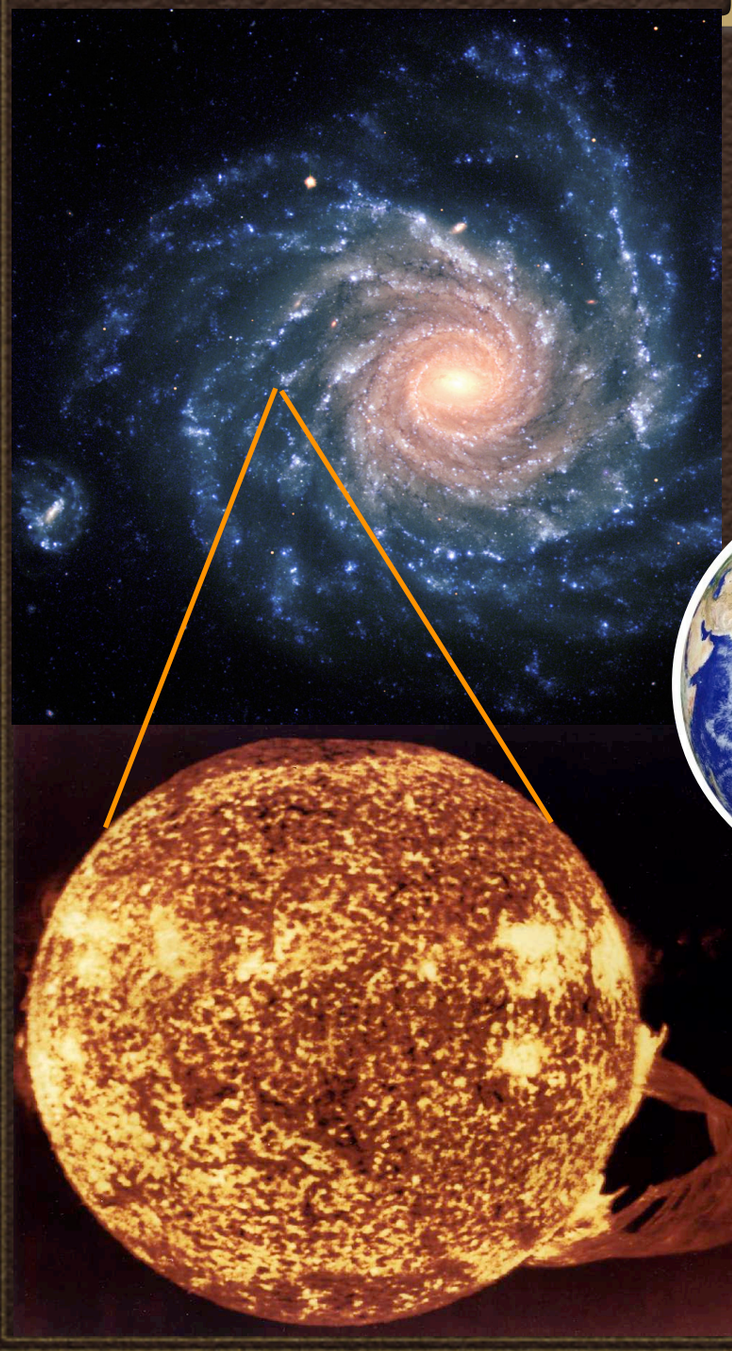
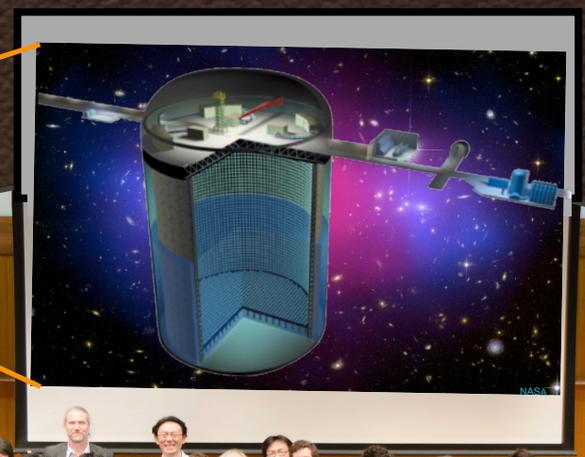
Indirect WIMP Searhes with Super-Kamiokande



TeV Particle Astrophysics Conference 2013
UC Irvine, California
8/28/2013

Michael Smy



~60% ~25% ~6% ~3% ~5% <1% <1%

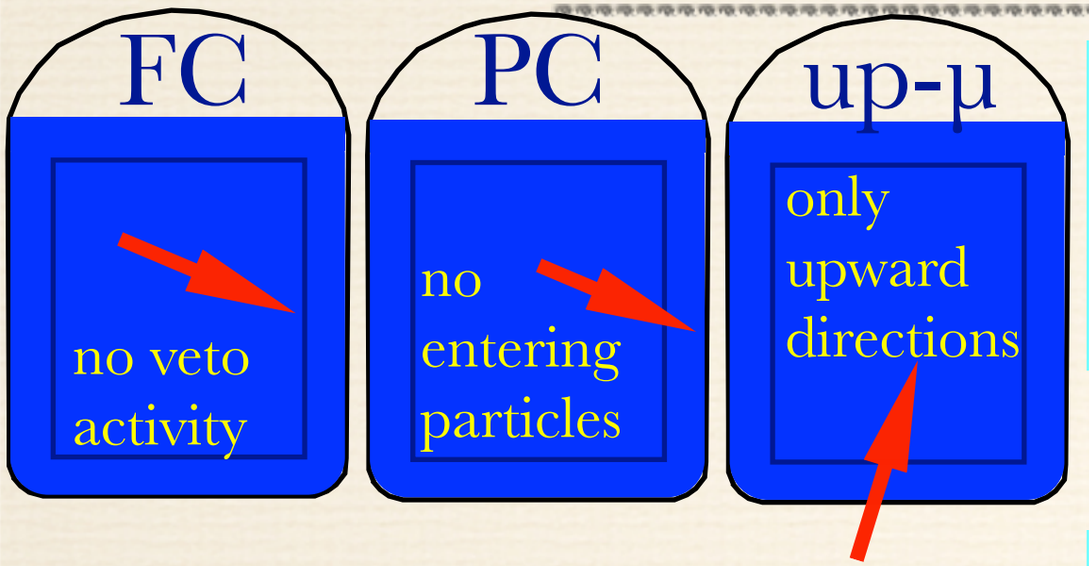
Indirect Limits from Neutrinos

- given a massive object (e.g. earth core or sun)
- WIMPs can get trapped in gravitational potential, if they loose energy via nucleon scattering
- search for neutrino emission from WIMP annihilation above backgrounds such as atmospheric neutrinos
- assume WIMP capture rate=WIMP self-annihilation rate for a constant WIMP density inside the object
- infer nucleon scattering (governing the capture rate) from search for annihilation

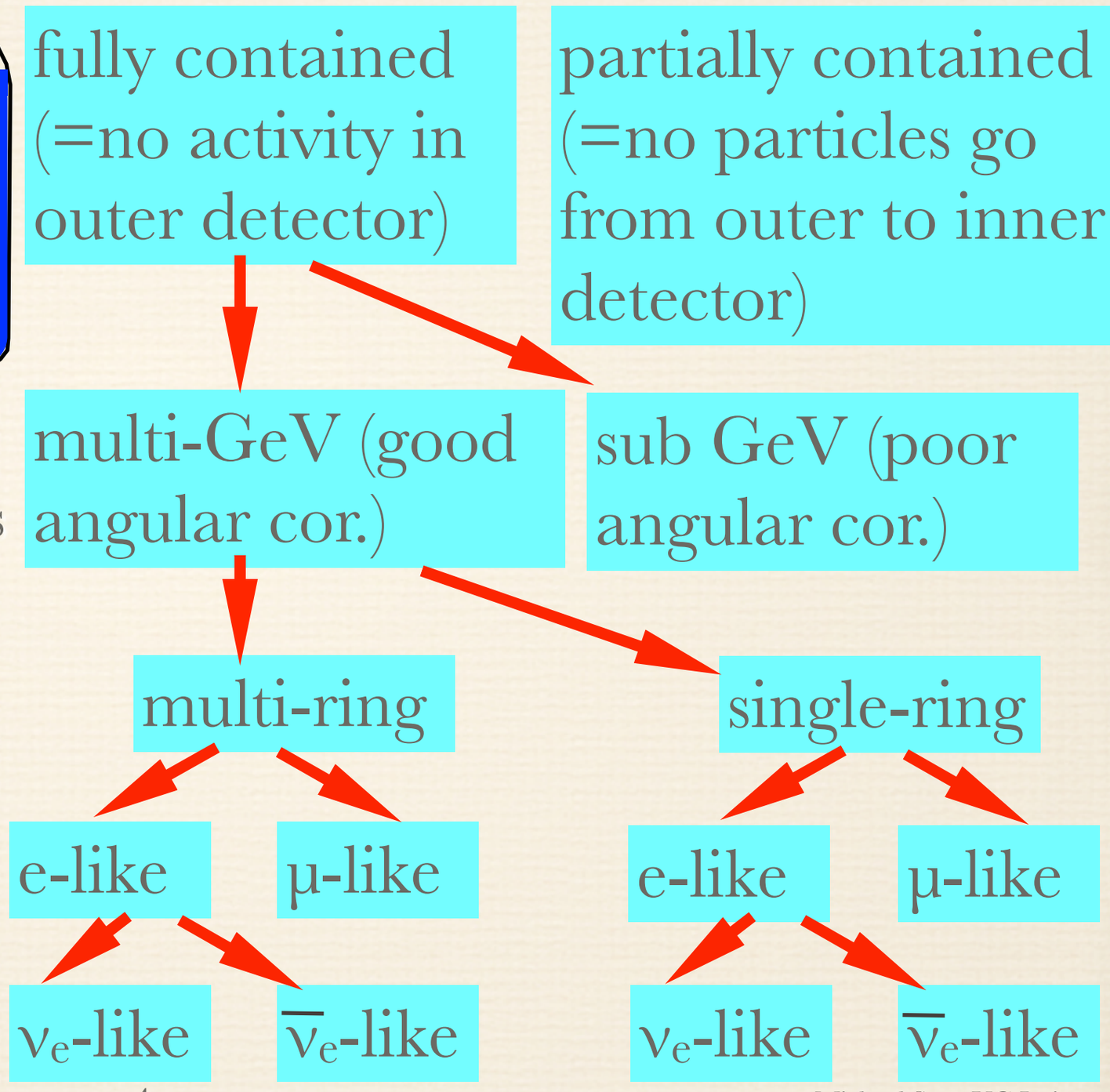
Search for Solar WIMPs

- sun is large accumulation of protons, few neutrons
- therefore probe spin-dependent cross section
- look for excess neutrino emission in solar direction
- WIMP pair annihilation to fermions in a single channel
  - light $q\bar{q}$ channel: make and stop $\pi^{(\pm)}$ (<100 MeV ν's)
  - $\tau^+\tau^-$ channel (>~2 GeV):
  - $b\bar{b}$ channel (>~5 GeV):
  - $W^+W^-/t\,\bar{t}$ channel (>~100 GeV):

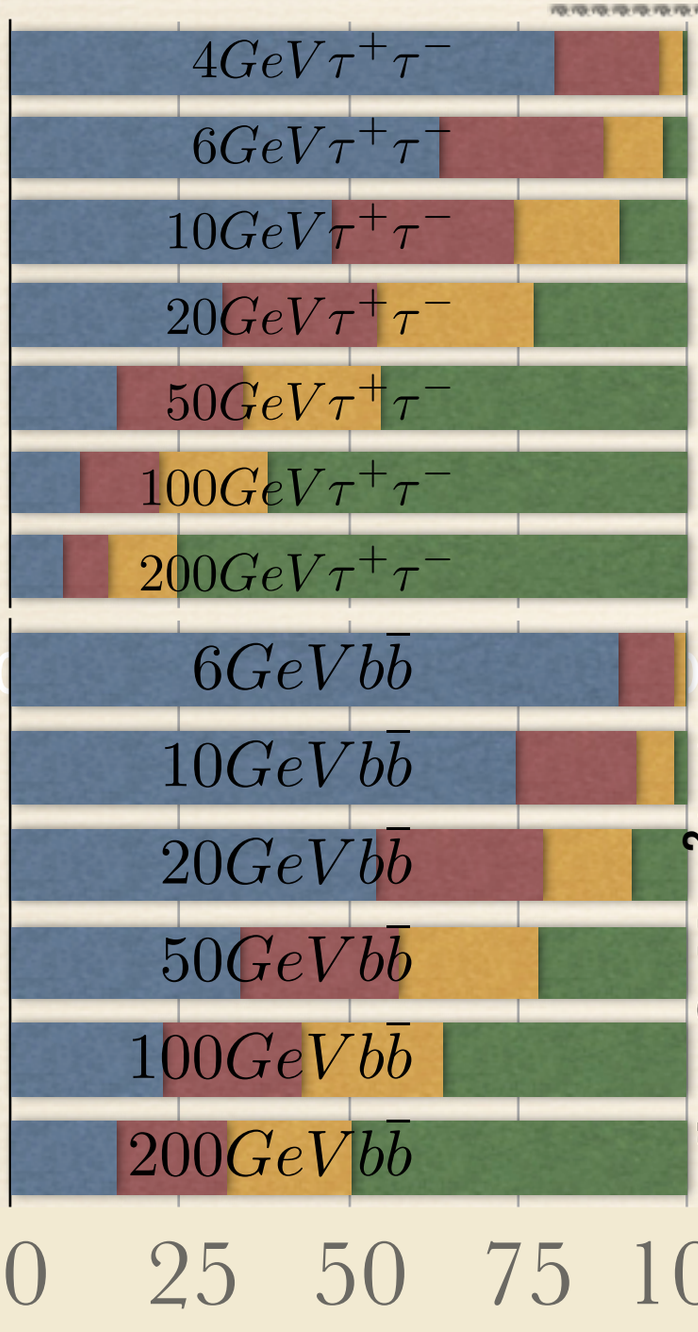
Super-K Atmospheric ν Samples



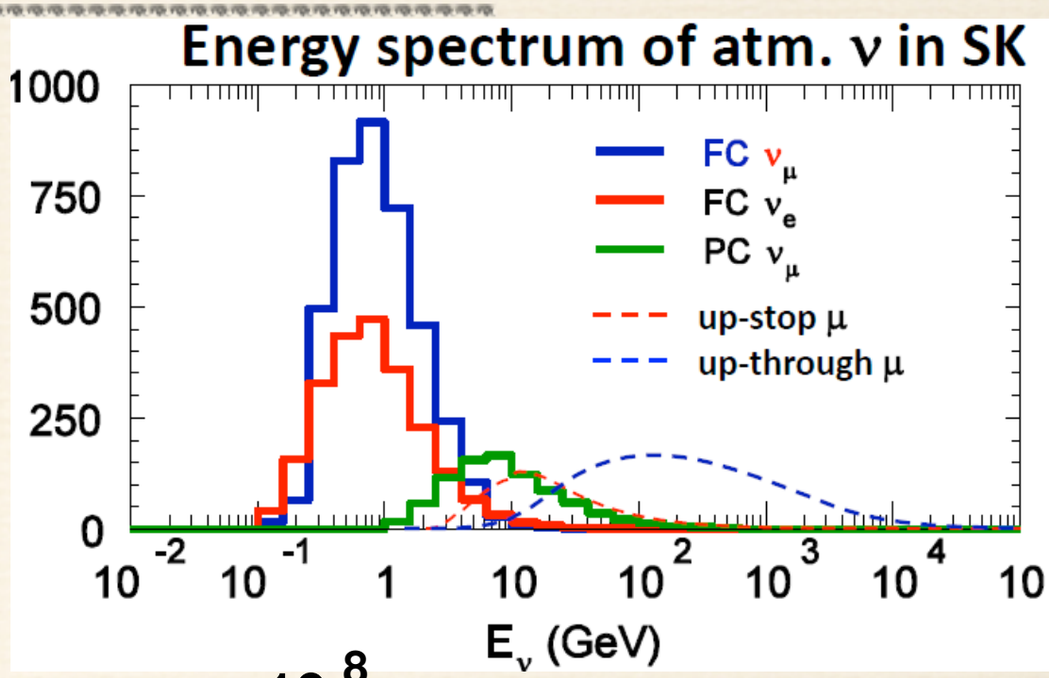
- sample divided by momentum, PID, #of tracks
- only FC events have measured energy
- only multi-GeV events have well-measured ν dir. & E
- PC and up-μ are always muons (good dir. but no E)

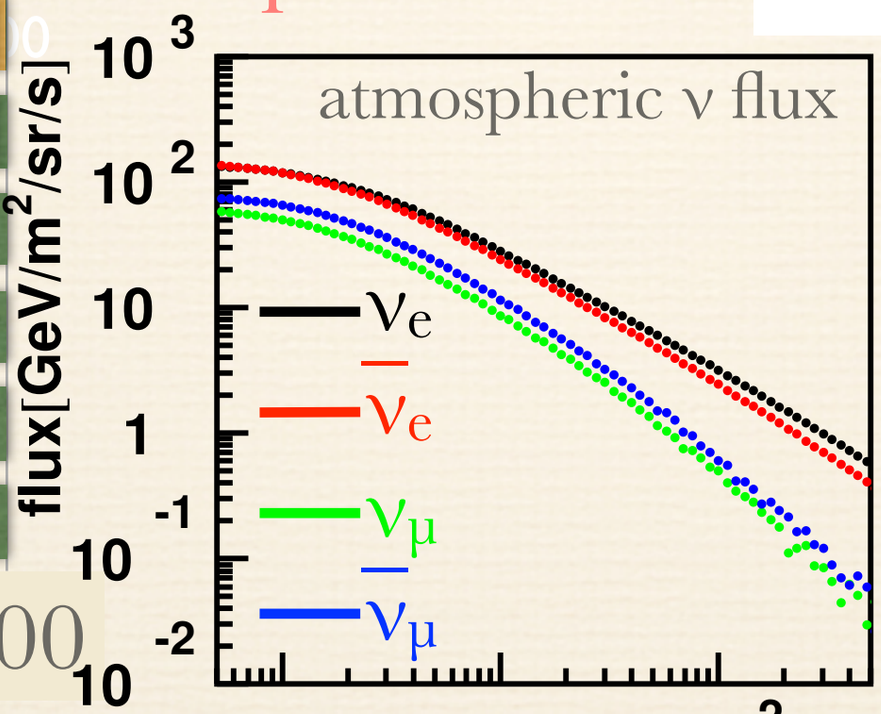


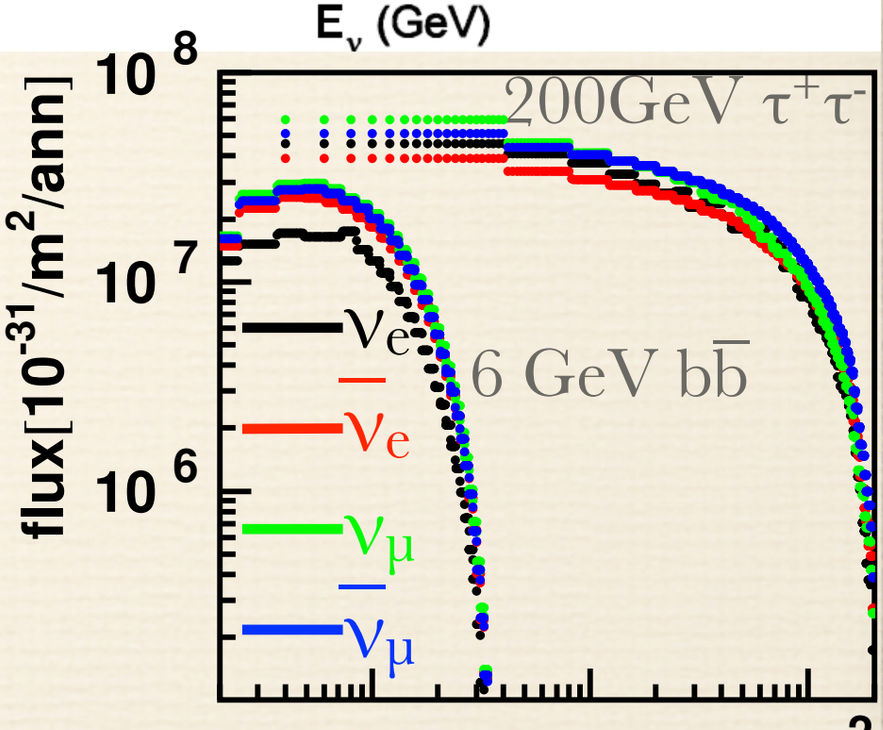
Atmospheric and WIMP ν Spectrum



➠ For low mass (<10GeV), most of the WIMP signal goes to contained samples: FC+PC

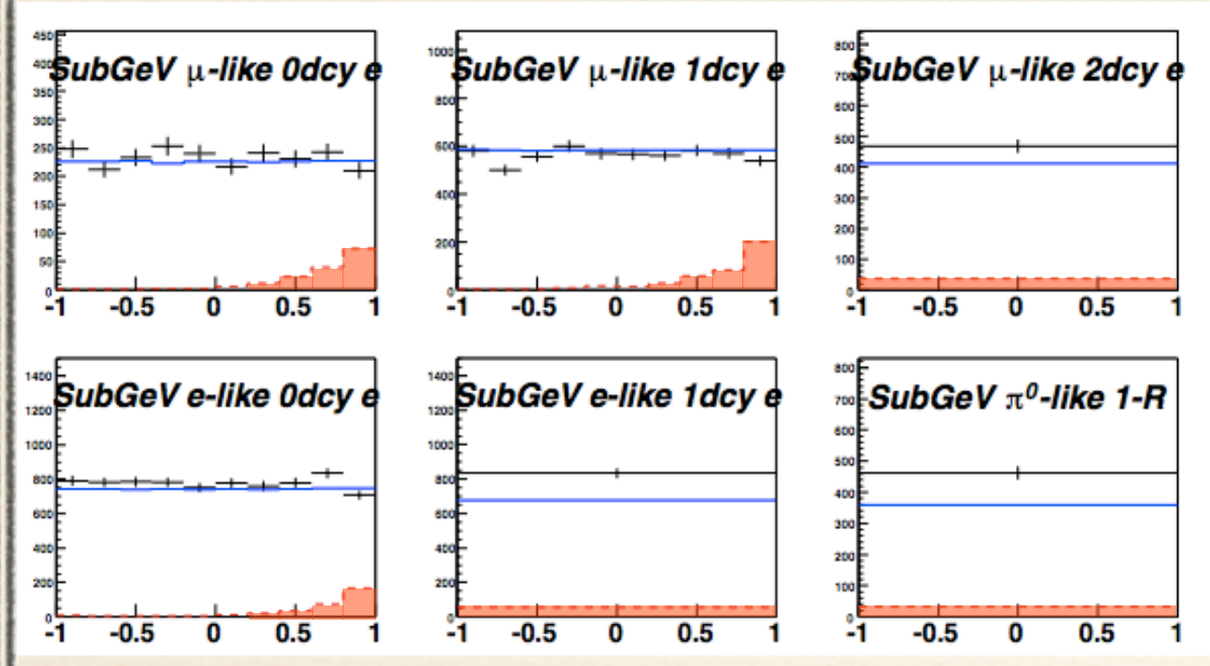


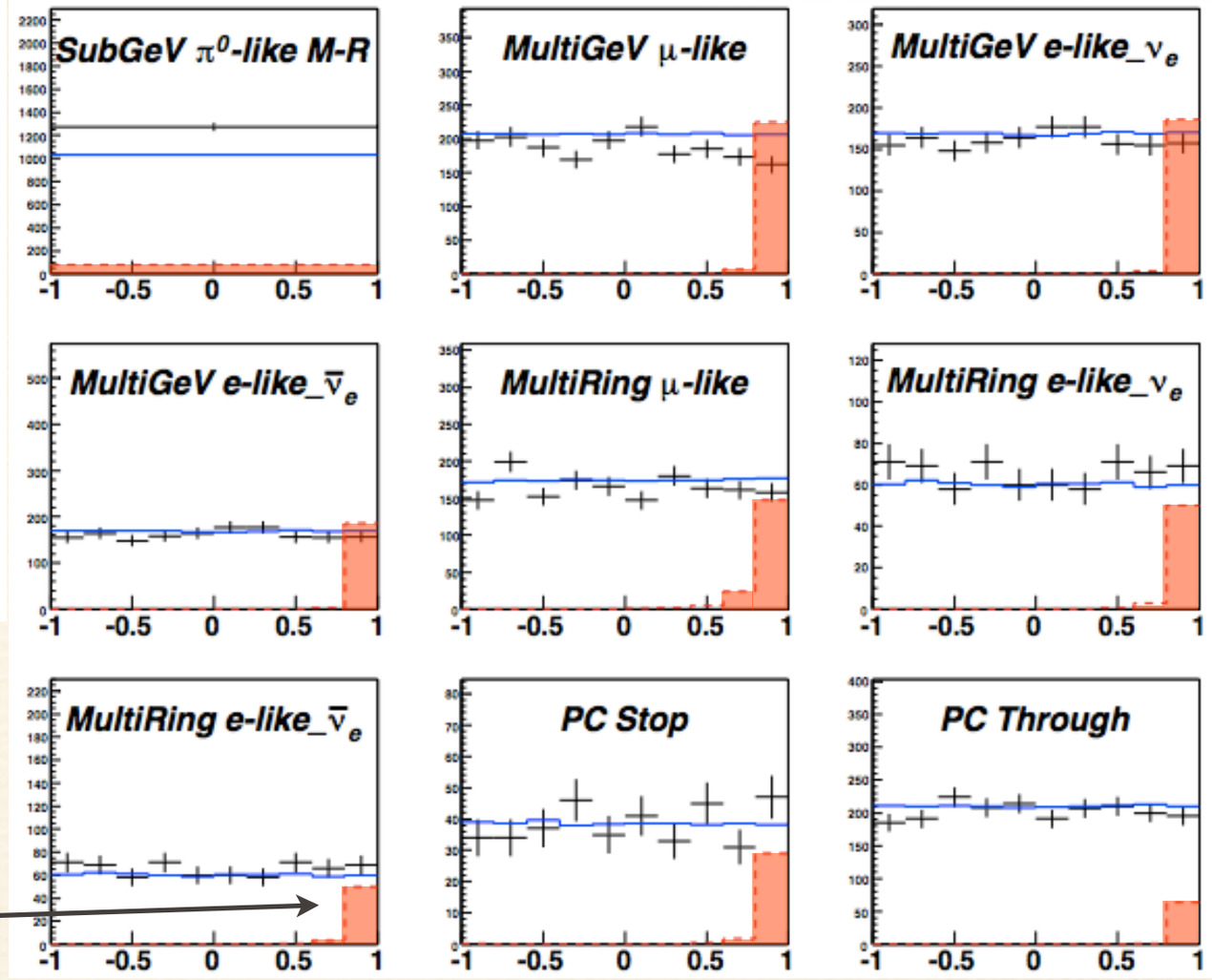




Courtesy K. Choi, Nagoya University

Atmospheric Neutrino Data (3903d)





- χ^2 fit in 684 bins using energy, angle & flavor
- WIMP ν parameter

$$\chi^2 = 2\Sigma_{n=1}^{\#of\,bins}[N_n^{BG}(1+\Sigma_j f_j^n \varepsilon_j) + \beta N_n^{\chi}(1+\Sigma_k f_k^n \varepsilon_k) - N_n^{data} + N_n^{data} ln(\frac{N_n^{data}}{N_n^{BG}(1+\Sigma_j f_j^n \varepsilon_j)+\beta N_n^{\chi}(1+\Sigma_k f_k^n \varepsilon_k)})] + \Sigma_j(\frac{\varepsilon_j}{\sigma_j}) + \Sigma_k(\frac{\varepsilon_k}{\sigma_k})$$

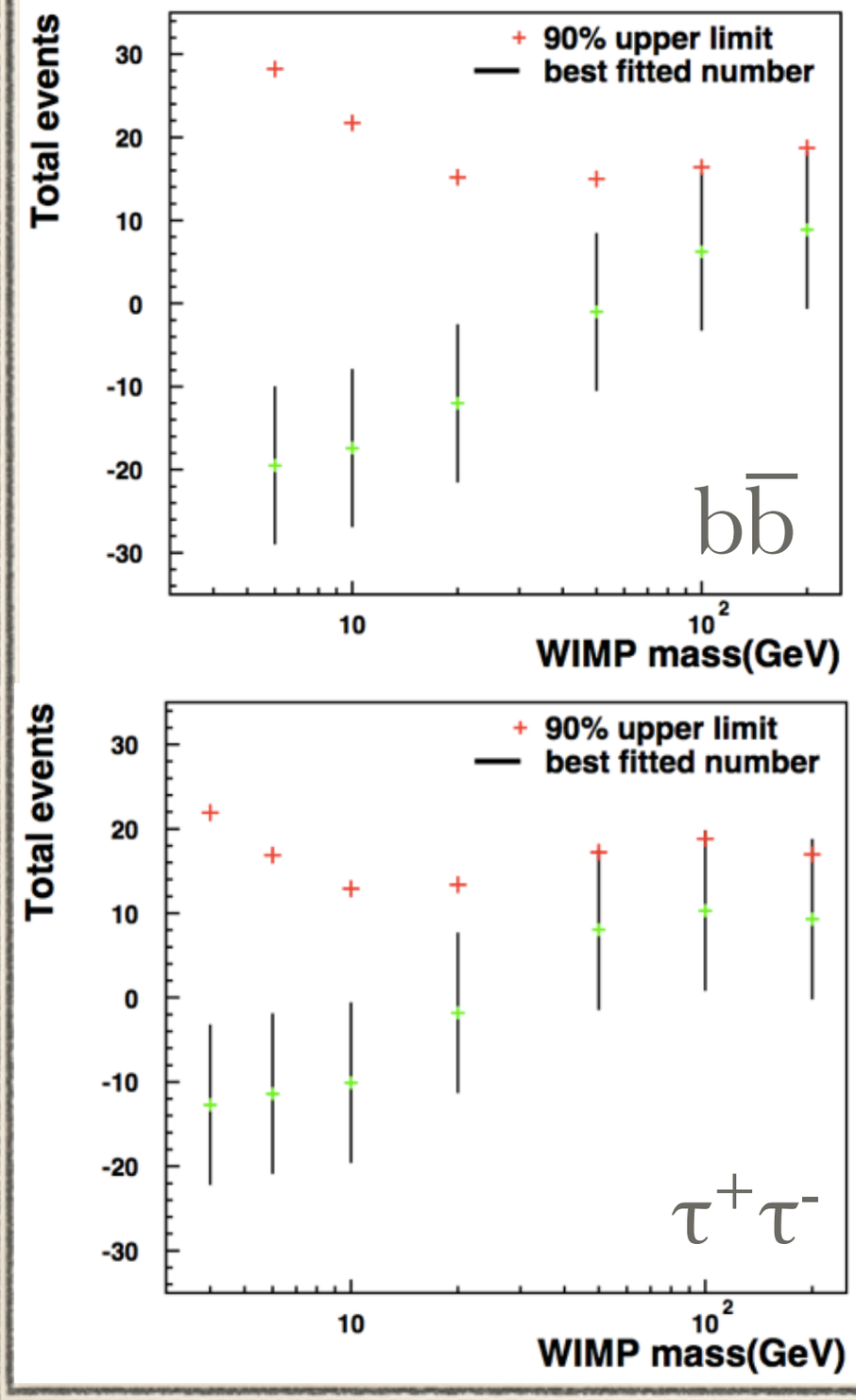
SK-I-IV Data

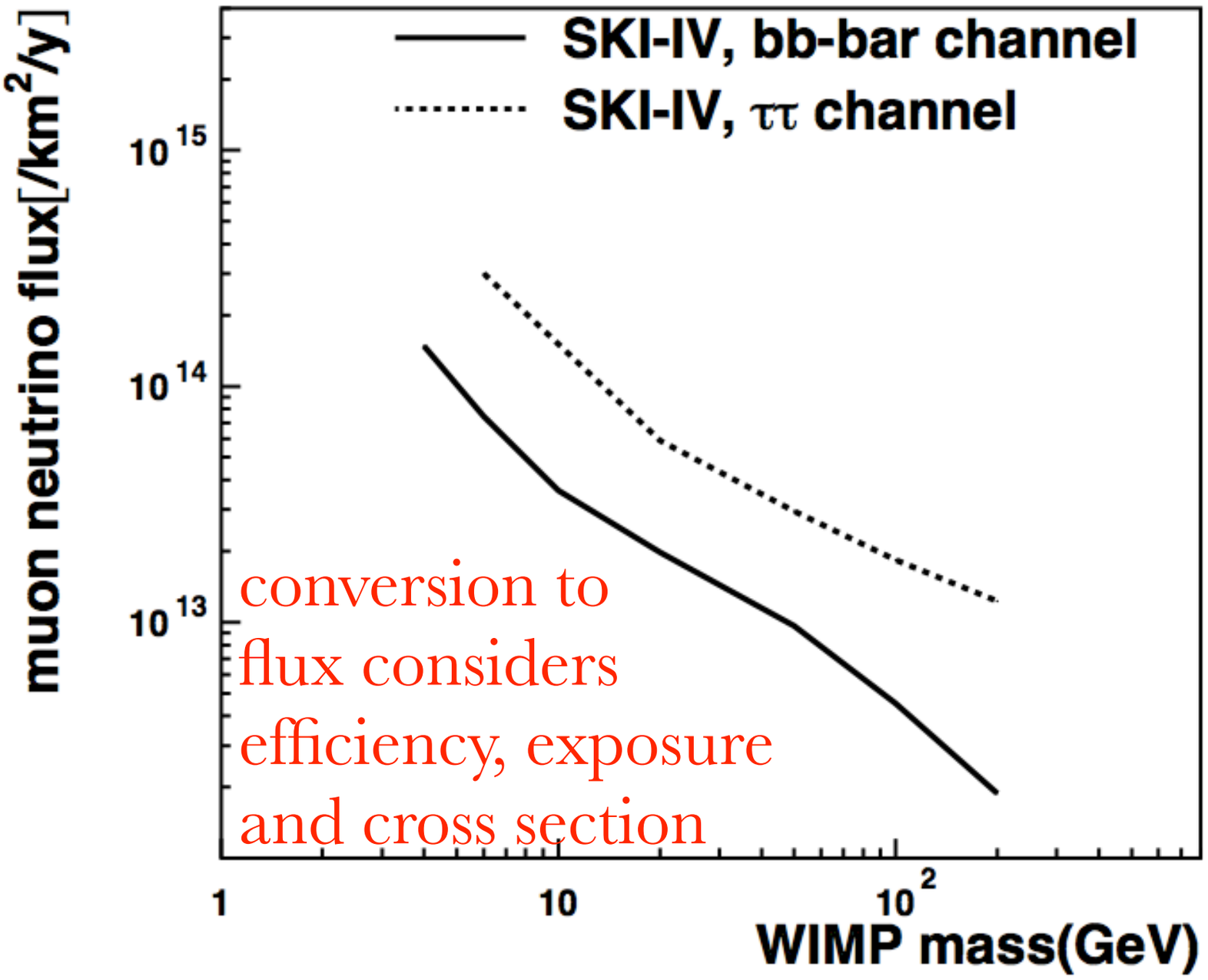
Atm. ν MC

10 GeV WIMPs (arbitrary norm.)

Courtesy K. Choi, Nagoya University

90% C.L. Bayesian Limits



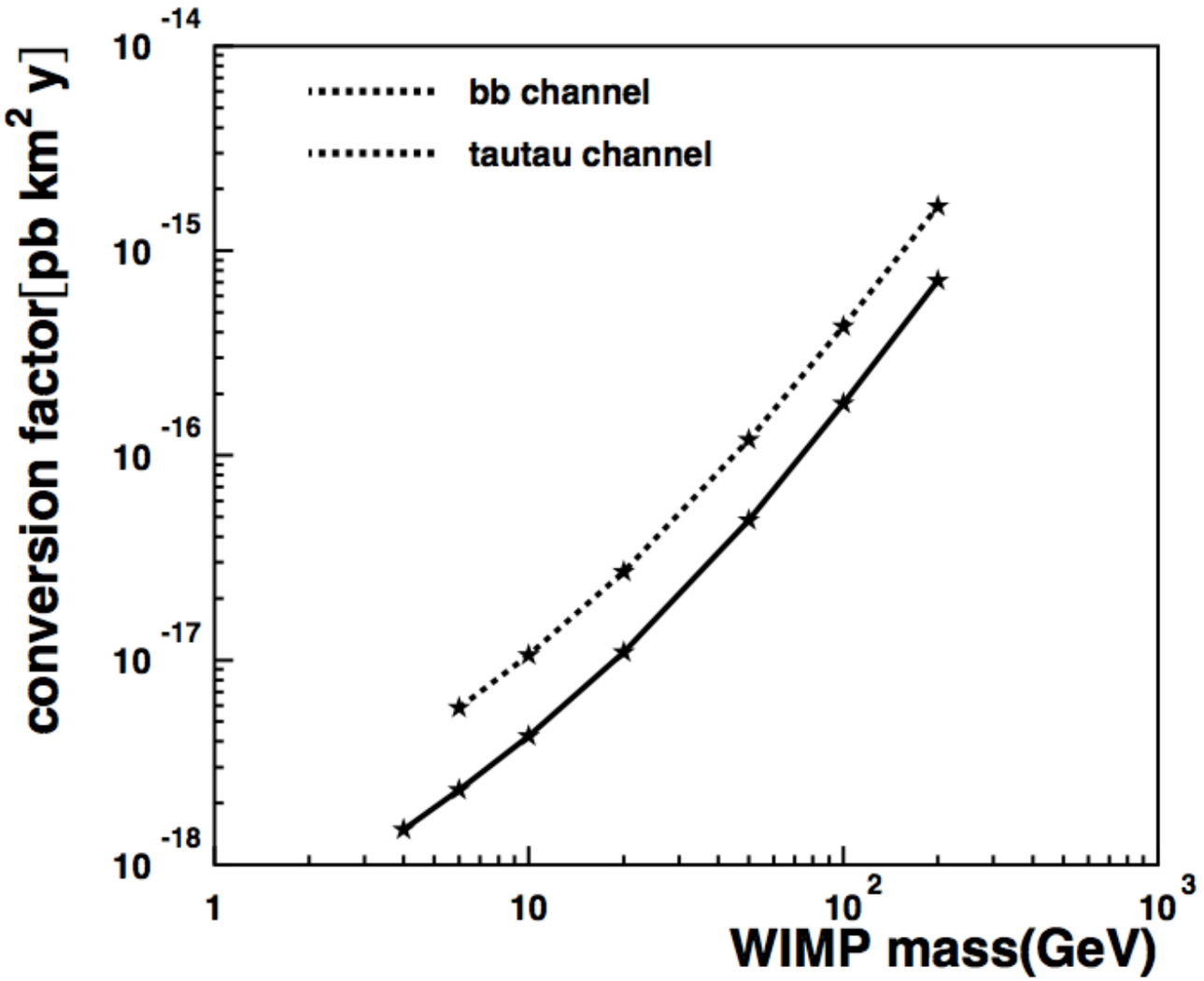


Courtesy K. Choi, Nagoya University

Neutrino Flux ➛ $\sigma_{\chi\text{-}p}$(SD)

calculated using DarkSusy:

- WIMP energy density: ρ=0.3GeV/cm^3
- circular solar v_{sun}=220km/sec; Maxwellian WIMP velocity with 3D dispersion v_d=270km/sec
- elastic scattering off nuclei; only axial vector coupling (SD)
- equilibrium between capture and annihilation
- evaporation negligible >~4GeV



Courtesy K. Choi, Nagoya University

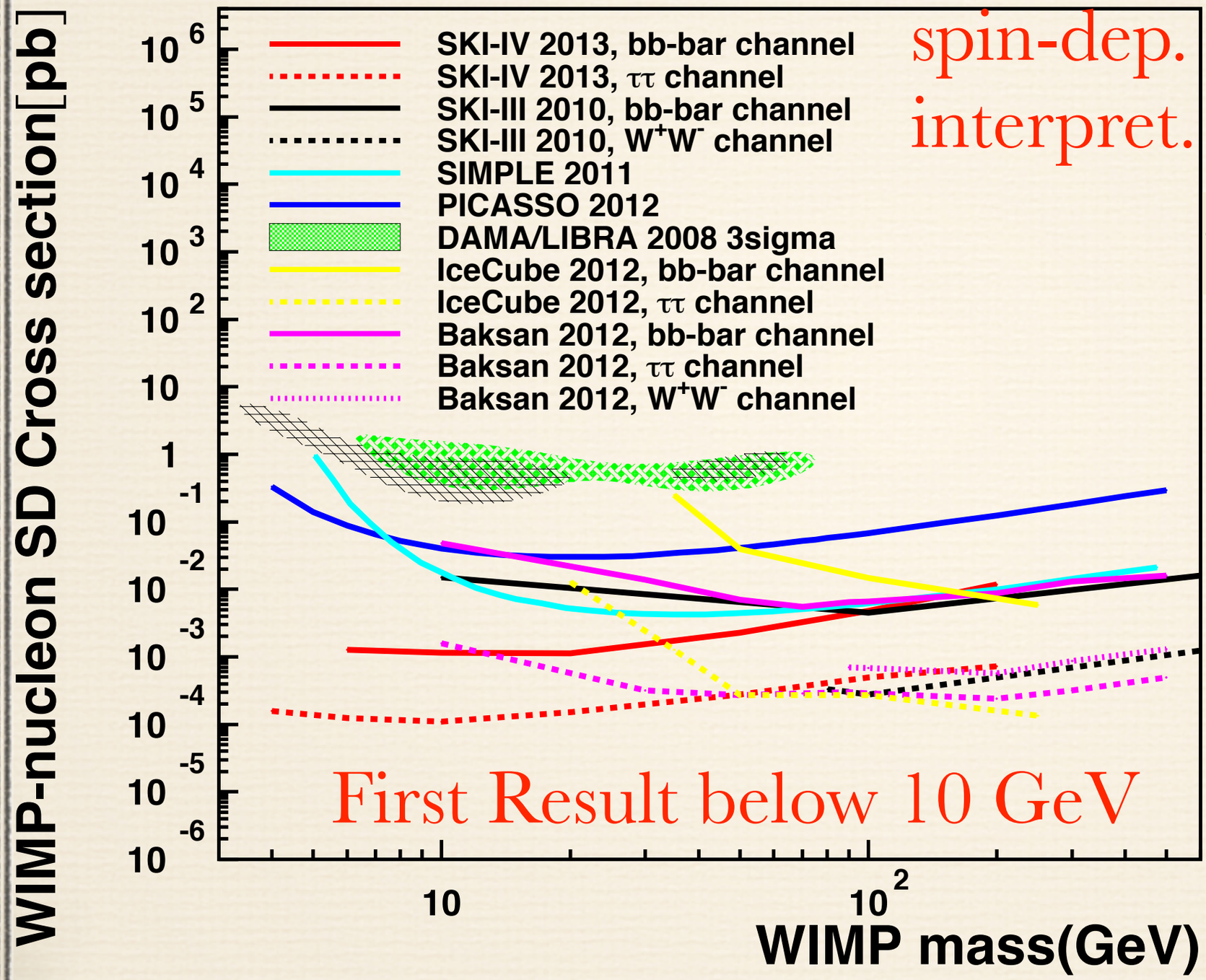
Systematics

fit systematics (don't affect results much):
neutrino oscillation parameters, atmospheric neutrino flux uncertainties, neutrino interaction, reconstruction, etc.

Capture:
total SD capture error<7%; larger for increasing WIMP mass (hydrogen has no form factor; solar model dependence is small since most of the sun is still hydrogen; negligible evaporation above 4 GeV; solar diffusion is negligible for low WIMP masses but rise to ~3% at 200 GeV)

SI sensitivity of solar WIMP search is surprisingly good

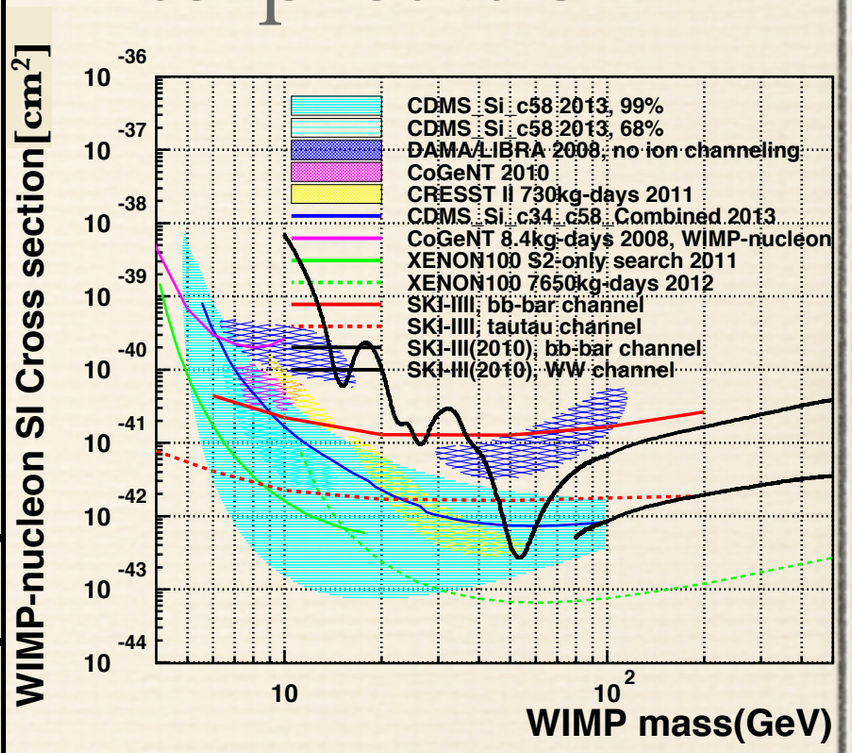
Limits and Comparison



spin-dep. interpret.

First Result below 10 GeV

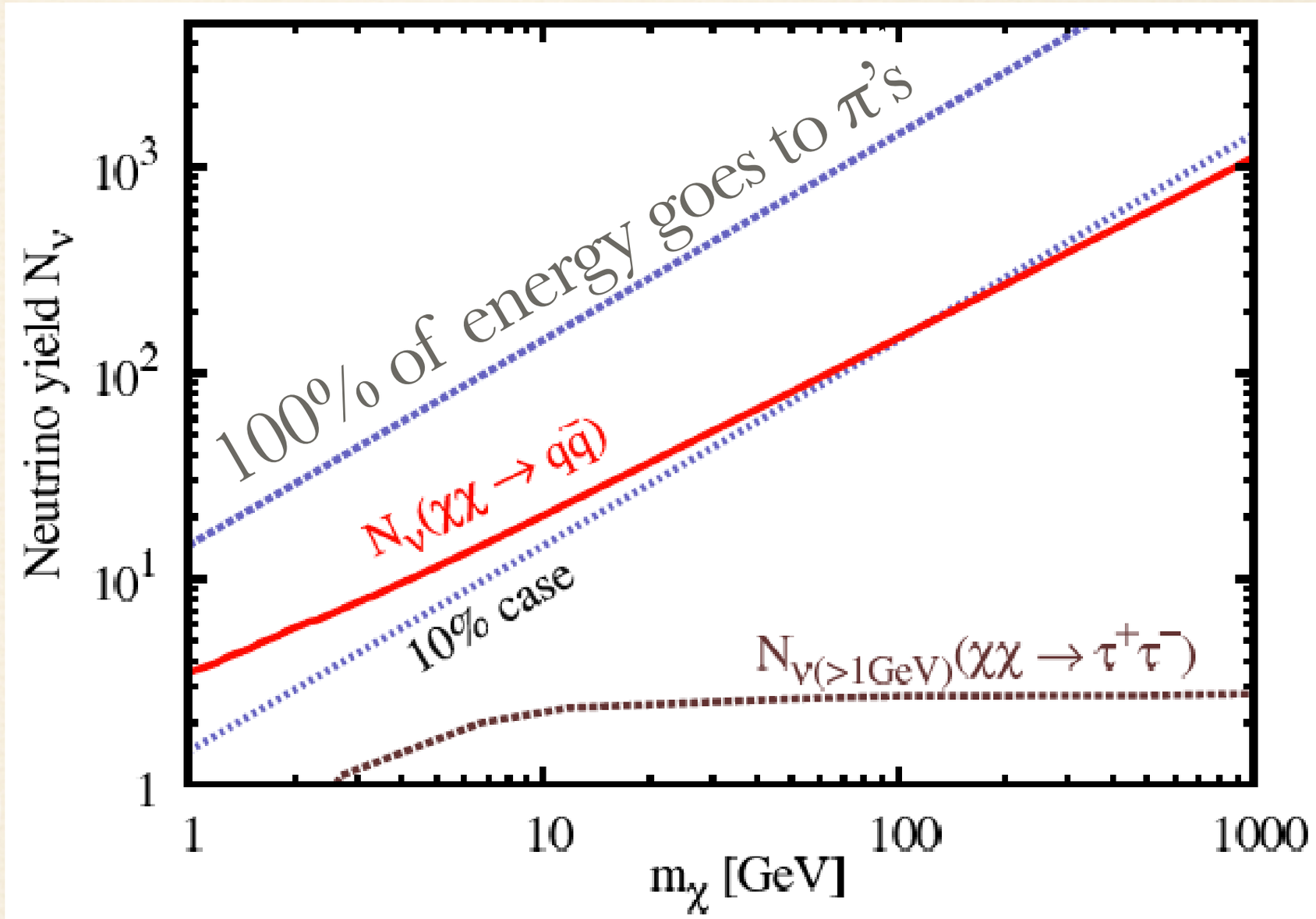
spin-independent interpretation



Courtesy K. Choi, Nagoya University

Light Quark Channels
(Rott, Siegal-Gaskins, Beacom)

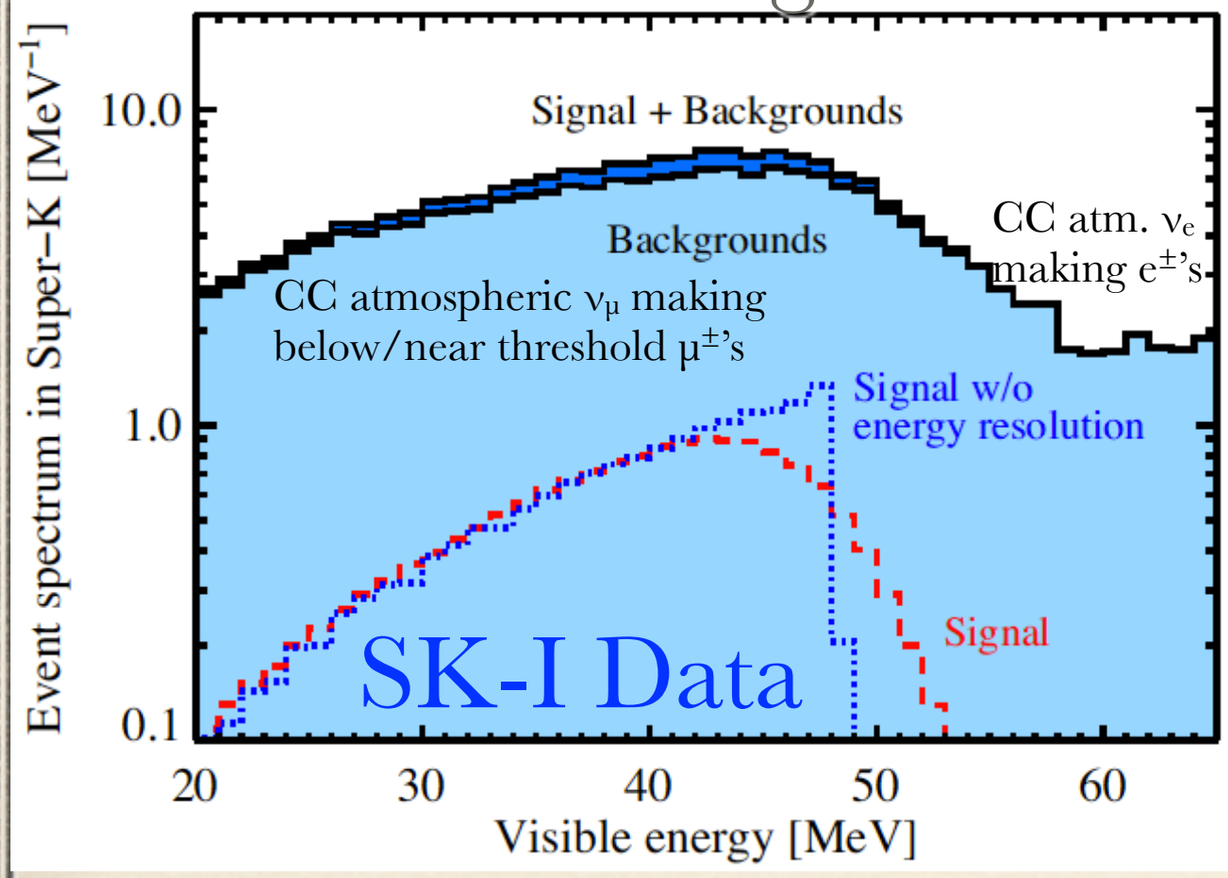
- quarks hadronize, make pions, stop them
- produce low energy $\bar{\nu}_e$'s: $\pi^+ \rightarrow \mu^+ \nu_\mu$; $\mu^+ \rightarrow e^+ \bar{\nu}_\mu \nu_e$; $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ ($P \sim 1/6$)
- $\bar{\nu}_e p \rightarrow e^+ n$

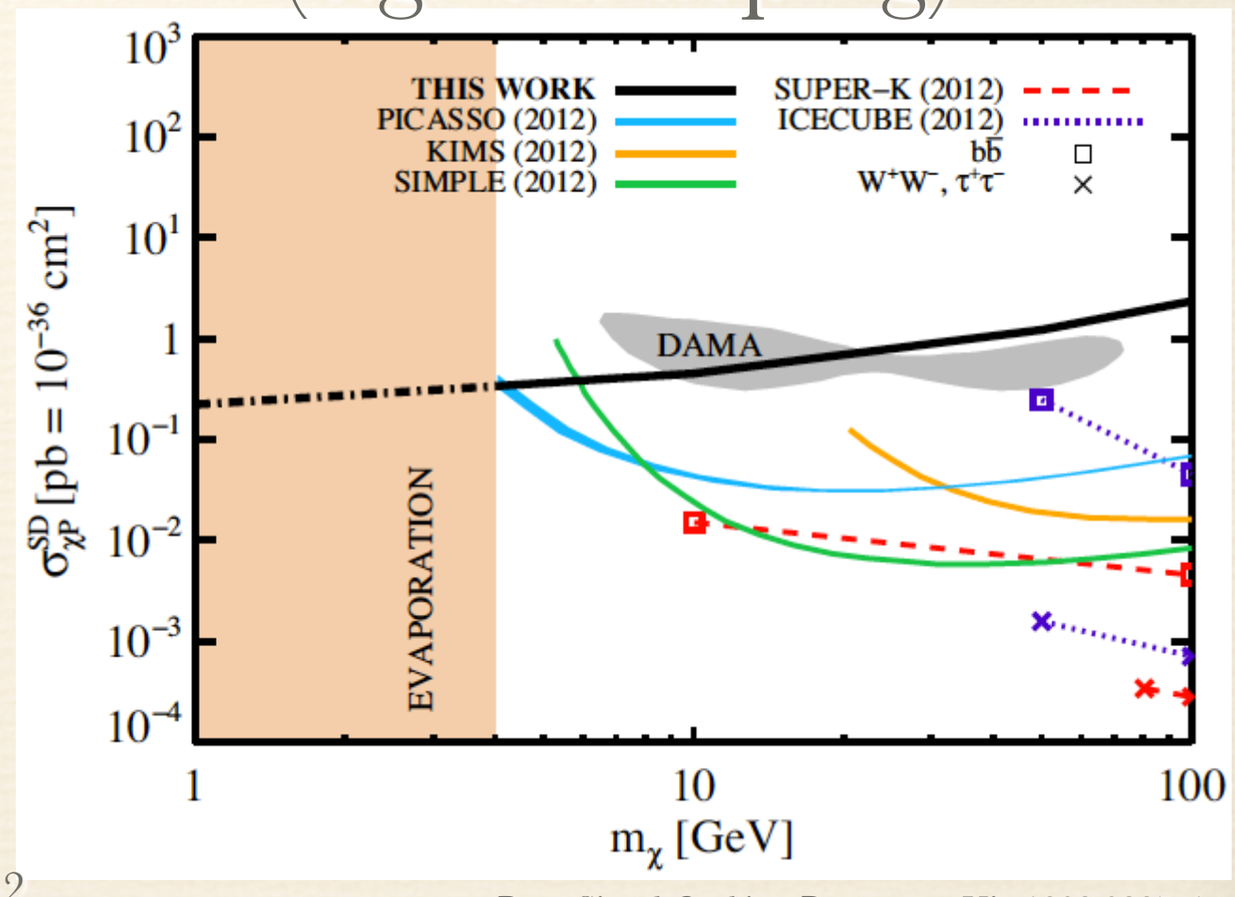


Rott, Siegal-Gaskins, Beacom: arXiv 1208.0827v1

Light Quark Channels
(Rott, Siegal-Gaskins, Beacom)

- less stringent than $b\bar{b}$, $\tau^+\tau$-
- less dependency on annihilation channel
- needs background reduction (e.g. Gd doping)

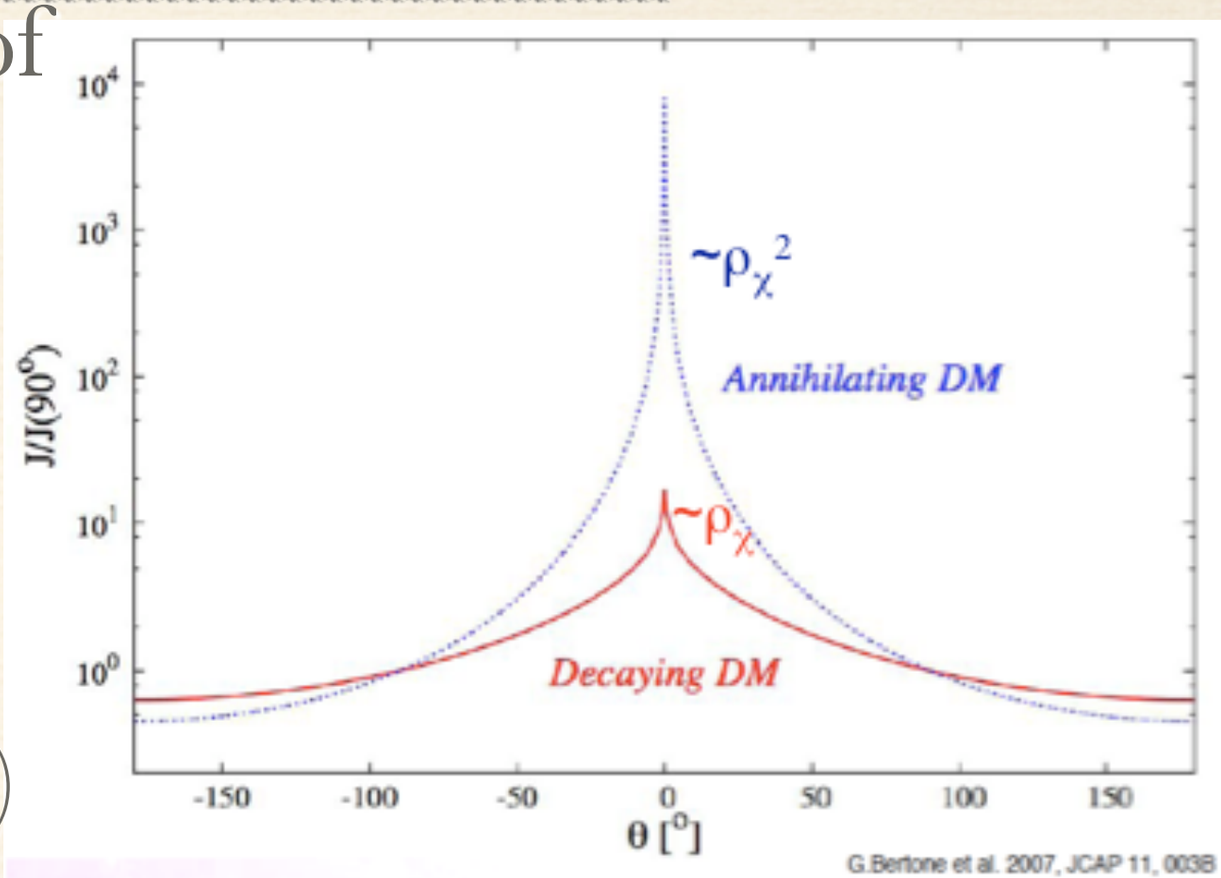




Rott, Siegal-Gaskins, Beacom: arXiv 1208.0827v1

Search for Annihilation in Galactic Halo

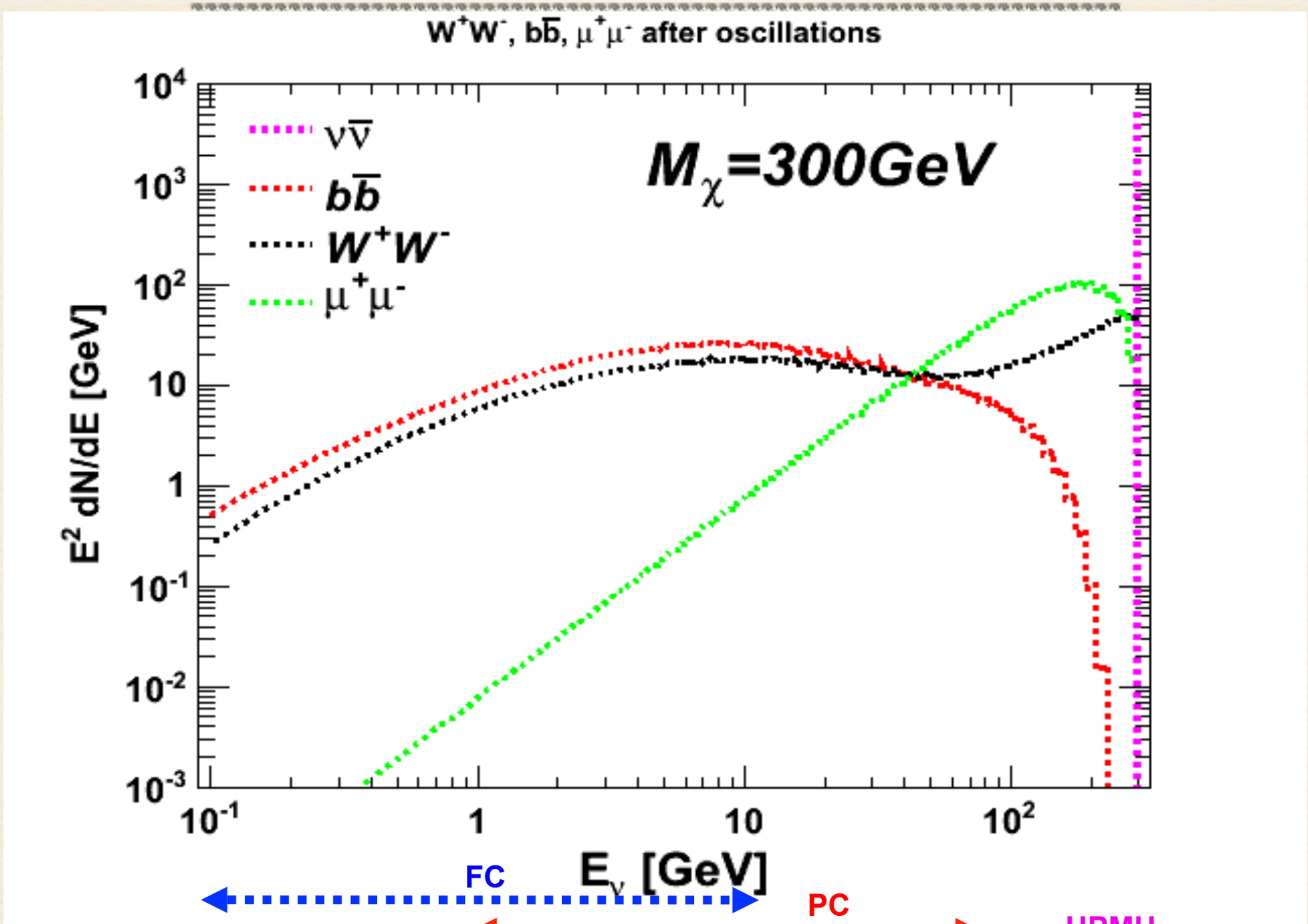
- related to positron excess of AMS/PAMELA/FERMI (hot topic)
- signal strongly peaked @ galactic center
- GC duty cycle ~71% (upμ) and 100% (FC/PC)
- assume 100% annihilation to one single fermion pair
- $\cos\theta_{sun} \rightarrow \cos\theta_{GC}$



G.Bertone et al. 2007, JCAP 11, 003B

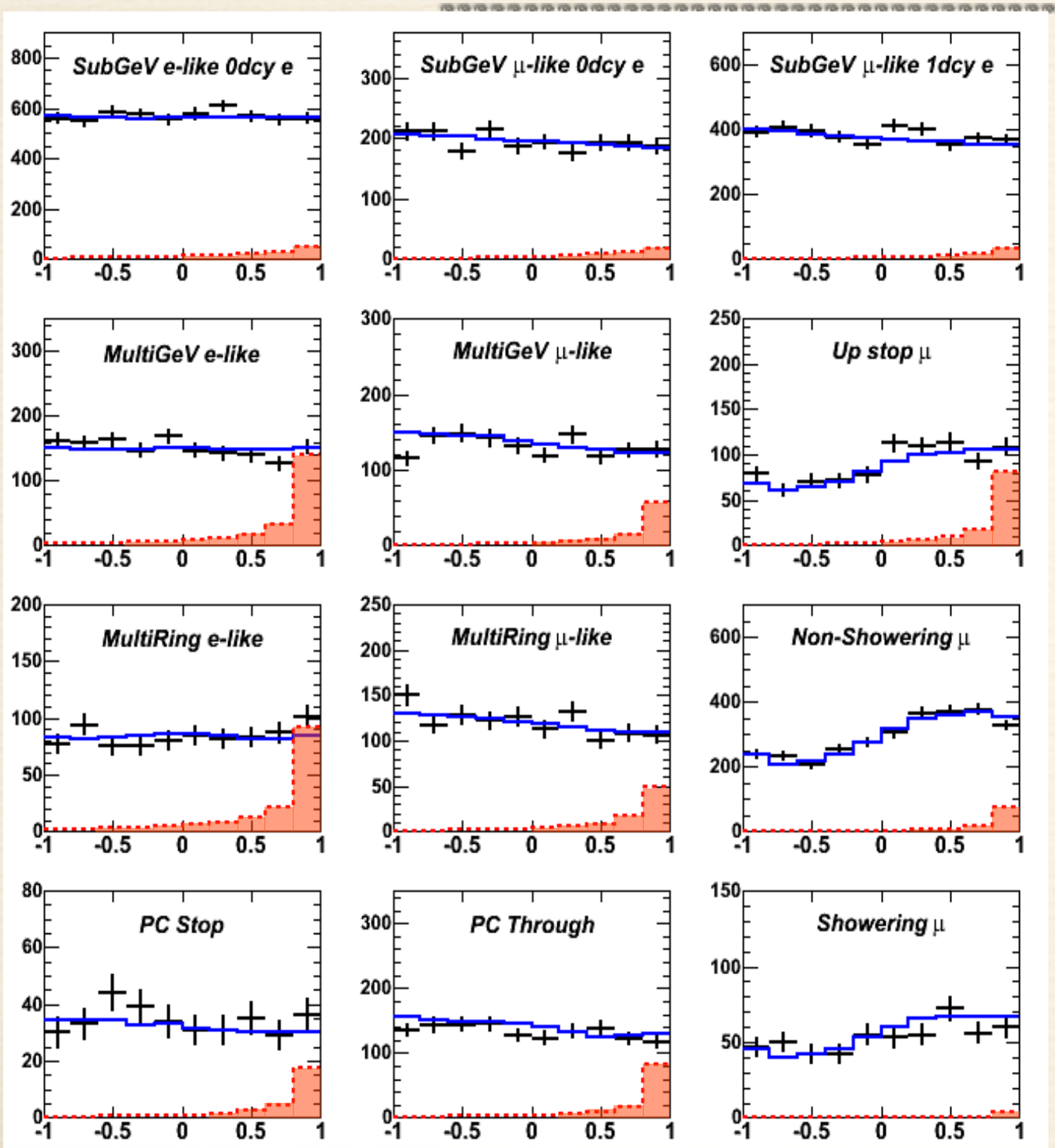
- fit atmospheric ν samples with a DM component for each channel
- place limit on $\langle\sigma_A v\rangle$

Neutrino Spectrum from DM



Courtesy P. Mijakowski, National Centre for Nuclear Research (Warsaw, Poland)

Search for Annihilation in Galactic Halo



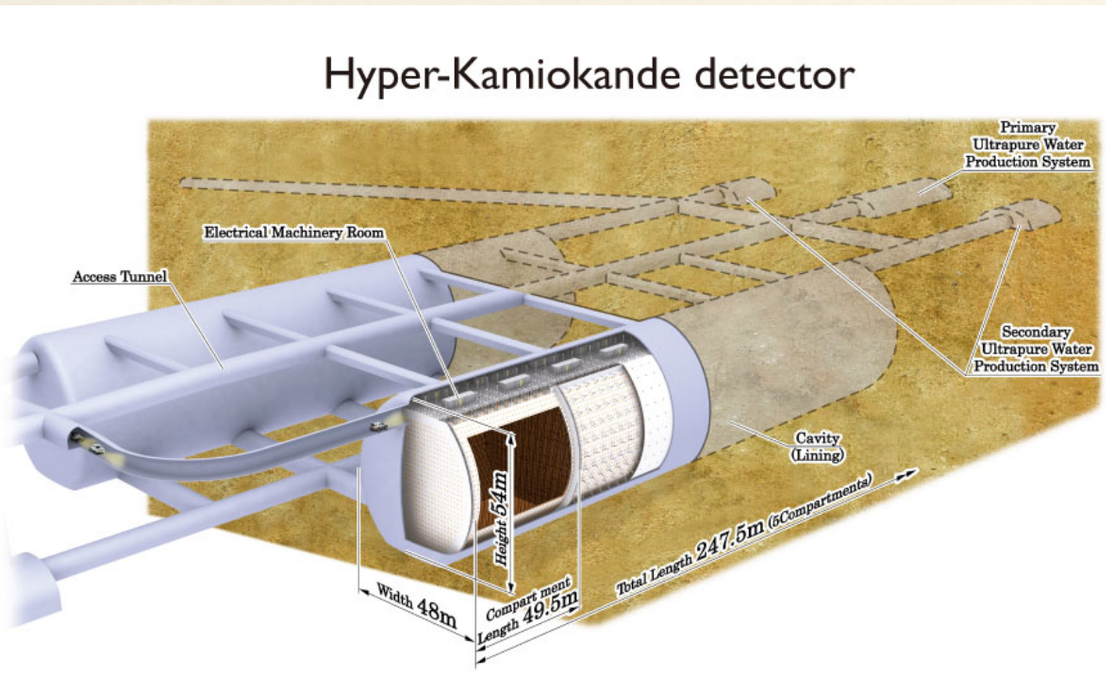
- $b\bar{b}$ channel shown
- 100 GeV WIMPs shown
- no significant excess seen
- WIMP ν flux is the same in each flavor
- currently updating to SK-IV
- stay tuned for published limits!

SK-I-III Data
Atm. ν MC
100 GeV WIMPs (arbitrary norm.)

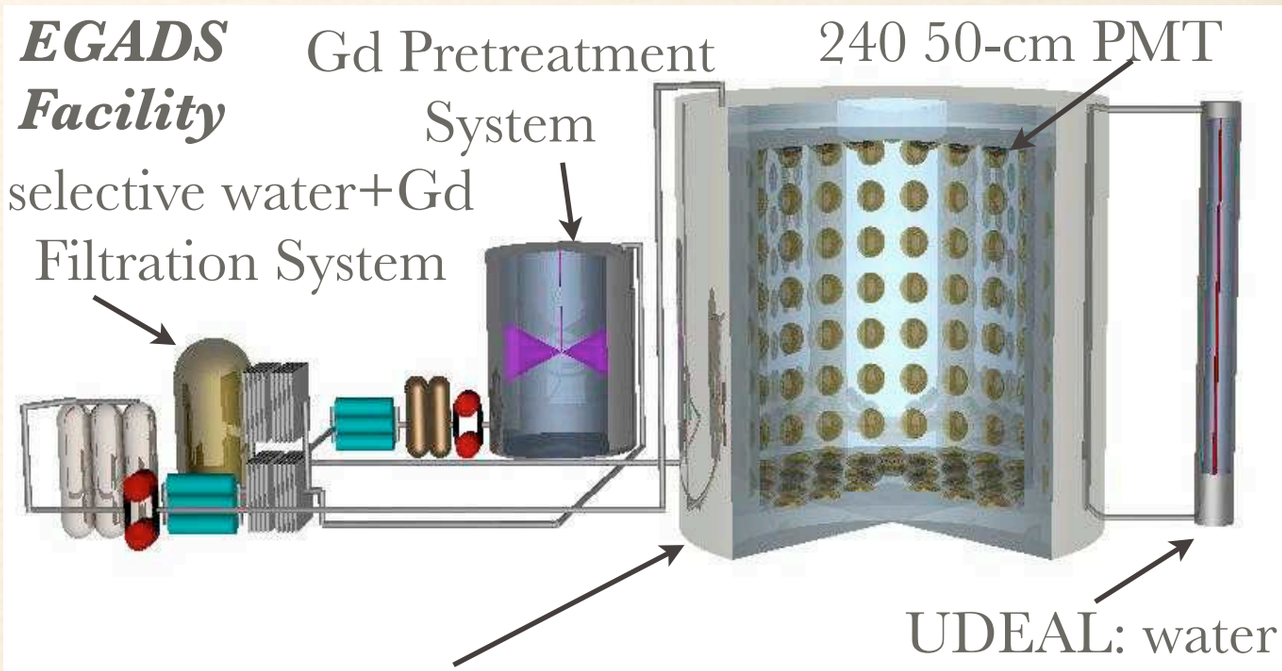
Courtesy P. Mijakowski,
National Centre for Nuclear Research (Warsaw, Poland)

Future of this Analysis

- analysis has backgrounds, so it improves with square root of exposure
- Hyper-K: expect at least ~factor of five improvement
- HK: add. improvement from containment of larger energy deposits
- perhaps improvement from n tagging using Gd doping (light quarks)



Michael Smy, UC Irvine



Courtesy A. Kibayashi Okayama University

Conclusions

- in spite of a detector mass far below ICECUBE, Super-K WIMP searches remain interesting, especially in the low mass region
- search for solar WIMPs, terrestrial WIMPs (update of 2004 result will come soon!), and annihilation in the galactic center/halo