Particle and AstroParticle physics in China.

Status and perspectives. Part II

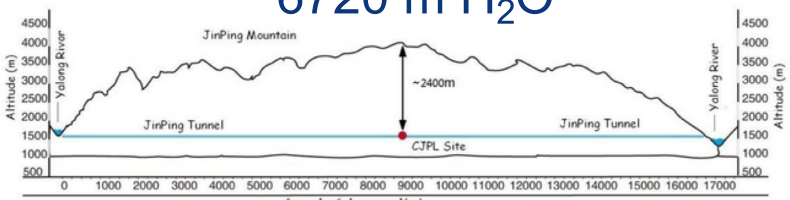
Based on a talk of Yifang Wang at 20th Lomonosov Conf., Aug. 19, 2021

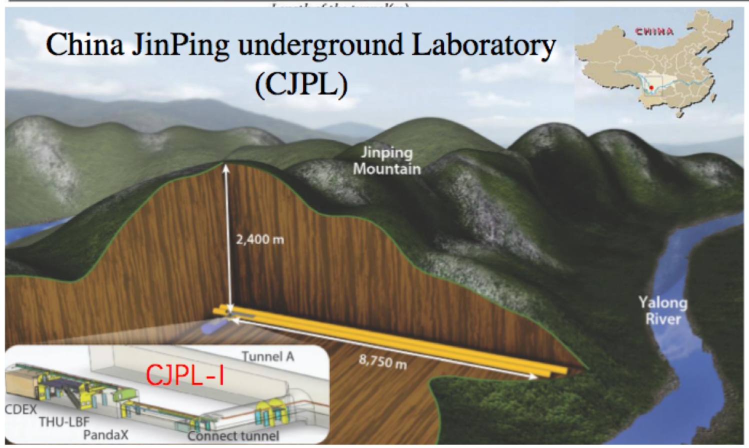
By Oleg Fedin

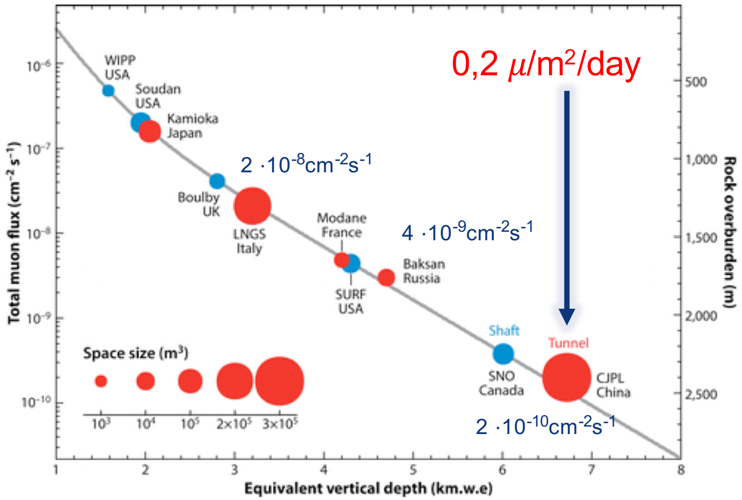
JinPing underground Laboratory

http://jinping.hep.tsinghua.edu.cn/

~6720 m H_2O

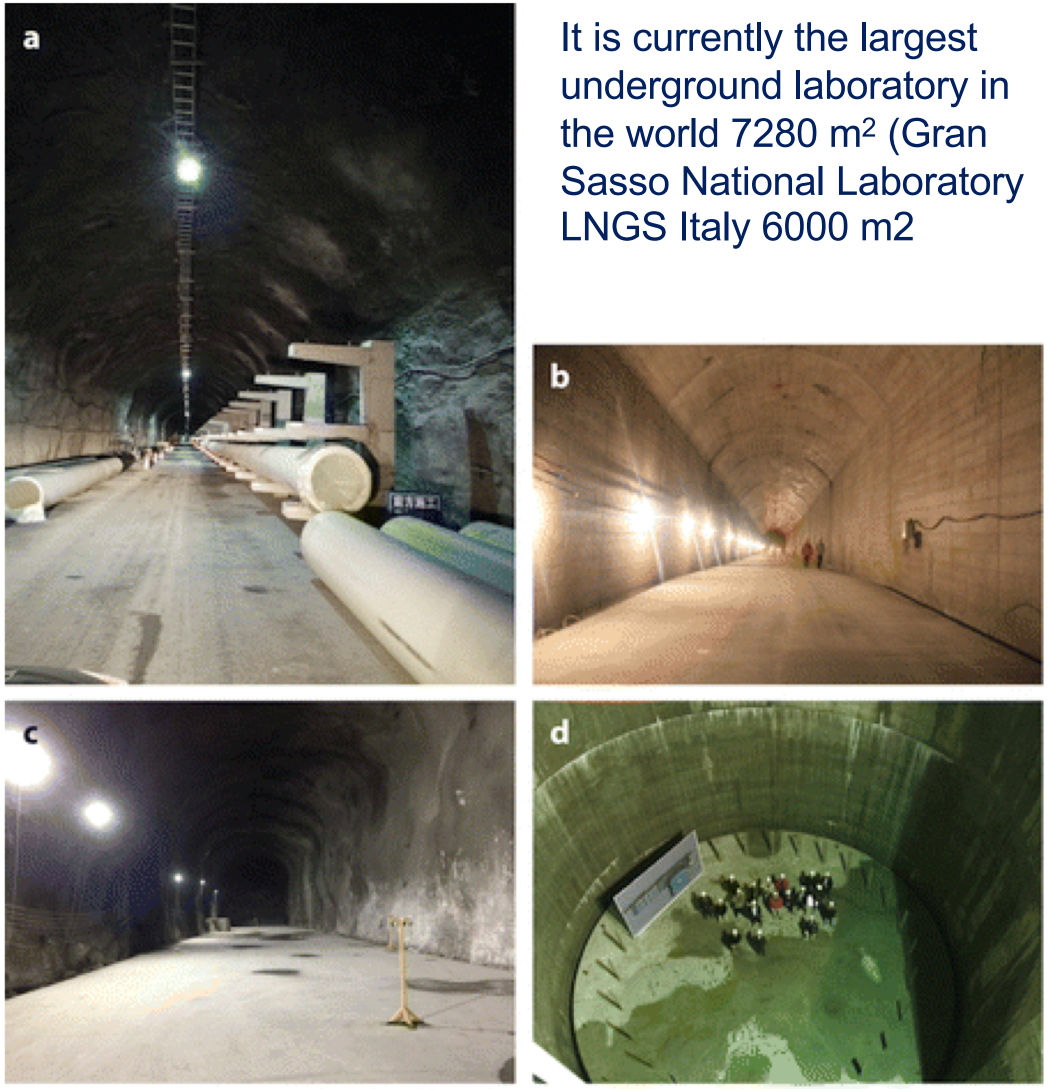






Ann. Rev. Nucl. Part. Sci. 67(2017) 231

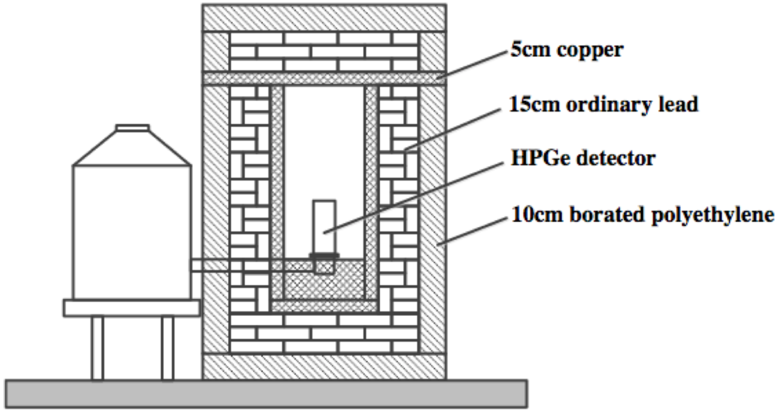
It is currently the largest underground laboratory in the world 7280 m² (Gran Sasso National Laboratory LNGS Italy 6000 m2



Cheng J-P, et al. 2017.
Annu. Rev. Nucl. Part. Sci. 67:231–51

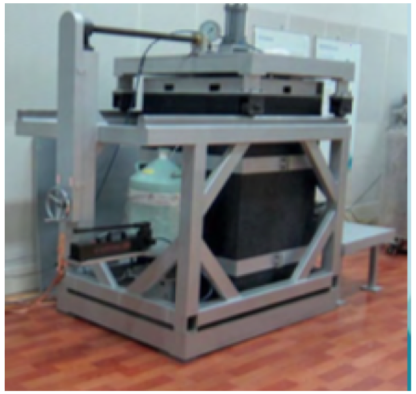
CJPL-II Radioactivity Background Control

- GeTHU: low level high purity germanium (HPGe) gamma spectrometer
- Ge crystal h=59.8 mm&D=59.9 mm.
- The cryostat is made of ultra-low background aluminum (ULB Al).
- All the raw material used during construction of CJPL-II were investigated by GeTHU.



CJPL-I low background facility

GeTHU-I



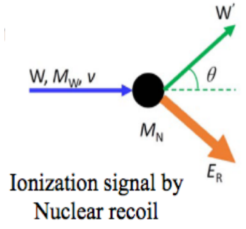
GeTHU-II

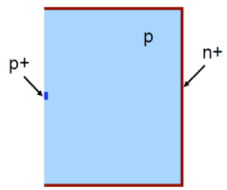
Experiments at JinPing laboratory

- CDEX - China Dark Matter Experiment
  - Searching for light DM by P-type Point-Contact Germanium detectors
  - Formed in 2009, 11 institutions and ~70 people
- PandaX - Particle and Astrophysical Xenon Experiments
  - Collaboration started in 2009 (includes ~40 people) 7 institutions
  - is a series of experimental projects that utilizes of a dual-phase xenon time projection chamber (TPC) detector
  - to search for dark matter particles
  - to detect ^{136}Xe neutrinoless double beta decay
  - The collaboration has now entered into the multi-ton stage of the project, PandaX-4T.
- JUNA - Jinping Underground Experiment for Nuclear Astrophysics
  - direct measurement of (α,γ), (α,n) reactions in hydrostatic helium burning and (p, γ), (p, α) reactions in hydrostatic hydrogen burning.

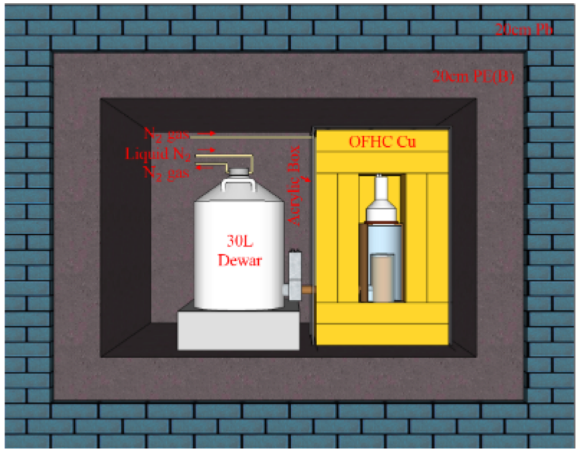
CDEX - China Dark Matter Experiment

- DM detection w/Ge prepared since 2003 and started in 2005 in Y2L (5g) –Yang Yang Underground Lab in South Korea;
- CDEX-1: Development of PPC Ge detector, bkg understanding, since 2011;
- CDEX-10: Performances of Ge array detect (or immersed in LN2, since 2016;
- CDEX-10X: Home-made Ge detector and Ge crystal growth;
- **Toward future ton-scale DM experiment**

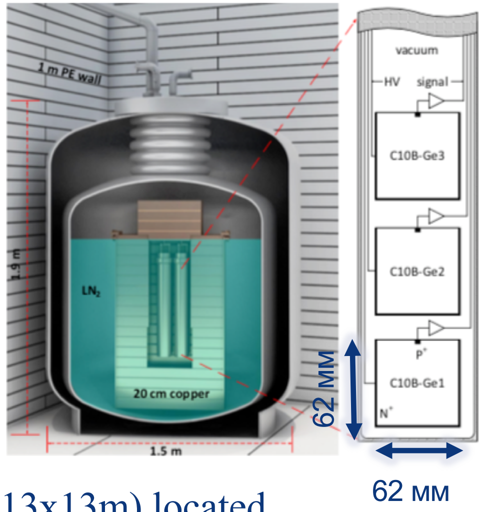




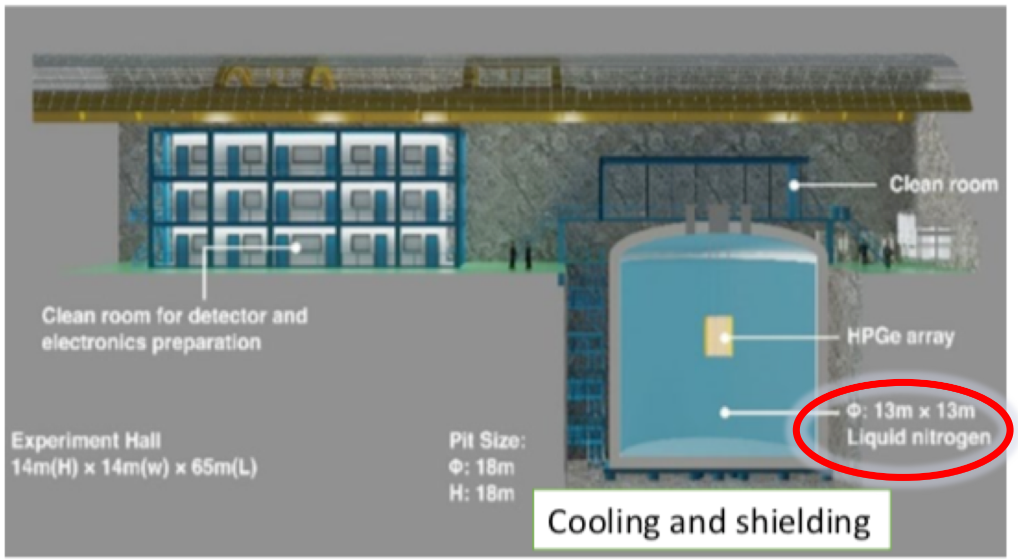
CDEX-1A&B: 1kg PPC Ge x 2



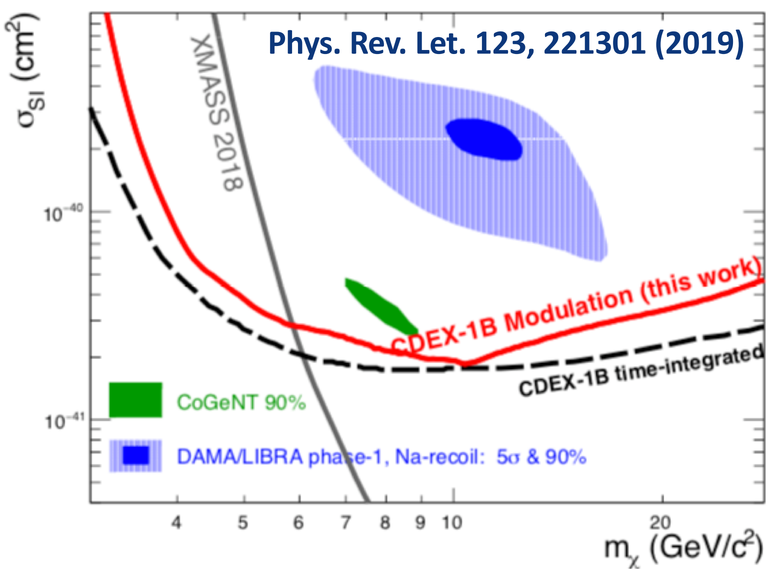
CDEX-10: ~10kg PPC Ge array

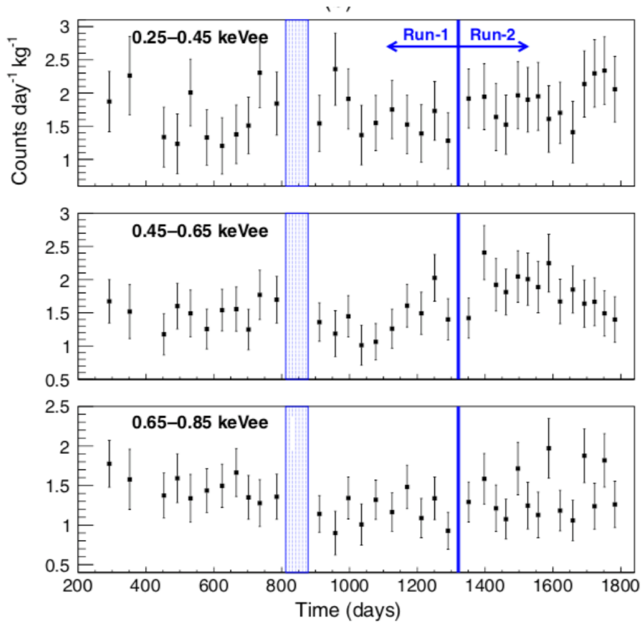


CDEX10X moving to a 1725m3 LN2 tank (φ13x13m) located in the pit; Construction of LN2 tank kicked off in Nov. 2018 and done end of 2019;



CDEX results



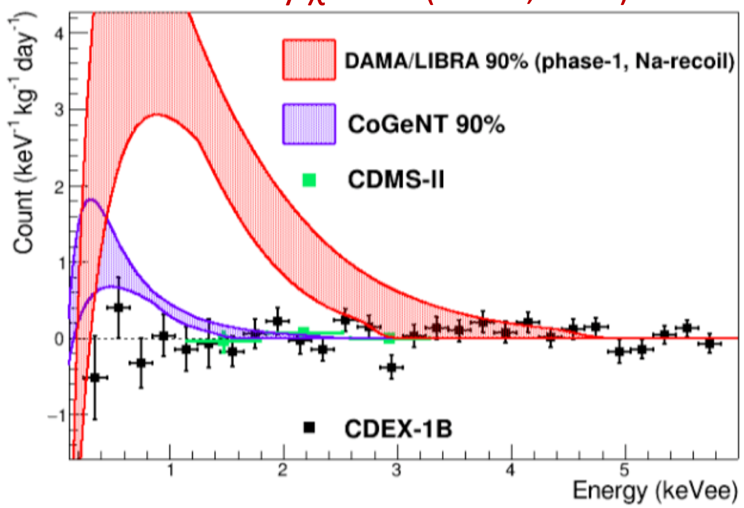


- run-1 to run-2: change of shielding.
- 0.25 – 0.85 keV: most important region for low mass WIMP
- χ2 test, (mean, RMS) consistent with null profile.

$$i,\ j,\ k = (\text{energy}, \text{time}, \text{run}).$$

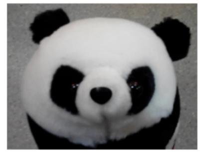
$$\chi_i^2 = \sum_{k\in \text{Run}}^{2} \sum_{j\in \text{Time}}^{N} \frac{\left[n_{ijk} - P_{ijk} - B_{ik} - A_i \cos\left(\frac{2\pi(t_j-\phi)}{T}\right)\right]^2}{\Delta_{ijk}{}^2},$$

modulation amplitudes consistent with null-results by χ2 test (mean, RMS)



- exclude DAMA phase-1 and CoGeNT at > 99.99%, 98% C.L.
- data consistent with null-hypothesis.
- other results (e. g. dark photon search, Axion search) will be available soon.

PandaX - Particle and Astrophysical Xenon Experiments

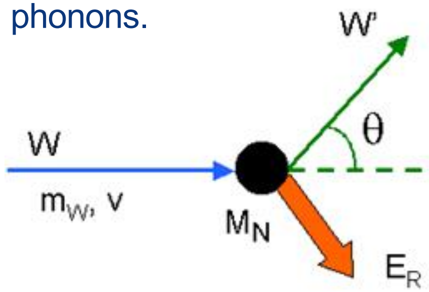


- PandaX-I:
  - Operated before November 2014;
  - **120 kg of xenon** (of which 54 kg served as a fiducial mass) to probe the low-mass regime (<10 GeV) and verify dark matter signals reported by other detector experiments.
  - the first dark matter experiment in China to use more than 100 kg of xenon in its detector
- PandaX-II :
  - operated between Oct. 2014 and June 2019.
  - **half-ton** scale dual-phase time projection chamber (TPC)
  - **in 2016 and 2017, PandaX-II produced the world leading constraints to dark matter-nucleon interactions.**
- PandaX-4T:
  - is expected start to operate in 2021
  - **6-ton of total Xenon and 4-ton sensitive target**
  - aims is to improve the dark matter sensitivity by one order of magnitude in comparison to PandaX-II
- PandaX-III searches for the possible neutrinoless double beta decay **with 200 kg to one ton** of 90% enriched ^{136}Xe in a high pressure (10 bar) gaseous Xenon TPC.

Operation Principle of Dual-Phase LXe TPC

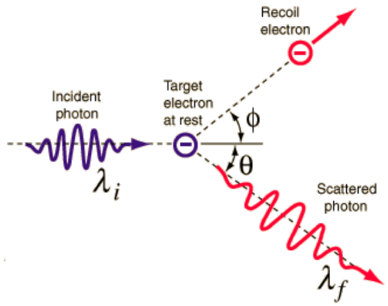
Signal:

- Nuclear recoil from WIMP collision
- Gives ionisation, scintillation and phonons.

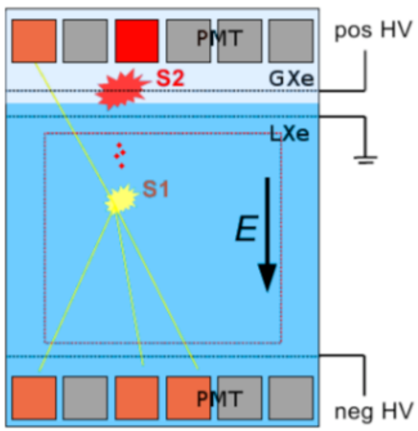


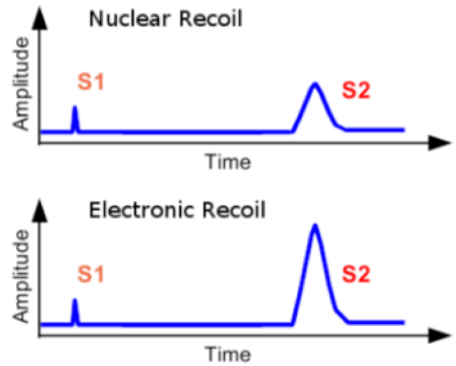
Background:

- Other nuclear recoils
- Electron recoils



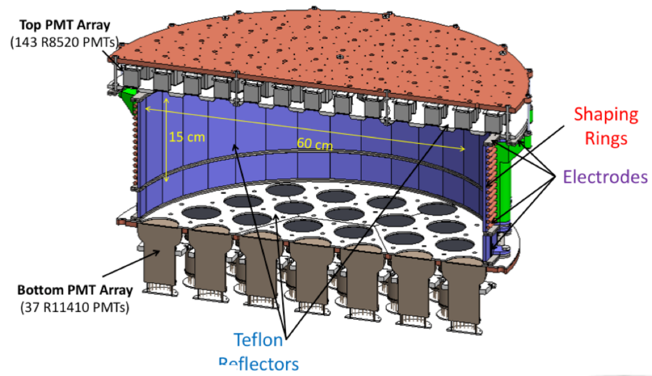
$$\mathrm{Xe}^* \xrightarrow{+\mathrm{Xe}} \mathrm{Xe}_2^* \rightarrow 2\mathrm{Xe} + h\nu.$$

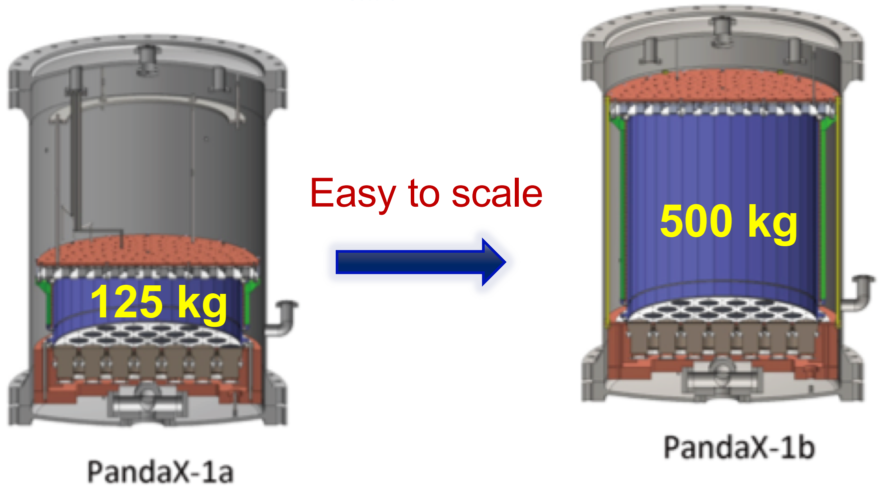




$$(S_2/S_1)_{WIMP} << (S_2/S_1)_{\gamma}$$

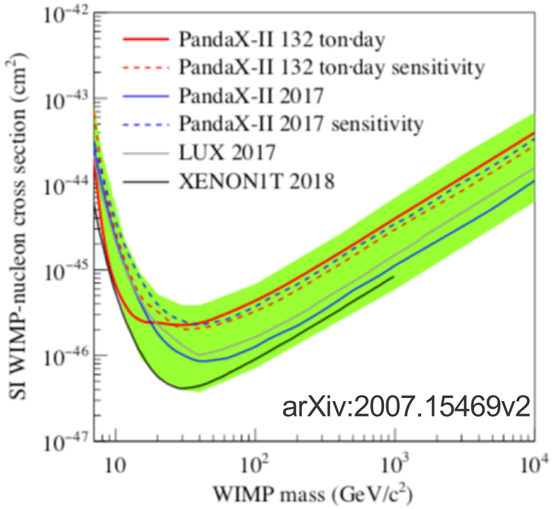
- All systems of Panda-X are designed for >500 kg active mass
- Easy transition from 125 kg to 500 kg:
  - Lengthen PTFE panels (and shaping rings)
  - Adjust overflow point
  - Increase HV
  - Fill more Lxe
- Everything else stays the same.





PandaX-II results

WIMP Search

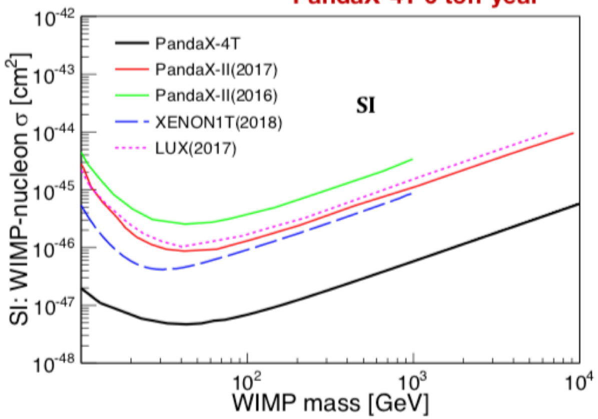


SI exclusion limits:

- 2.1×10^{-46} cm² for 40 GeV
- 1.4×10^{-45} cm² for 400 GeV

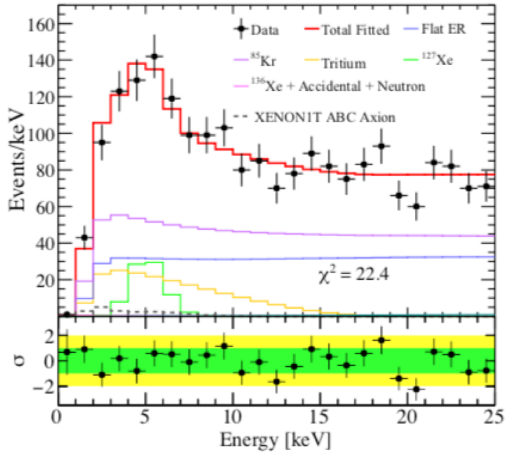
Expected Sensitivity

PandaX-4T 6 ton-year



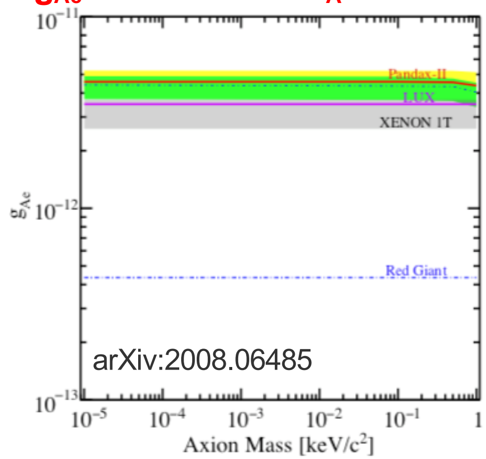
Axion Search

Low energy spectrum of electron recoil events

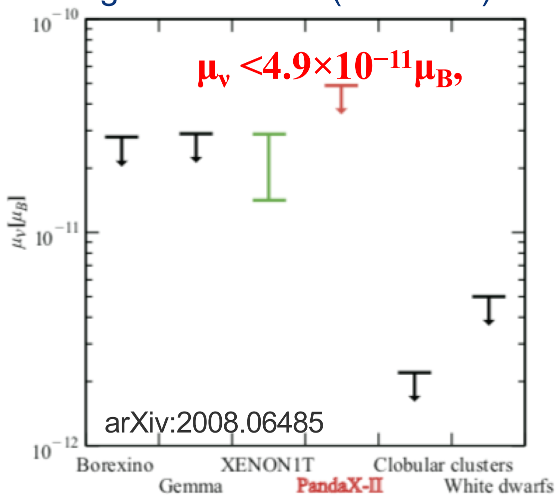


The upper limits on the solar axion coupling constant g_{Ae} (90% C.L.)

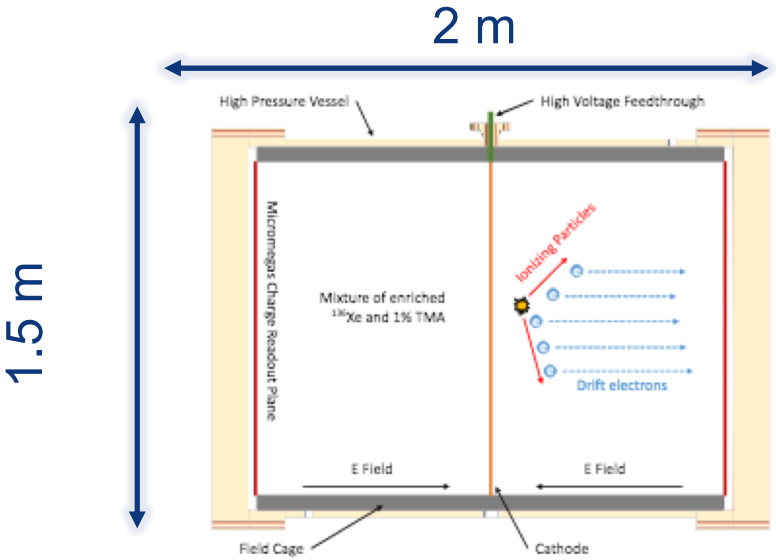
$g_{Ae} < 4.6 \times 10^{-12}$ $m_A < 0.1$ keV



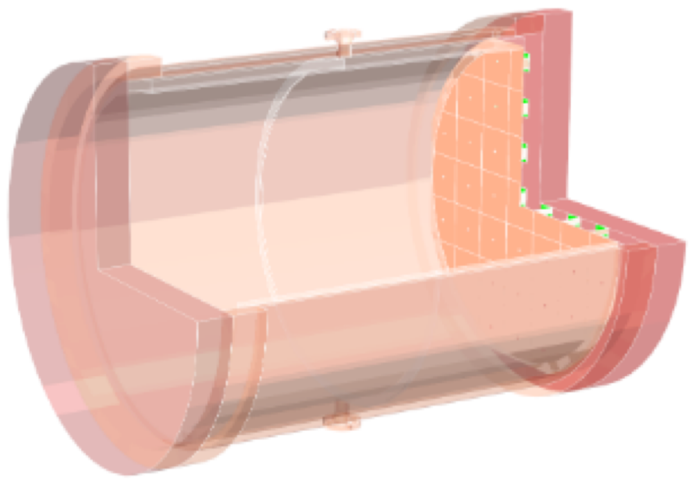
The upper limits on the neutrino magnetic moment (90% C.L.)



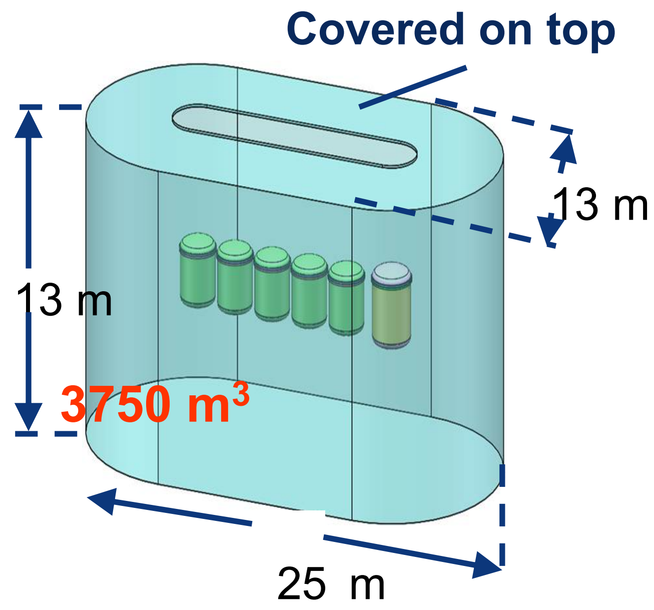
PandaX-III



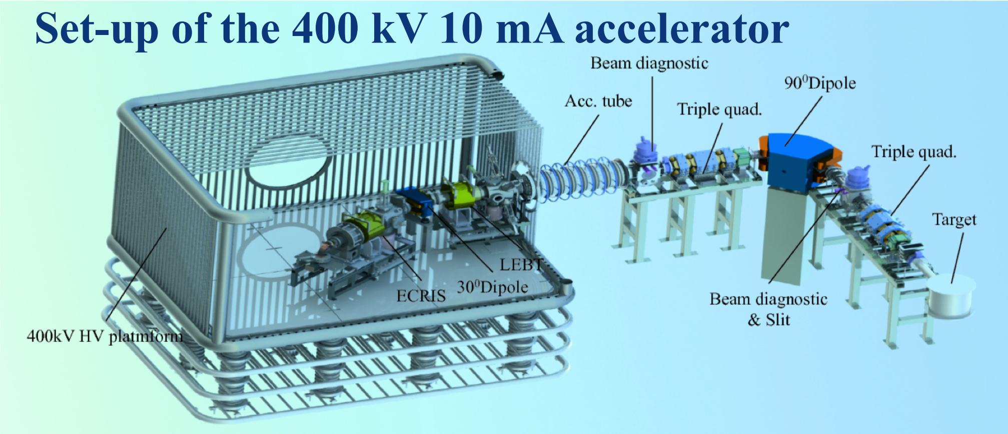
A cut-away of the TPC



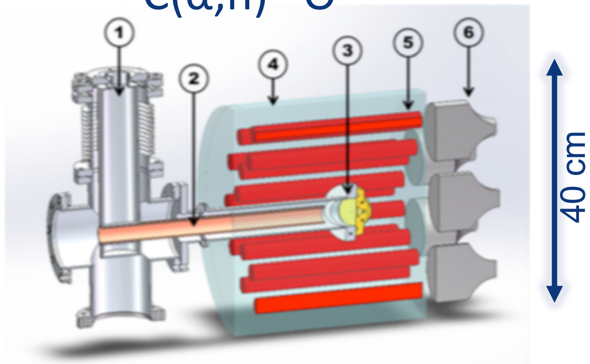
- A symmetrical TPC will be placed in the vessel with the cathode in the middle and two anode planes on the two ends (100kV)
- 90% enriched ^{136}Xe with 1% TMA (trimethylamine $(CH_3)_3N$) mixture
- Vessel - Oxygen-Free High Conductivity (OFHC) copper
- Readout - Micro-MEsh Gaseous Structure or Micromegas
- 200 kg prototype:
  - ✓ Energy resolution of 3% (FWHM) at the Q-Value of 2.458 MeV.
  - ✓ Signal efficiency of 35%.
  - ✓ Background rate of 10^{-4} c/keV/kg/yr
  - ✓ $T_{1/2}$~10^{26} year after 3 year of operation $m_{\beta\beta}$= 65-165 meV
- Water shield for PandaX III + future DM detector
- Ton scale experiment:
  - ✓ Energy resolution of 1%
  - ✓ Background rate of 10^{-5} c/keV/kg/yr
  - ✓ $T_{1/2}$~10^{27} year after 3 year of operation $m_{\beta\beta}$= 20-50 meV



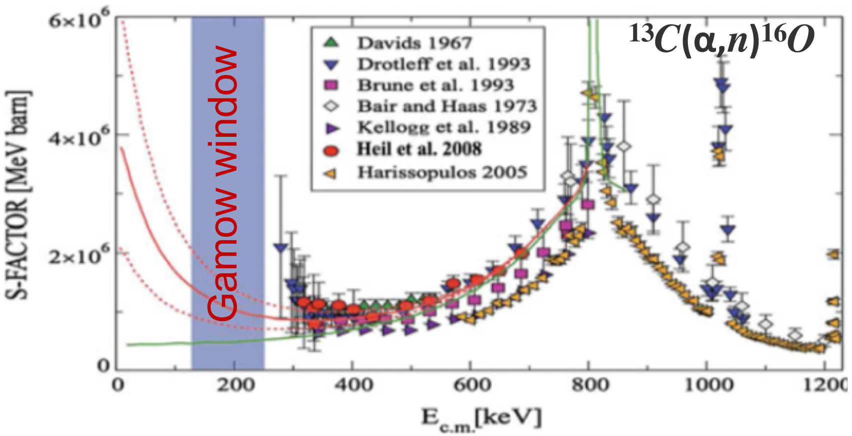
JUNA - Jinping Underground Experiment for Nuclear Astrophysics



$^{13}C(\alpha,n)^{16}O$



Schematic drawing of low background highly sensitive fast neutron detector. 1) LN2 cold trap; 2) Copper tube; 3) high power ^{13}C target; 4) Liquid scintillator; 5) ^{3}He detectors; 6) PMTs.



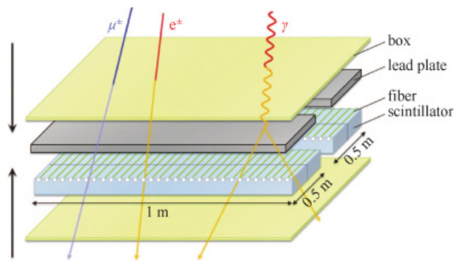
reaction	physics	current (keV)	current uncertainty(%)	ref.	JUNA (keV)	expected uncertainty (%)
$^{12}C(\alpha,\gamma)^{16}O$	Massive star	890	60	[30]	380	test
$^{13}C(\alpha,n)^{16}O$	s-process neutron source	279	60	[31]	200	20
$^{25}Mg(p,\gamma)^{26}Al$	Galaxy ^{26}Al source	92	20	[26]	58	15
$^{19}F(p,\alpha_\gamma)^{16}O$	Fluorine overabundance	189	80	[32]	100	10

$$S(E) \equiv \frac{E}{\exp(-2\pi\eta)}\sigma(E) \qquad \eta \equiv \frac{Z_1 Z_2 e^2}{4\pi\epsilon_0 \hbar v}$$

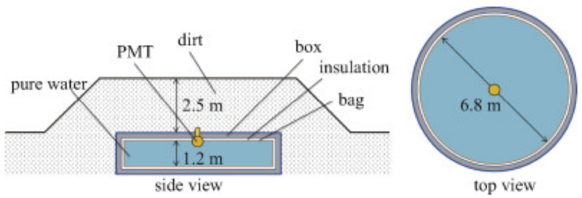
LHAASO - Large High Altitude Air Shower Observatory

- 4410 meters of altitude in the Sichuan province (Daocheng)
- 5195 ED electromagnetic particle detectors (1,3 km^2)
- 1171 MD muon detectors
- 78000m^2 WCDA (Water Cherenkov Detector Array)
- 18 WFCTA The wide field of view Cherenkov telescope array
- Construction completed
- Data taking started

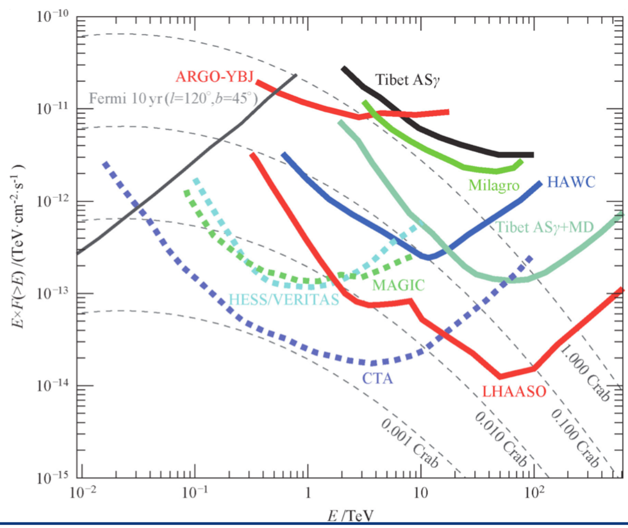
Schematic view of ED



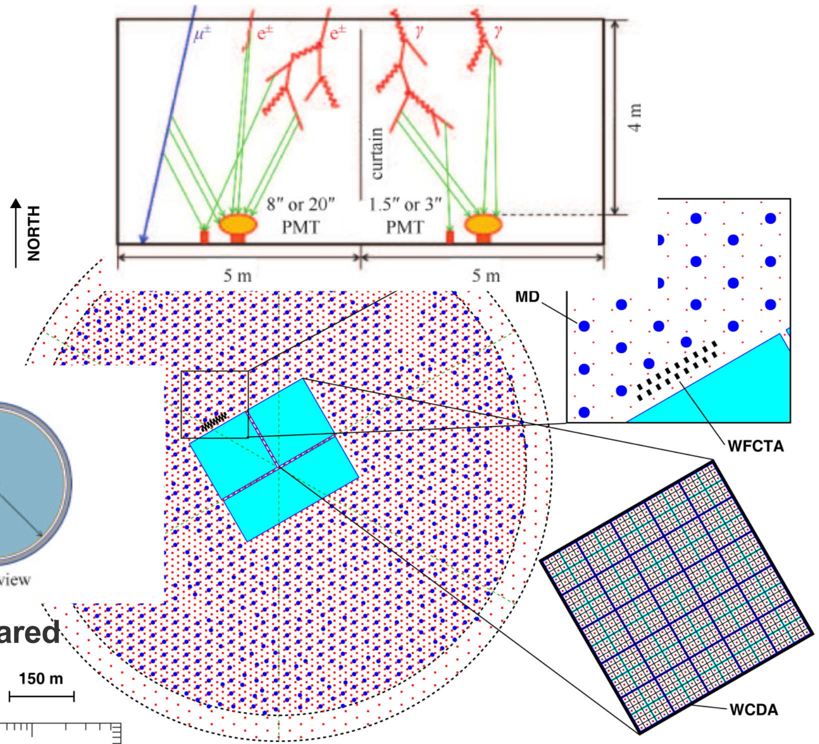
Schematic view of MD



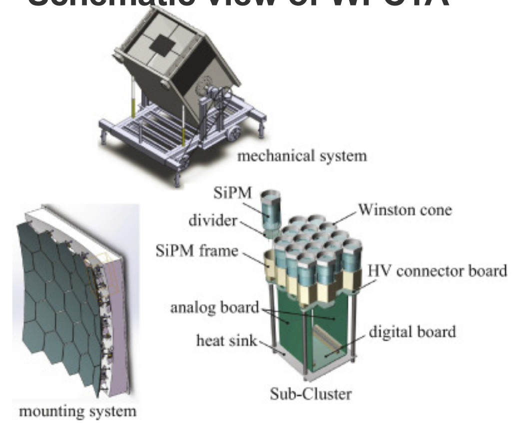
Sensitivity of LHAASO as compared with the other experiments



Schematic view of the WCDA detector

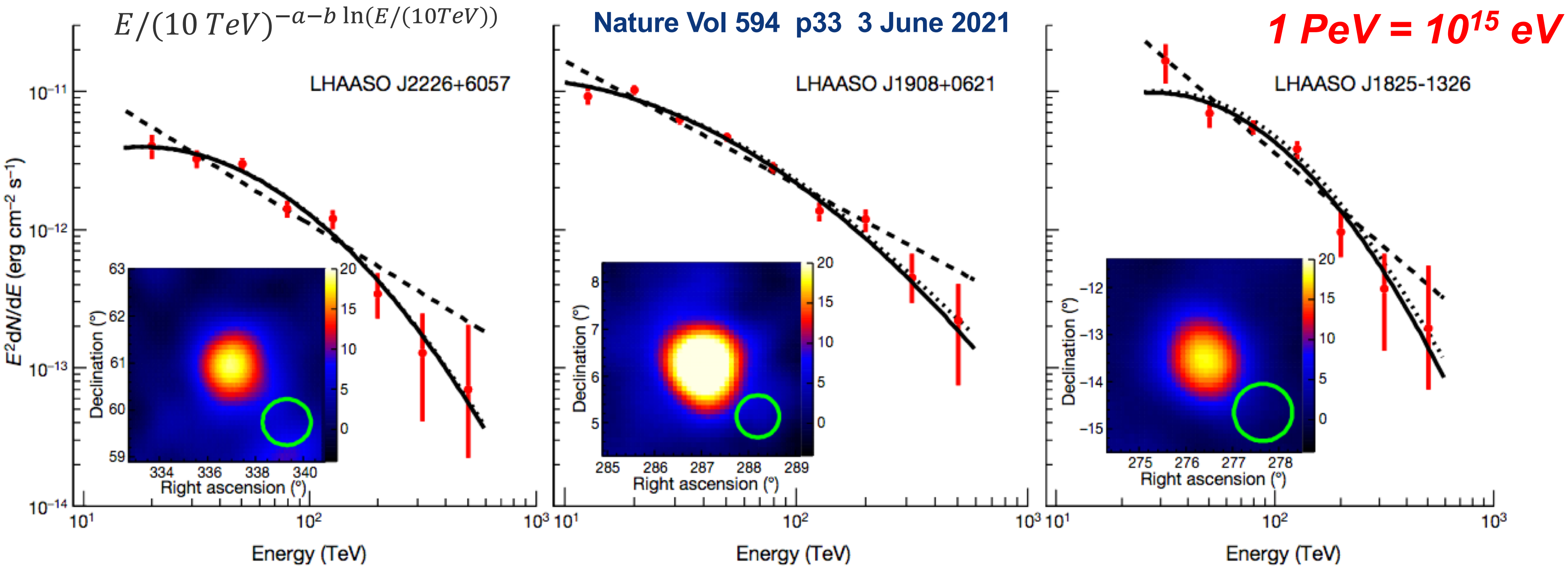


Schematic view of WFCTA



LHAASO

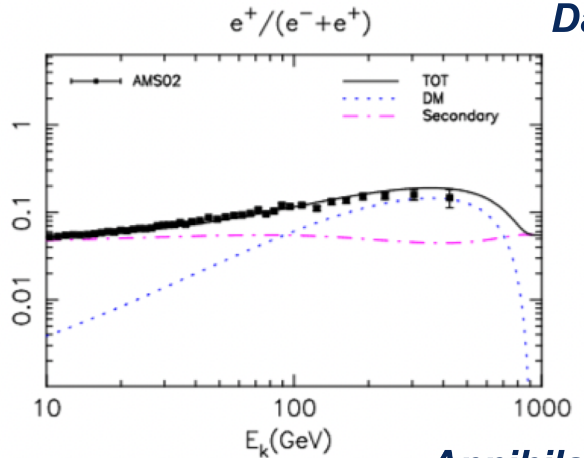
- Construction completed, data taking started
- The LHAASO has the features of large field of view, all weather, low energy threshold, and high sensitivity.
- Among the known gamma-ray sources, there are 103 sources of > 100 GeV and 187 sources of > 50 GeV existed in the field of view of LHAASO.
- Great results obtained:
  - Highest γ-rays from the Milky Way: 1.4 PeV
  - 12 identified γ-ray sources up to ~1 PeV ➔ PeVatrons in the Milky Way

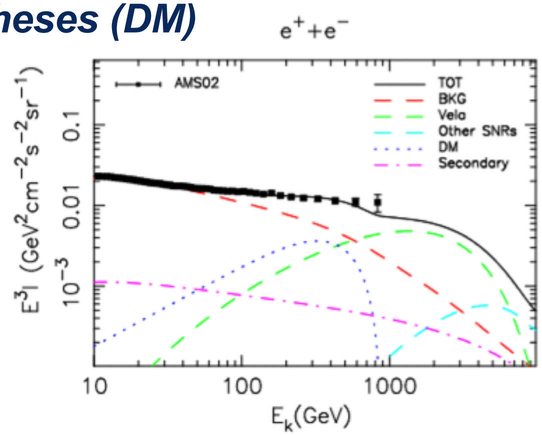


AMS02 Results

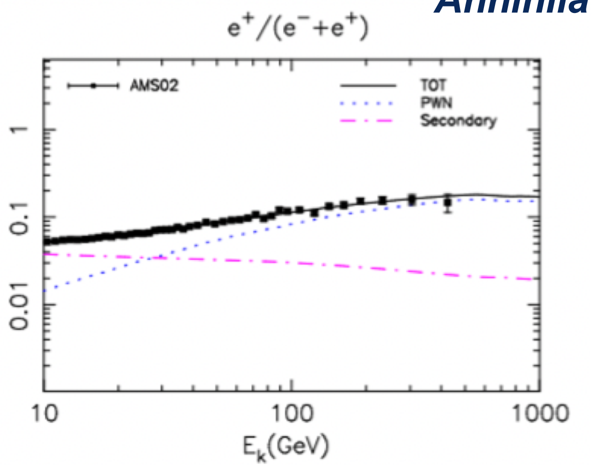
- **Positron excess** respect to pure secondary production (PAMELA, AMS-02)
- **Two hypotheses**
  - Dark Matter (DM)
  - annihilation Nearby Pulsar Wind Nebulae (PWN)
- How to distinguish among them?
  - An important contribution to our understanding can be obtained by **high energy (calorimetric) measurement of the e⁺+e⁻ flux**

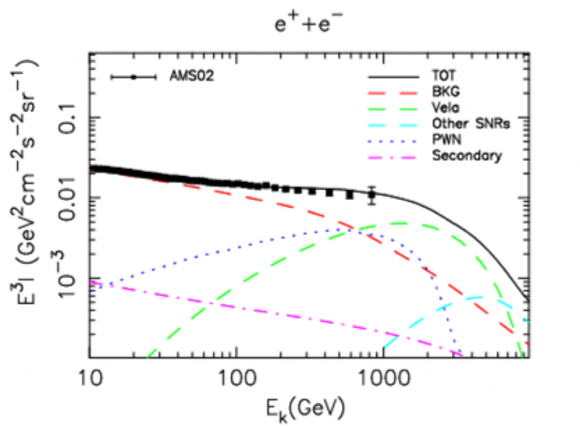
Dark Matter hypotheses (DM)



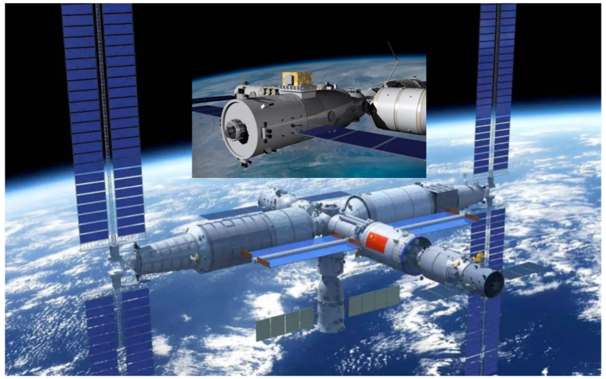


Annihilation Nearby Pulsar Wind Nebulae (PWN)



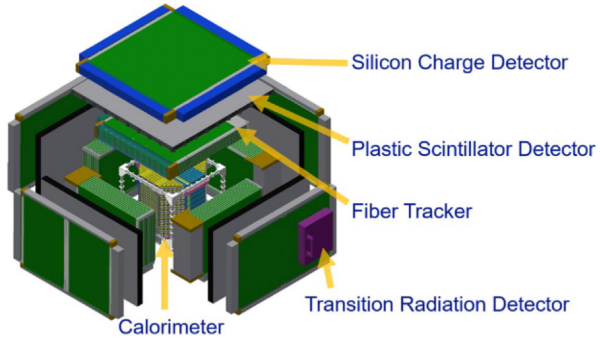


Cosmic-Rays in Space

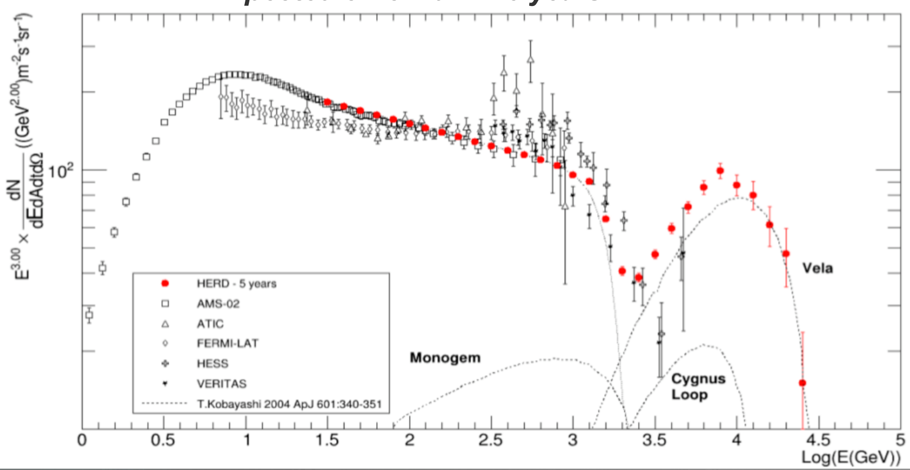


- 3D crystal calorimeter for dark matter searches and cosmic-rays (7500 LYSO crystals)
- Acceptance & energy range × 10
- Selected for the Chinese Space Station, to be launched in ~2027
- In collaboration with Italy, Sweden, Switzerland, …

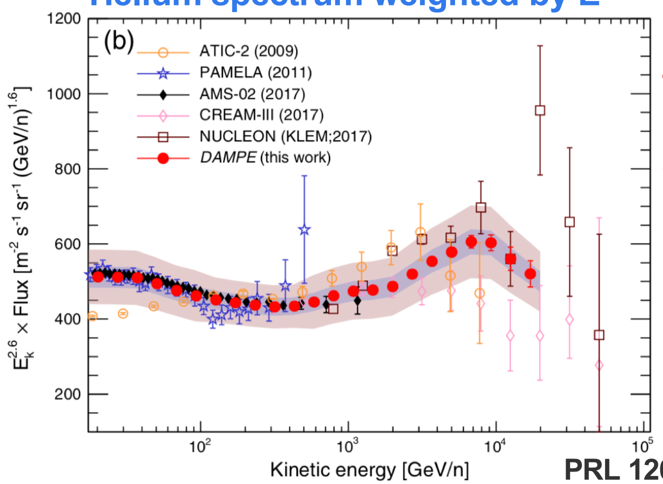
	X0(λ)	ΔE/E for e	e/p sep	GF m^2sr
HERD (2020)	55(3)	1%	10^{-6}	3.1
Fermi (2008)	10	12%	10^{-3}	0.9
AMS02 (2011)	17	2%	10^{-6}	0.12
DAMPE (2015)	31	1%	10^{-4}	0.3
CREAM (2015)	20(1.5)	--	--	--



Expected e^++e^- flux in 5 years



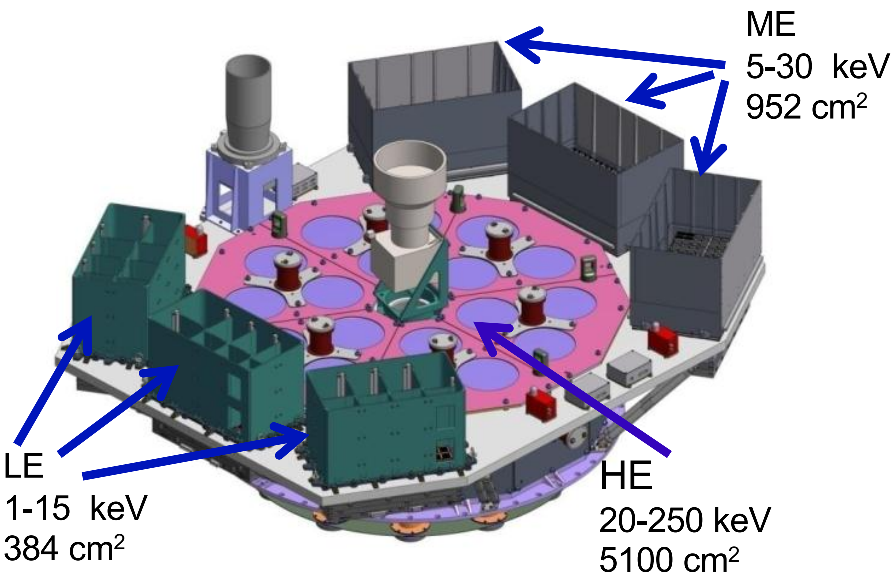
Helium spectrum weighted by $E^{2.6}$



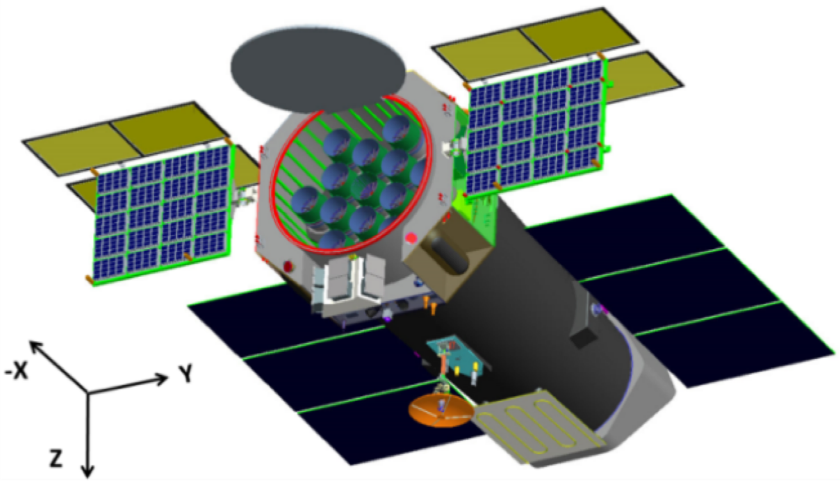
arXiv:1702.02352
Nucleon
Satellite
Resource-P-2

PRL 126, 201102 (2021)

X-ray astronomy in Space



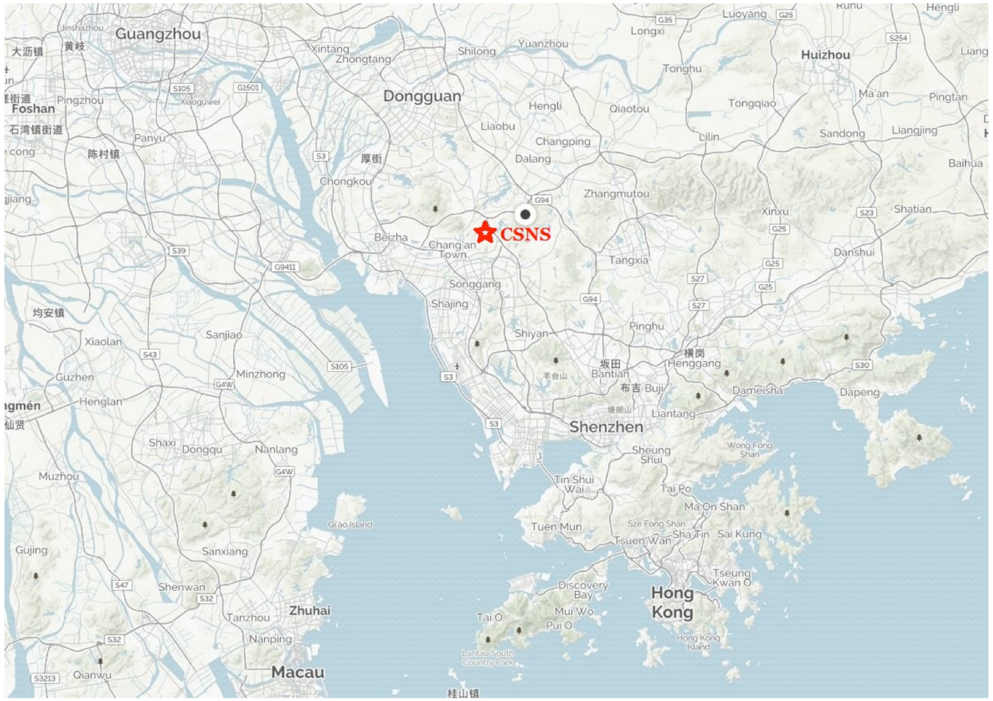
- Insight-HXMT satellite was launched on June 15, 2017
- Important results:
  - No EW signal during GW events
  - FRB 200428 originated from Magnetar SGRJ1935+2154
  - Highest magnetic field in the Universe



11.5 m × 8.78 m × 4.74m

- eXTP is the next generation telescope for "Enhanced X-ray Timing and Polarization Mission"
- A leading flagship observatory for black holes, neutron stars and extreme physics
- A large international collaboration

CSNS - Chine Spallation Neutron Source



- China Spallation Neutron Source (CSNS) is the first spallation neutron source, also the largest proton accelerator ever built in China.
- It mainly supports multidisciplinary research based on neutron scattering, but also other research based on proton beams, muon beams and white neutron beams.
- It is based on a high-power proton accelerator complex, with100kwt Phase-I, and 500 kW at Phase-II

CSNS - Timeline

CSNS will be built in two phases: 100 kW at CSNS-I and 500 kW at CSNS-II.
Total budget: ~2.3B CNY (or 350M USD)

Feb. 2001
Idea of building the CSNS discussed

Jun. 2005
Proposal approved in principle by the Central Government of People's Reput

Jan. 2006
Prototyping R&D started

Sep. 2008
Proposal approved by the National Development and Reform Commission

Oct. 2009
Feasibility study report approved

Apr. 2010
Preparation of the CSNS site selection started

Sep. 2011
Construction started & component fabrication started

May. 2012
Civil construction started

Oct. 2014
Installation of frontend and LRBT started in Linac tunnel

Apr. 2015
Installation of the RCS magnets started in RCS tunnel

May. 2015
The Helium Vessel of the target station installed

Dec. 2016
RCS commissioning started

Sep. 2017
First beam on Target

Mar. 2018
CSNS Phase-I project completed

Feb. 2019
CSNS beam power reached 50 kW

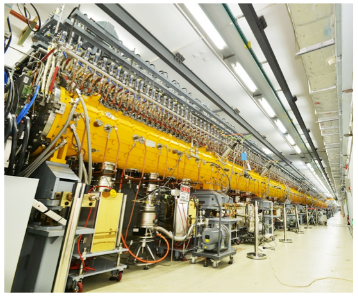
Apr. 2019
CSNS released scientific highlights for its first FY

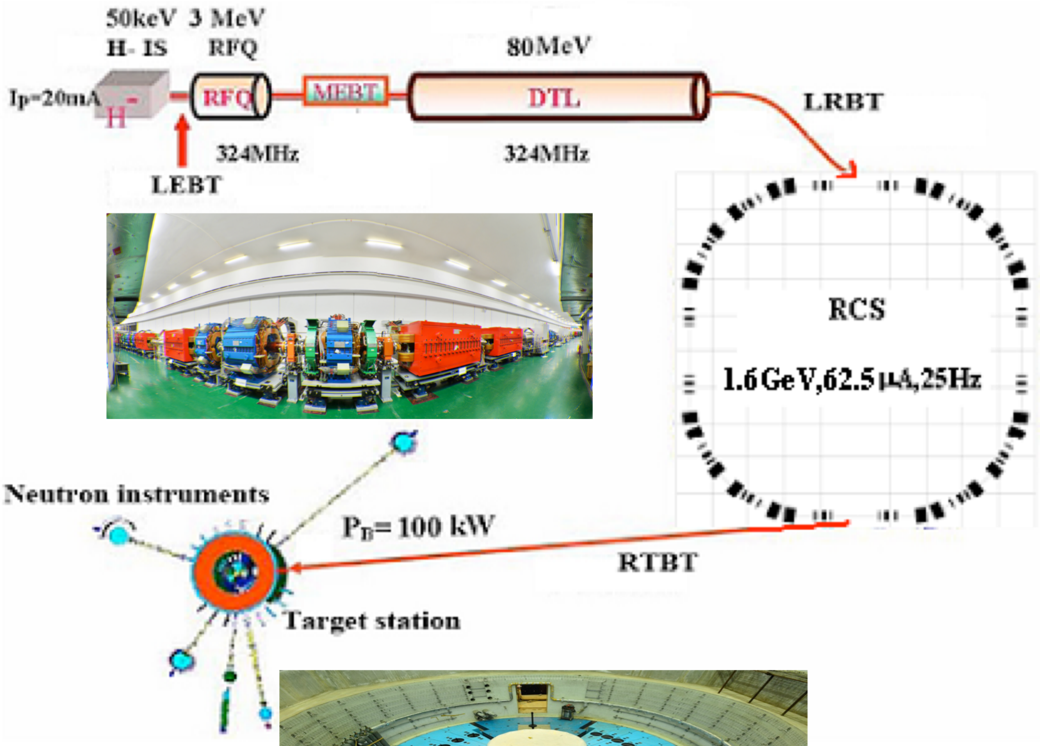
Sep. 2019
CSNS beam power reached 80 kW

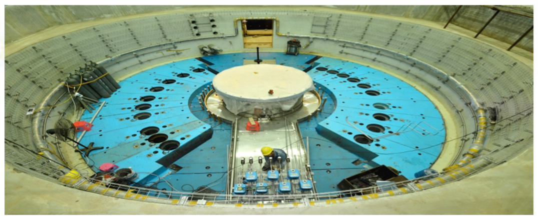
Mar. 2020
CSNS beam power reached design goal of 100 kW

Jan. 2021
CSNS finished construction of its first user instrument

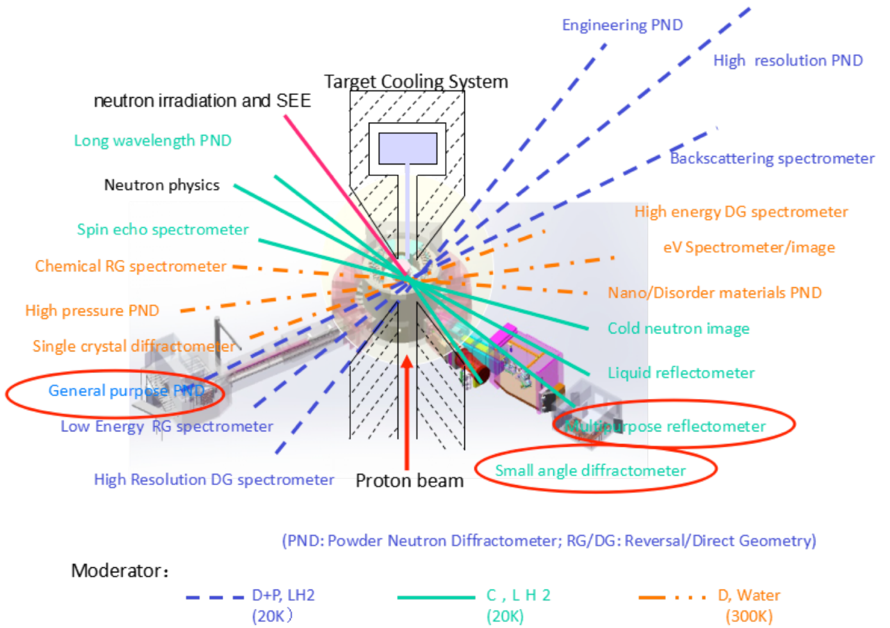
CSNS - *Facility*







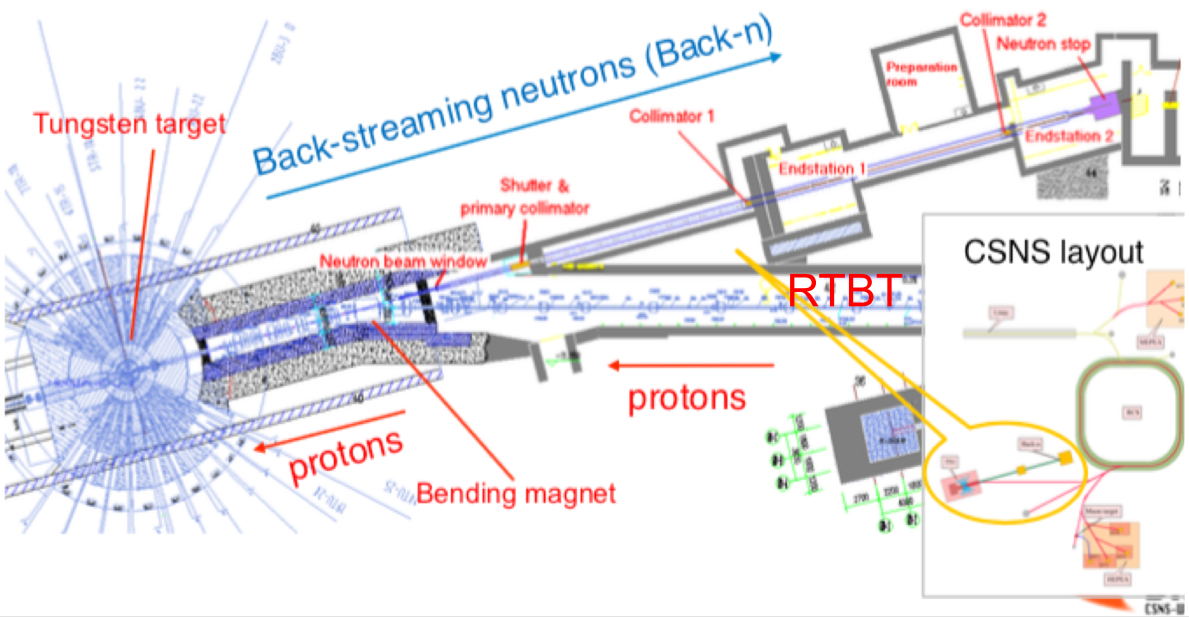
The Basic Parameters of CSNS		
Name	**CSNS-I**	**CSNS-II**
Beam power(kW)	100	500
Repetition rate(Hz)	25	25
Target number	1	1
Average current(μA)	62.5	312
Proton energy(GeV)	1.6	1.6
Linac energy(Mev)	80	250



Back-streaming neutrons

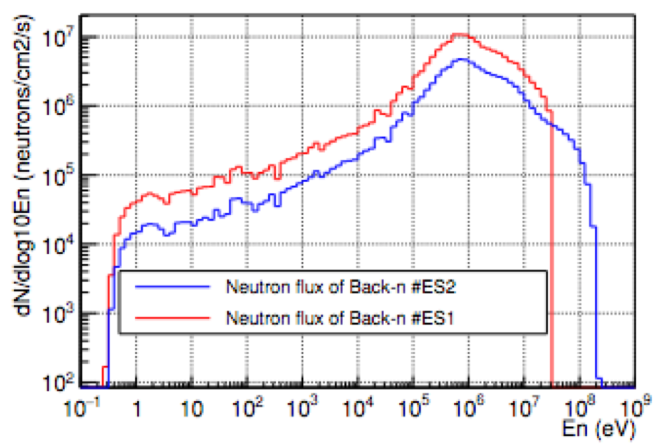
Back-streaming neutrons (Back-n) from the CSNS target into the RTBT (Ring to Target Beam Transport):

- Very intense, harmful to the devices in RTBT, should be carefully treated (collimation and bending/neutron stopper)
- Good energy spectrum and time structure, exploited as white neutron source (first its kind in the world)



Comparison of the neutron energy spectrum of Back-n #ES1 and #ES2.

EPJ Web of Conferences 239, 17018 (2020



谢谢你的关注