Detecting Solar dark matter neutrinos at KM3NeT from dark matter annihilations at the Solar core

DAE-BRNS HEP SYMPOSIUM

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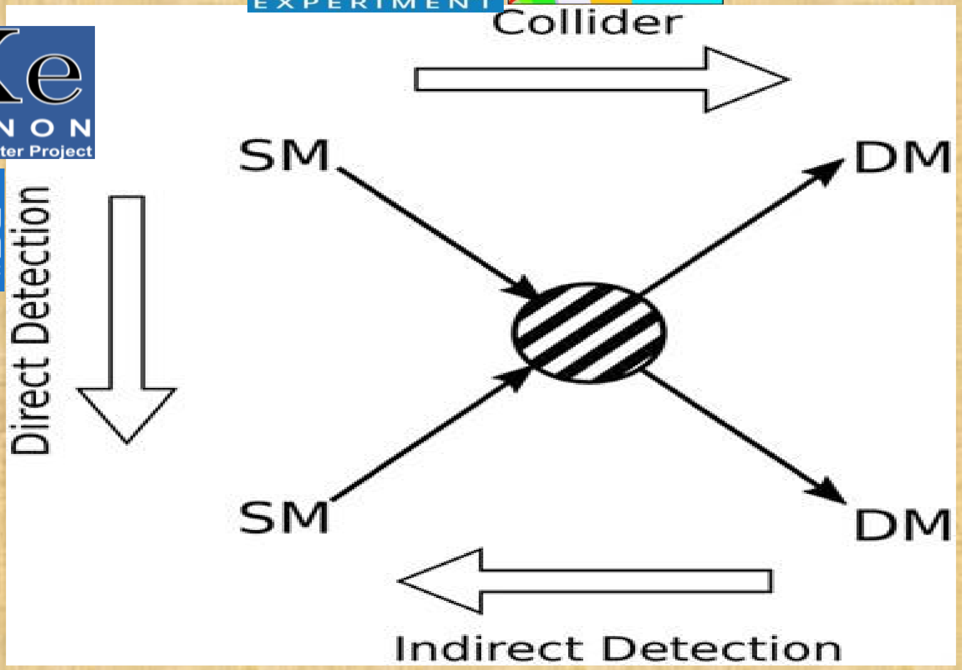
Dark Matter searches



Direct Detection:

- Dark matter interacts with some standard model states and we measure the recoil of the target particle in underground detectors. (momentum transfer to detector particle through elastic scattering).

Indirect Detection:

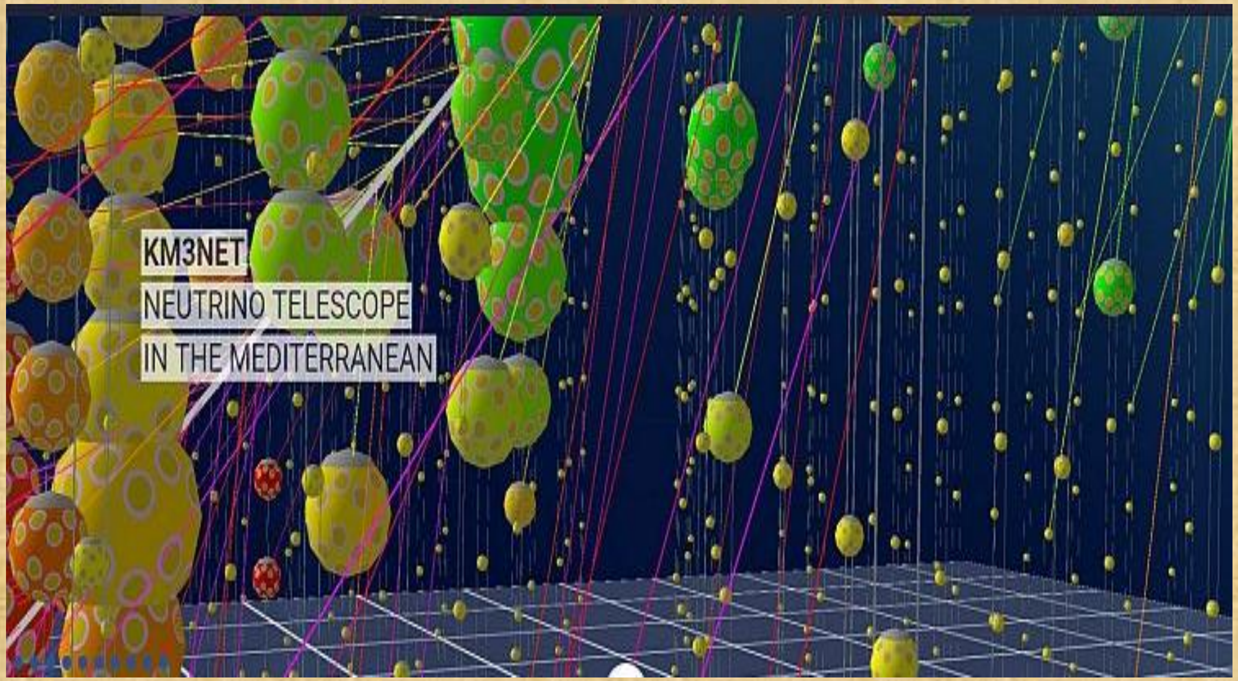
- Dark matter may be captured at the core of massive gravitating astrophysical objects where they can undergo self-annihilation to produce some standard model particles as the end products. One observes these annihilation products such as γ, ν, e^+ etc.

Collider Searches:

- Dark matter may be produced by colliding two standard model particles. By measuring the missing transverse momentum and missing energy the DM signal can be probed.

The KM3NeT Neutrino Telescope

- KM3NeT is the next generation deep-sea neutrino telescope currently being constructed in the Mediterranean sea
  - **ORCA:** Oscillation Research with Cosmics in the Abyss, study neutrino oscillation properties with special focus on mass hierarchy of neutrinos
  - **ARCA:** Astroparticle Research with Cosmics in the Abyss, search for neutrinos from distant astrophysical sources



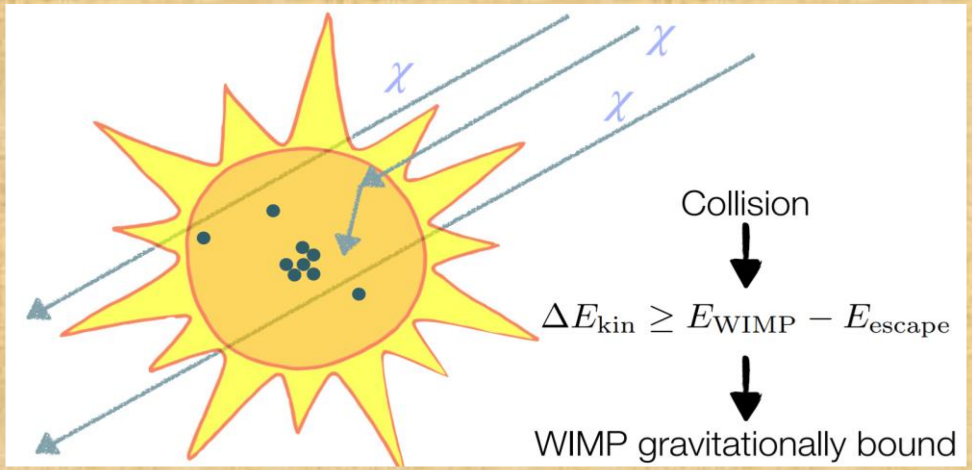
- The energy range for KM3NeT is GeV to PeV and it is sensitive for the energies that may be relevant for dark matter detection.
- It is a water Cherenkov detector which will use sea-water as detector material.

Dark Matter Capture in The Sun and Neutrino Production

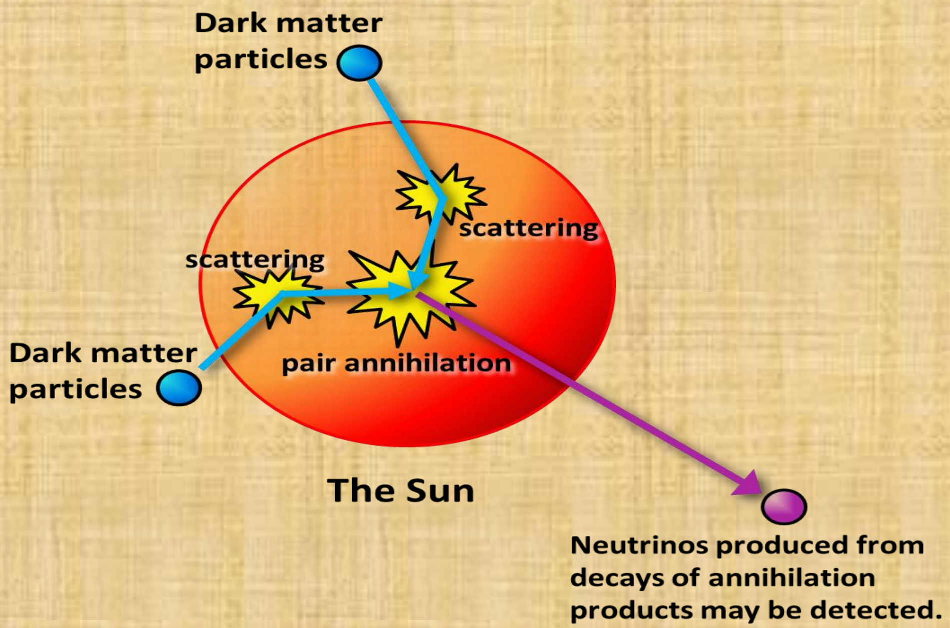
- Dark matter particles in the halo scatters with nuclei in the Sun and if they lose enough kinetic energy to fall below the escape velocity of the Sun, they become gravitationally bound inside the Sun.

- If accumulated inside the Solar core in considerable amount after being captured gravitationally, these DM particles may undergo the process of self-annihilation and produce high energy neutrinos along with other SM particles.

- We look for those DM induced Solar neutrinos in the neutrino telescopes such as KM3NeT.



Credit: Aaron Vincent



DM Capture, Annihilation, Evaporation

- Time evolution of the number density of dark matter particles in the Sun depends upon capture, annihilation and evaporation and is given by

$$\frac{dN}{dt} = C_C + (C_{SC} - C_{SE} - C_E)N - (C_{\text{ann}} + C_{\text{sevap}})\, N^2$$

arXiv:1811.00557 [hep-ph]
arXiv:1408.5471 [hep-ph]

with general solution

$$N(t) = \frac{C_C \tanh\left(\frac{t}{\xi}\right)}{\frac{1}{\xi} - \frac{C_{SC} - C_{SE} - C_E}{2} \tanh\left(\frac{t}{\xi}\right)},$$

$$\text{where } \xi^{-1} = \sqrt{C_C(C_{\text{ann}} + C_{\text{sevap}}) + (C_{SC} - C_{SE} - C_E)^2/4}.$$

- C_C = rate of DM capture due to nuclei-DM elastic scattering
- C_E = rate at which captured DM evaporate by scattering
- C_{SC}, C_{SE} *and* C_{sevap} = rates for DM self-capture, self-ejection and self-evaporation

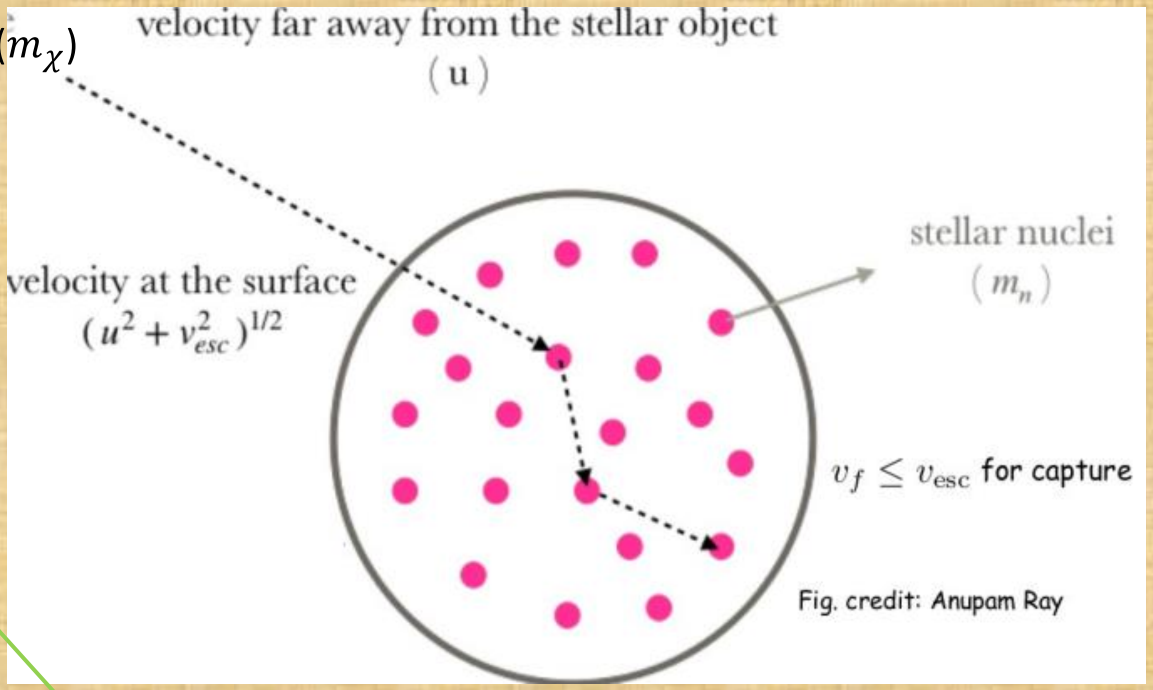
For DM masses $m_\chi \geq 10$ GeV the contribution of evaporation terms are negligible.

DM Capture Rate: Formalism

- The capture rate per unit volume due to species i is given by

$$\frac{dC_c}{dV} = \underbrace{\frac{\rho_\chi}{m_\chi}\int \frac{(u^2+v_{esc}^2)}{u} f(u)du}_{\text{DM flux}}\ \underbrace{\boxed{n_i}}_{\text{No. density of targets}}\ \underbrace{\boxed{\sigma_i^{\chi n}}}_{\text{DM-nucleon cross-section}}\ \underbrace{\boxed{P(w)}}_{\text{Capture probability}}$$

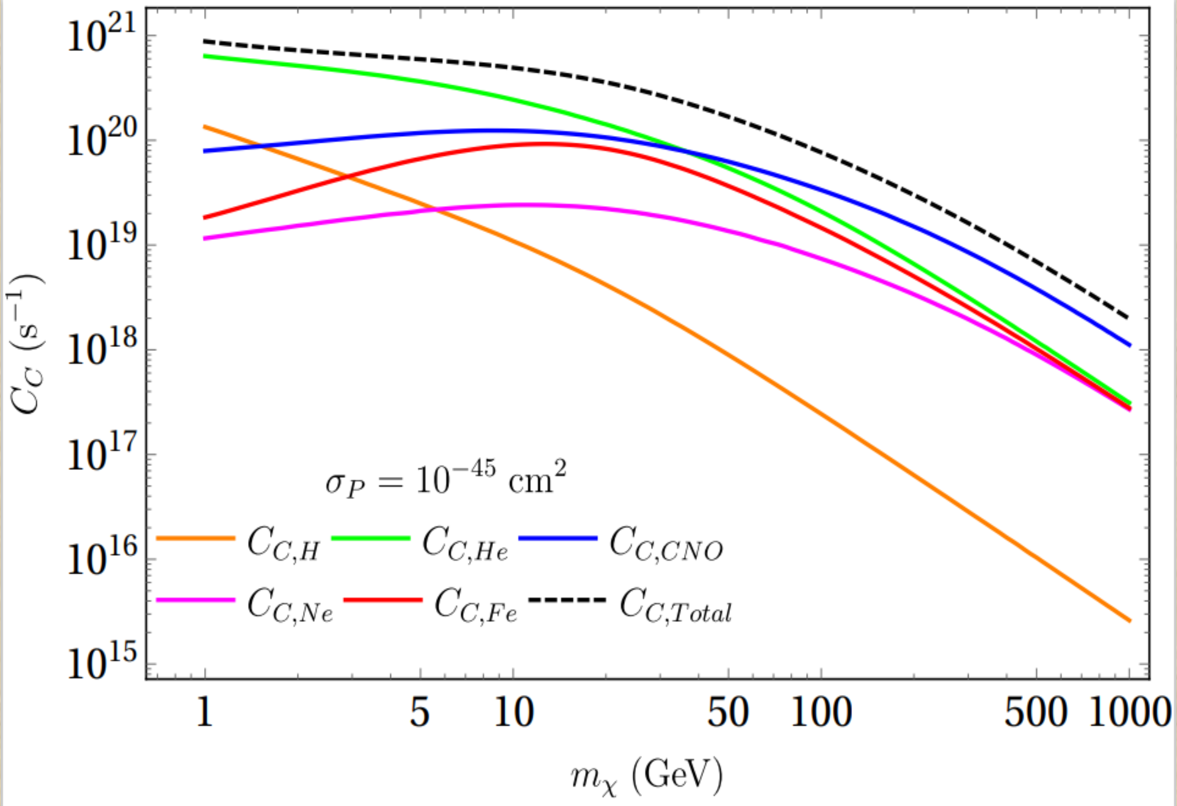
DM particle (m_χ)

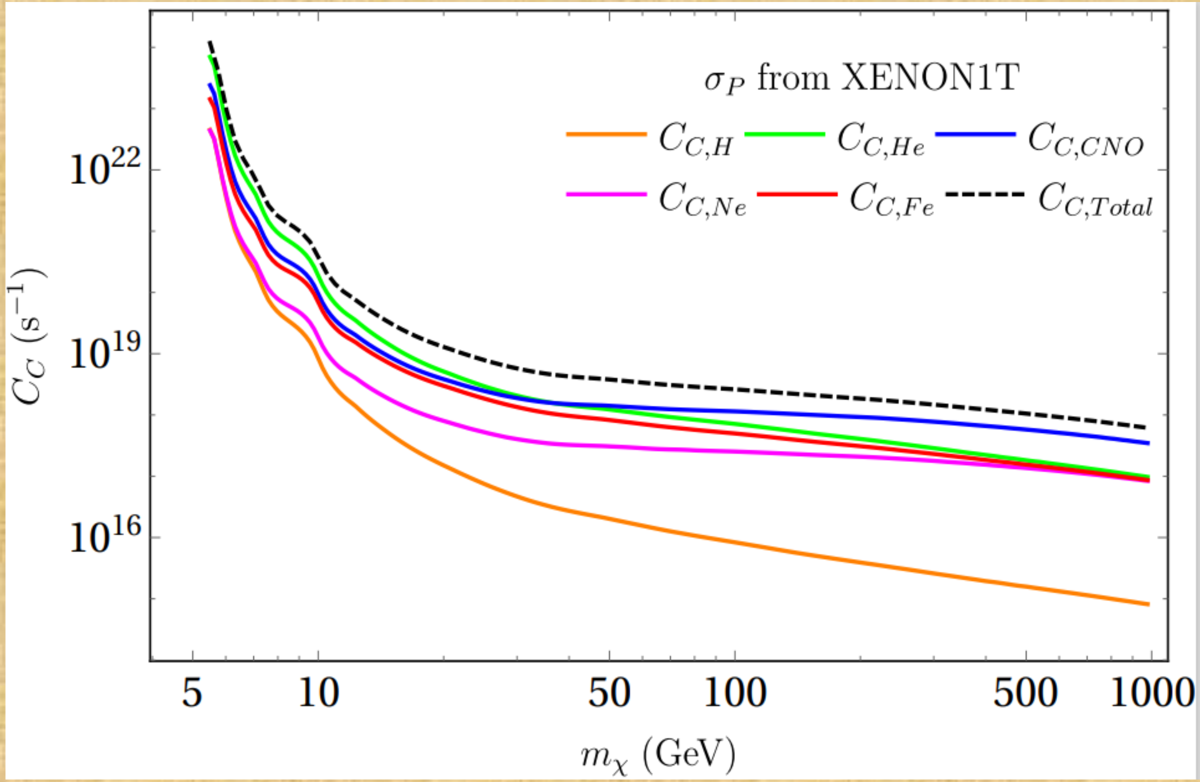


A. Gould, Astrophys. J. 321, 571 (1987)
arXiv:0907.3448 [astro-ph.HE]

DM Capture Rate: Results

(Computations in this work)





DM Annihilation Rate

- The annihilation rate of the gravitationally captured DM within Sun

$$C_{\rm ann} = \frac{1}{2}\langle\sigma v\rangle \int_0^{R_\odot} 4\pi r^2 A^2 \exp\left(\frac{-m_\chi \Phi(r)}{T_{\rm core}}\right) dr$$

Where

- $<\sigma v>$: thermally-averaged annihilation cross-section
- A: atomic mass number
- $\phi(r)$: gravitational potential at distance r from the centre of the Sun
- T_{core}: core temperature of the Sun

Detection Rate of Muon Event

- The differential neutrino flux of i^{th} flavour from DM annihilation

$$\left(\frac{d\phi}{dE}\right)_i = \frac{\Gamma_A}{4\pi R^2}\sum_F B_F \underbrace{\left(\frac{dN}{dE}\right)_{F,i}}_{}\,,$$

Where Γ_A, the total rate for WIMP annihilation in the Sun, is given by

Differential neutrino spectrum

PPPC: Cirelli et al 1012.4515

$$\Gamma_A = C_{\text{ann}} N^2$$

- The total detection rate of muon flux at ground based experiments like KM3NeT due to WIMP annihilation in the Sun is given by

$$\Gamma_{\text{detect}} = (2.54\times 10^{-29}\text{yr}^{-1})\,\frac{\Gamma_A}{\text{sec}^{-1}}\left(\frac{m_\chi}{\text{GeV}}\right)^2 \sum_{i=\nu,\bar{\nu}} a_i b_i \sum_F B_F \underbrace{\langle N_Z{}^2\rangle_{F,i}}_{} \times A_{\text{eff}},$$

where A_{eff} is the muon effective area at KM3NeT detector

Second moment of i^{th} flavour neutrino spectrum for channel F

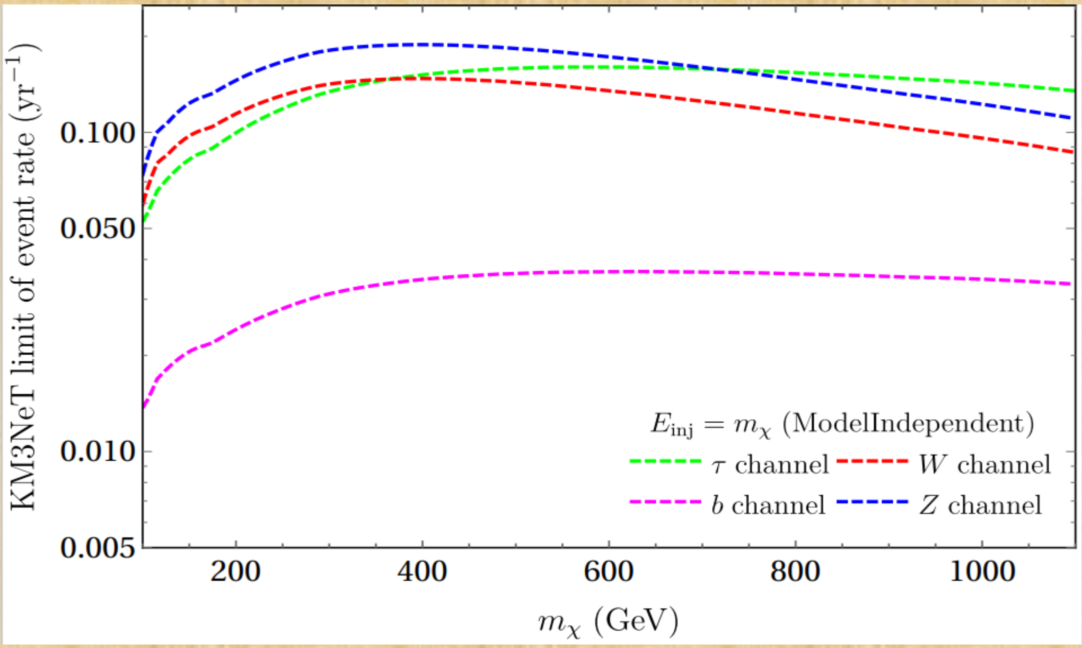
G. Jungman and M. Kamionkowski, Phys. Rev. D 51, 328 (1995)

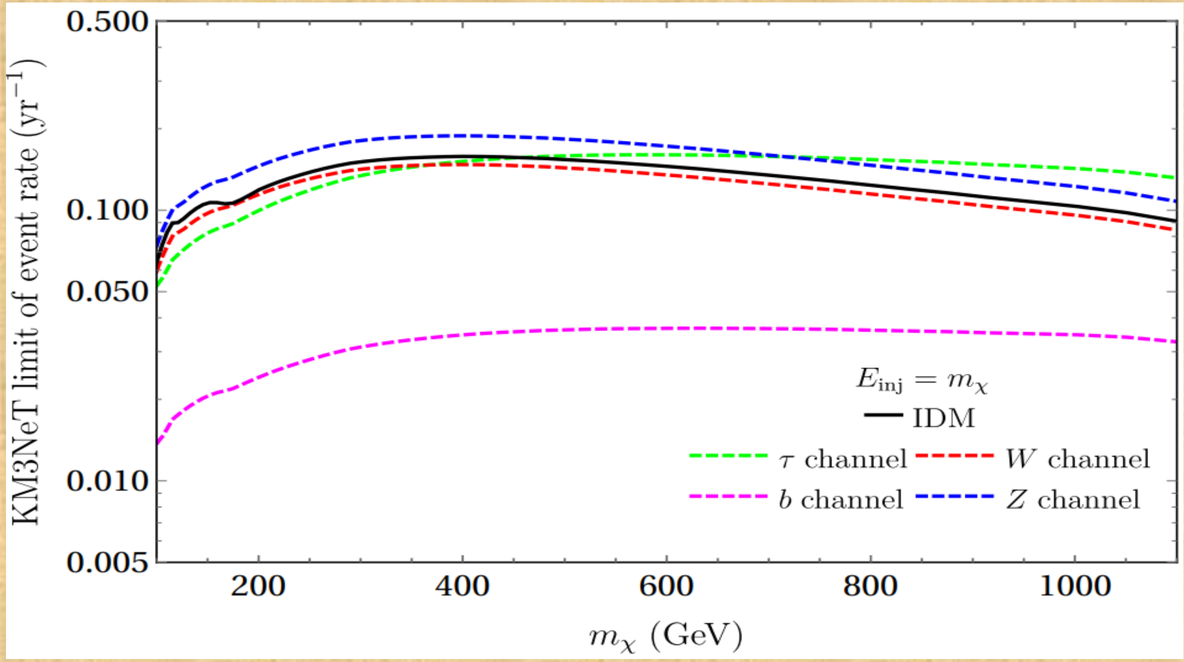
S. Adri´a n-Mart´ınez et al., J. Phys. G: Nucl. Part. Phys. 43, 084001 (2016)

KM3NeT upper limit of muon event rates

- We have estimated the upper bounds of the event rates for neutrino induced muons where neutrinos are originating from the dark matter annihilation in the Sun.

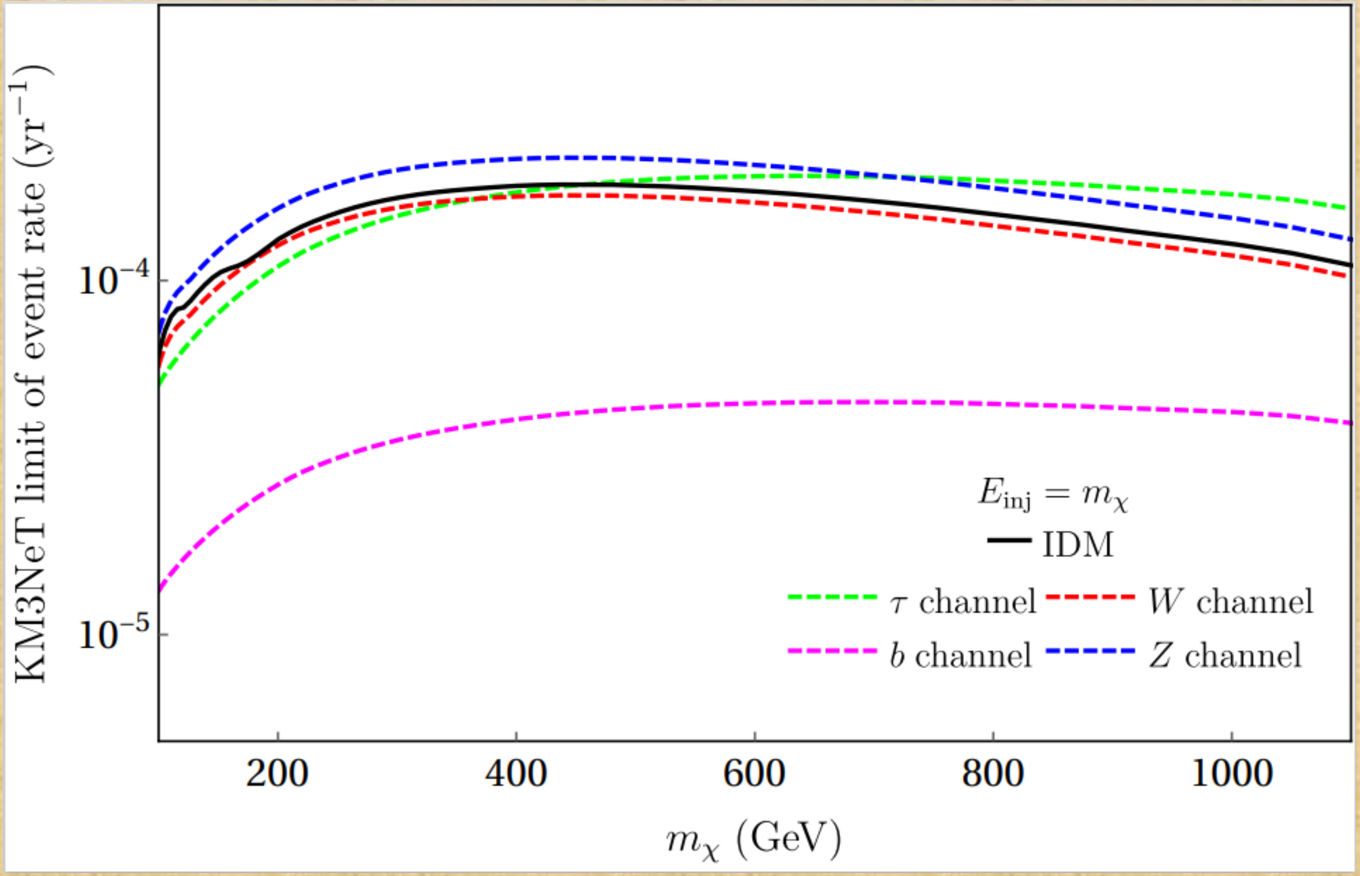
- We first consider a model independent scenario and obtain the neutrino induced muon event rates upper limit for four dark matter annihilation channels $\bar{\chi}\,\bar{\chi} \rightarrow (\tau\,\bar{\tau},\ b\bar{b},\ W^+W^-,\ Z\bar{Z})$ and then consider a DM candidate following a particle physics model, namely Inert Doublet Model (IDM).





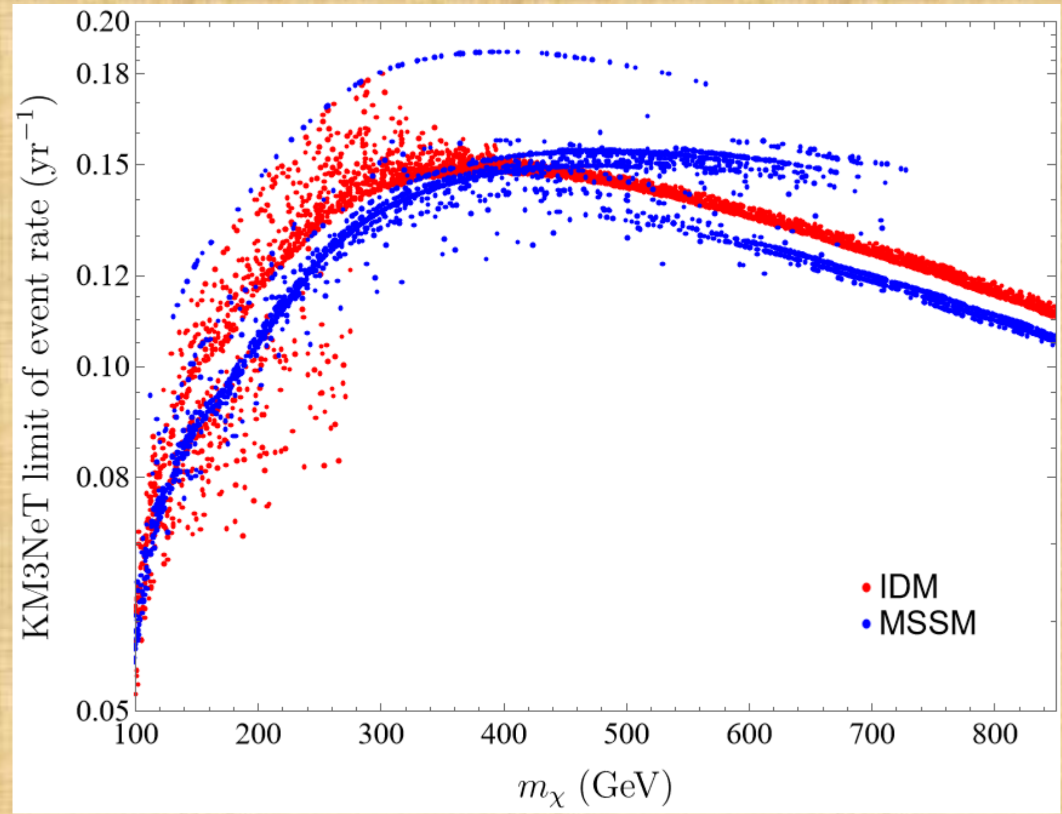
KM3NeT upper limit of muon event rates(contd.)

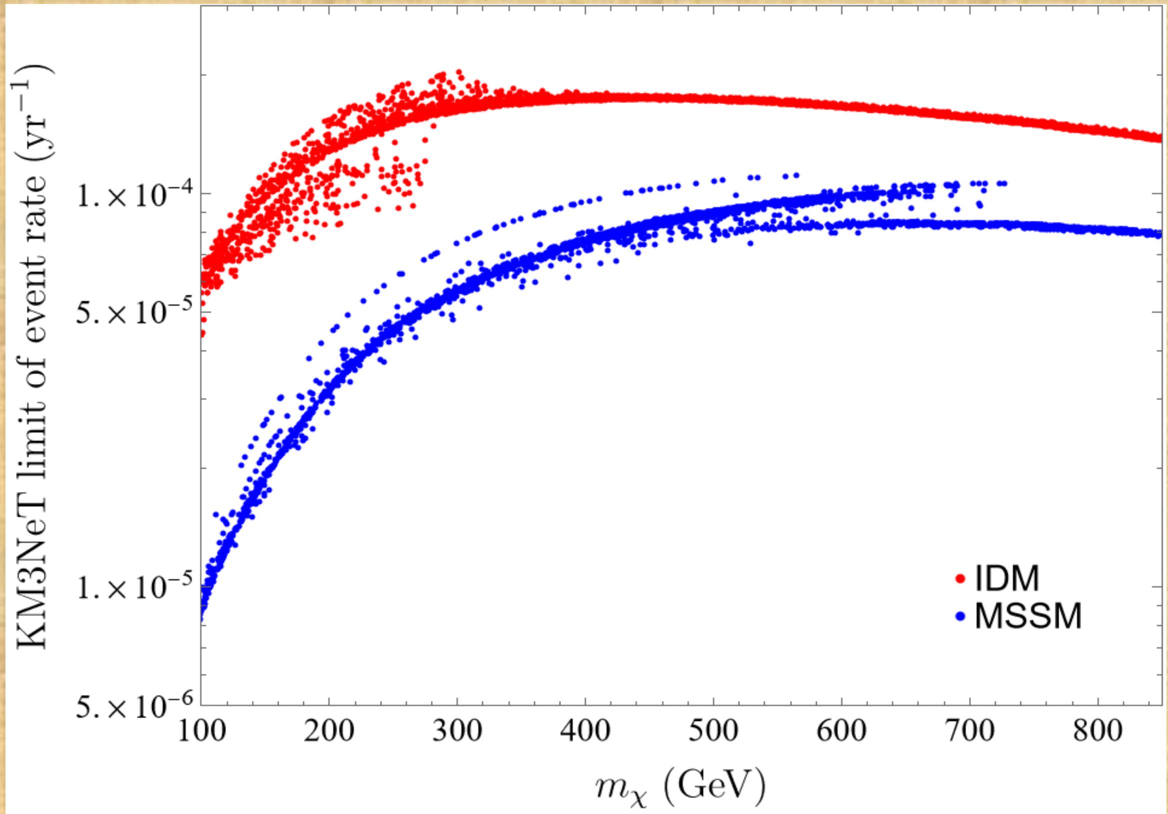
- Muon event rates when using the results from XENON1T direct detection experiment



Comparison of Event Rates for DM in IDM and MSSM models

- Here we consider another popular particle physics DM model; Minimal Supersymmetric Standard Model (MSSM)





σ^{SI} from: A. Gould, Astrophys. J. 321, 571 (1987)

Using XENON1T results

Summary and Discussions

- We have studied the potential of KM3NeT neutrino telescope to search for neutrinos originating from WIMP annihilation in the Sun.
- We have computed the DM capture rate inside the Sun from different solar processes.
- The model independent analysis are done at first and upper limit of ν_μ detection rates for four dark matter annihilation channels $\chi\bar{\chi} \rightarrow (\tau\,\bar{\tau},\ b\bar{b},\ W^+W^-,\ Z\bar{Z})$ are obtained.
- The upper limit of neutrino induced muon event rates have been estimated and a comparison is made between two particle DM models, namely IDM and MSSM.
- We observe that KM3NeT upper limit for event rates is higher for neutrinos from IDM DM model than for those from MSSM model, when constraints from XENON1T results are used.

Thank you ☺

BACK UP

Second moment of i^{th} flavour neutrino spectrum

For $\chi\bar{\chi} \to \tau\bar{\tau}$ channel,

$$\langle N_Z{}^2\rangle_i(E_{\rm inj})\big|_\tau \simeq \Gamma_{\tau\to\mu\nu\bar{\nu}} h_{\tau,i}(E_{\rm inj}\tau_i)$$

For the self-annihilation channel $\chi\bar{\chi} \to b\bar{b}$, $\langle N_Z{}^2\rangle$ is expressed as

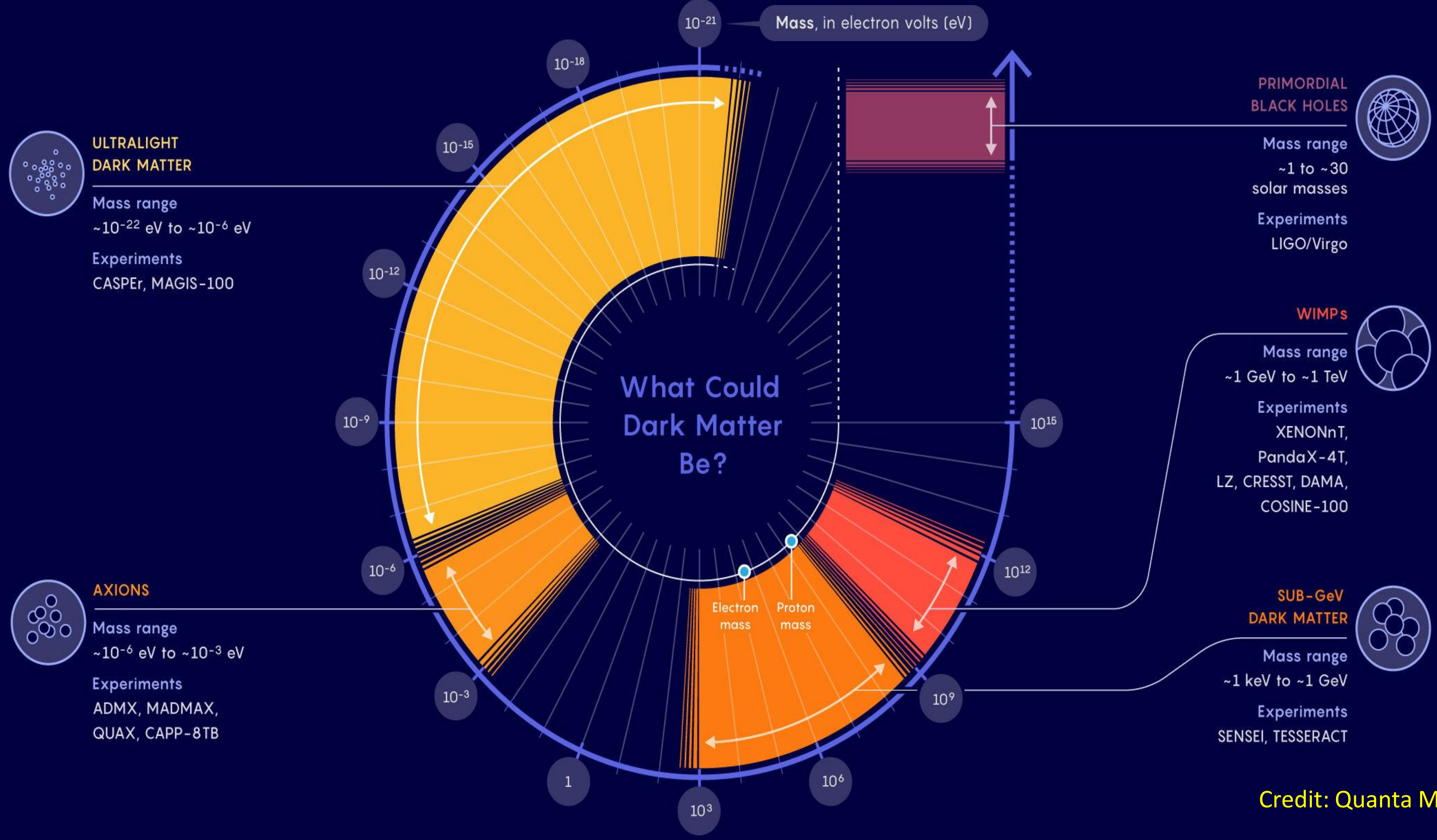
Energy loss during hadronization of b quark

$$\langle N_Z{}^2\rangle_i(E_{inj})\big|_b \simeq \Gamma_{b\to\mu\nu X}\frac{\langle E_d\rangle^2}{E_i^2} h_{b,i}\left(\sqrt{\langle E_d^2\rangle}\tau_i\right)$$

Finally, for the channels, $\chi\bar{\chi} \to W^+W^-$ and $\chi\bar{\chi} \to Z\bar{Z}$,

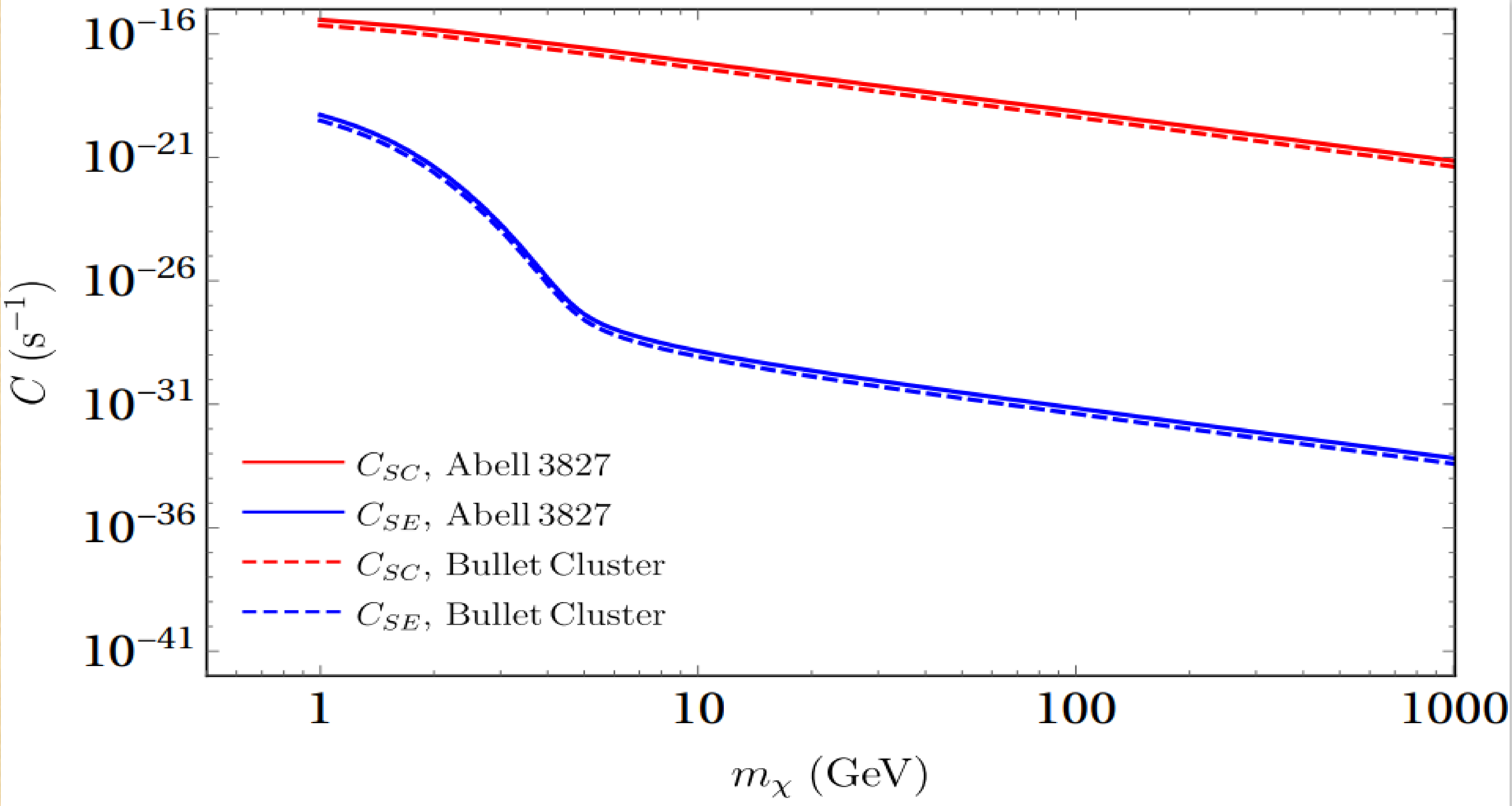
$$\langle N_Z{}^2\rangle_i(E_{\rm inj})\big|_W \simeq \frac{\Gamma_{W\to\mu\nu}}{\beta}\frac{2+2E\tau_i(1+\alpha_i)+E^2\tau_i^2\alpha_i(1+\alpha_i)}{E_{\rm inj}^3\tau_i^3\alpha_i(\alpha_i^2-1)(1+E\tau_i)^{\alpha_i+1}}\Bigg|_{E=E_{\rm inj}(1+\beta)/2}^{E=E_{\rm inj}(1-\beta)/2}$$

$$\langle N_Z{}^2\rangle_i(E_{\rm inj})\big|_Z \simeq \frac{2\Gamma_{Z\to\nu_\mu\bar{\nu}_\mu}}{\beta}\frac{2+2E\tau_i(1+\alpha_i)+E^2\tau_i^2\alpha_i(1+\alpha_i)}{E_{\rm inj}^3\tau_i^3\alpha_i(\alpha_i^2-1)(1+E\tau_i)^{\alpha_i+1}}\Bigg|_{E=E_{\rm inj}(1+\beta)/2}^{E=E_{\rm inj}(1-\beta)/2}$$

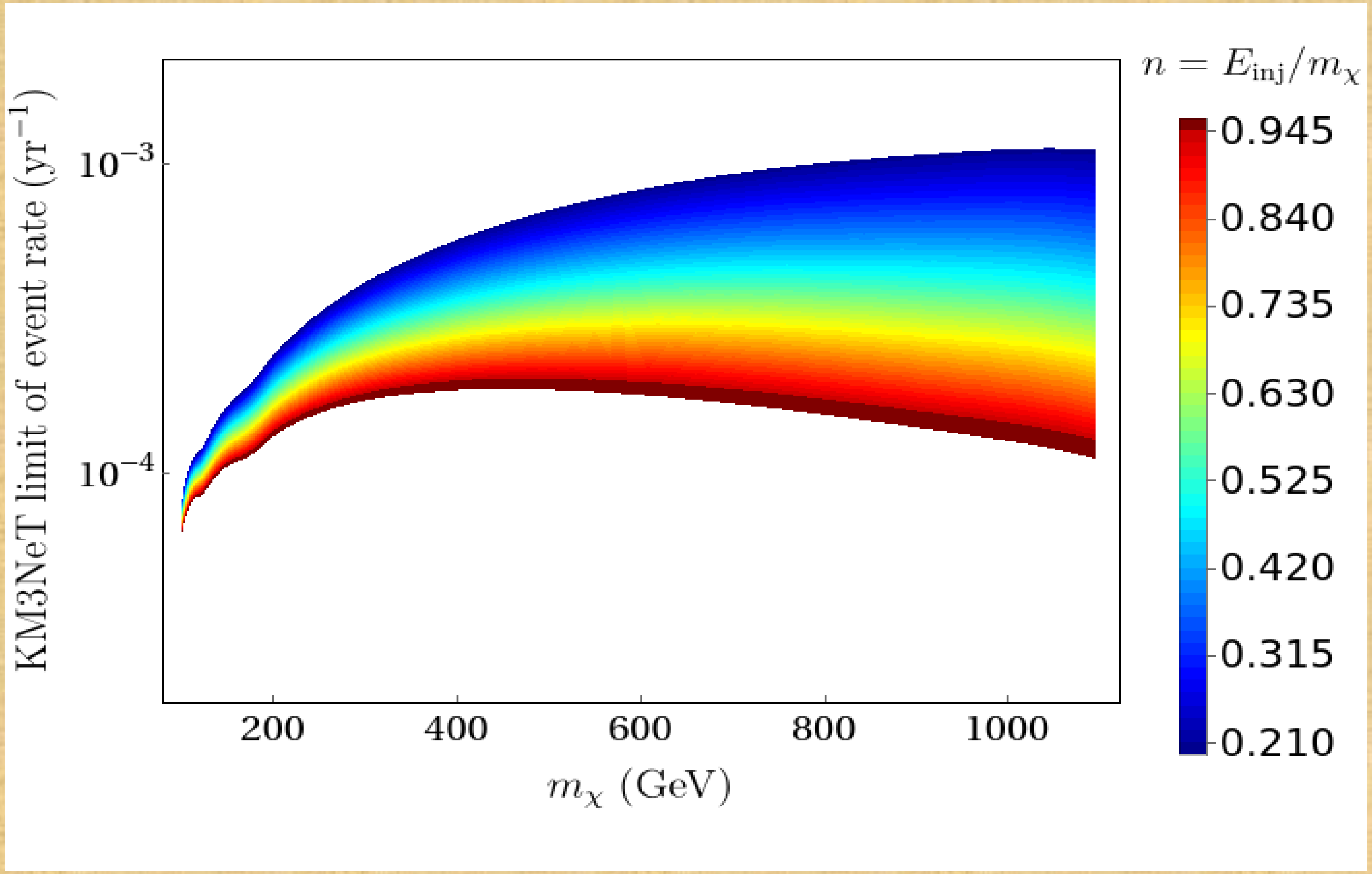


Credit: Quanta Magazine

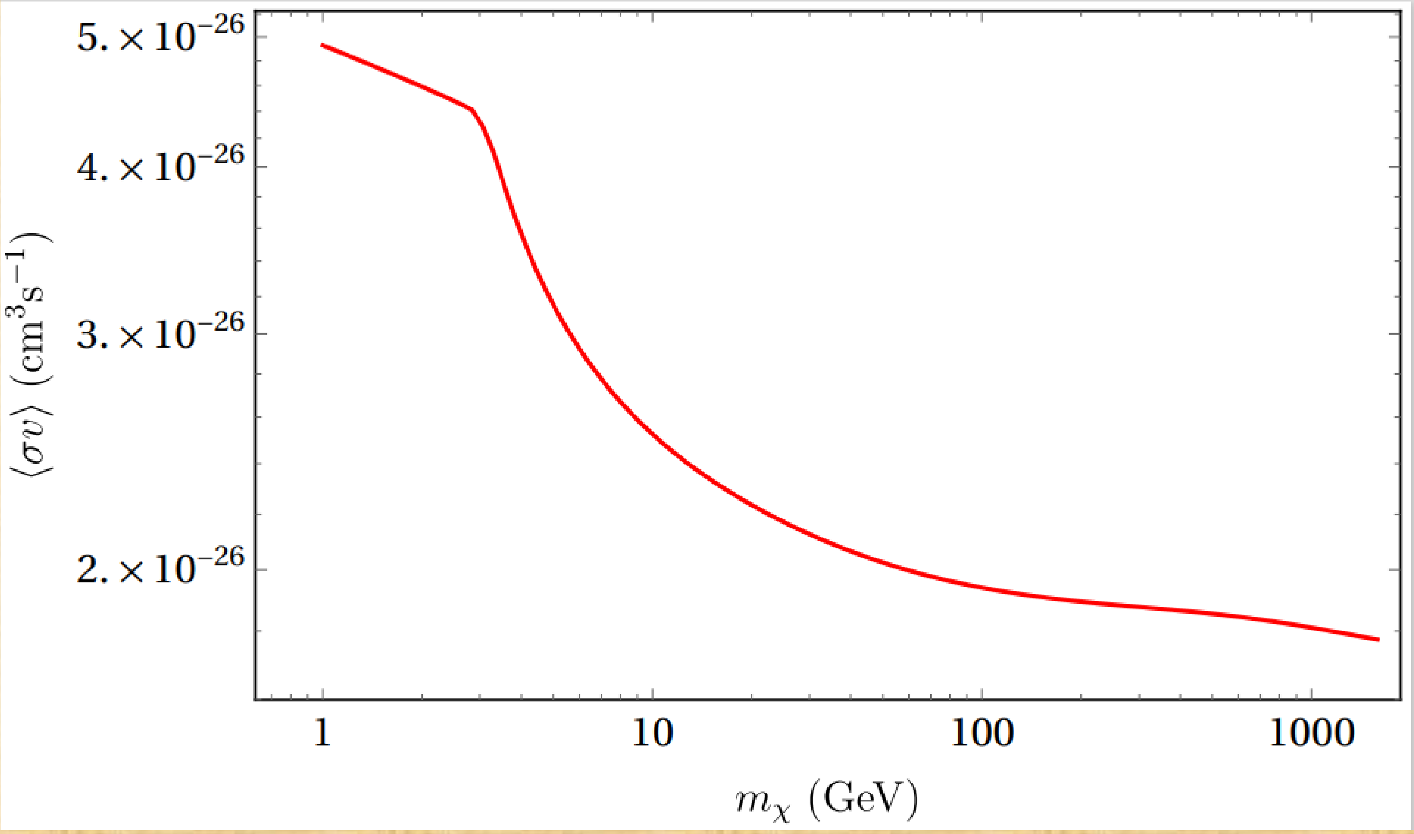
DM self-capture and self-ejection rates

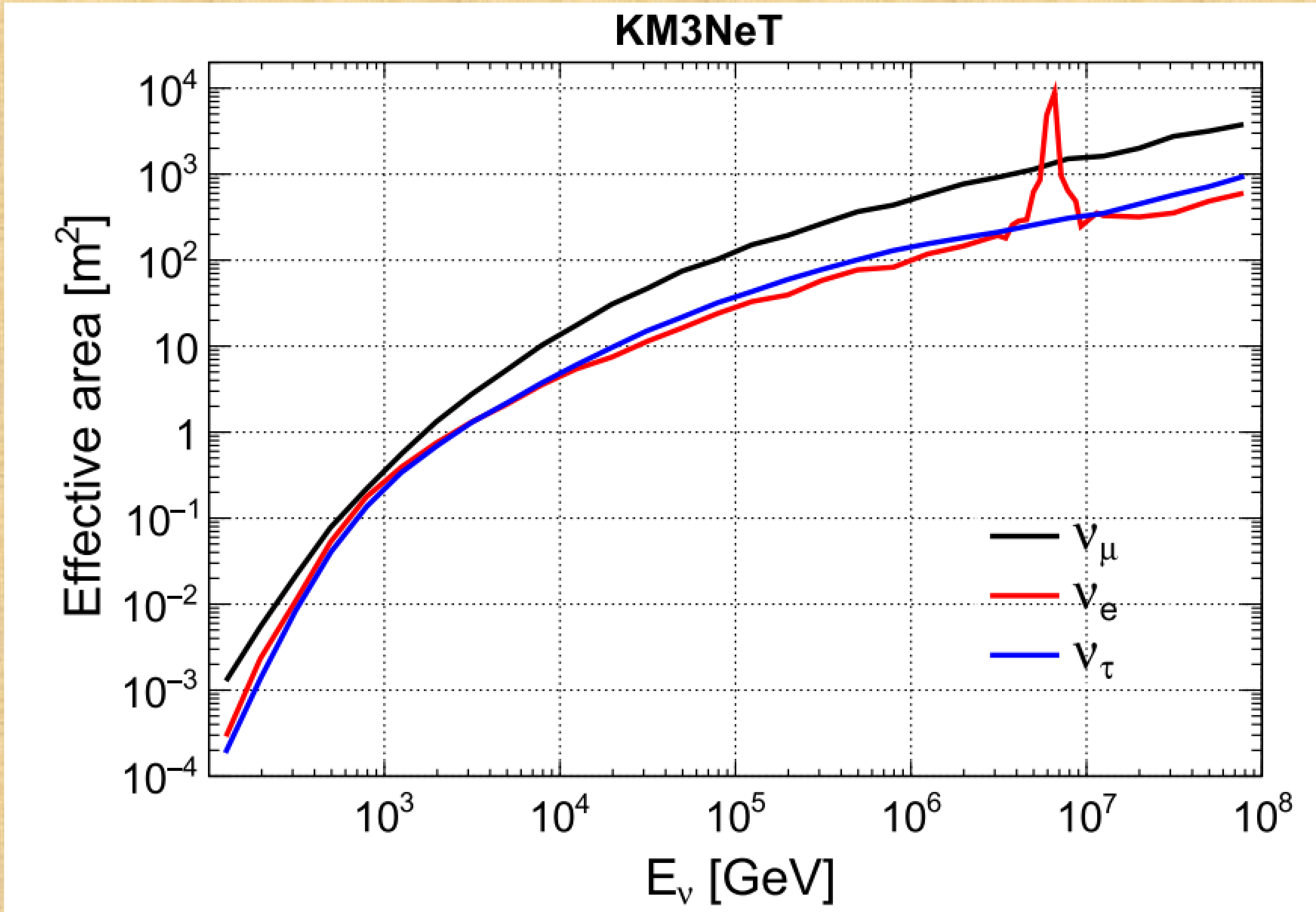


Contour representation of muon event rates



Model independent calculation of $< \sigma v >$





KM3NeT
Effective area [m^2]
10^4
10^3
10^2
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^3
10^4
10^5
10^6
10^7
10^8
E_ν [GeV]
ν_μ
ν_e
ν_τ