# Search for the Cosmic Ray Boosted Dark Matter at the PandaX-II Experiment

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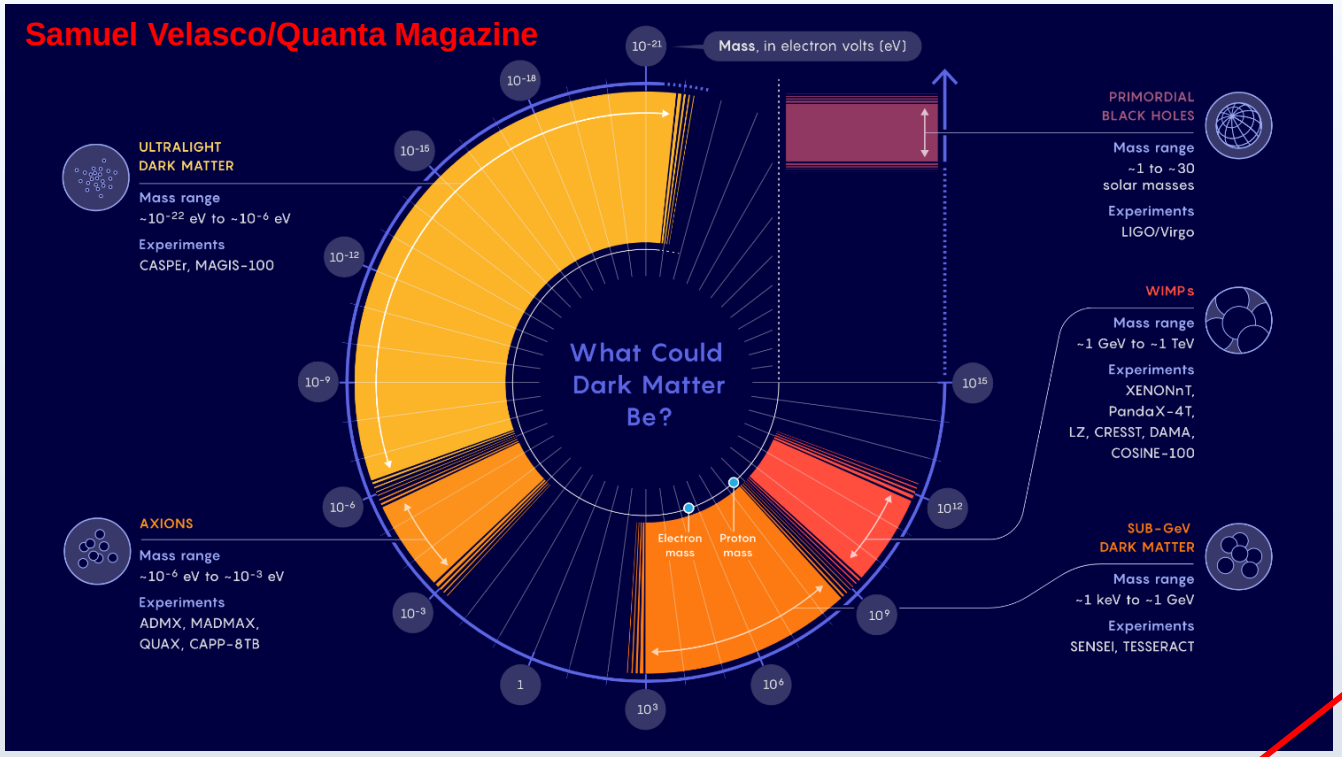
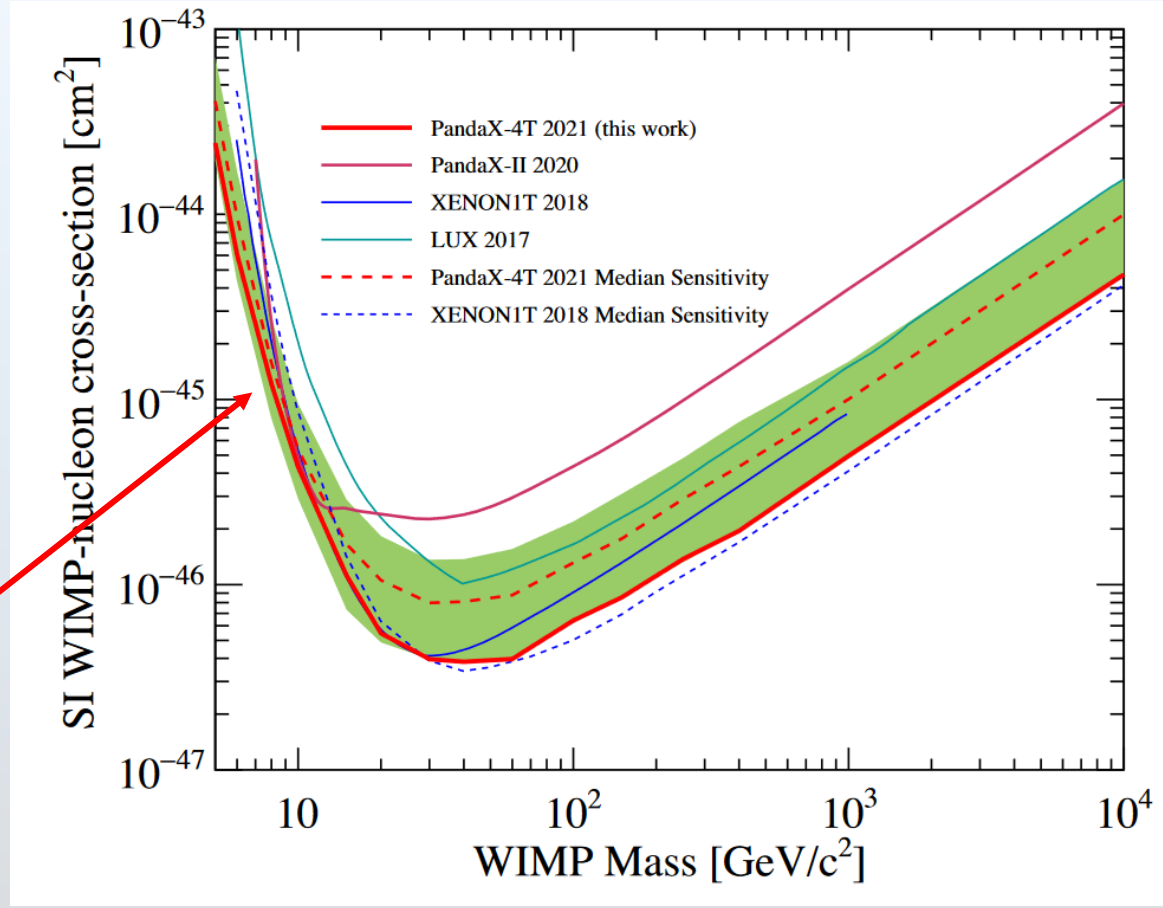
**On behalf of the PandaX-II collaboration**
**Assistance of S.F. Ge and Q. Yuan**

# Dark Matter Candidates



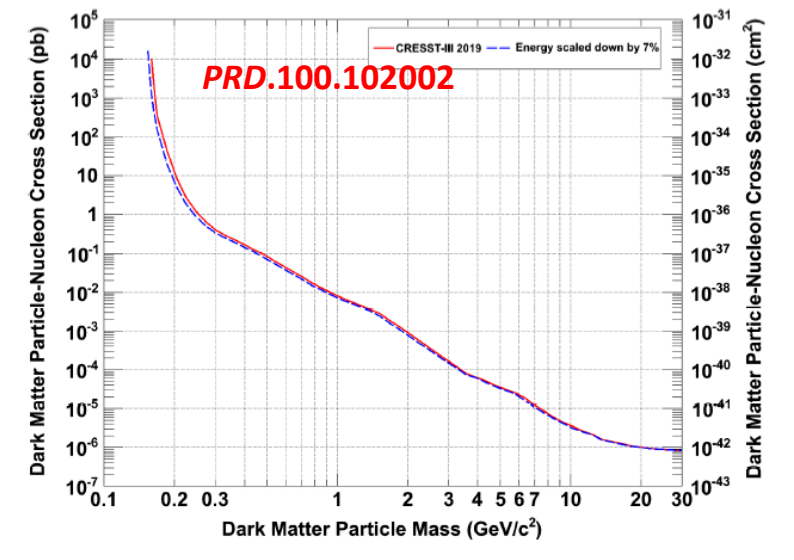

*Phys.Rev.Lett.* 127 (2021) 26, 261802

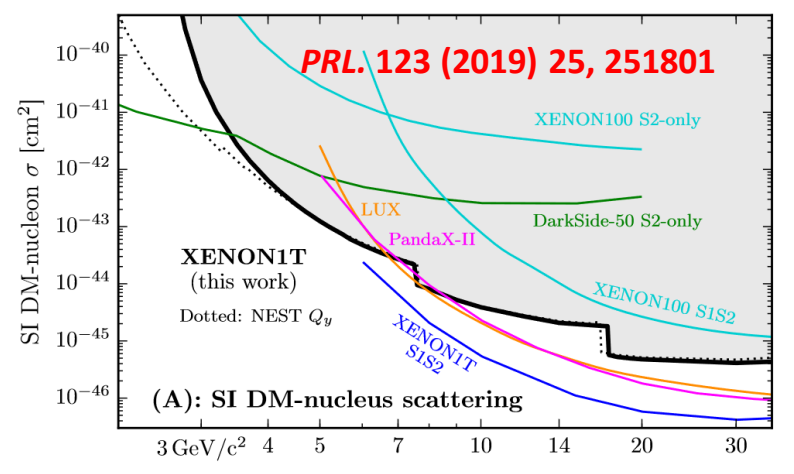



$$m_\chi^{min} \sim m_T / \left(\sqrt{2 m_T v_{max}^2 / E_{th}} - 1\right)$$

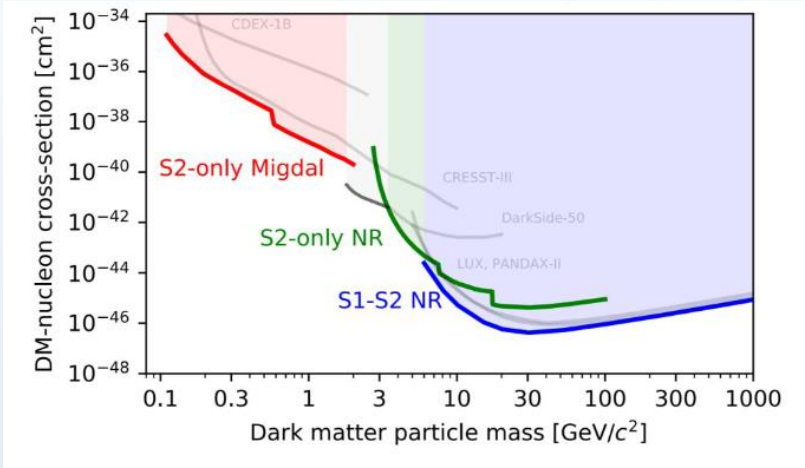
# Constraints for Sub-GeV region in DM DD experiments

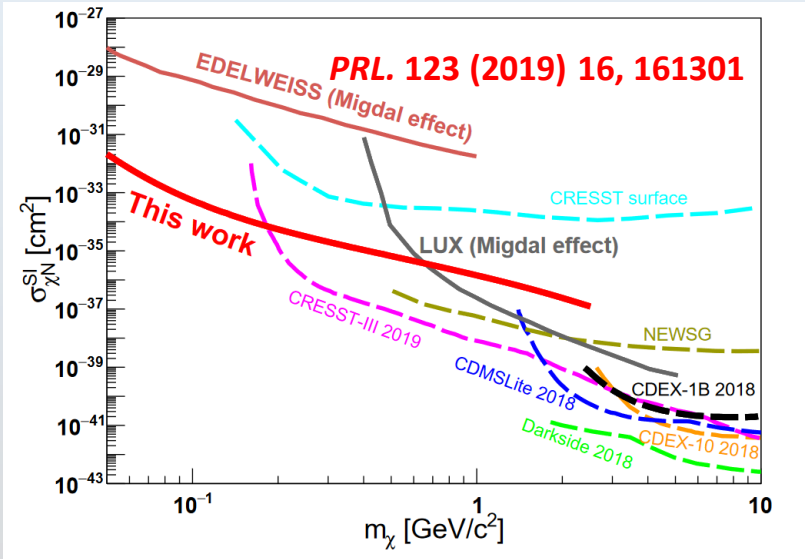
## Lower threshold



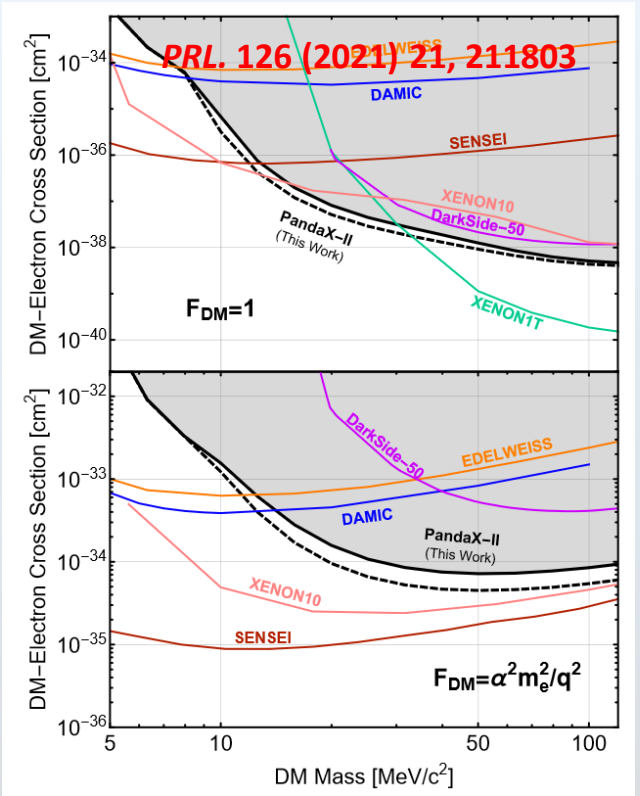




## Migdal effect



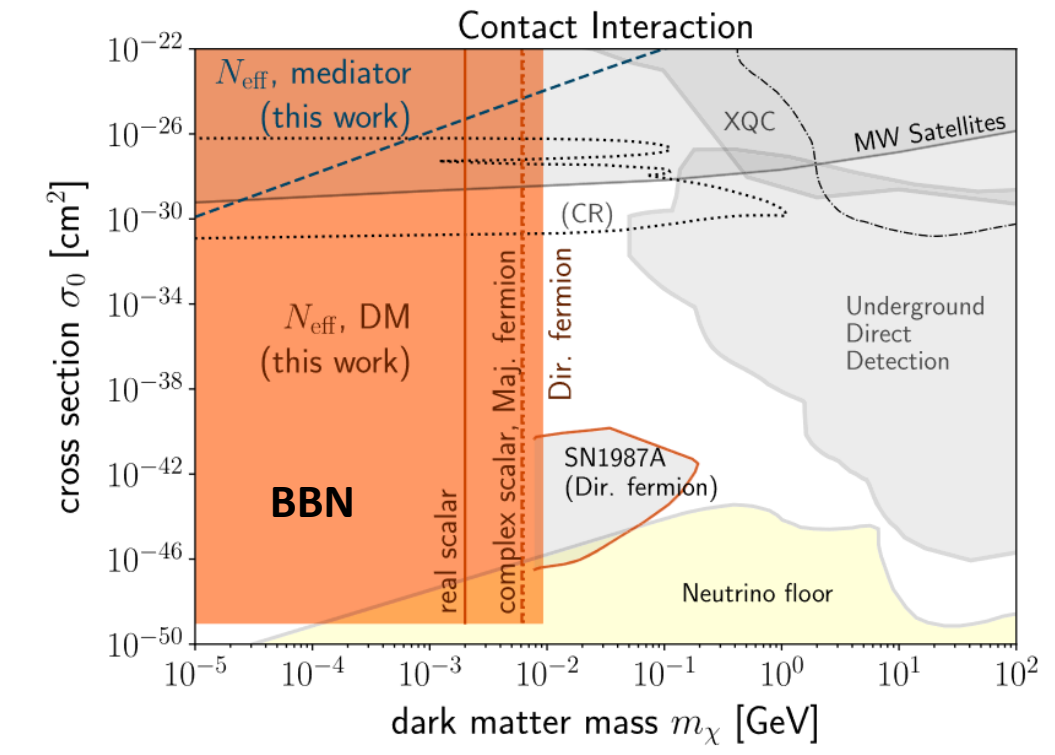




## DM-e

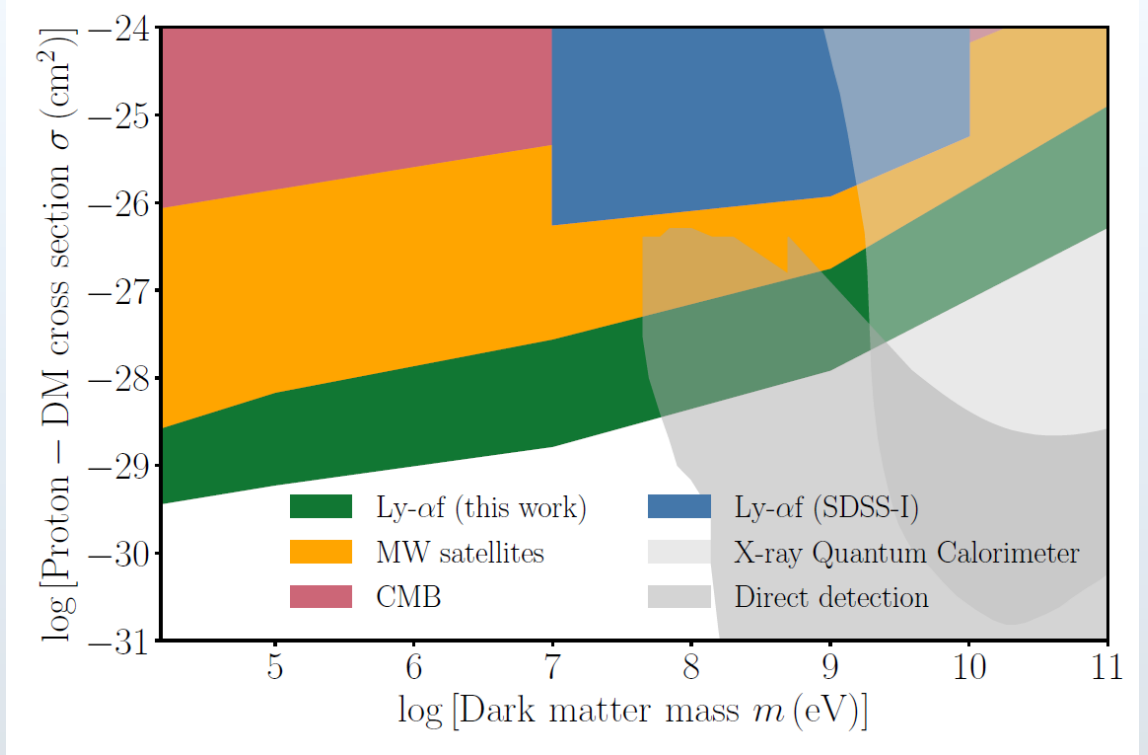


# Constraints for Sub-GeV region

*Phys.Rev.D* 101 (2020) 12, 123022

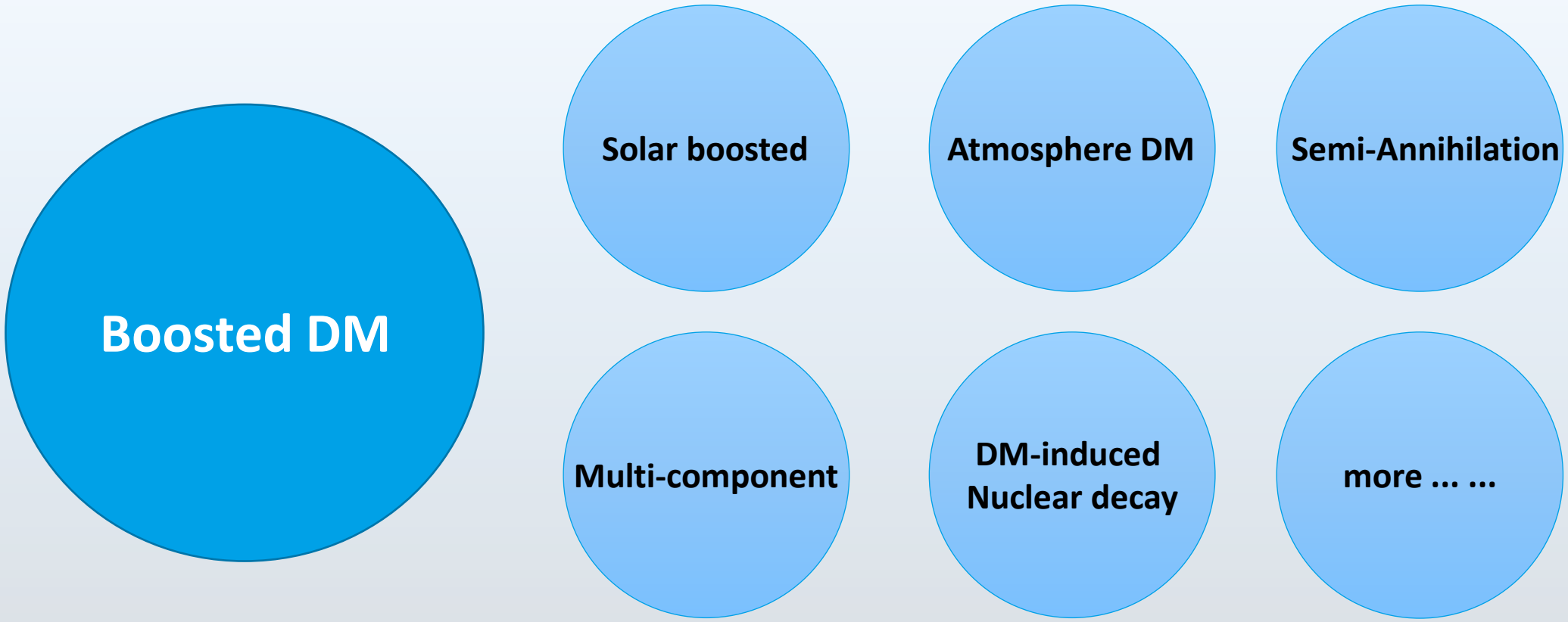



*Phys.Rev.Lett.* 128 (2022) 17, 171301

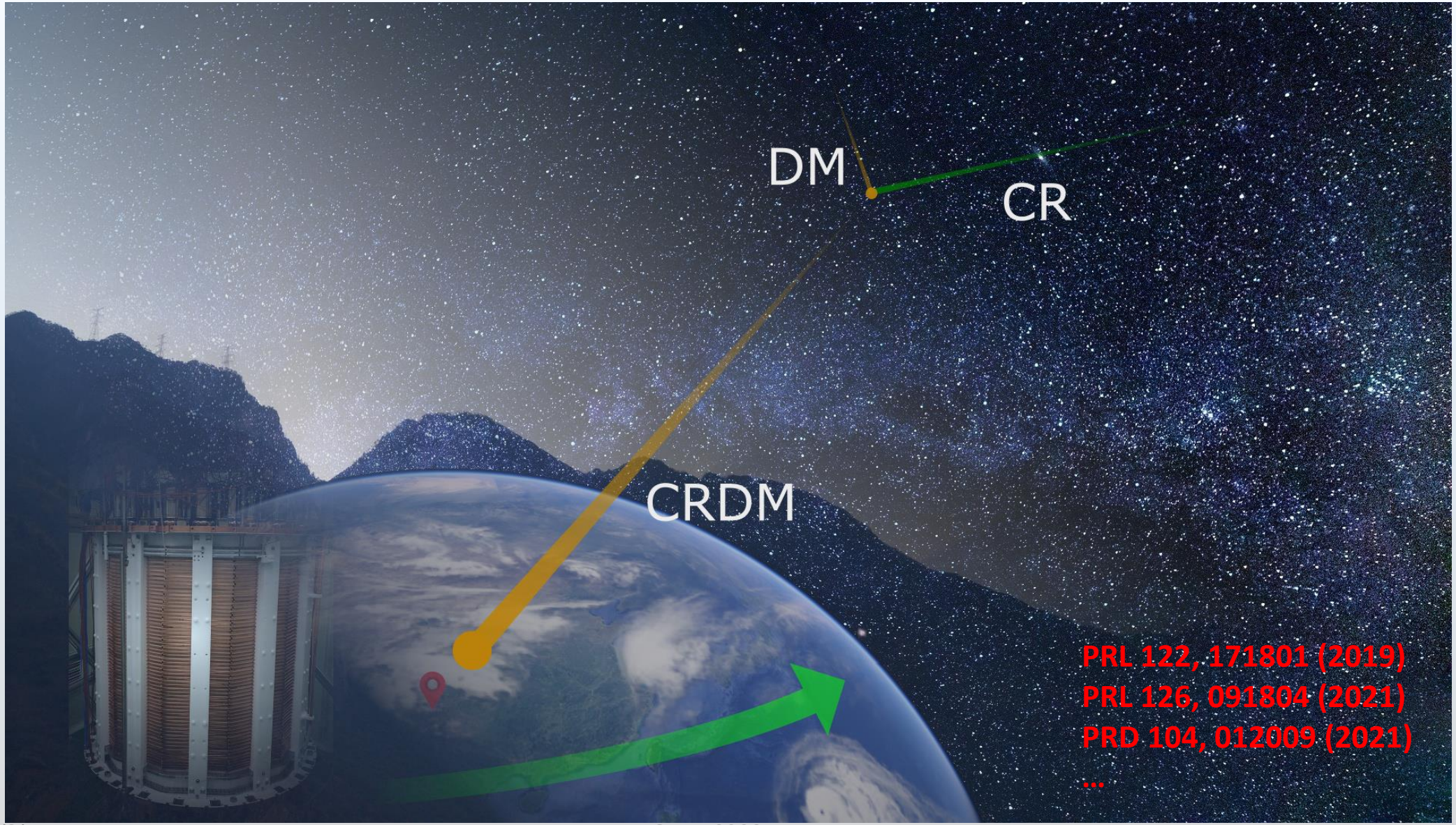



- A large mass range from MeV/c2 to GeV/c2 has not been explored by the DM DD experiment or the cosmological observables;

# Boosted Dark Matter

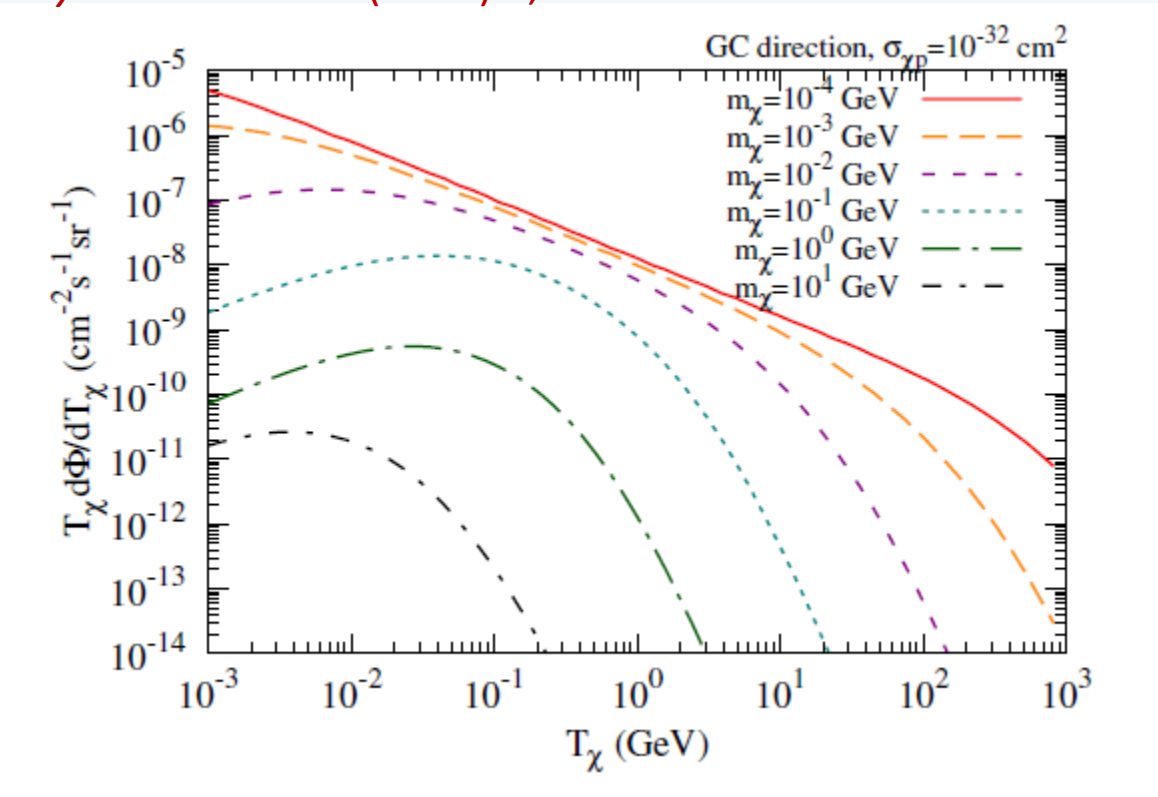


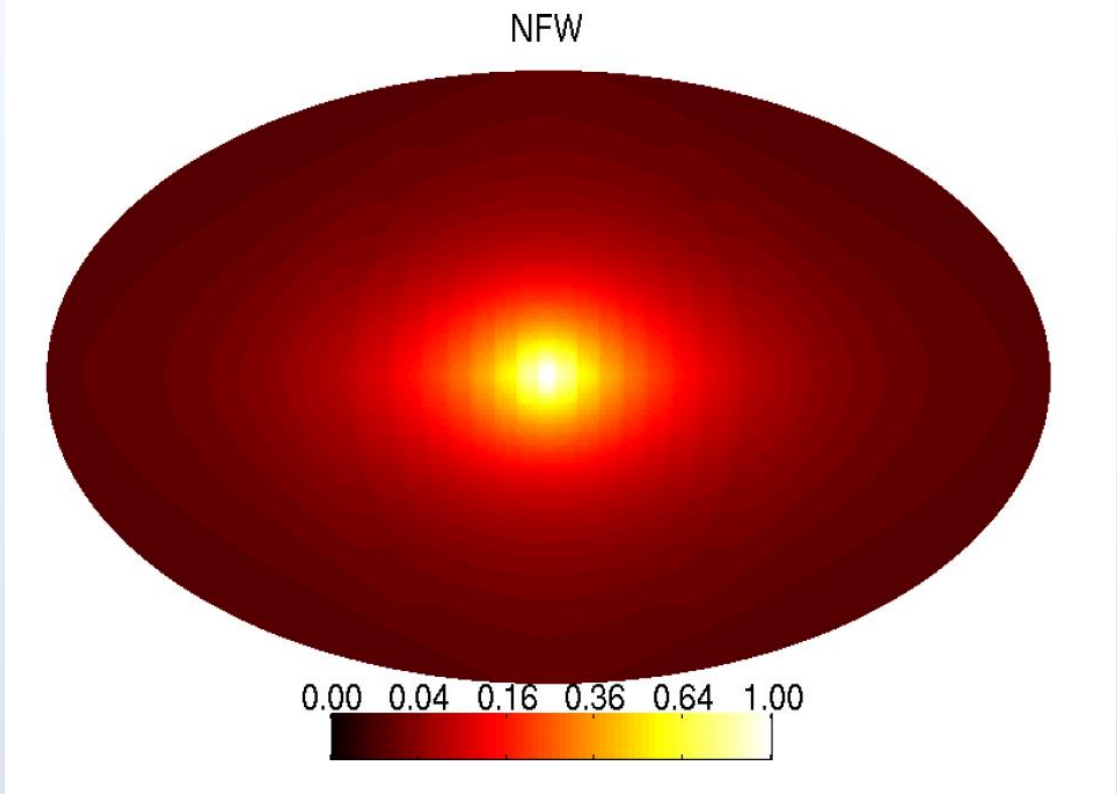
# Cosmic Ray Boosted Dark Matter (CRDM)



# DM accelated by cosmic rays

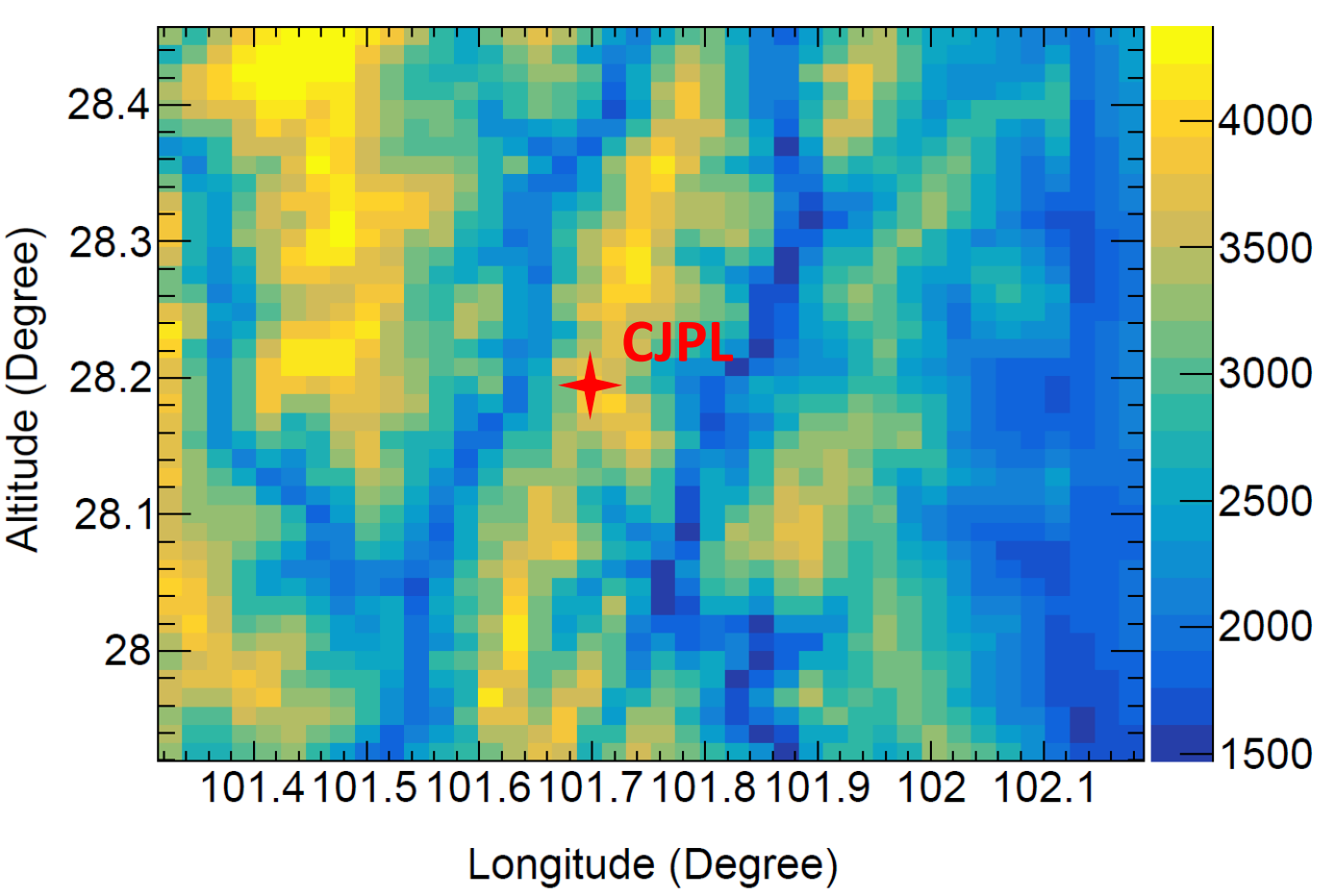
*Phys.Rev.Lett.* 126 (2021) 9, 091804




- Massive DM particles will be limited to high energy;
- CRDM flux mainly come from the Galaxy Center, and the spectrum is independent with the incoming angle to Earth;

# Jinping mountain




*Phys.Rev.D* 105 (2022) 5, 052005

**CJPL rock composition**

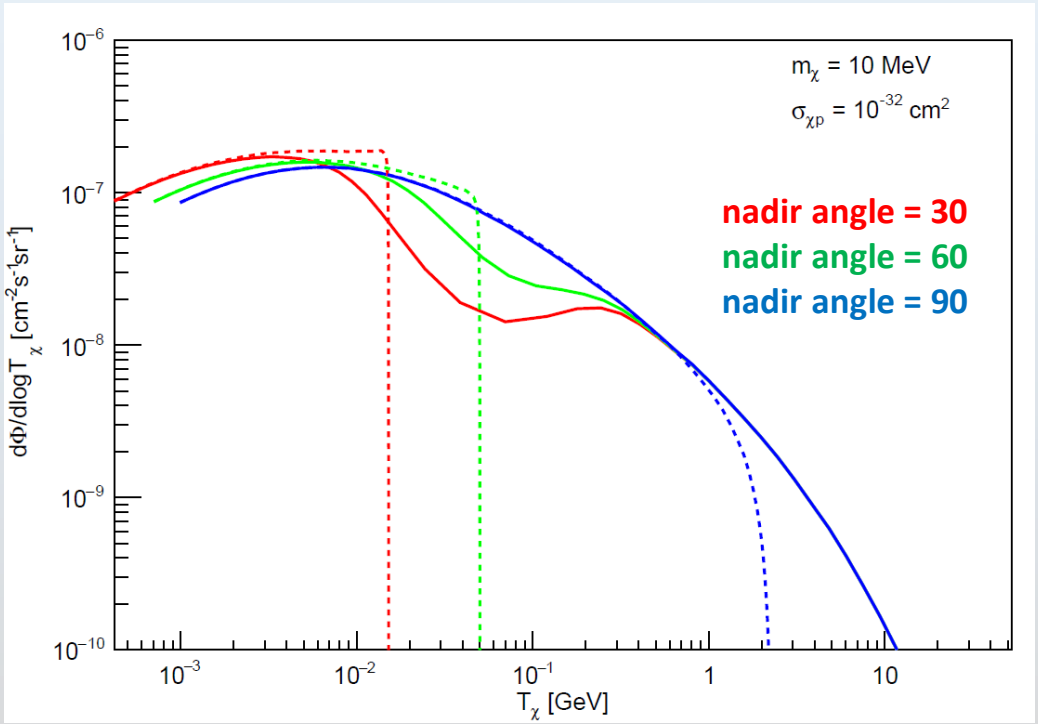
| element | O | Ca | Mg | C | Si | Al | Fe | K | Na | P |
|---|---|---|---|---|---|---|---|---|---|---|
| $f$ (%) | 46.42 | 31.96 | 11.50 | 9.59 | 0.19 | 0.15 | 0.10 | 0.07 | 0.01 | 0.01 |
| Z | 8 | 20 | 12 | 6 | 14 | 13 | 26 | 19 | 11 | 15 |
| A | 16 | 40 | 24 | 12 | 28 | 27 | 56 | 39 | 23 | 31 |

- Elevation points in ~50*50km is extracted from the Database;
- Ideal Earth structure beside the mountain is used;

# Earth attenuation – “ballistic trajectory” BT method

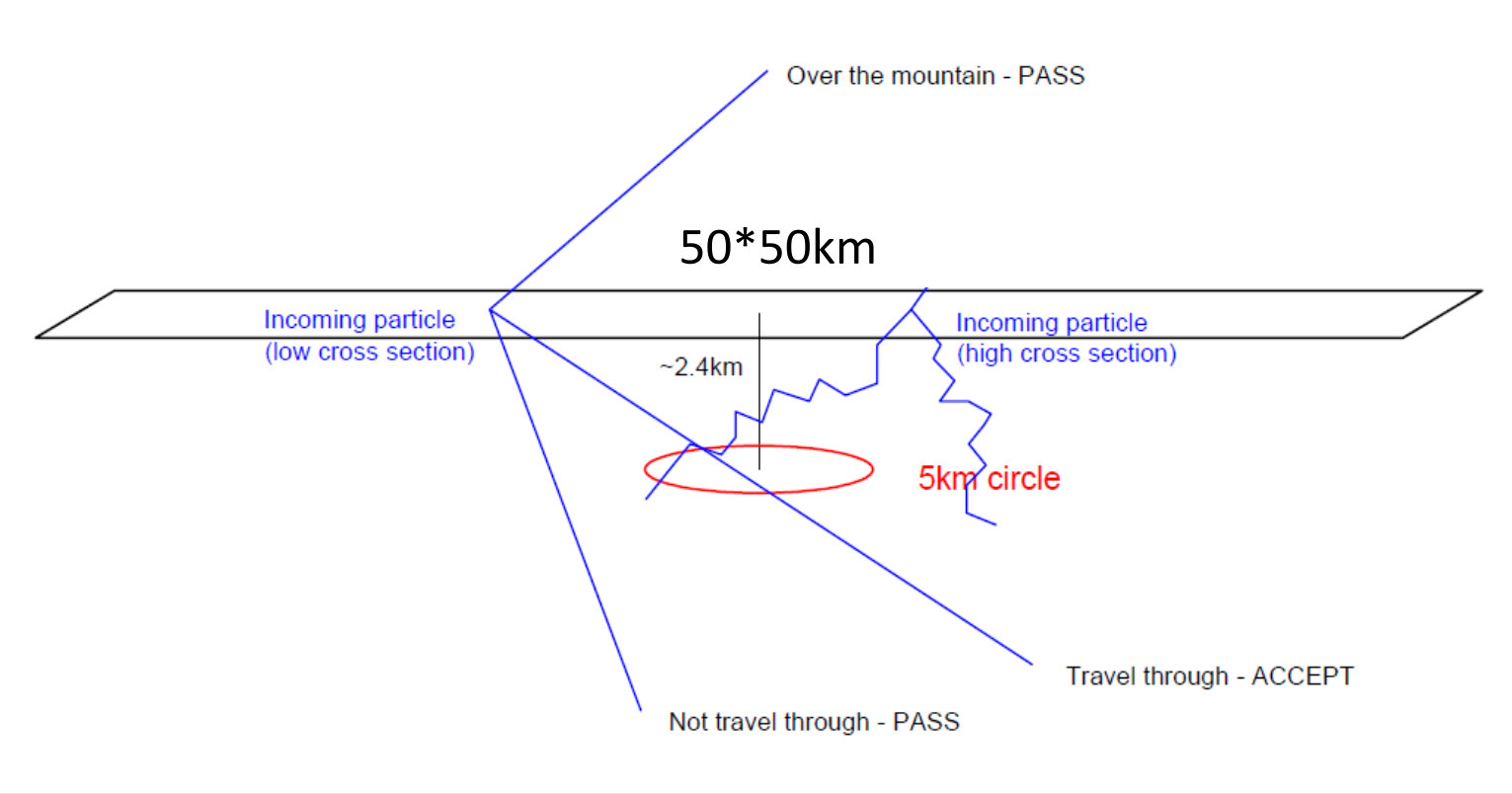
$$\left\langle \frac{dT_\chi}{dx} \right\rangle = -\frac{\rho_A}{m_A} \int_0^{T_r^{\max}} \frac{d\sigma_{\chi A}}{dT_r} T_r dT_r \,, \qquad (1)$$

$$\frac{d\sigma_{\chi A}}{dT_r} = \frac{\sigma_{\chi p} A^2}{T_r^{max}} \left[ \frac{m_A(m_\chi + m_p)}{m_p(m_\chi + m_A)} \right]^2 G_A^2(Q^2), \qquad (2)$$



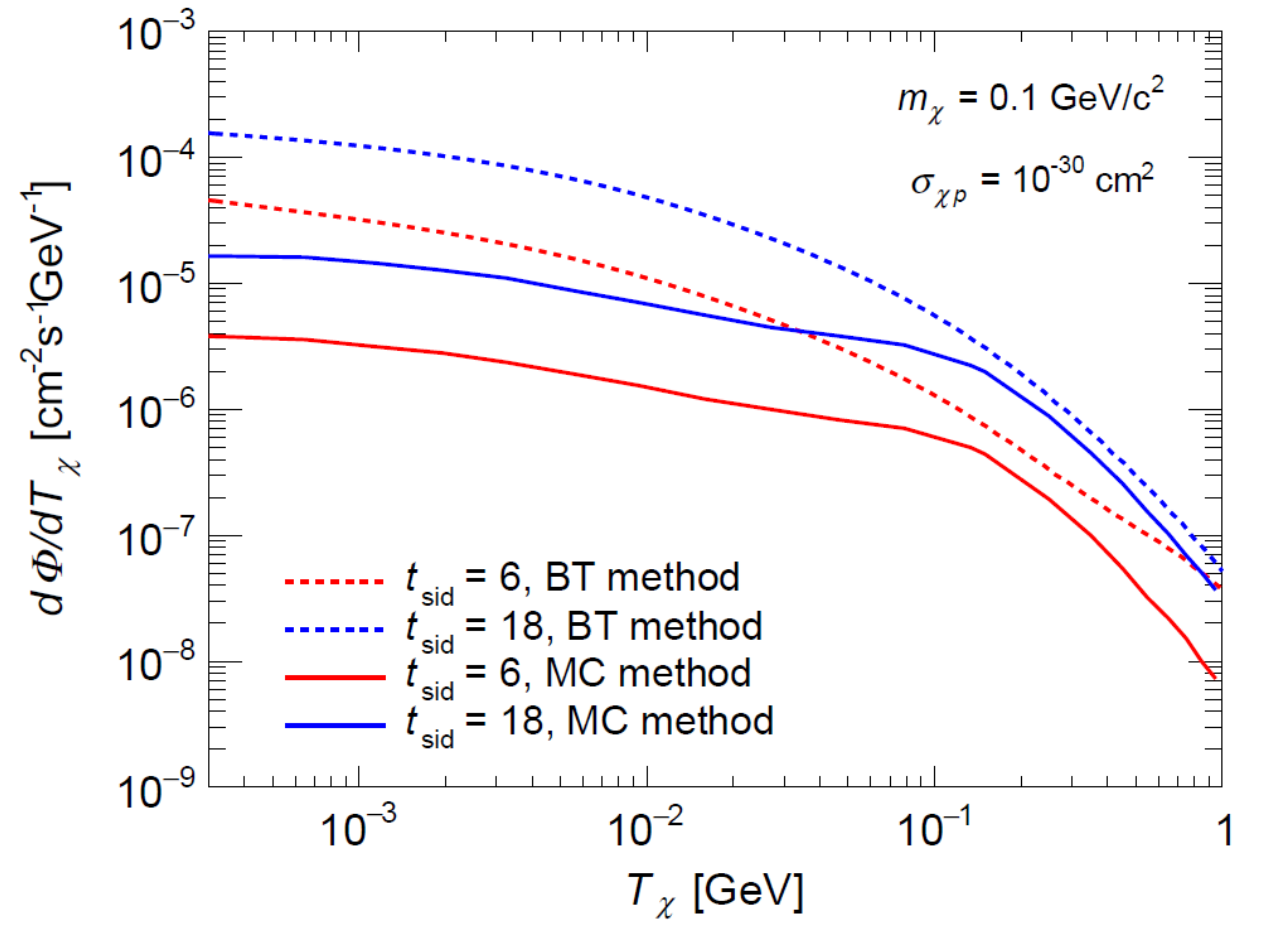

- BT method is assumed no deflection after each scattering in Earth, and calculated with the full solid angle;
- With and without the Earth nuclear form factor will bring a different in the attenuated spectrum;

# Earth attenuation – MC simulation




- The DM-nucleus collisions are simulated according to the total cross section based on the Earth form factor;
- Simulate until the DM cross the selection circle, or escape the mountain or stops;
- Only CRDM up-head of Jinping mountain is simulated, flux conservative considered;

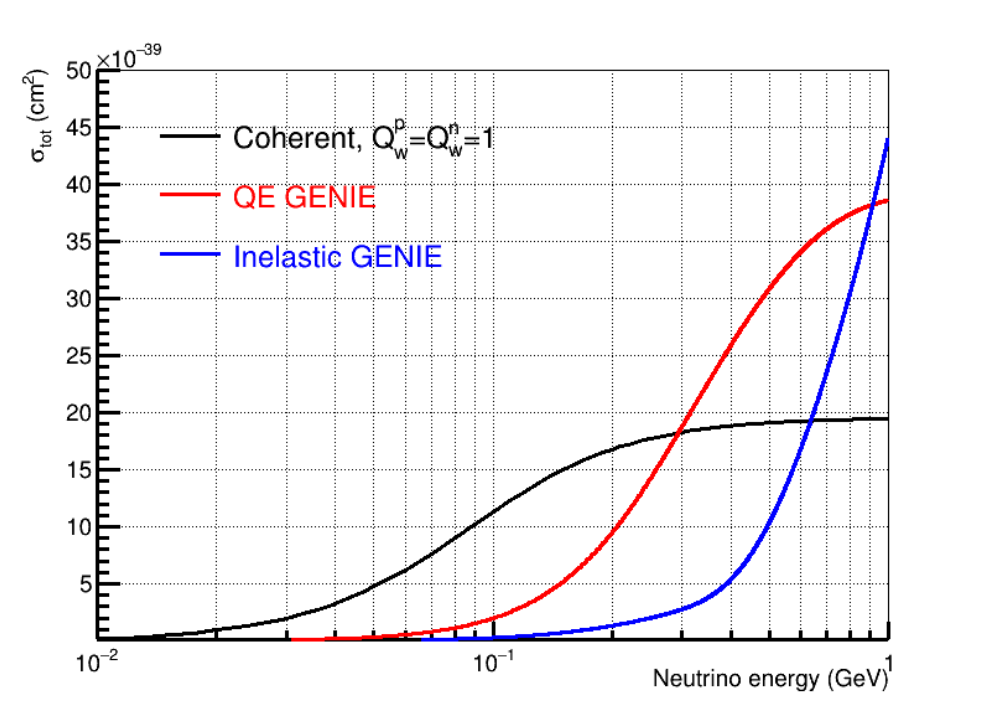
# Earth attenuation – CRDM attenuated spectrum




- The MC result is more conservative than BT method, and used in the analysis;
- CRDM diurnal modulation is derived from the attenuation effect;

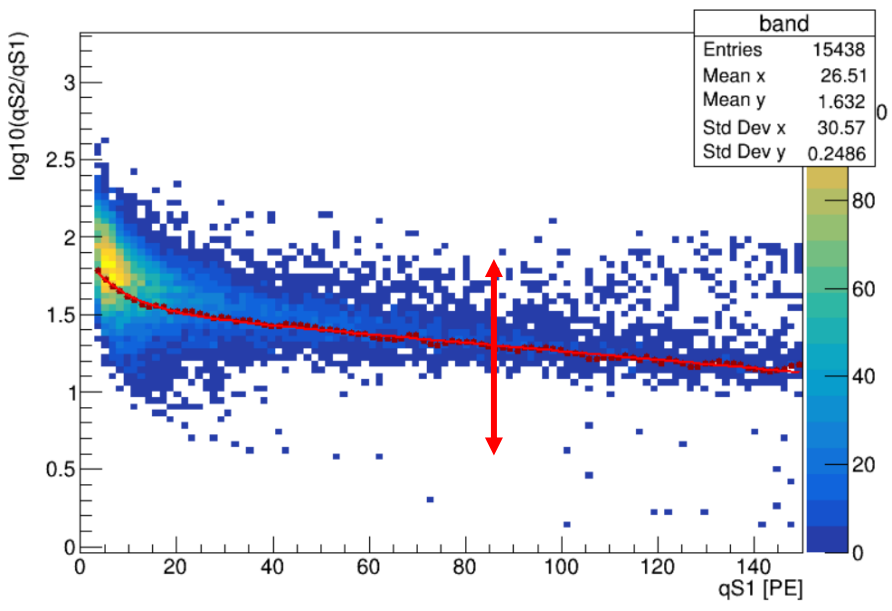
# CRDM signal in the Detector

$$\frac{dN_{\chi N}}{dT_r dt} = N_D \sigma_{\chi N} \int_{T_\chi^{min}(T_r)}^{\infty} \frac{FF_{\mathrm{Helms}}}{T_r^{max}(T_\chi)} \frac{d\Phi(T_\chi)}{dT_\chi dt} dT_\chi$$



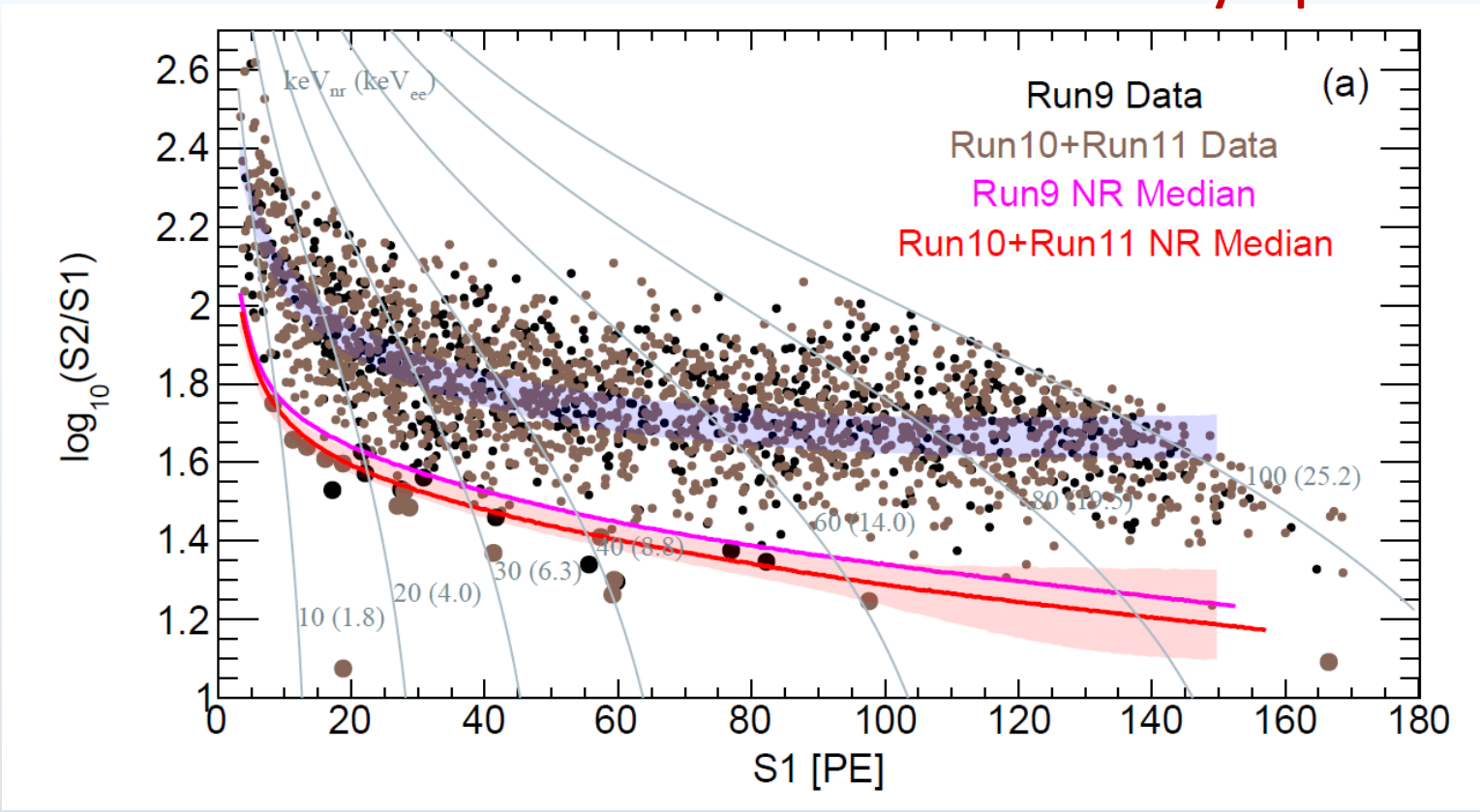

- Same NR scattering process as WIMPs;
- CRDM signal have the typical diurnal effect, which is the key information separate the signal with the background;
- Above 0.2 GeV incoming CRDM kinetic energy is ignored to avoid the incoherent and inelastic contributions;

# Candidates selection




- $R^2$<5.5e4 with 250.556 kg liquid xenon, in order to reduce the wall background;
- S1>3PE, S2>100PE and $E_{com}$<25keV$_{ee}$;
- Below NR median selection is applied, with 50% CRDM signal efficiency and exclude ~99% ER background;

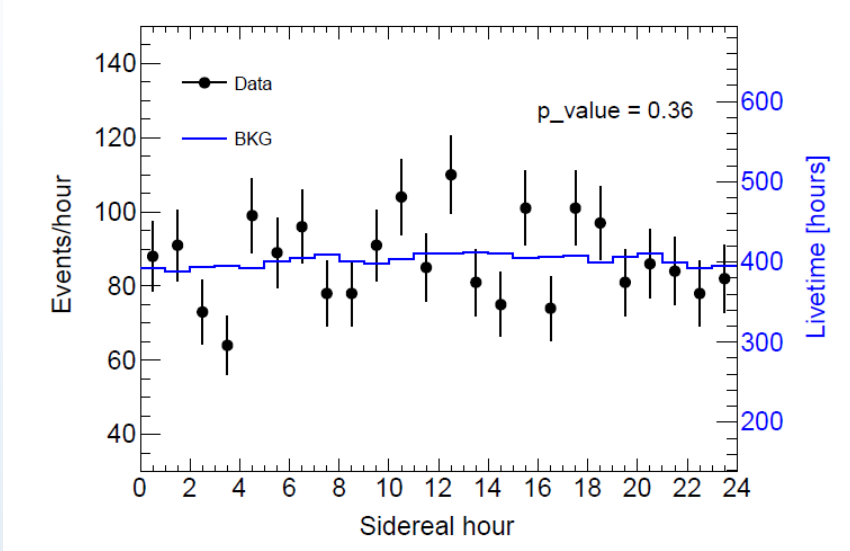
**100 Ton*Day Exposure**



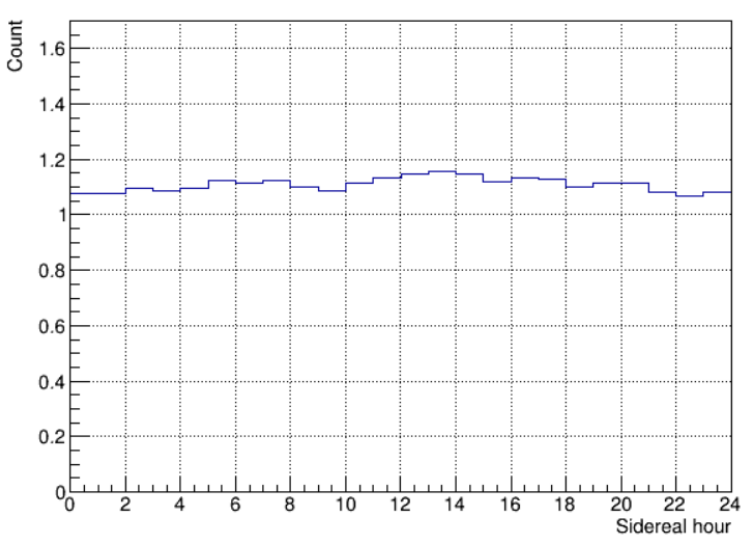

➢ 25 candidates from all cuts;

# Background table

| Item | Run9 | Run10 | Run11 | Total |
|---|---|---|---|---|
| Tritium | 0 | 0.83 | 3.91 | $4.7 \pm 1.9$ |
| $^{85}$Kr | 2.16 | 0.45 | 8.49 | $11.0 \pm 3.3$ |
| $^{127}$Xe | 0.96 | 0.06 | 0 | $1.1 \pm 0.2$ |
| $^{136}$Xe | 0 | 0.01 | 0.04 | $0.05 \pm 0.01$ |
| Flat ER | 0.72 | 1.17 | 5.61 | $7.5 \pm 2.3$ |
| Neutron | 0.31 | 0.17 | 0.64 | $1.1 \pm 0.6$ |
| Accidental | 0.34 | 0.17 | 0.60 | $1.1 \pm 0.3$ |
| Total | 4.47 | 2.86 | 19.29 | $26.6 \pm 4.5$ |
| Data | 10 | 1 | 14 | 25 |




**Data above the NR median selection**



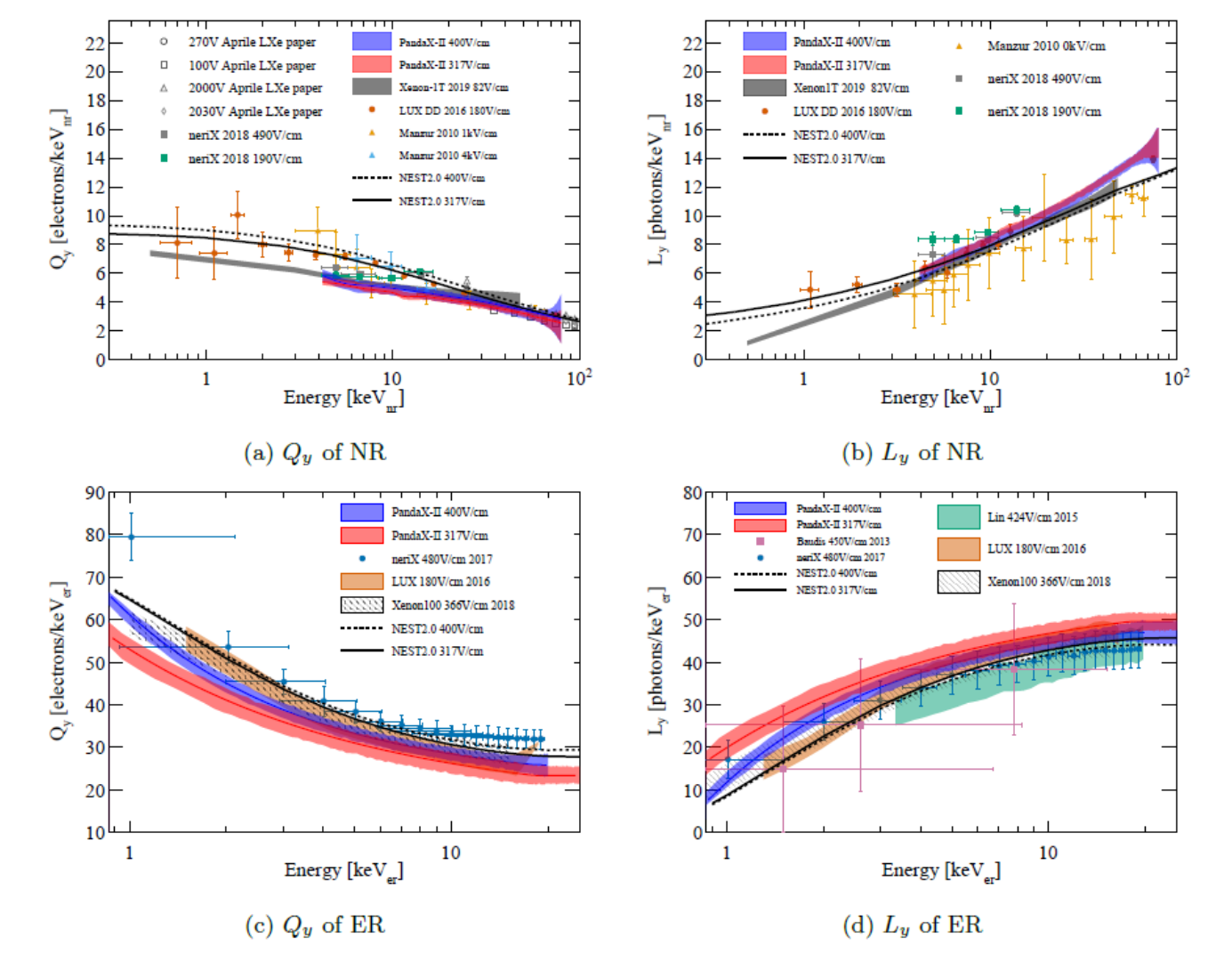

**BKG Sidereal hour distribution**

- 26.6 expected BKG compared to 25 candidates;

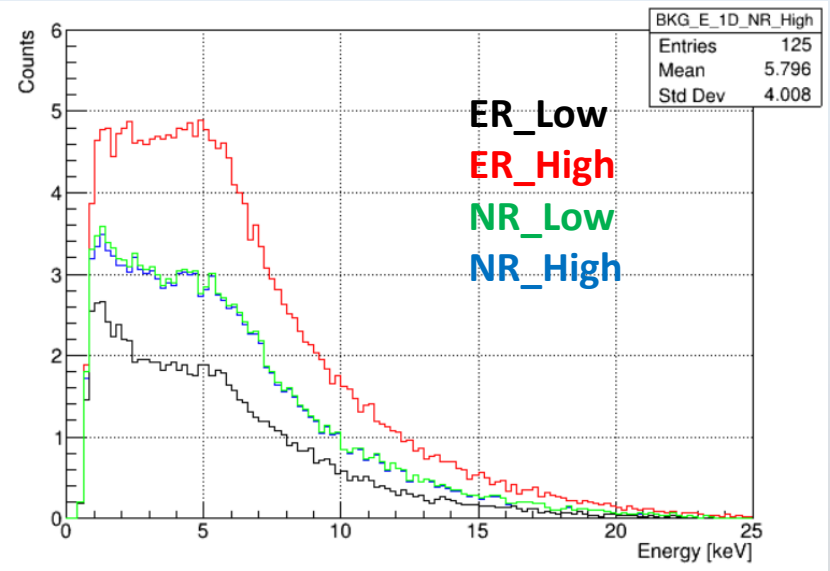
- Data above the NR median selection are used to validate the BKG diurnal independent distribution;

# Uncertainty applied

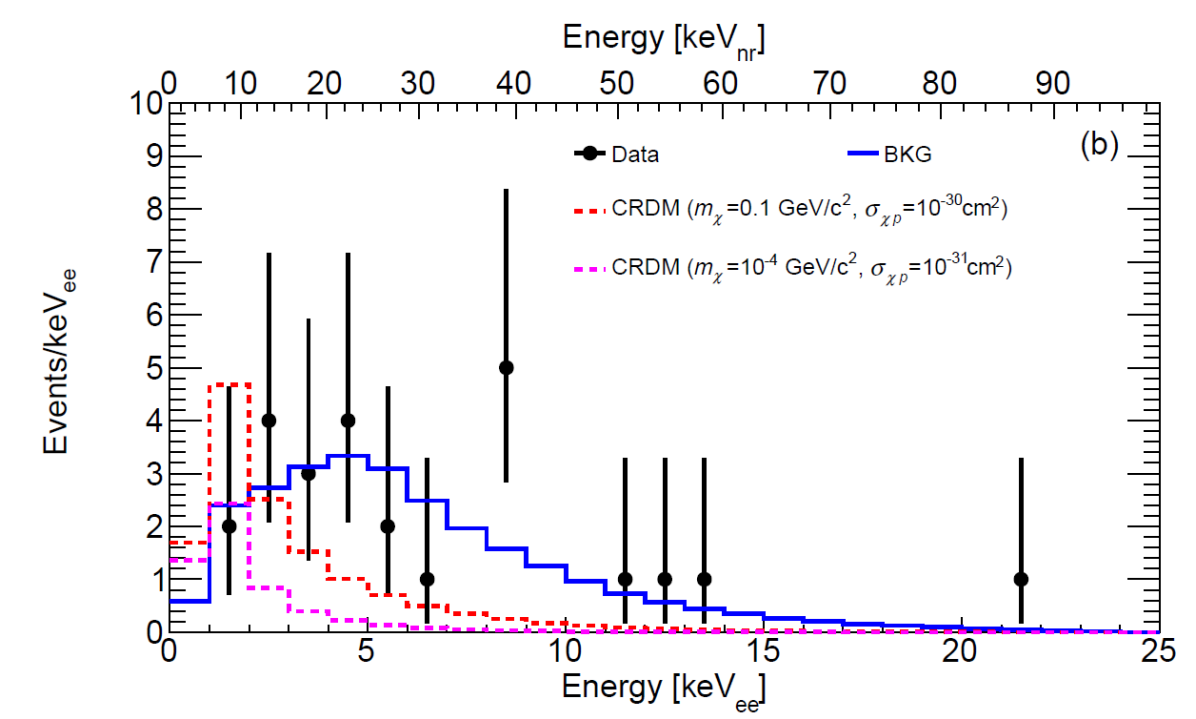
*Chin.Phys.C* 45 (2021) 7, 075001

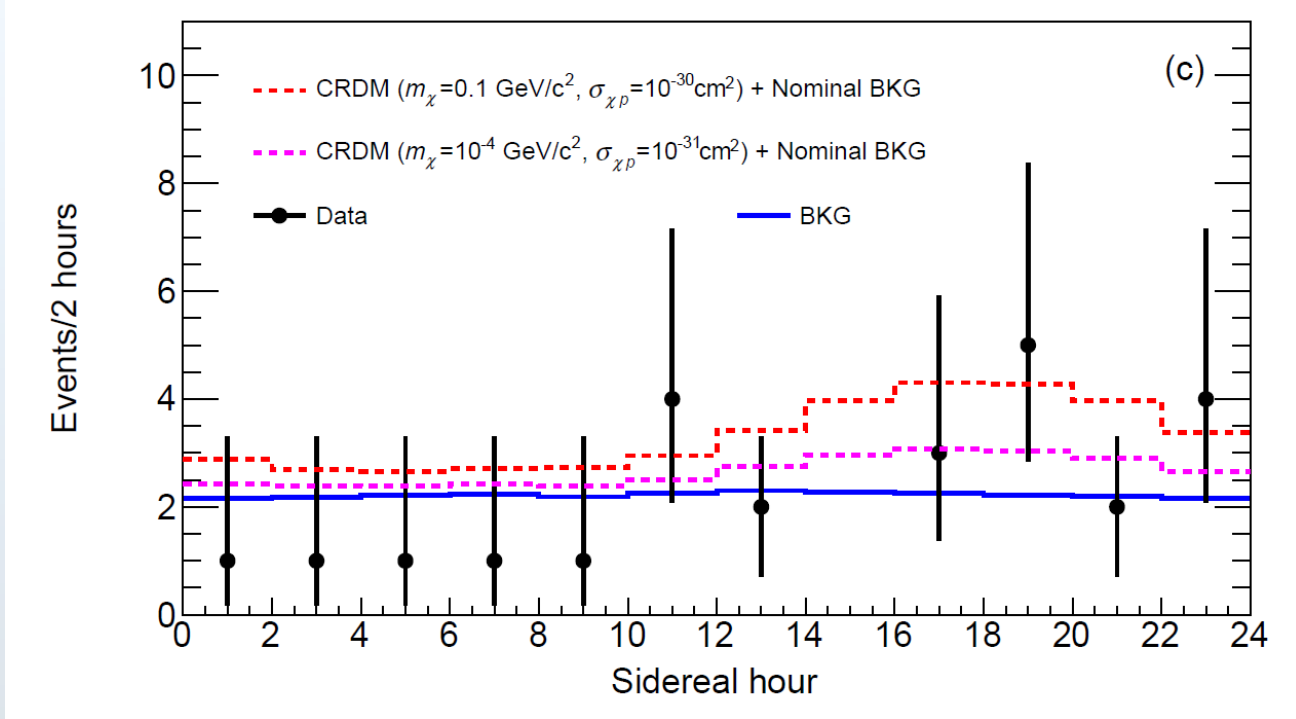



- LY and CY uncertainty from the calibration data is used for the pseudo-data generation (signal+bkg);



# Data&BKG&Signal



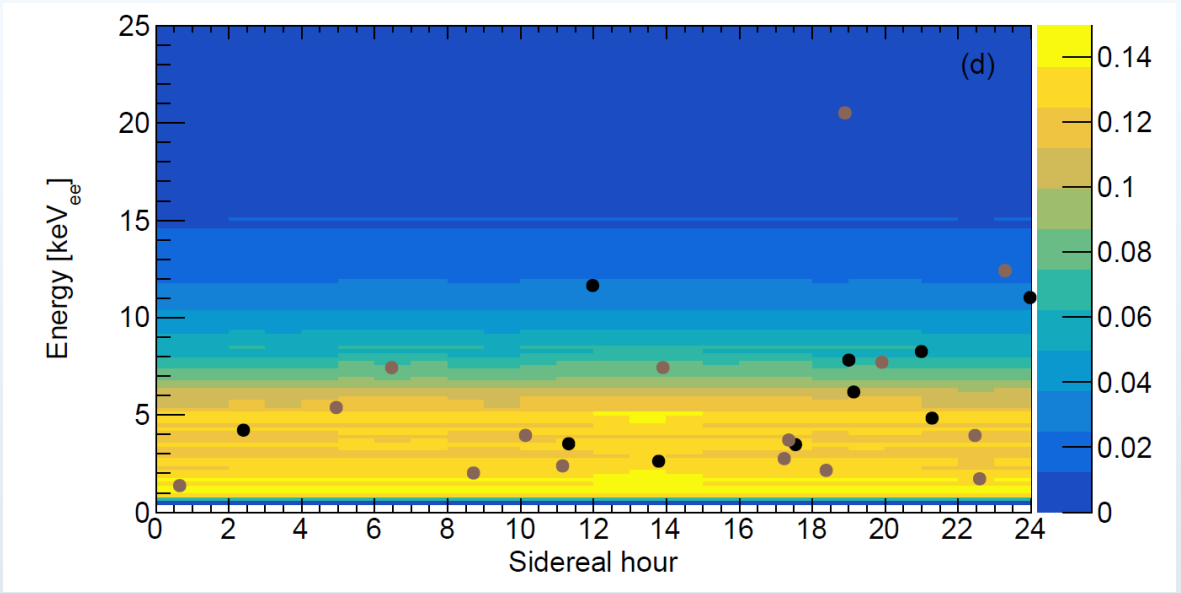

- No significant CRDM signal is found above the background;

# Fitting method - 2D profile likelihood

$$\mathcal{L}_{\mathrm{CRDM}} = \left[ \mathrm{Poiss}\left(N_{\mathrm{obs}} | N_{\mathrm{fit}}\right) \times \prod_{i=1}^{N_{\mathrm{obs}}} \left(l_s^i + l_b^i\right) \right] \times G\left(\delta_s, \sigma_s\right) G\left(\delta_b, \sigma_b\right), \tag{4}$$

where

$$l_s^i = \frac{N_s\left(1+\delta_s\right) \cdot P_{\mathrm{s}}\left(t_{\mathrm{sid}}^i, E_{\mathrm{ee}}^i\right)}{N_{\mathrm{fit}}}, \qquad l_b^i = \frac{N_b\left(1+\delta_b\right) \cdot P_b\left(t_{\mathrm{sid}}^i, E_{\mathrm{ee}}^i\right)}{N_{\mathrm{fit}}}. \tag{5}$$




- Sidereal hour and reconstructed energy as the analysis information;

# Final Result

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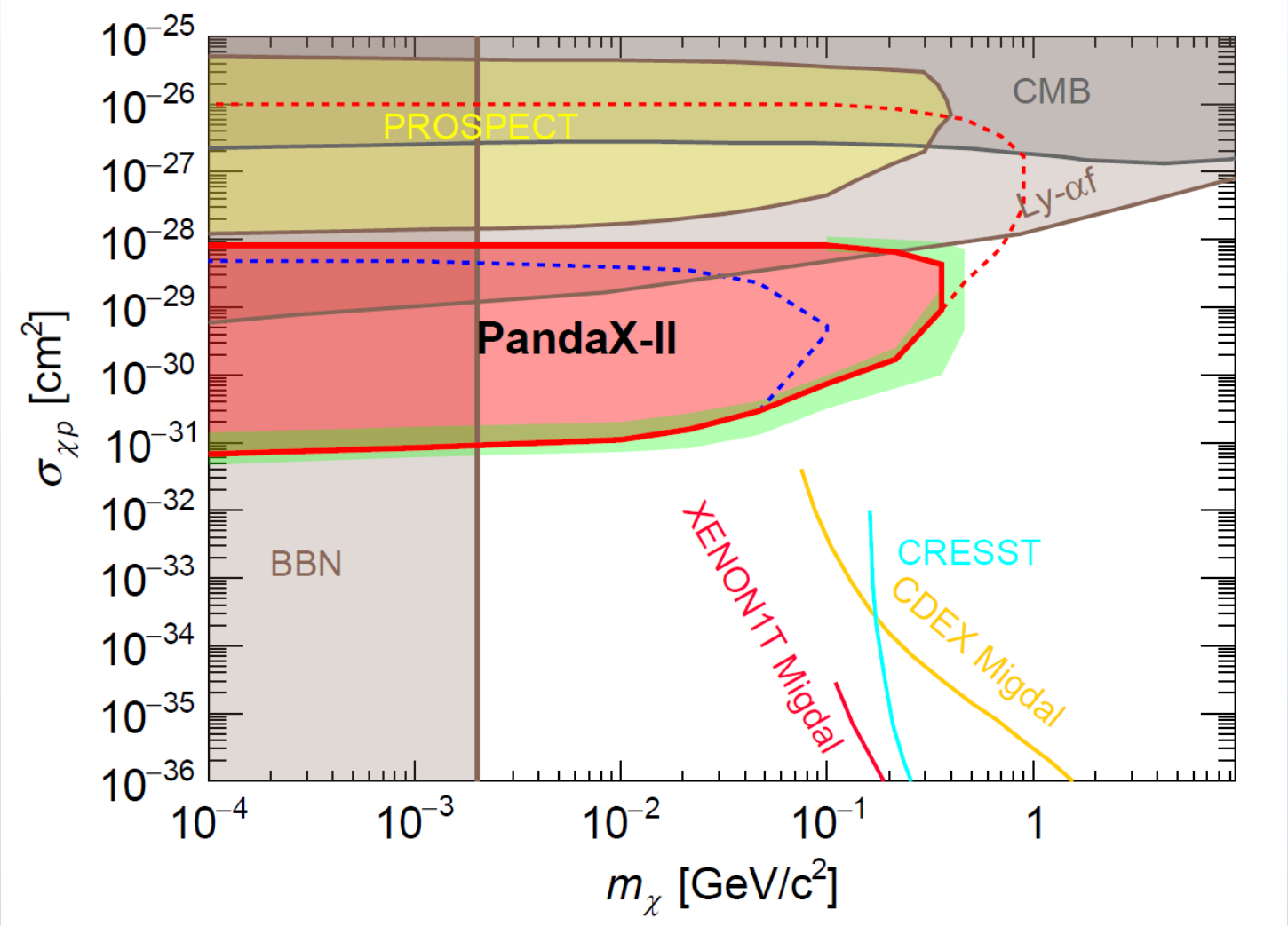


- First DD experiment data analysis with the CRDM;
- DM-N cross section exclusion from $10^{-31}$cm$^2$ to $10^{-28}$cm$^2$ at the DM mass from 0.1MeV to 0.1GeV;
- Cover a large area have not been constraint by DD or cosmological and astrophysical probes;

# Summary

- **Cosmic ray boosted dark matter is model independent, along with the specific diurnal modulation;**
- **Sidereal time and energy information are used for this analysis, with the PandaX-II 100Ton*Day data;**
- **Cover a large sub-GeV DM region, with a large area have not been constraint by DD or cosmological and astrophysical probes;**
- **More sensitive search for CRDM is in process with the PandaX-4T data;**


THANKS FOR
YOUR
ATTENTION !

# Backup - DM and CRs propagation uncertainty