Detecting electron neutrinos from solar dark matter annihilation by JUNO

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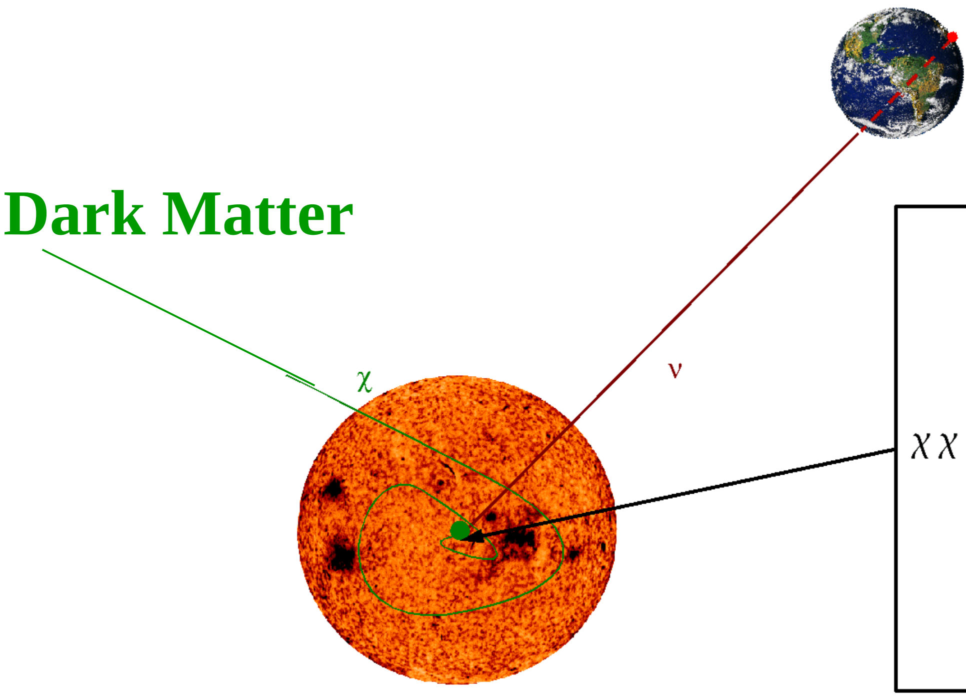
Outline

- **Neutrinos from Solar dark matter annihilation**
- **JUNO performances**
  - **JUNO experiments**
  - **Analysis results**
- **Summary**

W.L. Guo, JCAP 01 (2016) 039, arXiv:1511.04888

(1) DM captured and annihilation in the Sun

Physical picture：



$$\chi\chi \to \begin{bmatrix} \nu\bar{\nu} \\ b\bar{b} \\ t\bar{t} \\ \tau^-\tau^+ \\ W^-W^+ \\ Z^0Z^0 \\ Higgs + \text{other particles} \end{bmatrix} \to \nu + \bar{\nu} + \text{other particles}$$

DM elastically Scatter $\propto \sigma_{Ni}$ → **DM can be captured** $v_{DM} < v_{esc}$ → **Thermalized and Accumulated in core** → **Annihilation** $\propto N^2$ → **Neutrinos**

DM evolution in the Sun

Evolution function:

$$\dot{N} = C_\odot - C_A N^2$$

$$C_A = \frac{\langle \sigma v \rangle}{V_{\rm eff}},$$

$$\langle \sigma v \rangle = 3 \times 10^{-26} \mathrm{cm^3 s^{-1}}$$

$$V_{\rm eff} = 5.8 \times 10^{30}\ \mathrm{cm}^3 \left(\frac{1\mathrm{GeV}}{m_D}\right)^{3/2}$$

Capture rate:

$$C_\odot^{\rm SI} \approx 4.8 \times 10^{24} \mathrm{s}^{-1} \frac{\rho_0}{0.3\,\mathrm{GeV/cm^3}} \frac{270\,\mathrm{km/s}}{\bar{v}} \frac{1\,\mathrm{GeV}}{m_D} \sum_i F_i(m_D) \frac{\sigma_{N_i}^{\rm SI}}{10^{-40}\,\mathrm{cm}^2} f_i \phi_i S\left(\frac{m_D}{m_{N_i}}\right) \frac{1\,\mathrm{GeV}}{m_{N_i}}, \tag{2.3}$$

$$C_\odot^{\rm SD} \approx 1.3 \times 10^{25} \mathrm{s}^{-1} \frac{\rho_0}{0.3\,\mathrm{GeV/cm^3}} \frac{270\,\mathrm{km/s}}{\bar{v}} \frac{1\,\mathrm{GeV}}{m_D} \frac{\sigma_p^{\rm SD}}{10^{-40}\,\mathrm{cm}^2} S\left(\frac{m_D}{m_p}\right), \tag{2.4}$$

G. Jungman, M. Kamionkowski, K. Griest, Phys. Rept. 267, 195 (1996)

Annihilation rate:

$$\Gamma_A = \frac{1}{2} C_A N^2 = \frac{1}{2} C_\odot \tanh^2 (t_\odot \sqrt{C_\odot C_A})$$

$>>1$ → **Equilibrium**

At equilibrium, $\Gamma_A = C_{\rm sun}/2$， which only depends on σ_{Ni} or σ_p

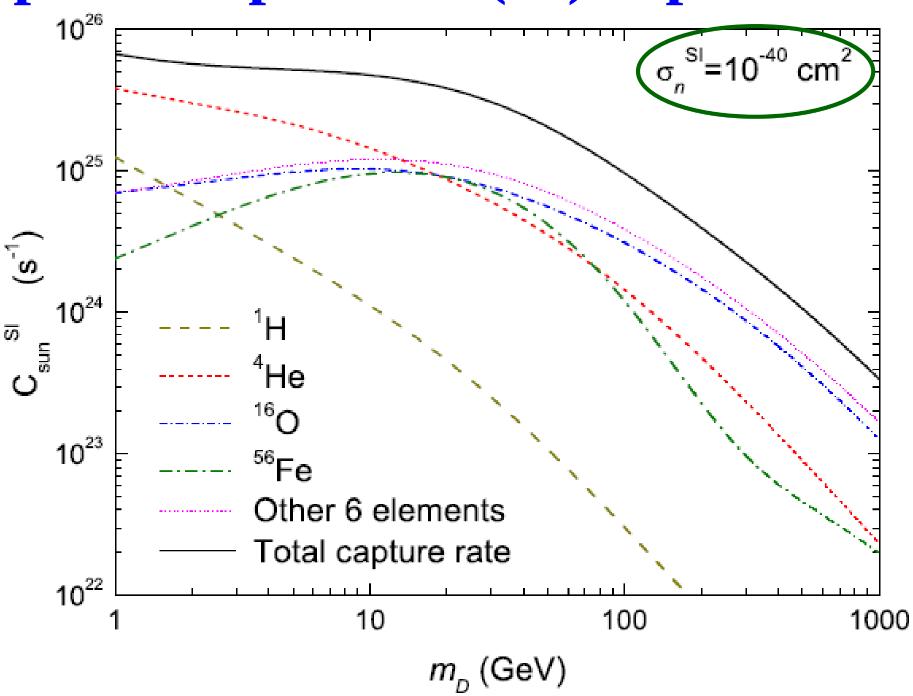
DM capture and annihilation equilibrium

Equilibrium Condition:

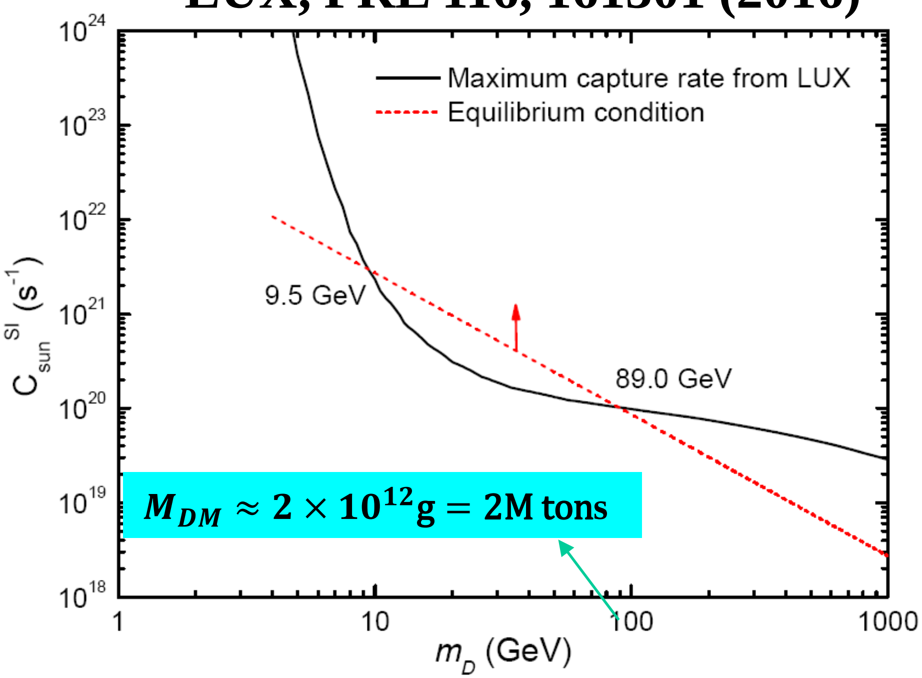
$$t_\odot \sqrt{C_\odot C_A} \geq 3.0 \Rightarrow \tanh^2[t_\odot \sqrt{C_\odot C_A}] \geq 0.99$$

$$\left.\begin{array}{l}\langle \sigma v \rangle = 3 \times 10^{-26} \mathrm{cm}^3 \mathrm{s}^{-1} \\ t_\odot \simeq 4.5\ \mathrm{Gyr}\end{array}\right\} \quad \boxed{C_\odot \geq 8.6 \times 10^{22} / (m_D / 1\mathrm{GeV})^{3/2} \mathrm{s}^{-1}}$$

Spin-Independent (SI) capture rates:



LUX, PRL 116, 161301 (2016)



DM capture and annihilation equilibrium

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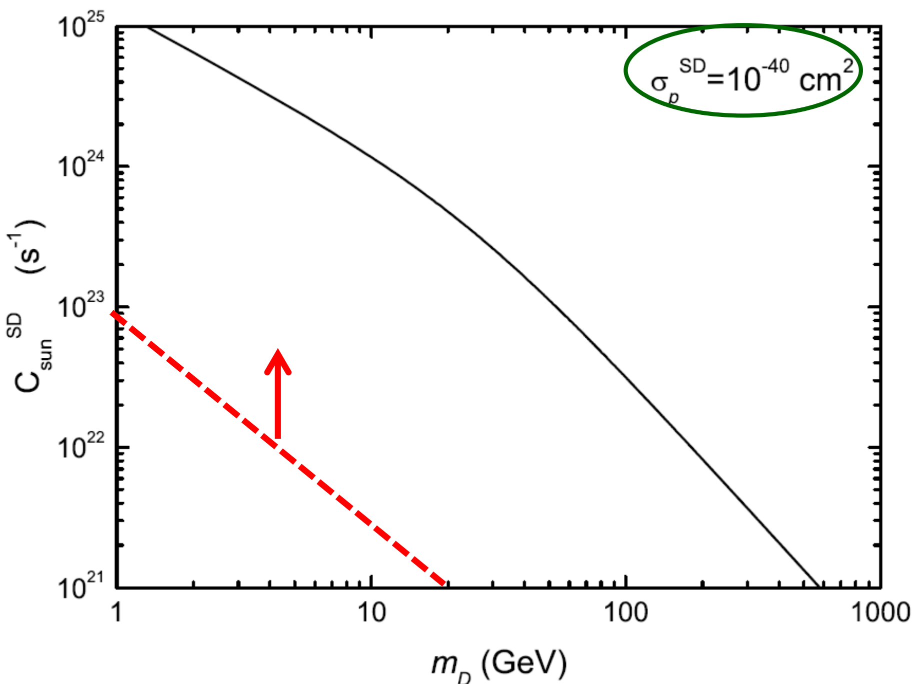
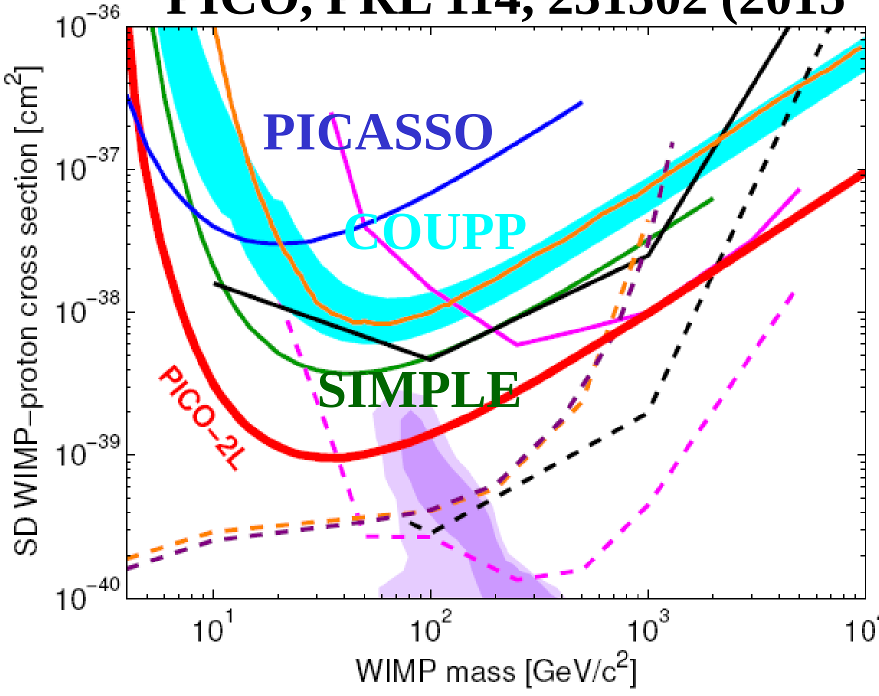
Spin-Dependent (SD) capture rates:



PICO, PRL 114, 231302 (2015



Neutrino fluxes from solar DM annihilation

Neutrino Fluxes:

$$\frac{d\Phi_{\nu_e}}{dE_\nu} = \frac{\Gamma_A}{4\pi R_{\rm ES}^2}\frac{dN_{\nu_e}}{dE_\nu} \simeq \frac{C_\odot}{8\pi R_{\rm ES}^2}\frac{dN_{\nu_e}}{dE_\nu}$$

$R_{\rm ES} = 1.496 \times 10^{13}\ \rm cm$ is the Earth-Sun distance

Differential neutrino energy spectrum:

- **Final states interactions**
  Hadronization, interactions, decay
- **Neutrino interactions**
- **Neutrino oscillations**

WimpSim

Blennow, Edsjo, Ohlsson, arXiv: 0709.3898

Input parameters:

Annihilation Channels: $\chi\chi \to \nu\bar{\nu}, \tau^+\tau^-, b\bar{b}$

Monoenergetic

Continuous

Dark matter mass: $4\ \mathrm{GeV} \leq m_D \leq 20\ \mathrm{GeV}$

Oscillation parameters:

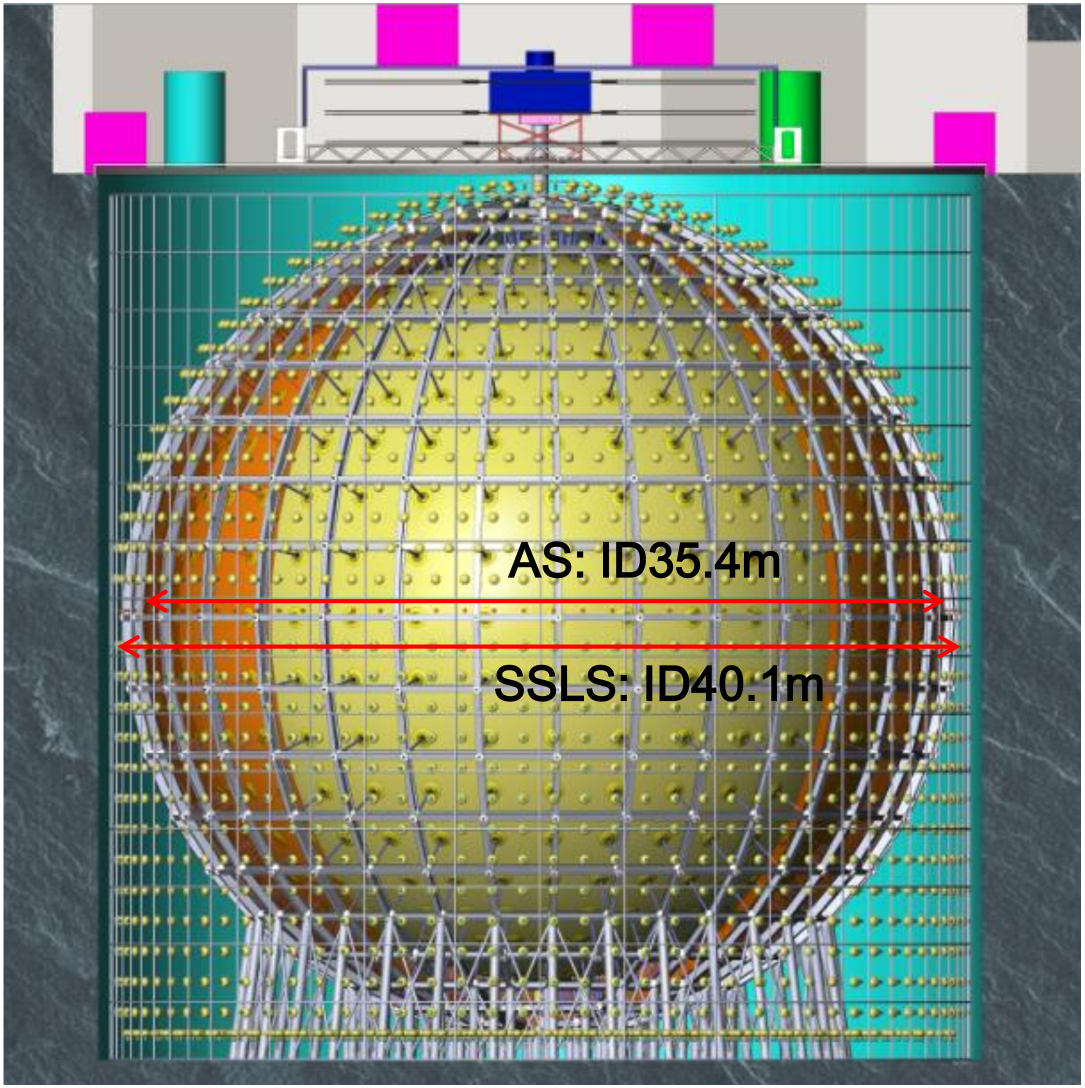
$\sin^2\theta_{12} = 0.308,\quad \sin^2\theta_{23} = 0.437,\quad \sin^2\theta_{13} = 0.0234,$

$\Delta m_{21}^2 = 7.54 \times 10^{-5}\mathrm{eV}^2,\quad \Delta m_{31}^2 = 2.47 \times 10^{-3}\mathrm{eV}^2,\quad \delta = 0^\circ.$

(2) Jiangmen Underground Neutrino Observatory (JUNO)

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

JUNO detector and physical potentials



- **20 kton liquid scintillator**
- **3% energy resolution**

  ~18000 20” + ~25000 3” PMTs
- **Rich physical possibilities:**
  - ✓ **Neutrino MH using reactor neutrinos**
  - ✓ **Precision measurement of oscillation parameters**
  - ✓ **Supernova and Diffuse supernova neutrinos**
  - ✓ **Solar, Geo- and Sterile neutrinos**
  - ✓ **Atmospheric neutrinos**
  - ✓ **Dark matter searches**
  - ✓ **Nucleon decay**
  - ✓ **other exotic searches**

See talk by Ranucci and Neutrino Physics with JUNO, J. Phys. G 43, 030401 (2016)

Neutrino signals in JUNO

The expected event numbers:

$$N_S = N_n\, t \int_{E_{th}}^{m_D} \left[\frac{d\Phi_{\nu_e}}{dE_\nu} \sigma_{\nu_e} + \frac{d\Phi_{\bar{\nu}_e}}{dE_\nu} \sigma_{\bar{\nu}_e} \right] \epsilon(E_\nu)\, dE_\nu$$

$N_n \simeq 20\,\mathrm{kton}/m_n$

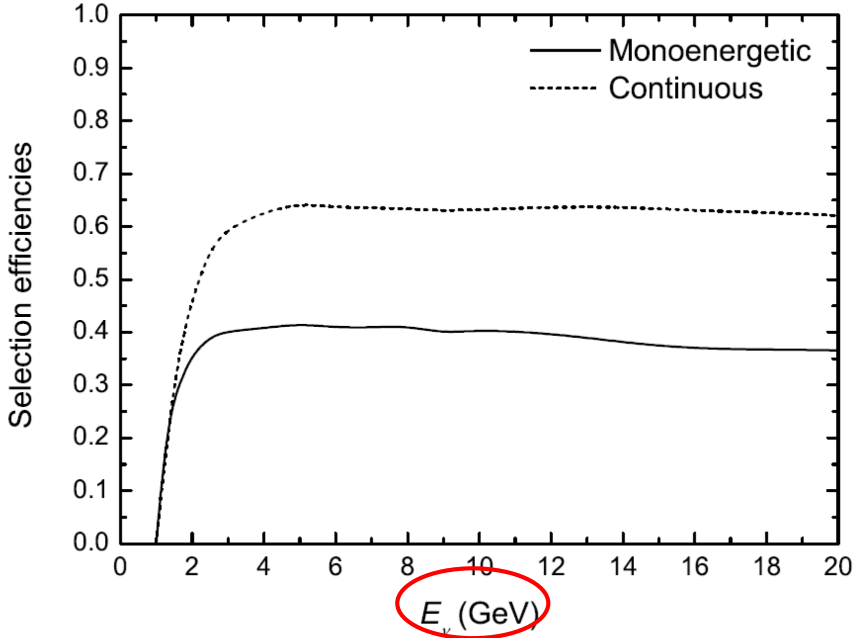
$t = 10$ years

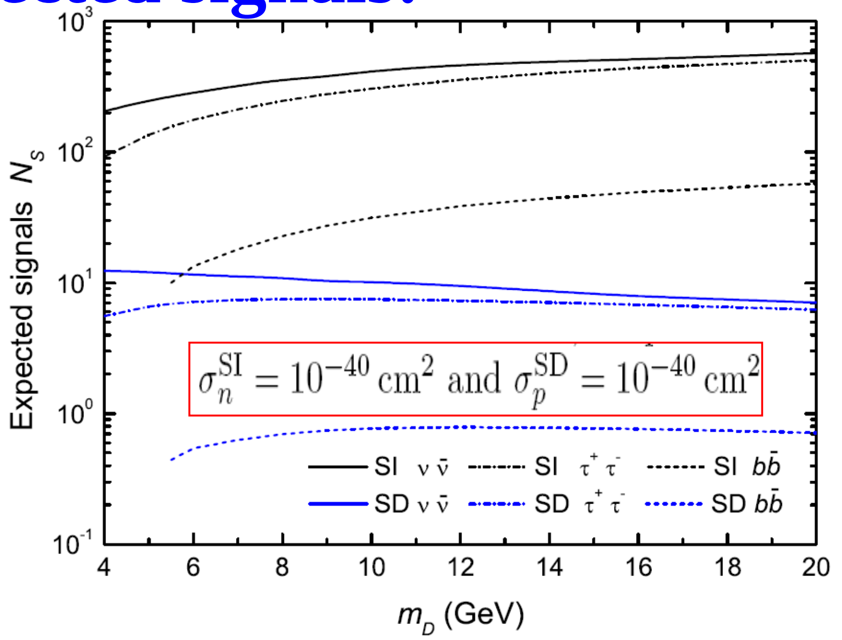
Selection conditions (MC and 10° $e^\pm$ angular resolution):

$\nu\bar{\nu}$: $Y_{vis} > 0.5$, $Ee_{vis} > 1$ GeV, $\theta < 20^\circ\sqrt{10/E_\nu}$, $E_{vis}/E_\nu > 0.9$, $E_{th} = 0.9E_\nu$

$b\bar{b}, \tau^+\tau^-$: $Y_{vis} > 0.5$, $Ee_{vis} > 1$ GeV, $\theta < 30^\circ$, $1 < E_{vis} < E_\nu$, $E_{th} = 1$GeV

Selection efficiencies and Expected signals:





Atmospheric neutrino background

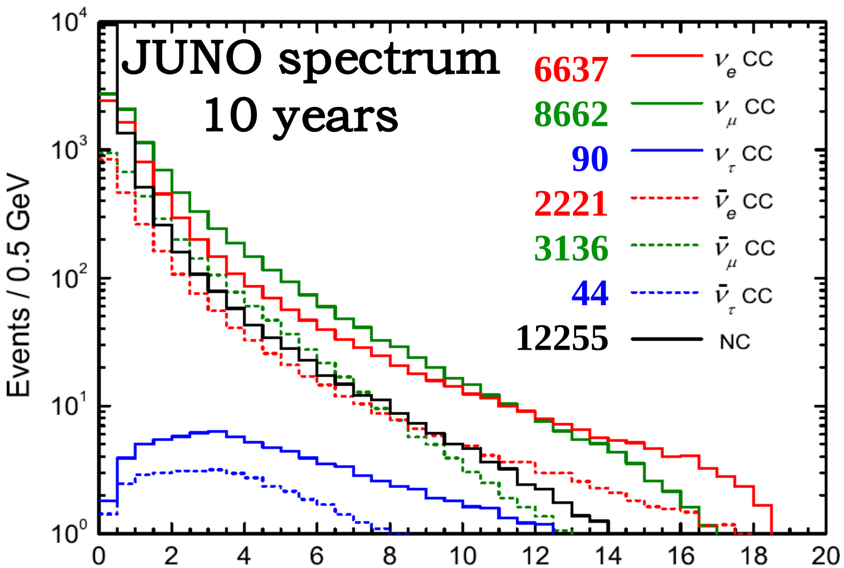
CC backgrounds: All direction → Average → Cone

$\nu\bar{\nu}$: $Y_{vis} > 0.5$, $Ee_{vis} > 1$ GeV, $E_{vis}/m_D > 0.9$

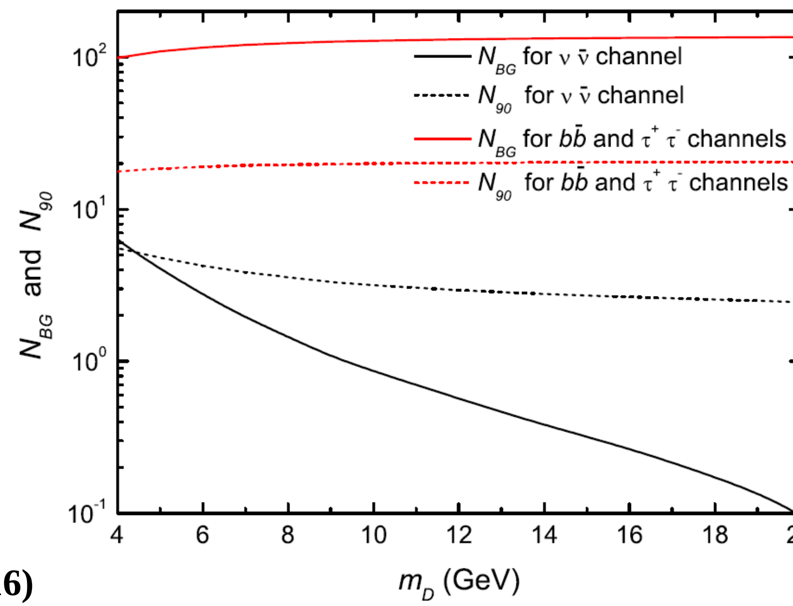
$b\bar{b}, \tau^+\tau^-$: $Y_{vis} > 0.5$, $Ee_{vis} > 1$ GeV, $1 < E_{vis} < m_D$

NC backgrounds: Neglect!

½ CC, Several hadrons, Misidentification rate



J. Phys. G 43, 030401 (2016)



JUNO upbounds on Ns:

$$90\% = \frac{\int_{N_S=0}^{N_{90}} L(N_{\rm obs}|N_S)dN_S}{\int_{N_S=0}^{\infty} L(N_{\rm obs}|N_S)dN_S}$$

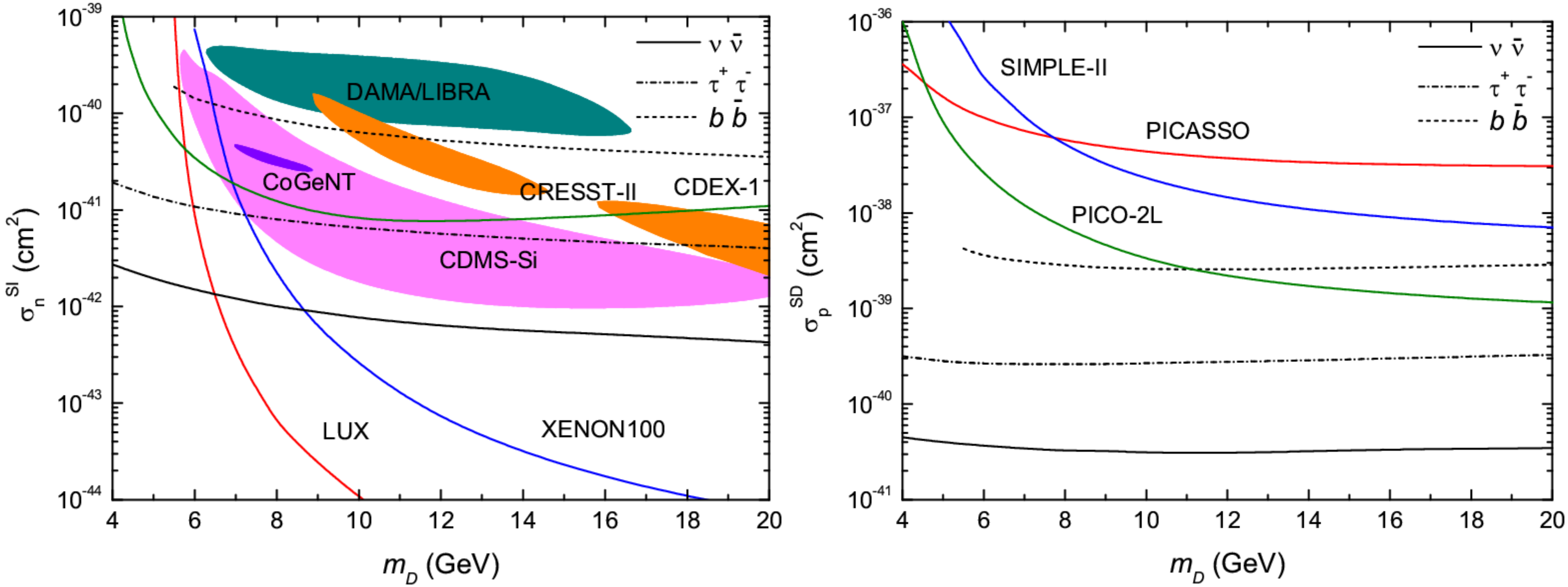
$$L(N_{\rm obs}|N_S) = \frac{(N_S + N_{\rm BG})^{N_{\rm obs}}}{N_{\rm obs}!}e^{-(N_S+N_{\rm BG})}$$

$$N_{\rm obs} = N_{\rm BG}$$

JUNO sensitivity from $\nu_e/\bar{\nu}_e$

JUNO 10 years sensitivities:

W.L. Guo, JCAP 01 (2016) 039
arXiv:1511.04888



Summary:

- For the SD case, JUNO can give better limits than the DM direct searches
- For the SI case, a very narrow region in $\nu\ \bar{\nu}$ channel can give better limits

Thanks !

SI Experimental limits

Upper bounds on the SI elastic WIMP-nucleon cross section: