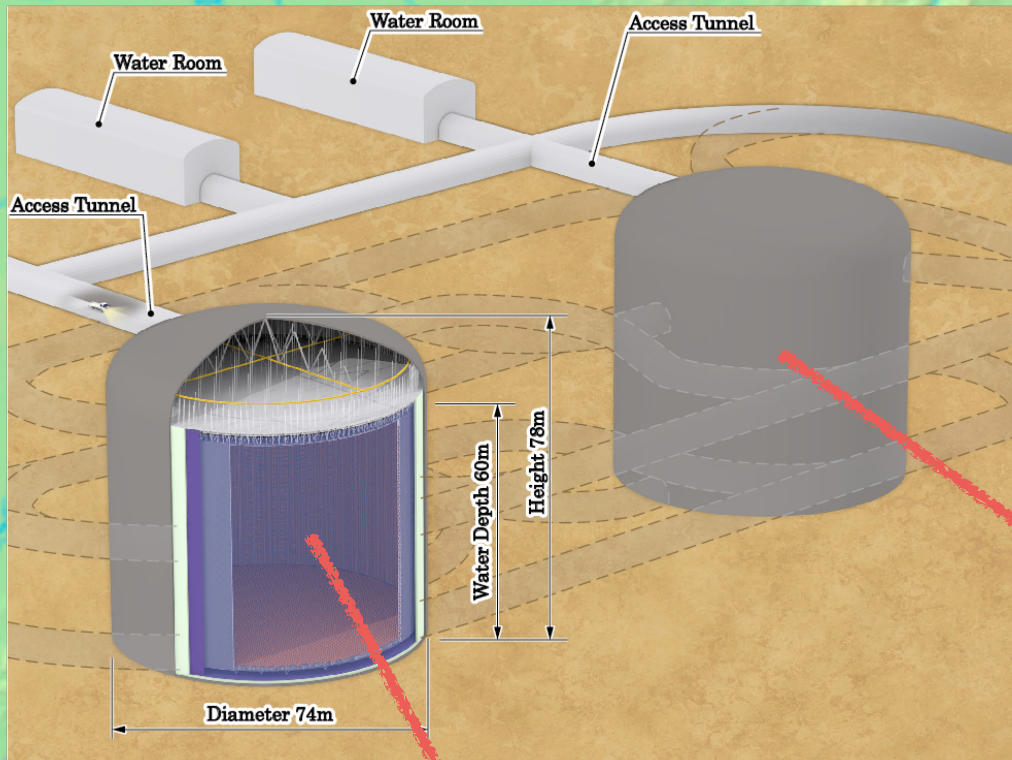


Carsten Rott

Sungkyunkwan University, Korea
rott@skku.edu

Feb 16, 2017

Thanks to Akimichi Taketa (ERI, Tokyo)

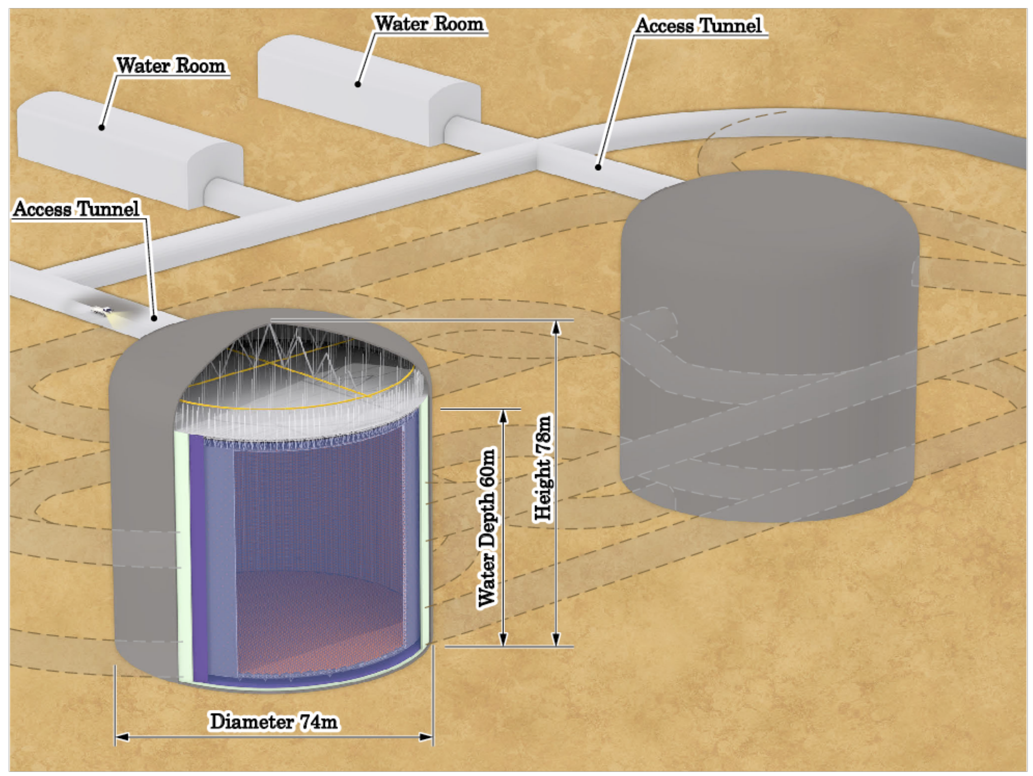
T2HKK Meeting Kashiwa 2017

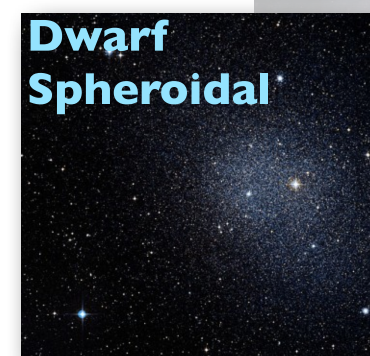
Overview

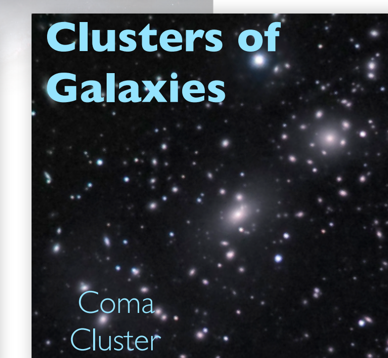
- Motivation
- Dark Matter Search
  - Benefits for T2HKK
- Neutrino Geophysics
  - Benefits for T2HKK
- Discussions and Conclusions

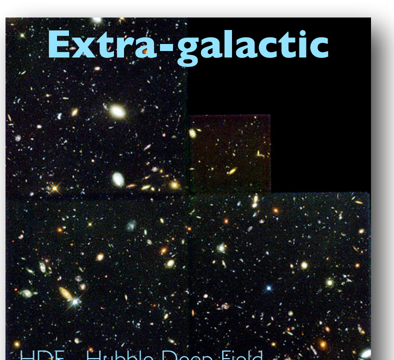
Dark Matter Searches with Neutrinos

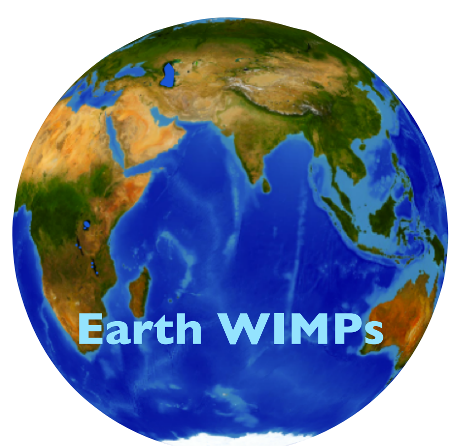
Dark Matter Signals at Hyper-K









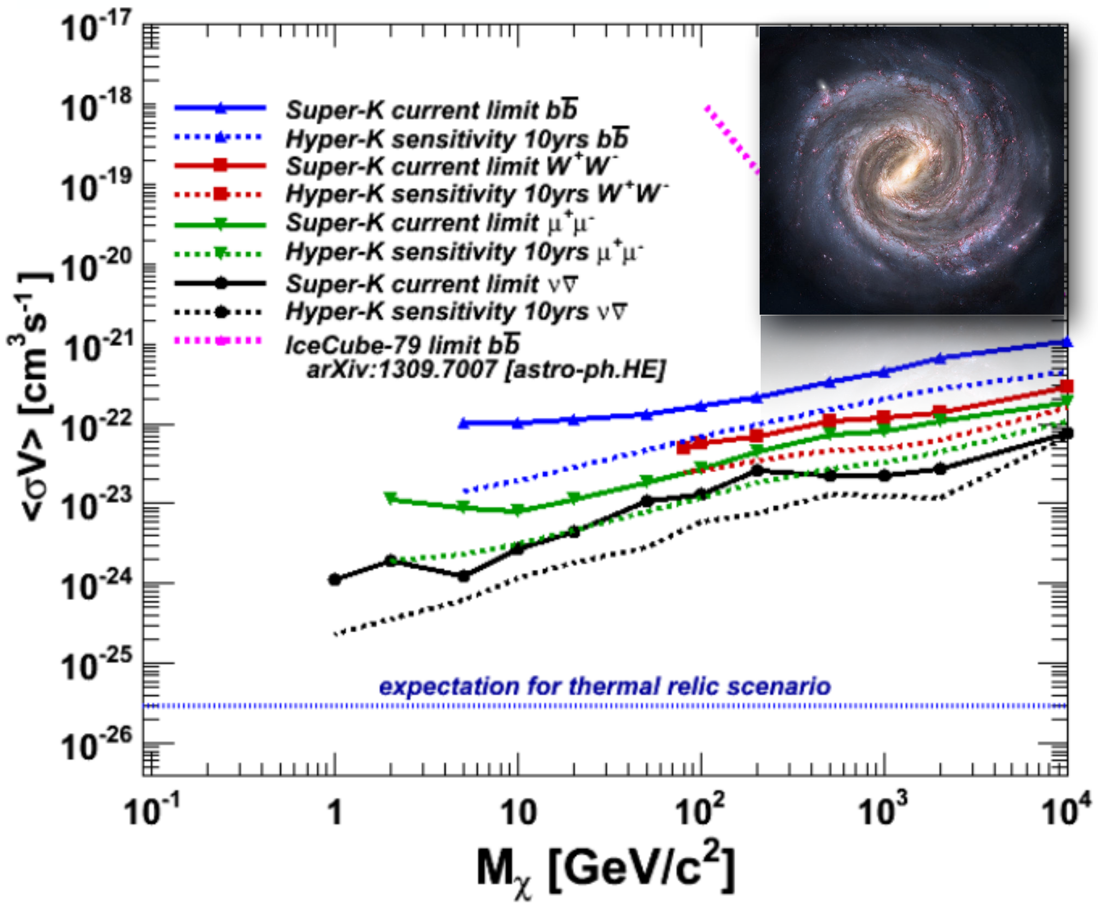


Dark Matter Sensitivities for Hyper-K

Super-K bounds / Hyper-K Sensitivity

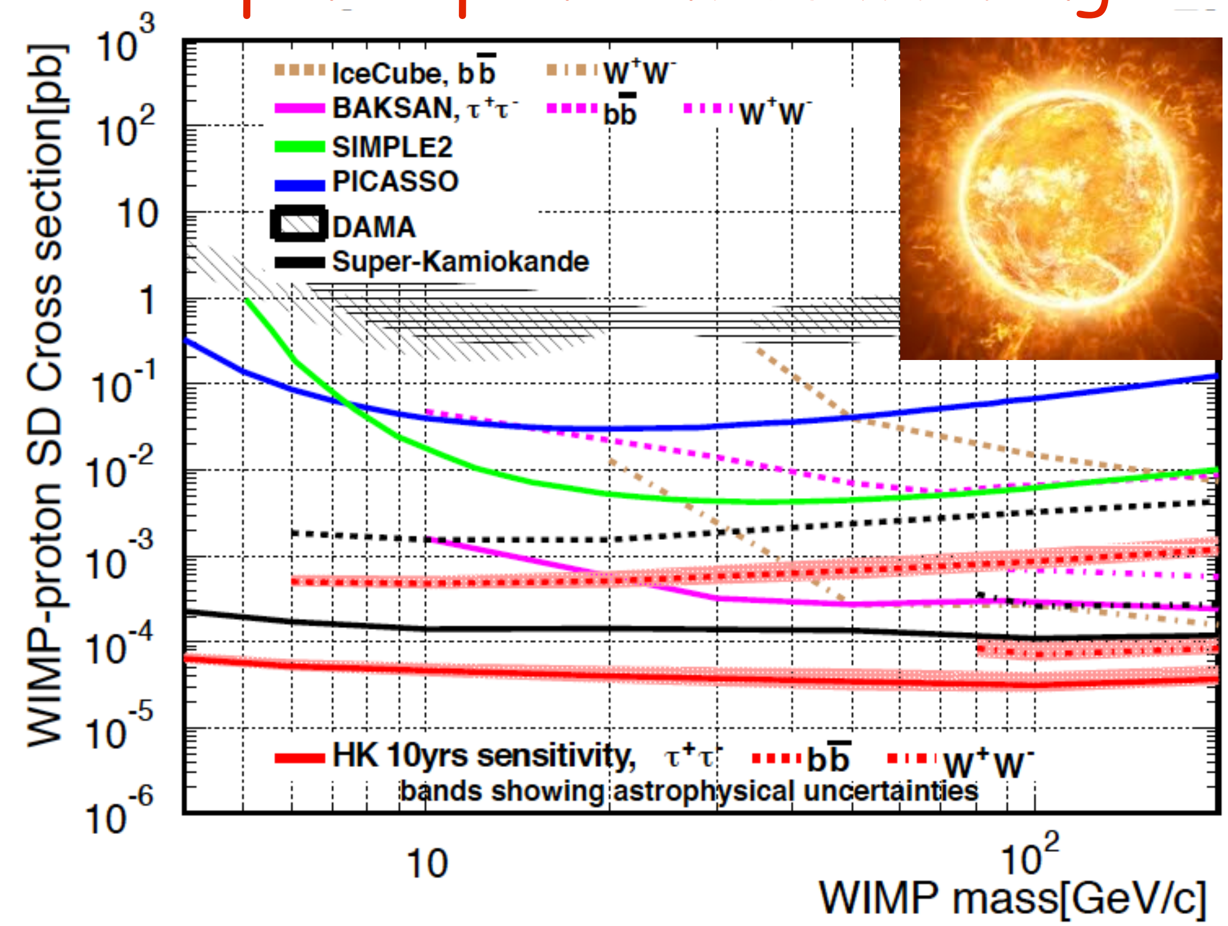
Galactic Halo

Self-annihilation cross section



Solar Dark Matter

Spin-dependent scattering



- Main background atmospheric neutrinos
  - Benefits for Korean Neutrino Detector
    - Reduced systematic uncertainties on atm. neutrino background (but already same / off-source method)
    - Improved detector acceptance uncertainty with two detectors ?
    - Potential to increase effective volume, relaxed fiducial cut at deeper site ?

Neutrinos from stopped meson decay in the Sun

Low-Energy Neutrinos from the Sun

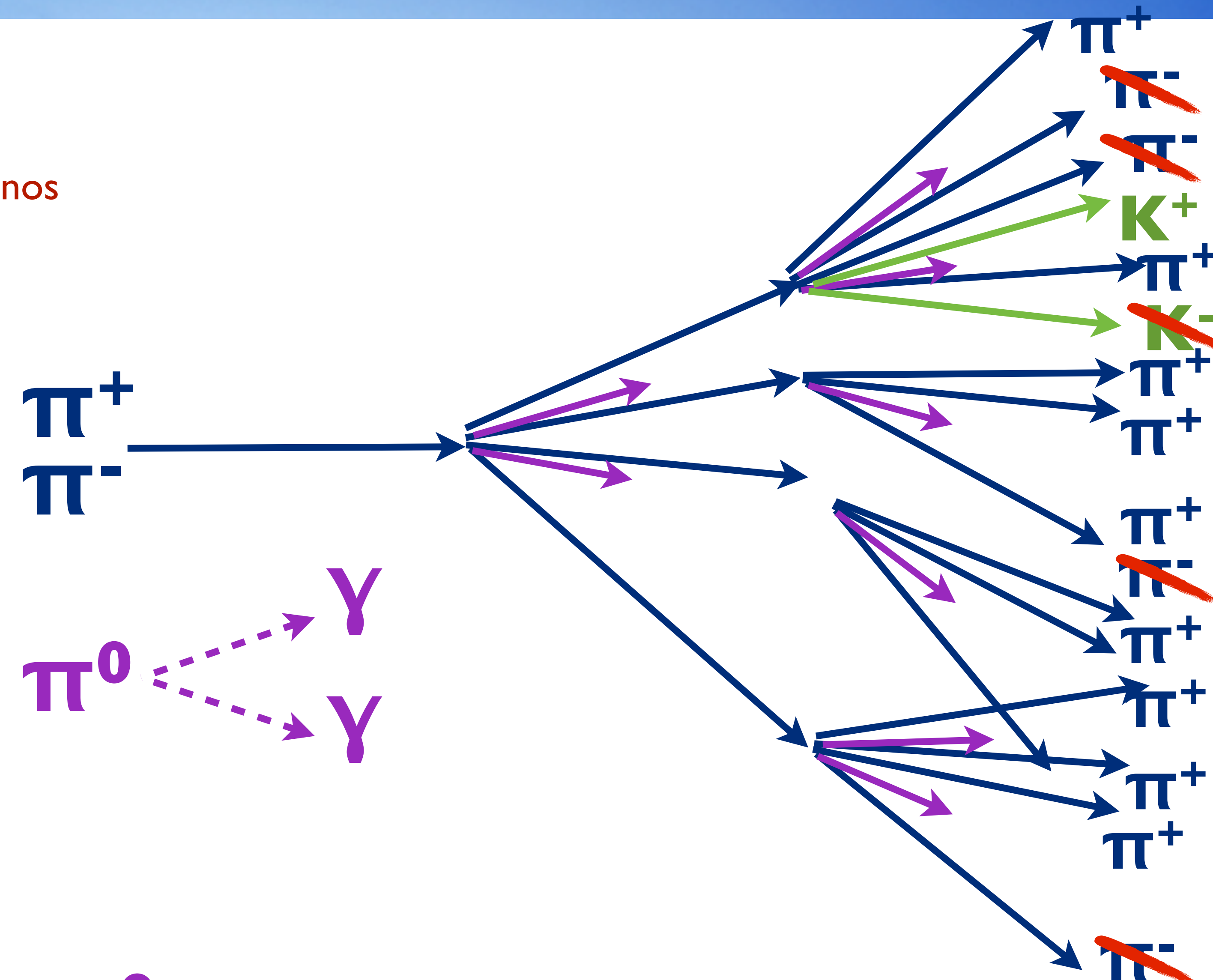
Possible annihilation channels:

$q\bar{q}, gg, c\bar{c}, s\bar{s}, b\bar{b}, t\bar{t}, W^+W^-, ZZ, \tau^+\tau^-, \mu^+\mu^-, \nu\bar{\nu}, e^+e^-, \gamma\gamma$

few neutrinos

some "high energy" neutrinos in decays
⇒ basis of present day searches

dominant decay into hadrons



Charged pions and kaons decay at rest producing mono-energetic neutrinos

$\pi^+ \rightarrow \mu^+ \nu_\mu$ $E_\nu =$ 29.8MeV

$K^+ \rightarrow \nu_\mu \mu^+$ $E_\nu =$235.5MeV

$\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$

π^0

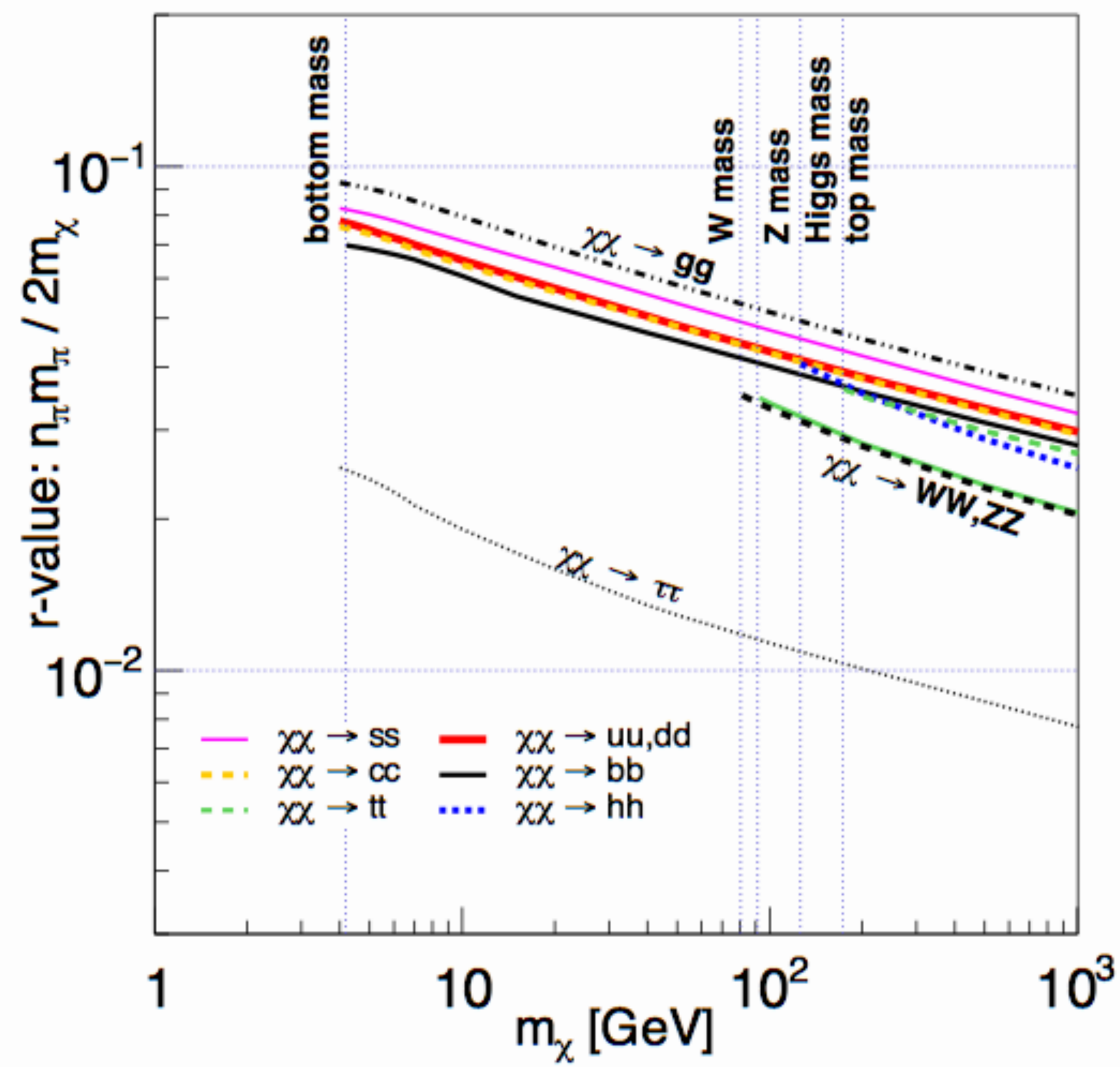
- Lifetime too short to interact

π^-

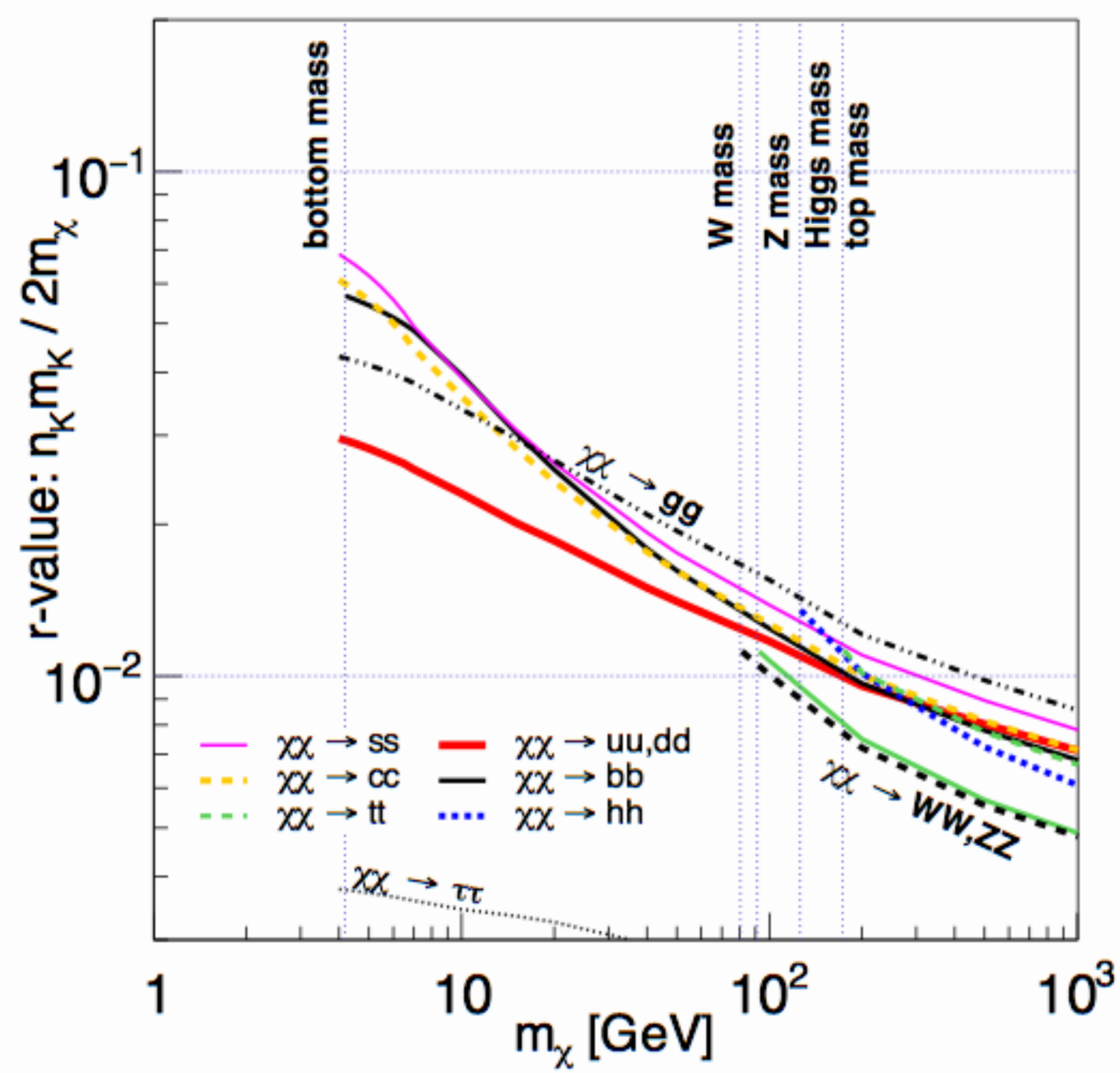
- Interaction length short compared to losses
- Produces secondary particles in collision with protons
- Dominant energy loss term is π^0 production

Pion and Kaon yields

π^+ r-value - fraction of center-of-mass energy which goes into π^+



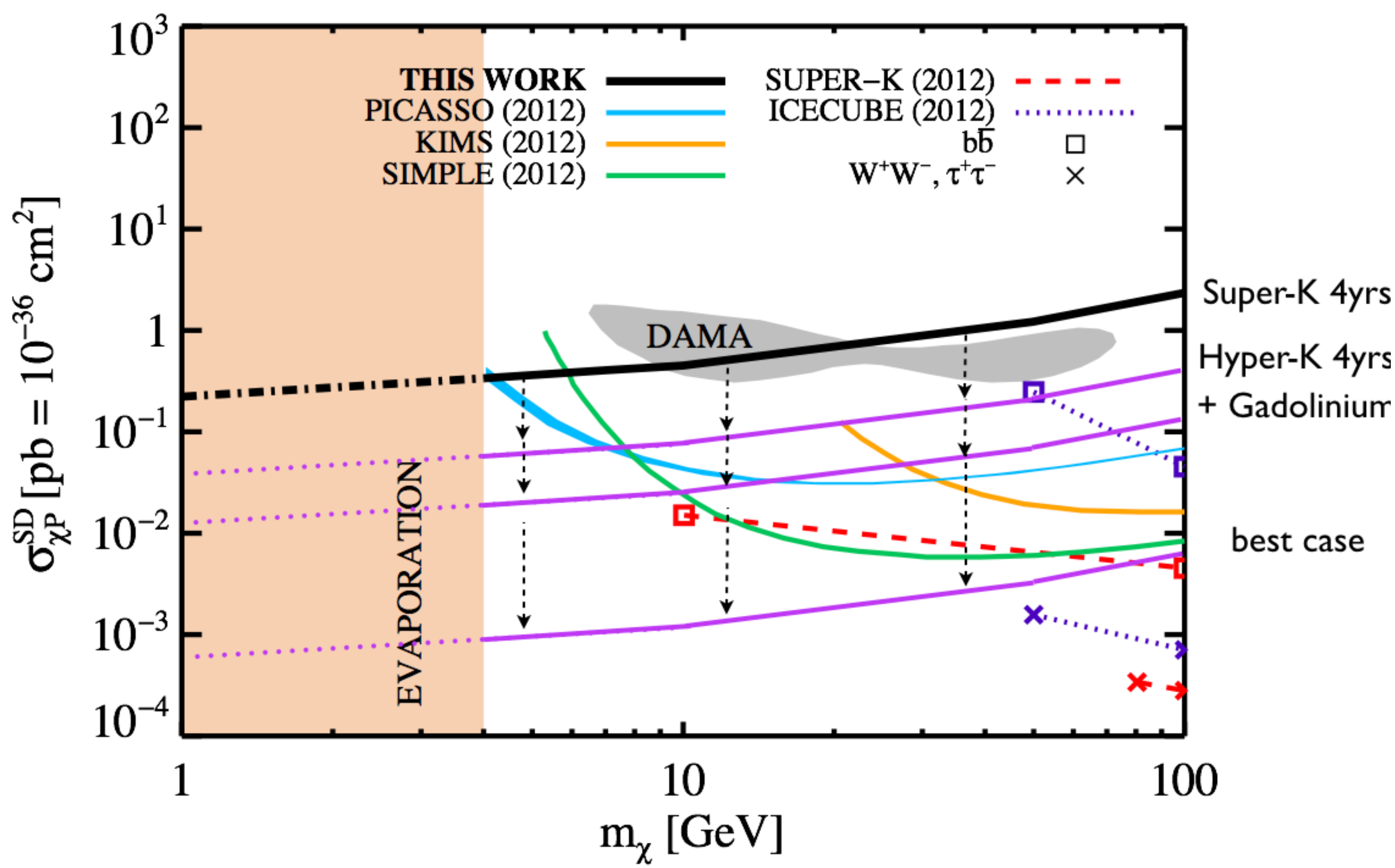
K^+ r-value - fraction of center-of-mass energy which goes into K^+



For low dark matter masses difference between flux from stopped pion and kaon decay at rest can be used to disentangle annihilation final states

Sensitivity Super-K/Hyper-K

C. Rott, J. Siegal-Gaskins, J.F.Beacom Physical Review D 88, 055005 (2013) (arXiv1208.0827)



Hope we can replicate this with full Super-K / Hyper-K simulation

Previous searches relied on high energy neutrinos directly from the decays of annihilation products

Model the full hadronic shower in the Sun

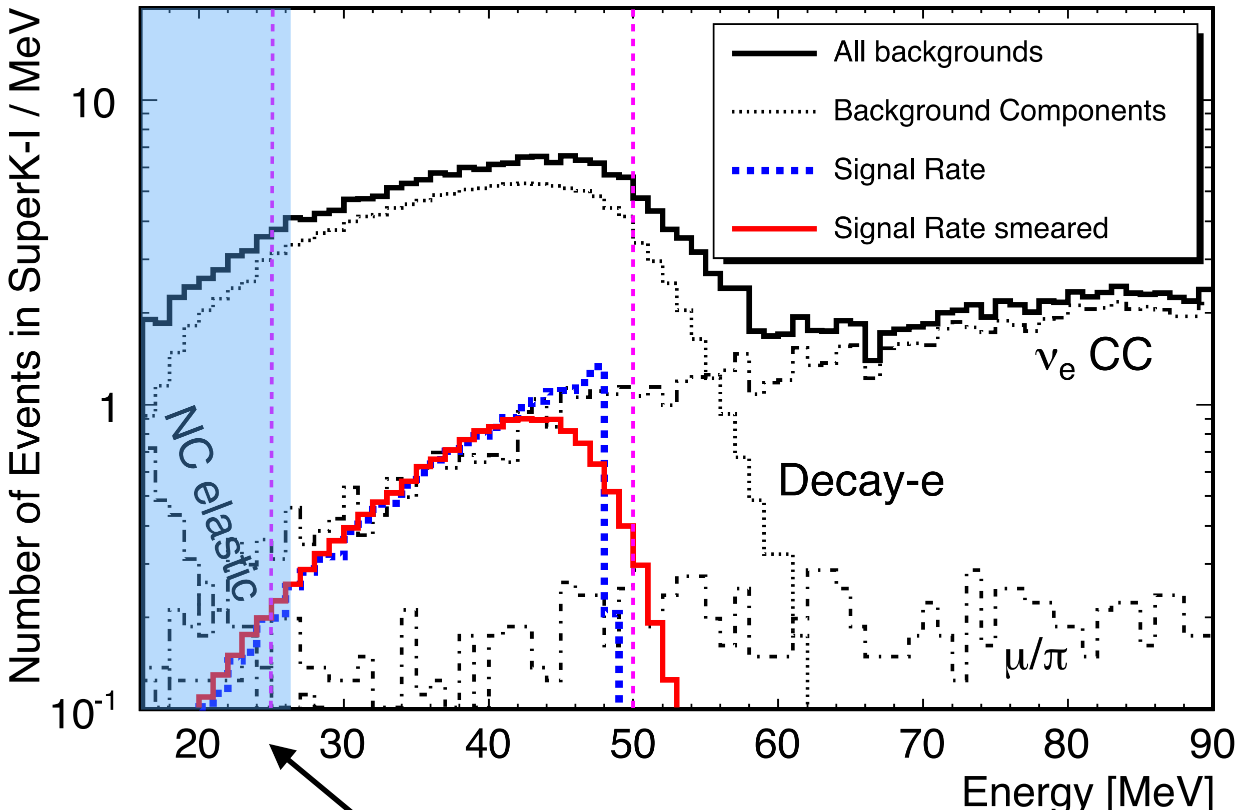
DM sensitivity continues to improve for low masses

Minimal dependence on annihilation channels

New key detection channel to compliment other searches

Super-K data can already be used to test DAMA/Libra

Spallation backgrounds



Spallation cut reduced signal efficiency

Takatomi Yano (Kobe)

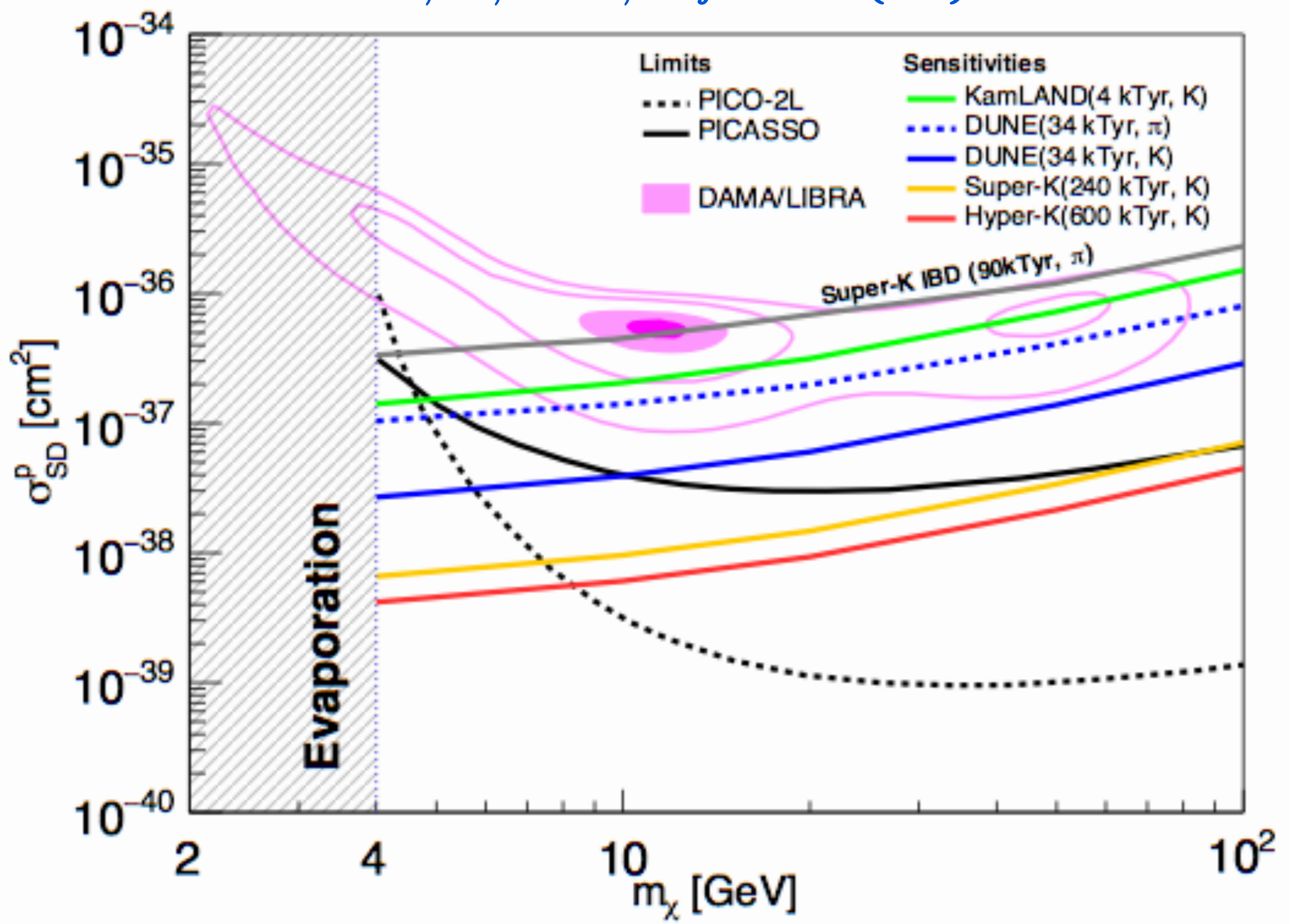
- Spallation cut condition is set to be :
  - Negligible Spallation background in search energy window.

Signal Eff. after spacut	$\mu \times 1$ 1000m	$\mu \times 2$ Mozumi Hakamagoshi	$\mu \times 2.5$ 820m	$\mu \times 5$ Tochibora
~20MeV	79%	62%	56%	29%
20~26MeV	90%	77%	75%	54%

- Spallation backgrounds have been investigated for DSNB neutrino analysis (see presentation from Takatomi Yano)
- Small improvement in sensitivity due increased signal efficiency at deeper site
  - Impact on signal small in energy region 25-50MeV.

Sensitivity

C.Rott, S.In, J.Kumar, D.Yaylali JCAP11(2015)039



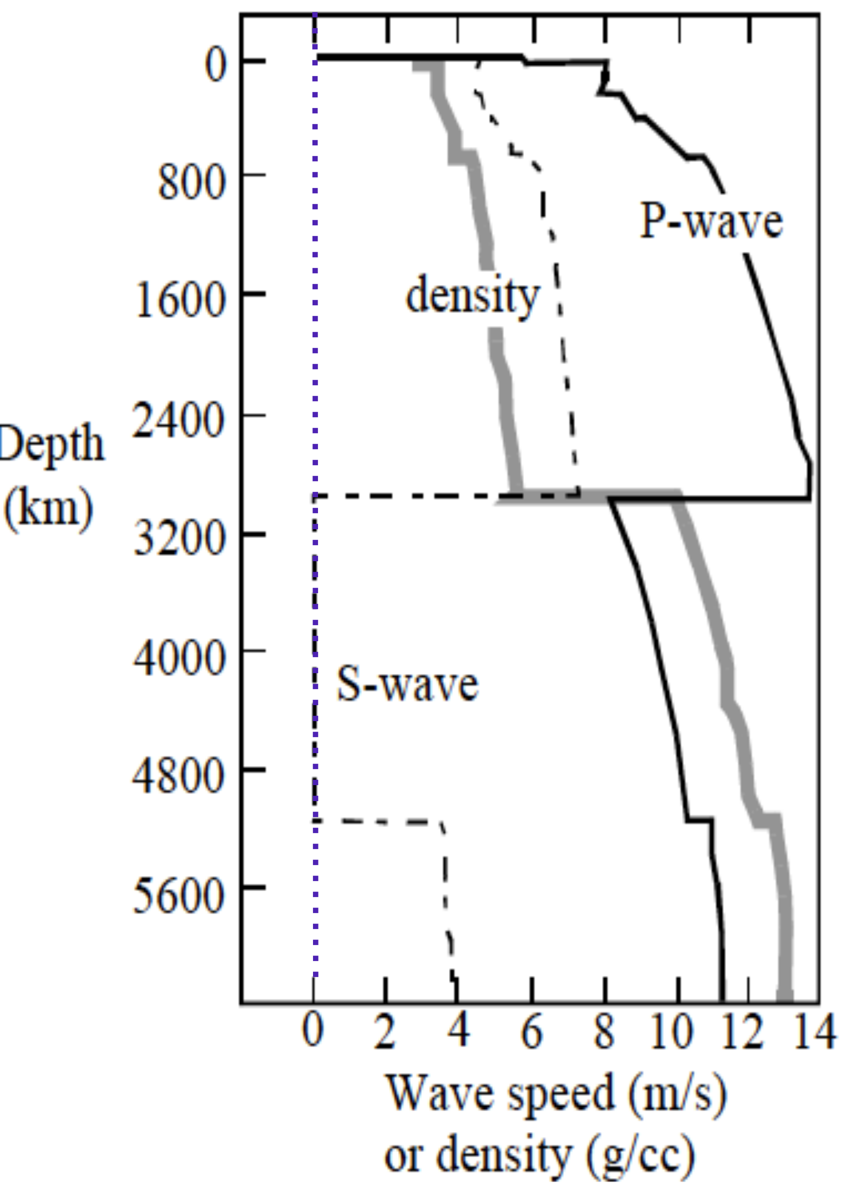
Hope we can replicate this with full Super-K / Hyper-K simulation

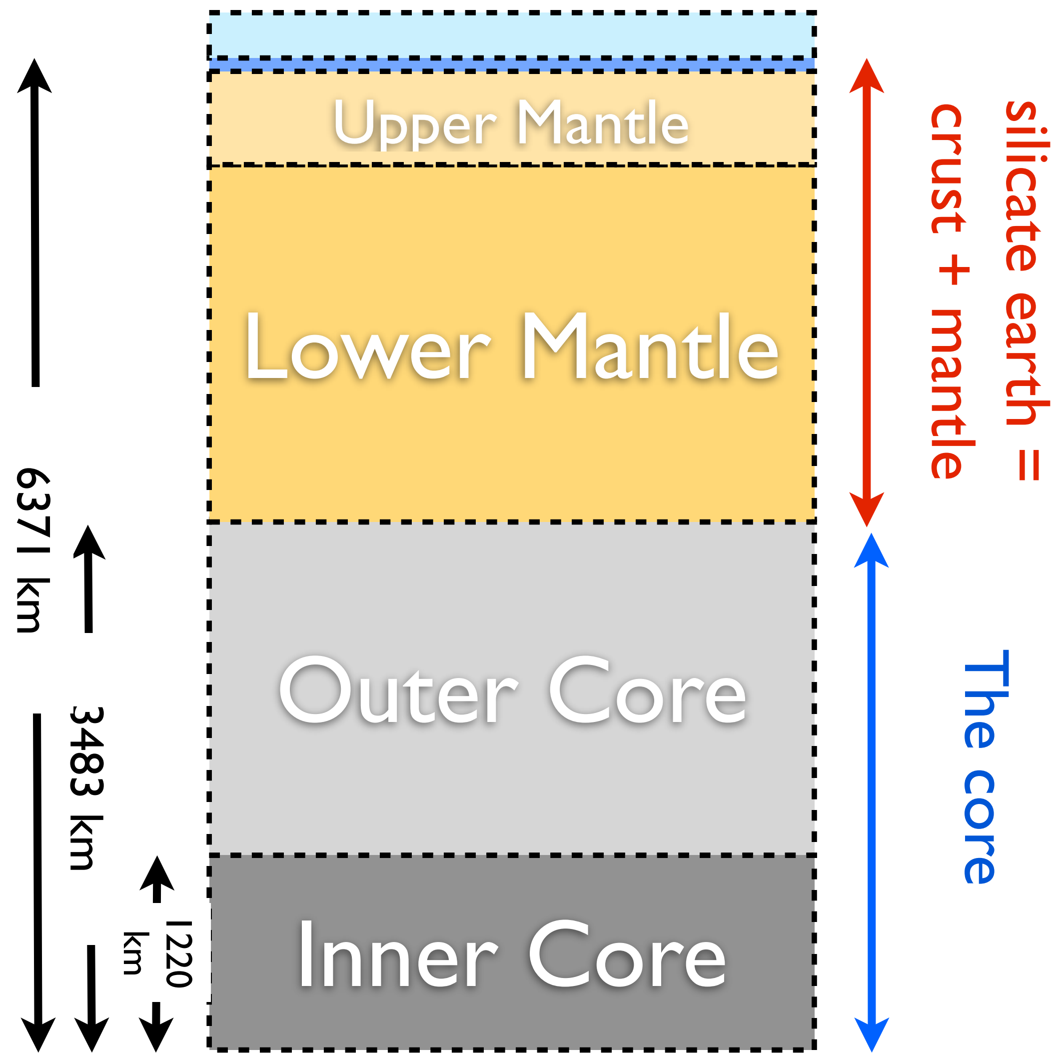
- Sensitivity to kaon line expected to be better than neutrino from pion decay at rest
  - Dominant background atm. neutrinos
  - Benefits from Korean detector, potential to reduced atm. flux uncertainties and detector acceptance understanding ?

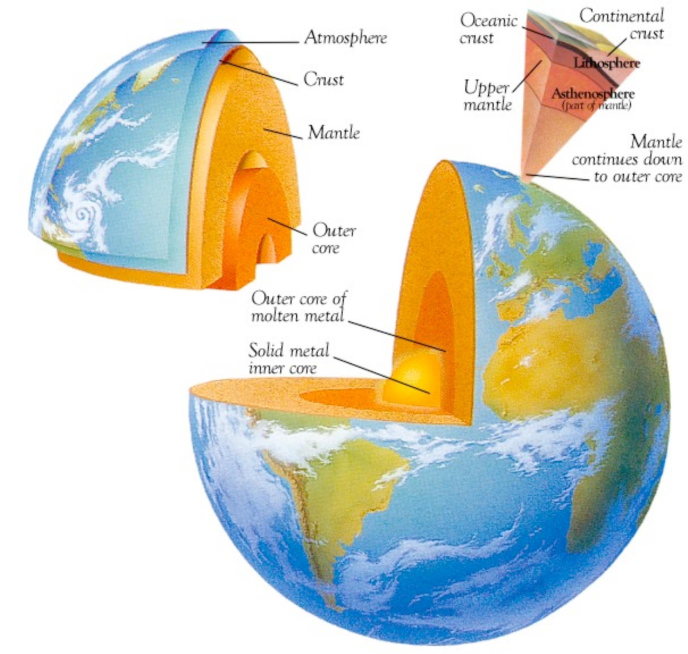
Neutrino Geophysics

Seismological profile of the Earth

William F. McDonough "The Composition of the Earth"



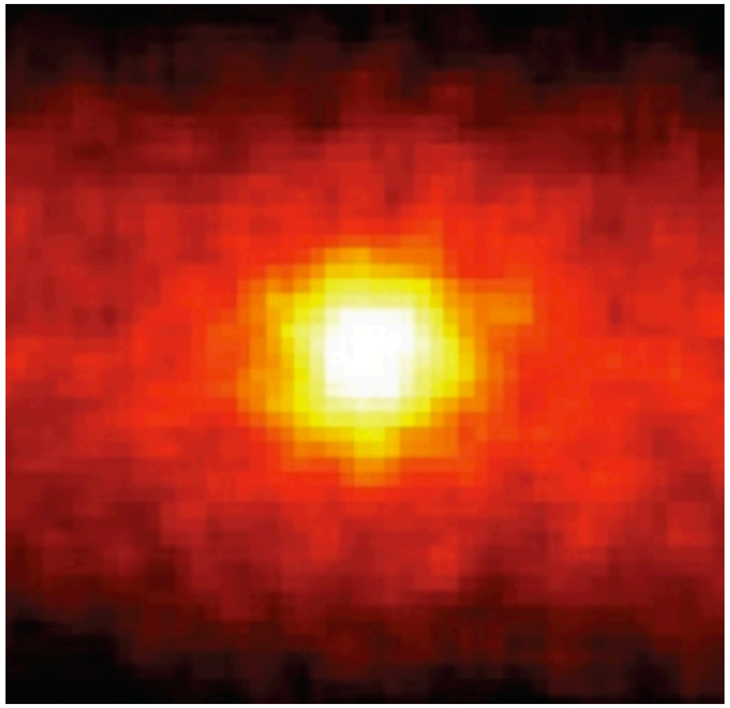




http://www.phys.hawaii.edu/~sdye/hnsc.html

- Density relatively well described through seismic measurements (⇒PREM)
- ... but **whats the composition ?**

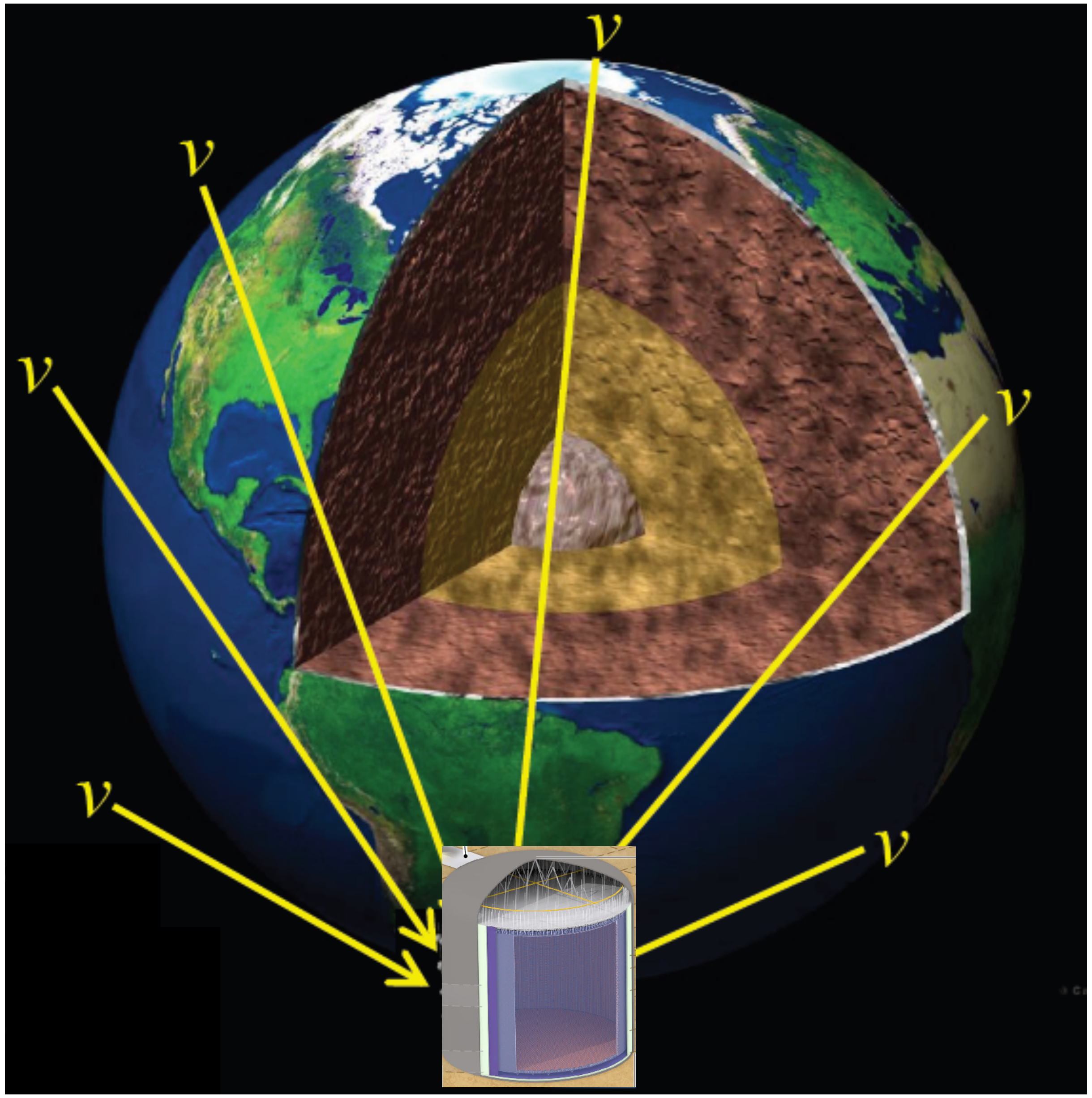
Searches at Hyper-K



- Neutrino Tomography with
  - Atmospheric Neutrinos
  - Solar Neutrinos
  - Galactic Supernova Burst Neutrinos

Motivation - Methodology

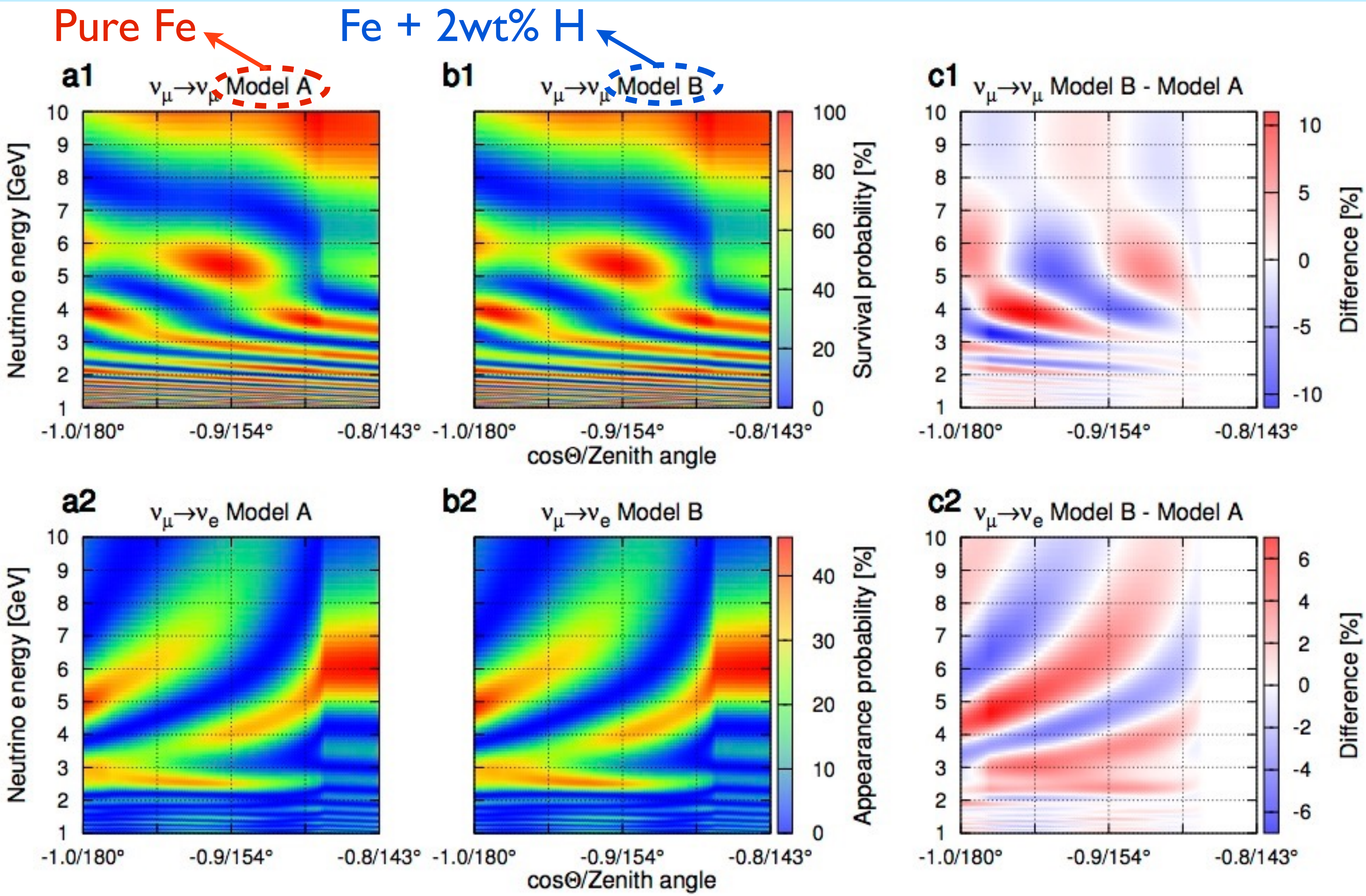
- The Earth matter density profile can be determined from seismic measurements
- Matter induced neutrino oscillation effects however dependent on the electron density
- Given a matter density profile the composition (or Z/A) along the neutrino path can be determined using neutrino signals (Oscillation tomography)



Electron density in core
Y_c=electron/nucleons

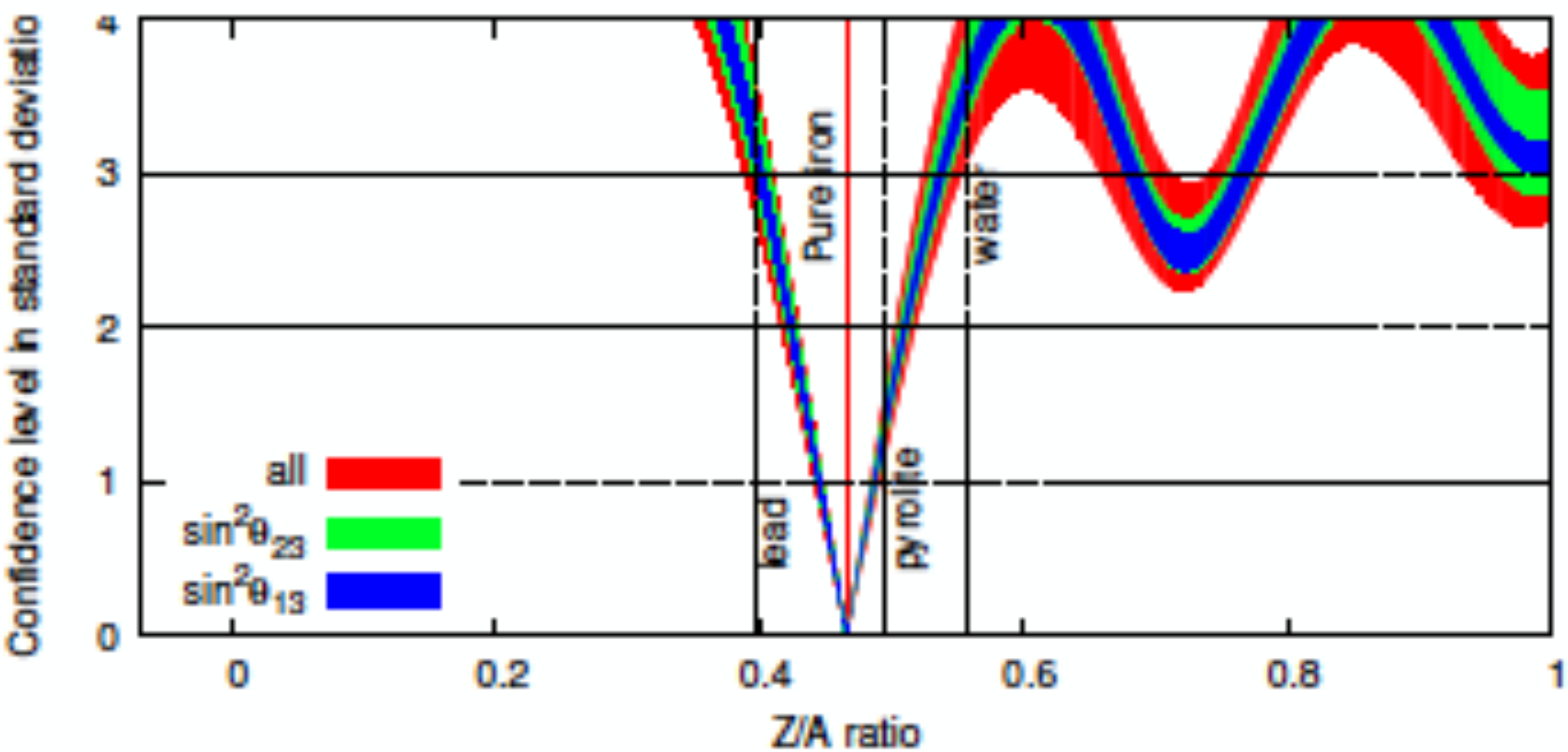
corresponding zenith angles for boundaries
inner core $\theta_\nu < 169°$ ($\cos\theta_\nu < -0.98$)
outer core $\theta_\nu < 147°$ ($\cos\theta_\nu < -0.84$)

Neutrino Tomography (atm. neutrinos)



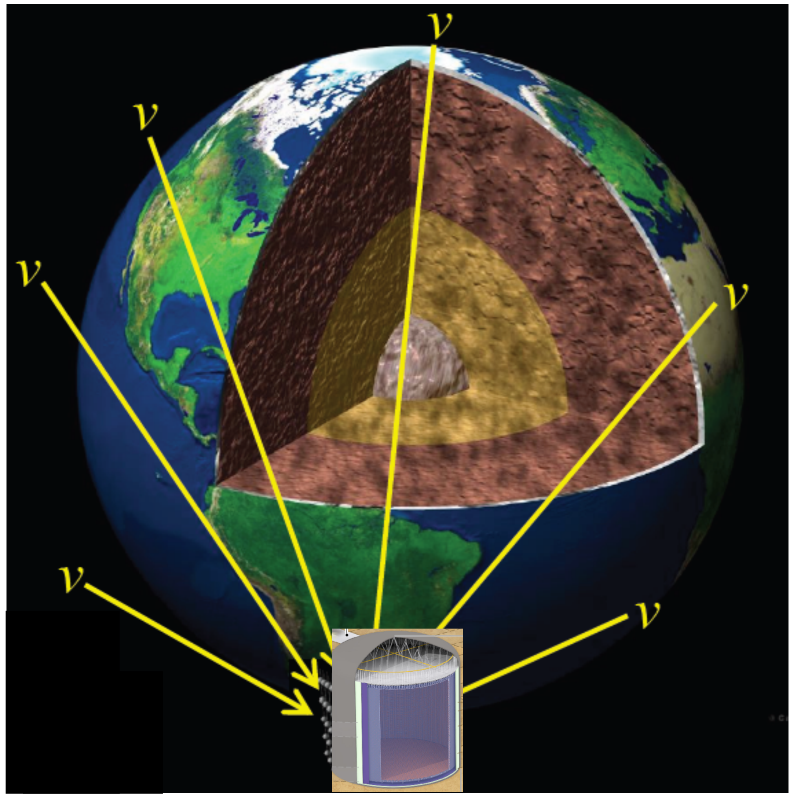
Neutrino Oscillation Tomography

- Neutrino oscillation tomography offers the potential to measure the Earth interior composition
    - High sensitivity to hydrogen
        - Z/A (Fe) ~0.47
        - Z/A (O) ~ 0.50
        - Z/A (H) ~1.00
- Hyper-K will be the first experiment that can measure the Earth core composition



Benefits Neutrino Oscillation Tomography - Atmospheric Neutrinos

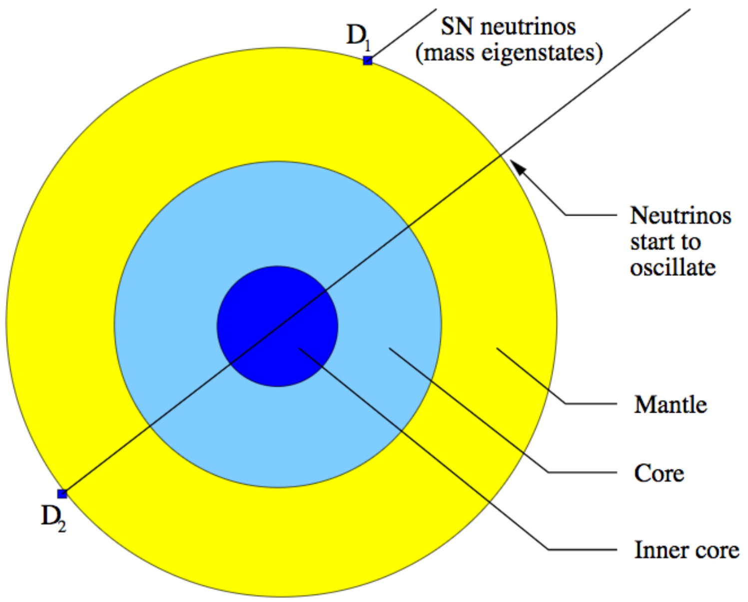
- Atmospheric neutrino flux needs to be well known
  - Two sites will help to reduce systematic uncertainties on the neutrino flux
- Status
  - Jonghyun Kim is redoing oscillation tomography study
    - Using Mark's package for Hyper-K detector response

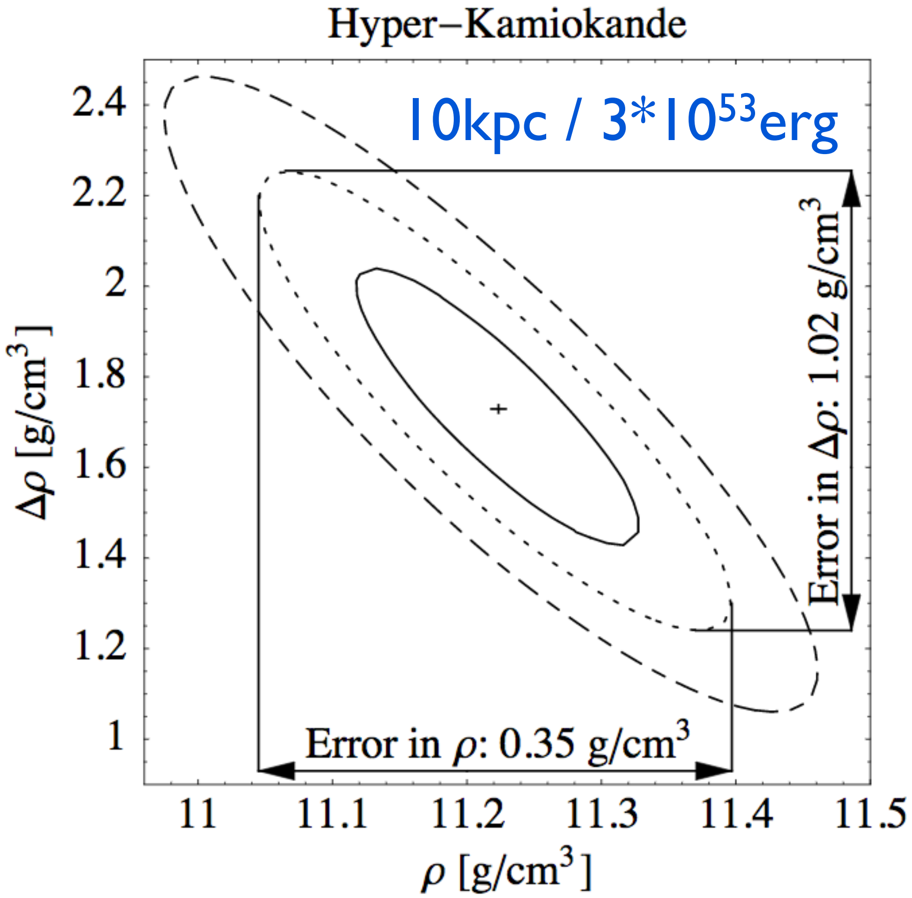


Atmospheric Neutrino flux for Korean site needs to be obtained for full study
Previous studies used Honda 2013 @ Super-K site

- Started discussions with SN theorists
  - Perform dedicated study for two identical detectors with T2HKK separation length
  - Previous works related to Supernova burst neutrino tomography
    - Borriello et al. 2012 https://journals.aps.org/prd/pdf/10.1103/PhysRevD.86.083004
    - Lindner et al 2003 https://arxiv.org/abs/hep-ph/0207238

Lindner et al (2003)





Papers conclude matter effects will be visible for nearby supernova, but we need detailed study on composition

Benefits Neutrino Oscillation Tomography - Solar Neutrinos

- Super-K observed day-night asymmetry (matter effects)
  - Sensitivity to Earth models needs to be determined for Hyper-K
    - Sun is a point source, different baselines can be explored with two detectors
    - Site benefits for Solar neutrinos also directly apply to this study
      - Increased efficiency due to lower spallation backgrounds

Thanks !

Backgrounds

K. Bays {Super-K Collaboration}
Phys.Rev. D85 (2012) 052007

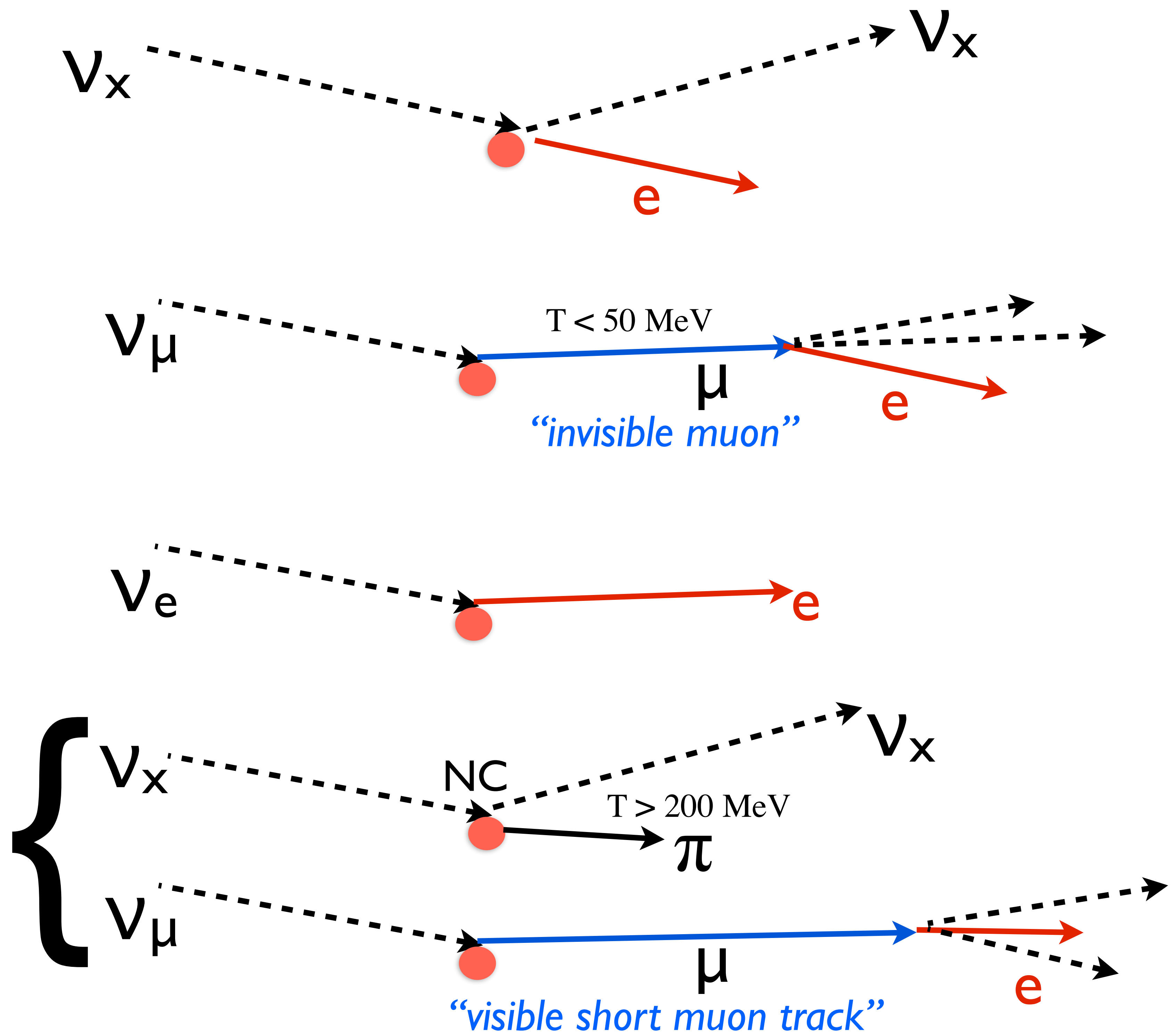
The background events mainly caused by the atmospheric neutrinos, solar neutrinos and muon-induced spallation products.

NC Elastic
"atmospheric"

Decay electron
"atm. muon neutrinos"

ν_e CC
"atm. electron neutrinos"

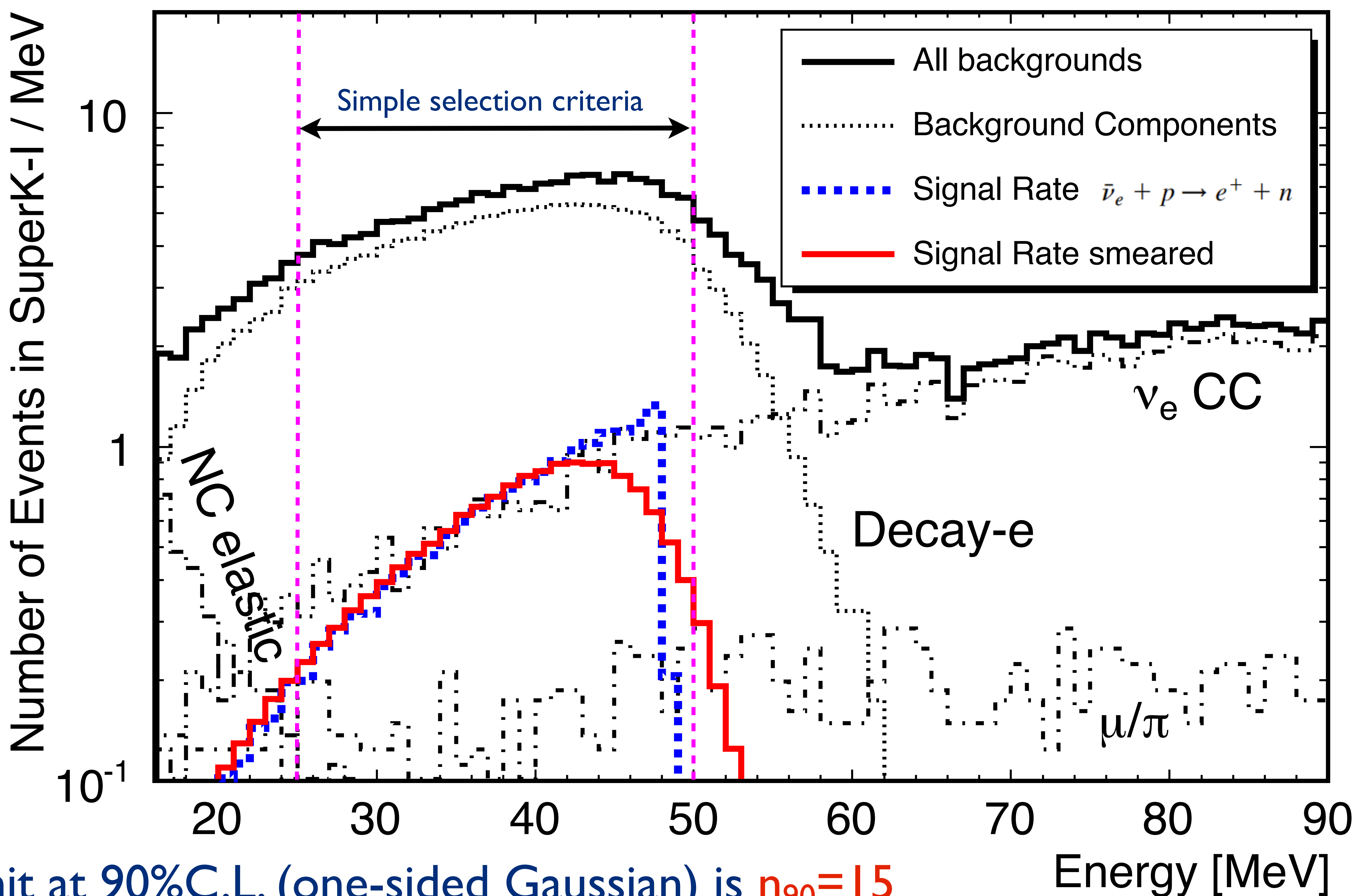
μ/π
"μ/π production from atm. neutrinos"



Sensitivity Calculation Super-K

Positrons carry energy of $E_e \simeq [E_\nu - 1.3\ \mathrm{MeV}](1 - E_\nu/m_p)$

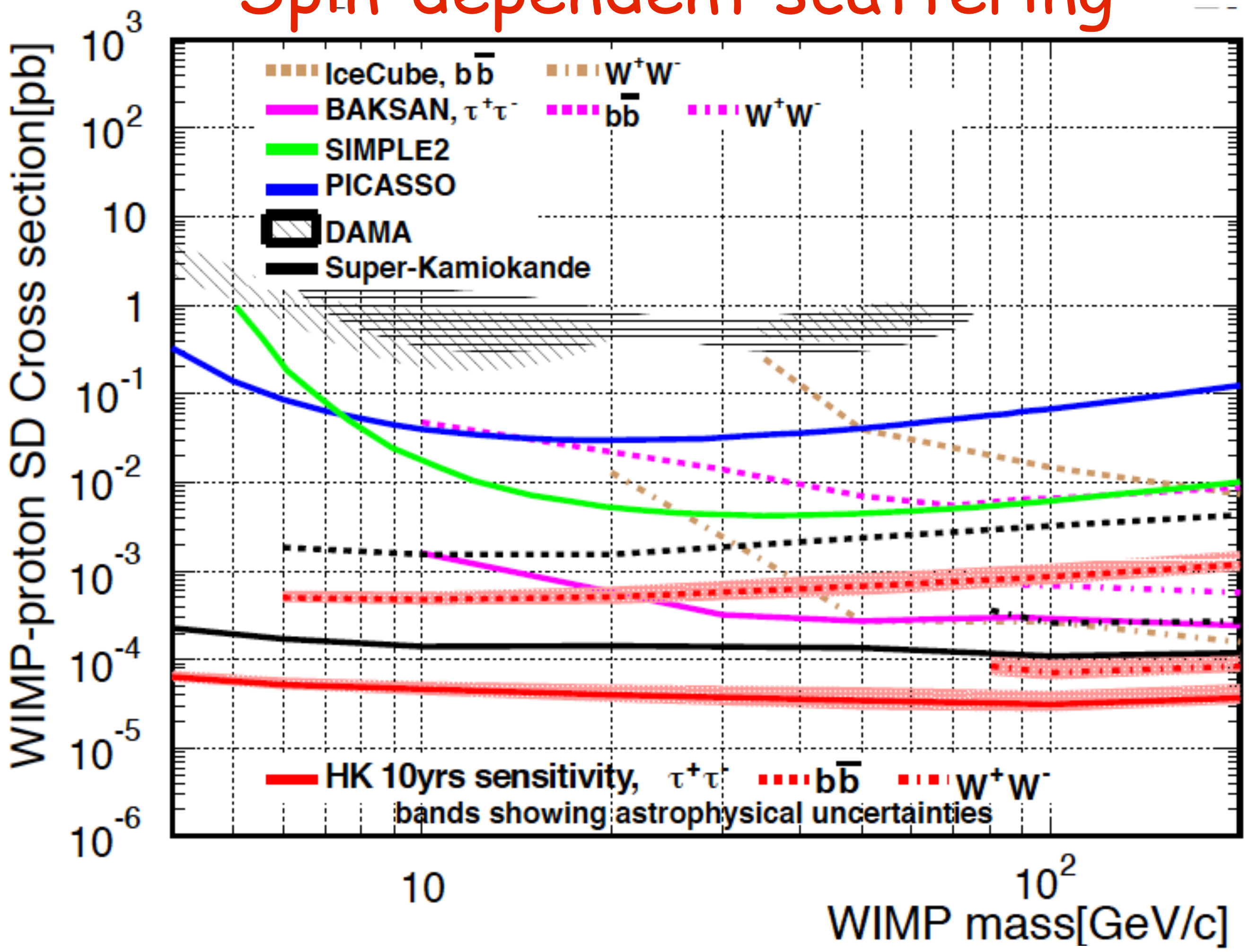
To visualize the signal has been scaled to be "detectable"



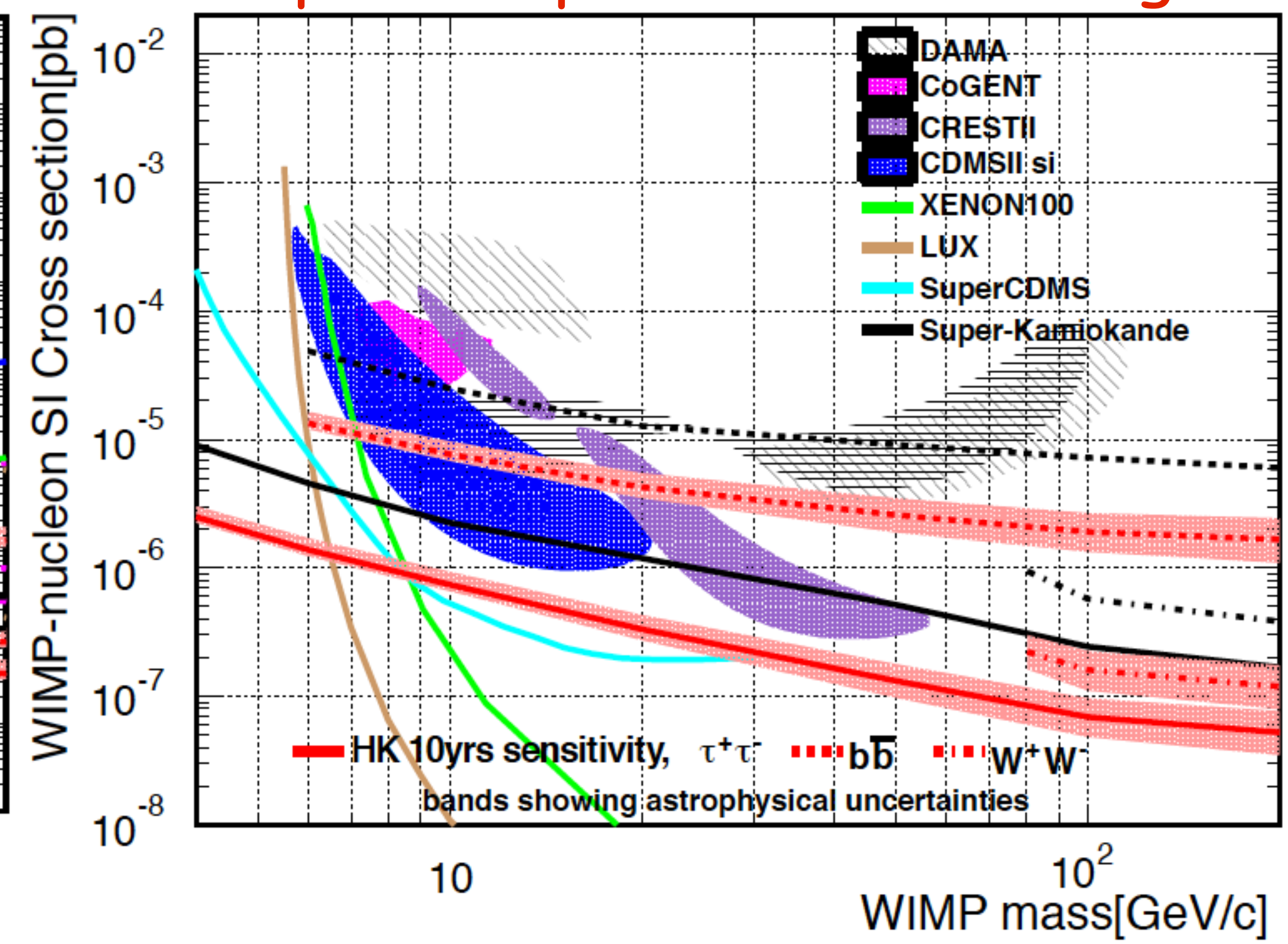
Limit at 90%C.L. (one-sided Gaussian) is n_{90}=15

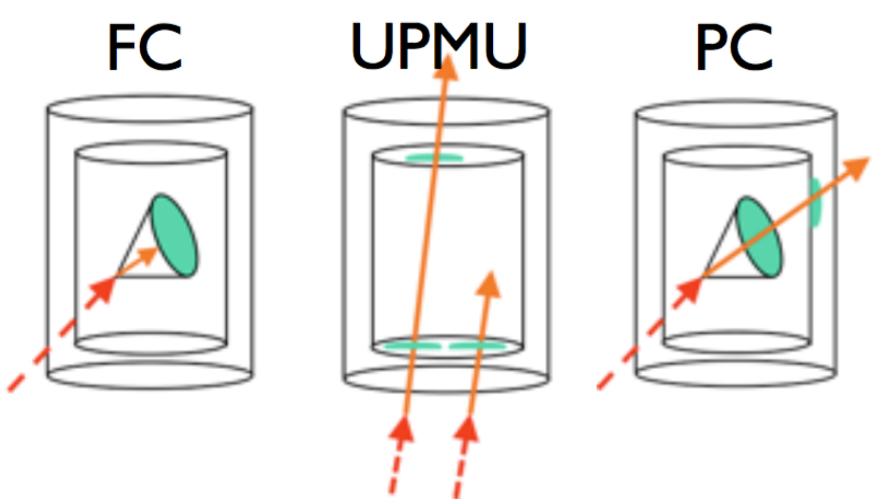
Solar WIMPs Hyper-K

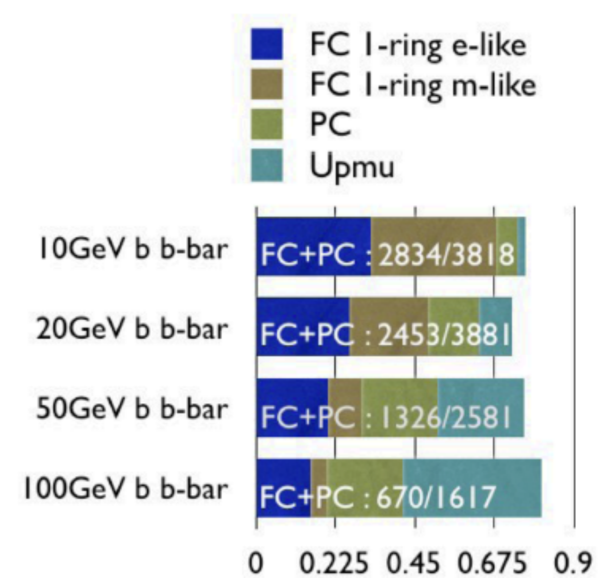
Spin-dependent scattering



Spin-independent scattering







Sensitivity based on Koun et al. (Super-K Coll.) (2014)

GC Sensitivity Hyper-K