Indirect search for WIMP by looking at the Sun with neutrino detector

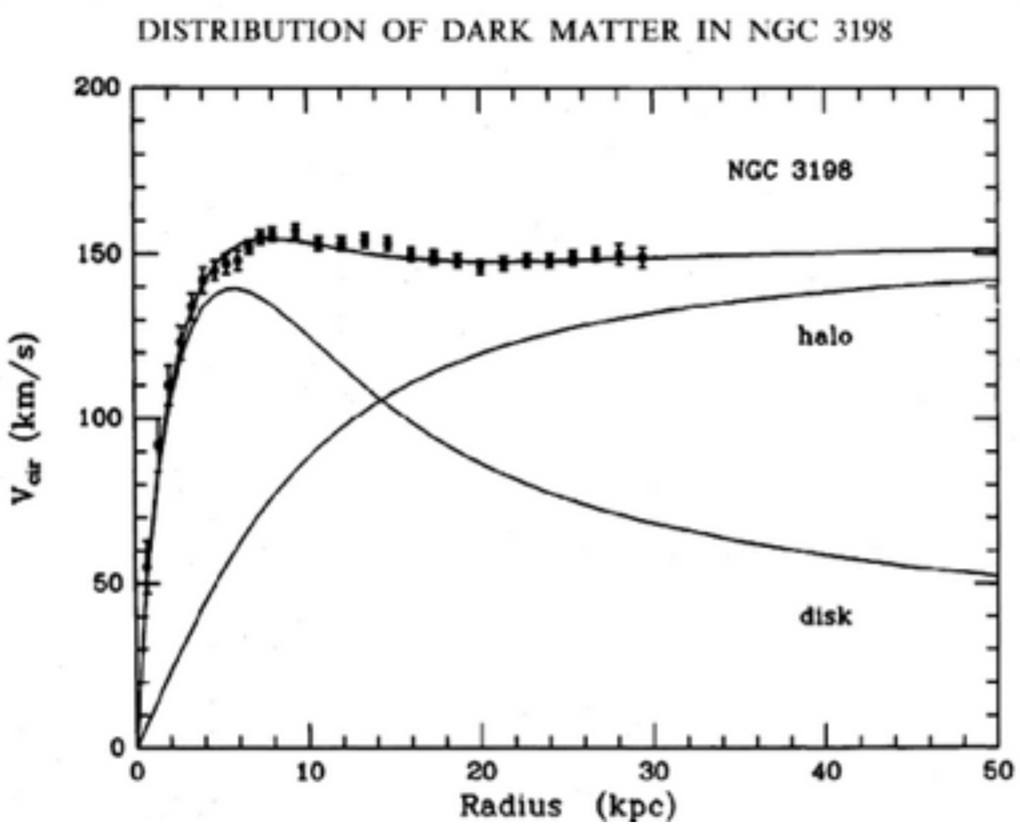
14’1’14

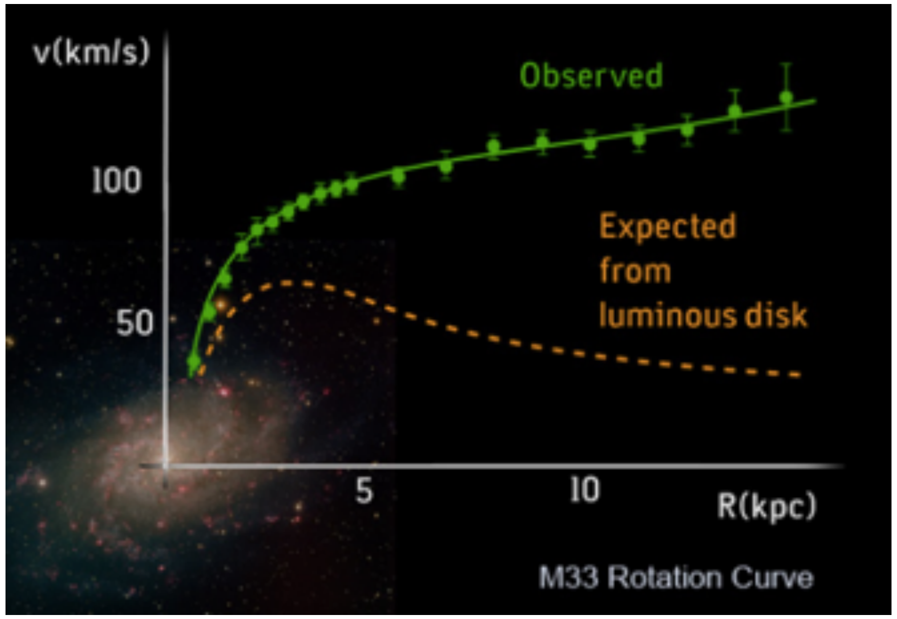
10th Yonsei-Saga workshop

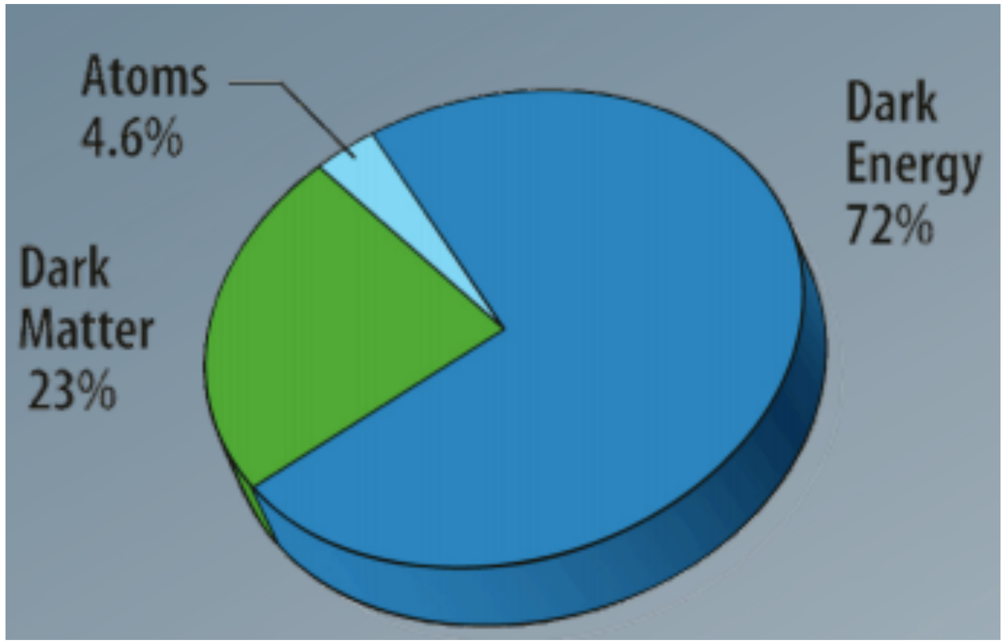
Nagoya Univ. Koun

Dark matter?

- Observations of ‘unknown not-interacting massive matter’

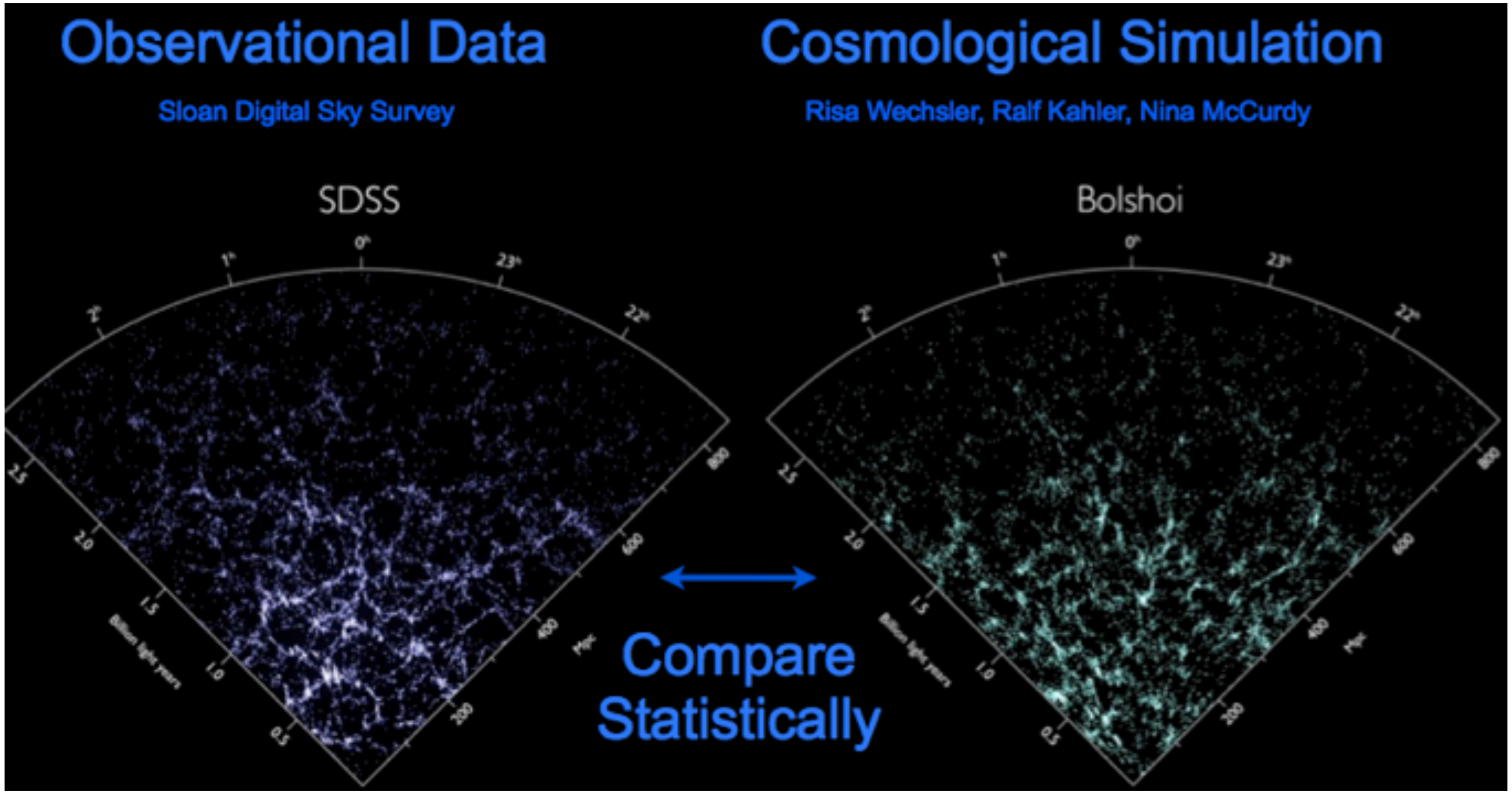






Dark matter?

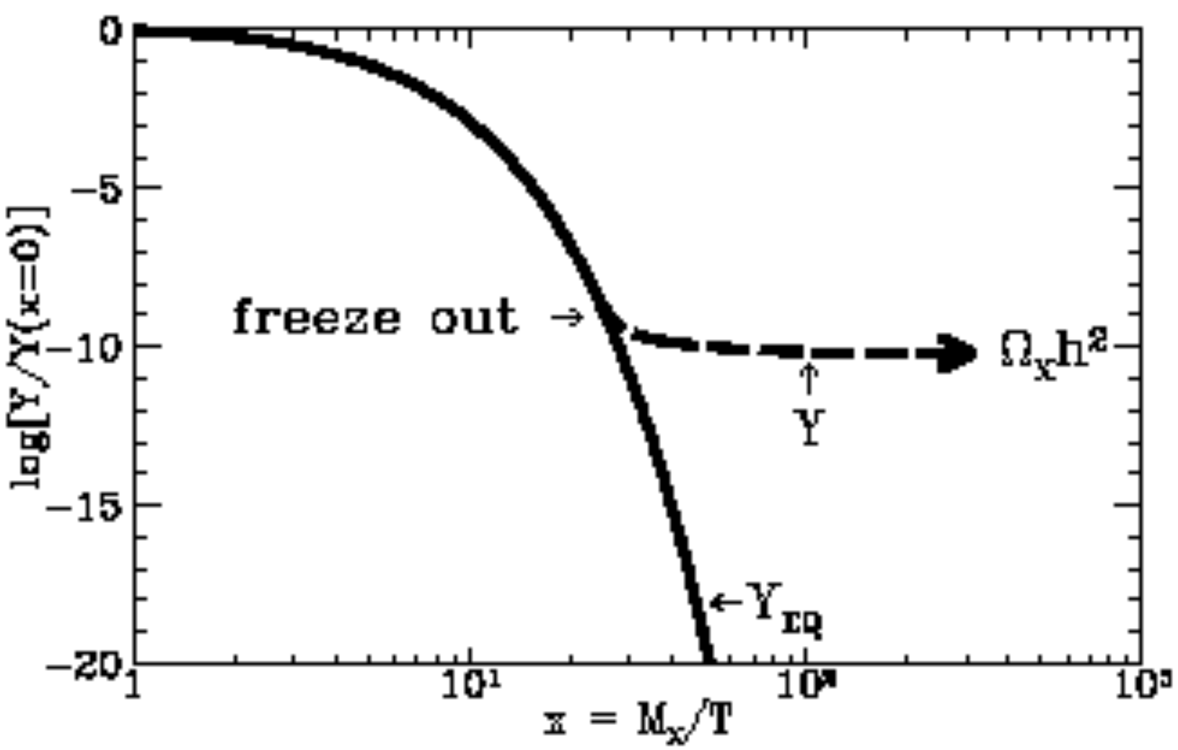
- Seed for cosmological structure formation is needed (cold dark matter)
- There's no explanation from our current understanding (no candidate in standard model(SM))

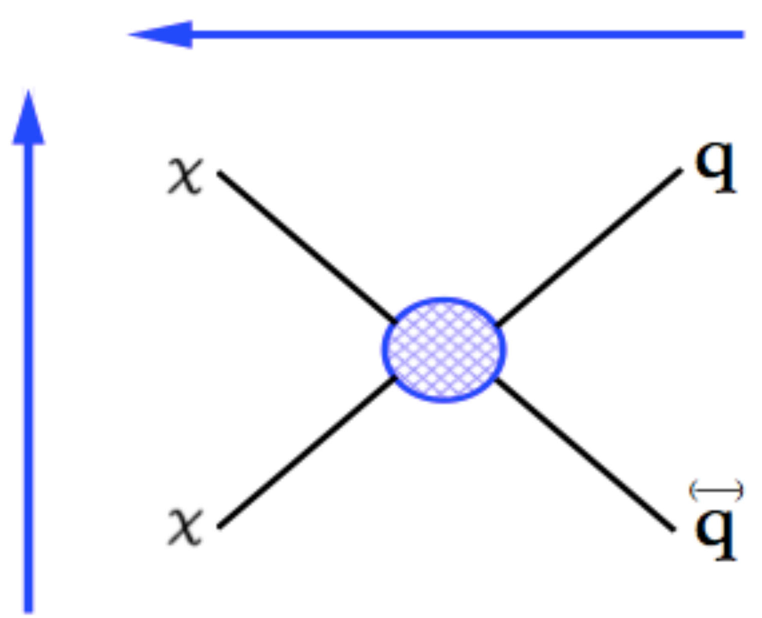


Search for the particle dark matter?

- we don’t have certitudinous strategy where to look at but we have ‘wishful thinking’ what we hope it to be - WIMPs, for example.
- era of data - models and strategies being motivated and constrained constantly
- unlike higgs, discovery of dark matter(DM) will be the starting point to understand it

Search for the WIMPs?





"WIMP"

seeking for a particle which can sorely explain DM relic density by its annihilation rate.

"WIMP miracle"

weakly interacting massive particles were there, in supersymmetry(SUSY) ; which accommodates not only nice dark matter candidate but also other beyond-SM issues...

"Crossing symmetry"

: the small annihilation cross section indicates the small scattering with ordinary matters

What current WIMP searches mean by 'WIMP'

<assumptions on distribution>

- virialized, form a DM halo in our galaxy, responsible for local density near the Sun (0.3GeV/cm3)

<assumptions on scattering to ordinary matter>

- 'elastic' scattering off nuclei
- only single interaction types (SD or SI)
- isospin conserving interaction

<assumptions on annihilation to ordinary matter>

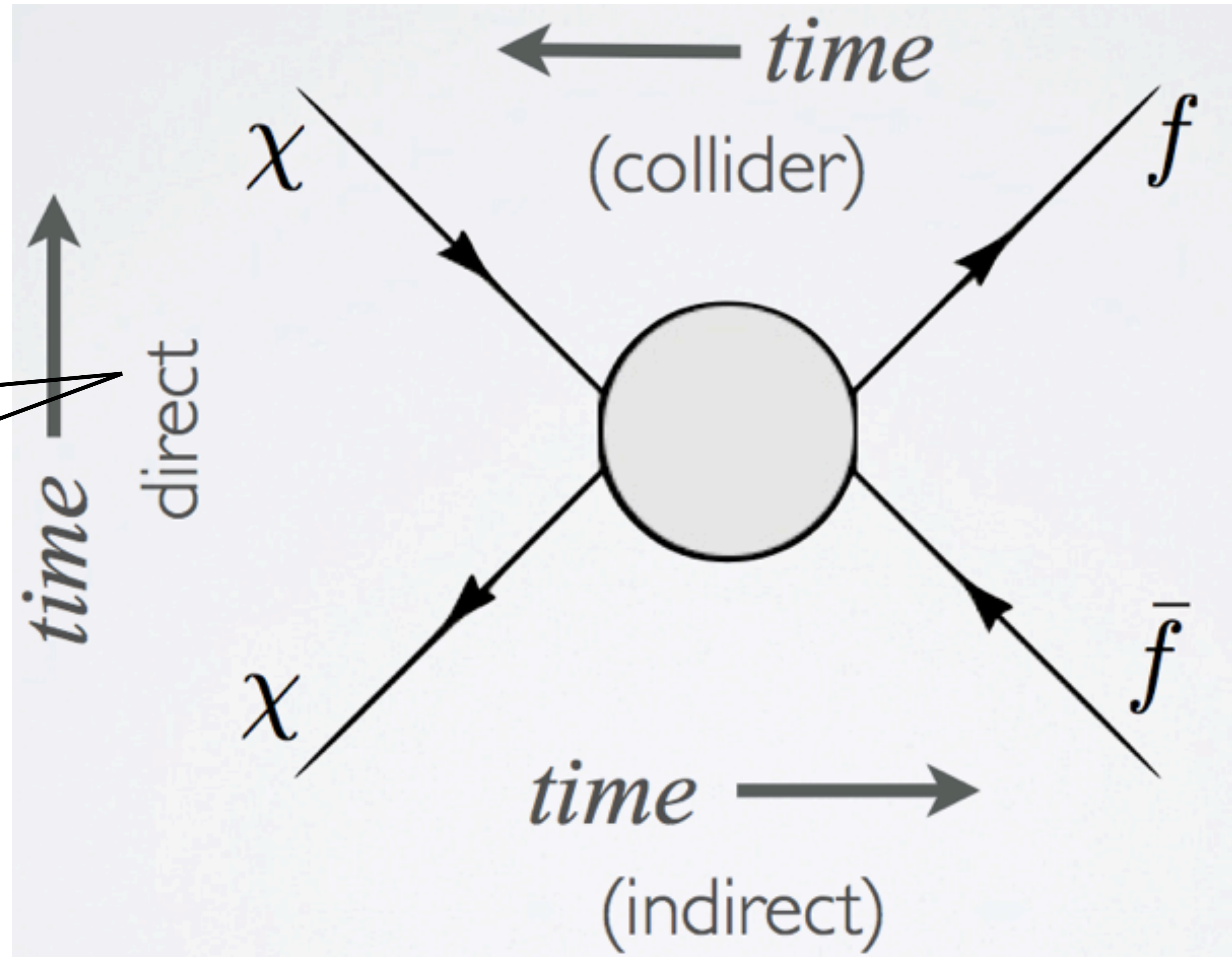
- "Majorana particle"
- single branching ratio

→ pair annihilation to a single pair of fermions/bosons

WIMP search

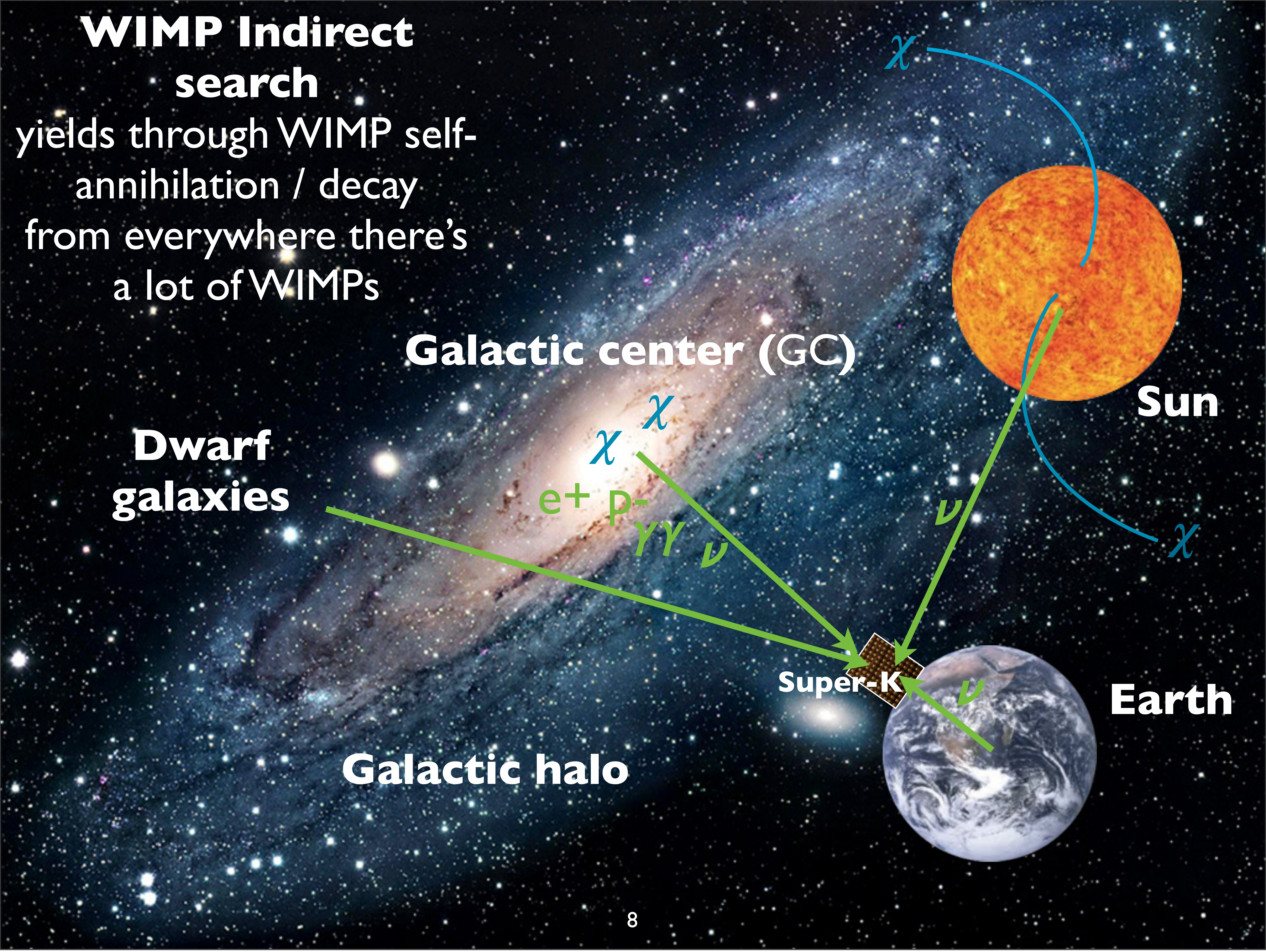
- constrain WIMP-nucleon scattering cross section

+ indirect solar / Earth neutrino search



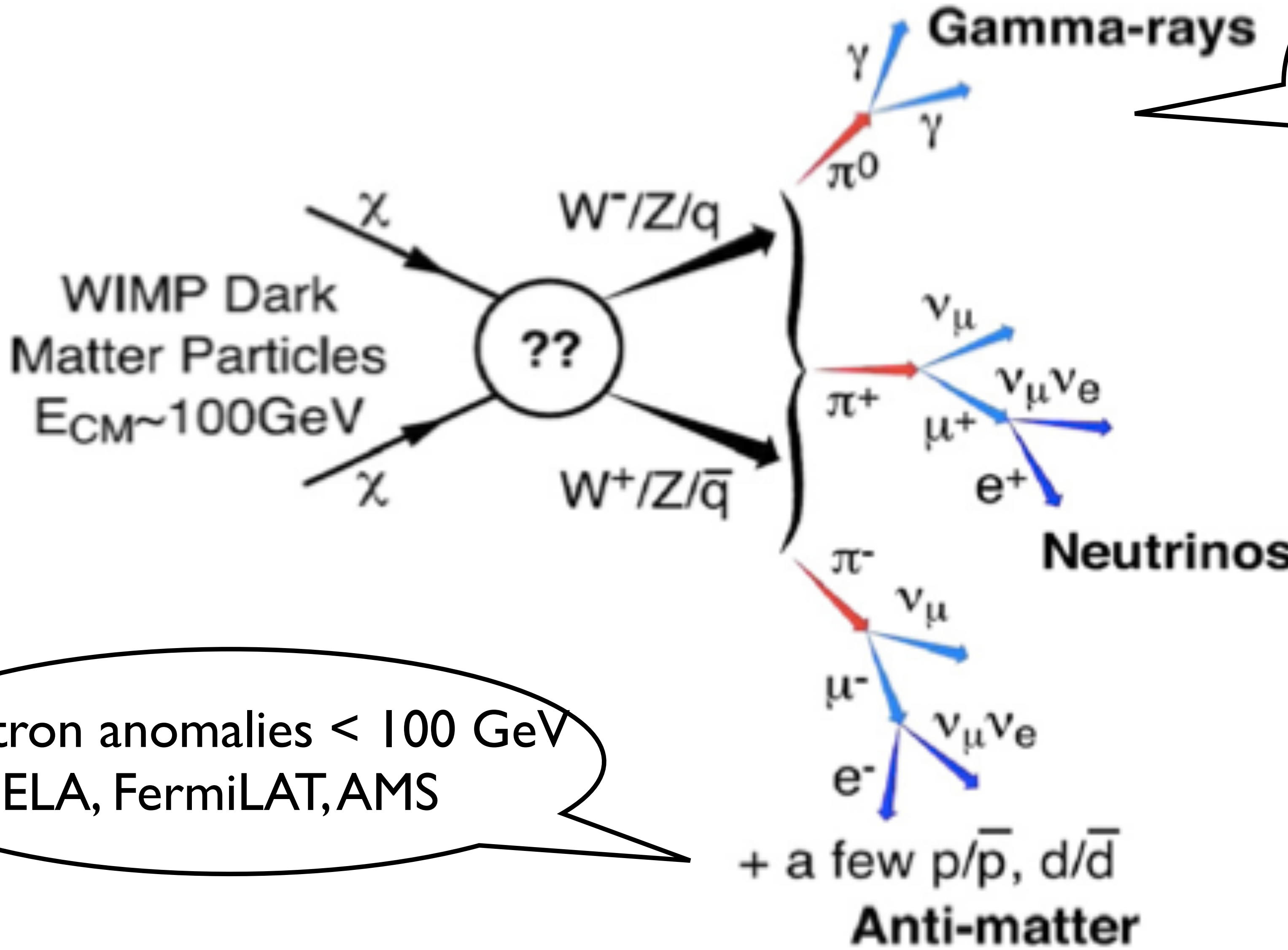
- constrain WIMP annihilation cross section / lifetime

IceCube


WIMP Indirect search
yields through WIMP self-annihilation / decay from everywhere there's a lot of WIMPs
Galactic center (GC)
Sun
Dwarf galaxies
χ
χ
χ
χ
e+ p-
γγ
ν
ν
ν
Super-K
Earth
Galactic halo

Indirect WIMP search

FermiLAT : 10-30 GeV
Bump in the GC
FermiLAT : 130 GeV Line
in the GC



positron anomalies < 100 GeV
PAMELA, FermiLAT, AMS

Up-to now, except colliders, only neutrino search haven't made any claim of anomalies from any target source.

☞ does it mean this way of detection is so trusty?

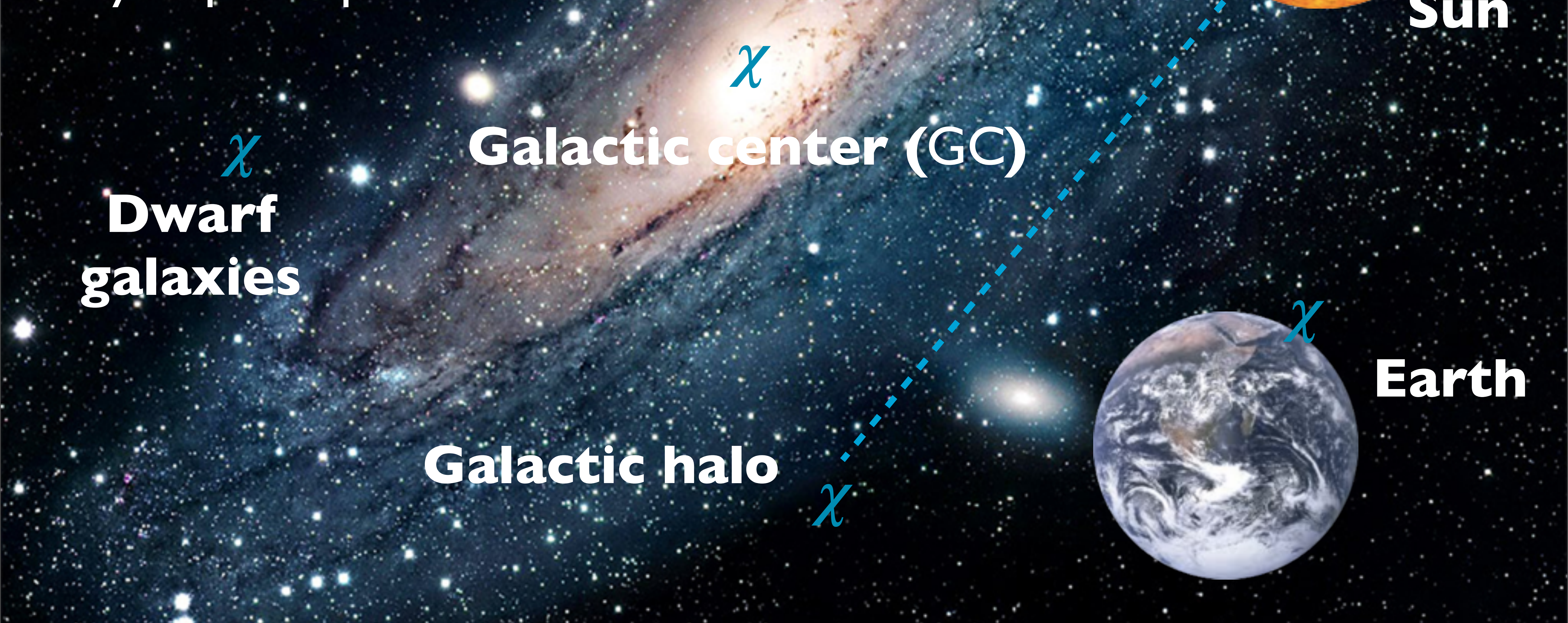
Indirect WIMP neutrino search

4 ways to do WIMP search using neutrino

- use muon yields (IceCube, Antares, BAKSAN, previous SK)
- use contained neutrino yields (DeepCore, brand new SK)
- use low energy neutrino yields (Carsten Rott et al(1208.0827), not yet done)
- produce WIMPs in a neutrino beam (deNiverville et al(1205.3499), not yet done)

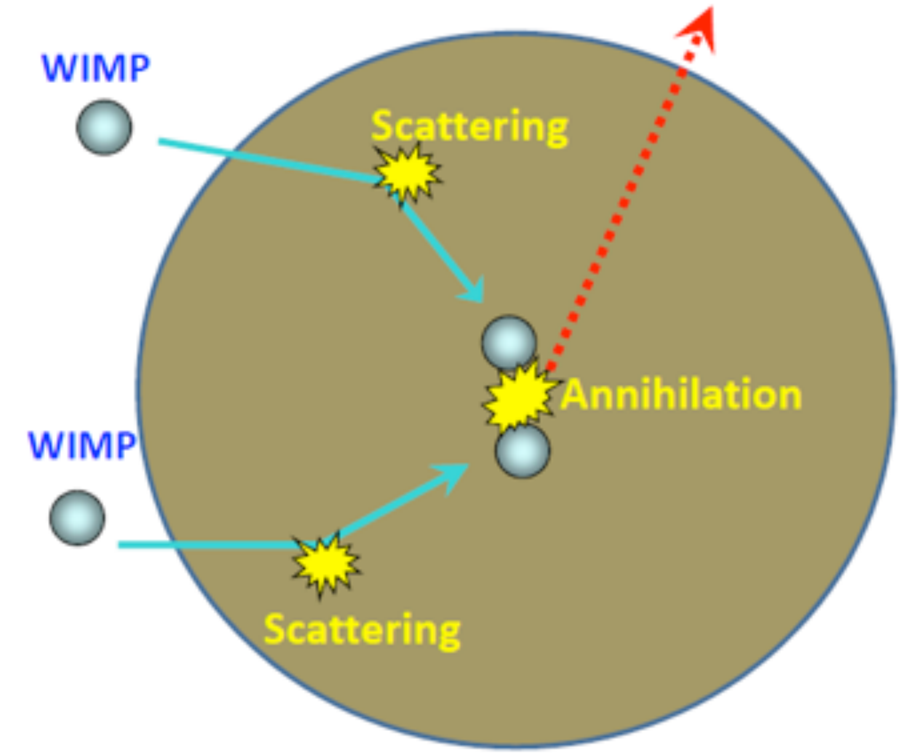
what is special about indirect WIMP search looking at the Sun or the Earth?

- The WIMP density in all the other source are thermally and gravitationally decided, (or 'naturally')
- but the WIMP density in the Sun / Earth are decided by 'capture process'



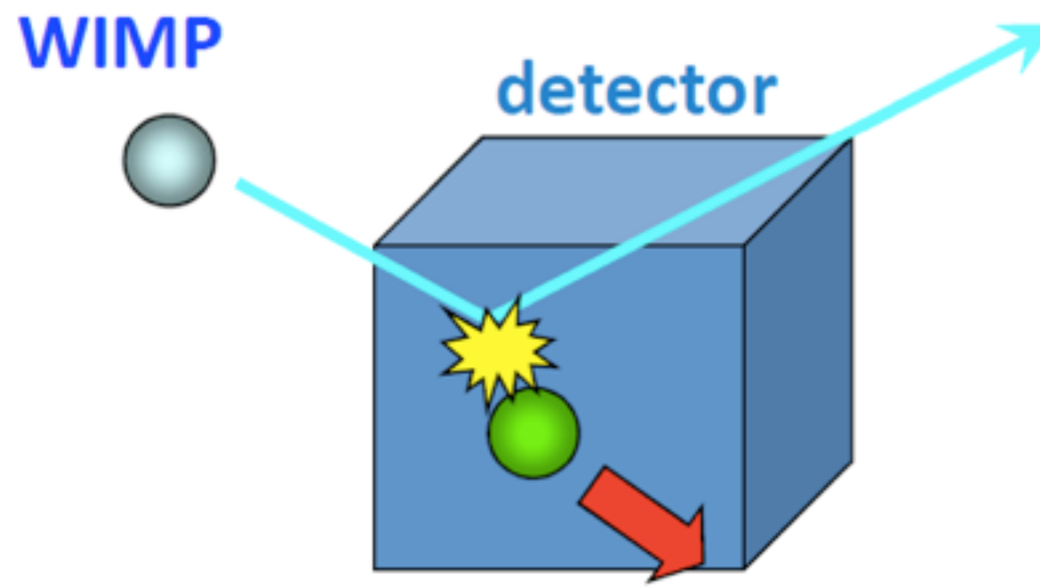
Capture process of the WIMPs in the Sun

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



2) remaining kinetic energy < escape velocity
-> gravitationally bound

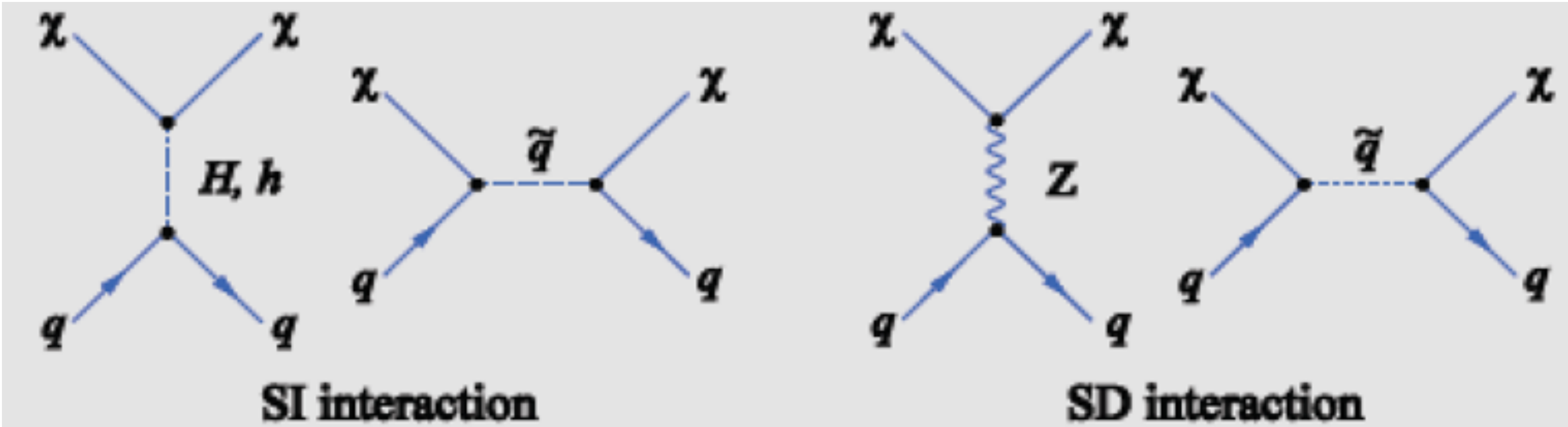
3) Undergoes additional scatters from elements and settles to the core.



- This scattering is the same with what we are waiting for in direct detections

→ Both sets limit on the WIMP-nucleon scattering cross-section

WIMP scattering to ordinary matter



$$\sigma_{SI} = \frac{4m_\chi^2 m_N^2}{\pi(m_\chi + m_N)^2}(Zf_p + (A-Z)f_n)^2 \qquad \sigma_{SD} = 32\frac{G_F^2\mu^2}{\pi}(a_p < S_{p(N)} > + a_n < S_{n(N)} >)^2 \frac{J+1}{J}$$

- Spin Independent(SI) interaction :

WIMP couples to the mass of nuclei

Dominant when the nuclei has large mass number

- Spin Dependent(SD) interaction :

WIMP couples to the spin of nucleus

Dominant when the nuclei has many unpaired proton

direct detections vs solar WIMP search

	direct search	solar WIMP search
scatters where	underground laboratory	inside the Sun/Earth
scatters to which	noble gas, NaI crystal, superheated liquid...	mainly Hydrogen + few heavier elements
signal	heat, ionization, scintillation	neutrino

Spin-dependent

50g H direct detection ~ 10-500m^2 neutrino detector

Spin-independent

1kg Ge direct detection ~ 10^4-$10^6$$m^2$ neutrino detector M.Kamionkowski Phys.Rev.Lett.74 5174(1995)

"Sun is a large Hydrogen WIMP detector for free"

Strong sensitivity to SD cross-section

How neutrino flux can be produced from WIMPs

- WIMPs pair annihilates to various fermions and bosons
  (remind:‘single branching ratio assumption’)

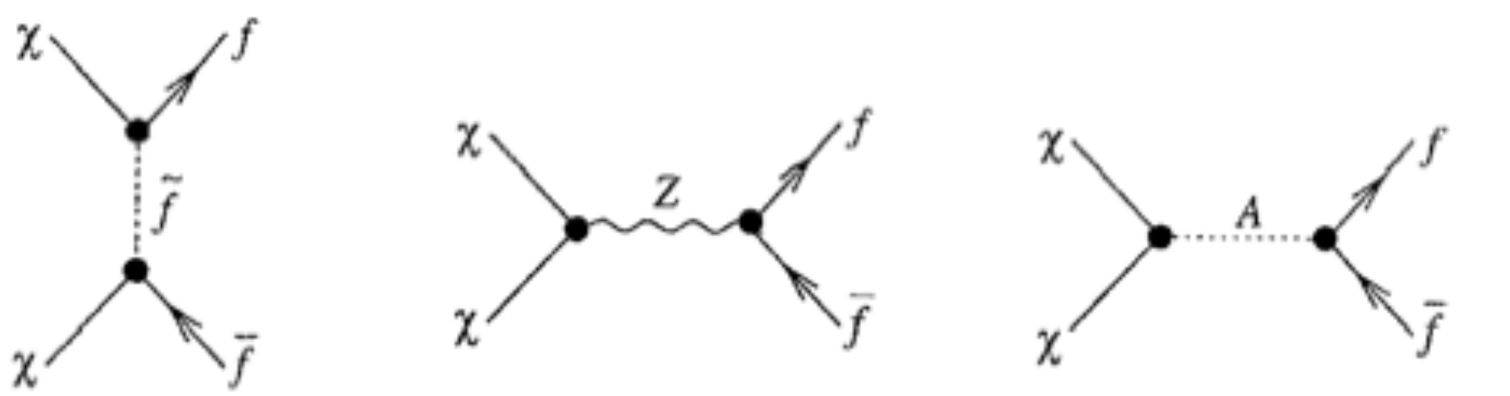
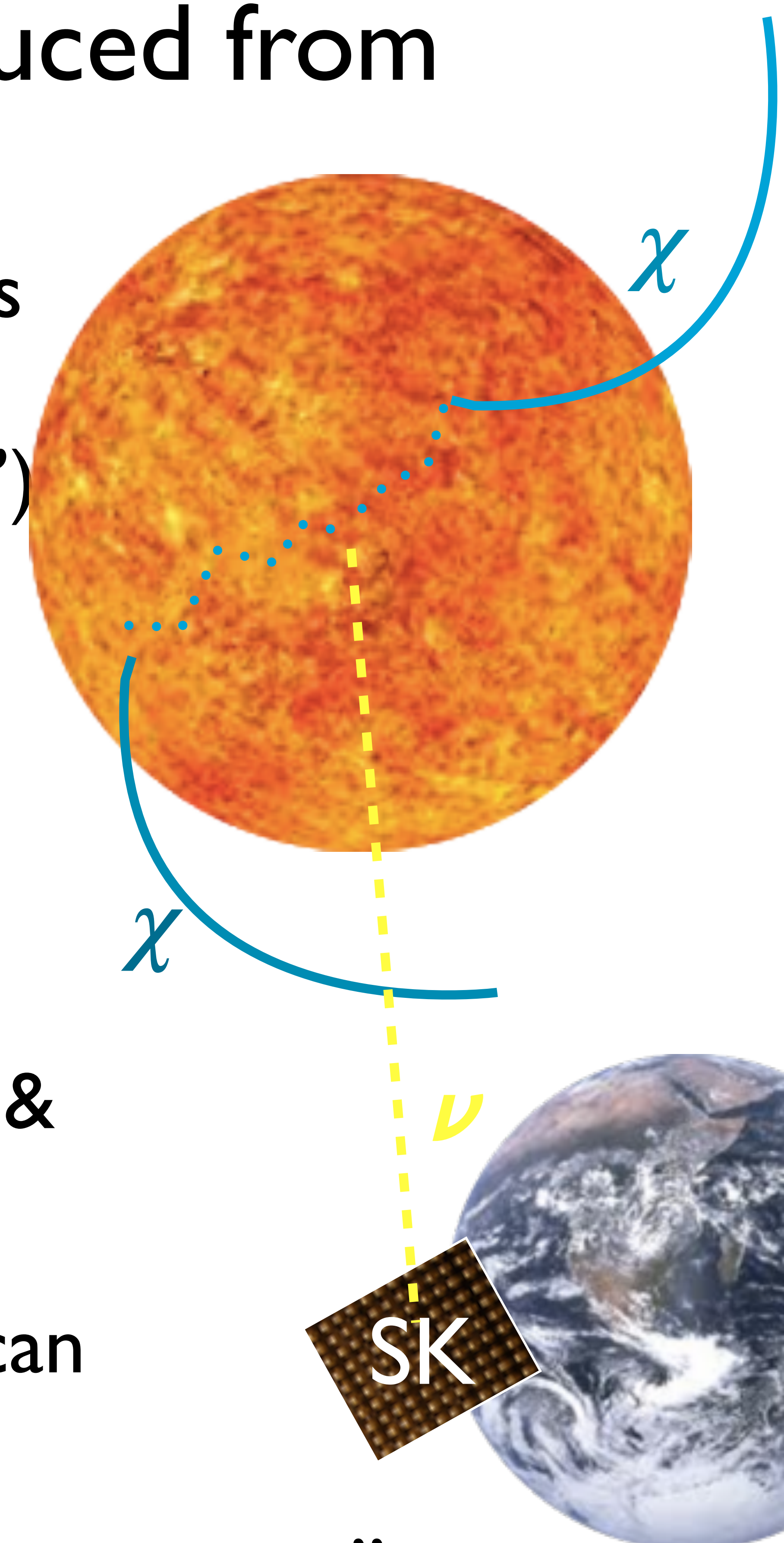


Fig. 16. Diagrams contributing to neutralino annihilation into fermions.



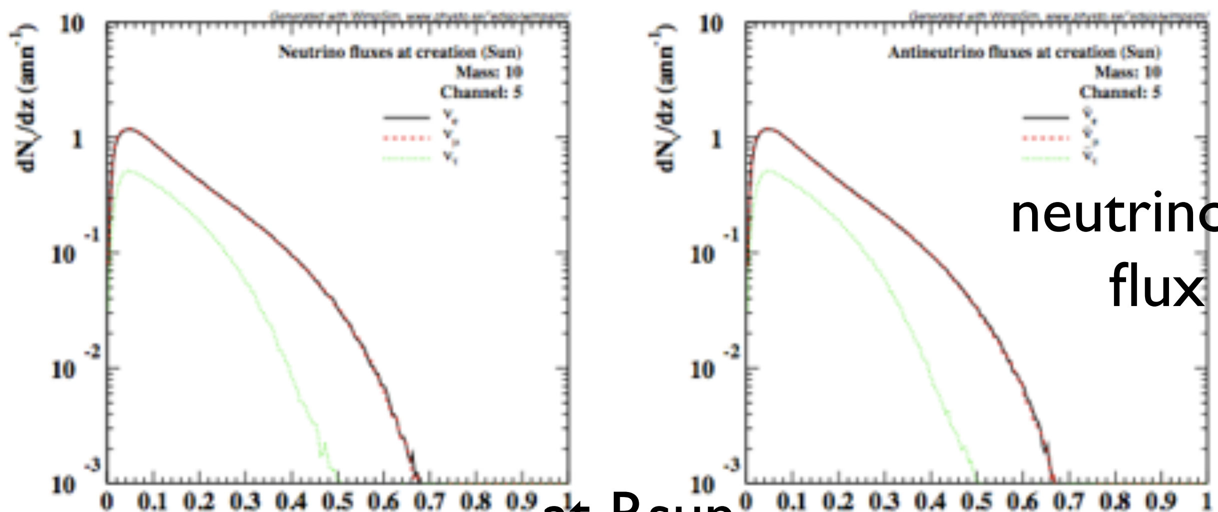
- energetic neutrino are produced by decay & hadronization

- among final products, neutrino is special : can escape solar medium

- Equilibrium between annihilation rate and capture rate”
  ⇒ Free from the huge uncertainty of annihilation cross section

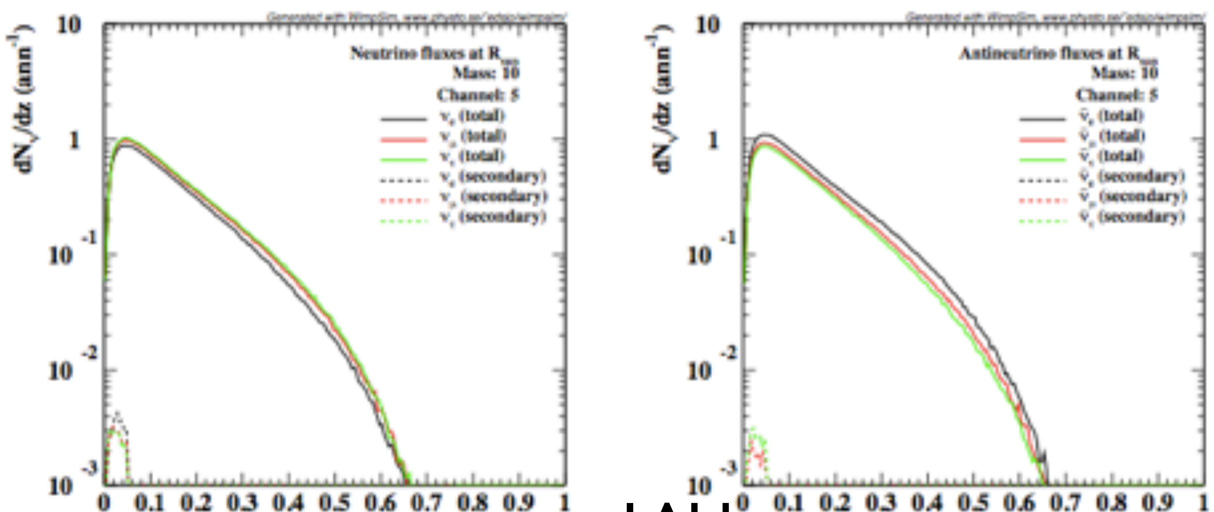
How the neutrino flux looks like on delivery

at creation

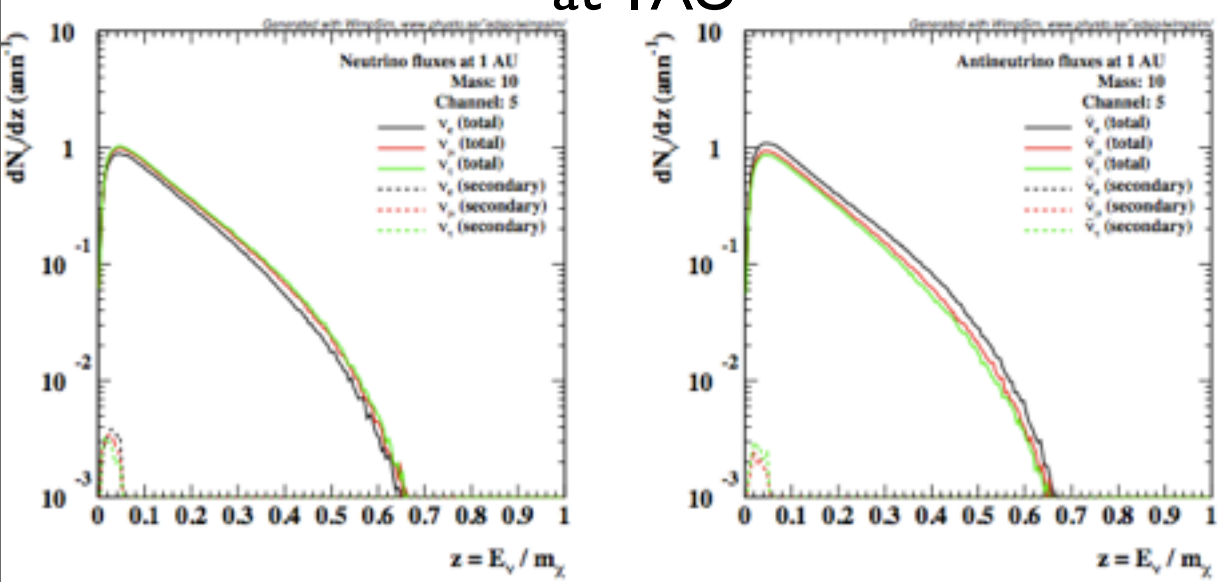


neutrino(left)/anti-neutrino(right)
flux for10GeV, bb channel

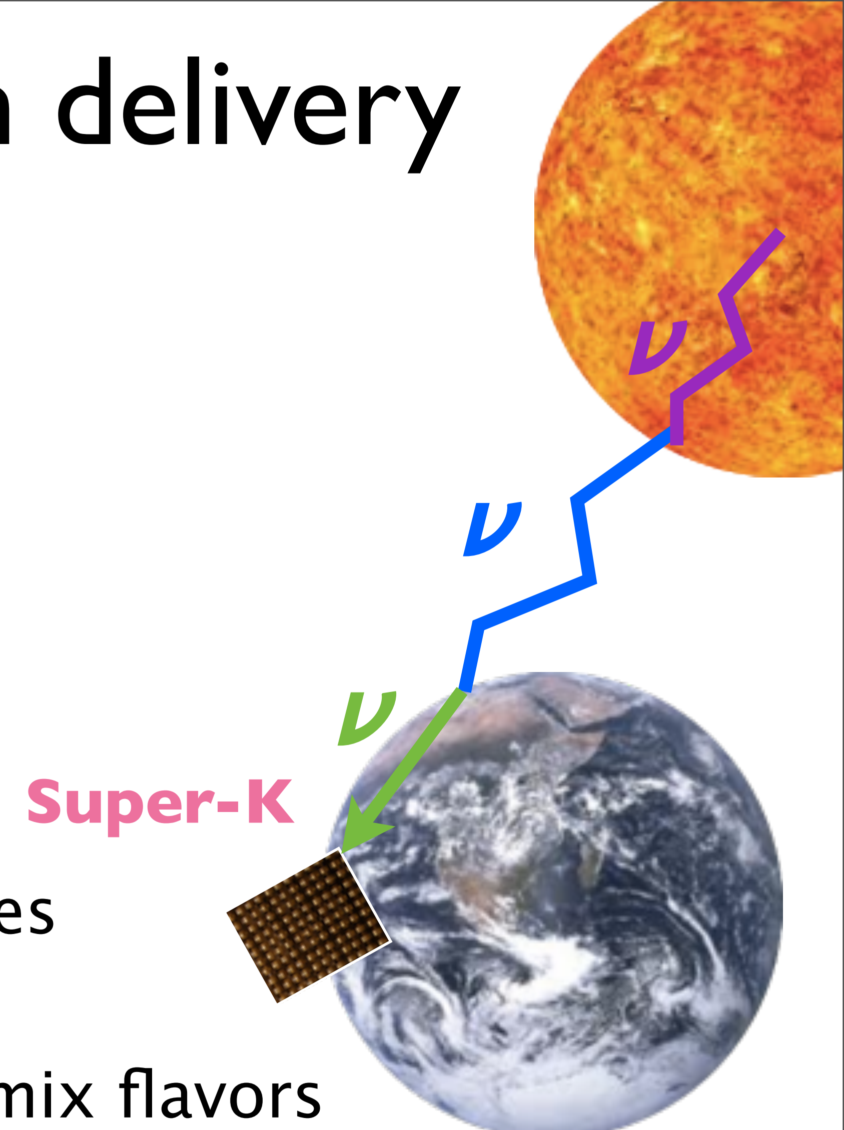
at Rsun



at 1AU



Energy/wimp mass



neutrino undergoes

☻ oscillation
which effectively mix flavors

including matter effects inside the Sun and the Earth

☻ interaction inside the Sun which brings absorption of high E neutrino by charged current (CC) interaction &

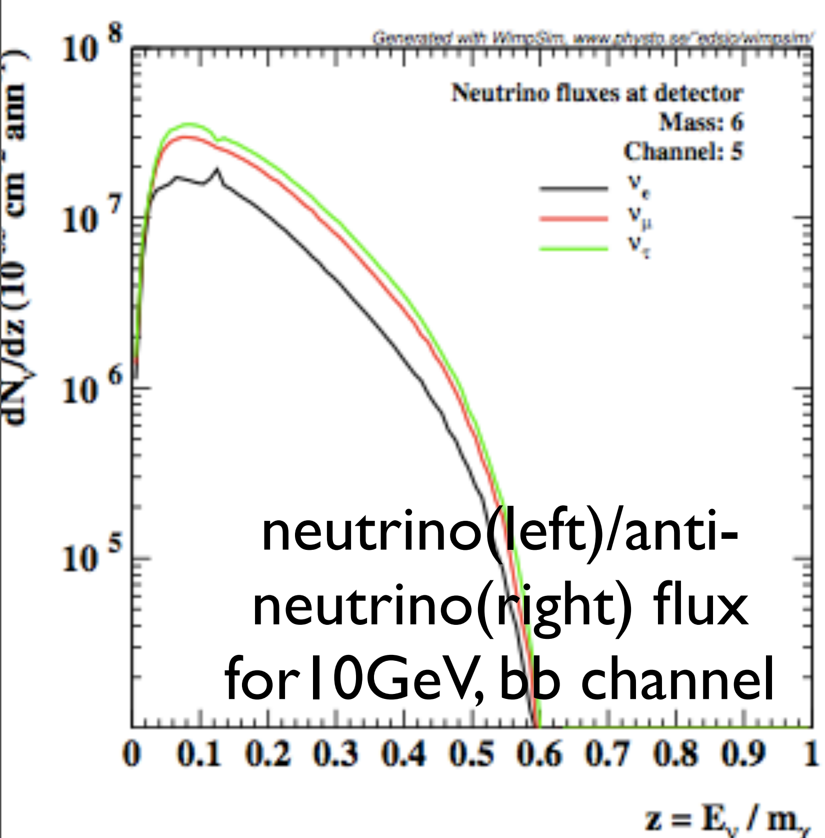
energy loss by neutral current (NC) interaction &
tau neutrino regeneration

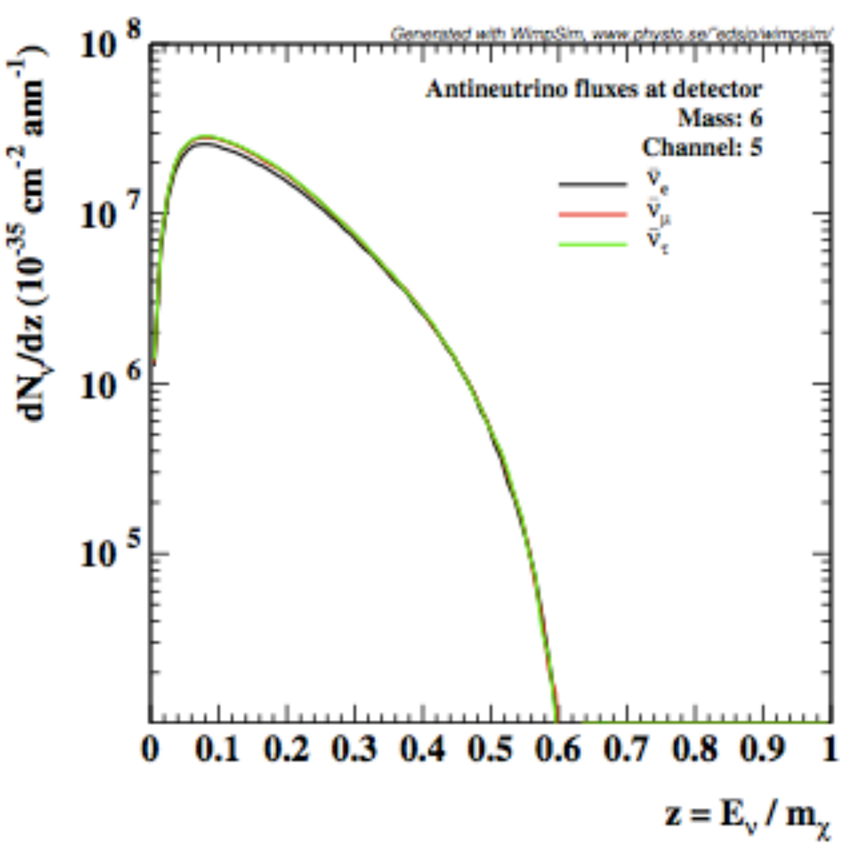
How the neutrino flux looks like at detector

WIMPsim(J. Edsjö, http://www.fysik.su.se/~edsjo/wimpsim/) & DarkSUSY(P. Gondolo et al., JCAP 07 (2004) 008)

Simulation package DarkSUSY/WIMPsim calculates

- particle physics for WIMP candidate (CMSSM neutralino)
- Capture/annihilation process
- Propagation inside the Sun/vacuum/the Earth considering oscillation & interaction



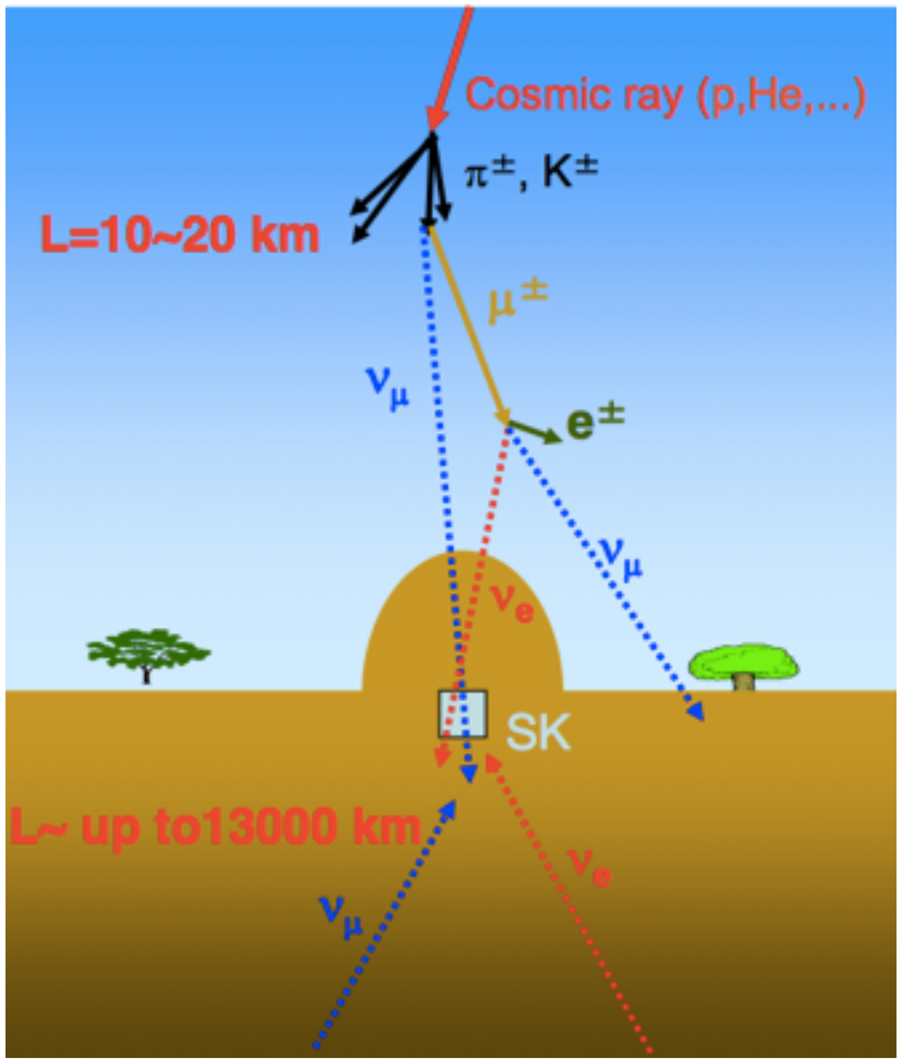


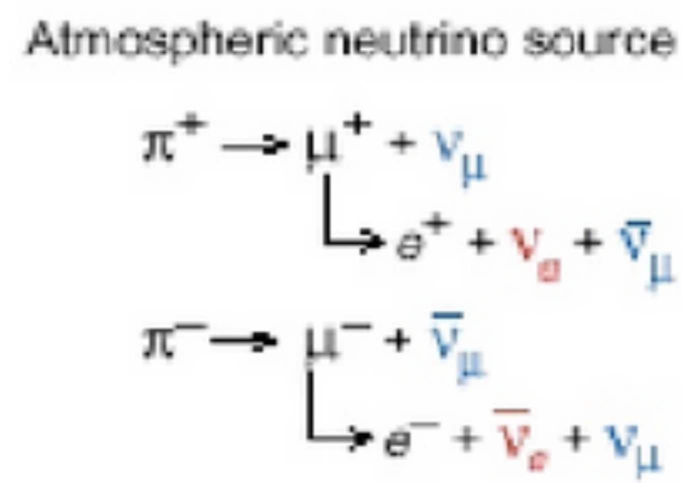
neutrino(left)/anti-neutrino(right) flux for10GeV, bb channel

WIMP flux simulated for SK site with 3 flavor oscillation parameters

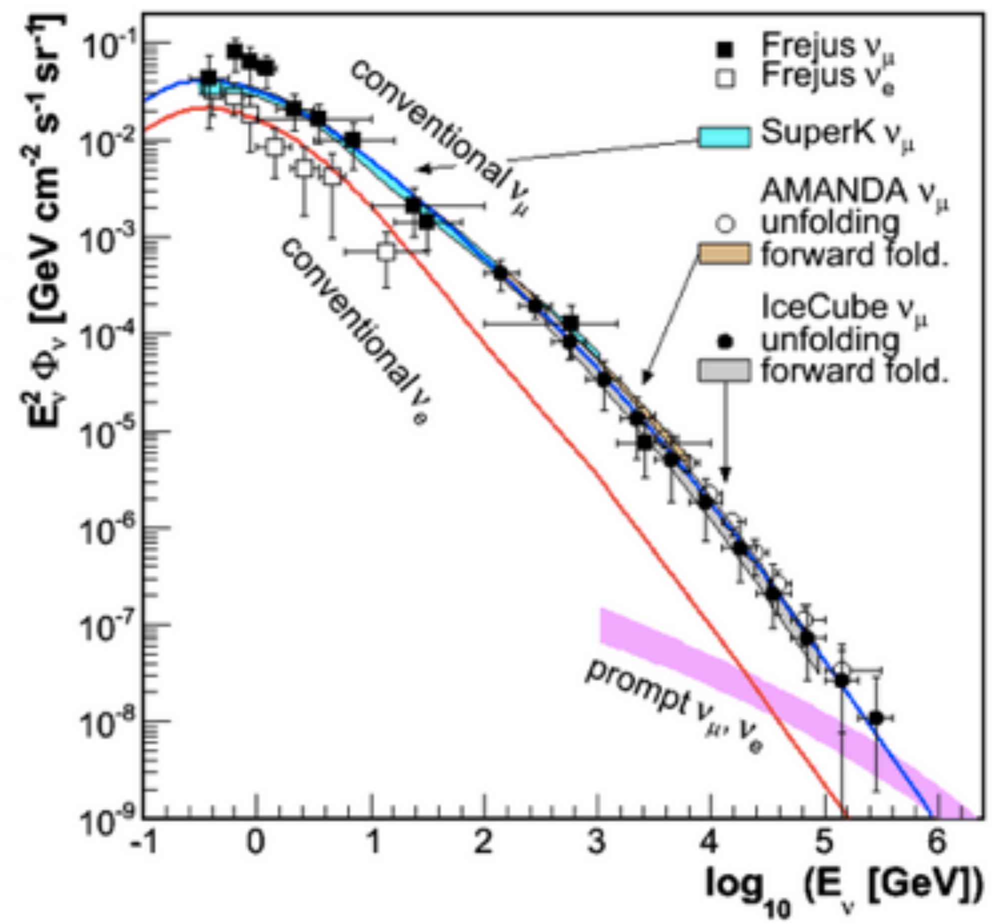
Back-ground

- Atmospheric neutrinos(GeV) produced by cosmic rays are back-ground.



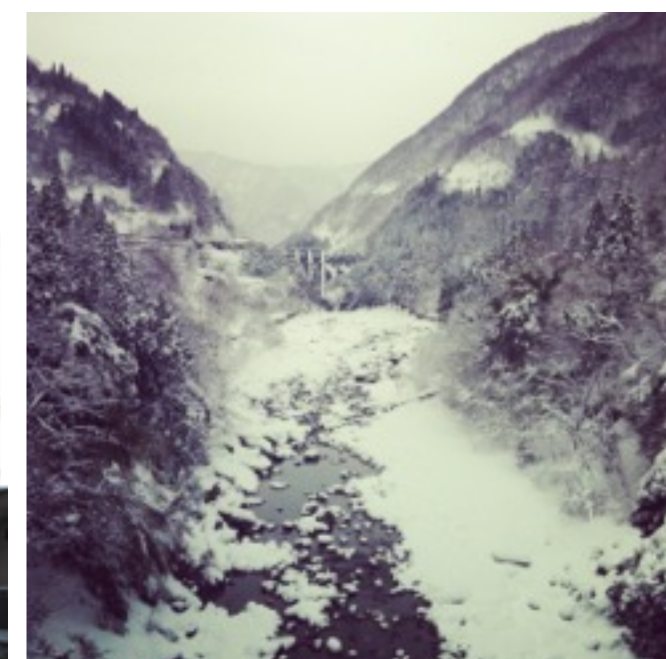


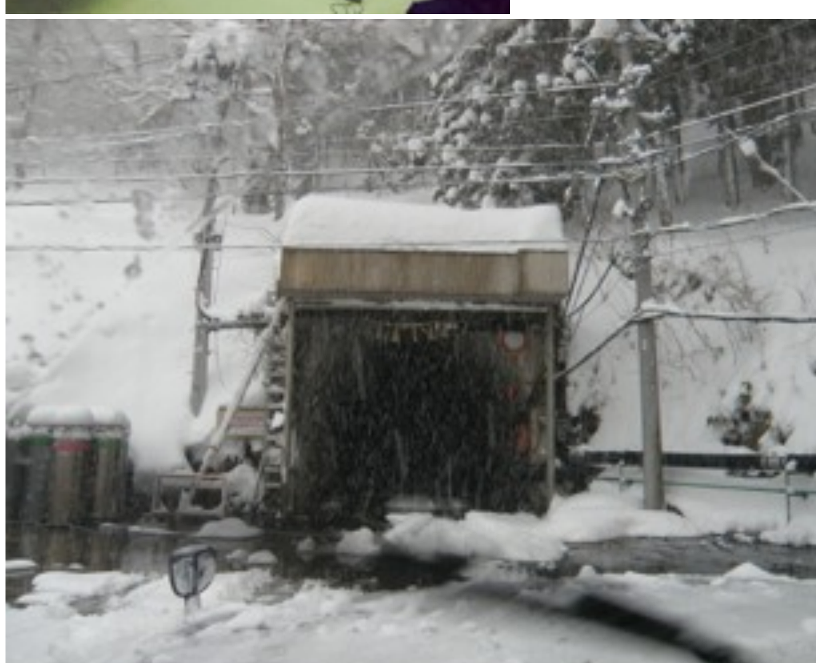
dflux/dE ~ E-2.7



back-ground for me, but signal for oscillation analysis fellows ;
initial flux prediction matches well with observation,
detector performance for these energy-ranged neutrinos are well understood.

Super-Kamiokande



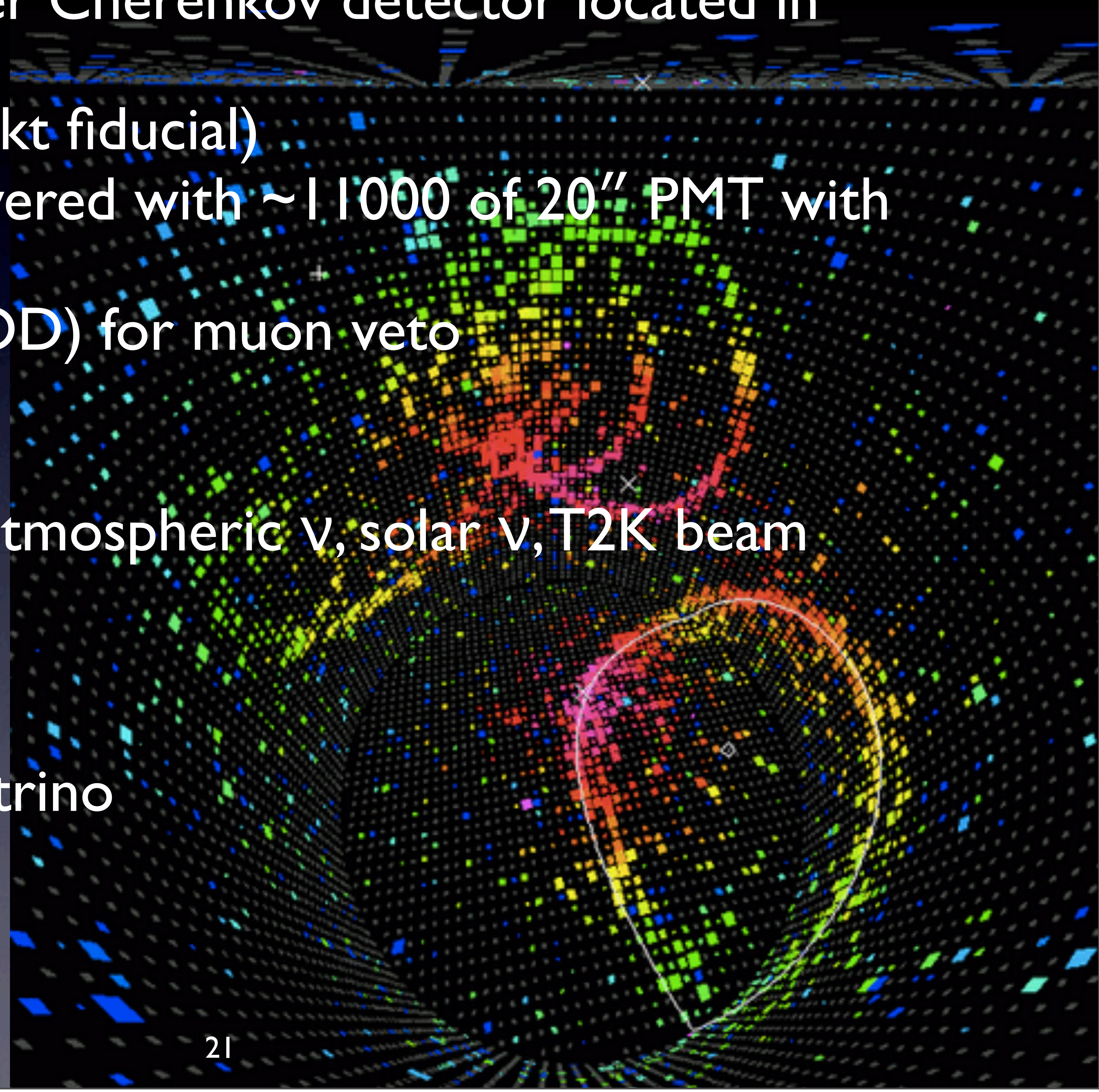


Super-Kamiokande

- The world largest water Cherenkov detector located in Kamioka mine
- 50kt pure water (22.5 kt fiducial)
- Inner detector(ID) covered with ~11000 of 20" PMT with acrylic cover
- 2m outside detector(OD) for muon veto

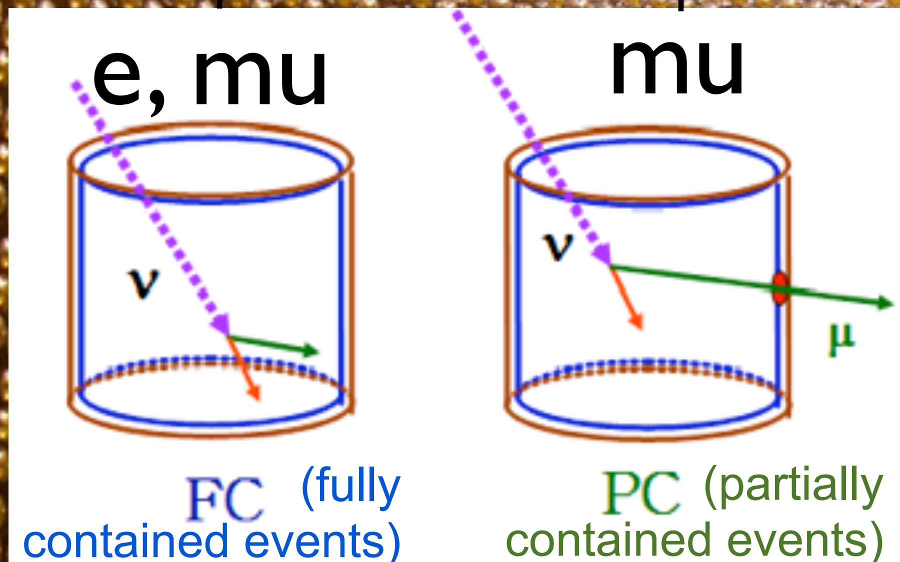
Analysis :

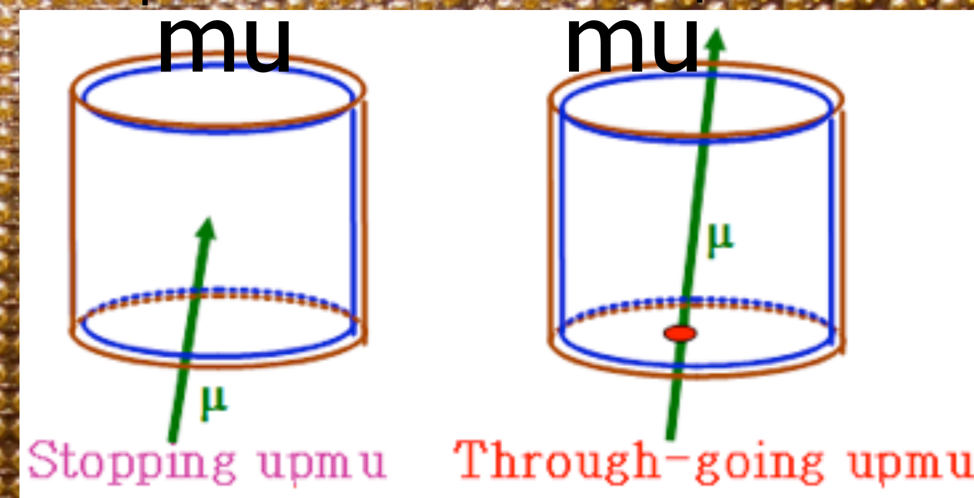
- Neutrino oscillation : atmospheric ν, solar ν, T2K beam
- Nucleon decay
- Astrophysics
  - Dark matter search
  - Supernova Relic Neutrino
  - monopole
  - LIV

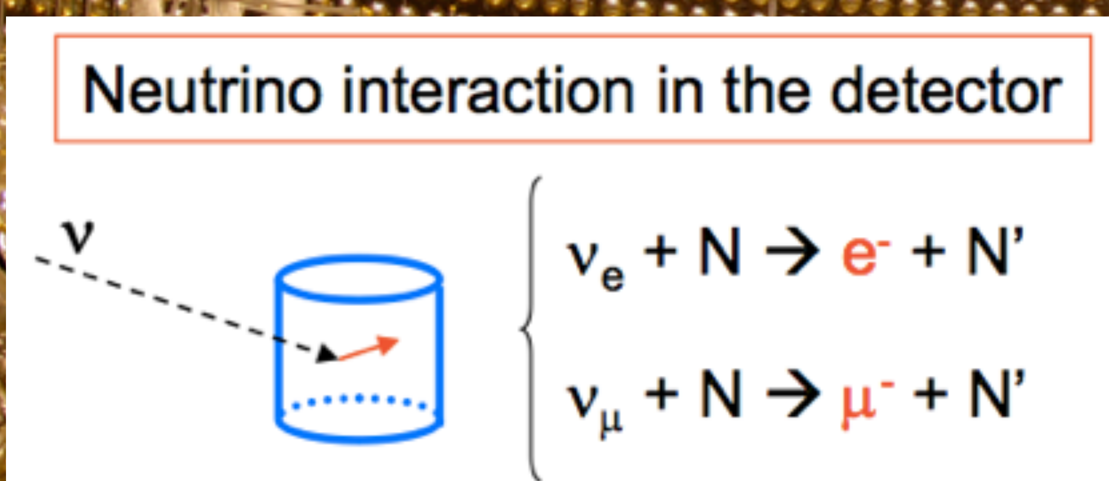


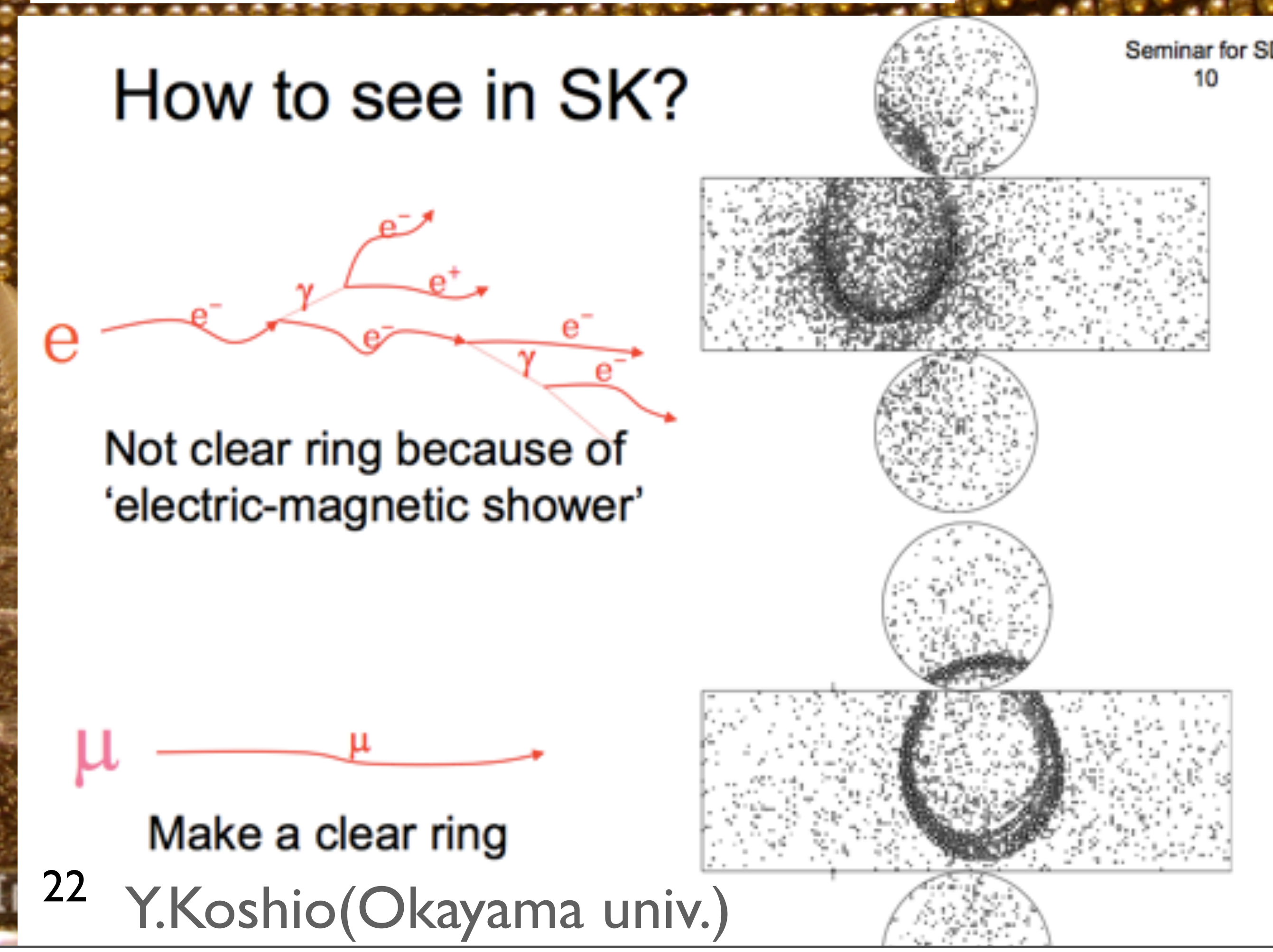
Events categories in Super-K

contained neutrinos | **up-going muons(upmu)**



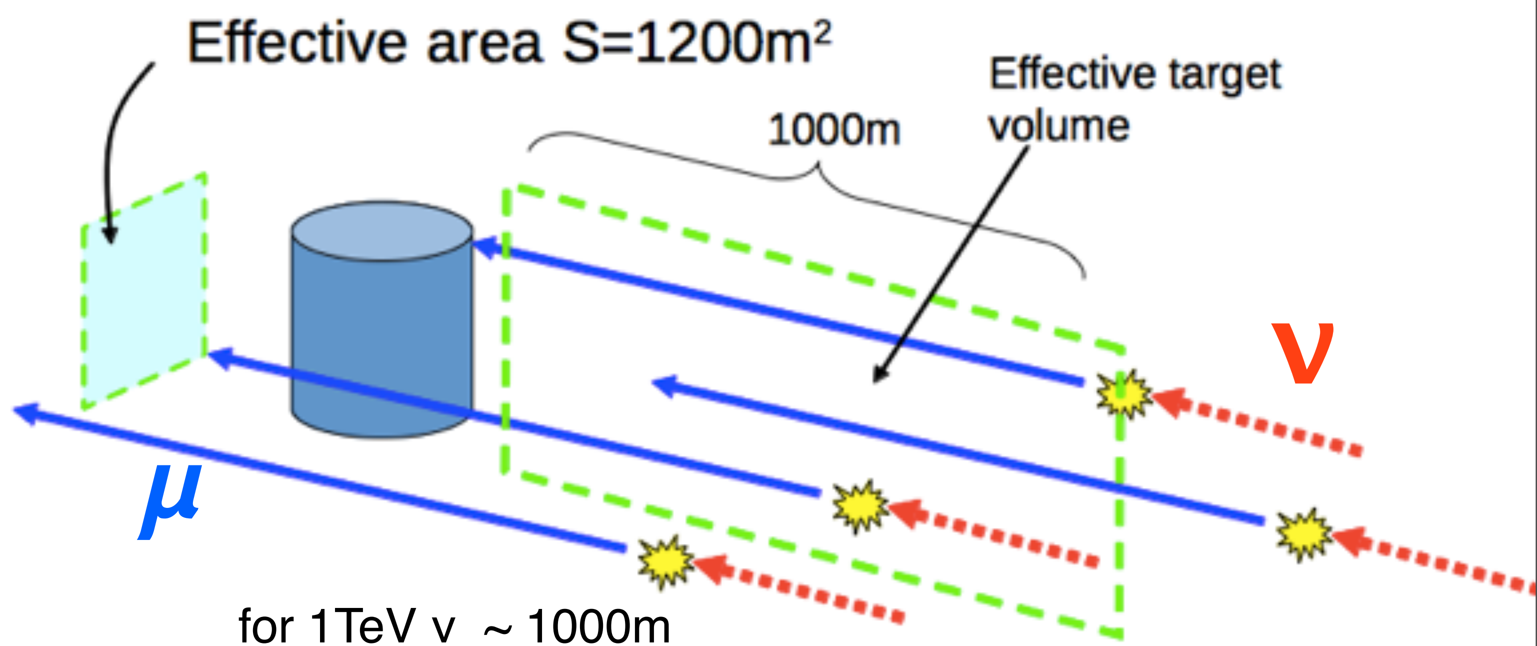


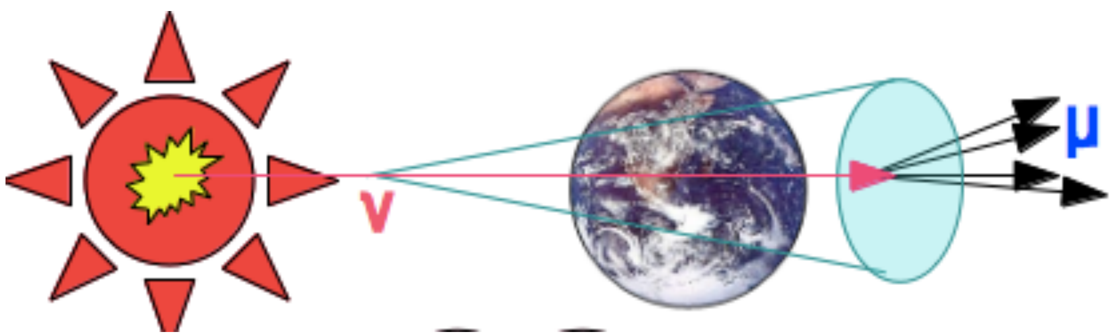




WIMP search using muon yield

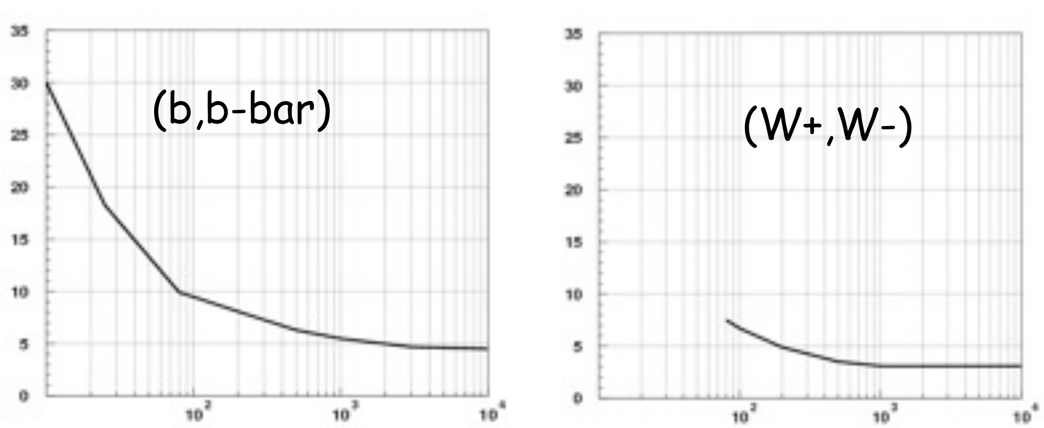
- low back-ground
- large effective area
- good angular resolution : look into signal region after applying angular cut





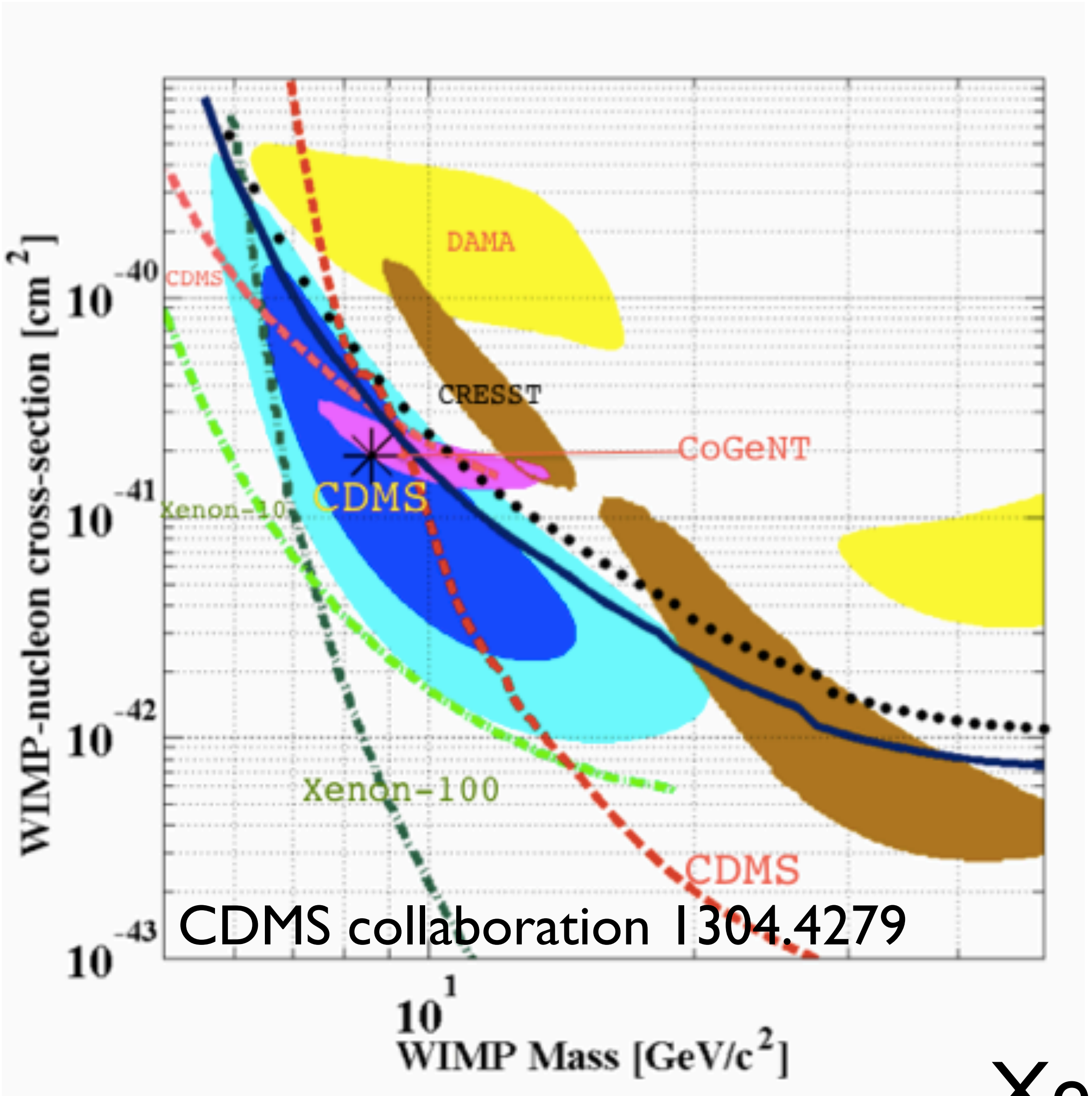
neutrino (Contained) : $\sigma \propto E$ V=const $N \propto E$

muon (stopping, through-going) : $\sigma \propto E$ $V \propto E$ $N \propto E^2$



So far Antares, IceCube, Super-Kamiokande and BAKSAN have reported null results (no WIMP)

Search for light WIMPs



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

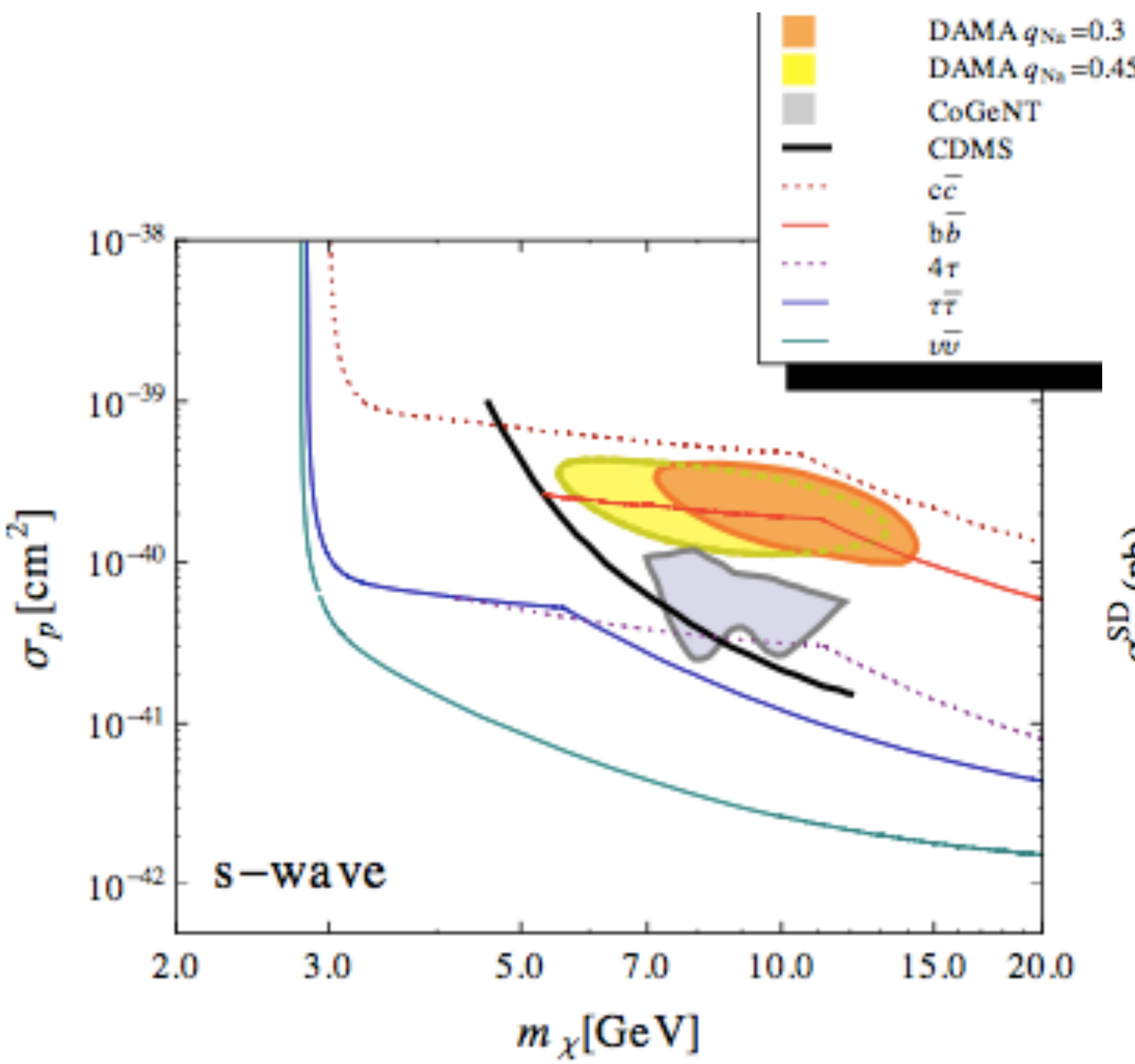
CDMS Ge / XENON10/100 conflict

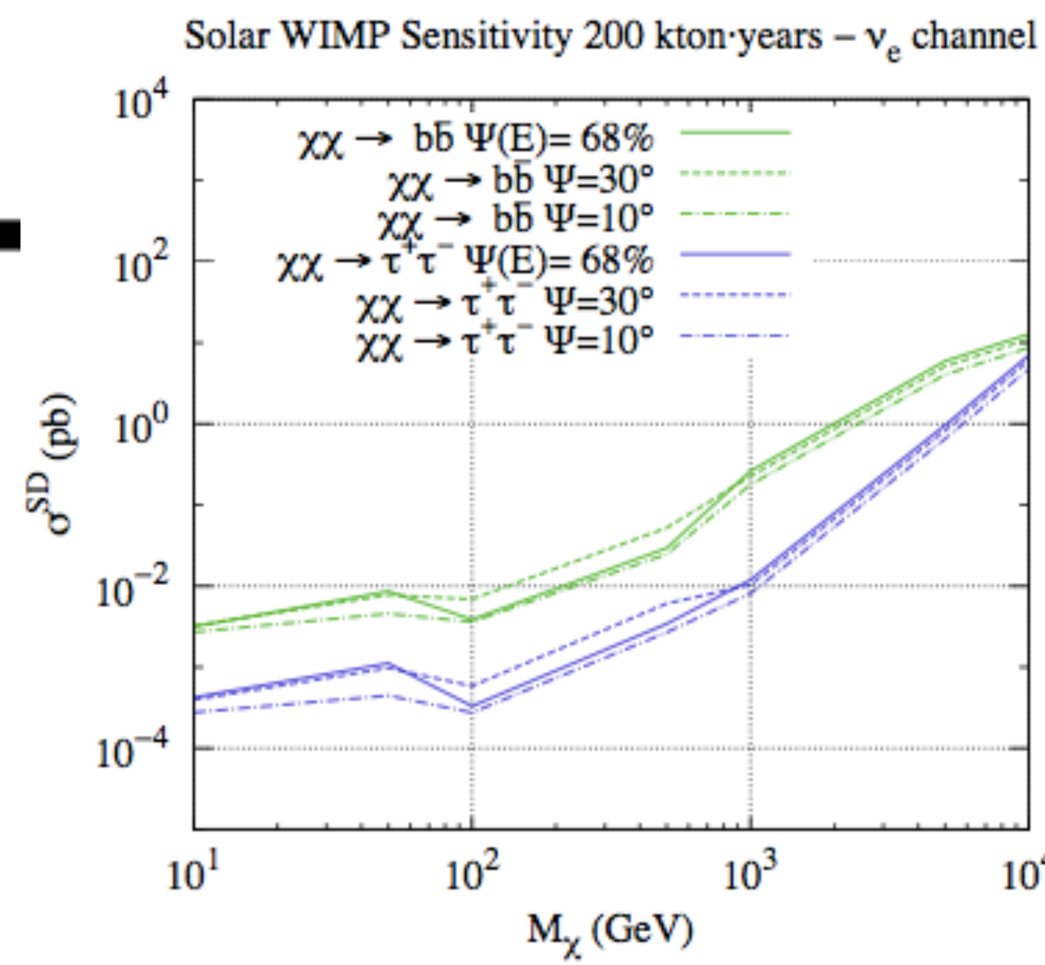
Xenon10, Xenon100 has come close to demonstrating sensitivity to a ~8GeV WIMP,
but Will be nice to have another independent experiment here

Mardon, Light-WIMP Lovefest, 2013

Search for light WIMPs in SK

Super-K, the most sensitive detector for few GeV neutrino, (lower energy threshold compared to IceCube, though the fiducial volume is much smaller) has power to search for light WIMPs.

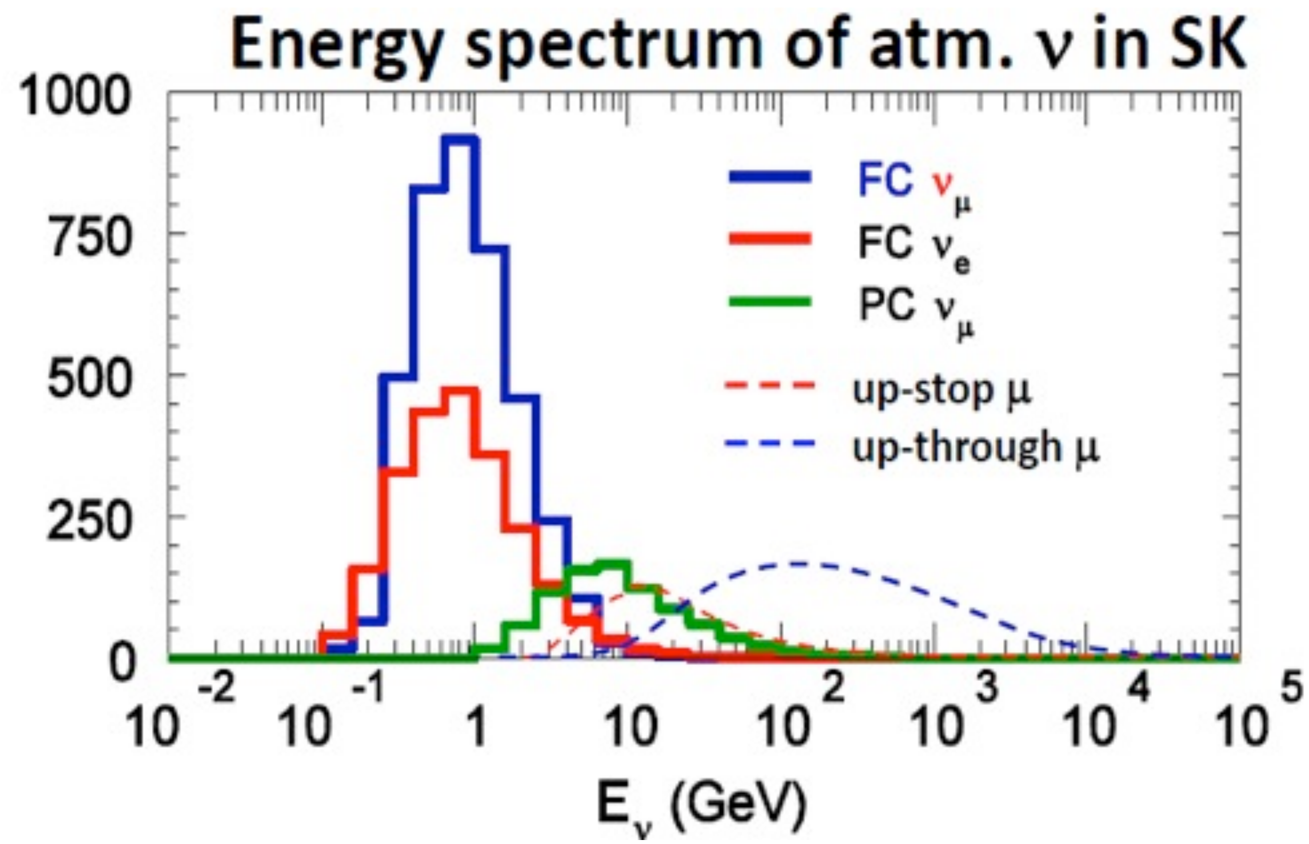




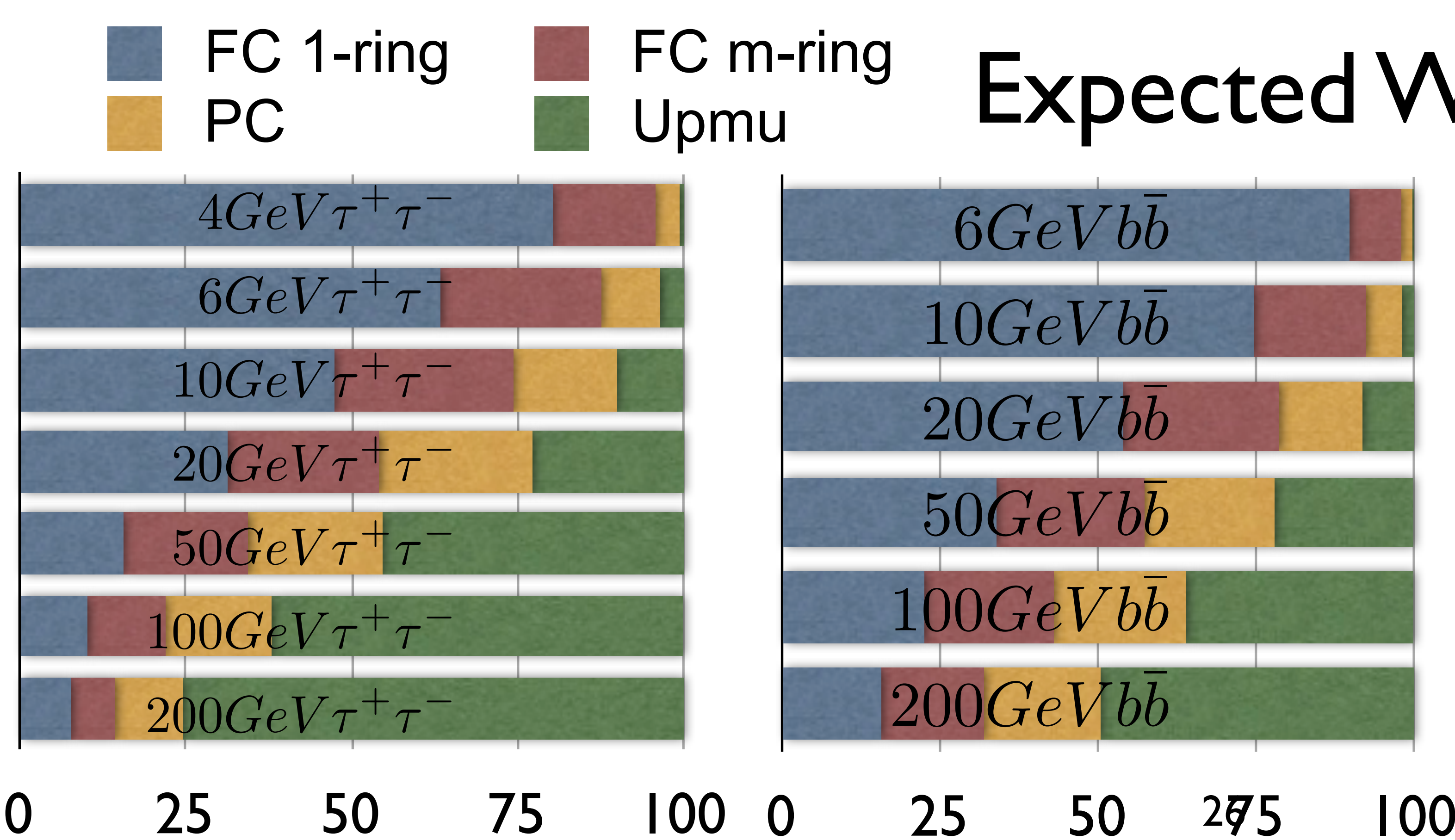
Right : Kappl, Winkler, 1104.0679

Rott, Tanaka, Itow, 1107.3182

How the events look like in SK



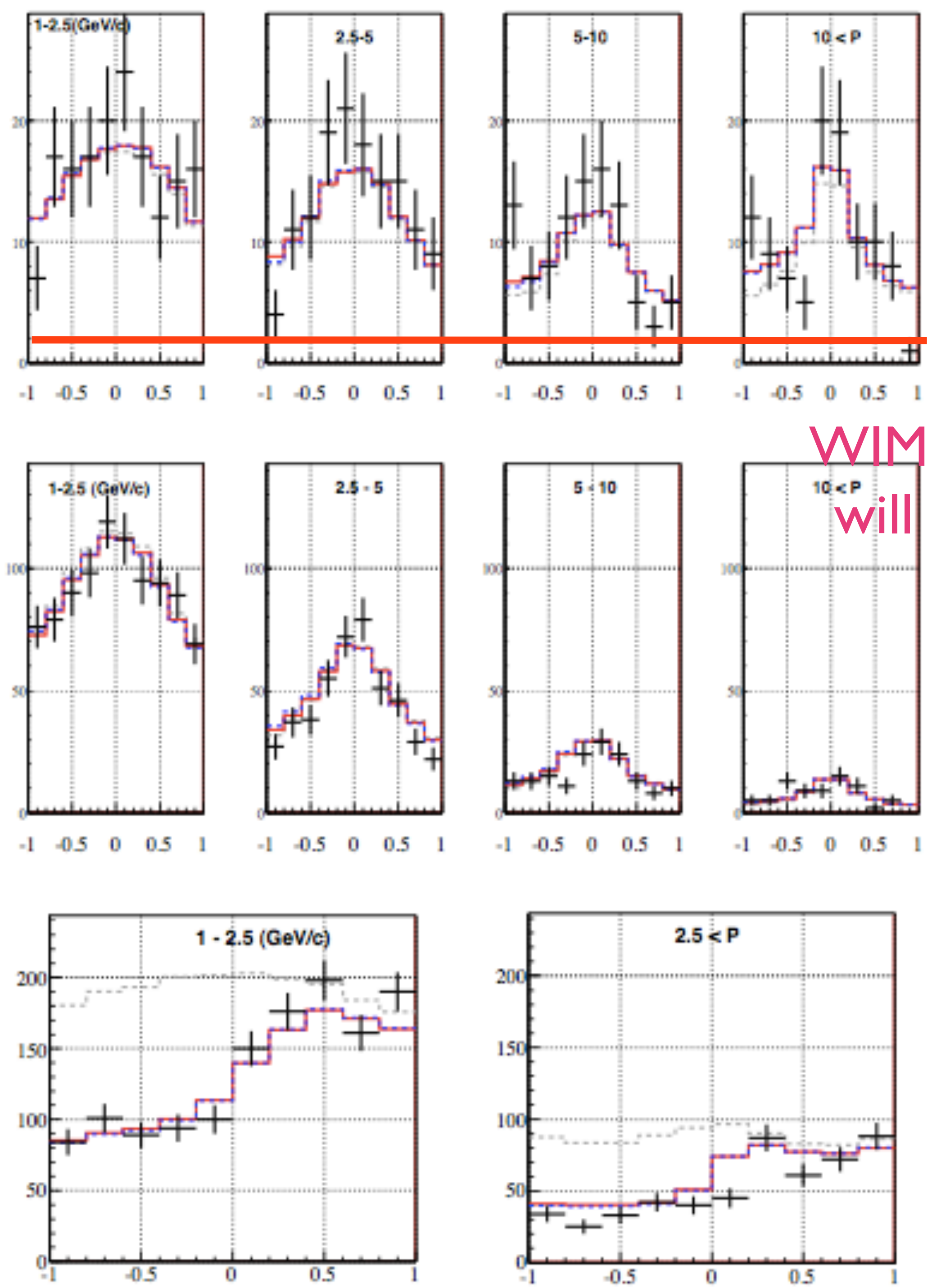
Expected WIMP event ratio



➠ By using contained events, signal acceptance significantly increase for light WIMPs.

how does the signal look like in SK, and how BG does

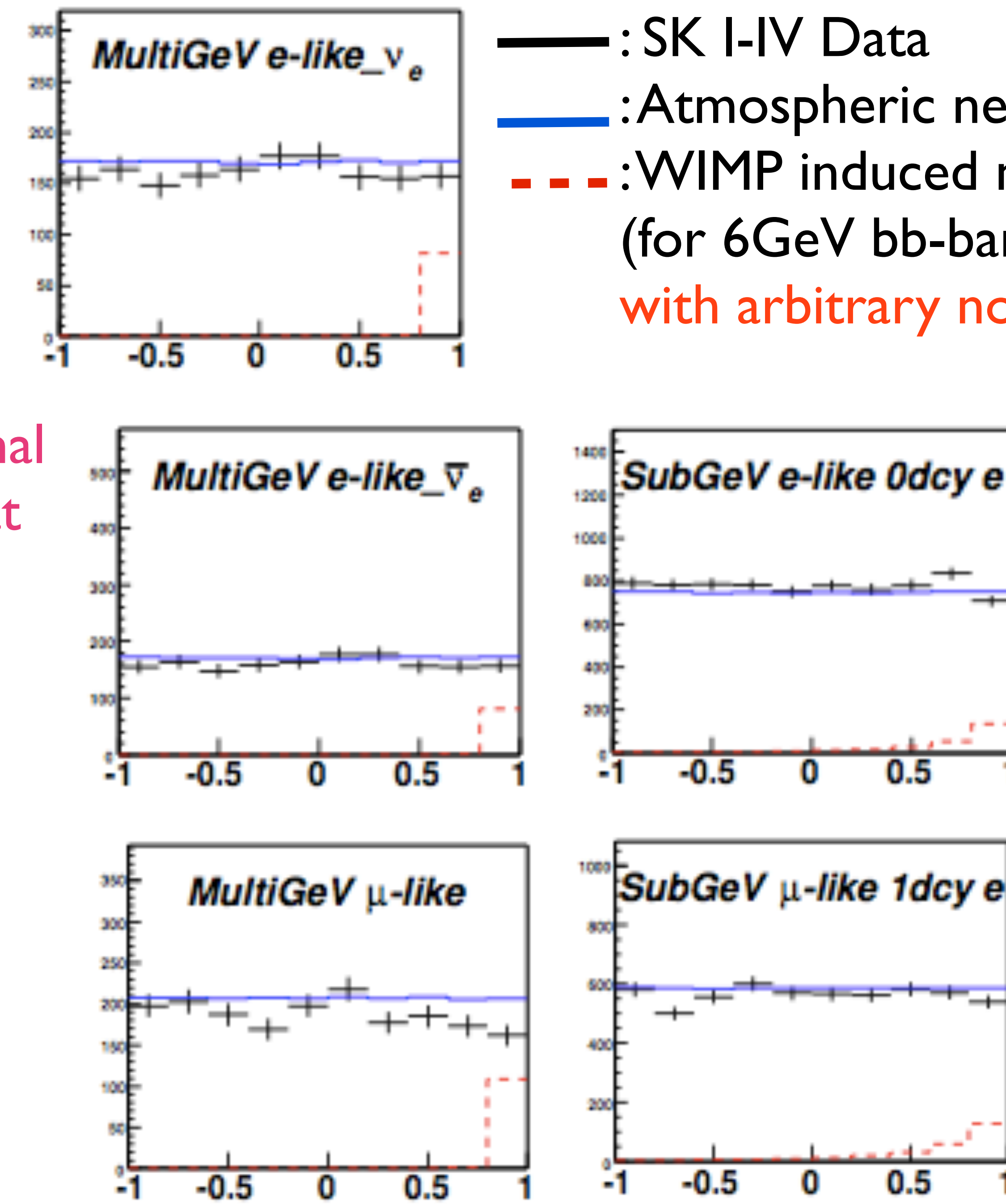
in zenith distribution



WIMP signal will be flat

down-going

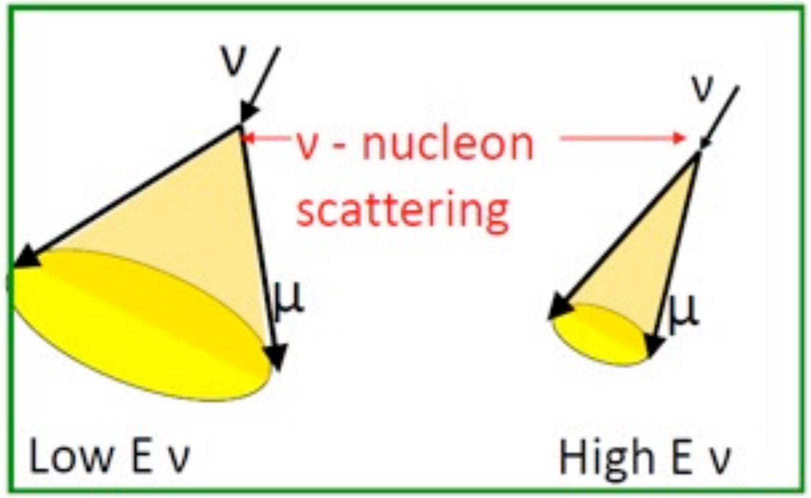
in CosΘsun distribution



: SK I-IV Data
: Atmospheric neutrino MC
: WIMP induced neutrino MC (for 6GeV bb-bar sample, with arbitrary normalization)

from the Sun

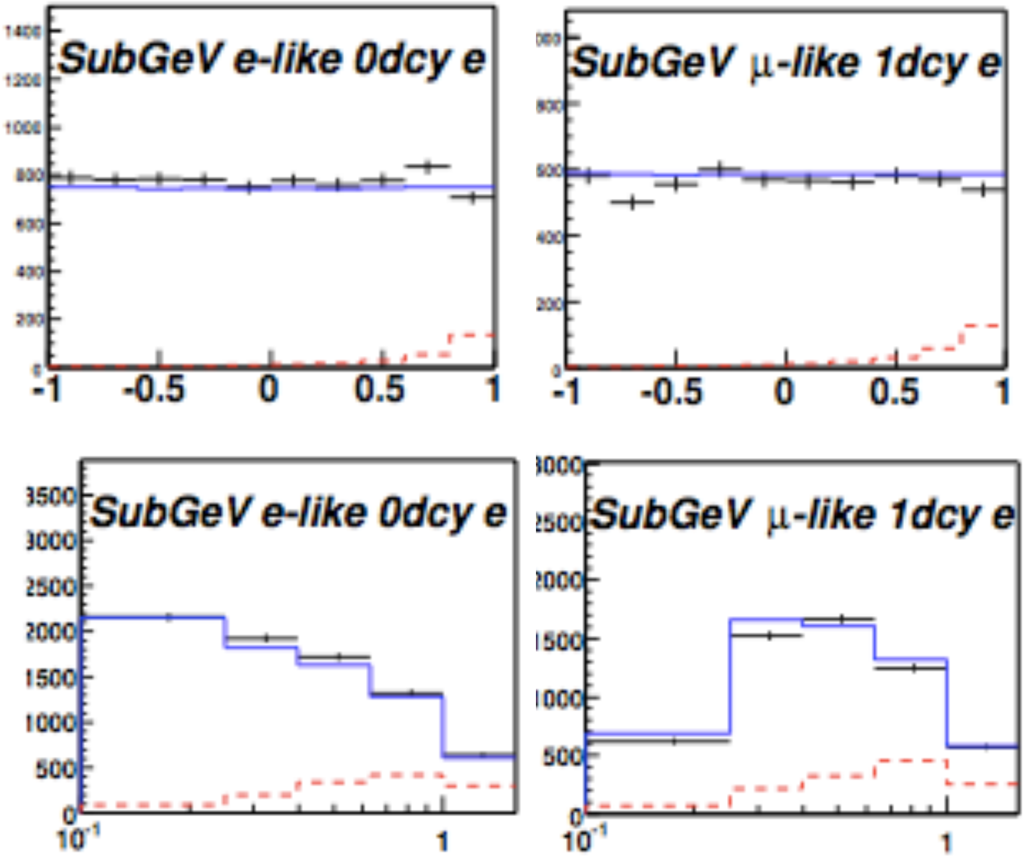
To use contained events : fitting approach



- angular resolution get worse to stay with angular cut approach
- use fitting between data and MC, as we do to constrain oscillation parameters
- bonus : use energy information,
  use e-like events

idea explained

e-like mu-like



angular distribution

momentum distribution

If there was a miss of our understanding in data because of unexpected extra component (WIMP-introduce neutrino), which has been until now accommodated with systematic errors, now will reveal. during fitting every bin simultaneously, the 'tendency' of misunderstood data will be filled with new WIMP contribution, and let us know how much of it we need.

Test signal contribution by pulled χ^2 method

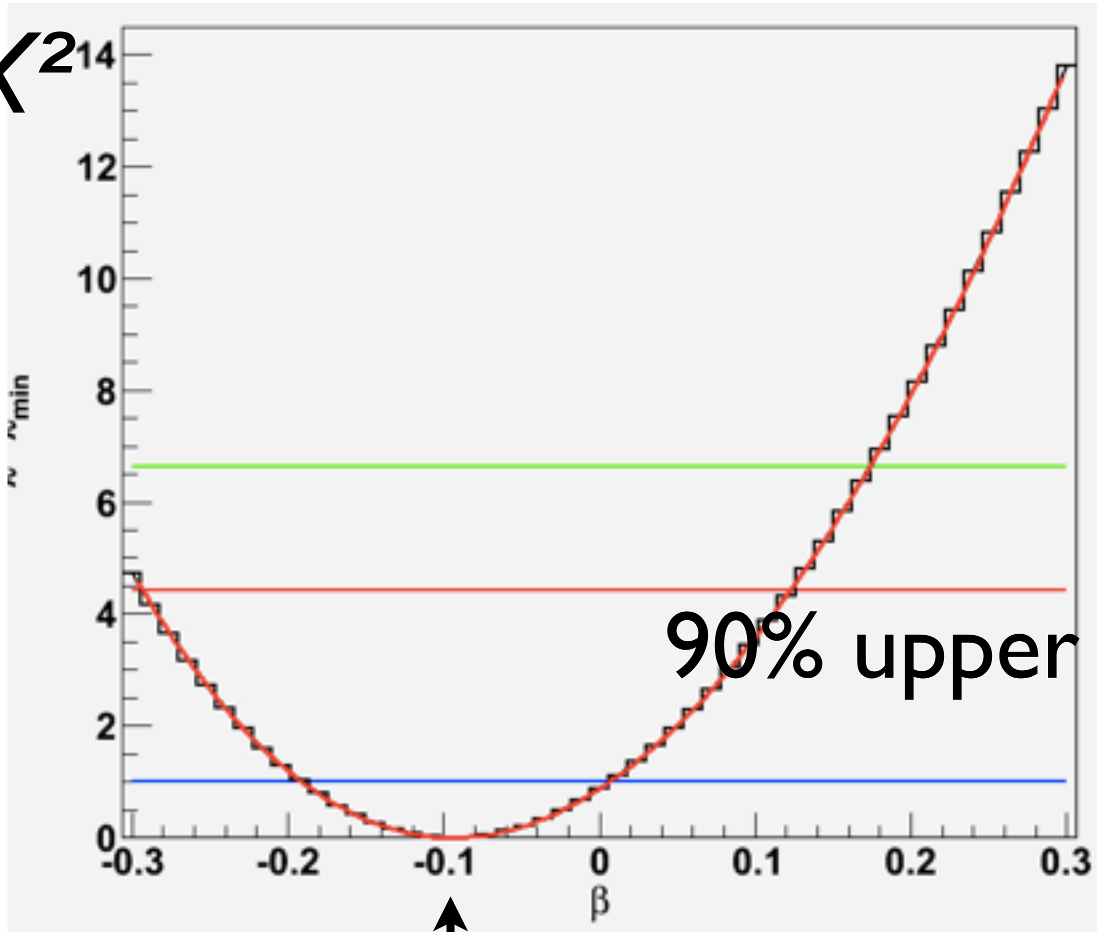
Maximum log likelihood fit for poissonian distributed SK data to "atmospheric neutrino + WIMP induced neutrino" to find best fit value of WIMP contribution

$$\chi^2 = 2\Sigma_{n=1}^{\#ofbins}[N_n^{BG}(1+\Sigma_j f_j^n \epsilon_j) + \beta N_n^{WIMP}(1+\Sigma_k f_k^n \epsilon_k) - N_n^{data} + N_n^{data} ln(\frac{N_n^{data}}{N_n^{BG}(1+\Sigma_j f_j^n \epsilon_j) + \beta N_n^{WIMP}(1+\Sigma_k f_k^n \epsilon_k)})] + \Sigma_j(\frac{\epsilon_j}{\sigma_j}) + \Sigma_k(\frac{\epsilon_k}{\sigma_k})$$

'pulled' way allows to accommodate systematic errors in the fitting

$$\partial\chi^2/\partial\epsilon_k = 0$$

Set Bayesian upper limit

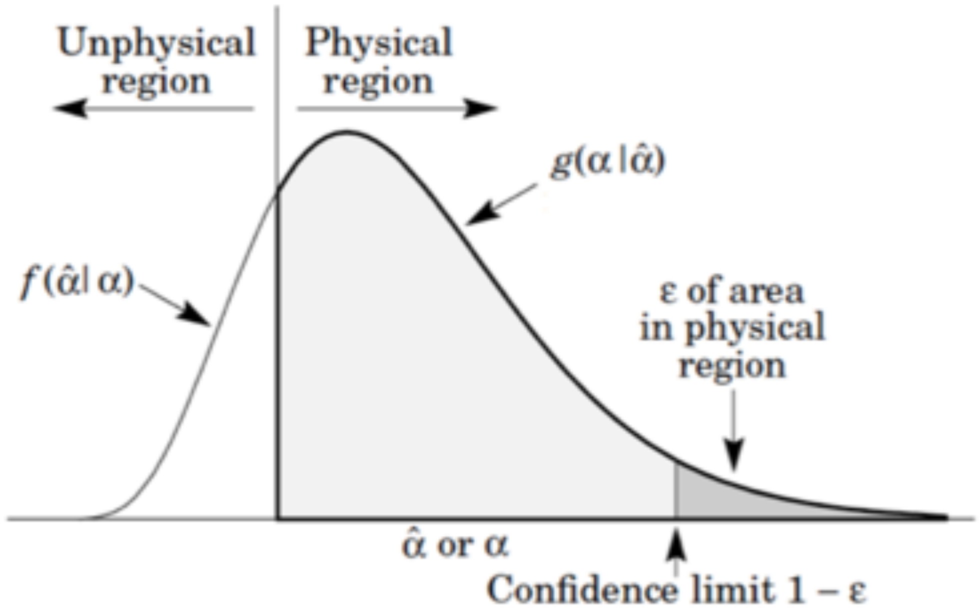


ΔX^2

90% upper limit

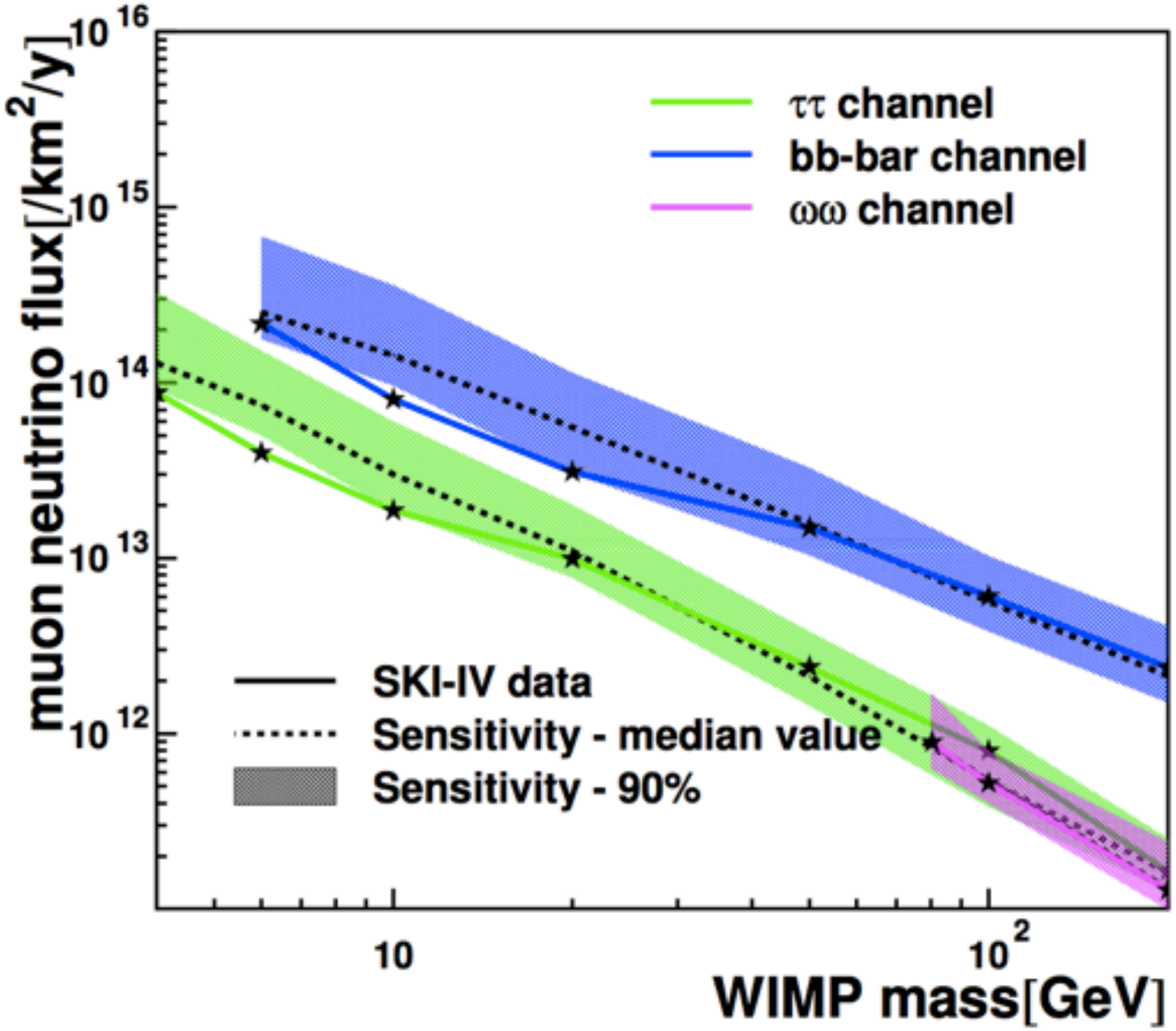
best fit WIMP contribution

What if our data favors 'negative contribution from WIMP'?



-> calculate Bayesian upper limit with flat prior

90% upper limit on WIMP-induced muon neutrino flux

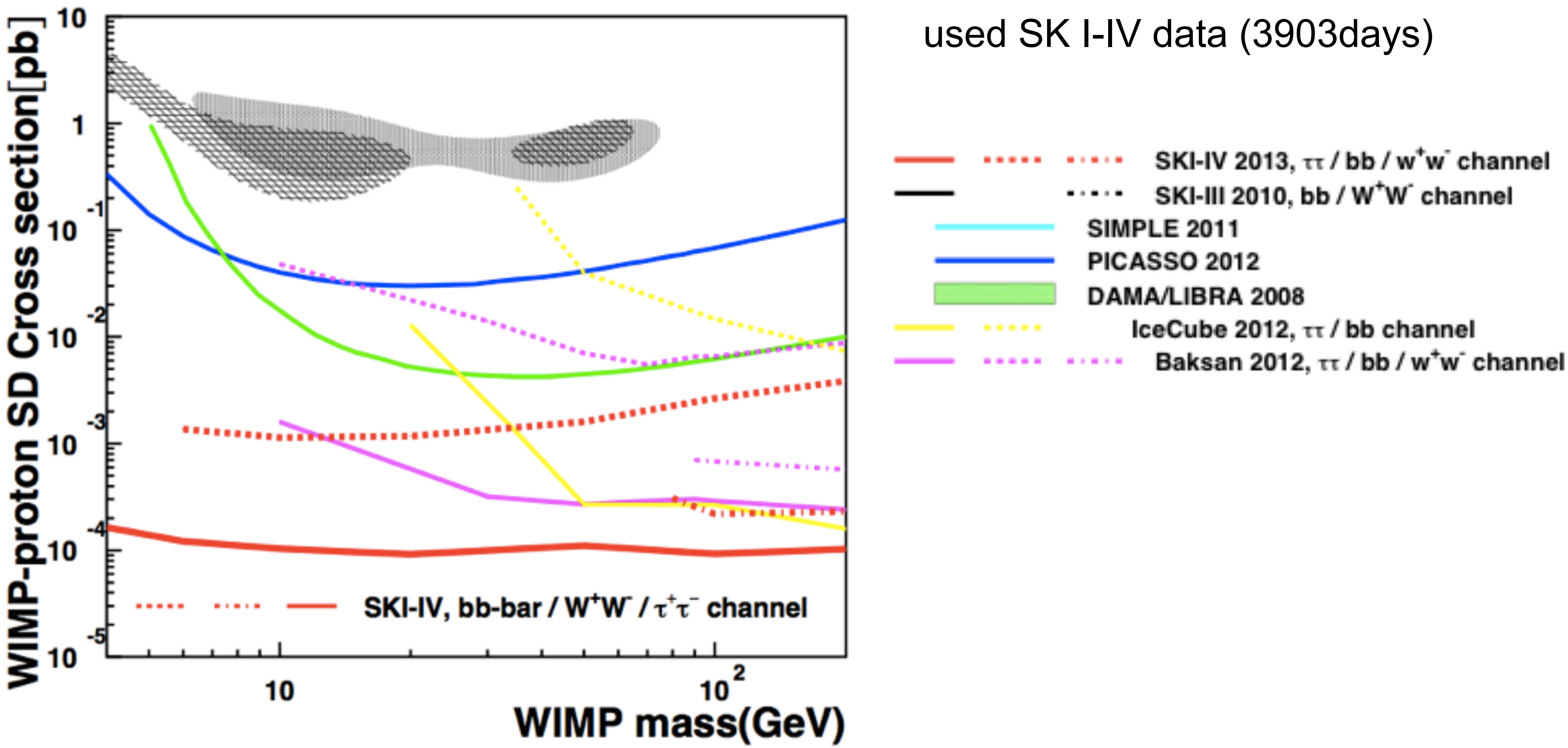


"flux ∝ annihilation ∝ capture ∝ scattering X-section"

Upper limit on flux -> upper limit on scattering X-section

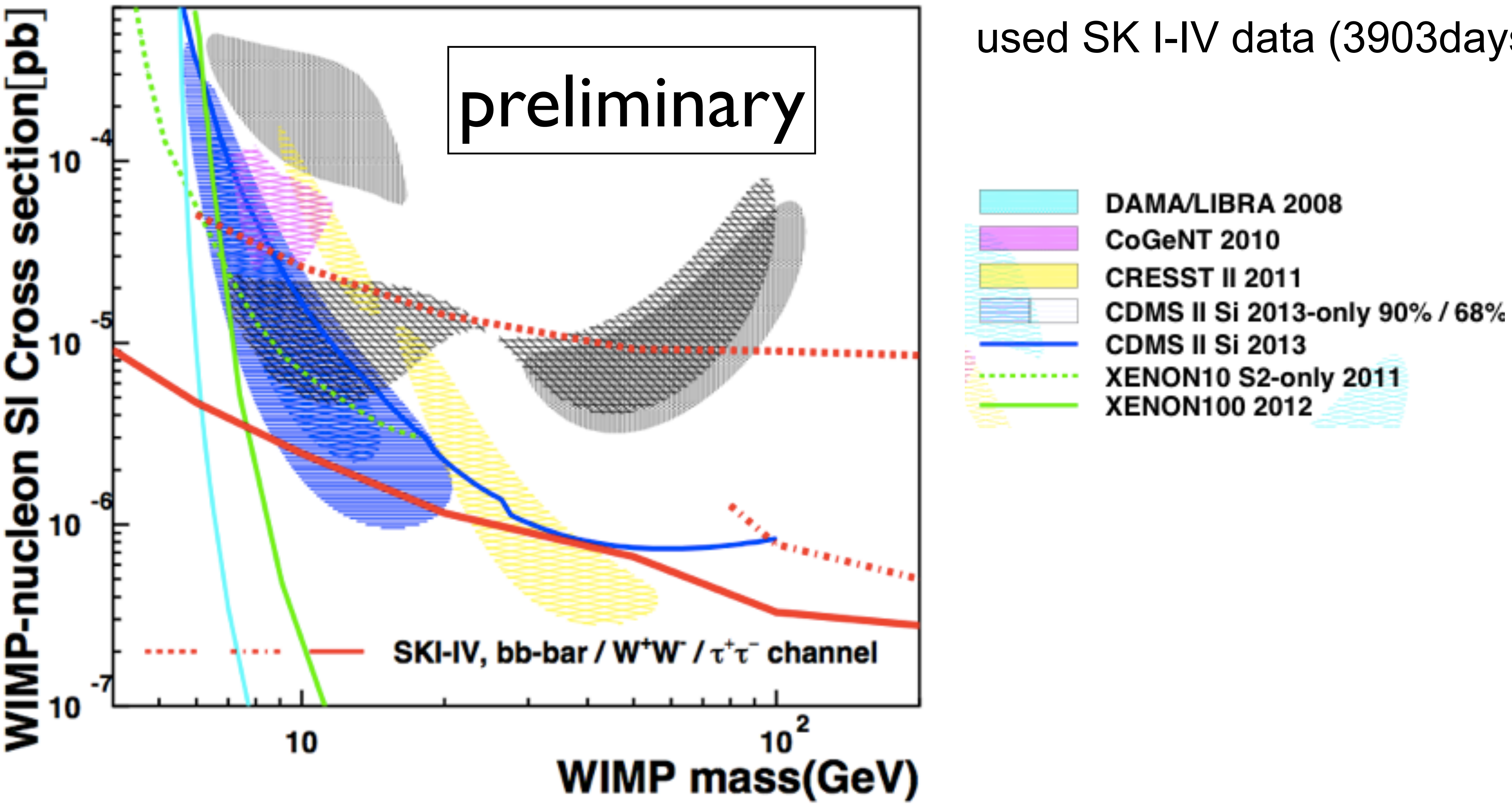
90% Upper limit on SD scattering X-section

used SK I-IV data (3903days)



result shown in 3 lines to be model independent

90% Upper limit on SI scattering X-section



used SK I-IV data (3903days)

The result surprisingly competes with human-made direct detectors.

→ important result from a very different detection strategy & uncertainties than direct searches.

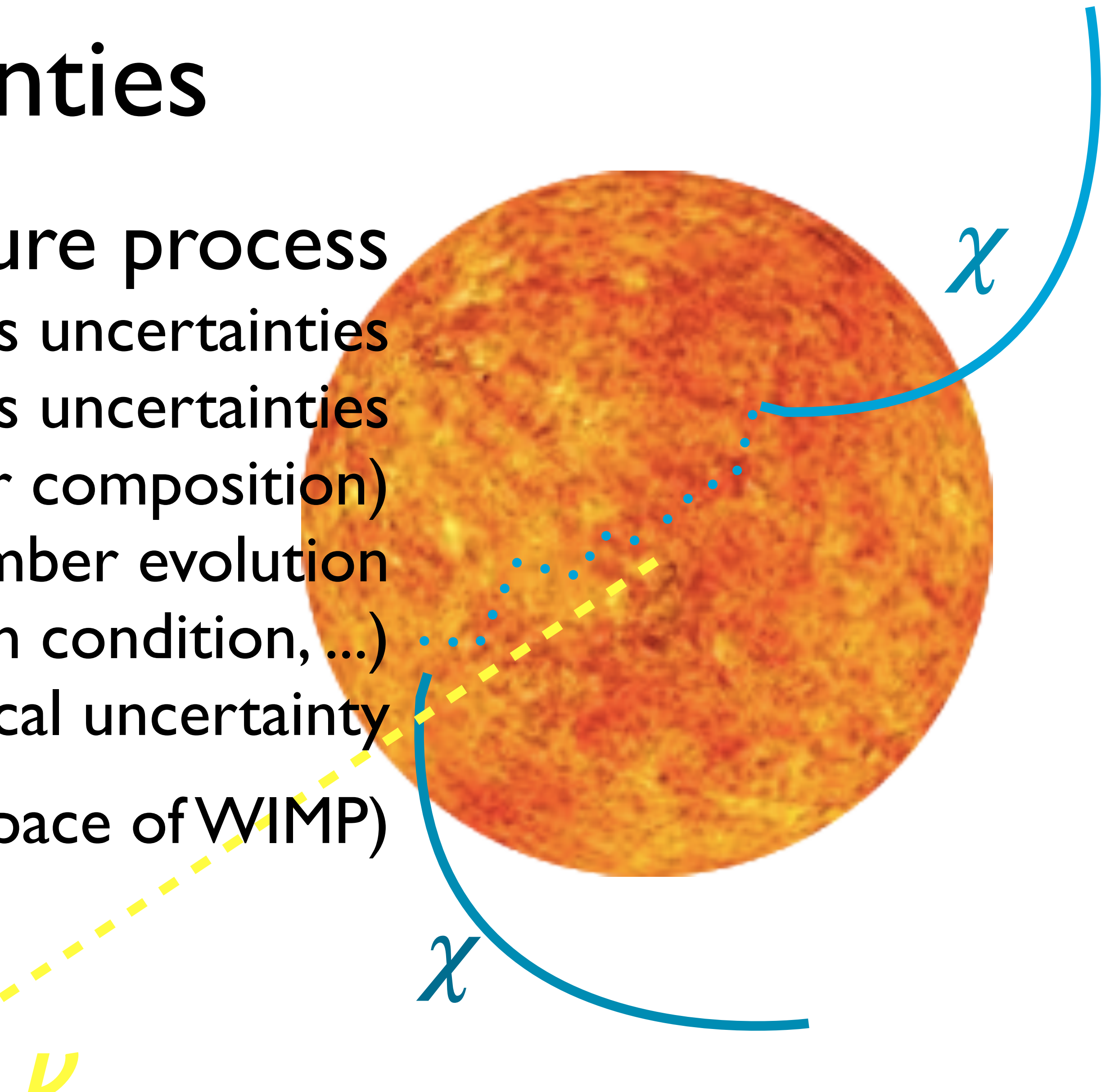
So, how much trusty is this result?

- It is good strategy in terms of sensitivity.
  Since suggested in early 80's, solar WIMP search has been most powerful analysis in SD WIMP search, & functioned as good independent/multiple attempt in SI WIMP search.

- Is it good strategy in terms of reliability?

Uncertainties

consider in interpretation →



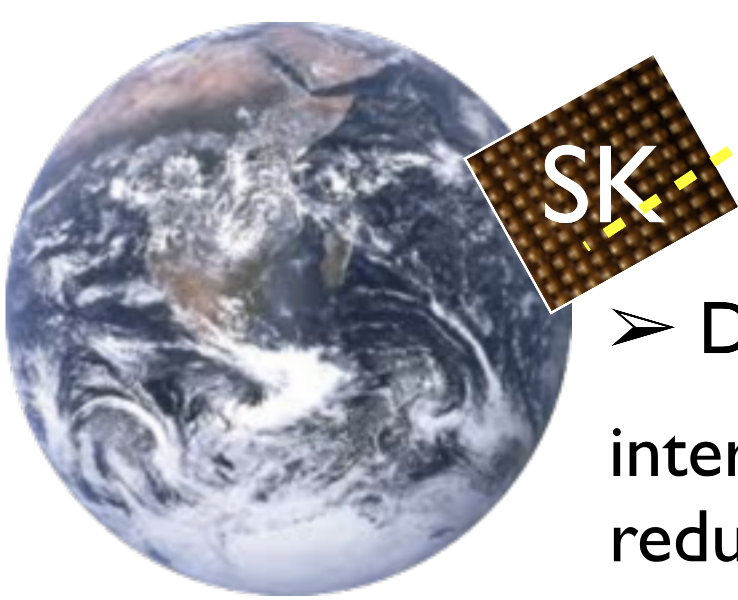
➢ In capture process

particle physics uncertainties
nuclear physics uncertainties
(form factor, solar composition)
WIMP number evolution
(Evaporation, Equilibrium condition, ...)
astrophysical uncertainty

(Local phase space of WIMP)

➢ In propagation : oscillation, interaction

treated in 'pulled method'



➢ Detector systematics ☞ neutrino interaction, event reduction, selection, reduction, reconstruction

uncertainties in neutrino propagation, detector response

not that enormous(results are driven by rather statistical error)
well-understood,
properly treated by pulled-method,
should be studied for individual detector (not for this talk)

(for example, for SK analysis 73 error sources are considered)

Systematic Error			SK-I fit	SK-I σ	SK-II fit	SK-II σ	SK-III fit	SK-III σ
FC reduction			0.005	0.2	0.008	0.2	0.061	0.8
PC reduction			-0.99	2.4	-2.12	4.8	0.034	0.5
FC/PC separation			-0.058	0.6	0.068	0.5	-0.28	0.9
PC-stop/PC-through separation (top)			7.84	14	-17.47	21	-20.03	31
PC-stop/PC-through separation (barrel)			-2.27	7.5	-31.51	17	3.44	23
PC-stop/PC-through separation (bottom)			-2.32	11.	-7.32	12	1.59	11
Non-ν BG (e-like)	Sub-GeV		0.077	0.5	0.004	0.2	0.003	0.1
	Multi-GeV		0.047	0.3	0.005	0.3	0.011	0.4
Non-ν BG (μ-like)	Sub-GeV		-0.01	0.1	0.02	0.1	0.052	0.1
	Multi-GeV		-0.01	0.1	0.02	0.1	0.11	0.2
	Sub-GeV 1-ring	μ-like 0-decay	-0.04	0.4	0.02	0.1	0.052	0.1
	PC		-0.02	0.2	0.14	0.7	0.85	1.8
Fiducial volume			-0.23	2	0.43	2	0.83	2
Ring separation	< 400 MeV	e-like	1.23	2.3	-1.67	1.3	0.12	2.3
		μ-like	0.37	0.7	-2.96	2.3	0.037	0.7
	> 400 MeV	e-like	0.21	0.4	-2.19	1.7	0.021	0.4
		μ-like	0.37	0.7	-0.90	0.7	0.036	0.7
	Multi-GeV	e-like	1.97	3.7	-3.35	2.6	0.19	3.7
		μ-like	0.91	1.7	-2.19	1.7	0.089	1.7
	Multi-ring sub-GeV	μ-like	-2.40	-4.5	10.56	-8.2	-0.24	-4.5
	Multi-ring multi-GeV	e-like	0.05	0.1	-2.45	1.9	0.16	3.1
		μ-like	-2.19	-4.1	1.03	-0.8	-0.21	-4.1
Particle identification	Sub-GeV	e-like	-0.007	0.1	0.13	0.5	0.004	0.1
		μ-like	0.007	-0.1	-0.13	-0.5	-0.004	-0.1
	Multi-GeV	e-like	-0.014	0.2	0.023	0.1	0.008	0.2
		μ-like	0.014	-0.2	-0.023	-0.1	-0.008	-0.2
Particle identification (multi-ring)	Sub-GeV	μ-like	-0.18	-3.9	-0.55	-2.2	-0.15	-3.9
	Multi-GeV	e-like	0.078	1.7	0.45	1.8	0.063	1.7
		μ-like	-0.13	-2.9	-0.86	-3.4	-0.11	-2.9
Energy calibration			-0.002	1.1	-0.56	1.7	-0.35	2.7
Up/Down asymmetry energy calibration			-0.4	0.6	-0.15	0.6	-0.03	1.3
Upward-going muon reduction	Stopping		-0.037	0.7	-0.14	0.7	0.14	0.7
	Through-going		-0.041	0.5	-0.10	0.5	0.10	0.5
Upward stopping/through-going μ separation			-0.04	0.4	0.006	0.4	0.04	0.6
Energy cut for upward stopping μ			-0.13	0.8	-0.26	1.4	0.78	2.1
Path length cut for upward through-going μ			0.39	1.8	-1.0	2.1	0.4	1.6
Upward through-going μ showering separation			9.42	9.0	2.28	13.0	6.1	6.0
BG subtraction of upward μ *	Stopping		4.16	16	-7.47	21	0.004	20
	Non-showering		-1.24	11	8.08	15	6.34	19
	Showering		2.27	18	-18.16	14	24.7	24
Multi-GeV Single-Ring Electron BG			5.95	16.3	-4.67	23.4	1.06	41.4
Multi-GeV Multi-Ring Electron BG			-4.38	35.6	-1.4	22.3	-36.8	38.0
Multi-GeV Multi-Ring e-like likelihood			-1.12	6.4	0.5	11.1	-0.3	5.3
Sub-GeV 1-ring π^0 selection	$100 < P_e < 250$	MeV/c	-3.94	11.2	-4.08	7.5	-5.34	7.7
	$250 < P_e < 400$		-4.05	11.5	-4.85	8.9	-18.37	26.4
	$400 < P_e < 630$		-8.23	23.4	-9.52	17.5	-8.70	12.5
	$630 < P_e < 1000$		-6.72	19.1	-5.81	10.7	-18.58	26.7
	$1000 < P_e < 1330$		-4.57	13.0	-6.03	11.1	-18.58	26.7
Sub-GeV 2-ring π^0			-0.31	2	0.024	2	0.009	1
Decay-e tagging			0.16	1.5	0.41	1.5	1.06	1.5
Solar Activity			0.6	20	27.9	50	3.78	20

Systematic Error			fit value	σ
Flux normalization	$E_\nu < 1$ GeV		34.7	25^a
	$E_\nu > 1$ GeV		8.8	7^b
ν_μ/ν_e				
	$E_\nu < 1$ GeV		-1.9	2
	$1 < E_\nu < 10$ GeV		-2.5	3
	$E_\nu > 10$ GeV		-3.7	5^c
$\bar\nu_e/\nu_e$				
	$E_\nu < 1$ GeV		5.54	5
	$1 < E_\nu < 10$ GeV		1.13	5
	$E_\nu > 10$ GeV		-0.10	8^d
$\bar\nu_\mu/\nu_\mu$				
	$E_\nu < 1$ GeV		-0.48	2
	$1 < E_\nu < 10$ GeV		-1.35	6
	$E_\nu > 10$ GeV		-1.75	6^e
Up/down ratio	< 400 MeV	e-like	-0.07	0.1
		μ-like	-0.23	0.3
		0-decay μ-like	-0.84	1.1
	> 400 MeV	e-like	-0.61	0.8
		μ-like	-0.38	0.5
		0-decay μ-like	-1.29	1.7
	Multi-GeV	e-like	-0.53	0.7
		μ-like	-0.15	0.2
	Multi-ring Sub-GeV	μ-like	-0.15	0.2
	Multi-ring Multi-GeV	e-like	-0.23	0.3
		μ-like	-0.15	0.2
	PC		-0.15	0.2
Horizontal/Vertical ratio	< 400 MeV	e-like	-0.01	0.1
		μ-like	-0.01	0.1
		0-decay μ-like	-0.03	0.3
	> 400 MeV	e-like	-0.14	1.4
		μ-like	-0.19	1.9
		0-decay μ-like	-0.14	1.4
	Multi-GeV	e-like	-0.33	3.2
		μ-like	-0.23	2.3
	Multi-ring Sub-GeV	μ-like	-0.13	1.3
	Multi-ring Multi-GeV	e-like	-0.29	2.8
		μ-like	-0.15	1.5
	PC		-0.17	1.7
K/π ratio in flux calculation			-12.9	10^f
Neutrino path length			-8.8	10
Sample-by-sample	FC Multi-GeV		-4.5	5
	PC + Up-stop μ		-7.1	5

Systematic Error		fit value	σ
MA in QE and single π		-2.4	10
CCQE cross section		0.66	1.0^a
Single meson production cross section		7.8	20
DIS cross section ($E_{\nu\mu} < 10$ GeV)		-0.16	1.0^b
DIS cross section		2.27	5
Coherent π production		1.53	100
NC/(CC)		1.51	20
Nuclear effect in ^{16}O nucleus		-13.8	30
Nuclear effect in pion spectrum		0.8	1.0^c
ν_τ contamination		1.0	30
NC in FC μ-like (hadron simulation)		-4.6	10
CCQE $\bar\nu_i/\nu_i$ (i=e,μ) ratio		0.84	1.0^a
CCQE μ/e ratio		1.12	1.0^a
Single π production, $\pi^0/\pi^\pm$ ratio		-29.0	40
Single π production, $\bar\nu_i/\nu_i$ (i=e,μ) ratio		-0.04	1.0^d
π^+ decay uncertainty Sub-GeV 1-ring	e-like 0-decay	-0.48	0.5
	μ-like 1-decay	0.77	-0.8
	e-like 1-decay	3.9	-4.1
	μ-like 0-decay	-0.77	0.8
	μ-like 2-decay	5.46	-5.7

uncertainties in particle physics

"As an experimentalist, not responsible for search for models accommodating current all results from colliders, direct searches, CMB measurements, but still we can't 100% escape from the particle physics concern because of 'assumptions' we put."

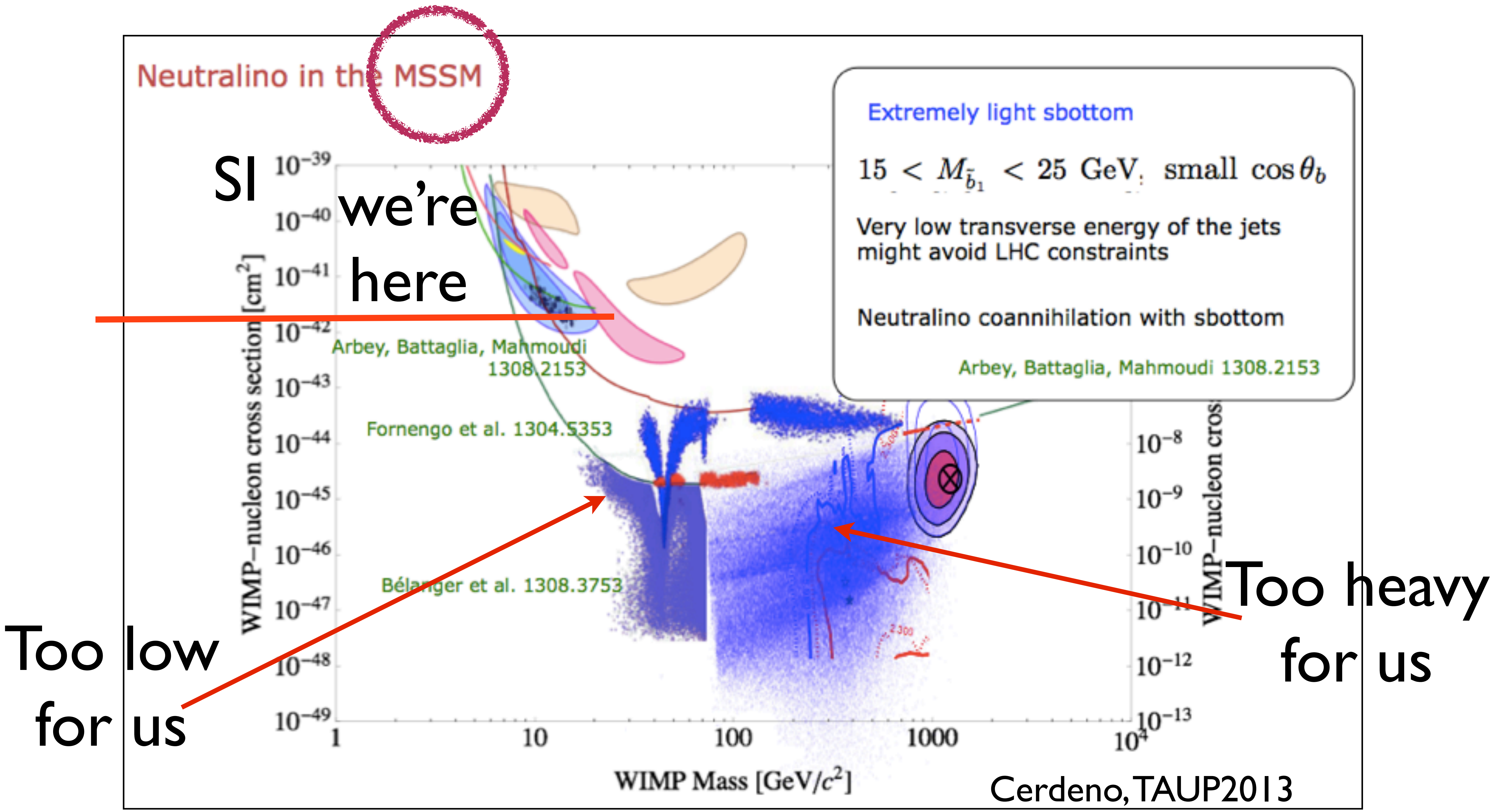
<assumptions on scattering to ordinary matter>

- 'elastic' scattering off nuclei
- axial vector(SD) and/or scalar(SI) interaction types
- isospin conserving interaction

how model-independent WIMP searches are?
-> need to look back into the particle physics assumptions we put

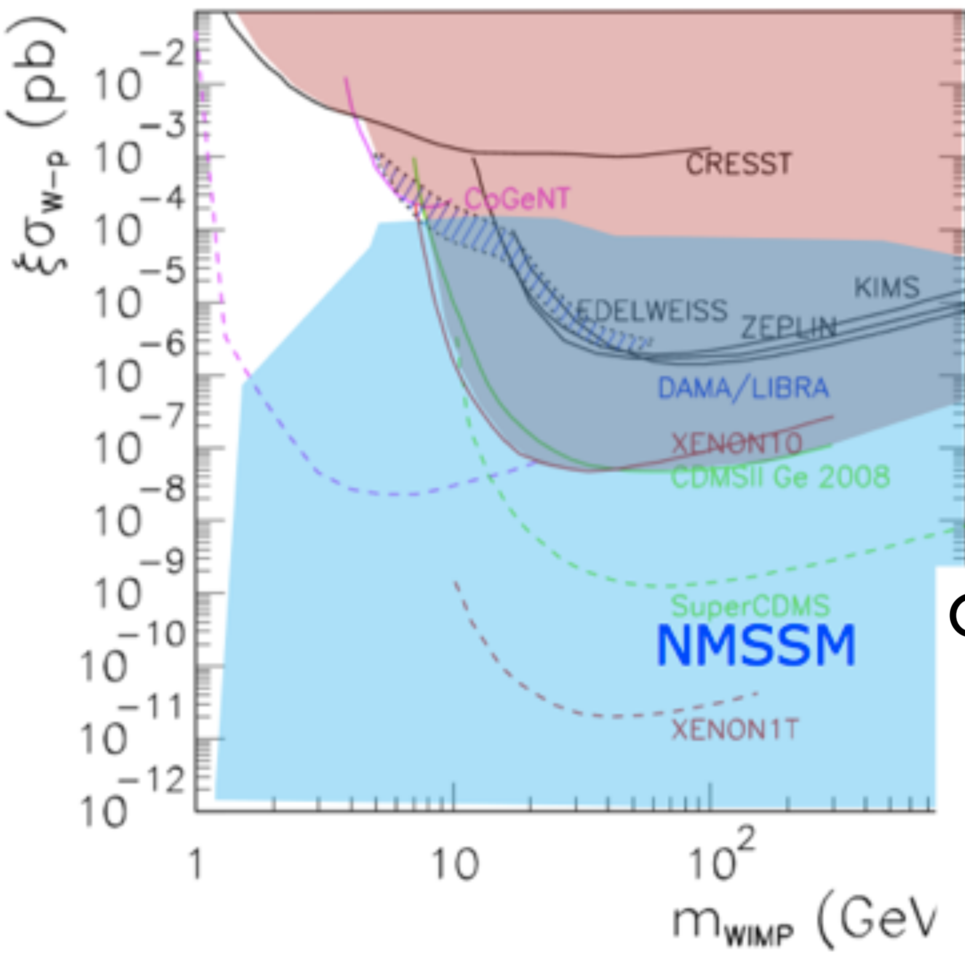
Search for light LSP in next-to-MSSM

- In model space, Neutralino in MSSM < 20GeV is essentially closed. But we can find theoretically well-motivated light WIMPs in nMSSM



Find a light WIMP candidate in next-to-MSSM (go to 'weird models')

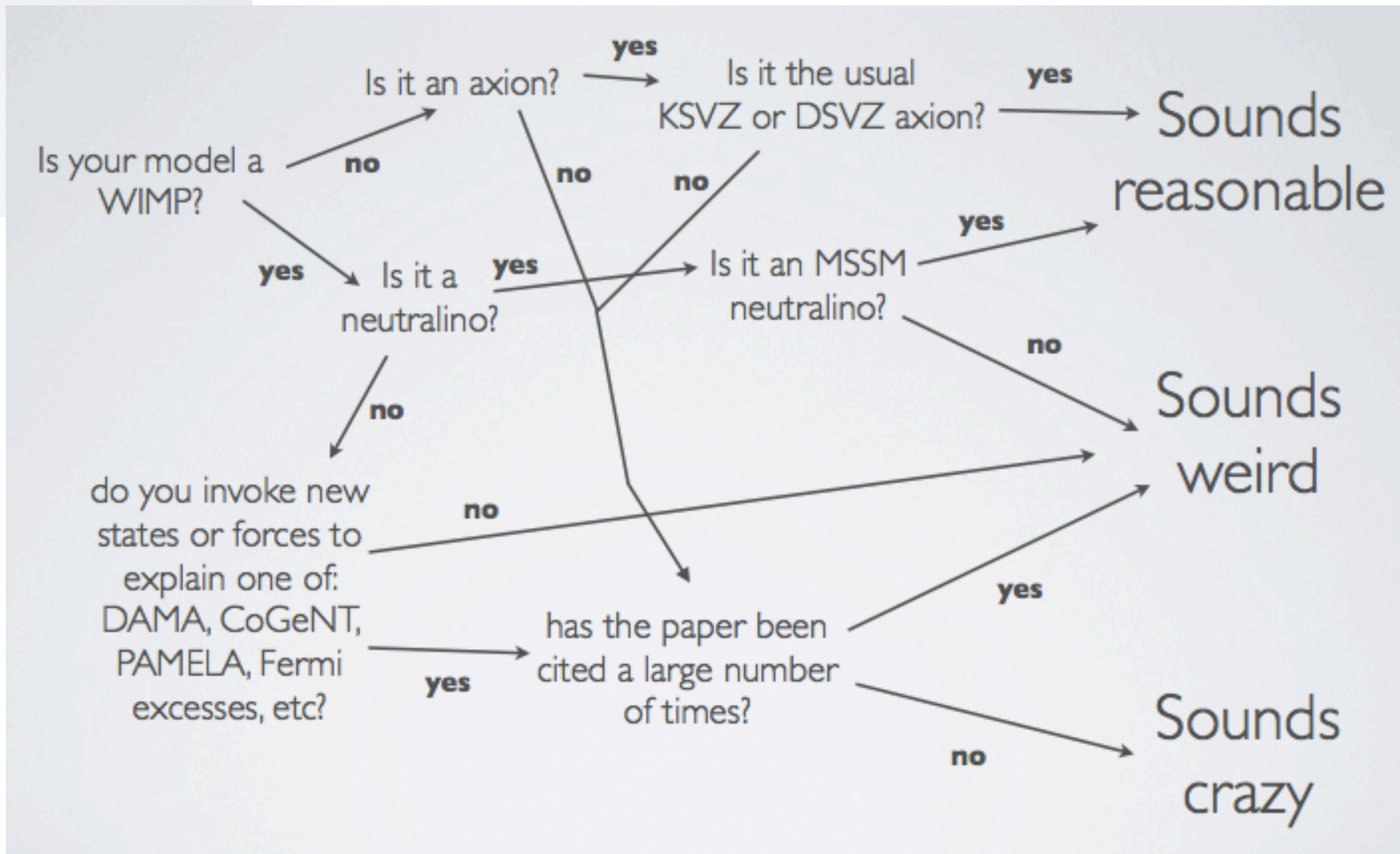
SI



Cerdeno

"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 a scattering cross-section consistent with the rate observed by CoGeNT and DAMA."

‘normal’ WIMPs are not all after all



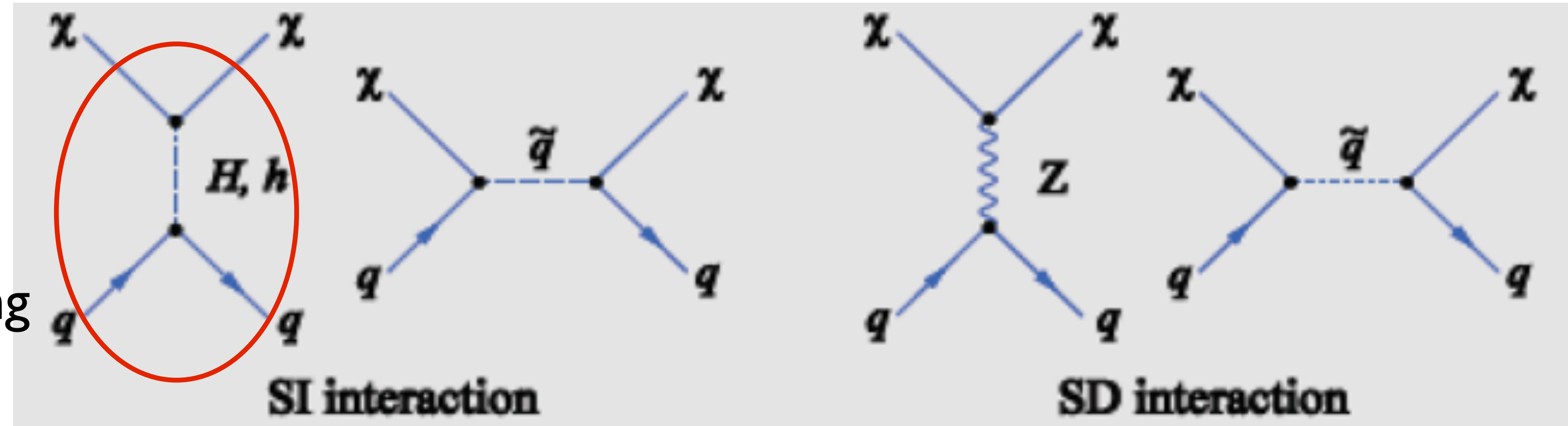
Neal Weiner, TAUP2013

break a 'still' model-dependent assumption

In our 'weird' model, customary assumed 'isospin conserving interaction' needs to be generalized -> 'isospin-violating dark matter' (IVDM)

$$\sigma_{SI} = \frac{4m_\chi^2 m_N^2}{\pi(m_\chi + m_N)^2}(Zf_p + (A-Z)f_n)^2$$

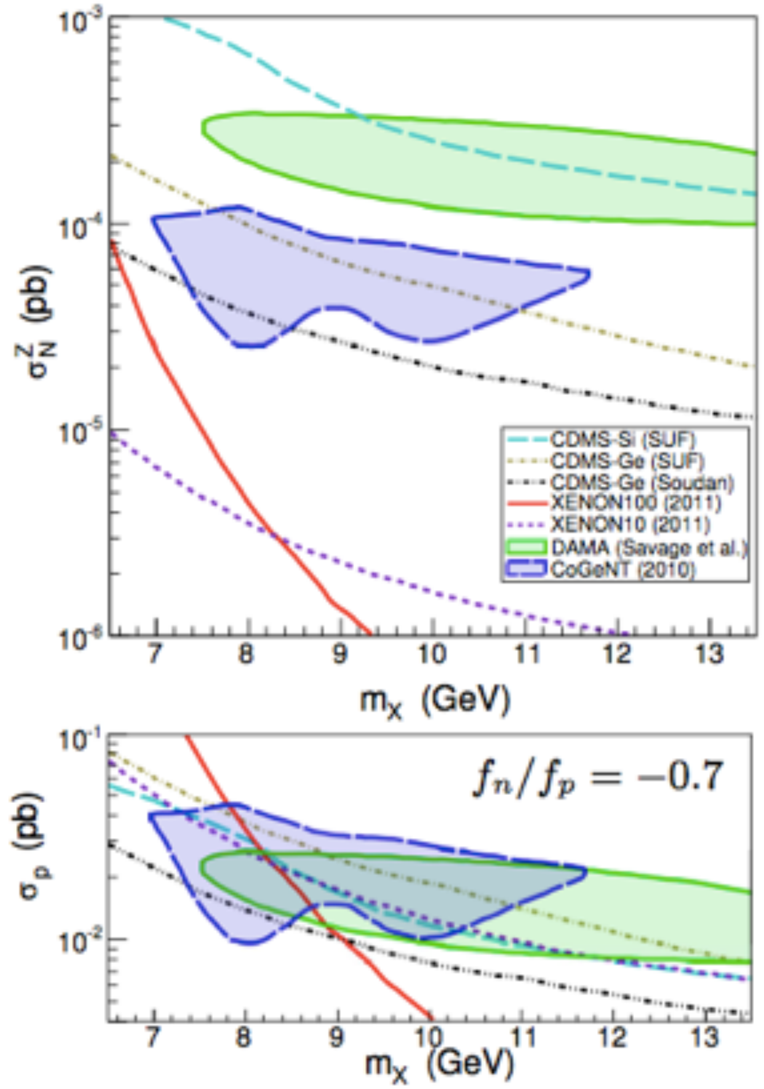
MSSM
wino/higgsino,
isospin-conserving



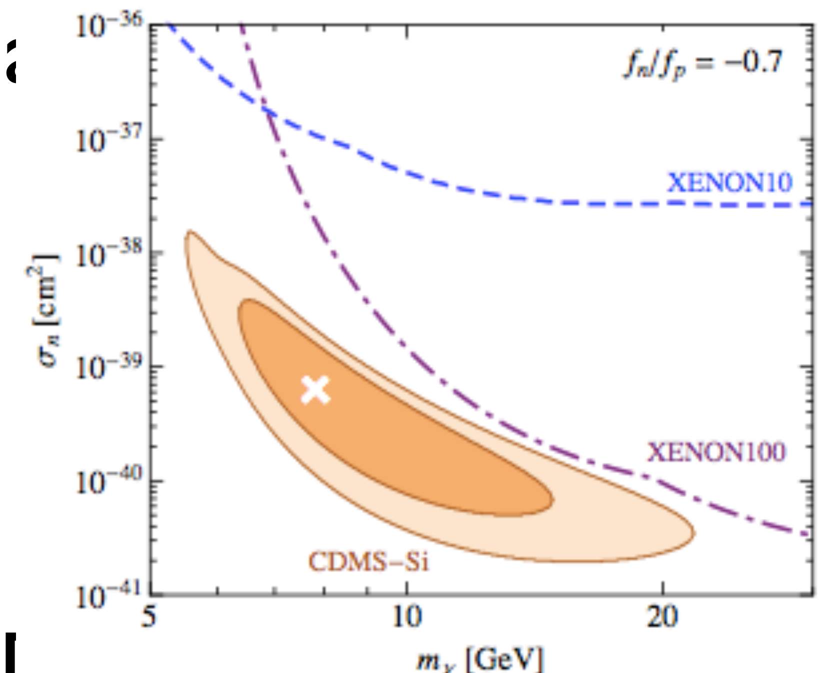
Actually not 'weird' but 'more general' thought this is...

More motivations for IVDM

Feng, Kumar, Marfatia, Sanford 2011



phenomenologically, it has been popular as a remedy to reconcile conflicting results (1003.0014, 1102.4332, 1103.3270, 1110.5338, 1112.4849, 1212.2043, 1302.5416, astro-ph/0408346, 1106.4044(about SK solar WIMP), 1108.0518(about sol many more)

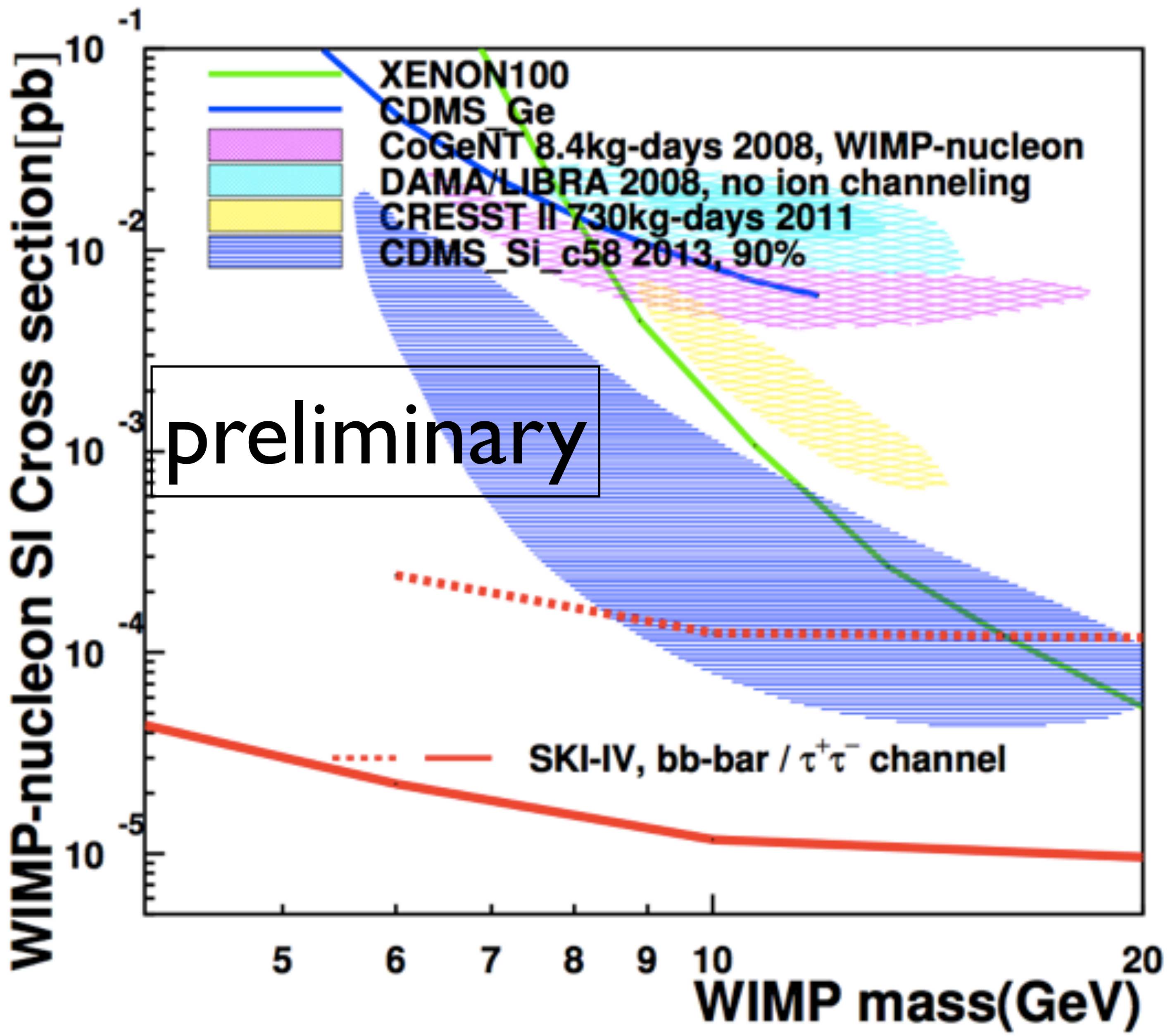


Frandsen et al. 2013

strength of solar WIMP analysis :
solar analysis has strong sensitivity for IVI
Due to the Sun chemical composition with
approximately 73% of hydrogen (less
susceptible to destructive interference between
proton and neutron couplings). (fn/fp < 0).

$$\sigma_A = \frac{\mu_A^2}{M_*^4}\left[f_p Z + f_n (A-Z)\right]^2 \times FF$$

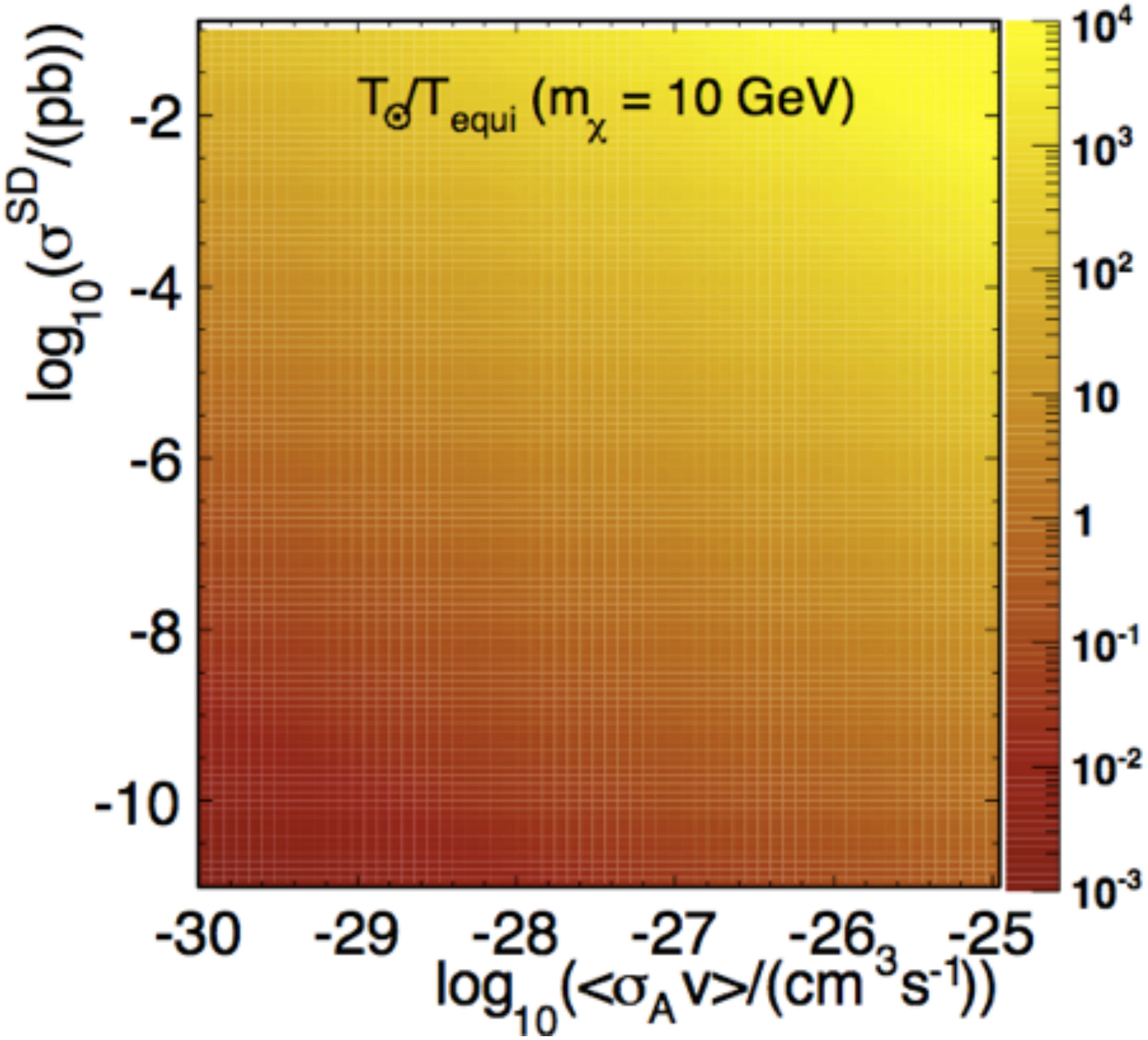
Search for isospin violating DM



90% Upper limit on SI scattering X-section for IVDM case (fn/fp = -0.7 assumed)

Cruciality of 'capture = annihilation equilibrium'

which i don't want to reveal in the places i have to advertise my analysis...



equilibrium condition scanned for CMSSM neutralinos

-> needs to be done for individual target model

uncertainties in nuclear physics

<foam factor>

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

SD : 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 : foam factor is expected to affect the solar analysis result max ~ 20% for heavy WIMP candidate

<SD cross-section calculation>

$$\sigma_{SD} = 32\frac{G_F^2\mu^2}{\pi}(a_p < S_{p(N)} > + a_n < S_{n(N)} >)^2\frac{J+1}{J}$$

Typically, "odd group assumption" for direct detections

-> relevant for pure Hydrogen detector

uncertainties in astrophysics

- After all, it is from 'indirect detection', isn't there huuuge astronomical uncertainties there?

I found a comment about AMS interpretation...

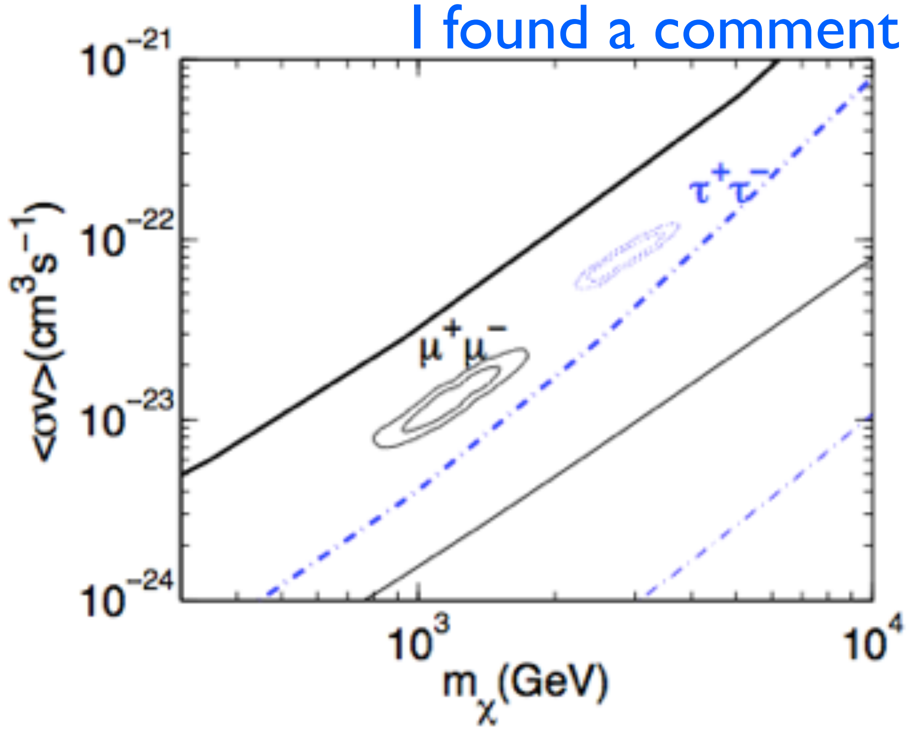


FIG. 8: 1σ and 2σ parameter regions on the $m_\chi - \langle\sigma v\rangle$ plane for the DM annihilation scenario. The lines show the 95% upper limit of Fermi γ-ray observations of the Galactic center (thin lines, with different normalization of the local density corrected, [50]) and dwarf galaxies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

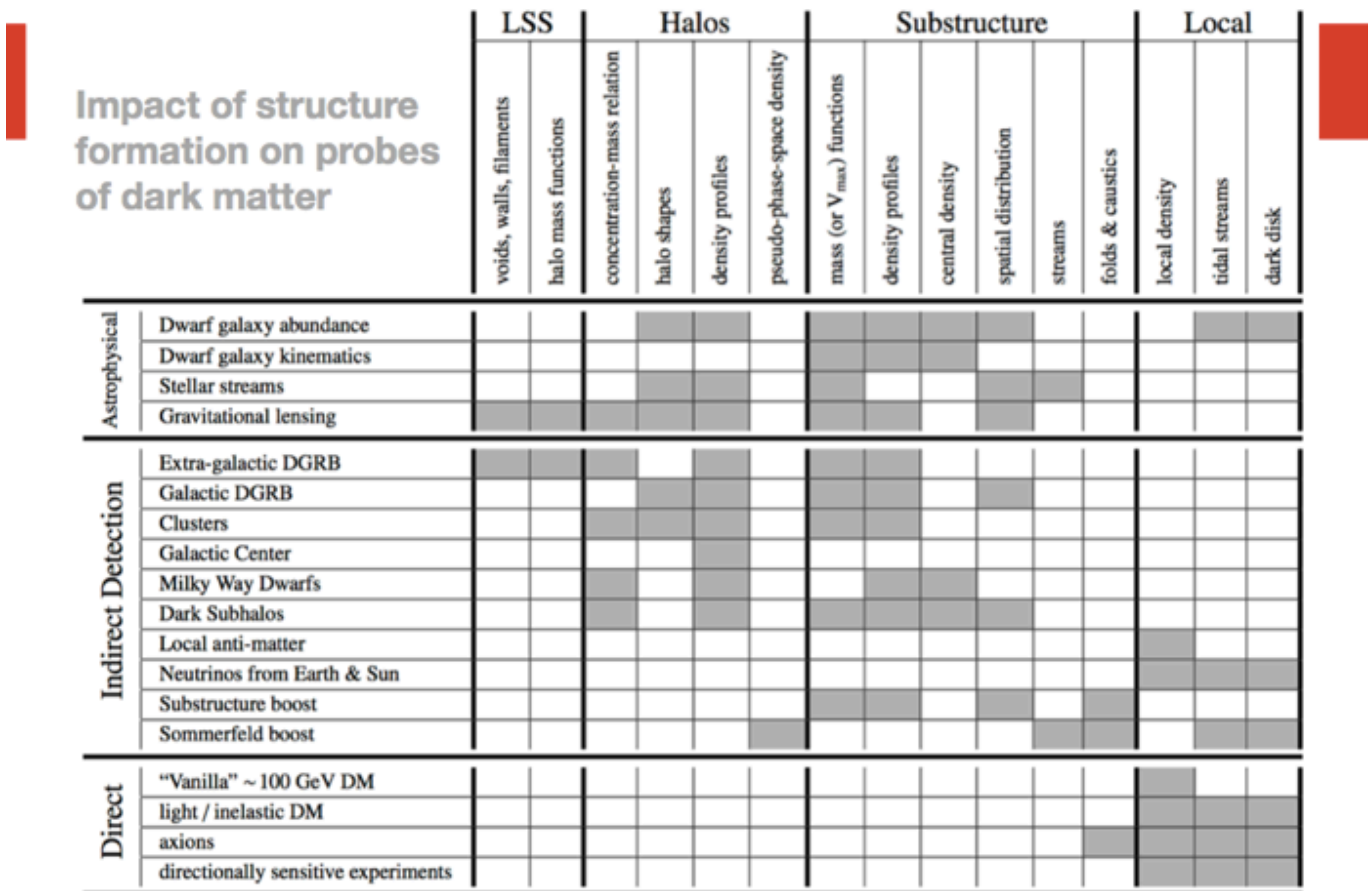
> The Galactic center γ-rays exclude the parameter space to explain the $e^\pm$ excesses. However it may suffer from the uncertainties of the density profile of DM in the halo center.

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

1304.1482 Yuan et al.

Astrophysical uncertainties

surprise 1) not THAT much source of uncertainties (no pulsar or something big between the Sun & us.
surprise 2) most of them shared with direct detections



Kuhlen, Vogelsberger & Angulo 2012

Wechsler, taup2013

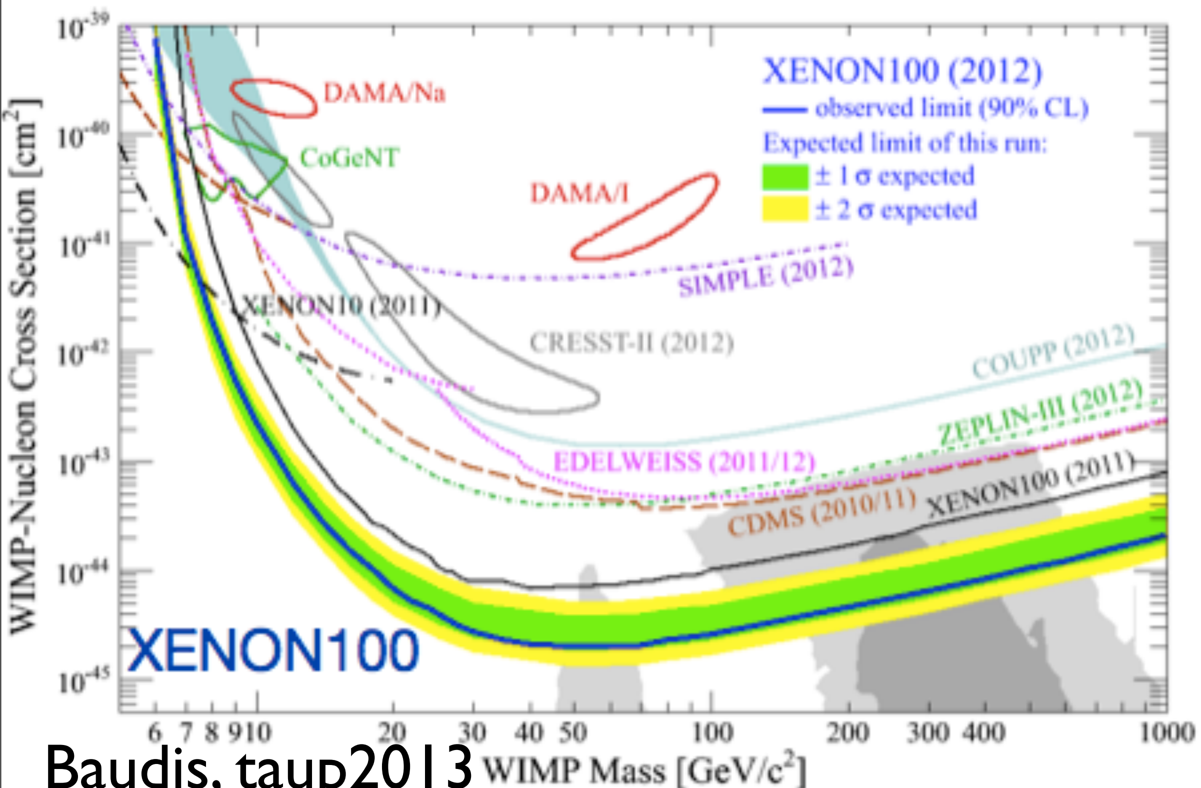
direct detections vs solar WIMP search

<table>
<tr><th></th><th>uncertainty range</th><th>direct searches</th><th>solar WIMP neutrino searches</th></tr>
<tr><td>Local DM halo density(ρ=0.3GeV/</td><td>0.25 GeV/cm³ < ρ0 < 0.70 GeV/cm³</td><td>1 ~ 2.8 times</td><td>1 ~ 2.8 times</td></tr>
<tr><td>escape velocity of local halo (544km/s)</td><td>-600km/s</td><td>large</td><td>></td></tr>
<tr><td>Vsun=220km/s</td><td>200 ~ 270km/s</td><td colspan="2" rowspan="2">rather small</td></tr>
<tr><td>Local DM velocity distribution function(VDF)</td><td>deviations from Maxwellian, etc</td></tr>
<tr><td>Extra structure of WIMPs</td><td>i.e. existence of dark disc</td><td><</td><td>large</td></tr>
</table>

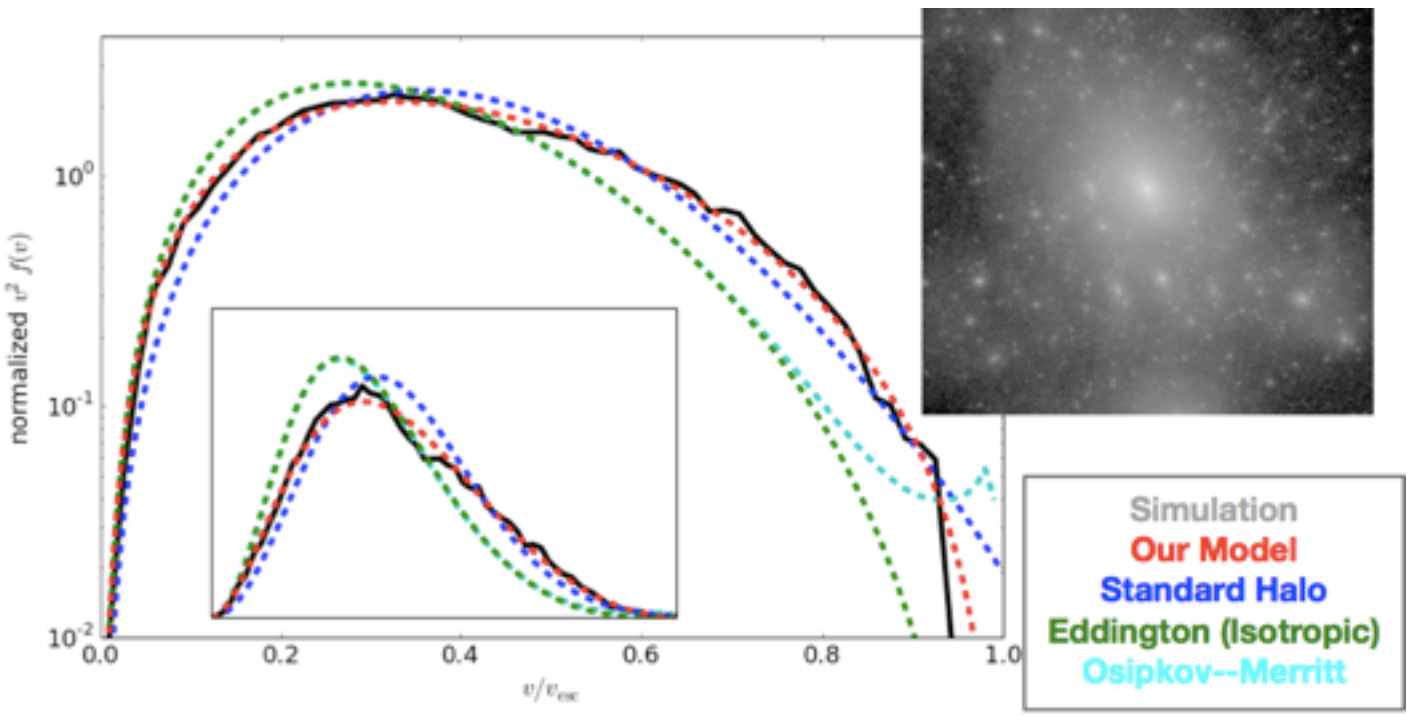
Same source but very different effect
-> need to be carefully studied individually

good to have very different detector

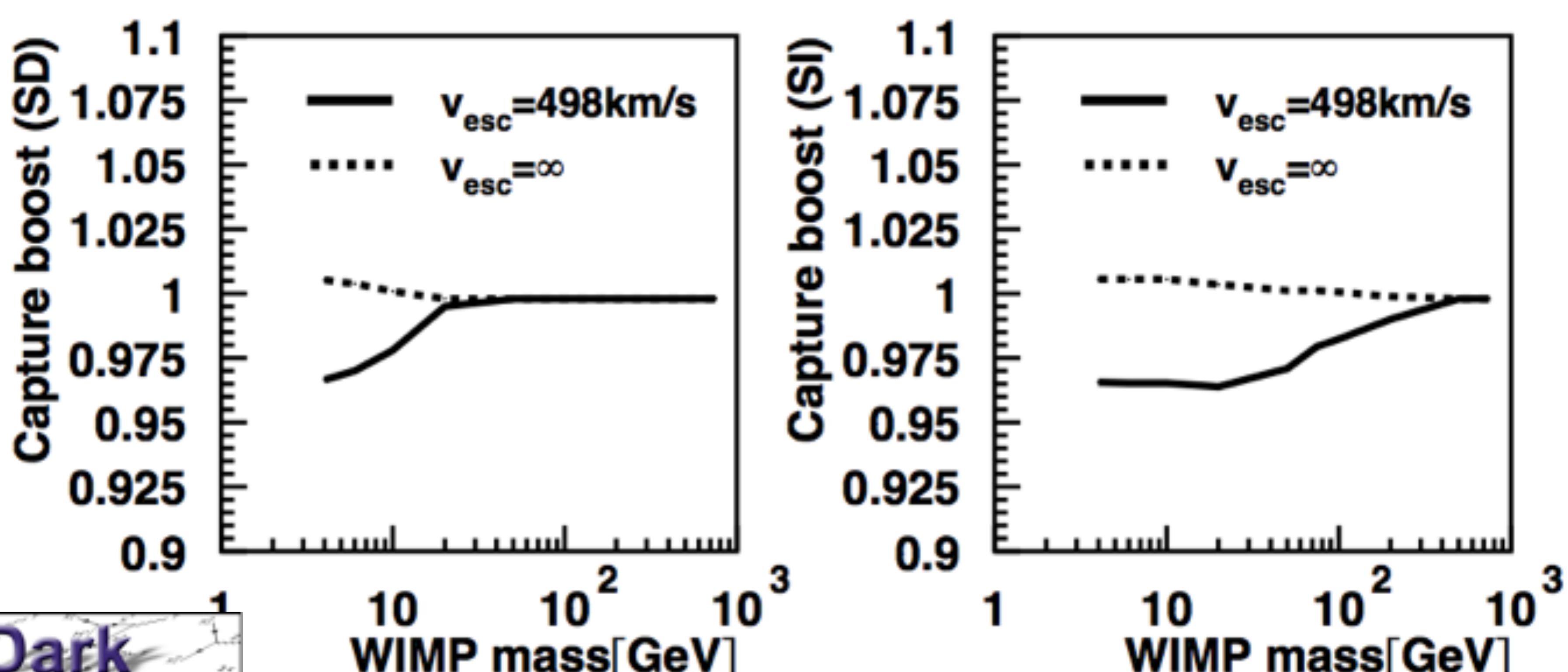
- at low mass where DD signals suddenly disappear



Baudis, taup2013



Wechsler, taup2013

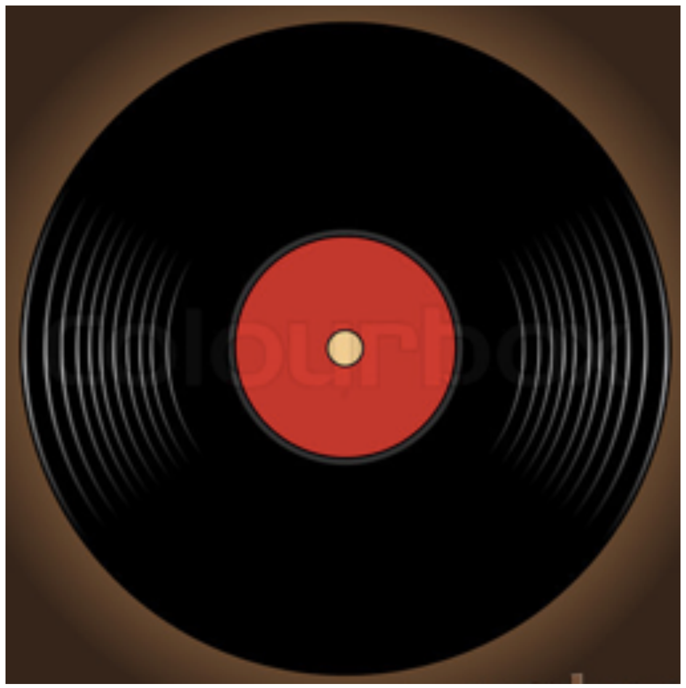


- with/without high velocity tail cut only few % for ID.

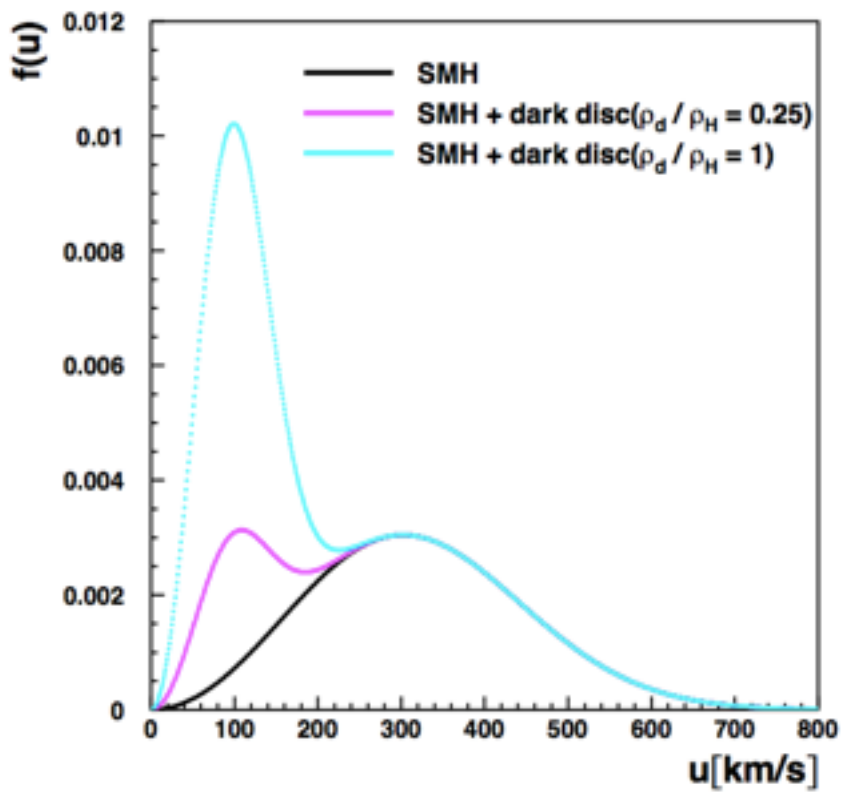
Koun, Rott, Itow 13012.0273

good to have very different detector

- what happens for possible modification of low velocity region?
  i.e. dark disc?



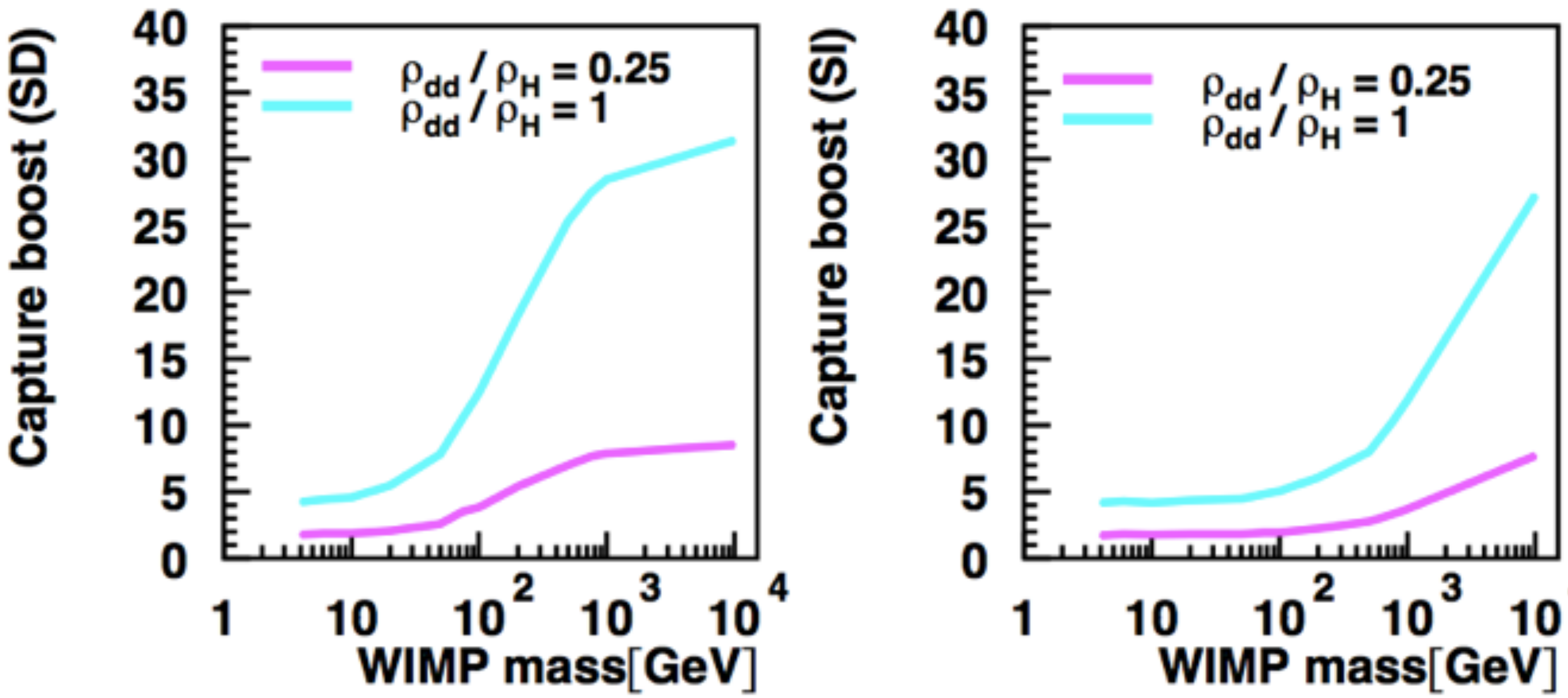
Existence of co-rotating invisible structure, dark disc in the solar neighbor, claimed to be robust by cosmological simulations



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

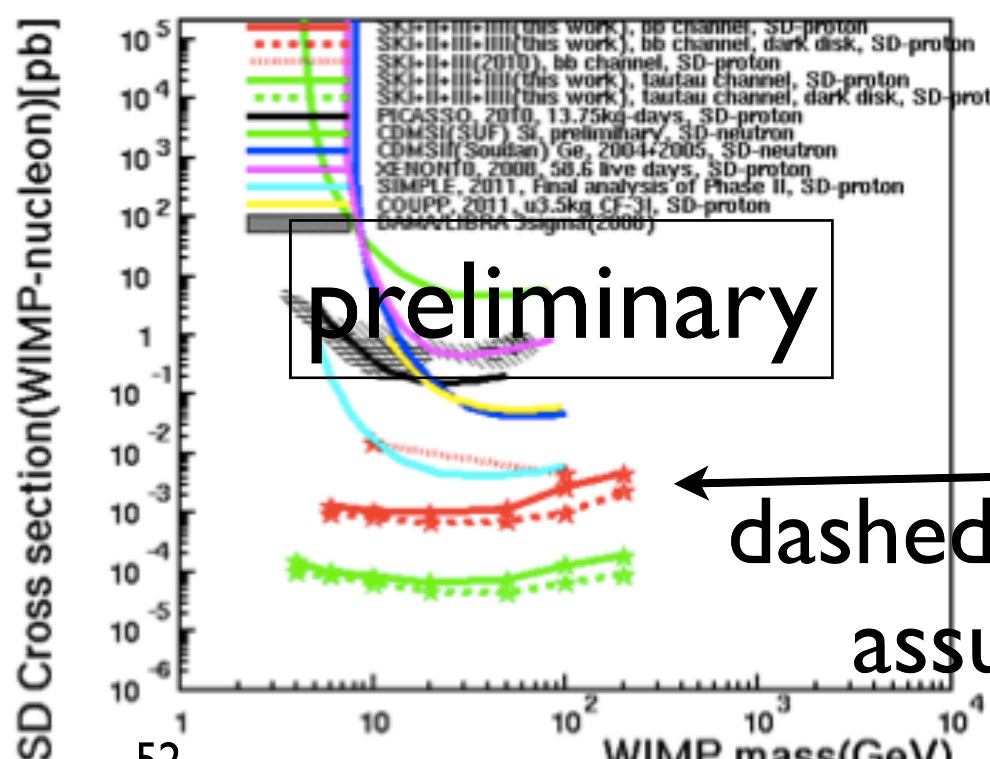
Abundance in low velocity region can boost neutrino detection

(Bruch et al, 0902.4001, Ling, 0911.2321)



Koun, Rott, Itow
13012.0273

Existence of dark disc makes the current interpretation of solar WIMP search versus direct detections stronger



dashed : dark disk assumption

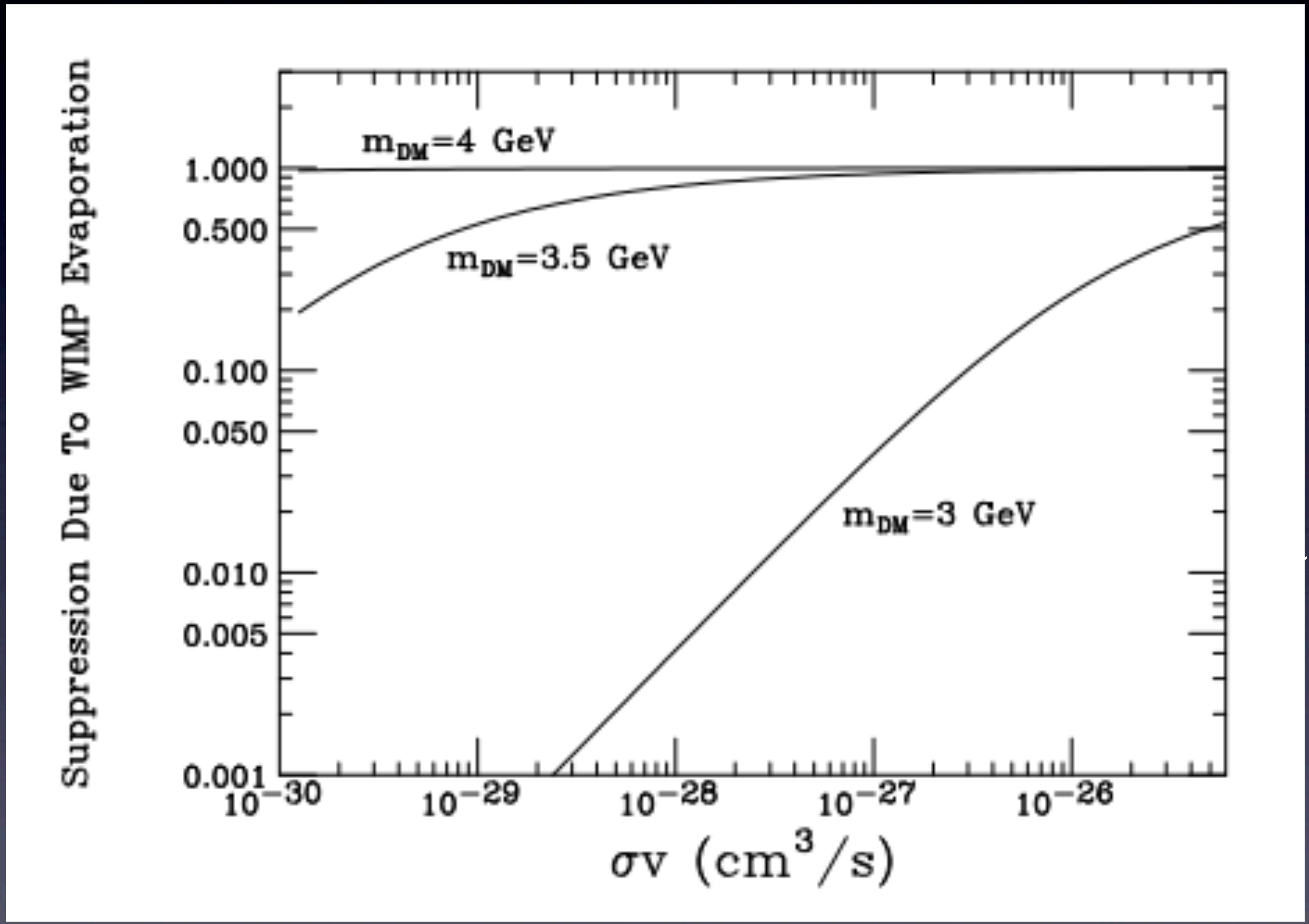
Conclusion

Solar WIMP search is a very strong strategy to examine light WIMPs.
➠ new analysis using neutrino yields : Increased signal acceptance using low energy & electron neutrino,
fitting with angle + energy + flavor informations
➠ SK result is current world's best in finding no WIMP competition in SD cross-section below 200GeV,
SI result excludes most of the claimed signal region with tautau channel, (consistent with recent LUX data) set the limit for very light WIMP (<8GeV).

Solar WIMP search uncertainties are not that enormous
➠ Astrophysical error sizes similar to direct detections; should be seriously (not indirectly) taken in parameter space
➠ Independent method & different responses to errors; can be a complementary method to untangle direct detection uncertainties

Thank you for listening to & inviting me!

Back Up



Suppression Due To WIMP Evaporation
1.000
0.500
0.100
0.050
0.010
0.005
0.001
m_{DM}=4 GeV
m_{DM}=3.5 GeV
m_{DM}=3 GeV
10^{-30}
10^{-29}
10^{-28}
10^{-27}
10^{-26}
σv (cm^3/s)

l.

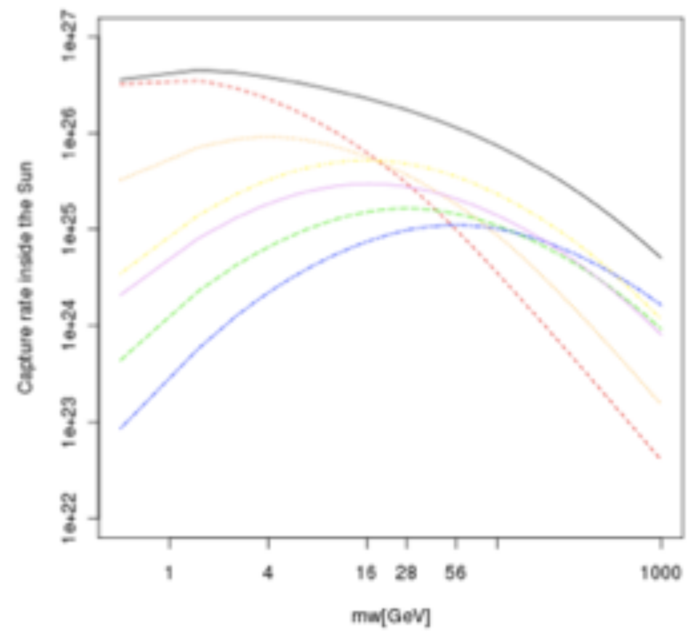
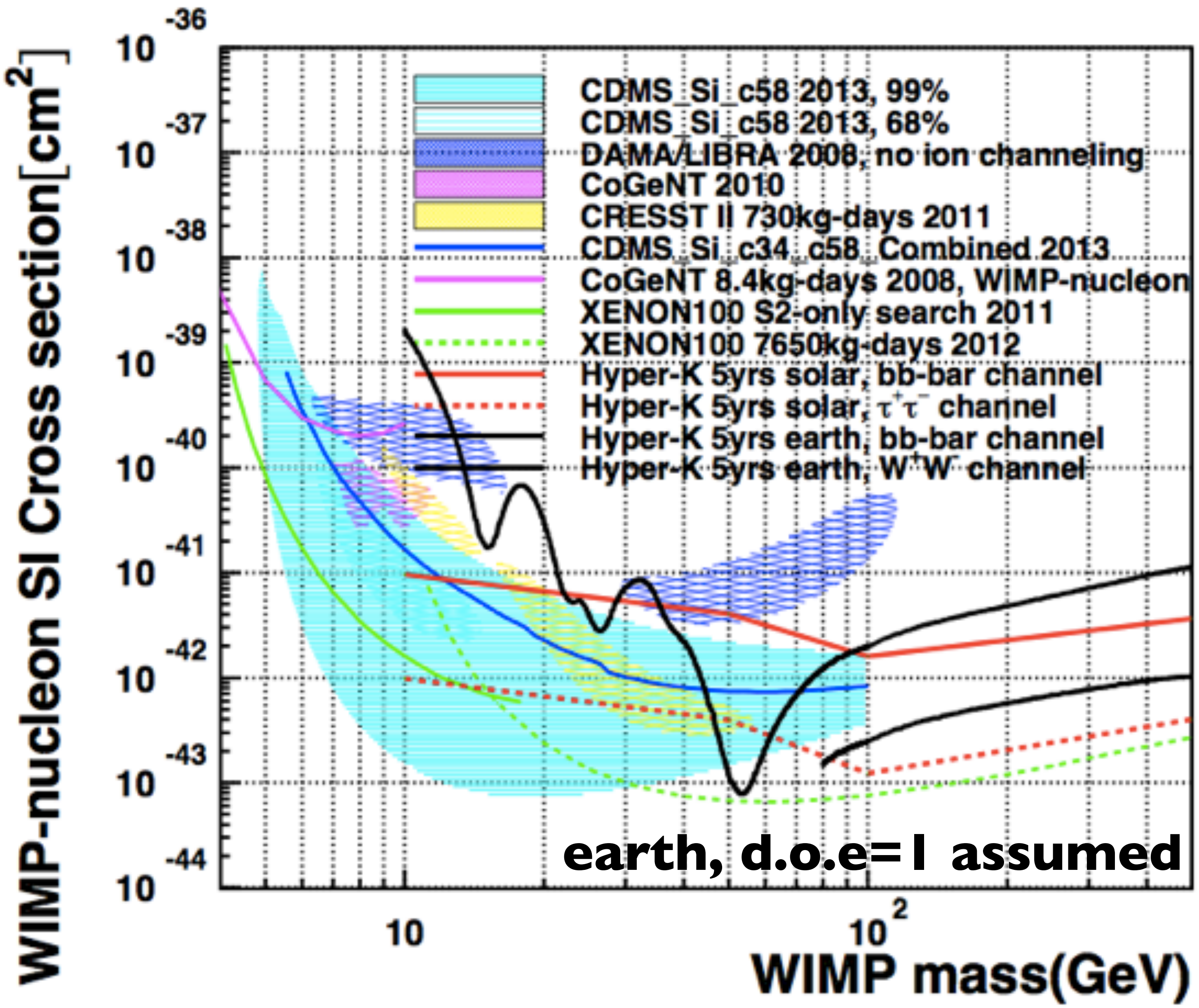


Figure 3.11: The capture rate of the Scalar-coupled WIMP in the Sun : *Black solid : Total, Red dashed : H, Orange dotted : He, Yellow dotdashed : O, Green longdashed : Si, Blue twodashed : Fe, Violet solid : the rest.*

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



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.

- Heavy element rich : strong sensitivity to SI cross section
- Resonant mass effect(strong for WIMP mass ~ Fe, Si..)

Uncertainties in capture process

Hydrogen detector is form factor error free!

Mainly Hydrogen ⇨ not much affects

no impact above 4GeV

negligible for low mass WIMP

recently went back to 'free space'(Sivertsson&Joakim, 1201.1895)

	form factor	Dark SUSY solar model	solar evaporation	solar diffusion
4~20GeV	1%	3%	<1%	<1%
50~100GeV	1%	4%	<1%	<1%
200GeV	1%	6%	<1%	<1%

combined all errors affect the solar analysis result < 7% for SD

taken account in conversion to WIMP-proton scattering cross-section limit