Search for Light Dark Matter in the PandaX-4T Experiment

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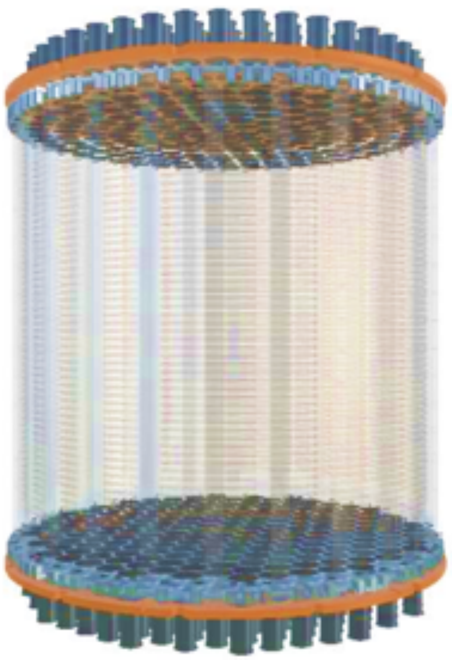


PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

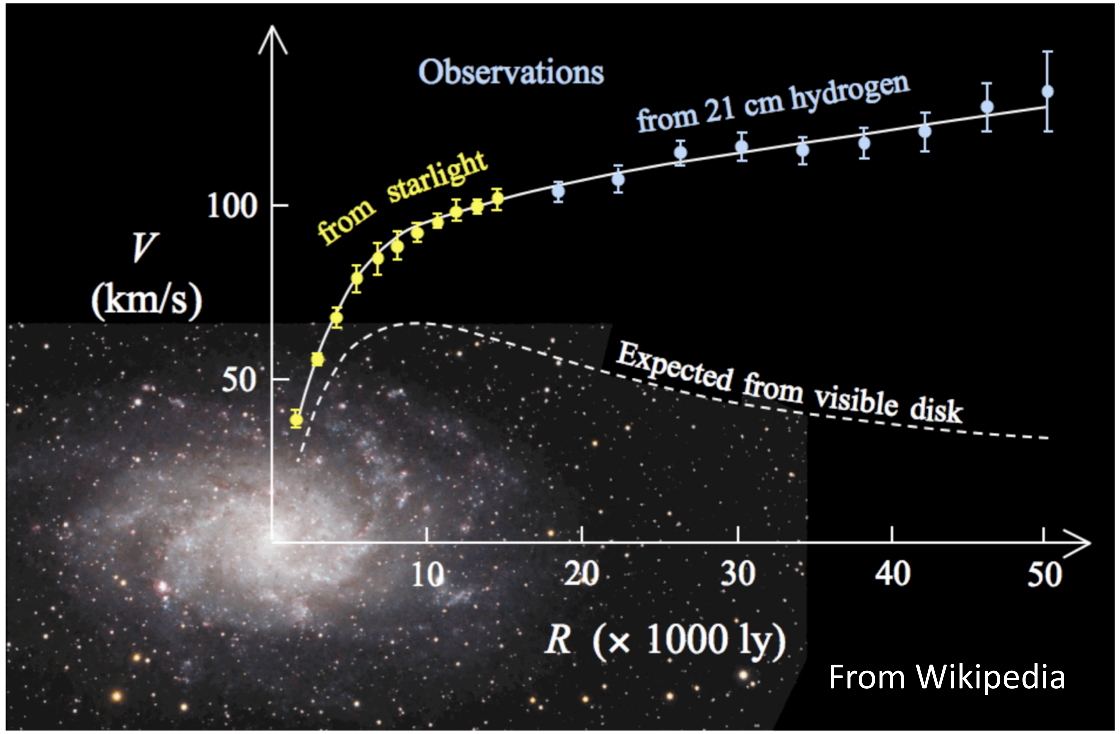
SHANGHAI JIAO TONG UNIVERSITY 1896

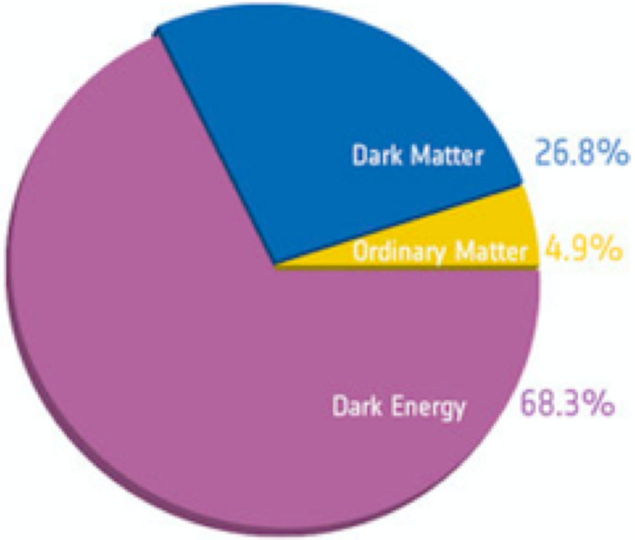
Content

- Dark matter introduction and detection technologies
- PandaX-4T dark matter experiment
- Light dark matter search method with PandaX-4T
- Summary and outlook

Dark matter evidence

Rotation curve of spiral galaxy M33





Gravitational evidences suggest dark matter is the dominant form of matter in Universe!

The dark matter landscape

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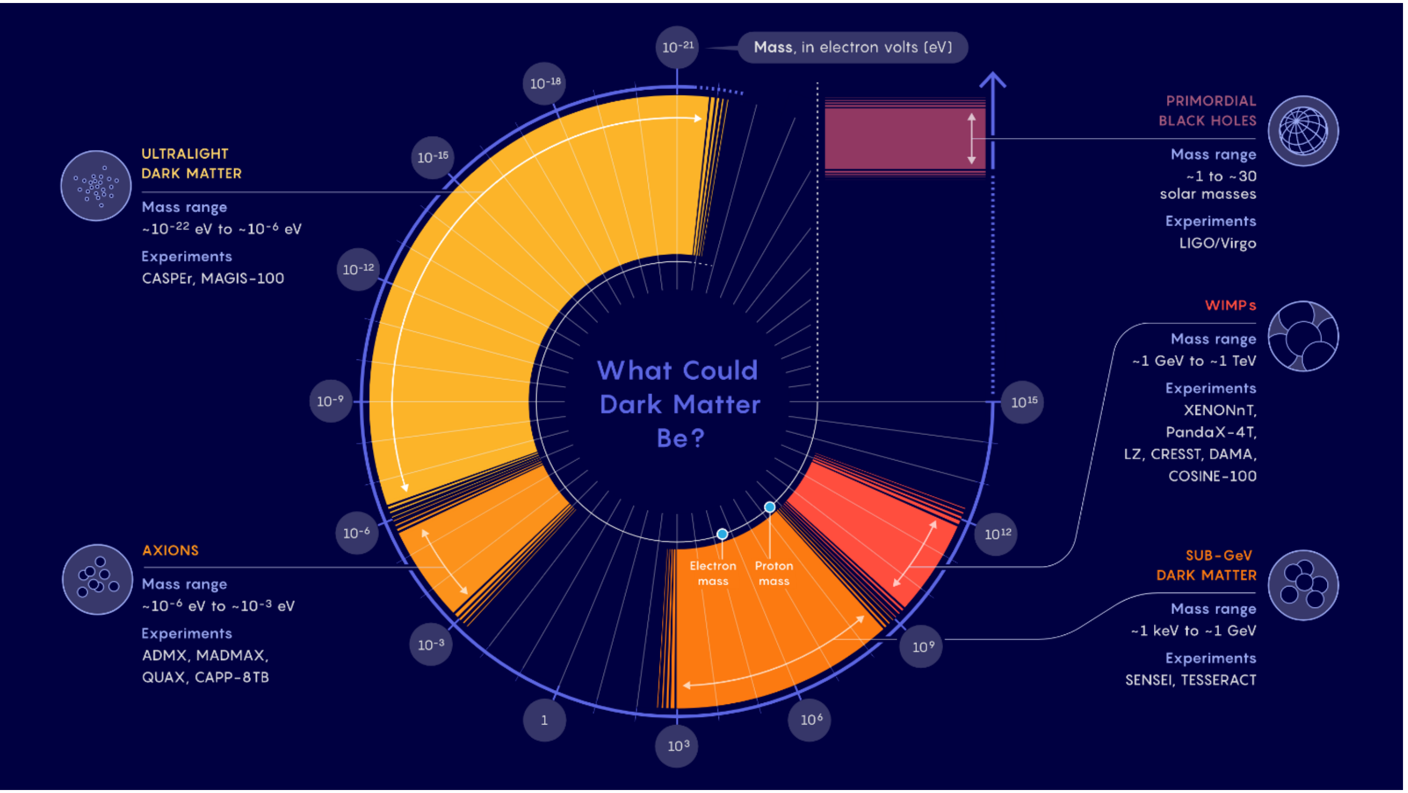
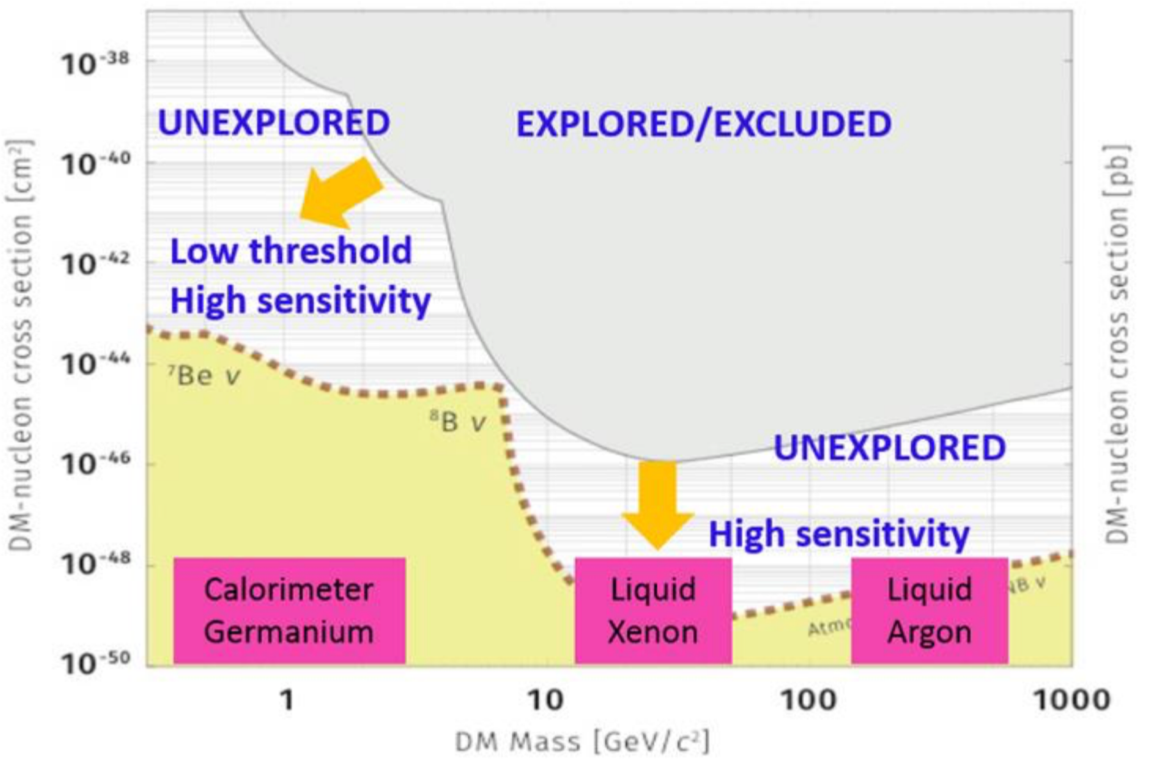
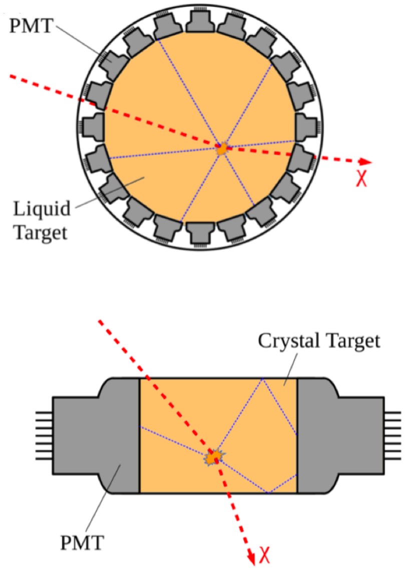
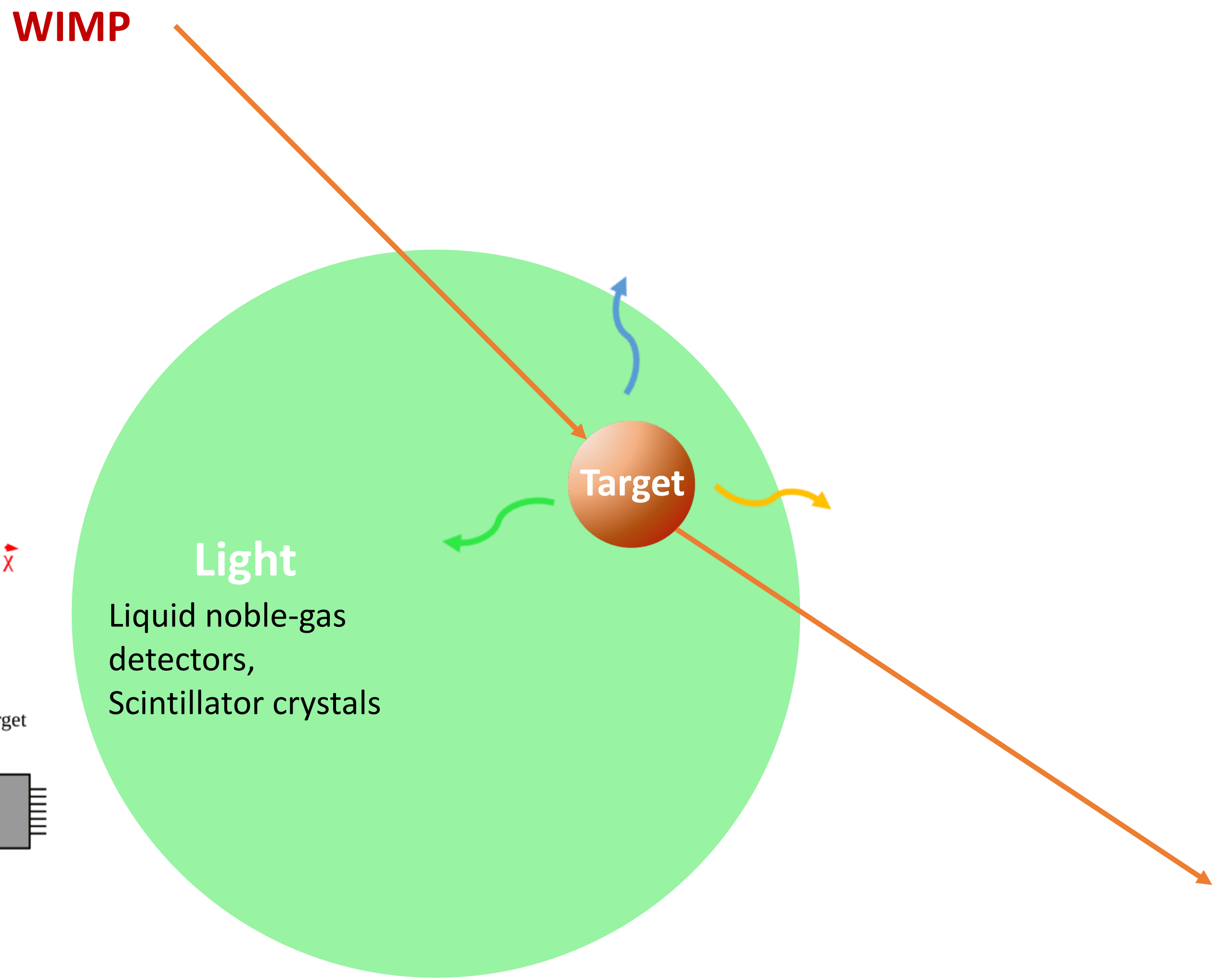


Samuel Velasco/Quanta Magazine

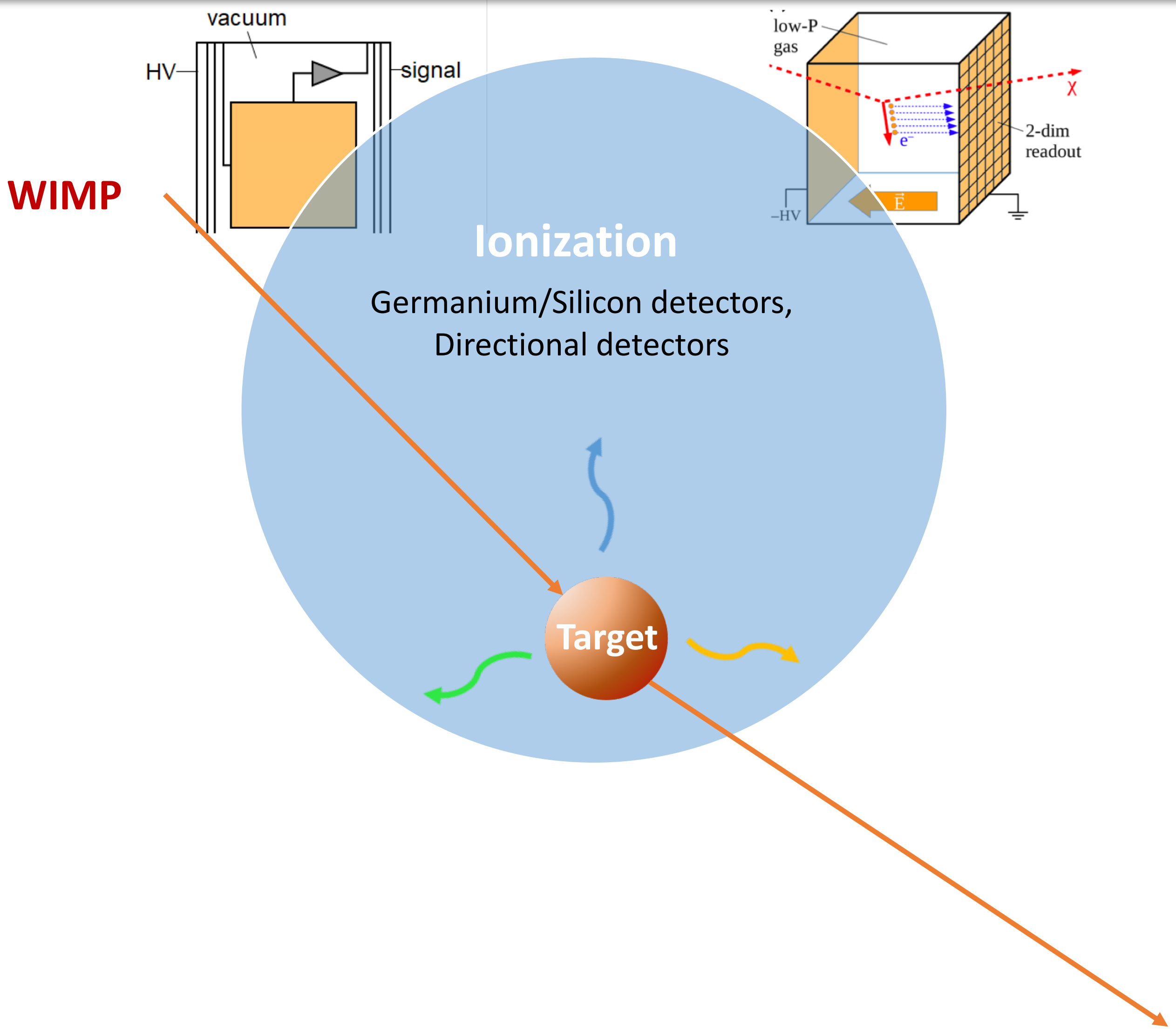


Dark matter detection technologies

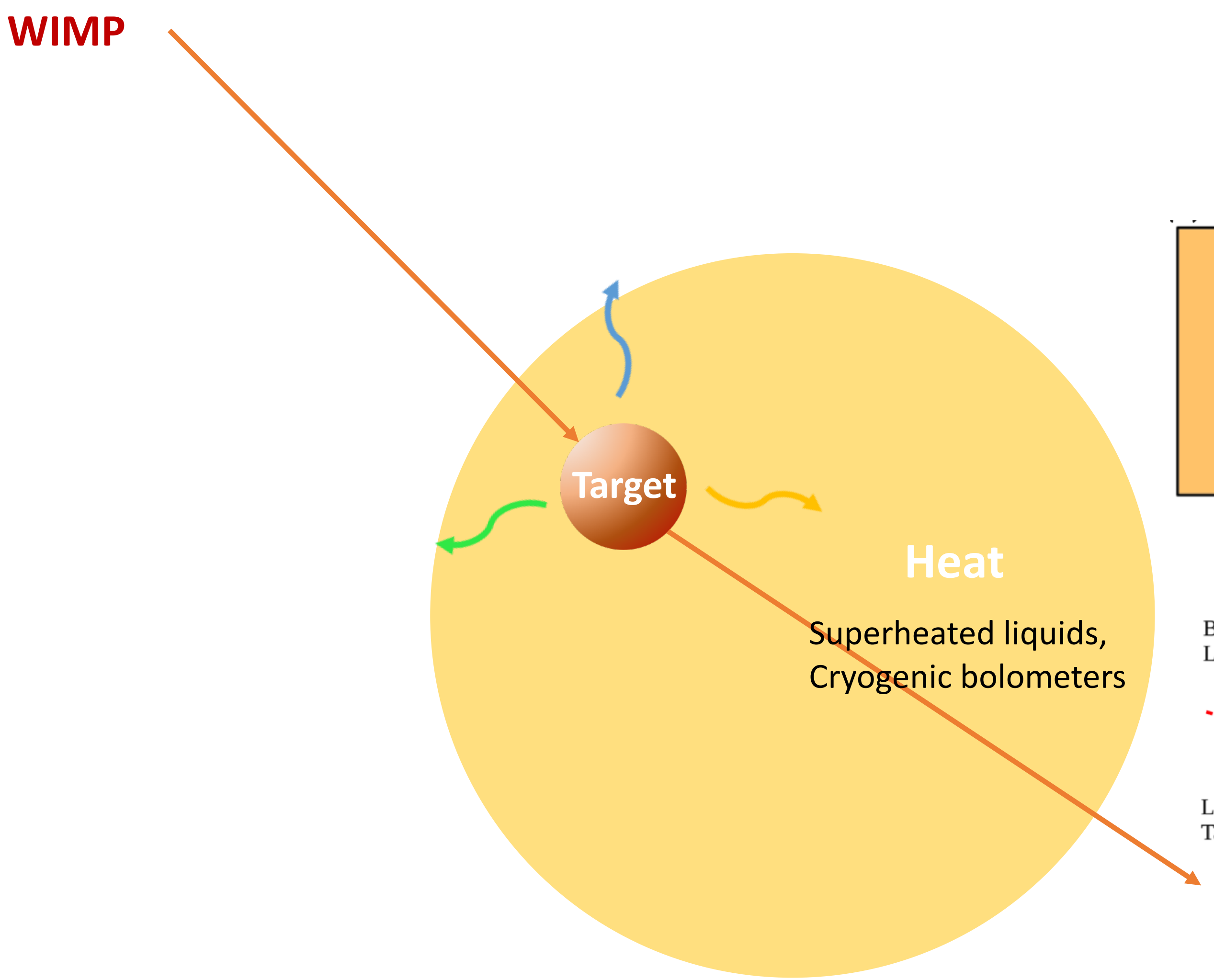


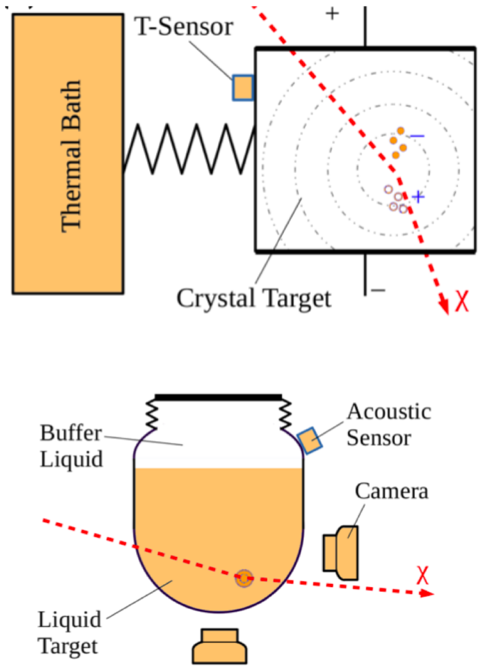


Dark matter detection technologies

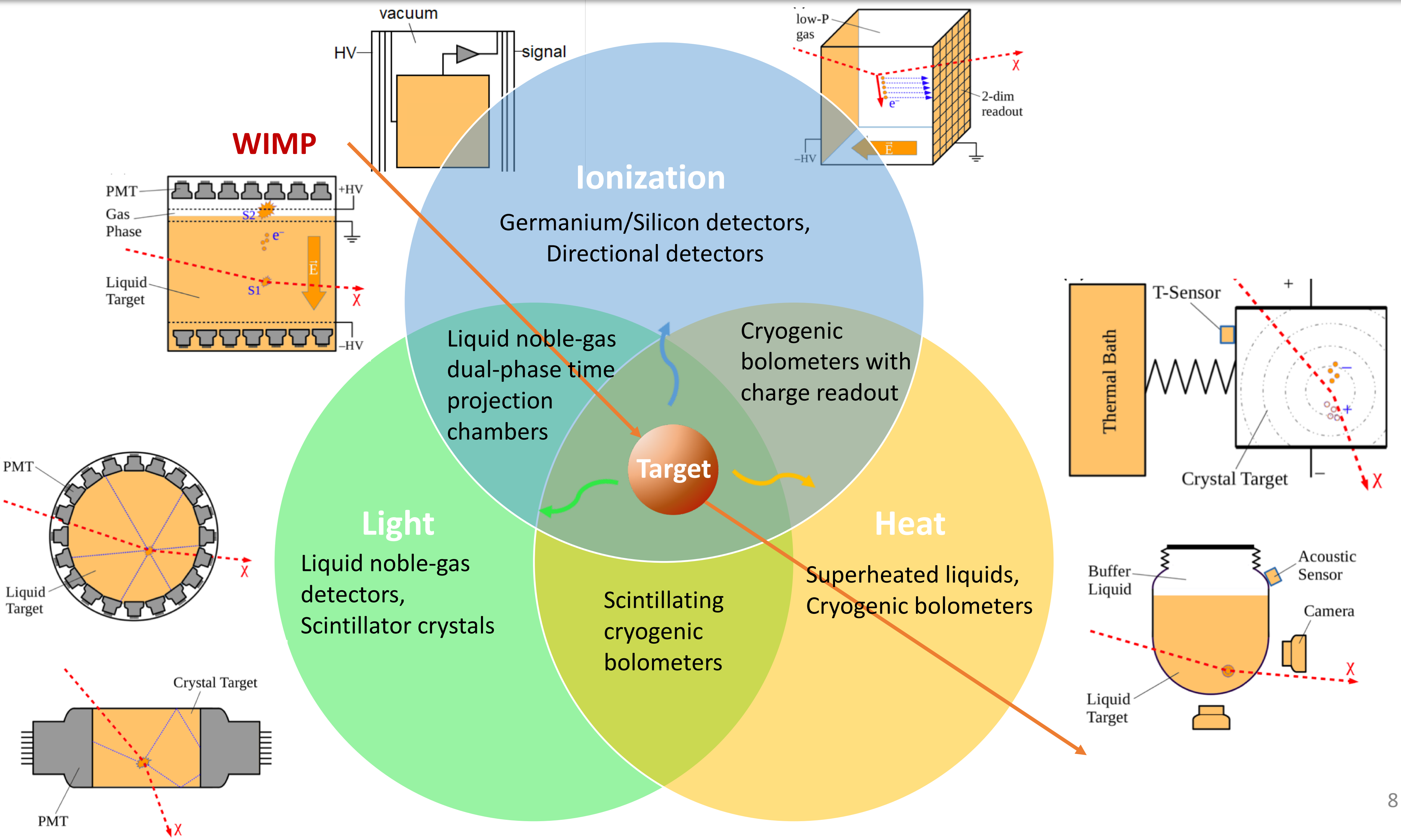


Dark matter detection technologies

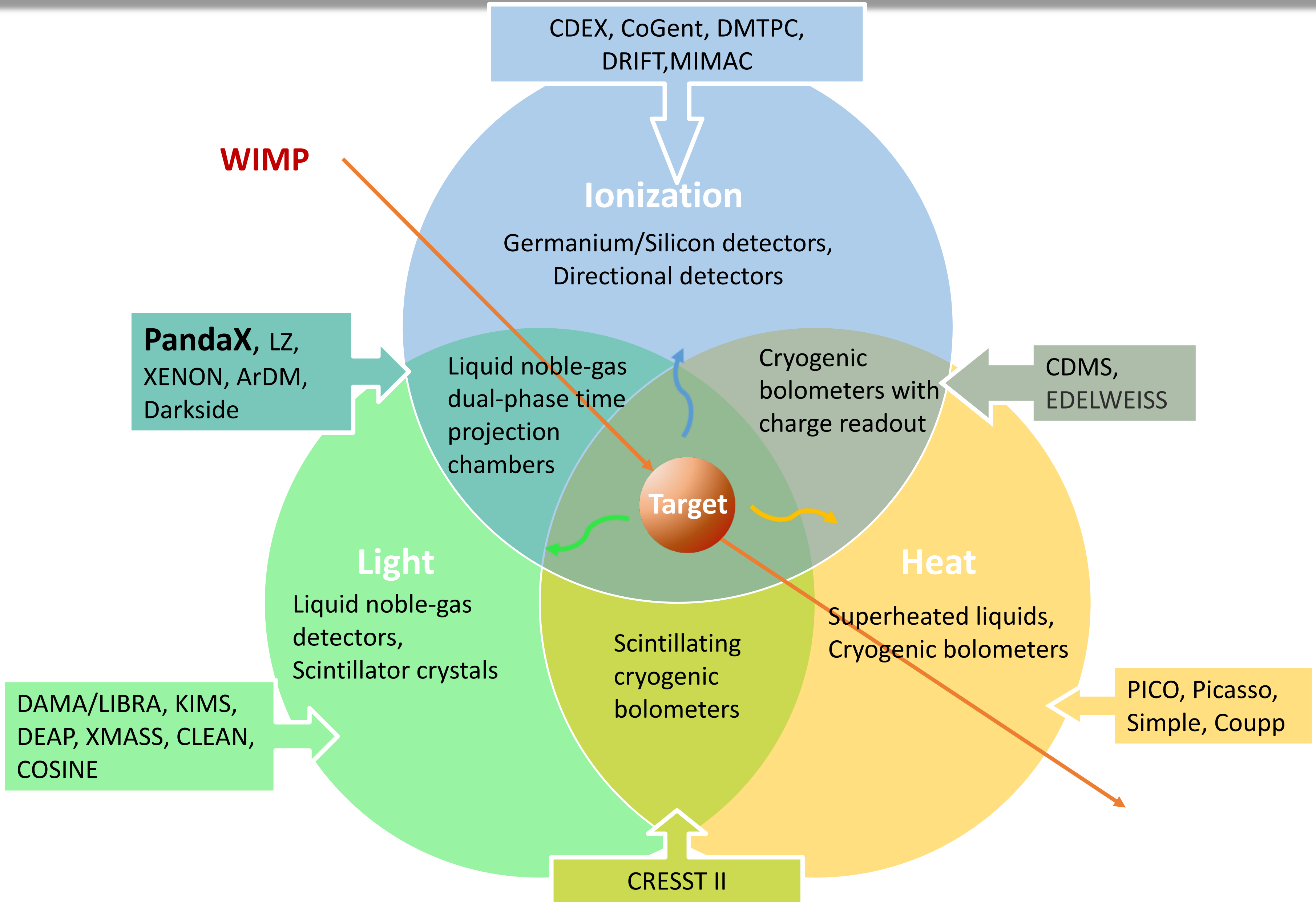




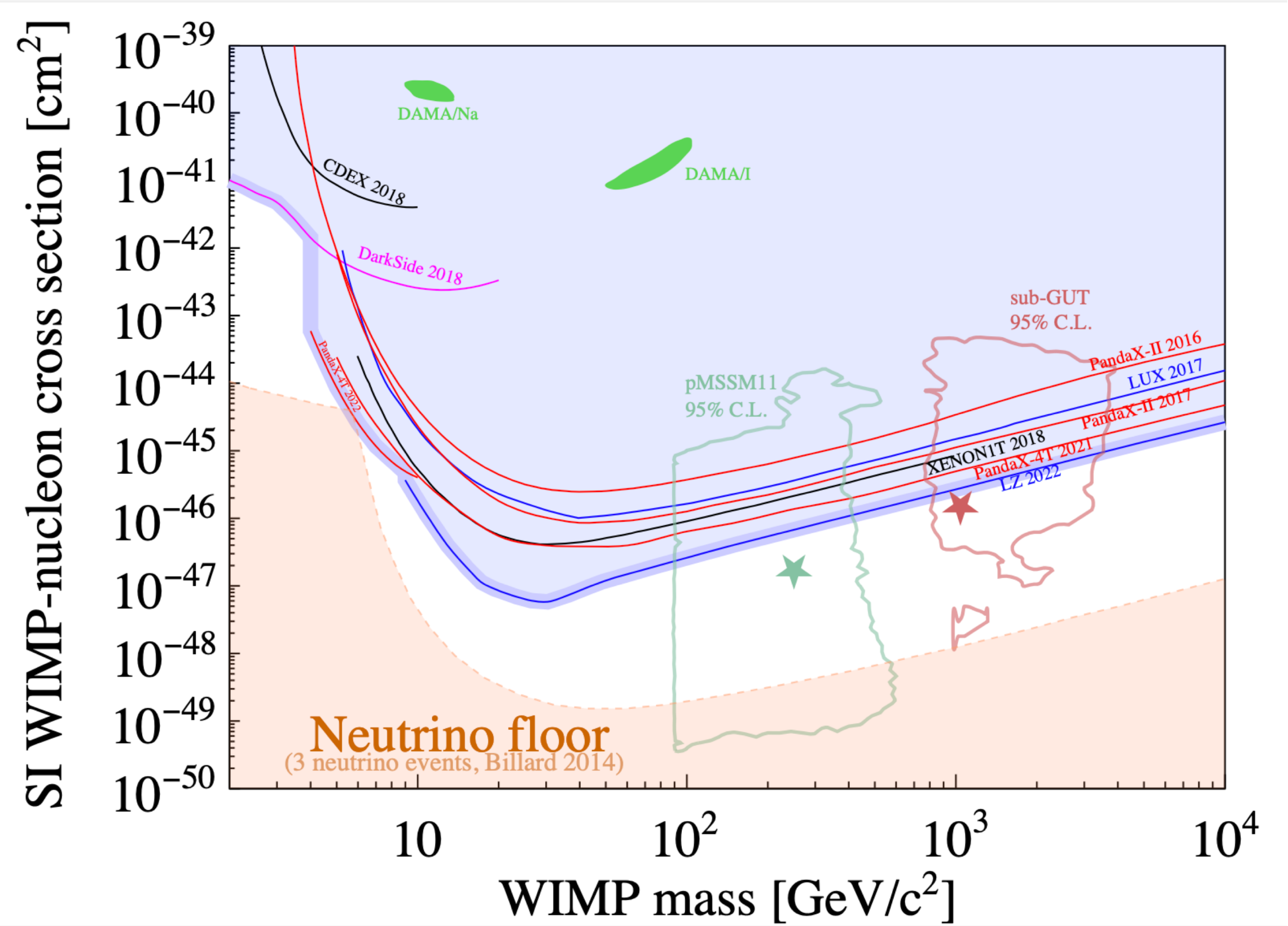
Dark matter detection technologies



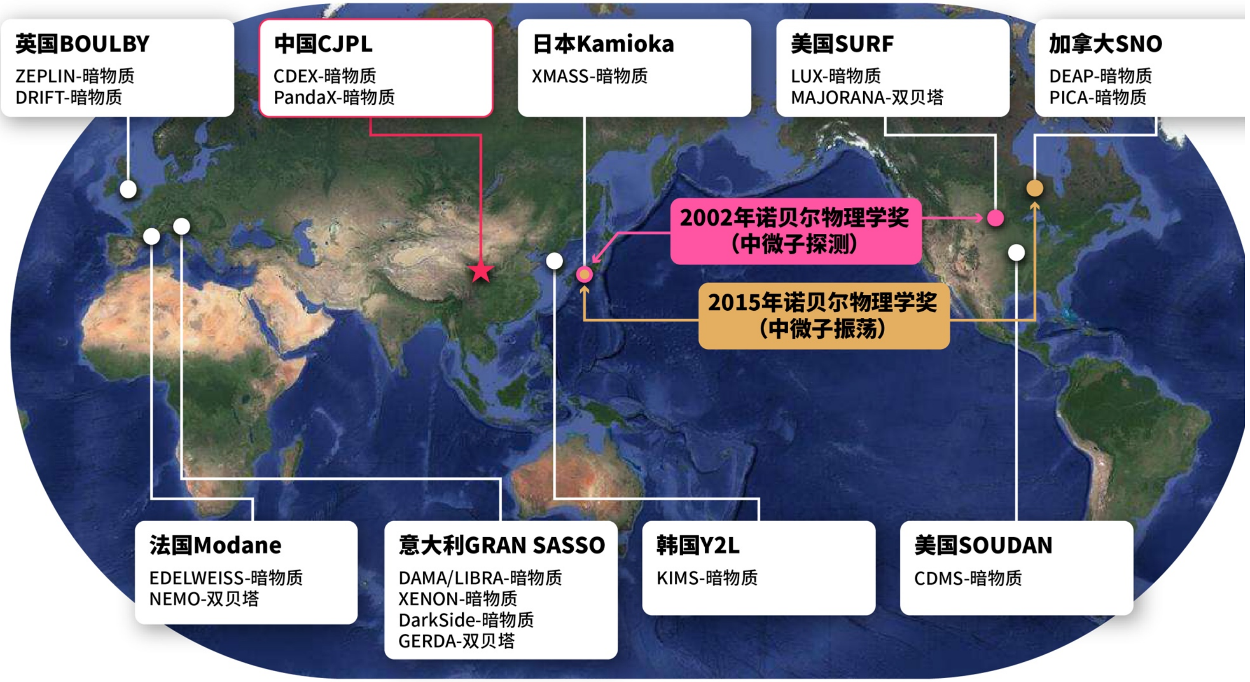
Dark matter detection technologies



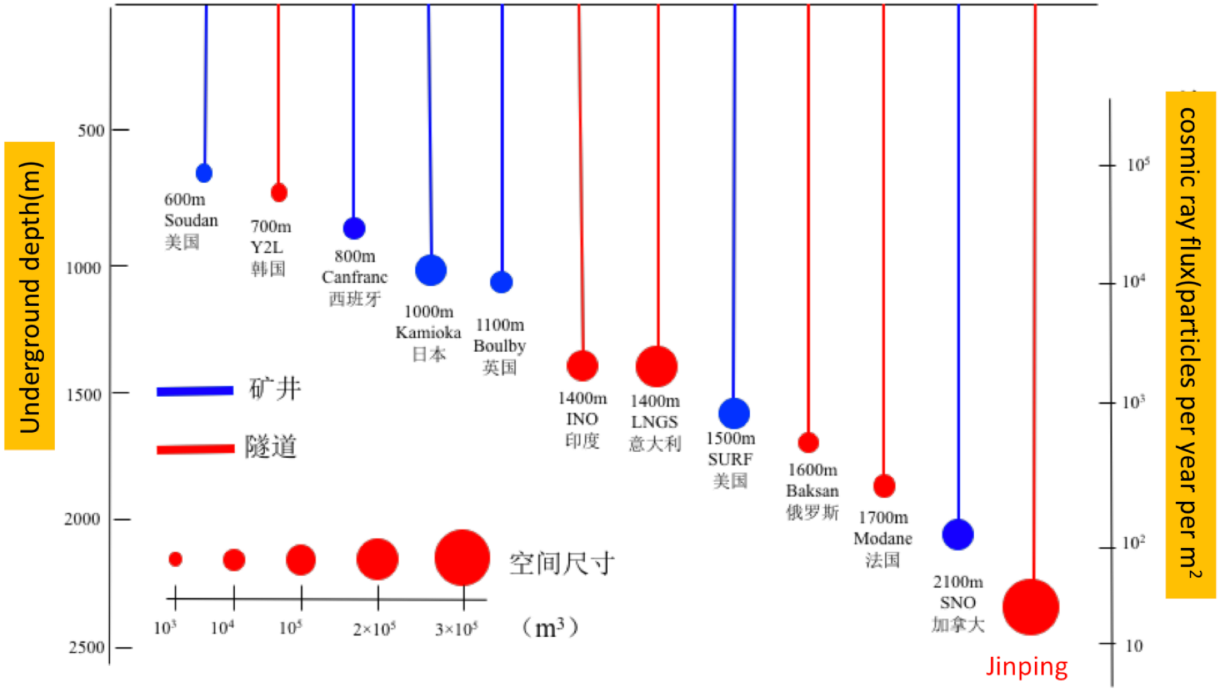
WIMP: hide and seek

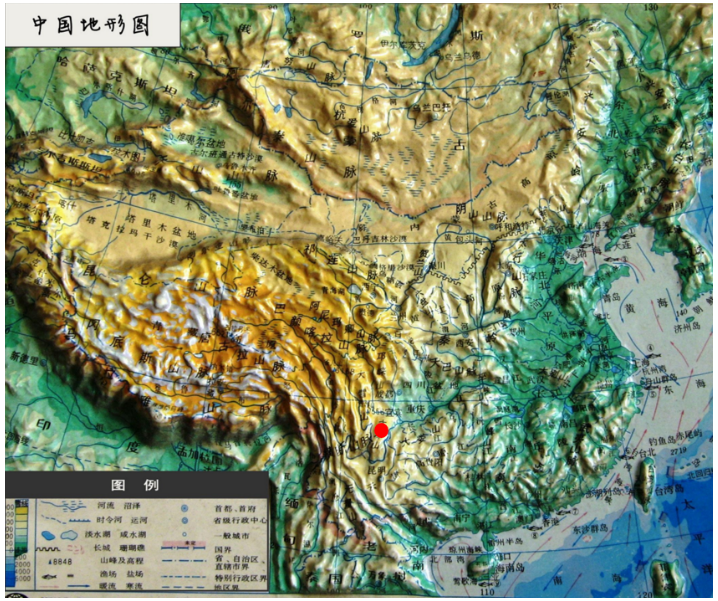


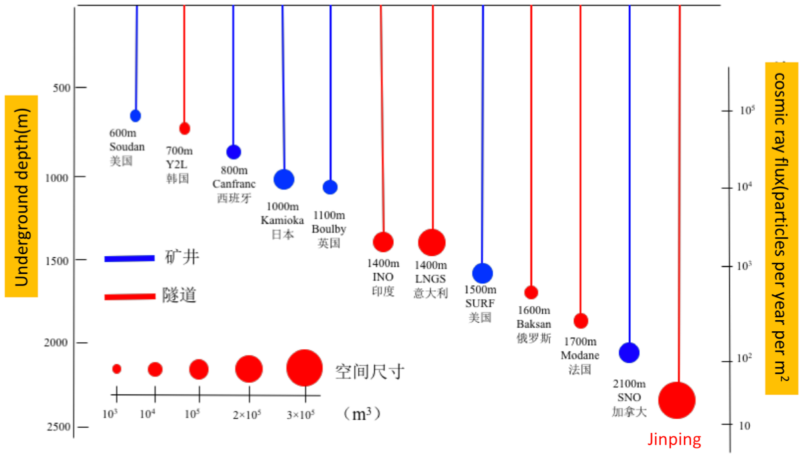
Worldwide underground laboratories



From Hao Ma's slides in China-LRT 2019

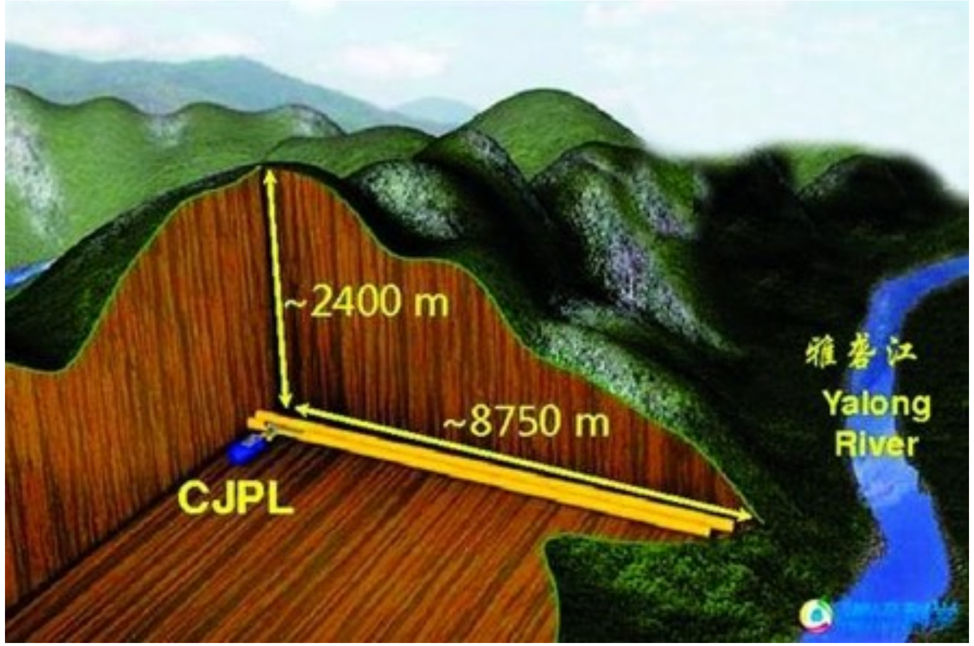






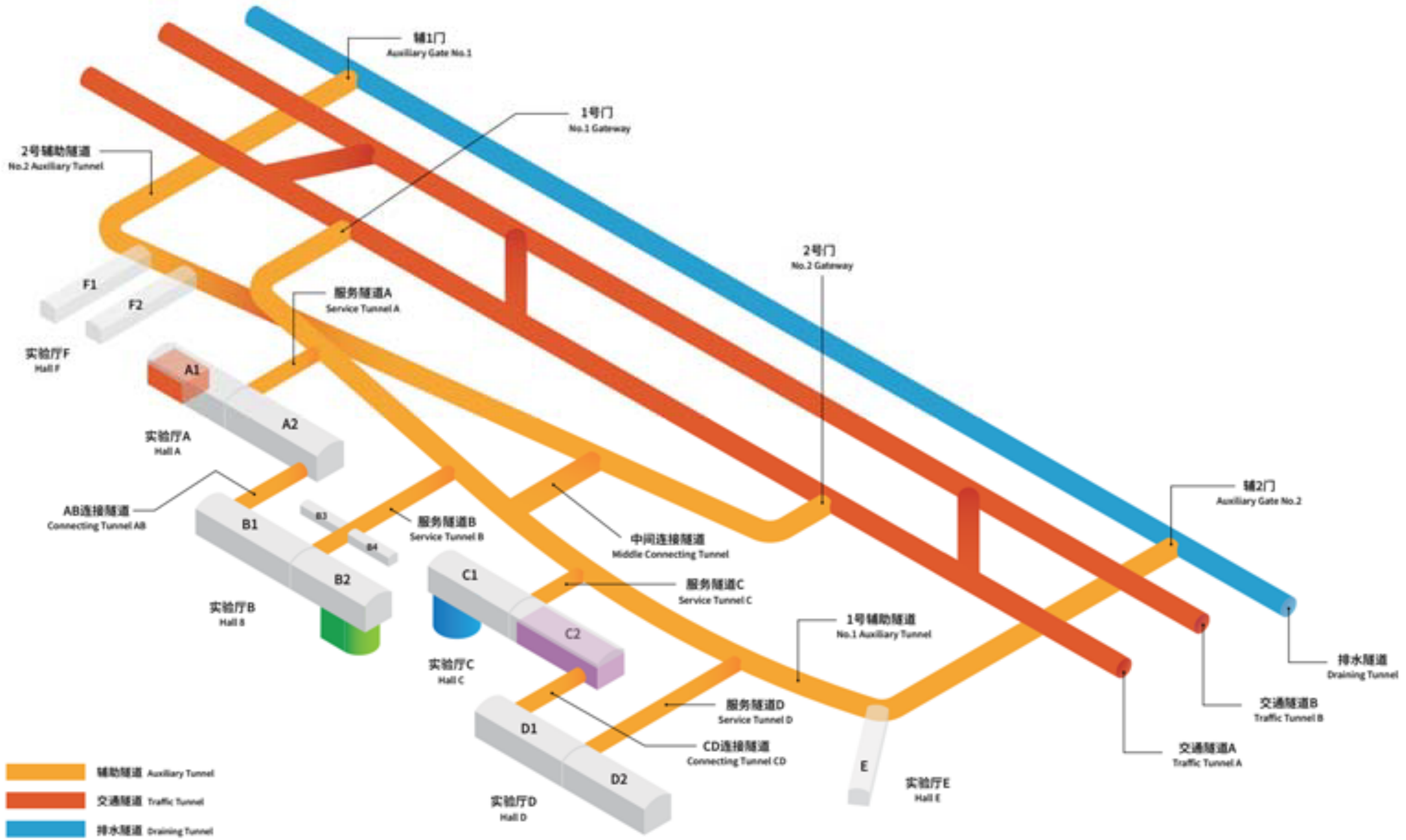
CJPL

- Deepest (6800 m.w.e)
- Horizontal access
- **Muon rate: ~1 count/week/m^2**



CJPL Phase-II

PandaX
PARTICLE AND ASTROPHYSICAL XENON TPC



PandaX Collaboration

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Particle and Astrophysical Xenon Experiments

PandaX experiment

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Collaboration formed

2009.3

2012.7

PandaX-I apparatus moved to Jinping

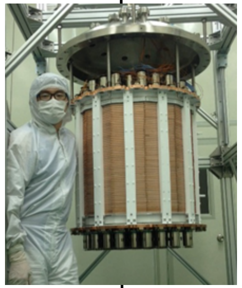
PandaX-I started

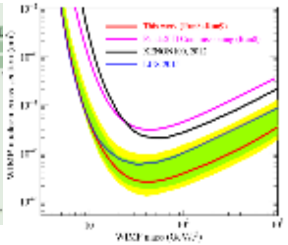
2014.3

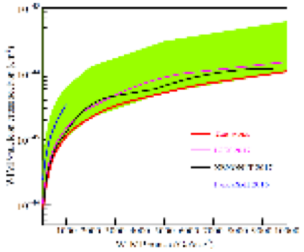
2014.5-10

PandaX-I, 120 kg operation

PandaX-II, 580 kg operation







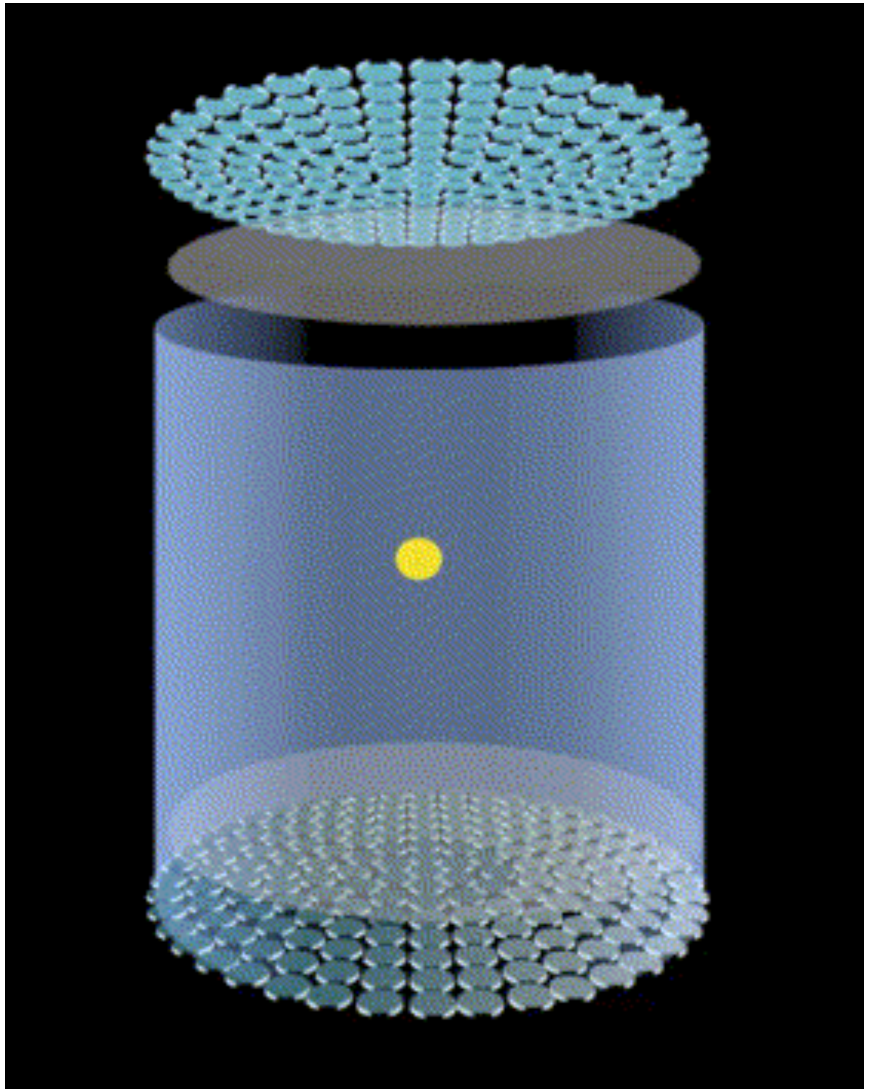
2016.7-2019.7

2019.8-

PandaX-4T moved to CJPL-II Commissioning was completed

Dual-phase xenon TPC

- **Dual-phase xenon time projection chamber**
- **High purity Xe target**
- **Self-shielding**
- **S1: prompt scintillation signal**
  - High light yield
- **S2: delayed ionization signal**
  - Electroluminescence in vapor phase
  - Sensitive to single ionization electrons



Dual-phase xenon TPC

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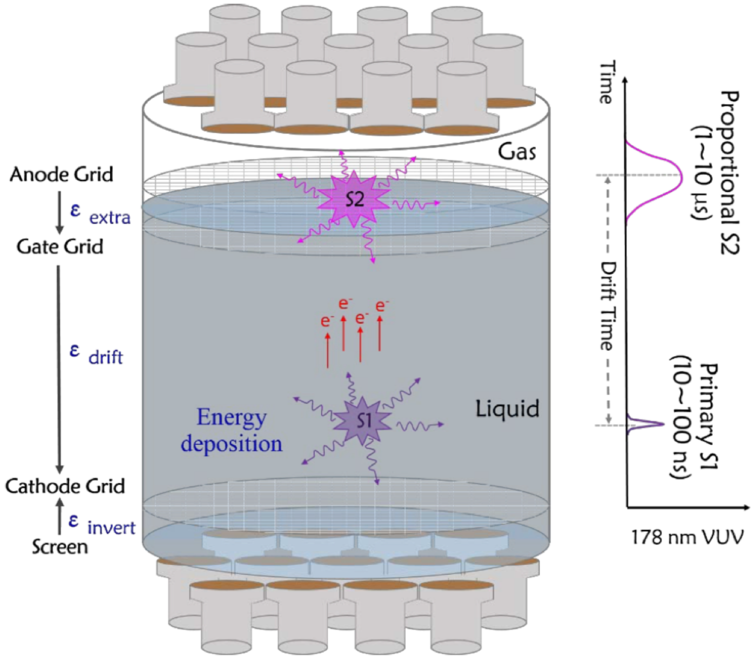
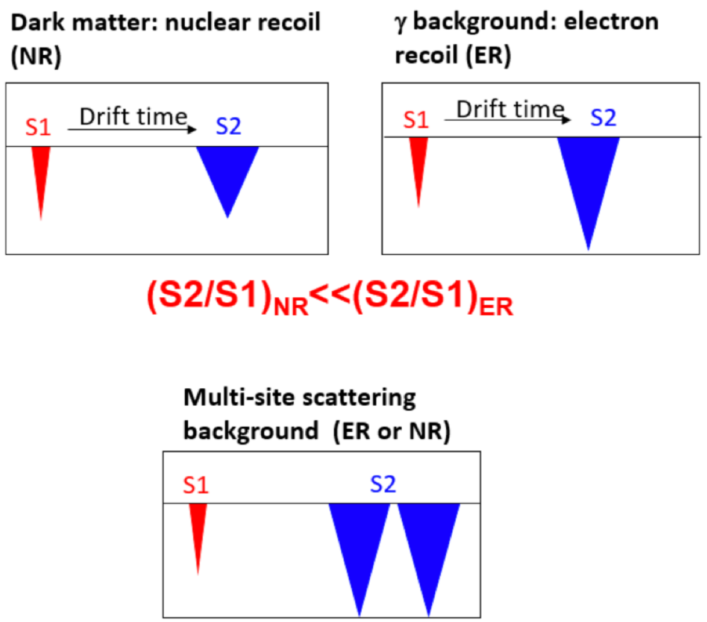
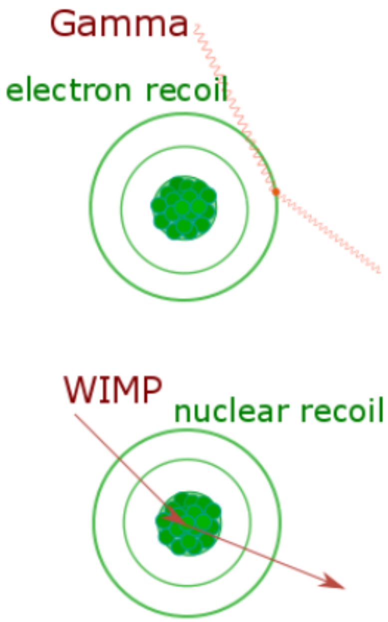
- **S1 + S2 event by event**
  - Electron recoil background rejection by ratio of charge(S2)/light(S1)
- **3D event reconstructions**
  - Z position from S1-S2 drift time
  - X-Y positions from S2 light pattern
  - reject external background







PandaX-4T experiment layout

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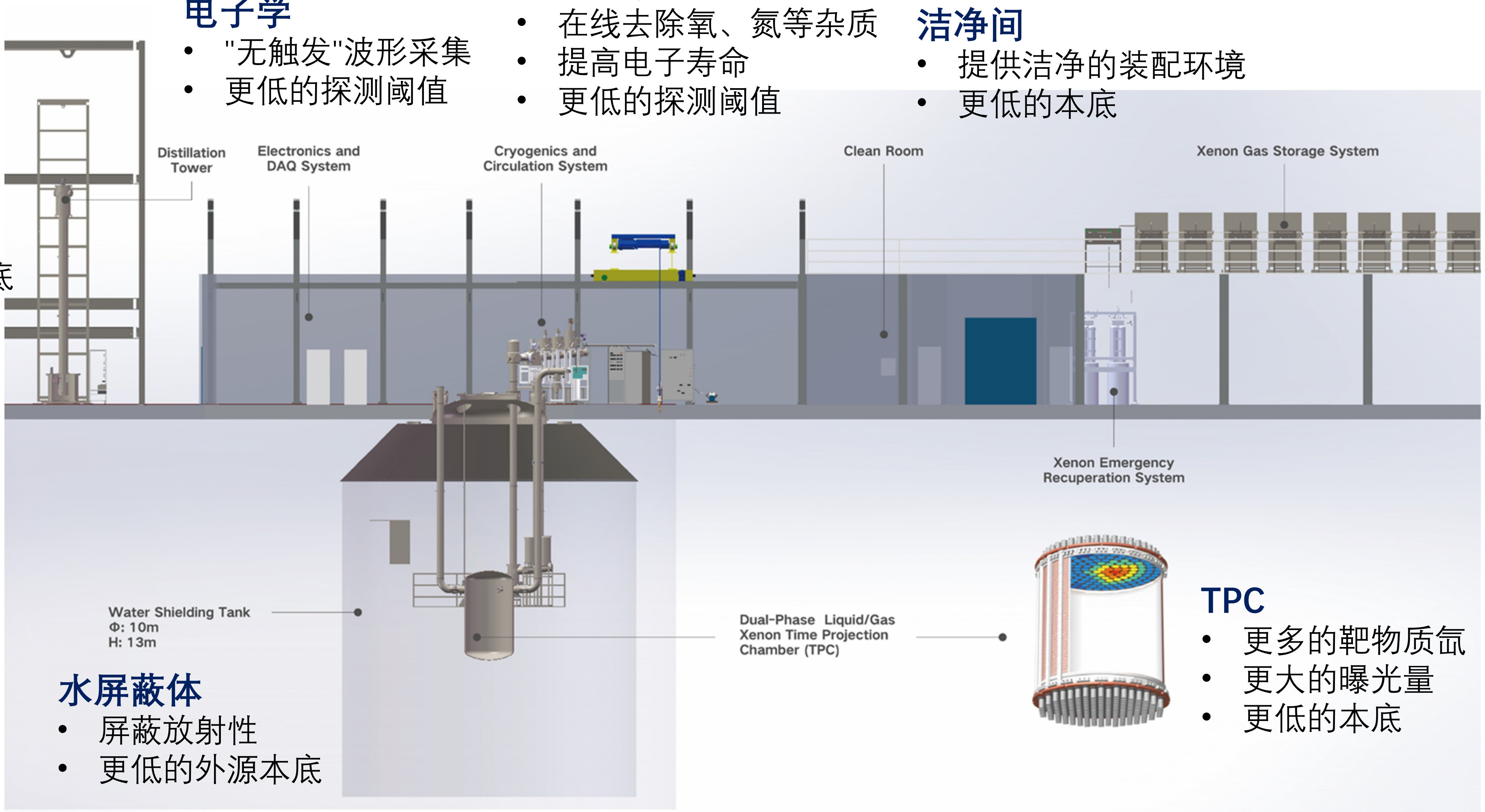
精馏塔
- 在线去除氪杂质
- 更低的TPC内部本底

电子学
- "无触发"波形采集
- 更低的探测阈值

循环系统
- 在线去除氧、氮等杂质
- 提高电子寿命
- 更低的探测阈值

洁净间
- 提供洁净的装配环境
- 更低的本底



水屏蔽体
- 屏蔽放射性
- 更低的外源本底

TPC
- 更多的靶物质氙
- 更大的曝光量
- 更低的本底

Infrastructure

Infrastructure

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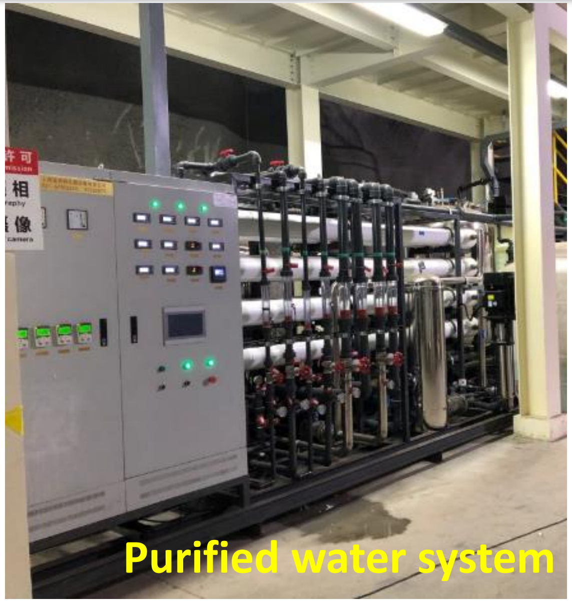
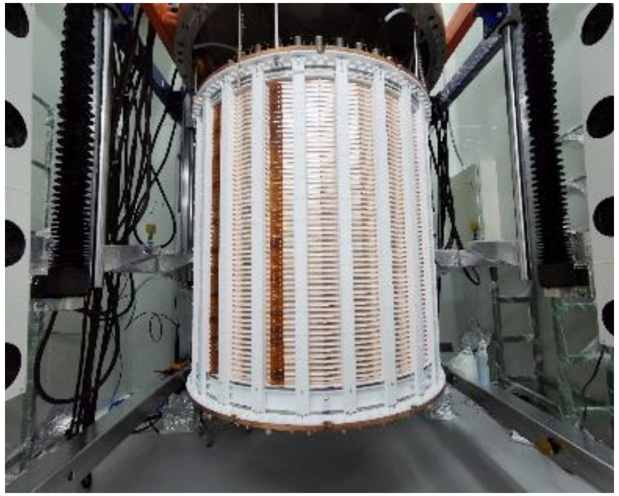
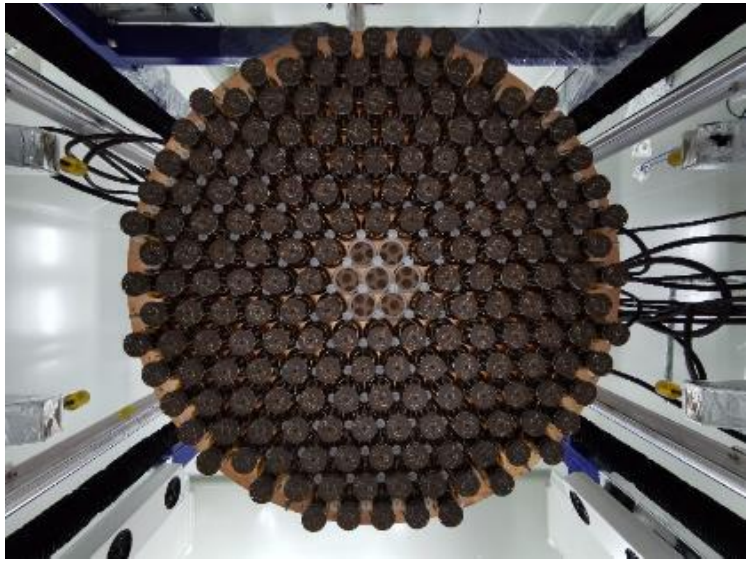


Gas, cryogenics and distillation systems

TPC installation





Electronics hut

Instrumented clean room

Ultrapure water filling

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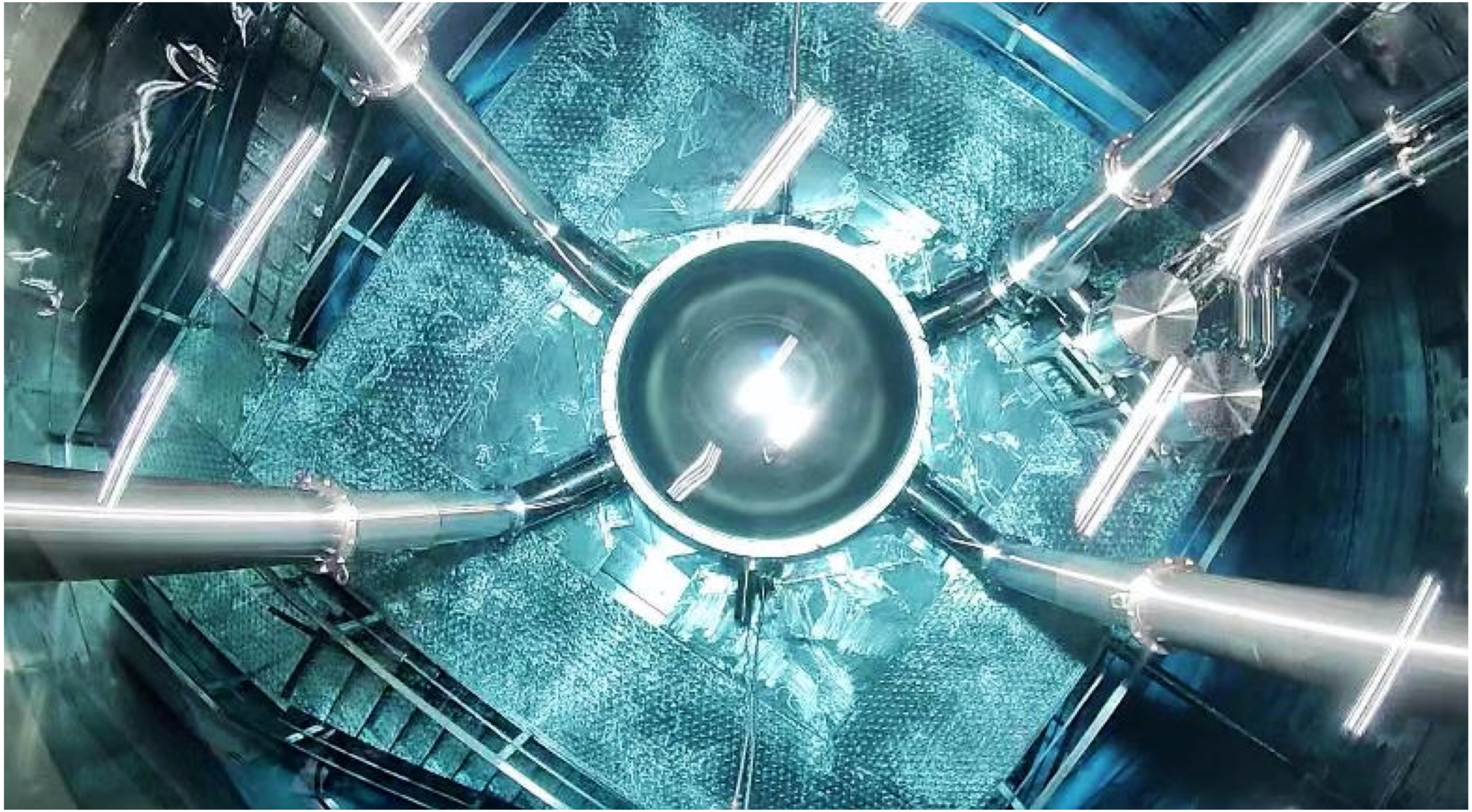
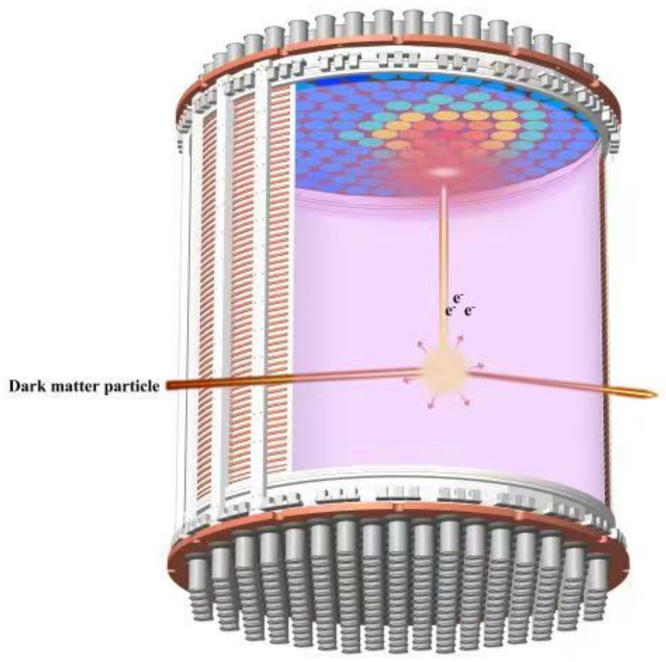
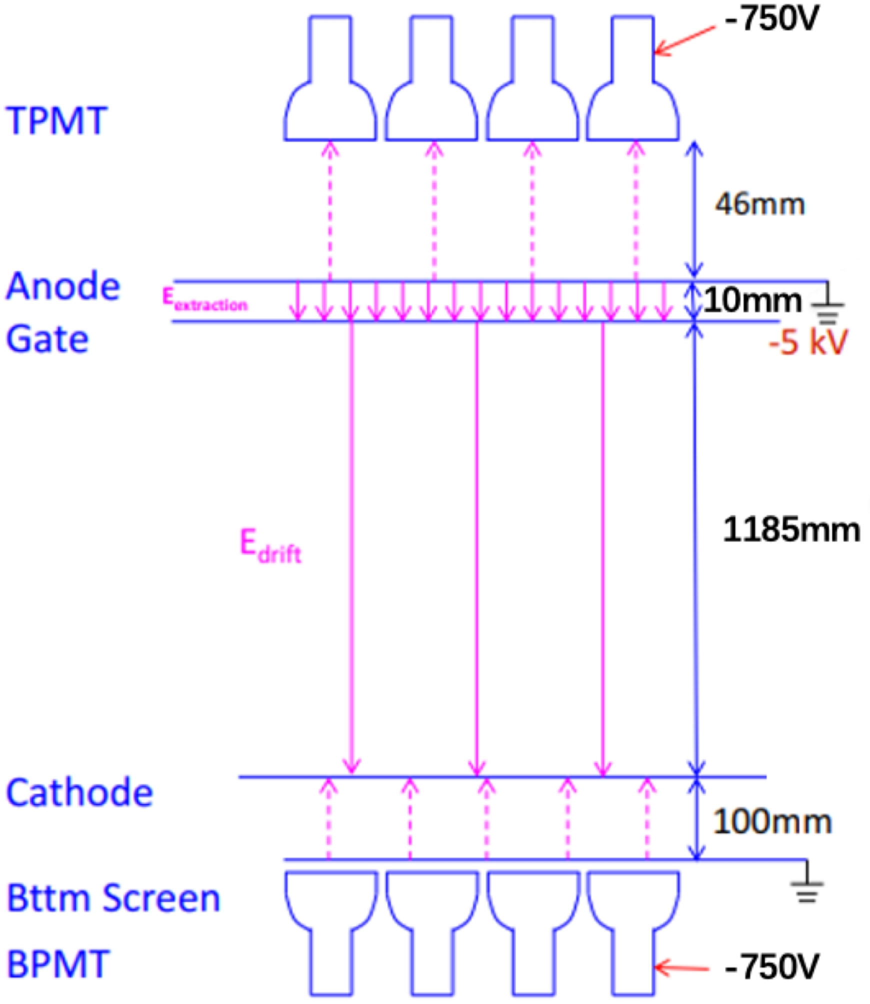


TPC operation conditions

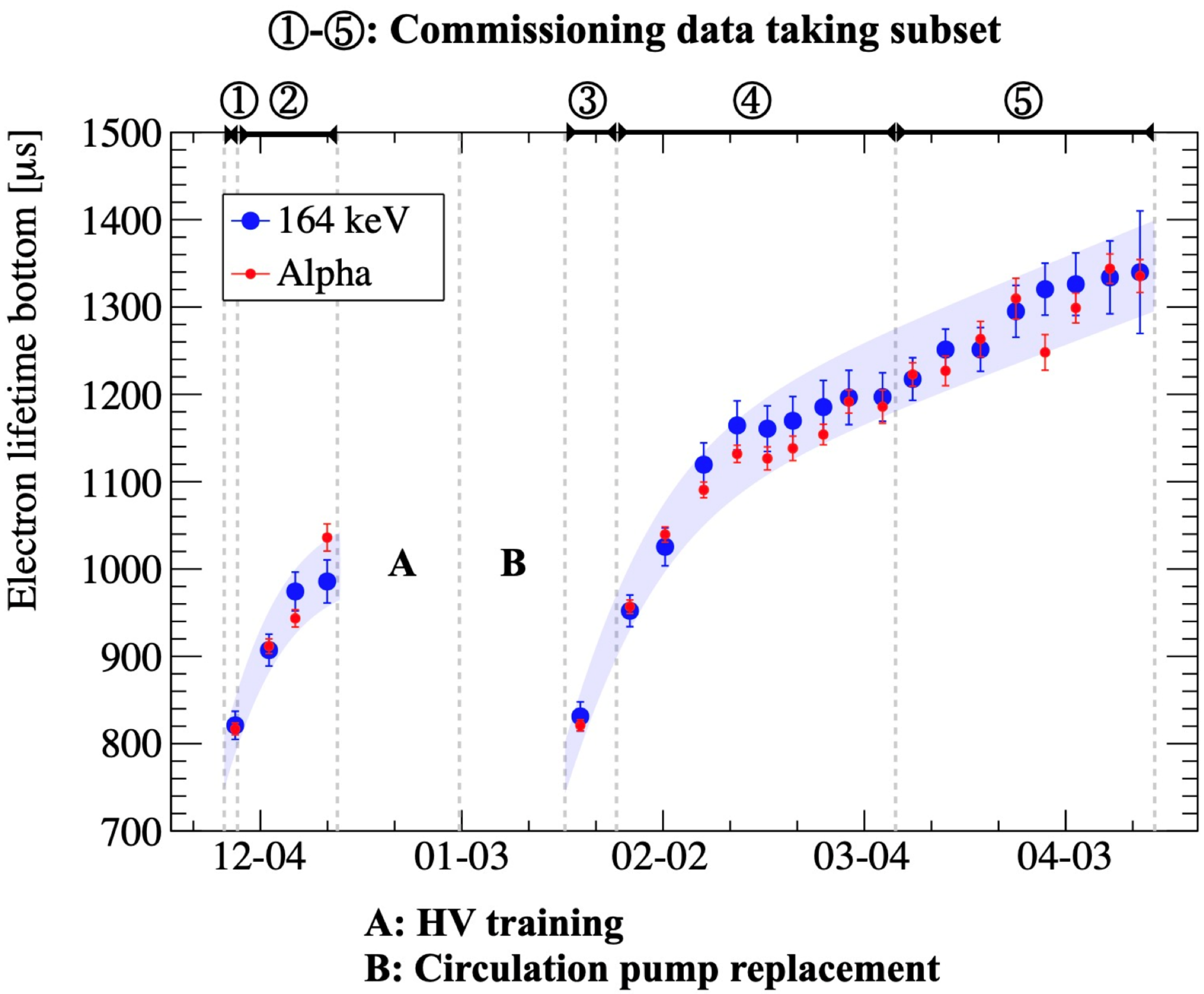




	Set1	Set2	Set3	Set4	Set5
Gate(kV)	-4.9		-5	-5	
Cathode (kV)	-20	-18.6	-18	-16	

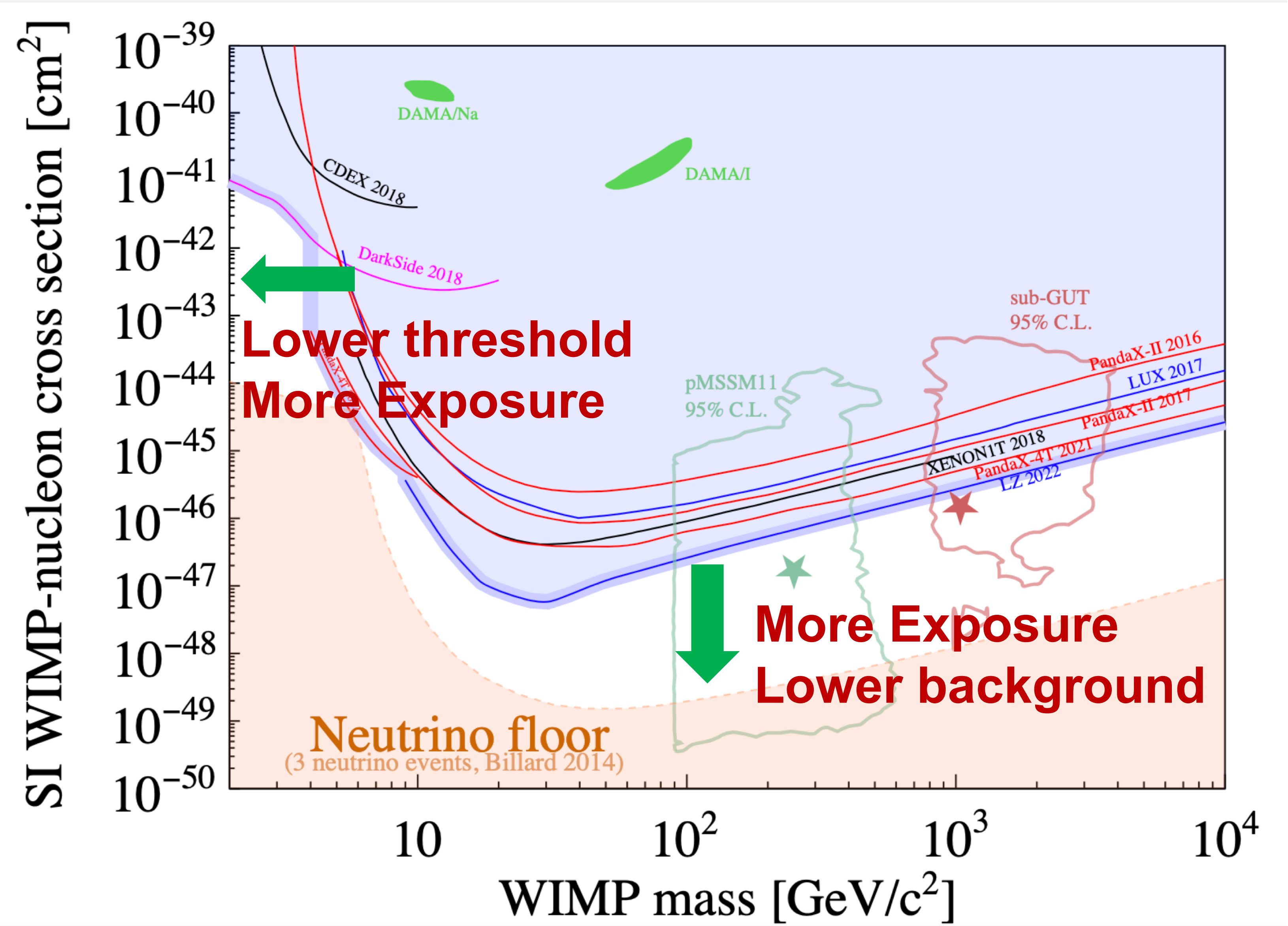
During the run, HV set at a few different values to avoid excessive discharges.

Data Taking History – 5 Subsets



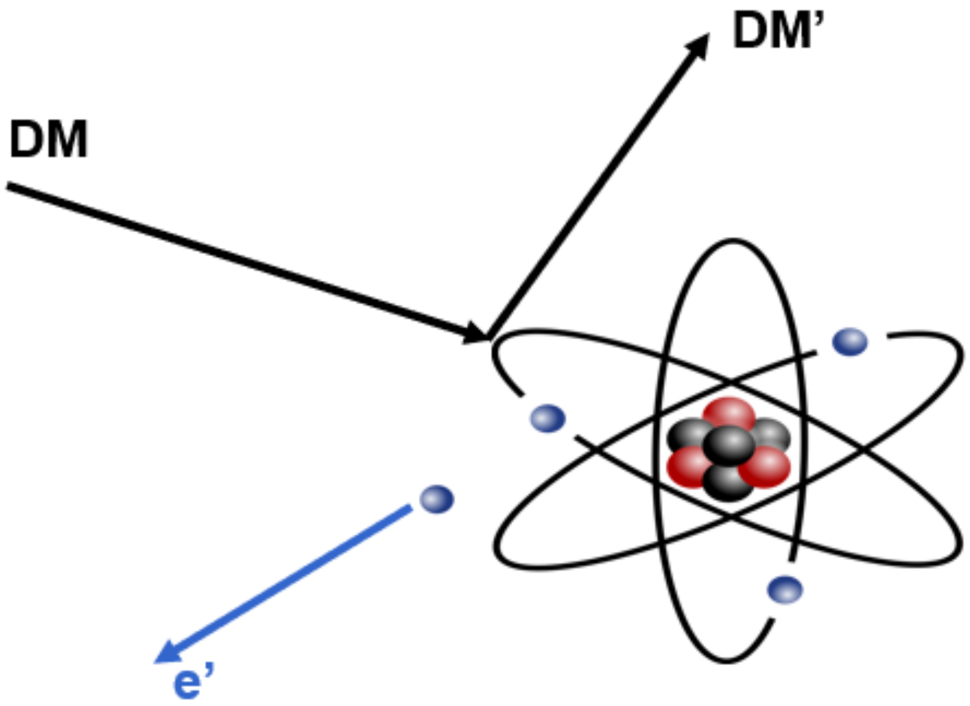
- ❑ Electron lifetime: *in situ* S2 vertical uniformity calibration
- ❑ Ref: the maximum drift time ~ 840 μs (field dependent)
- ❑ Two gas loops for purification
- ❑ Stable data running period: 95.0 calendar days

WIMP: hide and seek

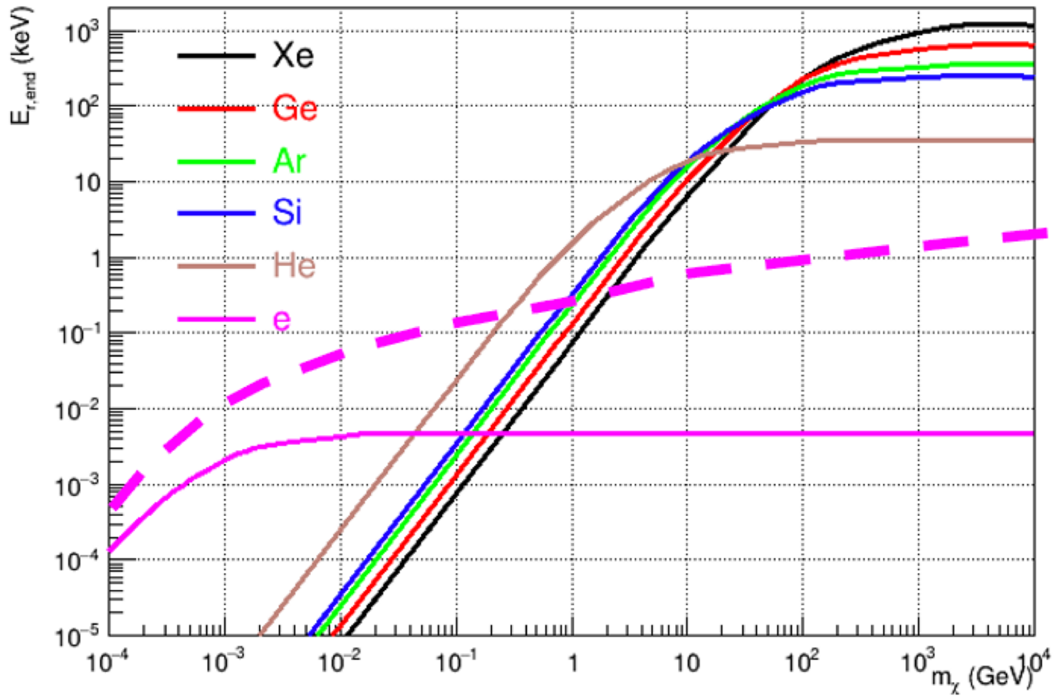


Light DM search

Light DM and shell electron interaction



DM and shell electrons interaction



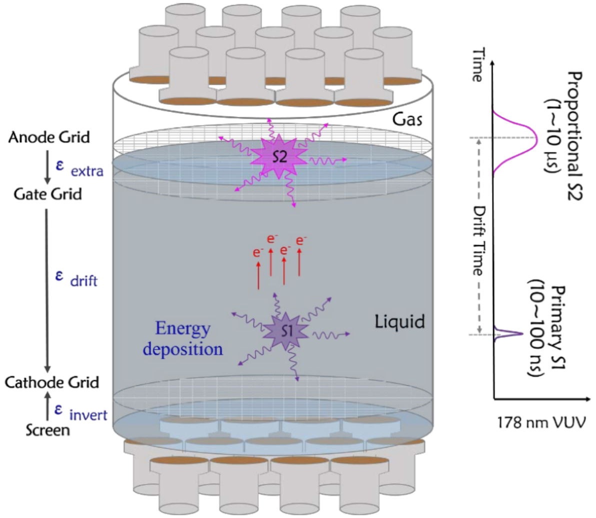
Recoil energy for different targets

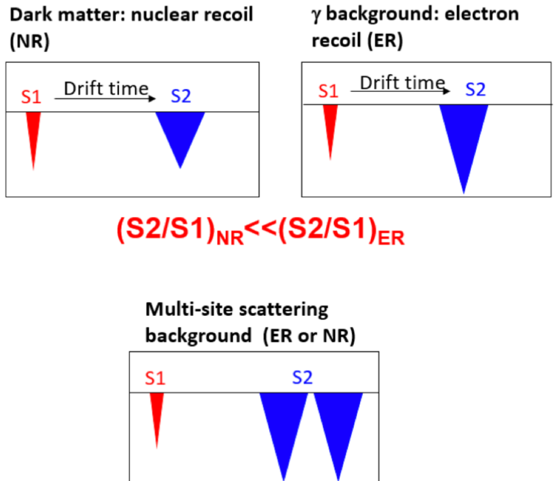
Conventional DM search

- **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

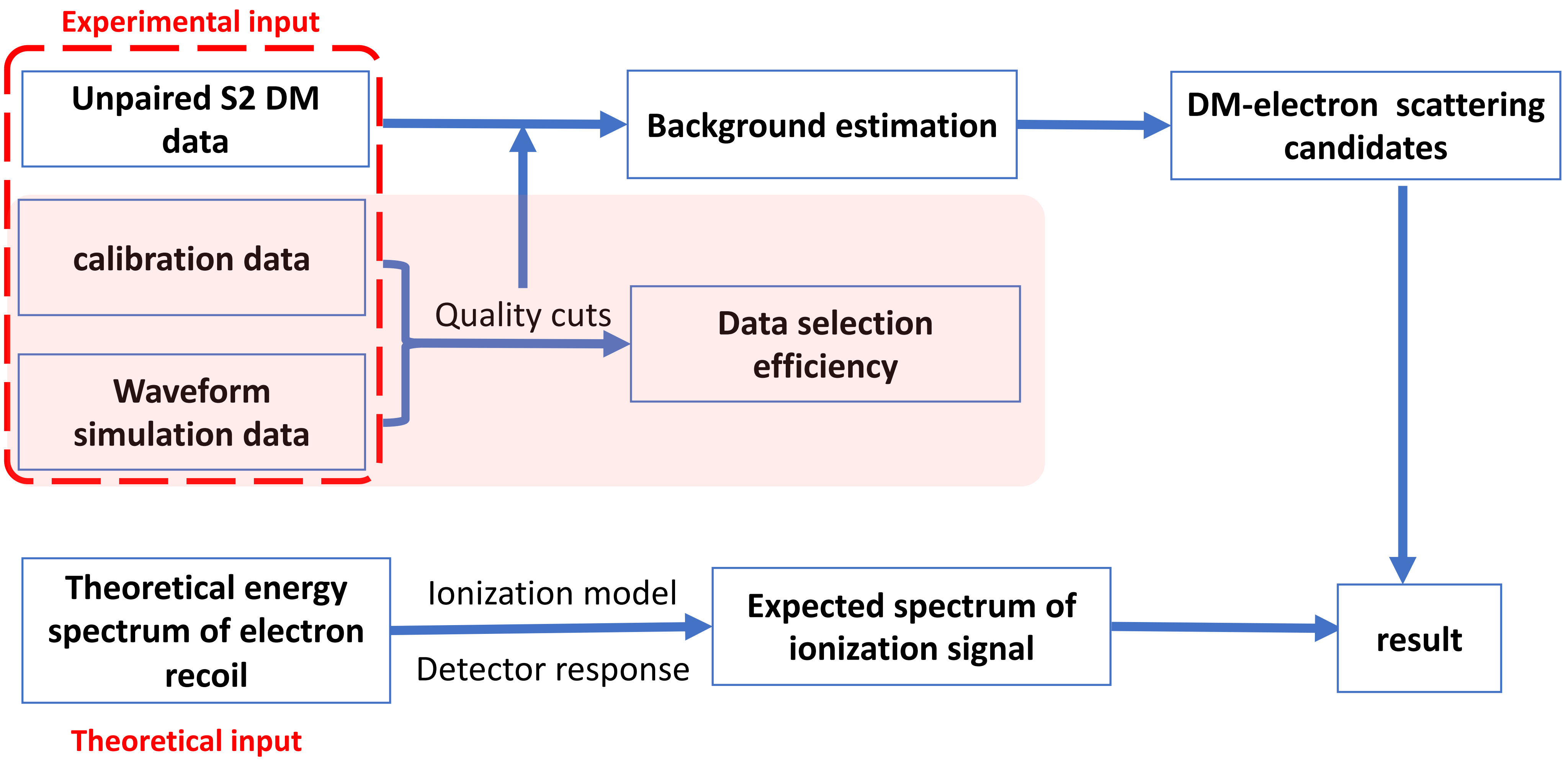
Light DM search

- **Un-paired S2 (US2) analysis**
  - Lower energy threshold ~ 70 eV, comparing energy threshold ~1 keV with S1 + S2 paired analysis
  - Sensitive to light DM (sub-GeV) interaction





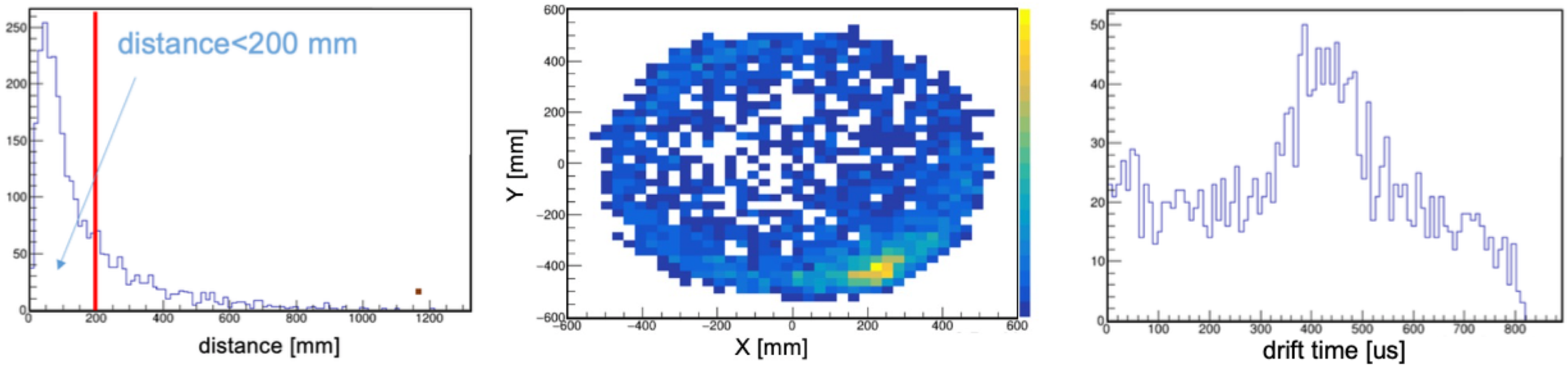
Analysis flow



Quality cut

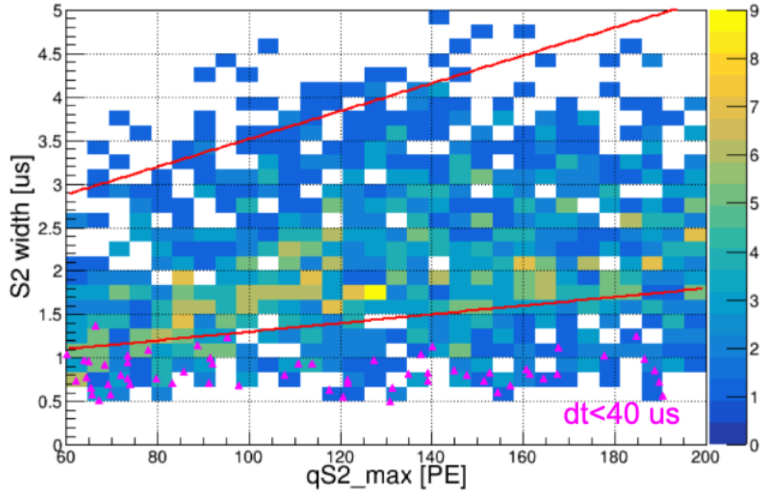
Data sets:

1. Double scattering events from neutron calibration data from AmBe and DD
2. Waveform simulation data

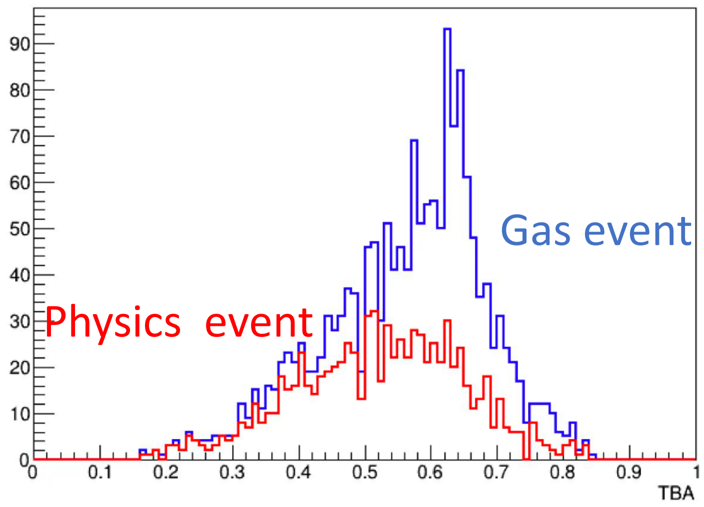


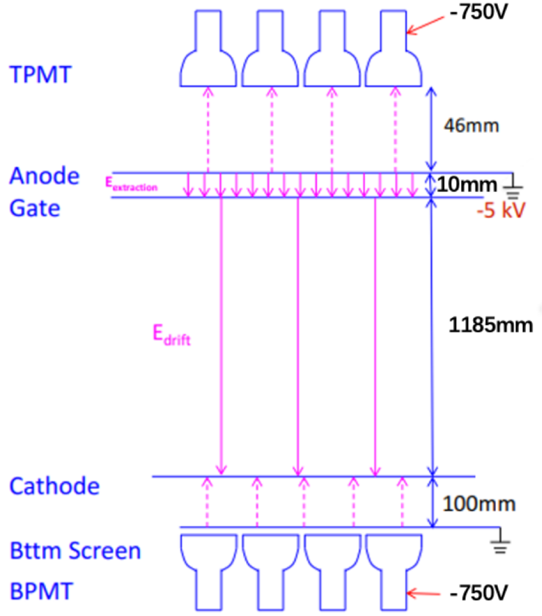
Quality cut

Cathode event and gas event

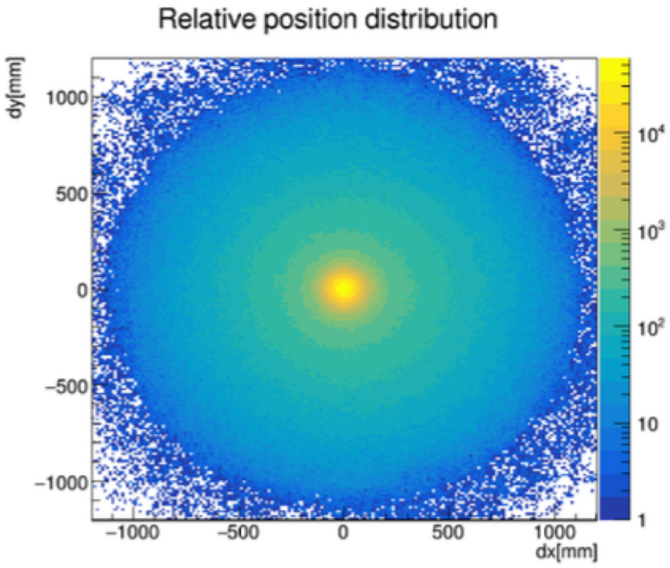


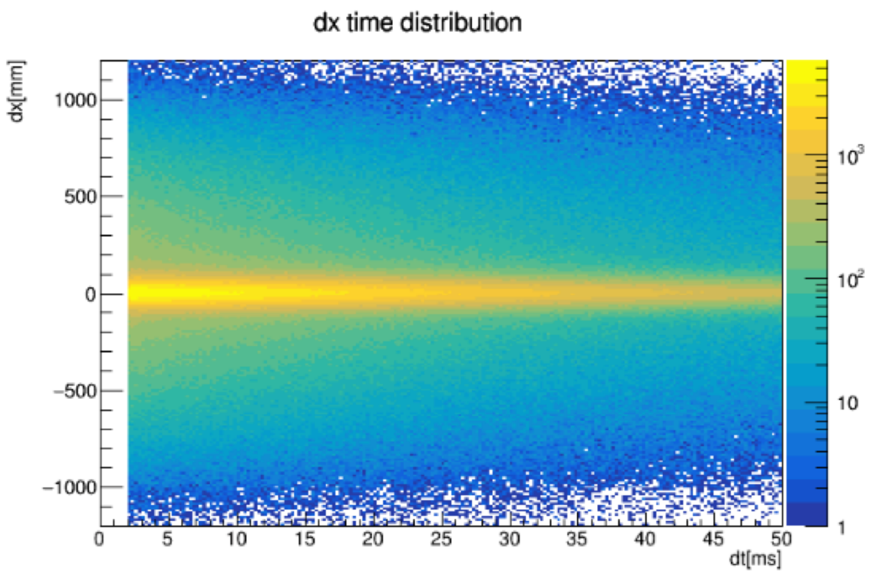
Gas event





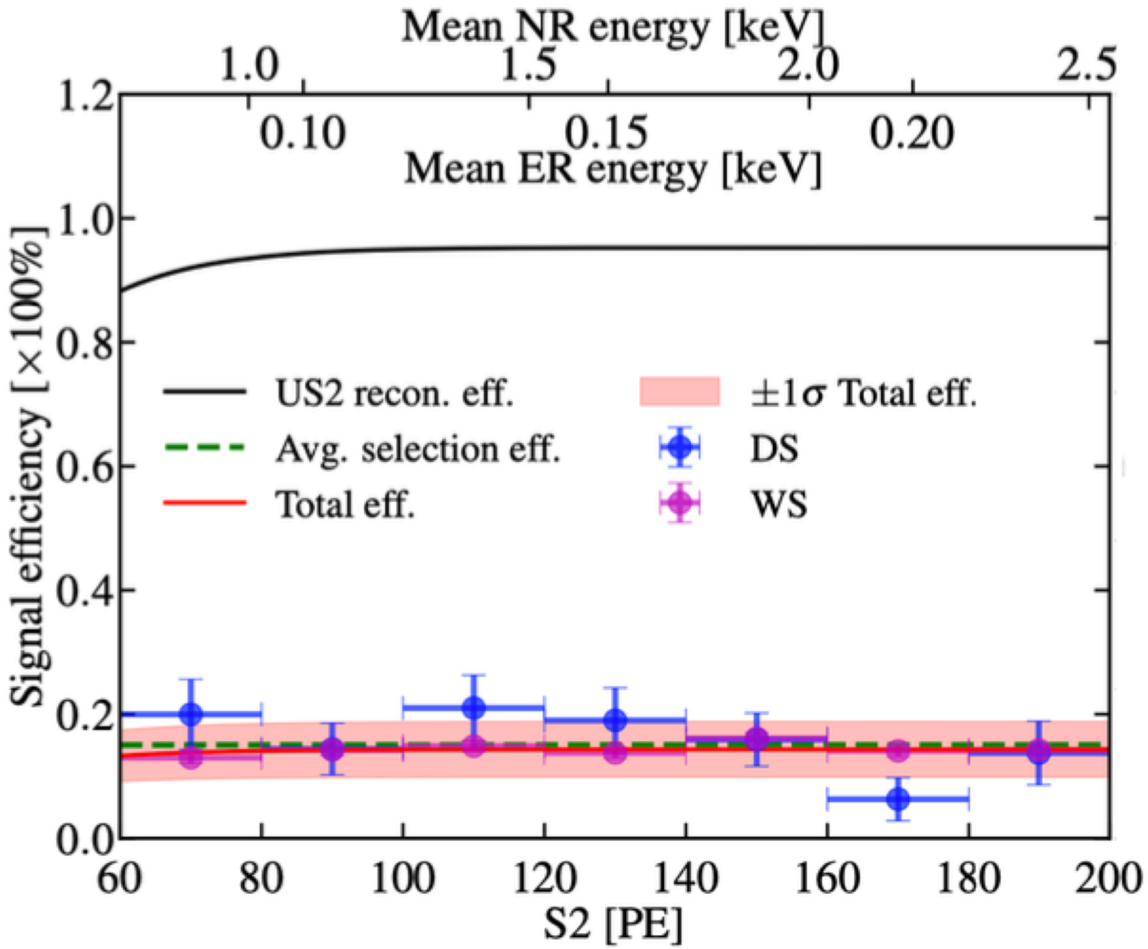
Electron burst event



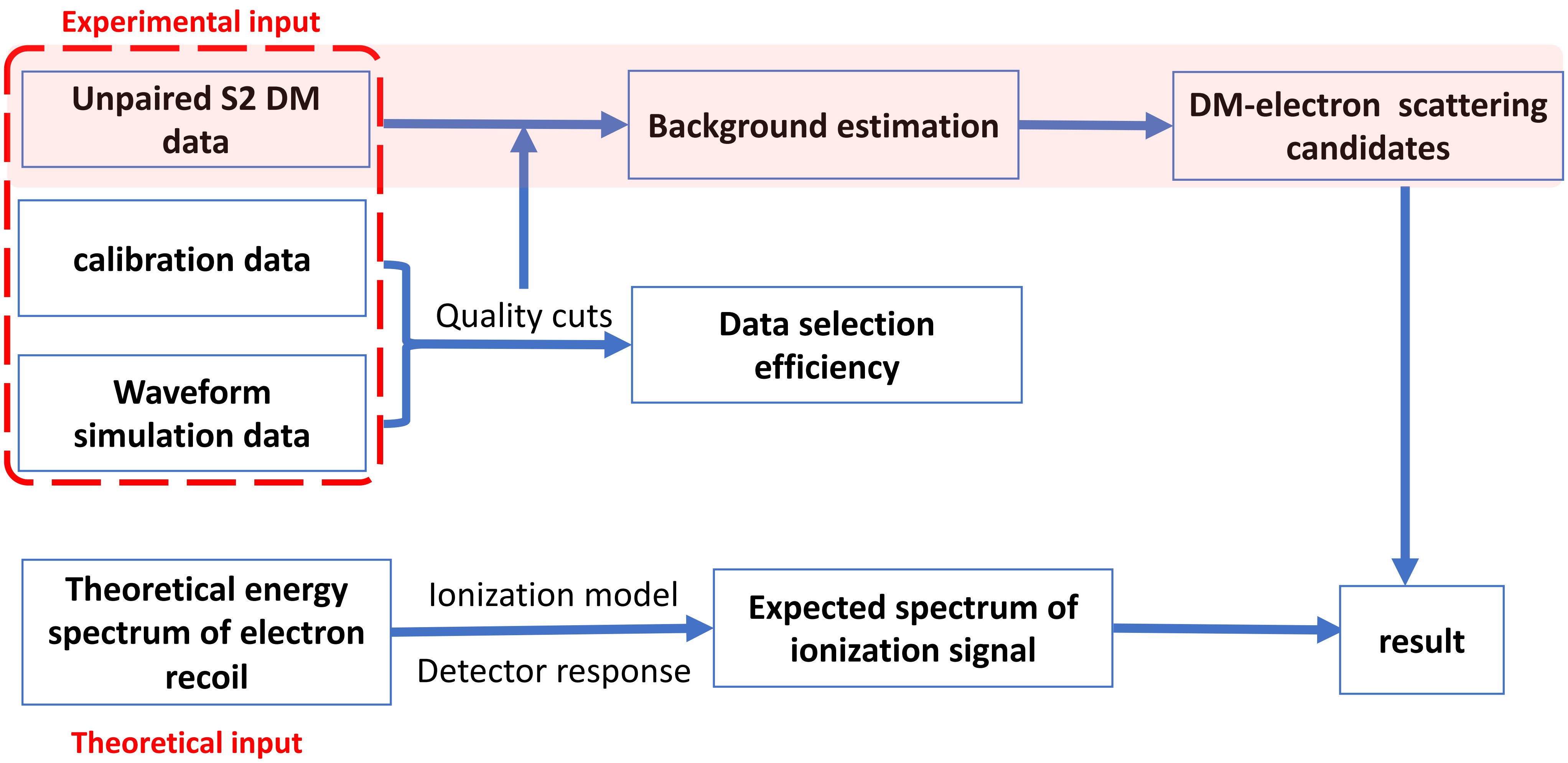


Quality cut

Data selection efficiency

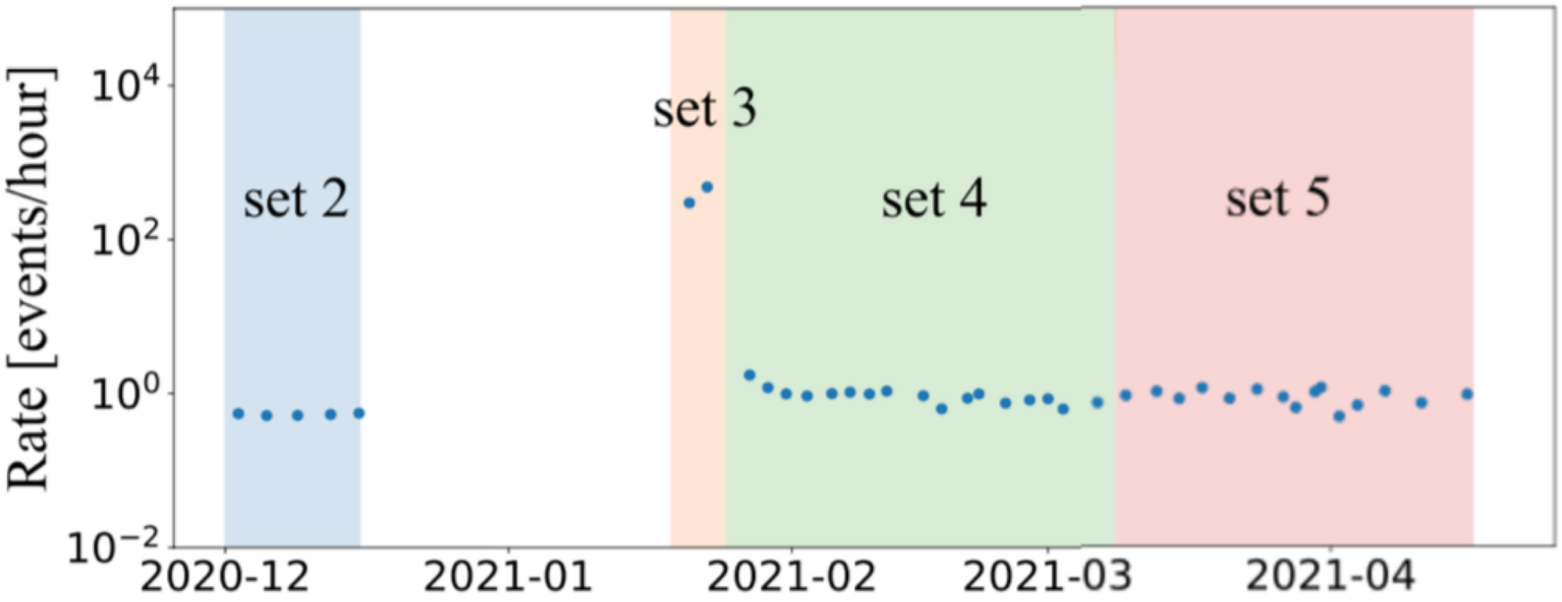


Analysis flow

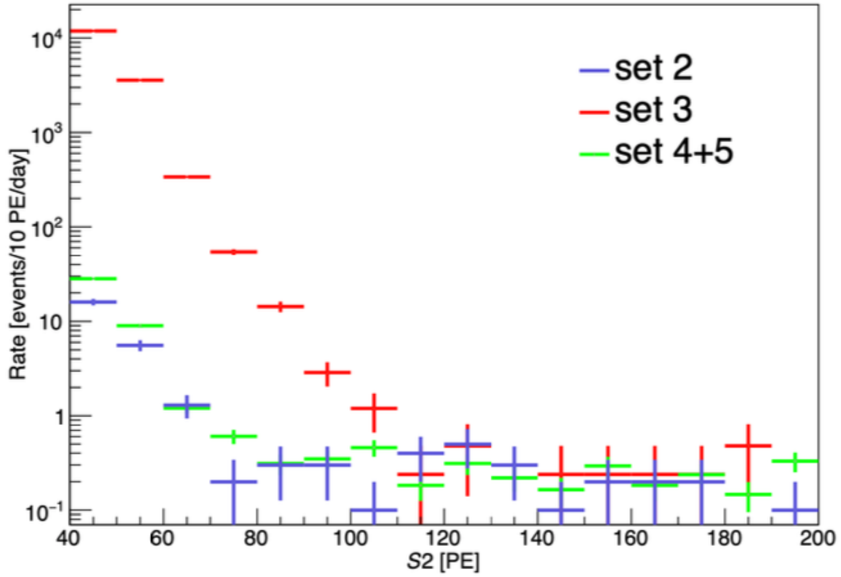


Background model

- Micro-discharging background



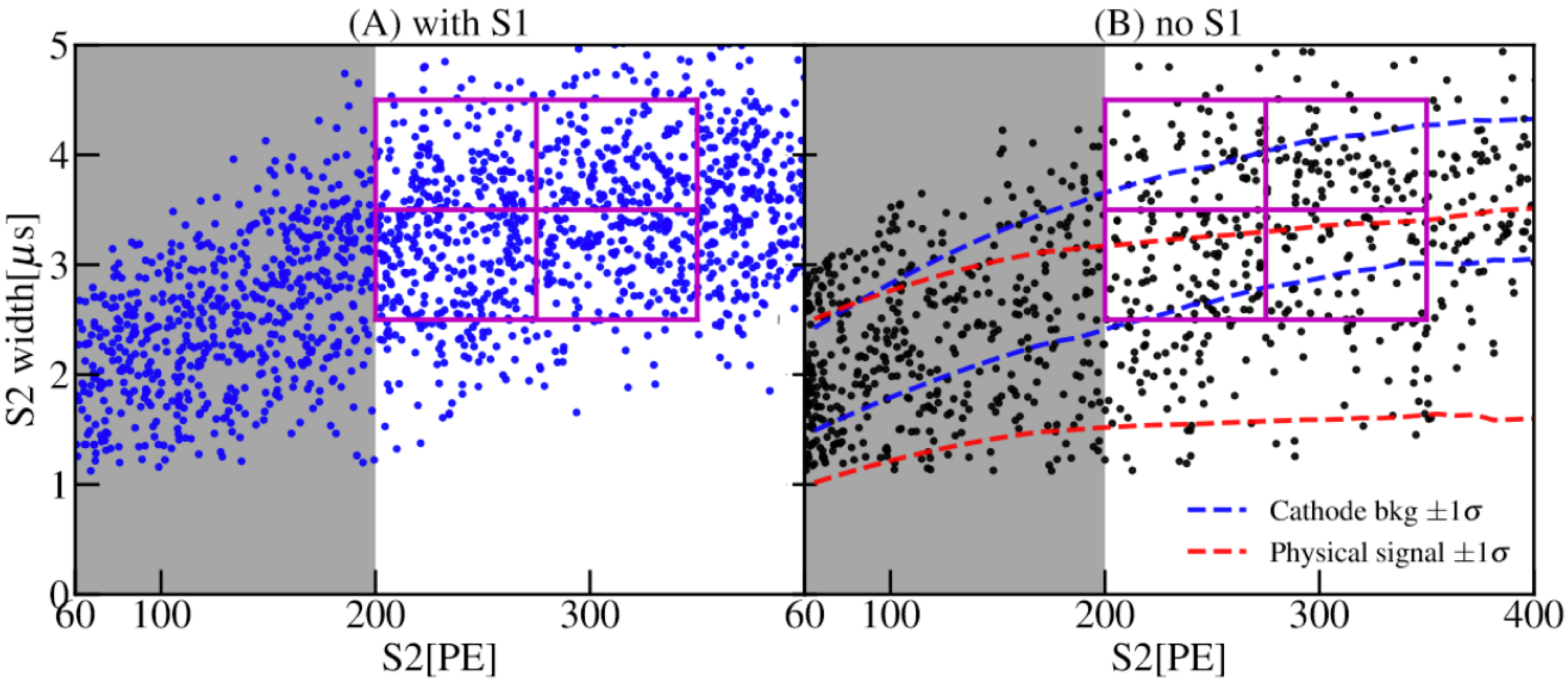
Time evolution



MD S2 shape

Background model

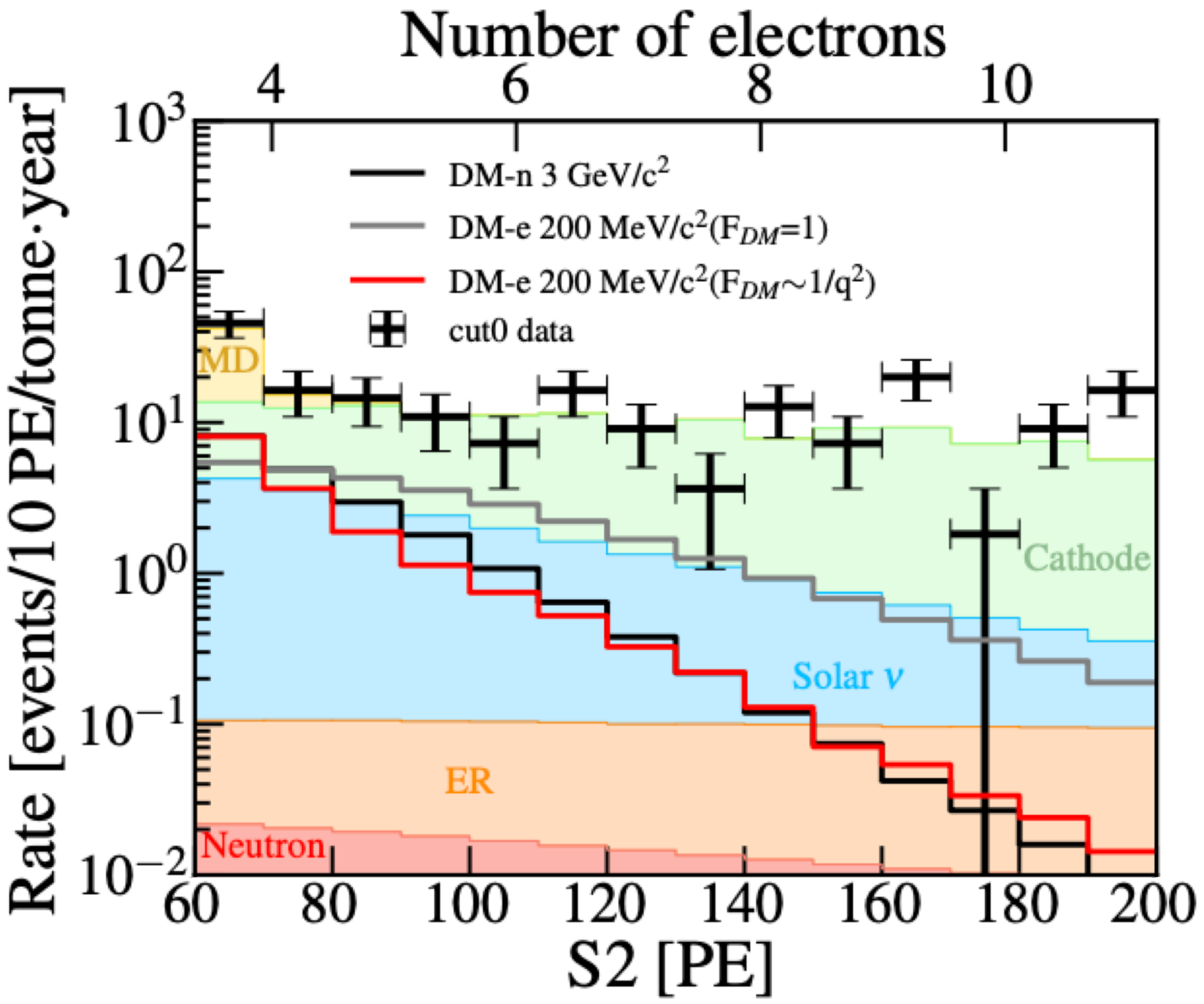
- Cathode background



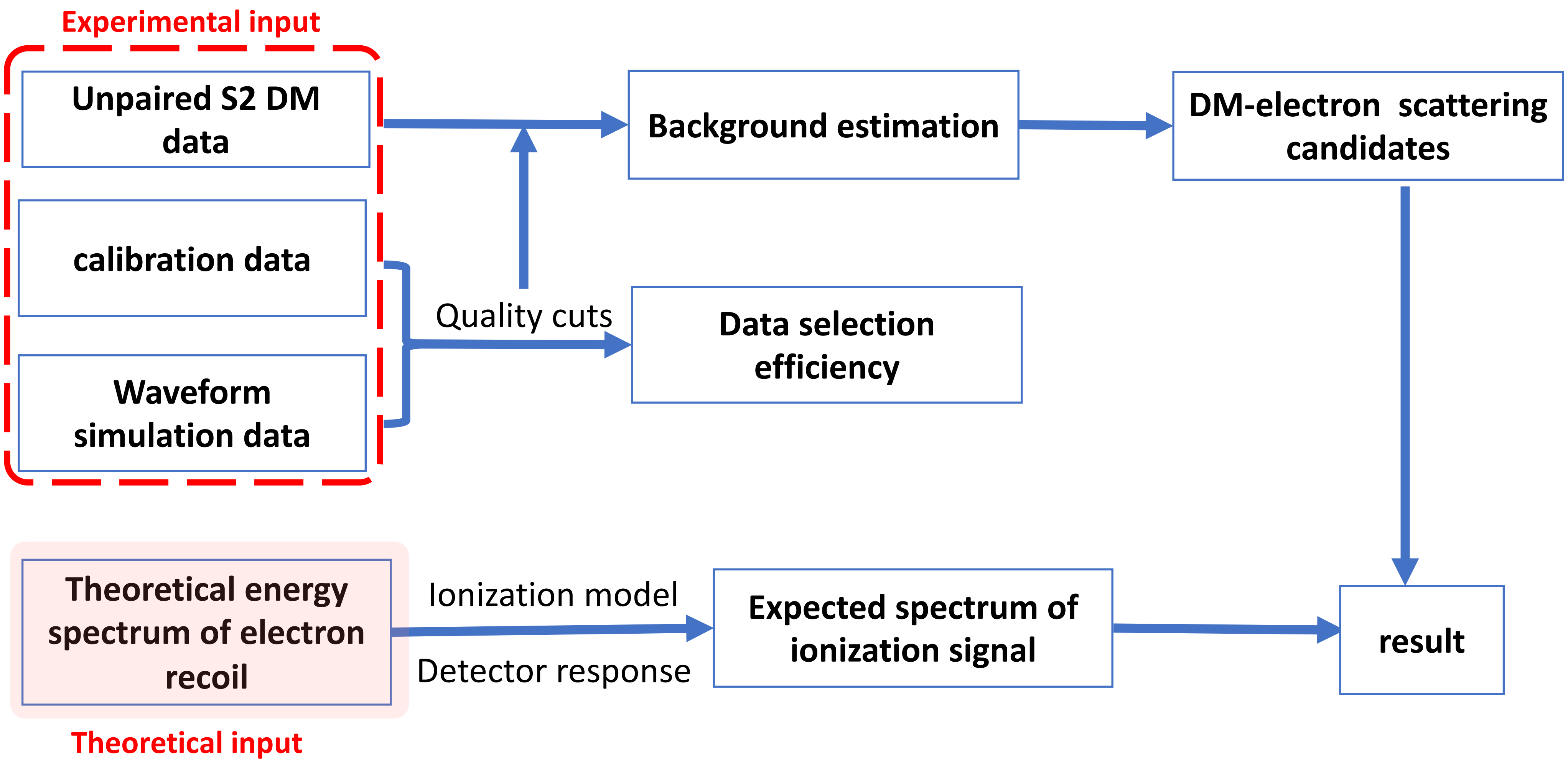
The ratio of cathode background in the control region is used to extrapolate the ratio in the ROI.

Background model

- Background contribution



Analysis flow



Theoretical energy spectrum of electron recoil

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- 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

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

N_T: atomic number of Xe

q: transfer momentum

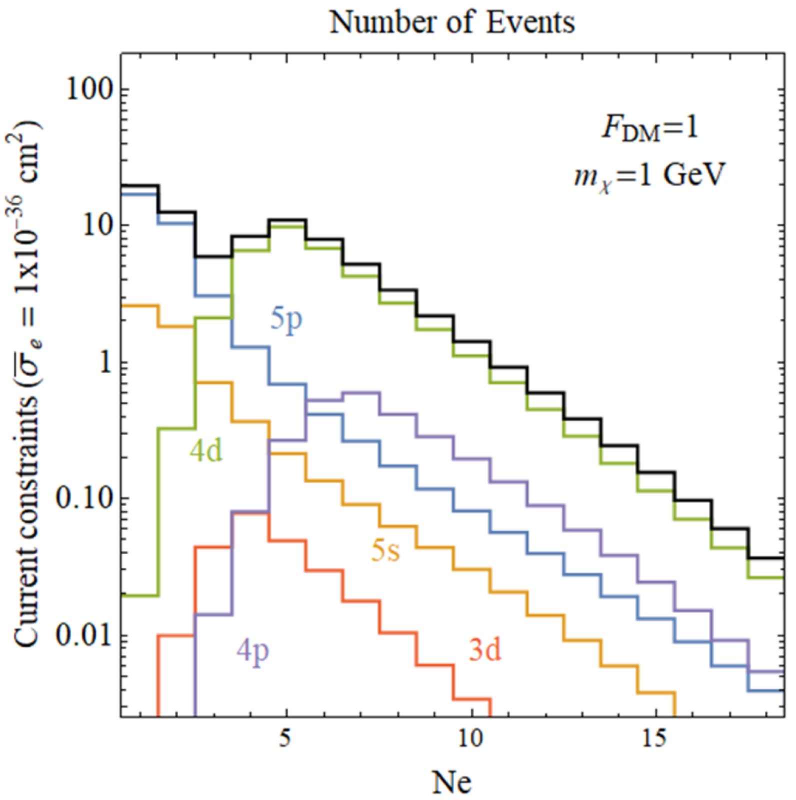
k: final momentum of electrons

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

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

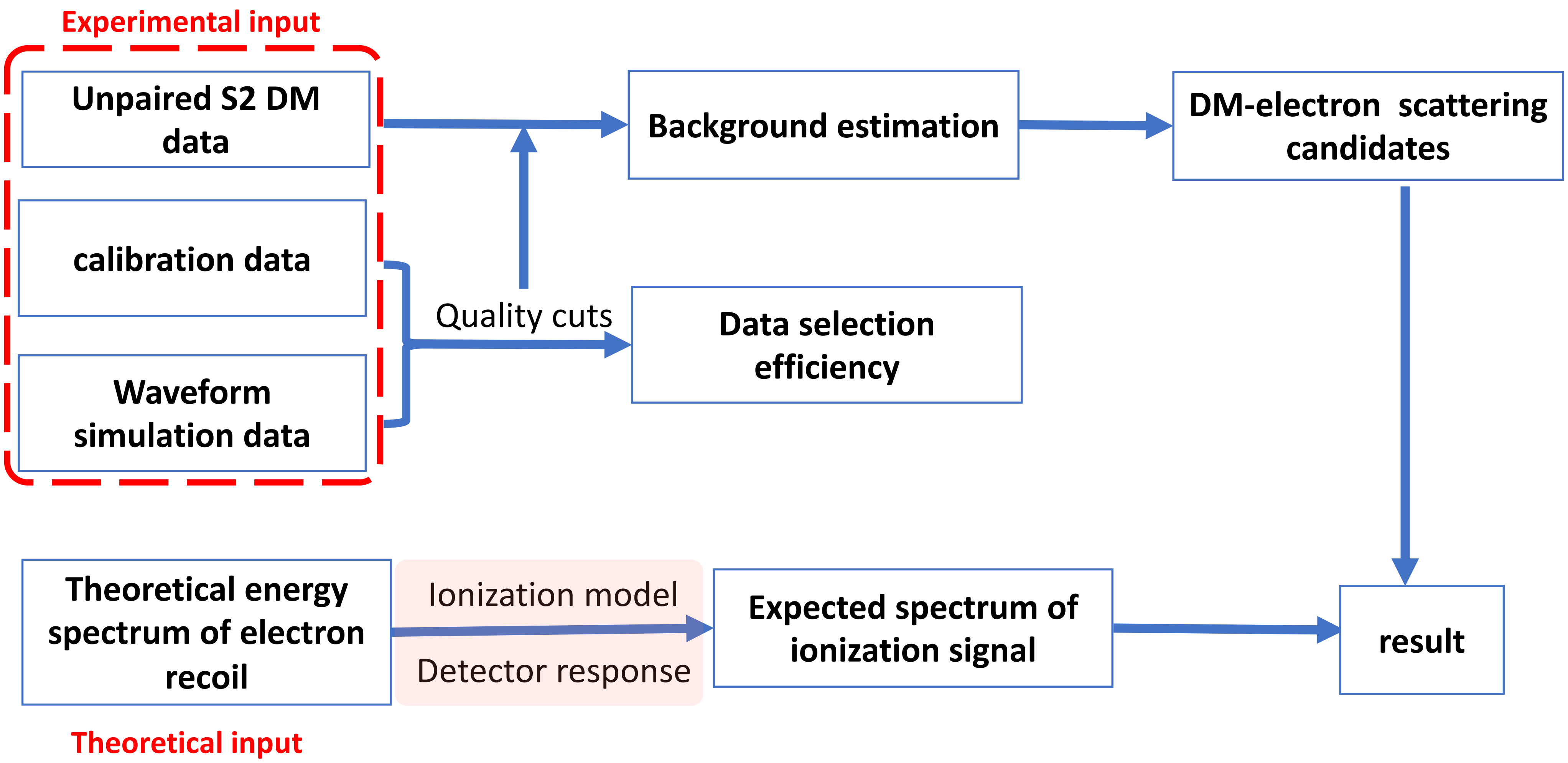
$f_{\mathrm{ion}}^{nl}(k,q)$: Ionization Form Factor

PHYSICAL REVIEW D 85, 076007 (2012)



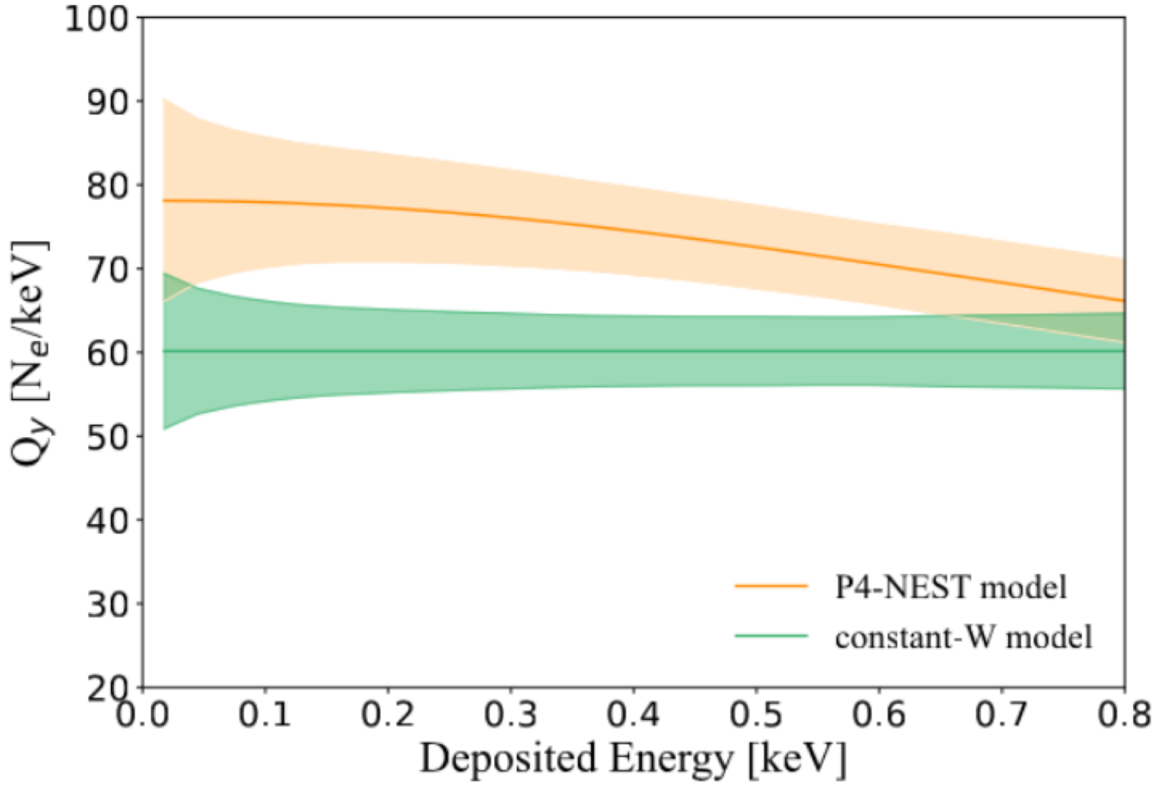
Electron-DM scattering ionization electron spectra in different shells (Assume m_χ=1 GeV、$\sigma = 10^{-36}\mathrm{cm}^2$)

Analysis flow

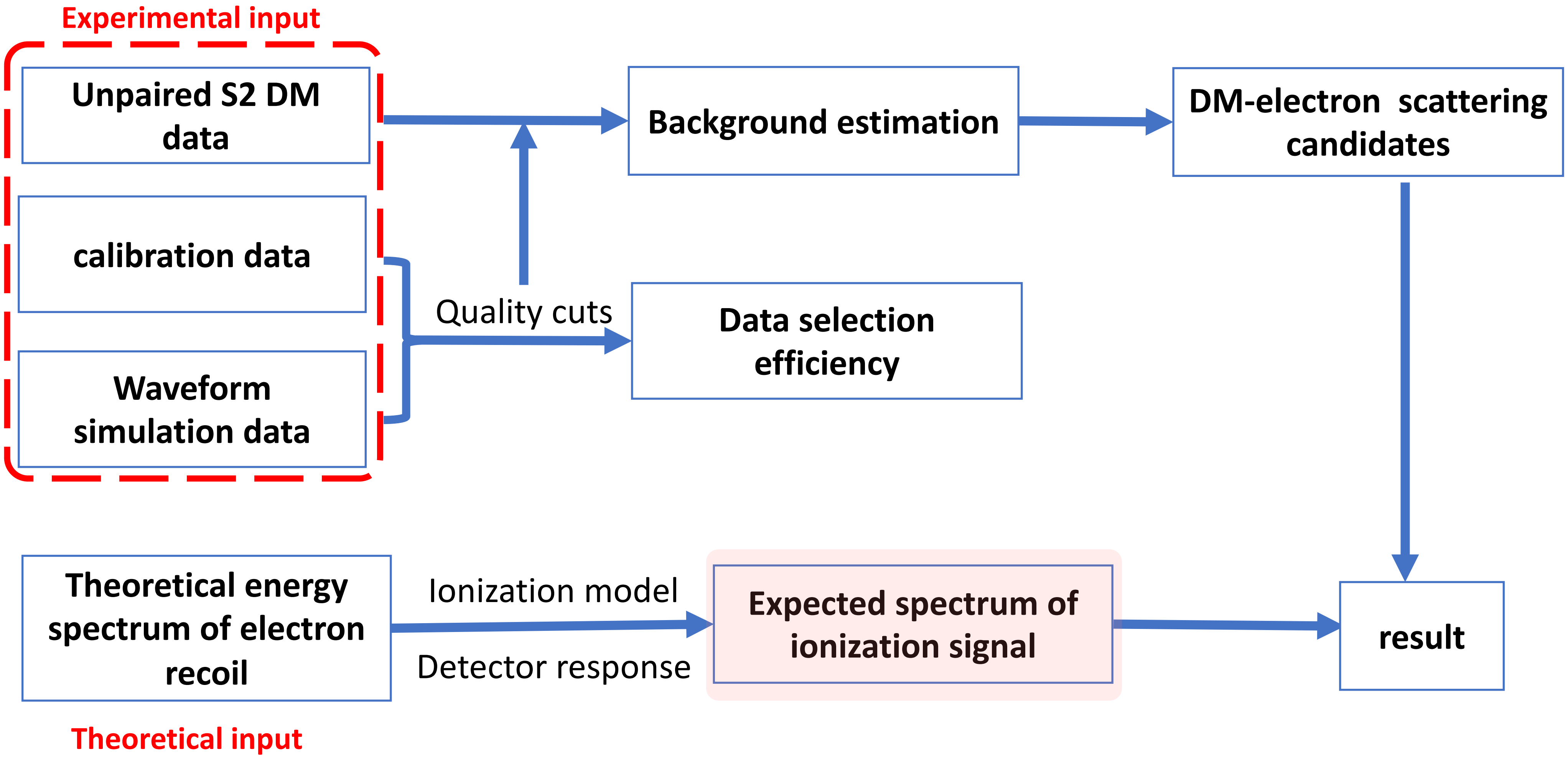


Ionization model and detector response

- Two models (P4-NEST model and constant) to describe produced ionized electrons are compared.
- Constant model is selected to conservative estimate the number of primary ionized electrons.
- Detector responses



Analysis flow



Expected spectrum of ionization signal

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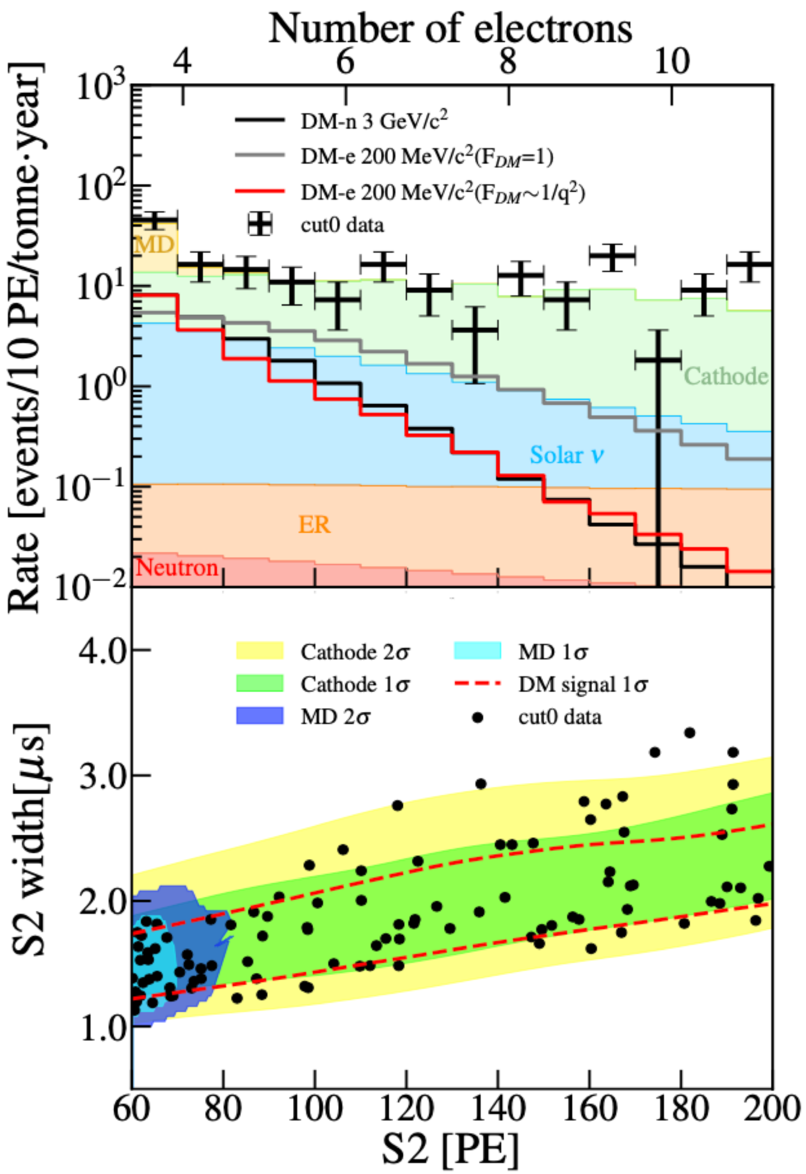
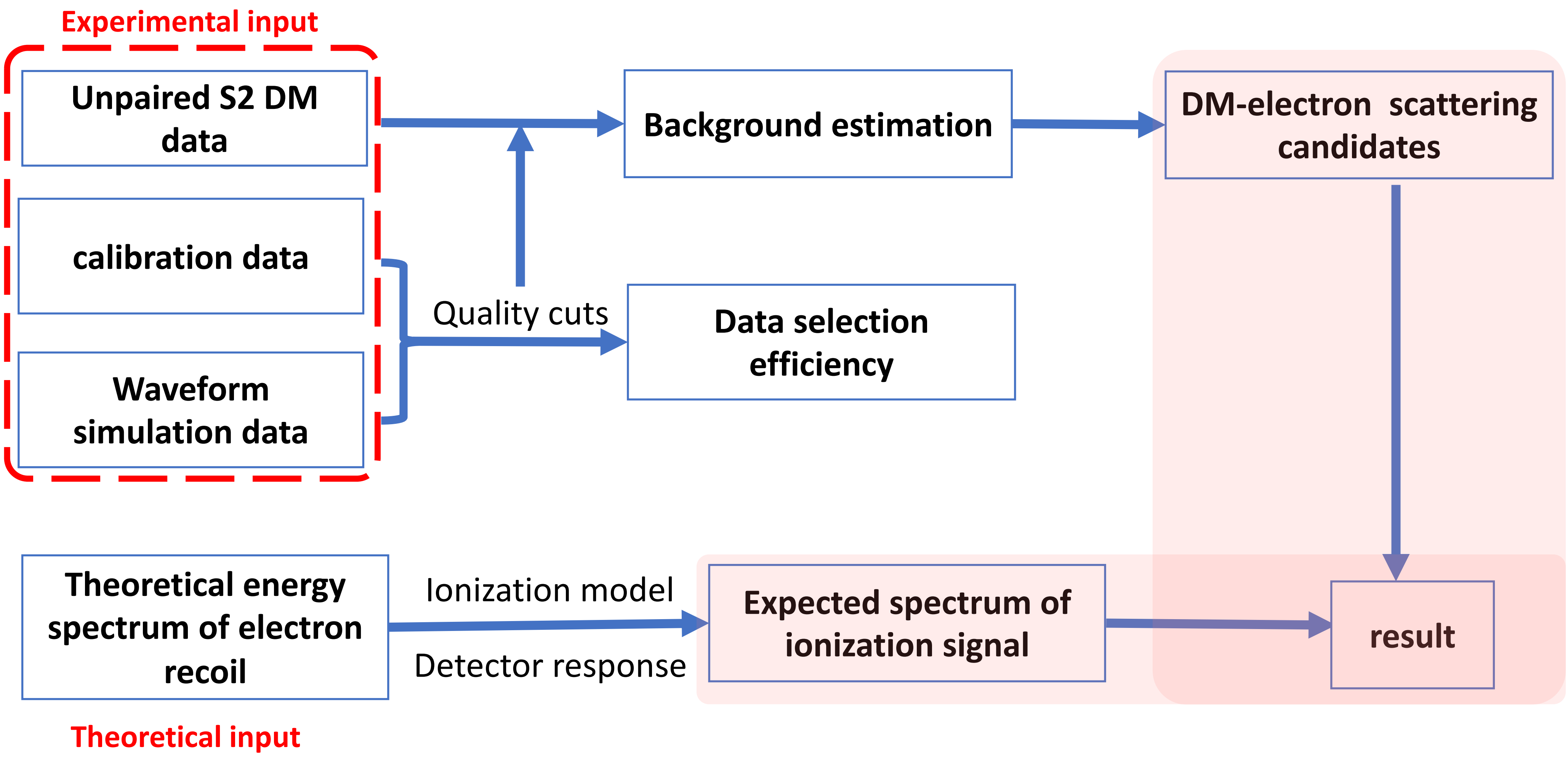
- For different DM masses and cross sections, the rates of electron-DM scatterings are generated.
- Compare the measured and expected number of candidates in ROI to constrain the cross section of interaction.



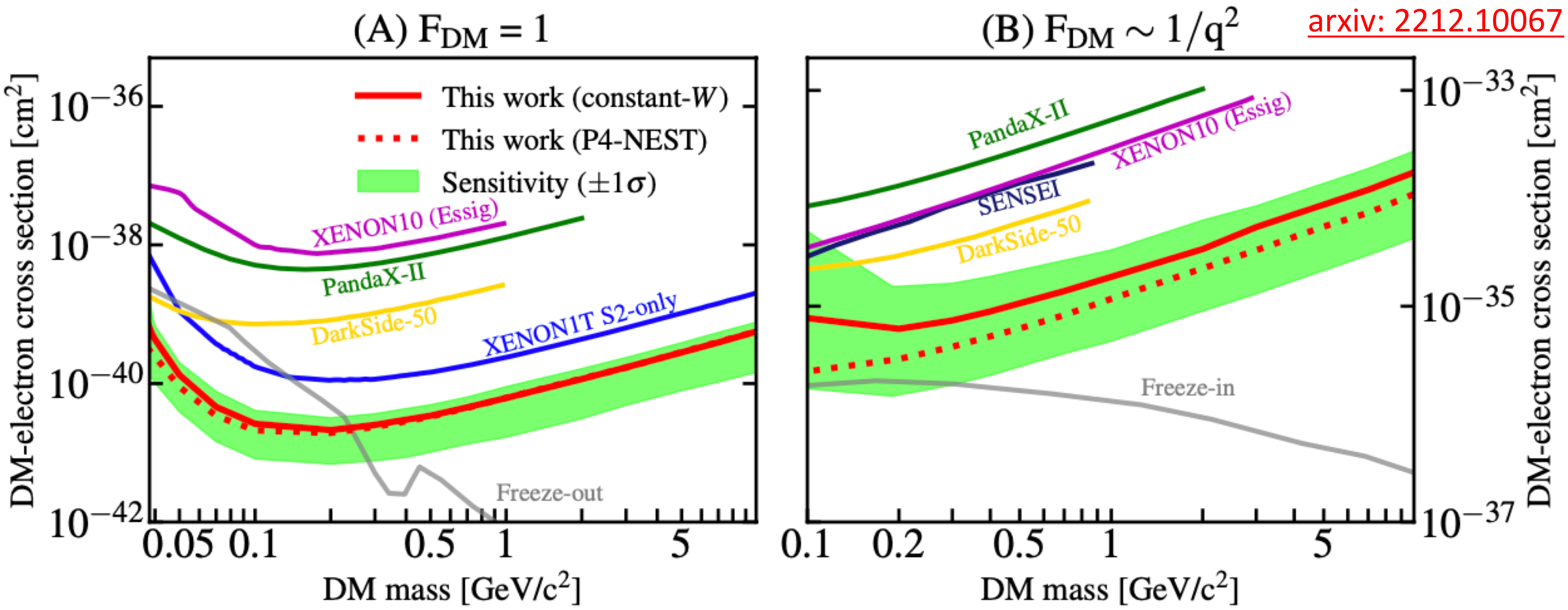
Analysis flow



DM-electron scattering constrain

PandaX — PARTICLE AND ASTROPHYSICAL XENON TPC

arxiv: 2212.10067



- The most stringent constraints for the DM- electron interactions with mass in range of 40 MeV/c^2 to 10 GeV/c^2 with F_{DM} =1, and 100 MeV/c^2 to 10 GeV/c^2 with $F_{DM} \sim 1/q^2$
- Our results challenge the freeze-out mechanism for DM mass range from 0.04 to 0.25 GeV/c^2 with F_{DM}=1, and are closing in on the freeze-in prediction with $F_{DM} \sim 1/q^2$, assuming such light DM provides the entire DM abundance.

Summary and Outlook

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- PandaX-4T has completed its commissioning run
- The unpaired S2 analysis method lowers the PandaX-4T energy threshold to 0.07 keV to probe light DM.
- The most stringent constraints for the DM- electron interactions with mass in range of 40 MeV/c^2 to 10 GeV/c^2 with $F_{DM}=1$, and 100 MeV/c^2 to 10 GeV/c^2 with $F_{DM} \sim 1/q^2$
- The PandaX-4T may provide more chances to detect light dark matter-electron scatterings with lower background and higher exposure.

Thank you

Welcome to use our PandaX data to test your novel models.