Search for Light Dark Matter–Electron Scattering in the PandaX-II Experiment

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- **DM-Electron Scattering**
- **PandaX-II Experiment**
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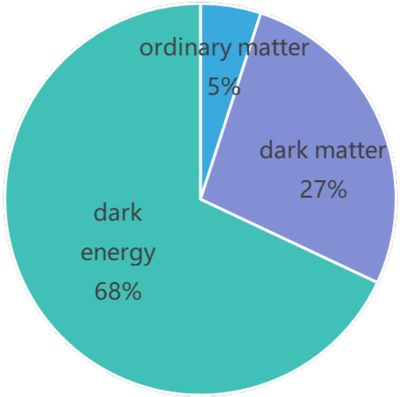
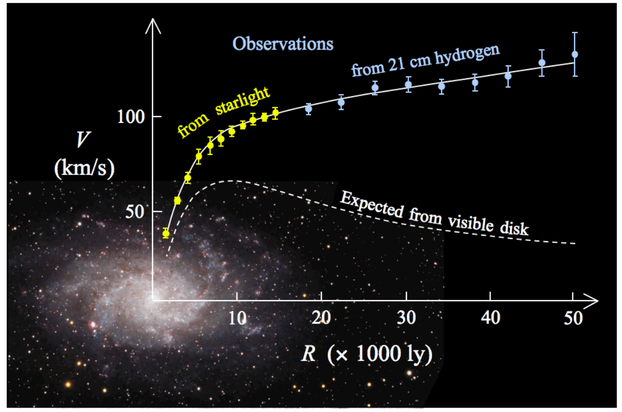
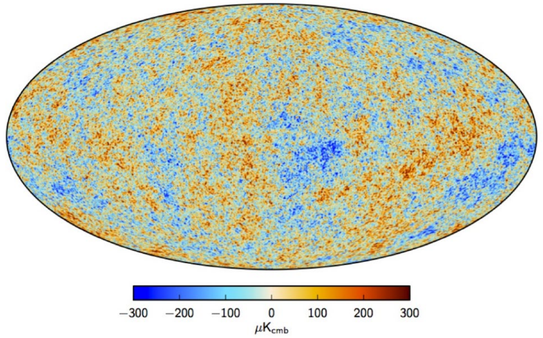
  - Result
- **Summary**

Evidences of Dark Matter





Rotation curve of spiral galaxy M33



CMB from Planck observatory by ESA

DM properties

- Mass
- No charge
- Tiny cross section

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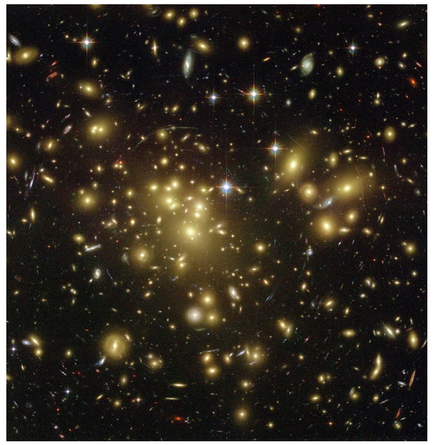
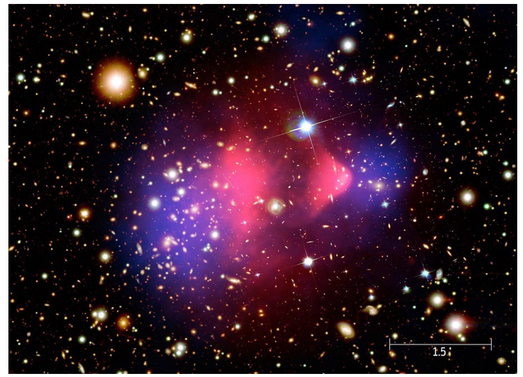
Candidates:

- Weakly interactive massive particle (WIMP)
- Axion
- Sterile neutrino

…



Gravitational lensing

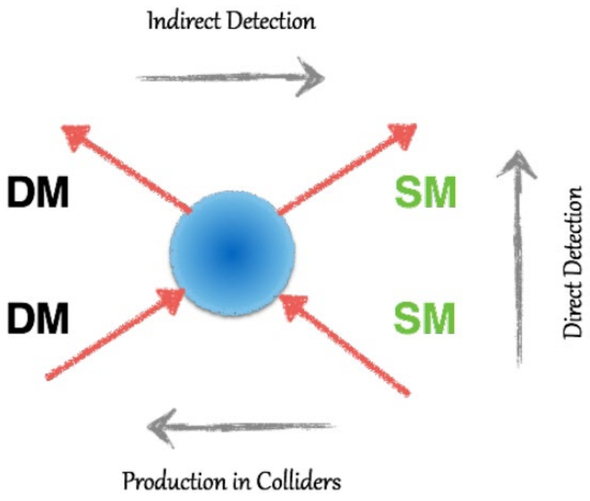


Bullet cluster

Detection of Dark Matter

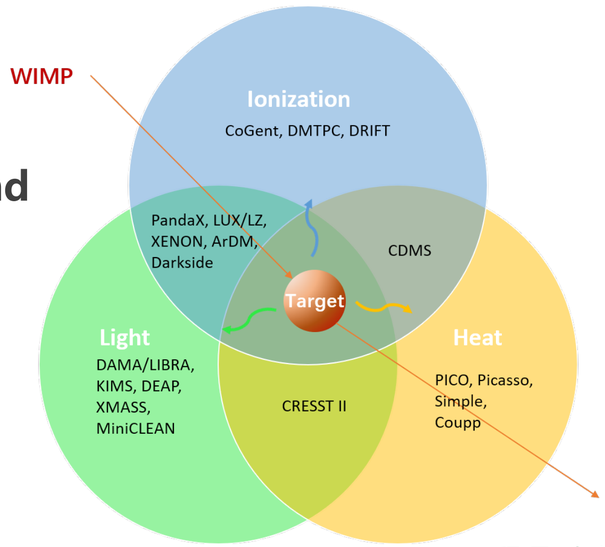
Detection methods

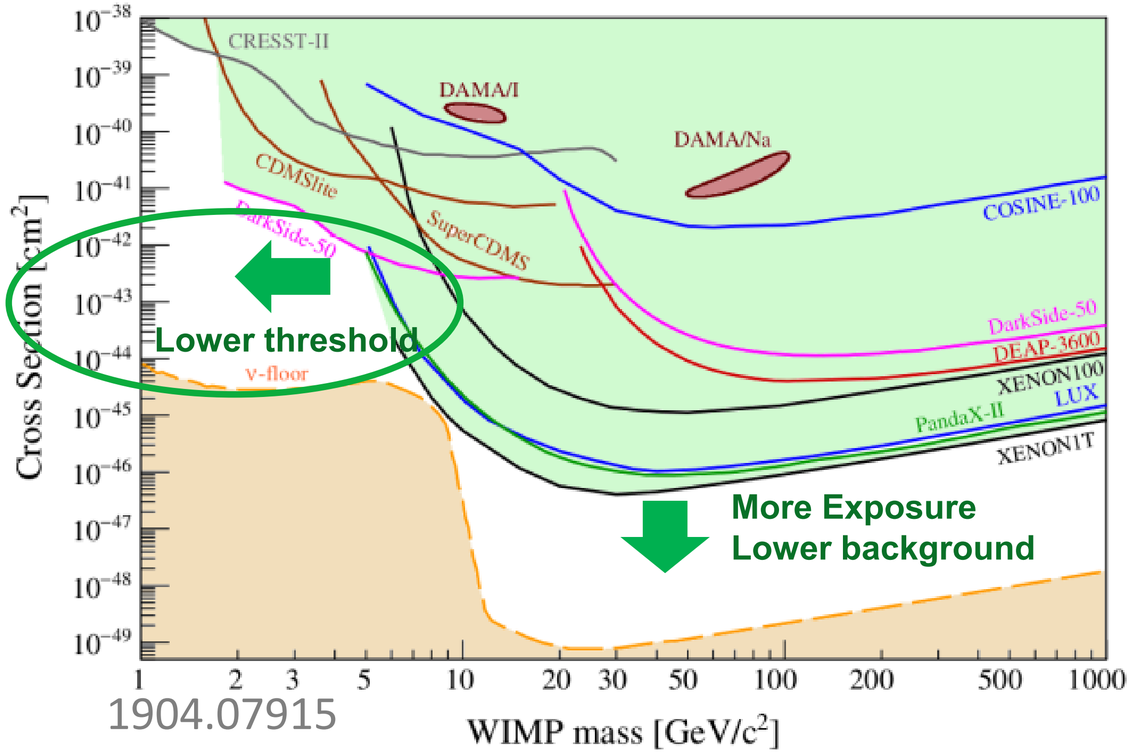
- Direct detection
- Indirect detection
- Colliders search



Direct detection

Search for **ionization, light and heat** signals produced by interacting between DM and target

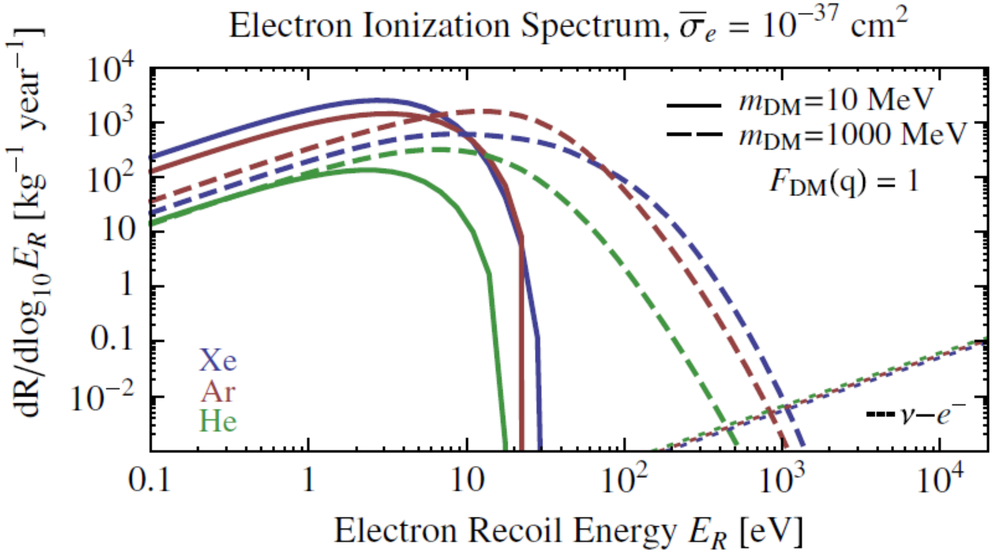




Constraints on spin-independent scattering

DM-Electron Scattering

- Ionization in atoms scenario: DM may scatter with an electron bound in energy level i, ionizing it to an un-bounded state with positive energy



Differential rates of DM-electron scattering

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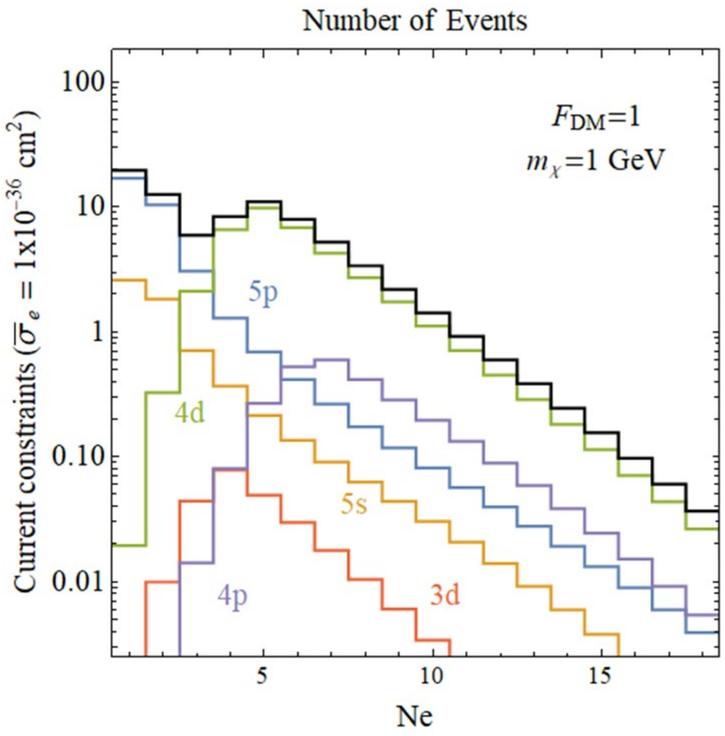
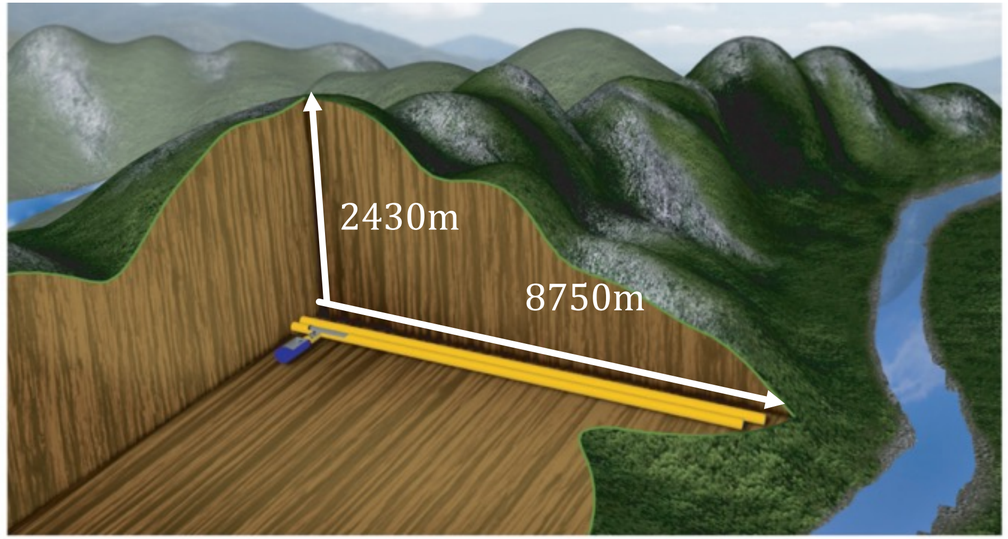


DM-electron scattering ionization electron spectra in different shells (xenon, assume m_x=1 GeV、$\sigma = 10^{-36}\mathrm{cm}^2$)

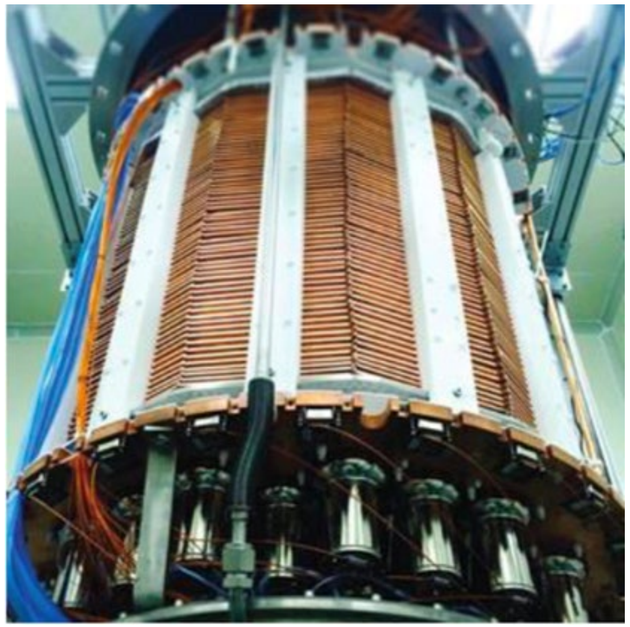
PandaX-II Experiment

The **P**article **AND A**strophysical **X**enon Experiment Phase **II**

- CJPL: < 0.2 muons/(m^2·day)
- 60 cm (D) * 60 cm (H) cylindrical two-phase time projection chamber (TPC)
- 580 kg liquid xenon in sensitive region as target
- 55 (top) + 55 (bottom) 3'' PMTs



China Jinping Underground Laboratory (CJPL)



the TPC of PandaX-II

PandaX-II Experiment

- **Two-phase TPC techniques**

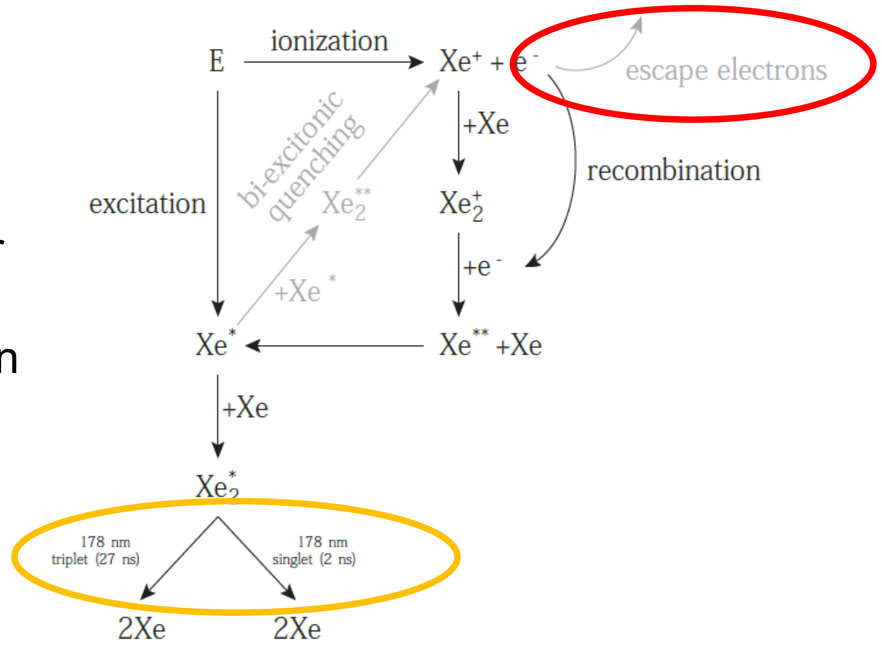
➢ High purity Xe target

➢ S1: prompt scintillation signal
  − High light yield

➢ S2: delayed ionization signal
  − Electroluminescence in vapor phase
  − Sensitive to a single ionization electron

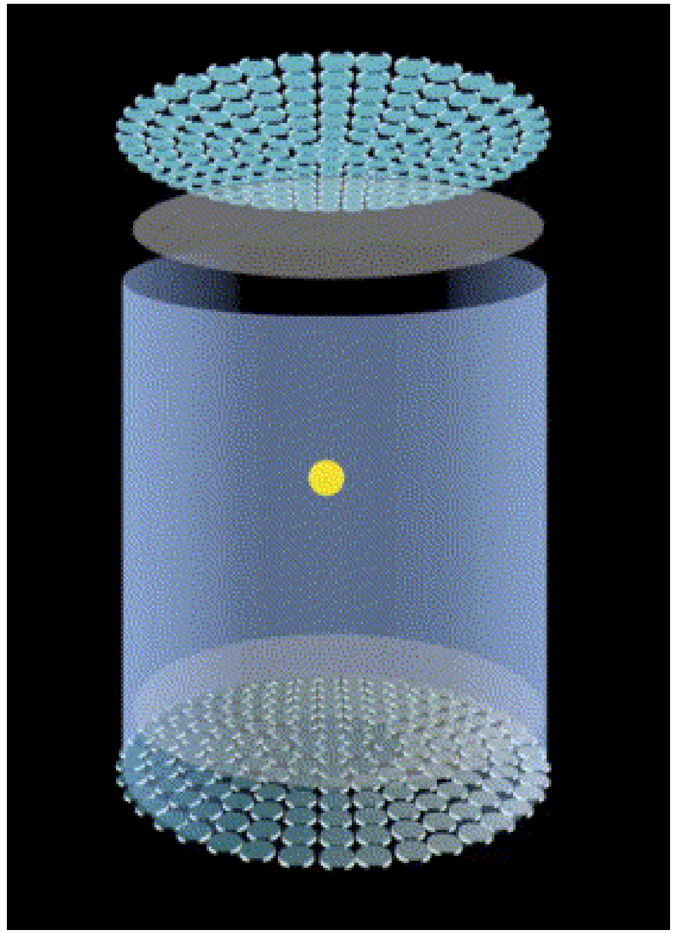
Ionization signal (S2)

- Single electron gain (SEG)
- Electron extracted efficiency (EEE)
- Drift loss (electron lifetime)



Scintillation light (S1)

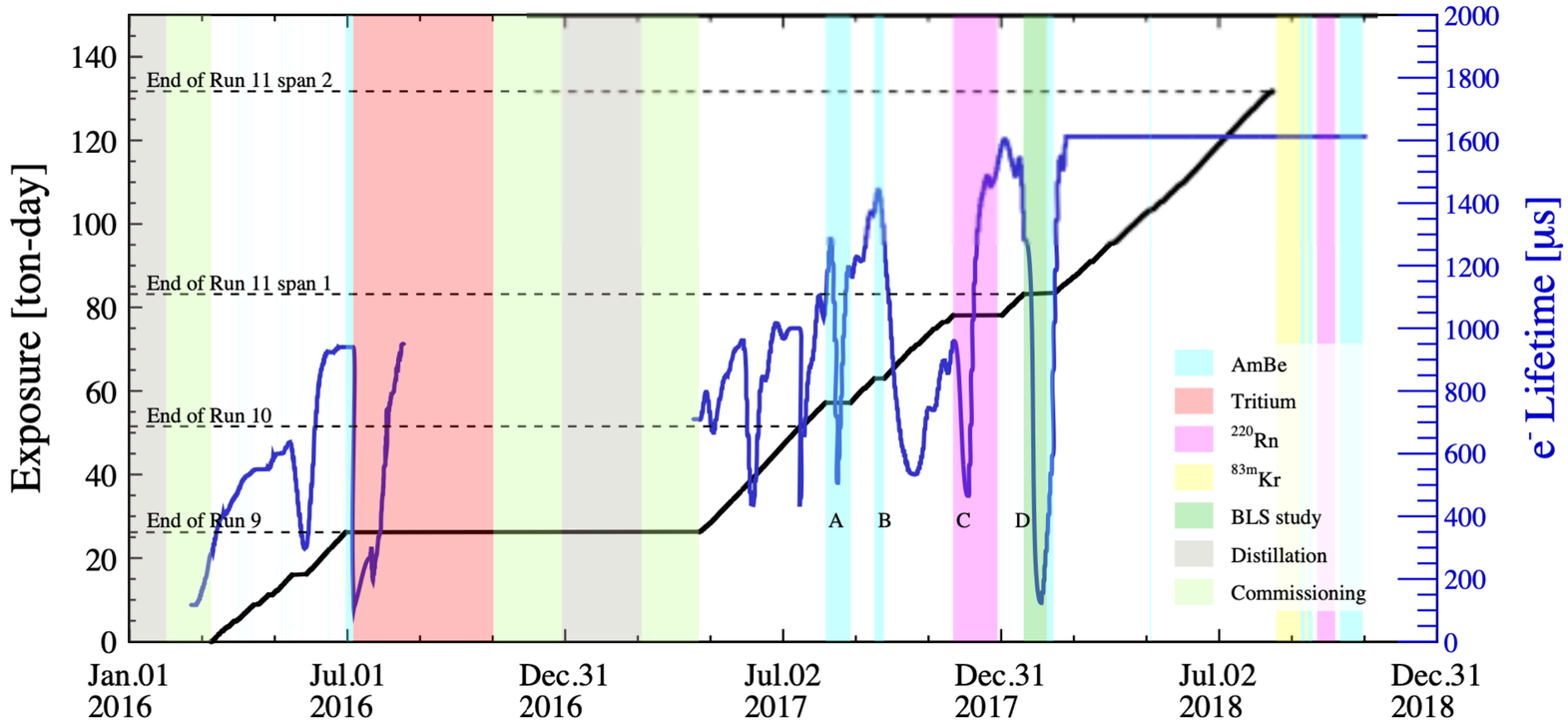
- Photon detection efficiency (PDE)



PandaX-II Experiment

- **Datasets**

Chin.Phys.C 44 (2020) 12, 125001



2019.06 “End-of-Run” completed

Physics runs:

Run 9:	79.6 days
Run 10:	77.1 days
Run 11, span 1:	96.4 days
Run 11, span 2:	147.9 days

Calibration runs:

- Nuclear recoil: AmBe
- Electron recoil: tritium, Rn-220, Kr-83m (injection)

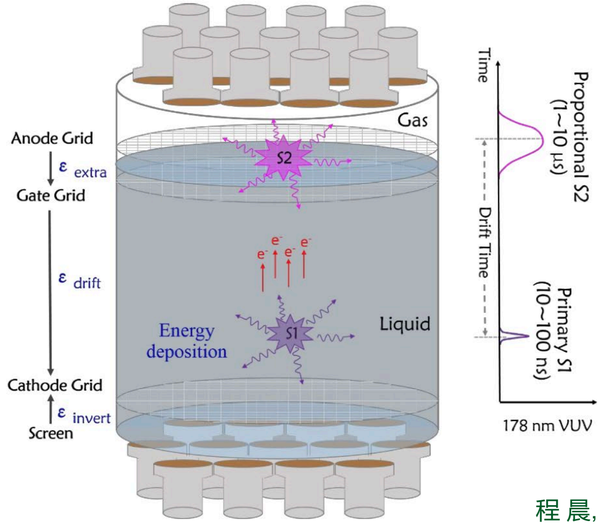
DM–Electron Analysis in PandaX-II Experiment

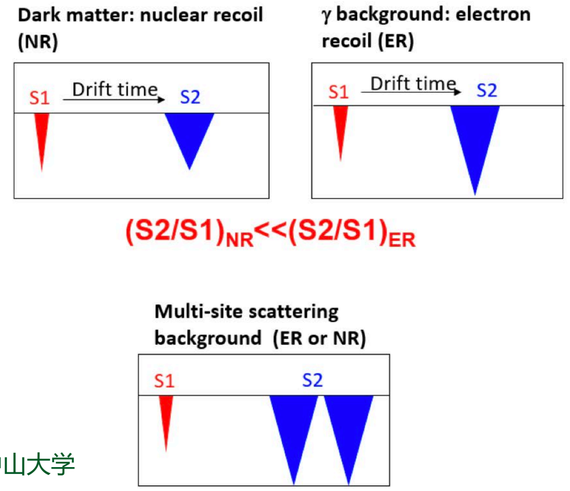
Conventional DM search

- **S1 + S2 paired event analysis**
  - Electron recoil background rejection by ratio of charge(S2)/light(S1)
  - Z position from S1-S2 drift time
  - X-Y positions from S2 light pattern

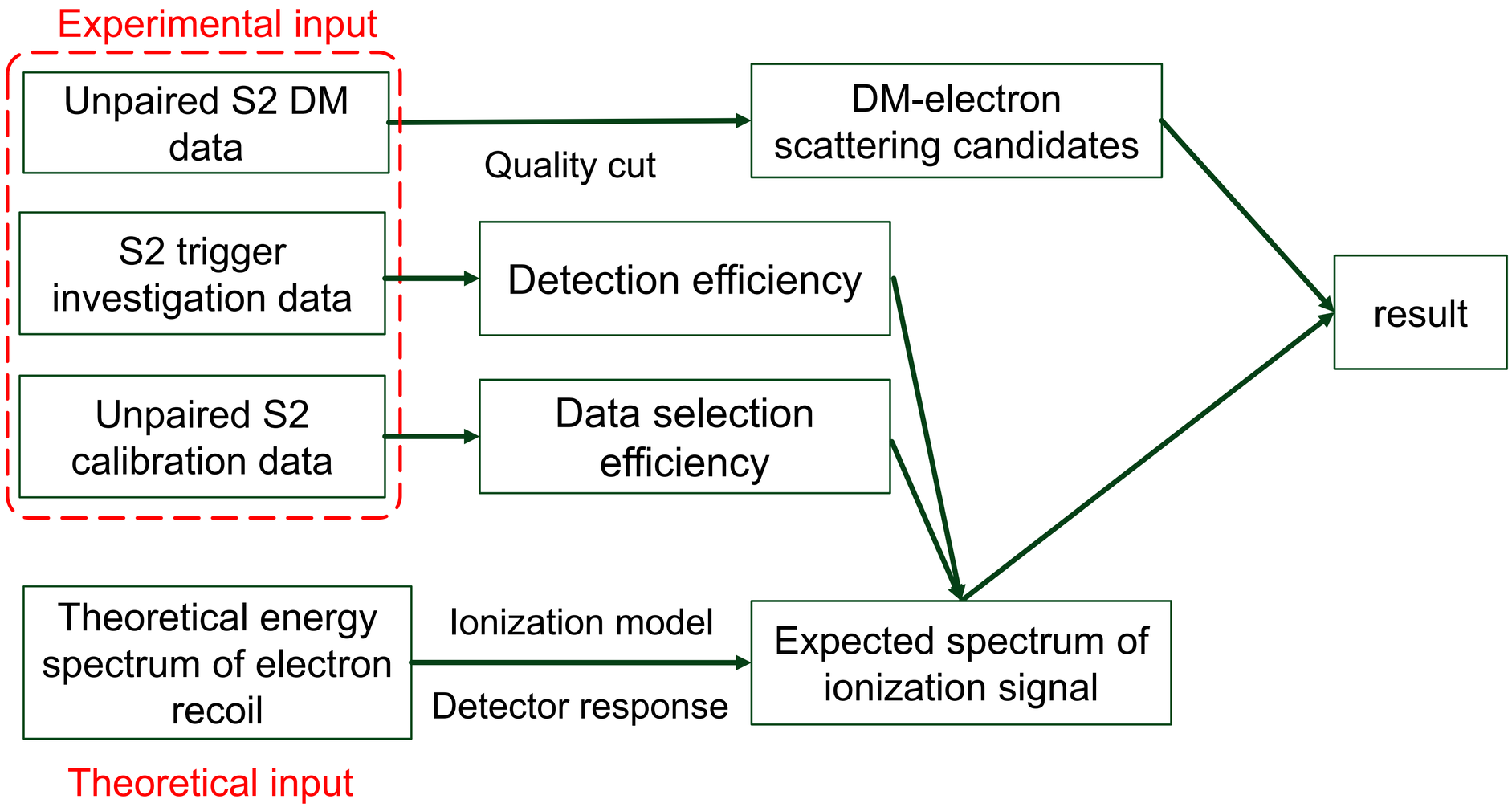
Light DM search

- **Un-paired S2 (US2) analysis**
  - Lower energy threshold ~ 80 eV (comparing energy threshold ~1 keV with paired analysis)
  - Sensitive to sub-GeV DM interaction



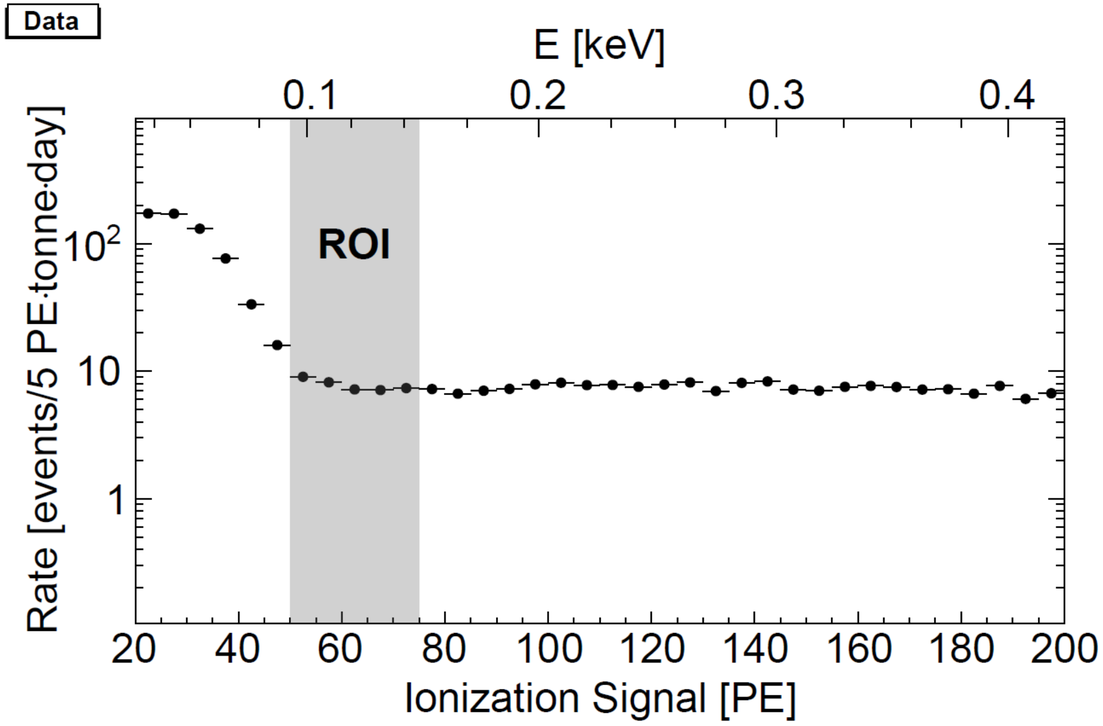


Analysis Flow



Analysis Flow

- **Data selection**
  - ➢ Develop quality cuts inherited from the conventional DM search analysis
  - ➢ Tighten three S2 waveform cuts (shape related)



The spectrum of DM-electron scattering candidates

	Run 9	Run 10	Run 11 span 1	Run 11 span 2	Total
Exposure (tonnes/day)	9.3	9.0	28.6		46.9
DM-electron candidates (events)	287	340	1194		1821
Flat ER background (events)	0.8	0.2	0.3	0.6	1.8
Tritium background (events)	0	0.1	0.2	0.3	0.6

The numbers of US2 candidates, exposure, and known ER background events for the three DM search runs

Analysis Flow

- **Detection efficiency and data selection efficiency**

  - Trigger efficiency is directly measured

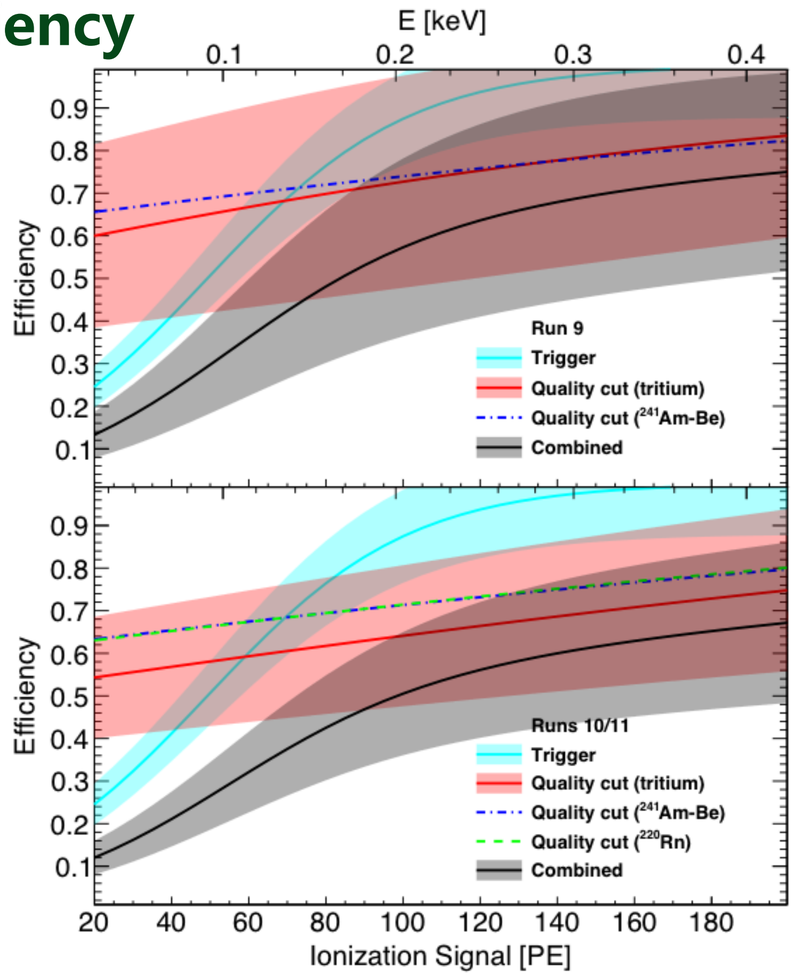
    (JINST 12 (2017) 08, T08004)

  - The data quality cut efficiency obtained from the tritium calibration run is used for conservative consideration.

  - Other calibration runs are used to validate data selection efficiency.

    Nuclear recoil: AmBe

    Electron recoil: Rn-220



Data selection efficiency curves acquired from different calibration sources

Analysis Flow

- **Ionization model and detector response**

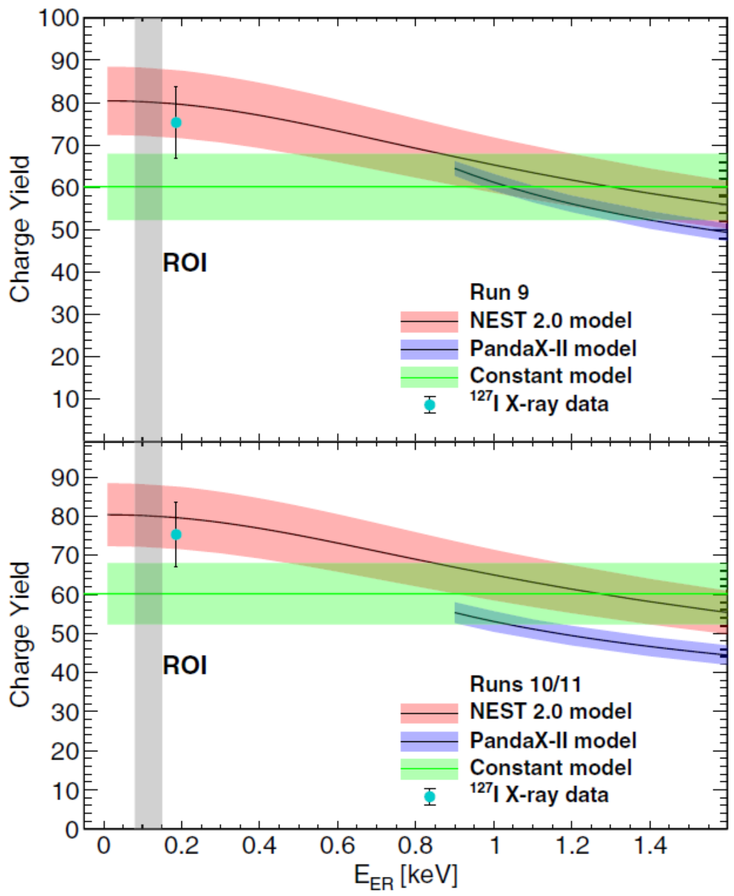
➢ Ionization model

− Three charge yield models (NEST 2.0, PandaX-II model and constant) to describe produced ionized electrons are compared

− Constant model is selected to conservatively estimate the number of primary ionized electrons.

➢ Detector responses

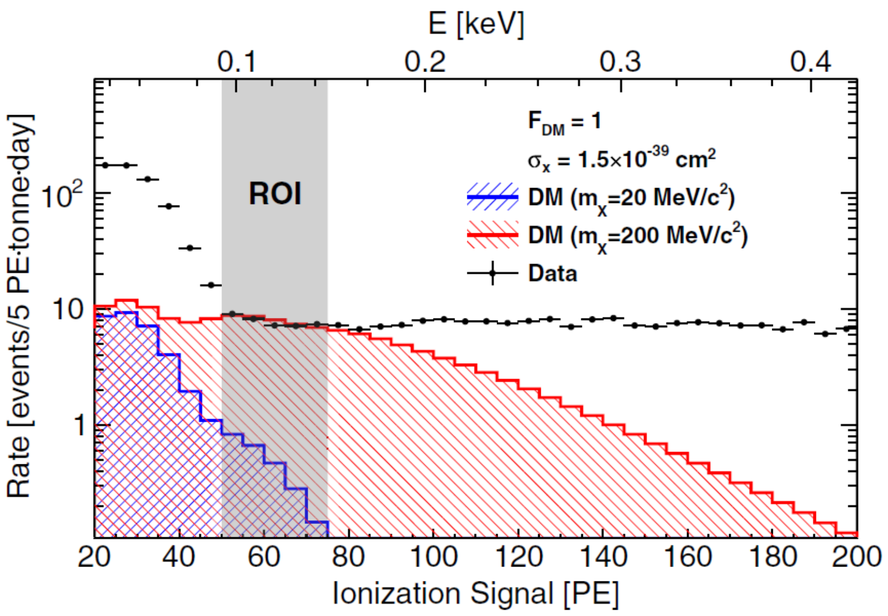
	Run 9	Run 10	Run 11
EEE (%)	46.4 ± 1.4	50.8 ± 2.1	47.5 ± 2.0
SEG (PE)	24.4 ± 0.4	23.7 ± 0.8	23.5 ± 0.8
σ_{SE} (PE)	8.3	7.8	8.1



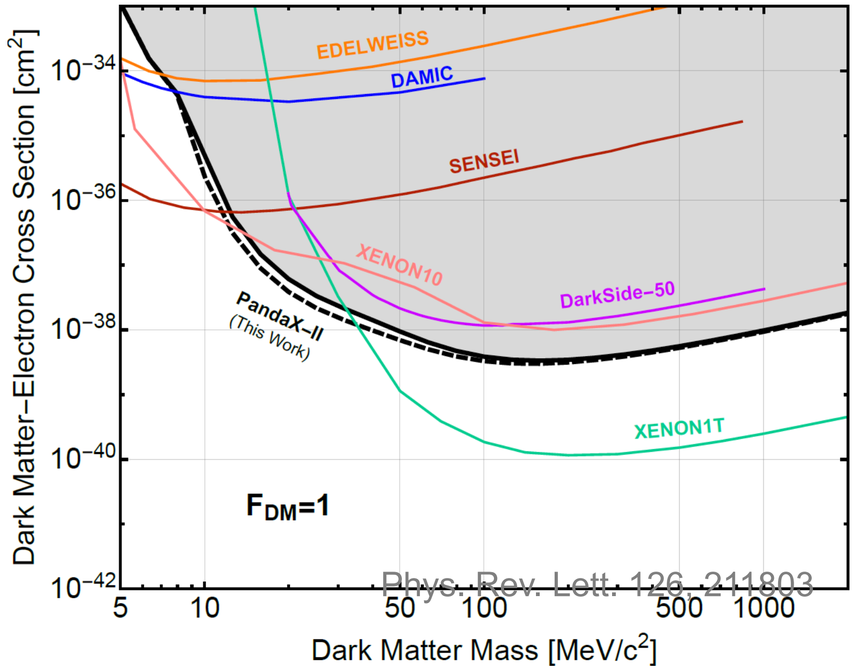
Charge yield vs ER energy for three DM search runs

Result

- For different DM masses and cross sections, the rates of electron-DM scatterings are generated to be compared with the measured candidates in ROI to constrain the cross section of interaction.
- We provide the world's most stringent limit within the dark matter mass range from 15 to 30 MeV/c^2, with the corresponding cross section from **2.5×10^{-37}** to **3.1×10^{-38} cm^2**
- The result published to Phys. Rev. Lett. 126, 211803



Detected ionization signals and expected signals from DM-electron scattering



90% C.L. upper limit on light DM-electron scattering cross section

Summary

- The unpaired S2 analysis method lowers the PandaX-II energy threshold to 0.08 keV to probe light DM
- 1821 candidates are identified within an ionization signal range between 50 and 75 photoelectrons, corresponding to a mean electronic recoil energy from 0.08 to 0.15 keV
- The world‘s most stringent limit via electron-DM scattering within the DM mass range from 15 to 30 MeV/c^2, with the corresponding cross section from **2.5×10^{-37} to 3.1×10^{-38} cm^2** is reported
- PandaX-4T experiment with more exposure and lower background may provide more chances to detect light DM-electron scatterings

Thanks!

Theoretical energy spectrum of electron recoil

- Ionization in atoms scenario: DM may scatter with an electron bound in energy level i, ionizing it to an un-bounded state with positive energy

- Differential event rate

$$\frac{\mathrm{d}R_{\mathrm{ion}}}{\mathrm{d}E_e} = N_T \frac{\rho_\chi}{m_\chi} \sum_{nl} \frac{\bar{\sigma}_e}{8\mu_{\chi e}^2 E_e} \int \mathrm{d}q\, |F_{\mathrm{DM}}(q)|^2 \left| f_{\mathrm{ion}}^{nl}(k,q) \right|^2 \eta(v_{\min}(q, E_e))$$

N_T: atomic number of Xe

q: transfer momentum

k: final momentum of electrons

$\mu_{\chi e}$: electron-WIMP scattering mass

$F_{\mathrm{DM}}(q)$: DM Form Factor

$f_{\mathrm{ion}}^{nl}(k,q)$: Ionization Form Factor

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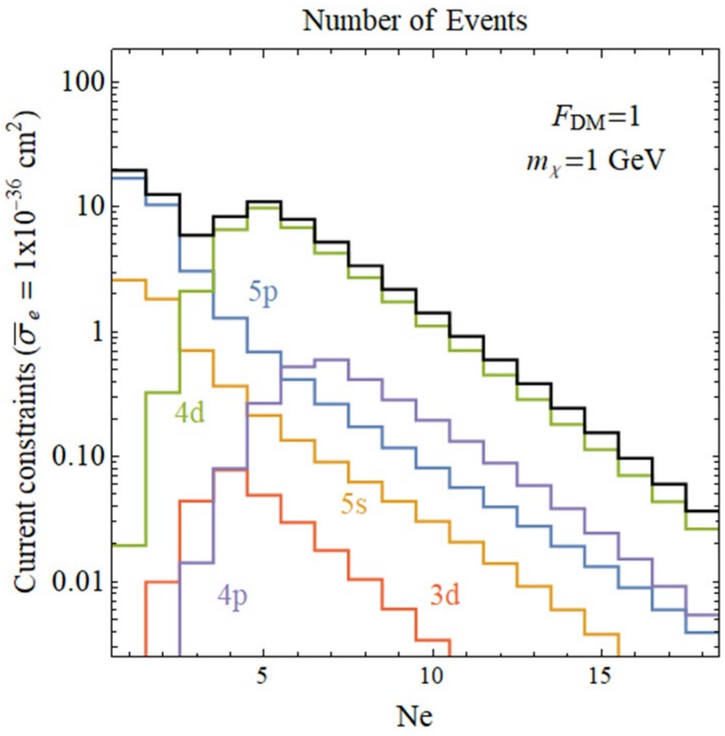
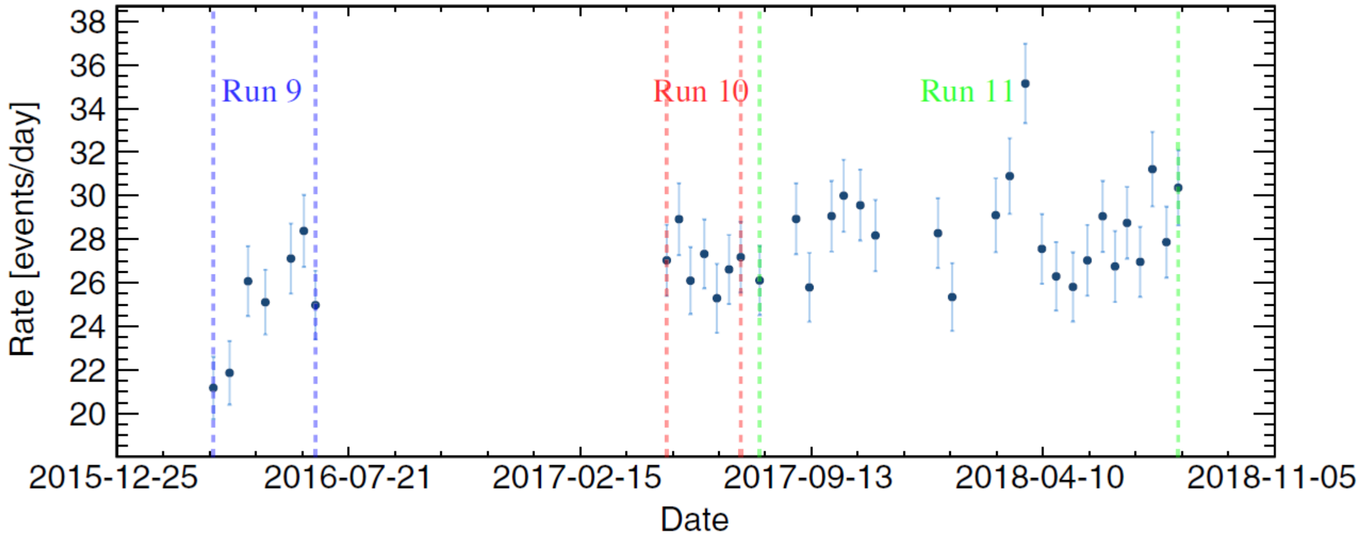


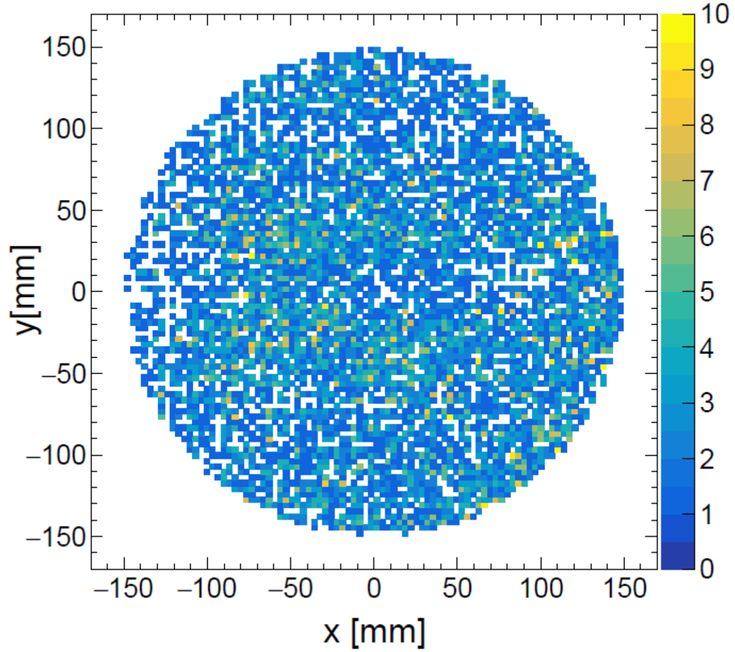
DM-electron scattering ionization electron spectra in different shells (xenon, assume m_x=1 GeV、$\sigma = 10^{-36}\mathrm{cm}^2$)

Candidates distributions

- Validate candidates time and spatial distributions



Event rate of the US2 signals (50 – 200 PE)



Spatial distribution of candidates

Potential

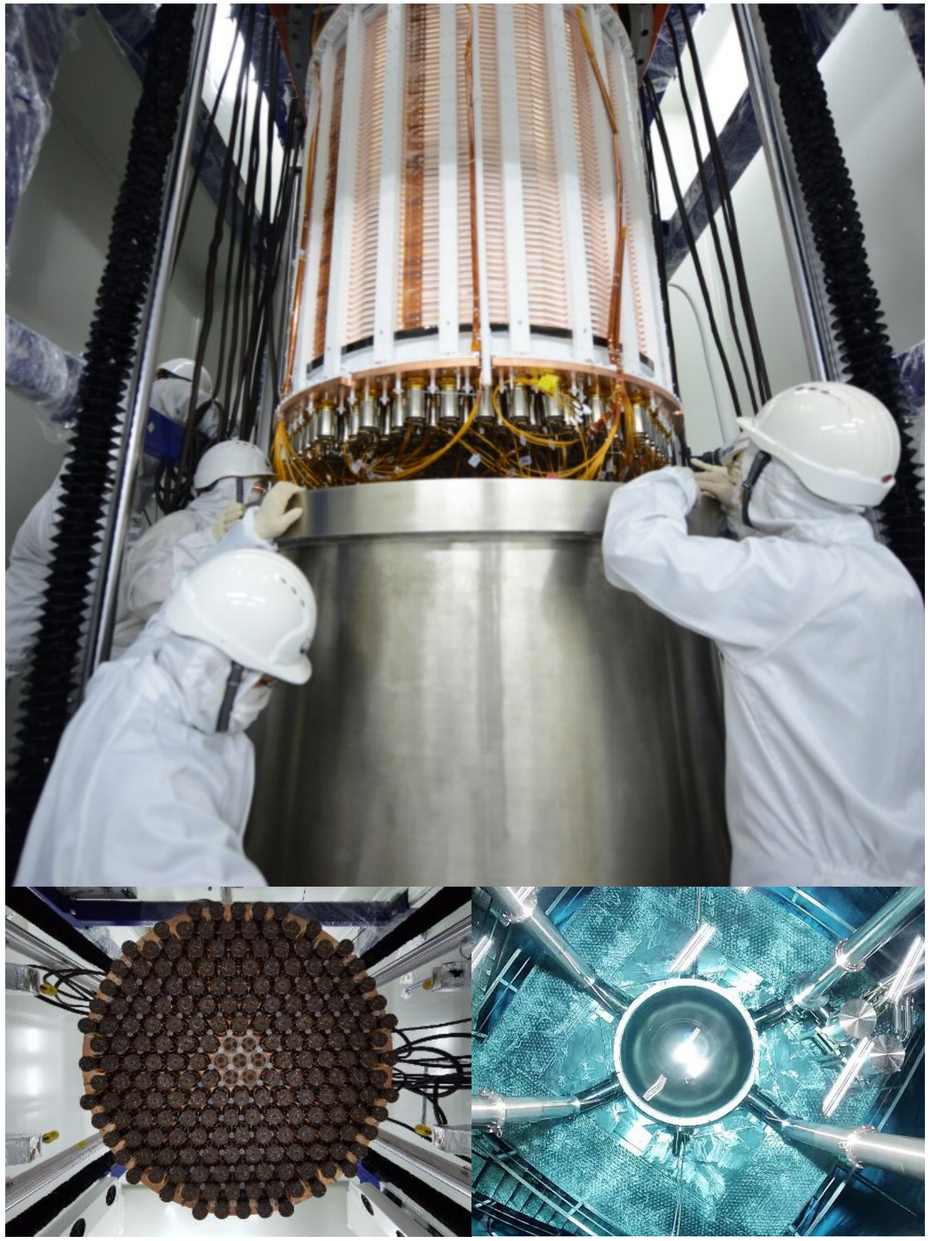
- **PandaX-4T**

➢ 4 tonne liquid xenon in sensitive region

➢ Lower background rate

➢ Commissioning run has been finished (arXiv:2107.13438)

➢ May provide more chances to detect light DM-electron scatterings



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