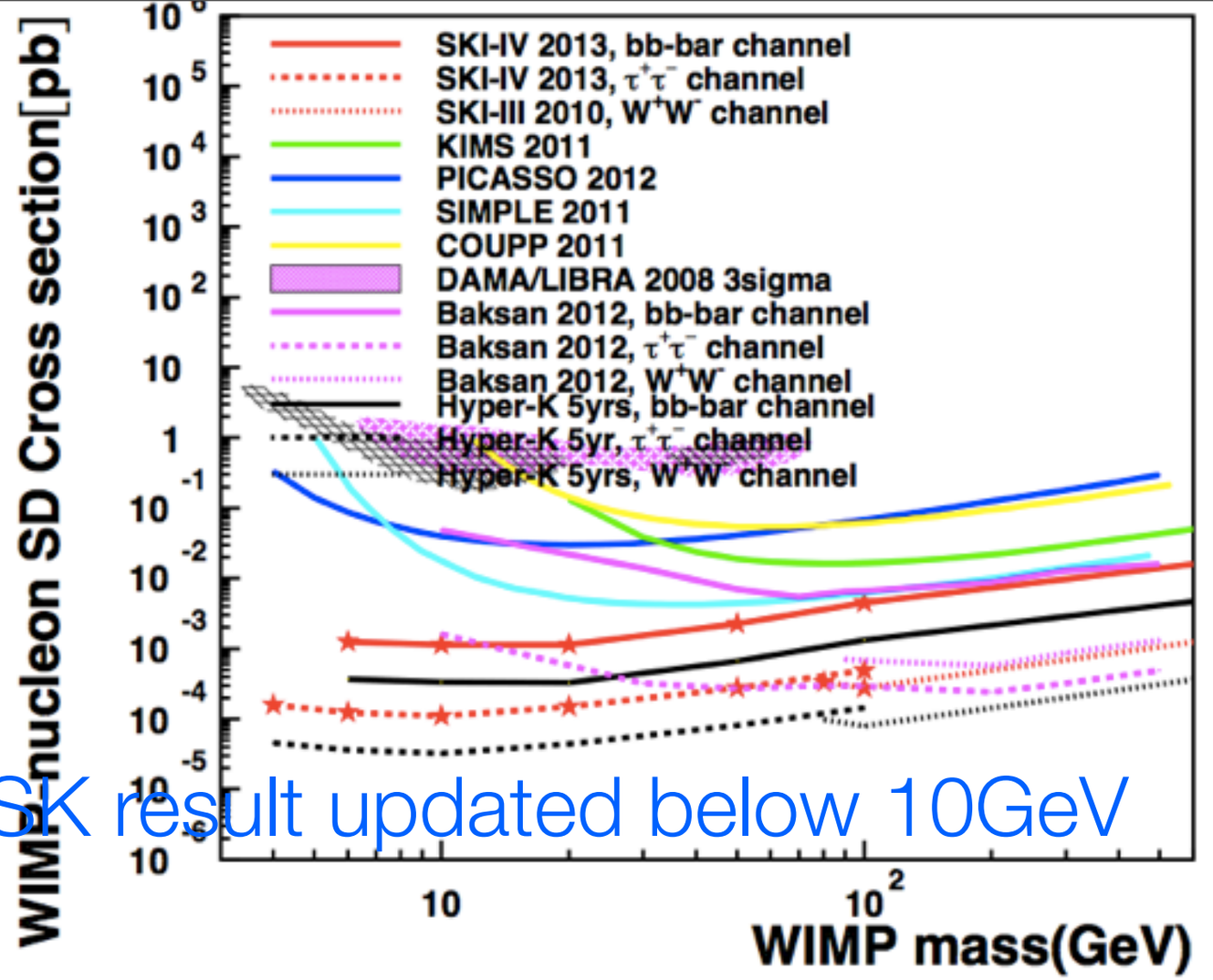
using every yield - fully contained, partially contained neutrino events & up-going muon events
using accumulated SK1-4 data (3903days fv22.5kton)
fit data / signal+BG in 2736 bins by pulled chi square method to use energy / angle / flavor information -> derive 90% Bayesian upper limit on WIMP induced neutrino events -> convert it to limit on neutrino flux -> limits on scattering cross section.



Improved solar analysis for SuperK :
increased signal acceptance using low energy & electron neutrino (for 10GeV bb WIMP, 50times), fitting with angle + energy + flavor informations.

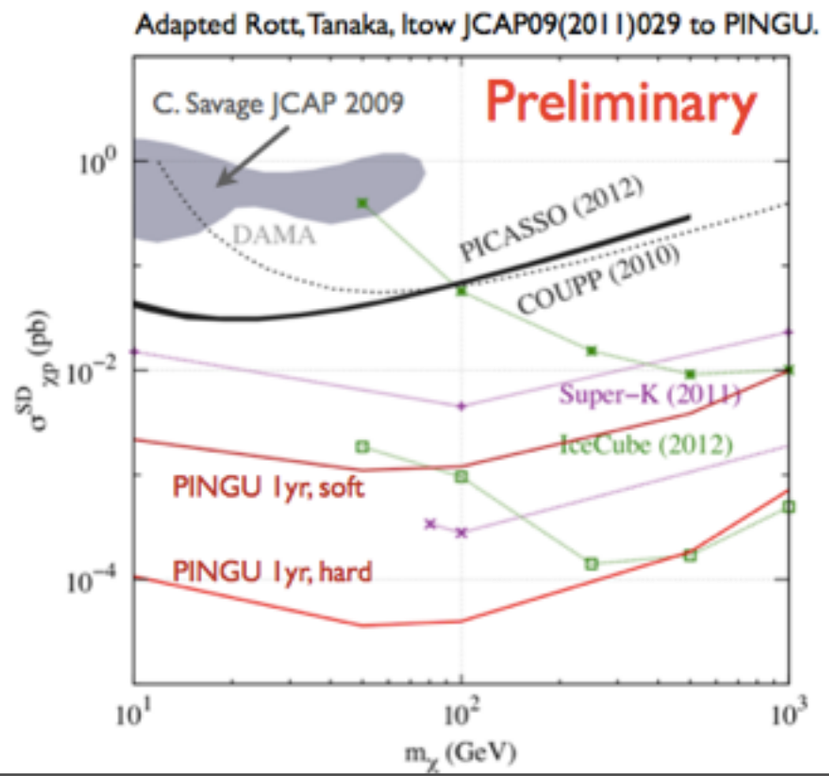
- Light WIMP search - current limits & Hyper-K sensitivity





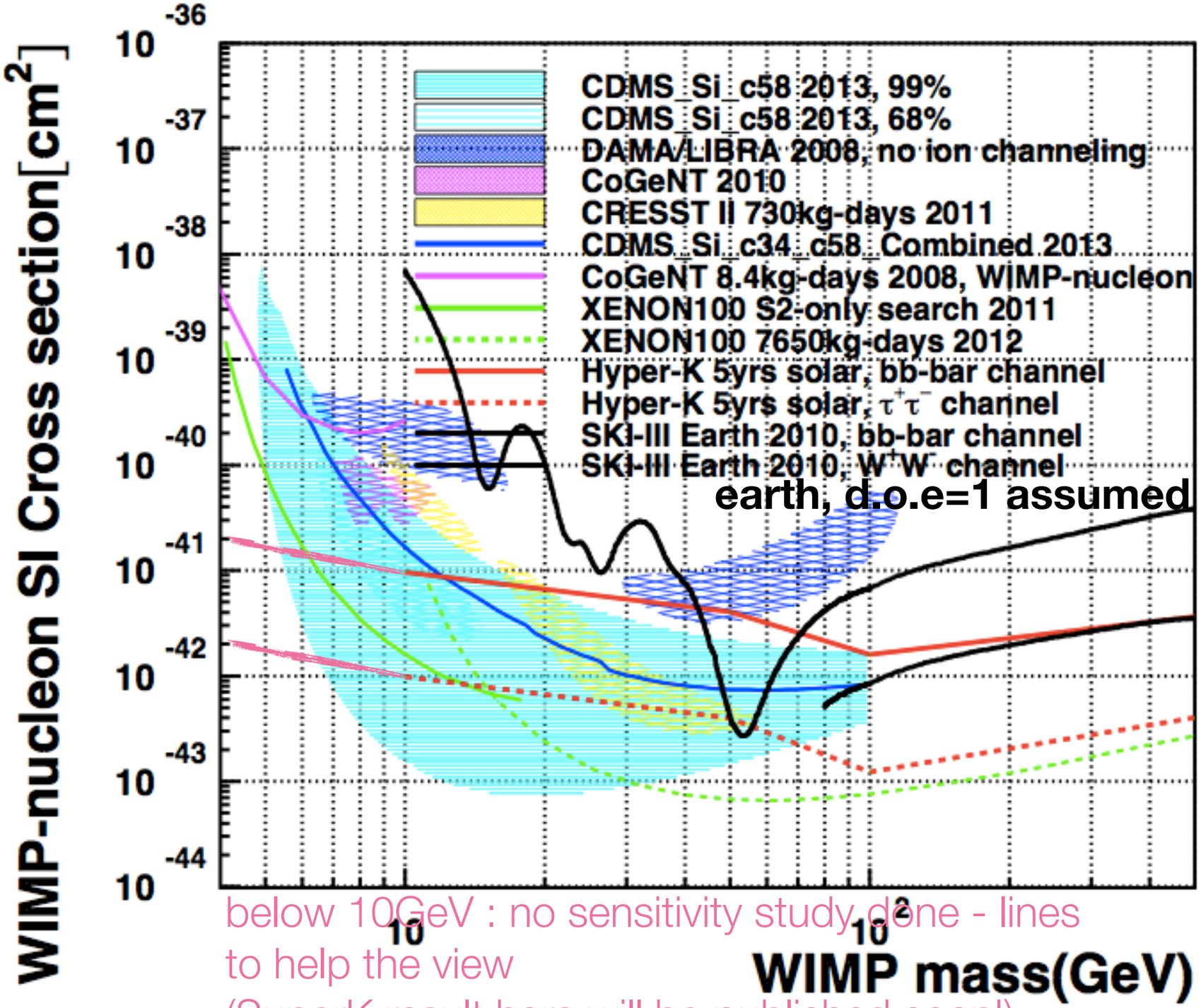
C.Rott's talk in 1st open meeting -> SK result updated below 10GeV

Hyper-K sensitivity : based on SK 2013 analysis
6-50GeV bb & 4-20GeV tautau
(contained events dominant)
: HK fiducial volume : 25 x Super-K
5yrs of HK will improve sensitivity by 3.5 times SK1-4
100GeV- bb & 50GeV- tautau(upmu dominant)
: HK effective area : 18times SK.
5yrs of HK will improve sensitivity by 3.4 times SK1-3



Hyper-K will keep best sensitivity in SD search & will be competitive with PINGU(who will start first?)

Spin-independent WIMP-proton scattering cross section

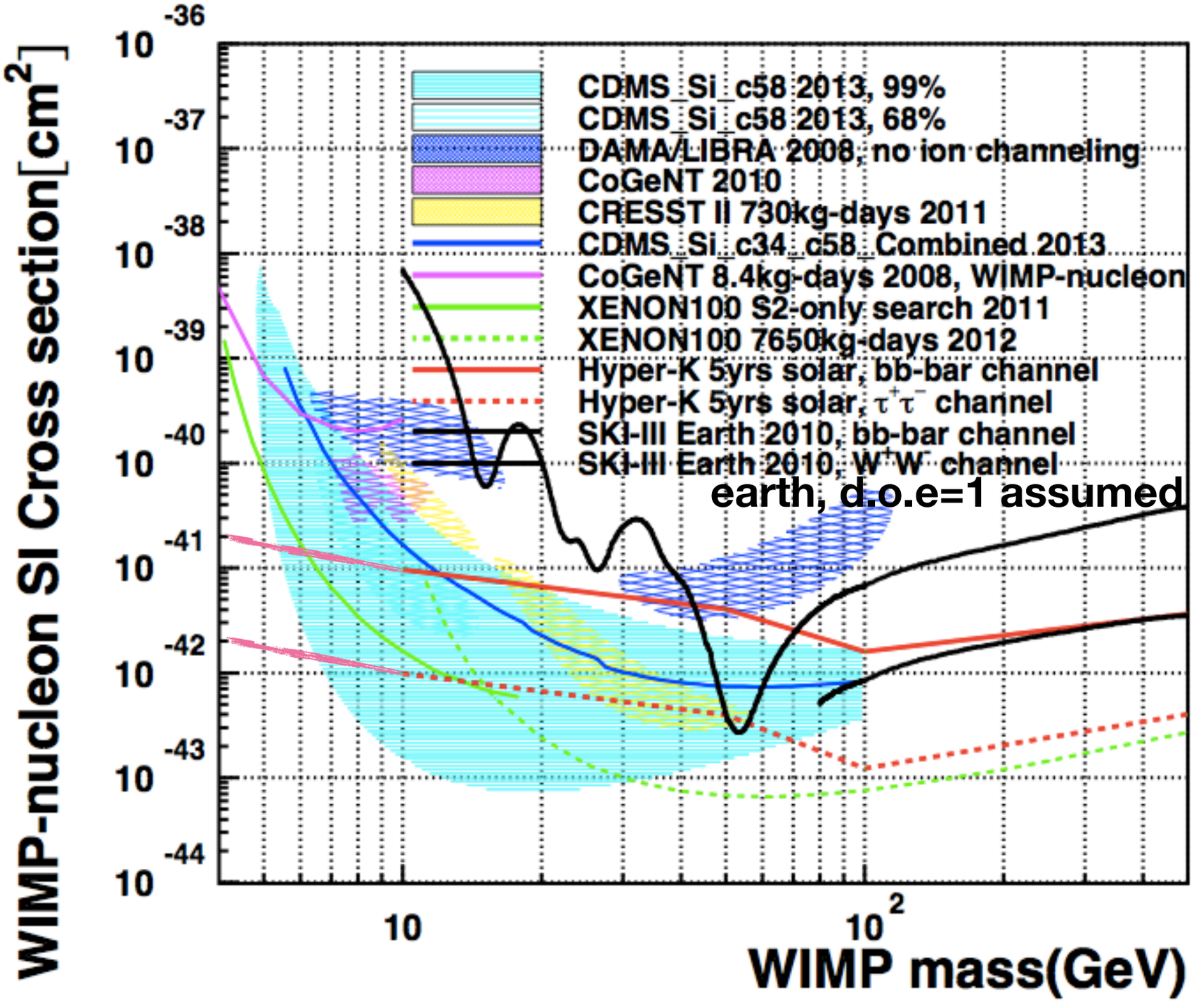


Hyper-K sensitivity : based on sensitivity study for 0.5Mton detector using contained events,
by Rott, Tanaka, Itow(1107.3182).
(with 10degree angular cut & low E threshold, for nu_e/anti nu_e WIMP induced neutrino flux)

below 10GeV : no sensitivity study done - lines to help the view

(SuperK result here will be published soon!)

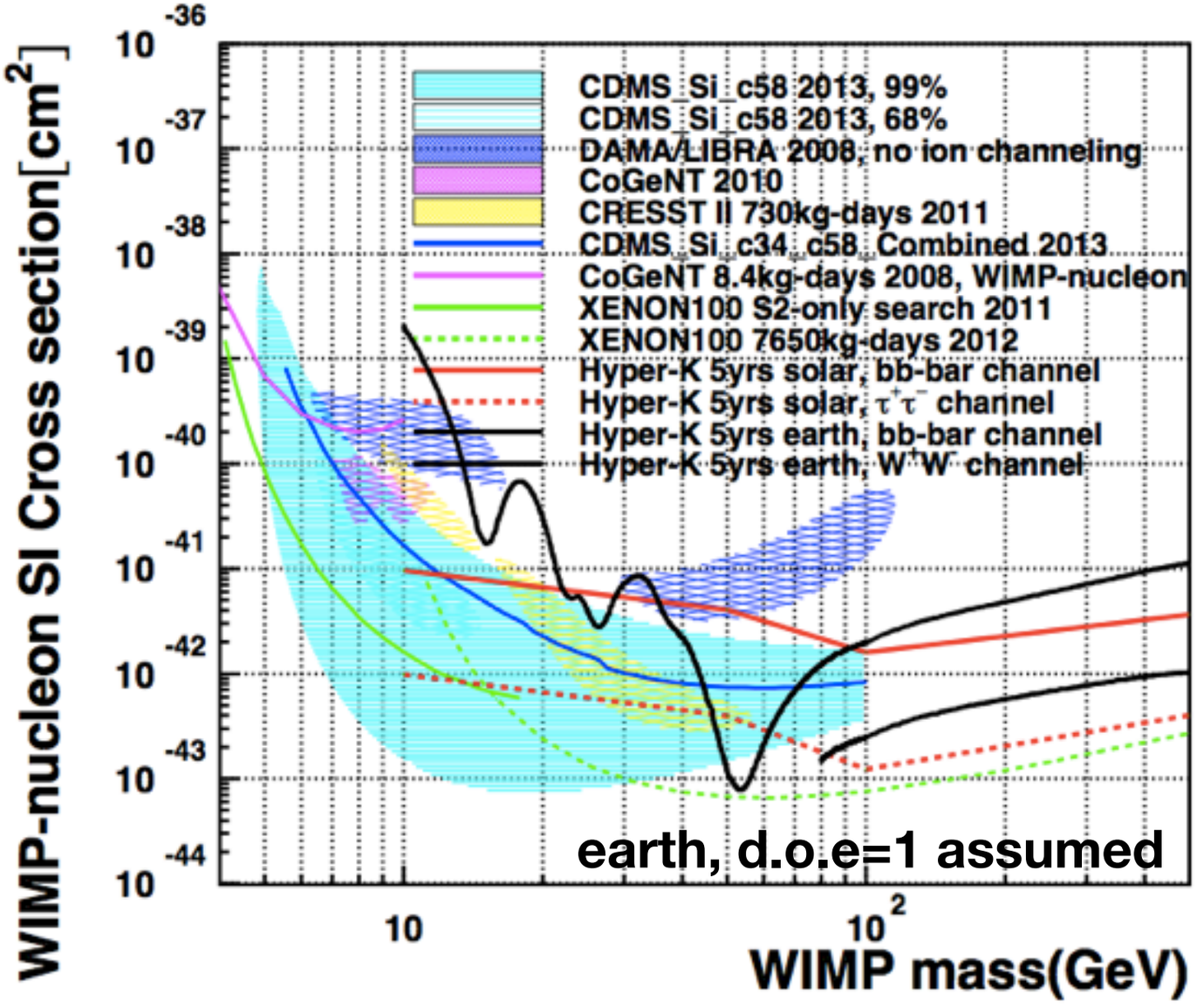
Spin-independent WIMP-proton scattering cross section

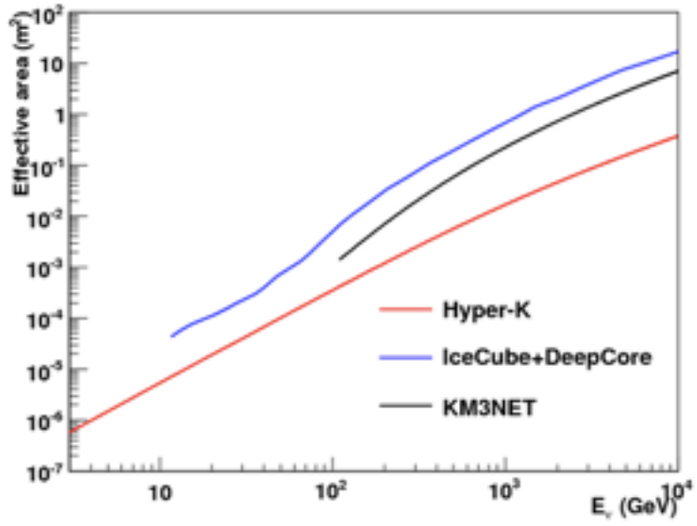


- Hyper-K can help understanding low mass WIMP
  - can examine CoGeNT signal
  - reach better sensitivity in very low mass than Xenon100

- Constraint from WMAP can give power in interpretation of HK result as favoring muon, tau, neutrino annihilation channels(Which gives stronger limits than conservative choice as bb-bar, etc)

Spin-independent WIMP-proton scattering cross section : Earth analysis





Ikeda(HK physics WG)

Hyper-K sensitivity : based on SK 2010 analysis(1108.3304, Tanaka et al.)
: HK effective area : 18times SK.
5yrs of HK will improve sensitivity by 3.4 times SK1-3

The Earth is known to have better power for SI search than the Sun.
However, the theoretical uncertainty on ‘equilibrium’ is more critical than the Sun.

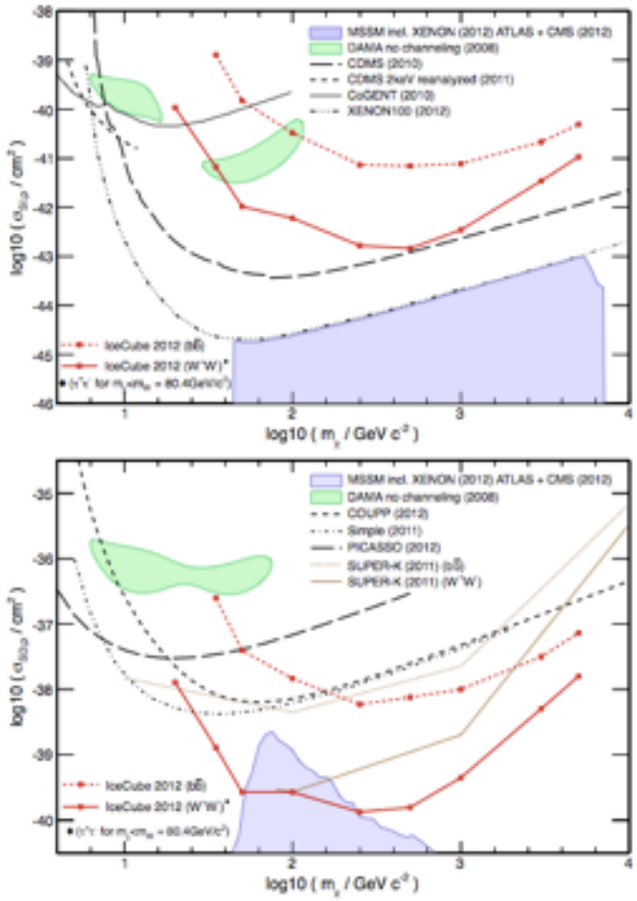
- Light WIMP search - Hyper-K target models

Hyper-K search for light LSP in MSSM

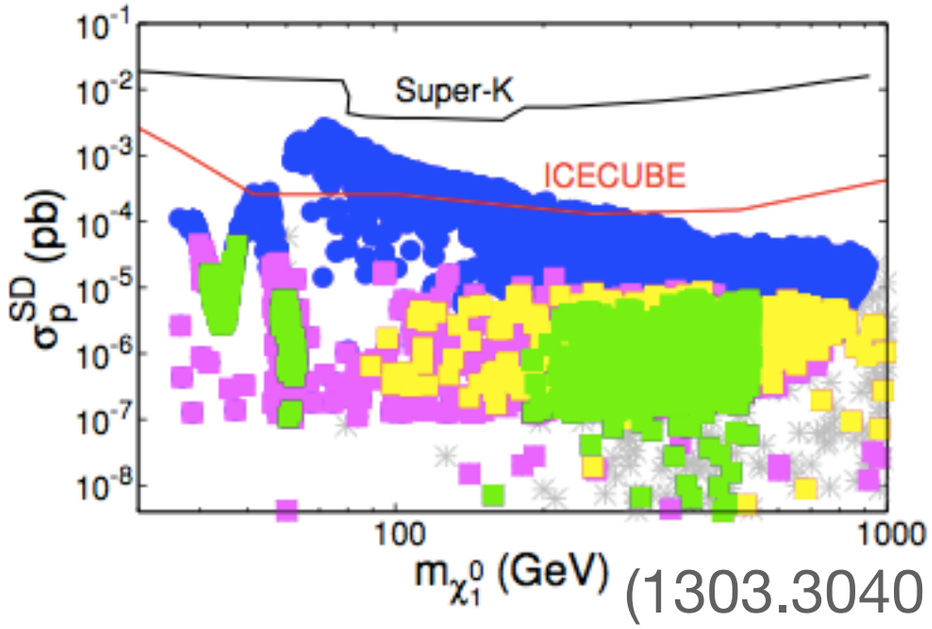
- any model which can explain claimed signals consistently?
  -> no. (1107.1604, 1304.3040, many papers)

- any model left for light WIMP?
  -> no. (1304.3040 : The low LSP mass region is essentially closed, yielding a rough bound m > 30 GeV. We thus find that the DAMA/CoGeNT/CRESST observations are incompatible with the MSSM.)

- can Hyper-K help in search for (heavier) LSP...?
  -> not really.. (parameter space remained are rather for heavy WIMPs, & SD cross section are suppressed for scanned models.)



MSSM-25(Silverwood et al,1210.0844) : model parameter space scanned for Neutralino LSP with constrains from accelerators, CMB, Direct detection SI null results



(1303.3040 Han et al.)

Hyper-K search for light WIMP in next-to-MSSM

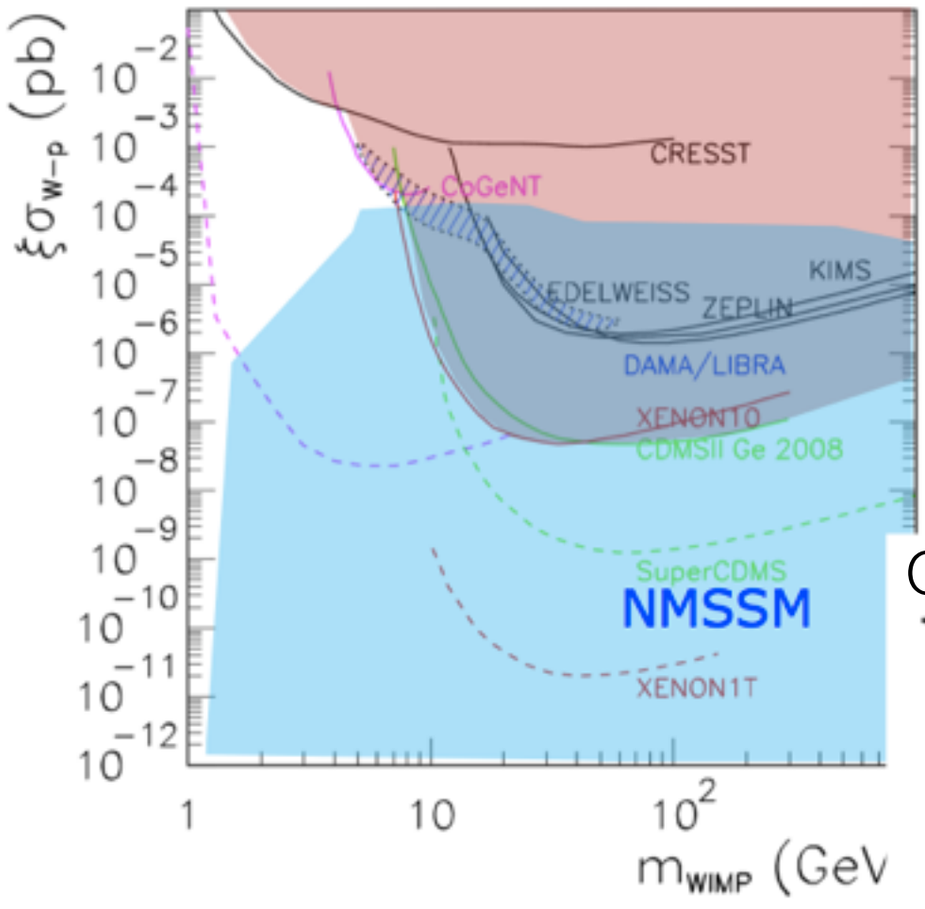
where we don't have to give up claimed DD signals
& light WIMP SUSY candidate!

"The mass of the LSP can be considerably smaller in the NMSSM and can still be compatible with the WMAP constraint on the relic density. Also NMSSM allows an elastic scattering cross section consistent with the rate observed by CoGeNT and DAMA. (lost ref...sorry)"

Couldn't find plot for SD model parameter space

Looks hopeful.
better yet,
not necessarily conserve isospin?

SI coupling

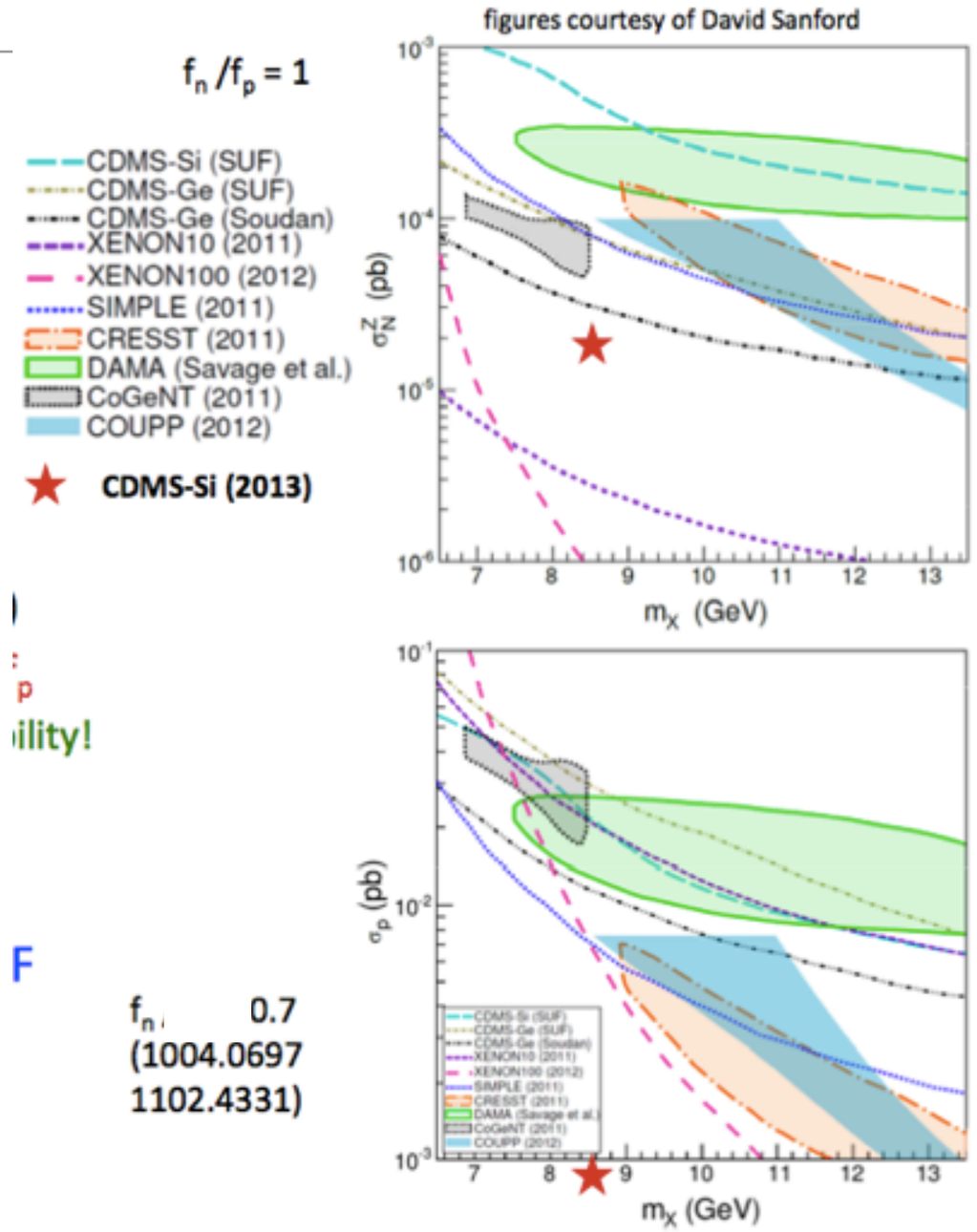


Cerdeno
PPT

Hyper-K search for isospin violating DM

motivation for isospin invariance assumption breaks if not light LSP in MSSM.(Kumar, 2013)
IVDM search would not only serve for certain model but brings more general discussion on DD results (also maybe more hopeful to explain DD signals)

- solar analysis has strong sensitivity for IVDM Due to the Sun chemical composition with approximately 73% of hydrogen (less susceptible to destructive interference between proton and neutron couplings).



Kumar PPT(2013)

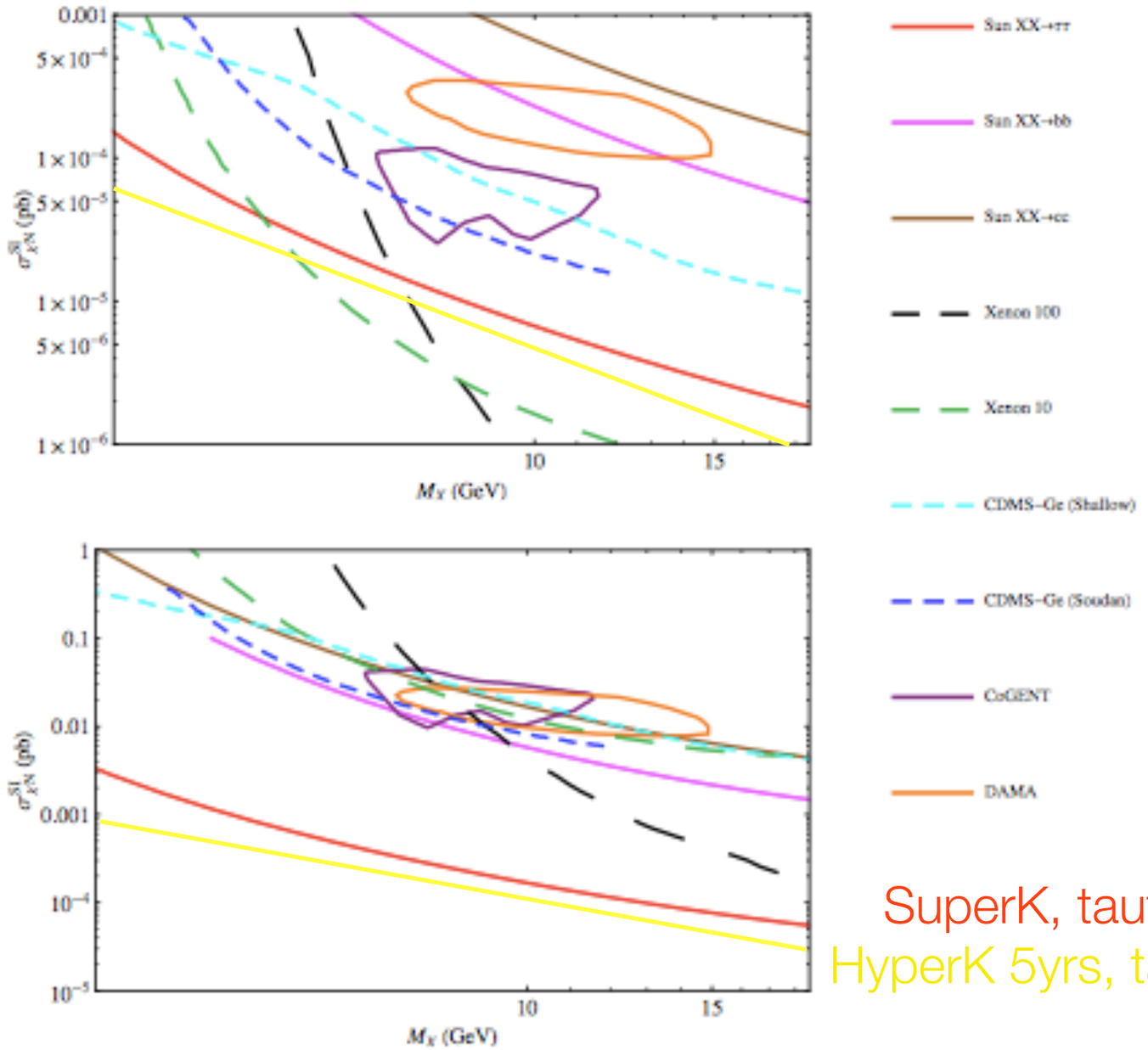


FIG. 3. Positive signals from DAMA (orange circle) and CoGeNT (purple circle) in view of other direct detection experiments (dashed line) and indirect detection of neutrino flux (solid curves) from DM solar capture and annihilation, in isospin conserving (upper panel) and violating (lower panel) cases. In each panel, from up to down the solid curves represent annihilation to final states $c\bar{c}$, $b\bar{b}$ and $\tau\bar{\tau}$, assuming 100% branching ratio.

1106.4044 Chen et al.

Conclusion

- Hyper-K is expected to have strong sensitivity in SD coupling WIMP as previously shown for up-going muon solar analysis(Ikeda) & contained neutrino analyses(Carsten Rott).

- Hyper-K will also take important roll in solving light SI coupling WIMP puzzle.
  - test large fraction of claimed signals if the WIMPs have significant fraction to tau tau channel
  - reach better sensitivity in very low mass than Xenon100
  - even more important in search for IVDM

- The sensitivity will improve with time, while direct detection at low mass are essentially limited by energy thresholds.

- Serving as an indirect detection with well understood uncertainties is important, as once the WIMP signal is finally confirmed by direct detections, to solve the uncertainties on isospin invariance & SD/SI coupling!