PandaX Dark Matter Search

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Outline

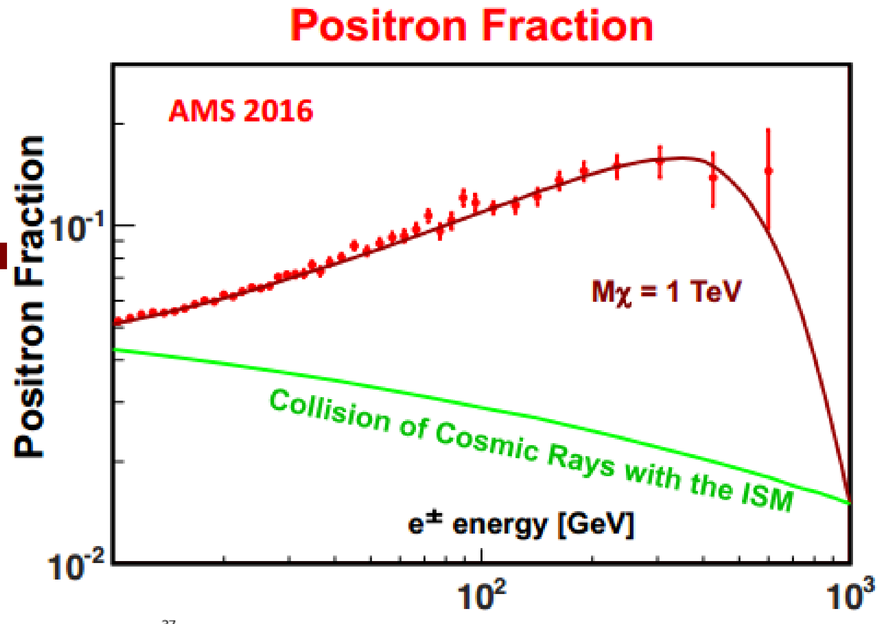
- Introduction to WIMP search and liquid xenon experiments
- PandaX experiment and China Jinping Underground Laboratory
  - Published results from PandaX
- 2017 data and preliminary physics analysis
- PandaX Future

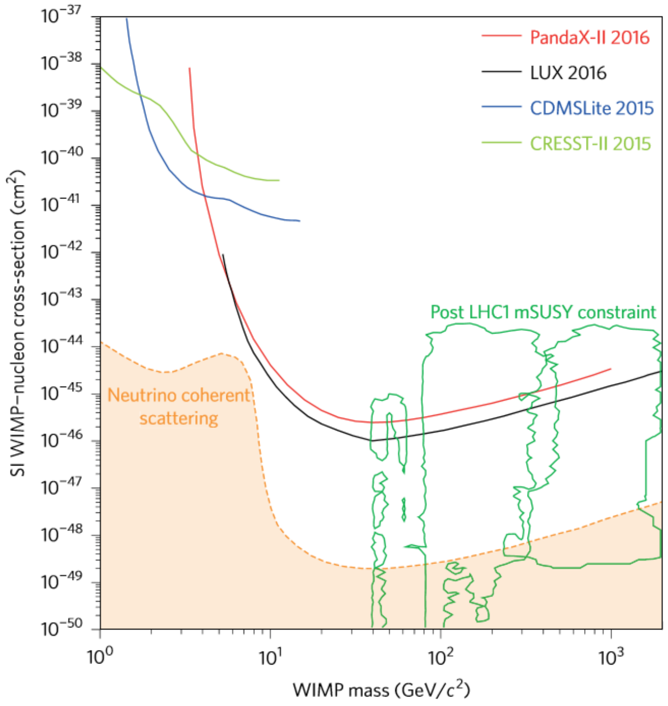
After 30 years of direct detection and over 5 orders of magnitude improvement in detection sensitivity, WIMPs are still at large!

Theorists are getting impatient…

Salient points:

- Indirect detection in AMS-II (and DAMPE, soon) might have observed tantalizing signals at TeV scale that could come from DM annihilation
- Experimental sensitivity has covered only part of regions where theories predict
- We are still 3 orders of magnitude away from the “neutrino floor”, after which experimental handle “may” still exist





Liu, Chen, Ji, Nature Physics 13, 212–216 (2017)

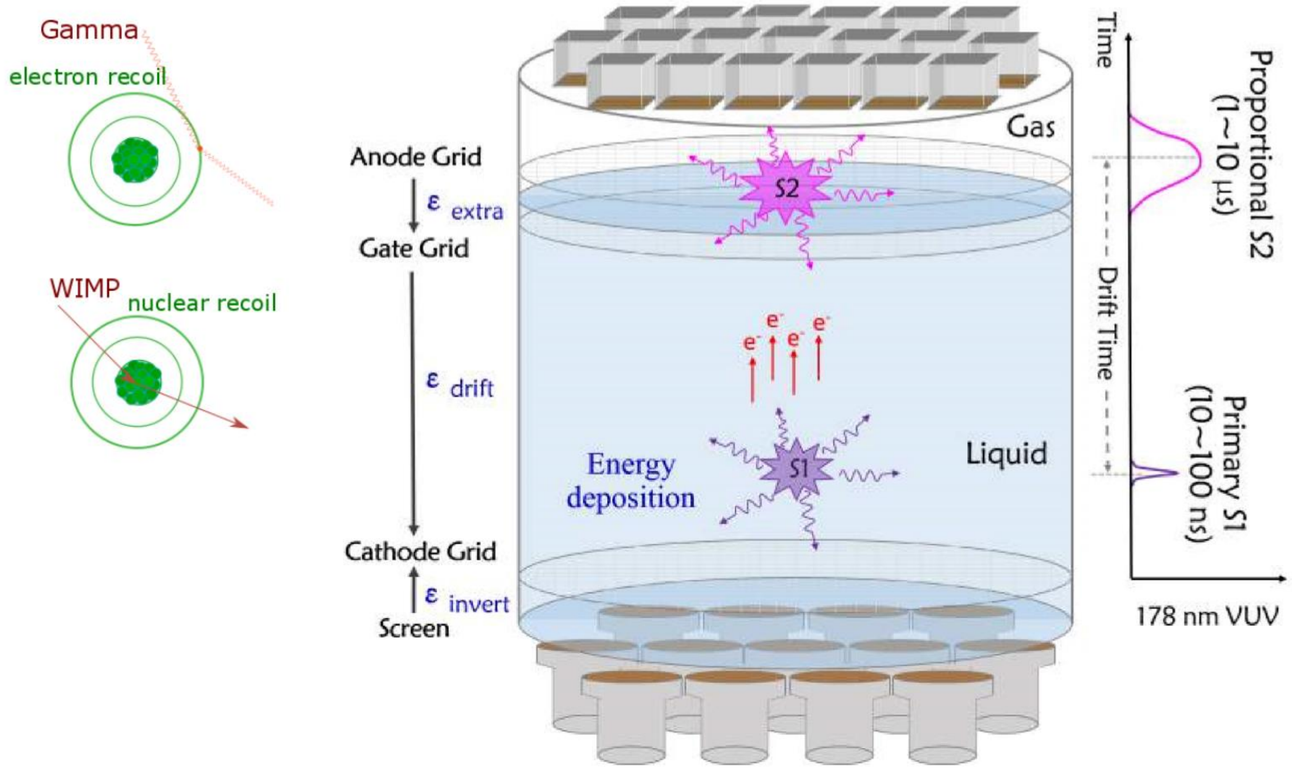
Xenon experiments are leading the pack

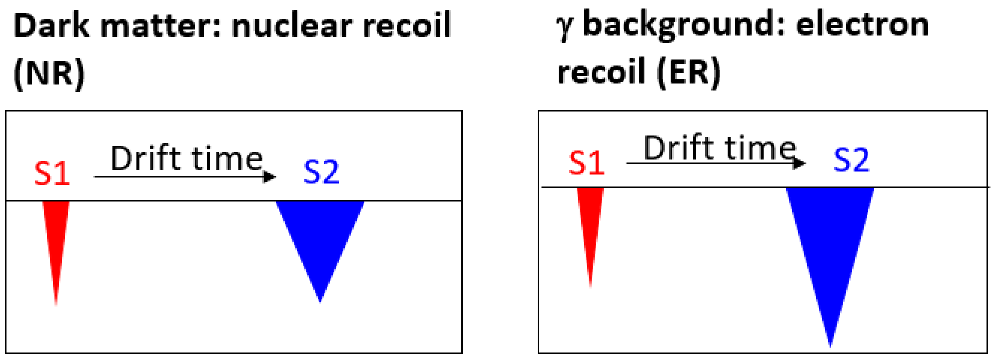
- Xenon has no long-lived radioactive isotopes that contaminate the search (^{136}Xe ββ-decay and Rn might become important in very large detectors).
- Xenon dual-phase technology measures both scintillation and charge, allowing excellent self-shielding and exploiting electric/nuclear recoil differences
- There appears no show stopper yet on the large size xenon dual phase technology

Past and present: 10kg ➡100kg ➡250kg ➡ 500kg ➡ 2ton

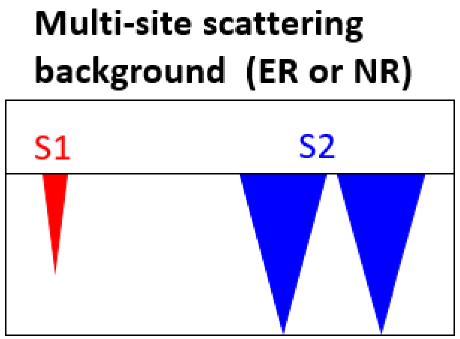
Future➡7 ton ➡30 ton? ➡100 ton?

Dual phase xenon experiments





$$(S2/S1)_{NR} << (S2/S1)_{ER}$$



Three xenon experiments (using similar tech)

- **XENON collaboration** (led by Columbia U, jointly by a few other inst. in US and a large European participation, funded by NSF and European agency)

  XENON10, XENON100, XENON1T, XENONnT

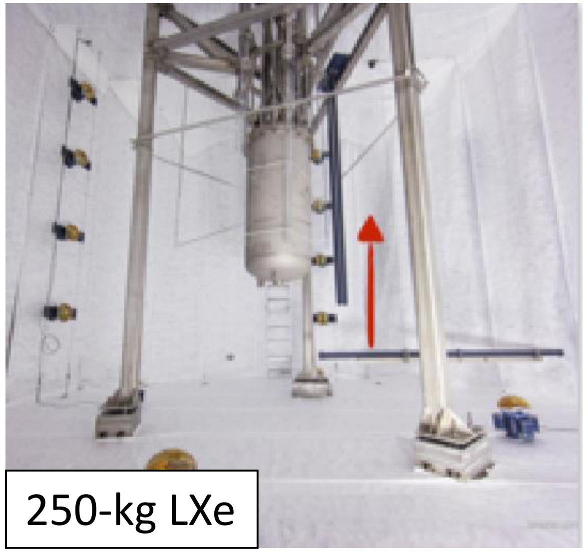
- **LUX-(ZEPLIN) collaboration** (mainly US and British Inst., funded by DOE)

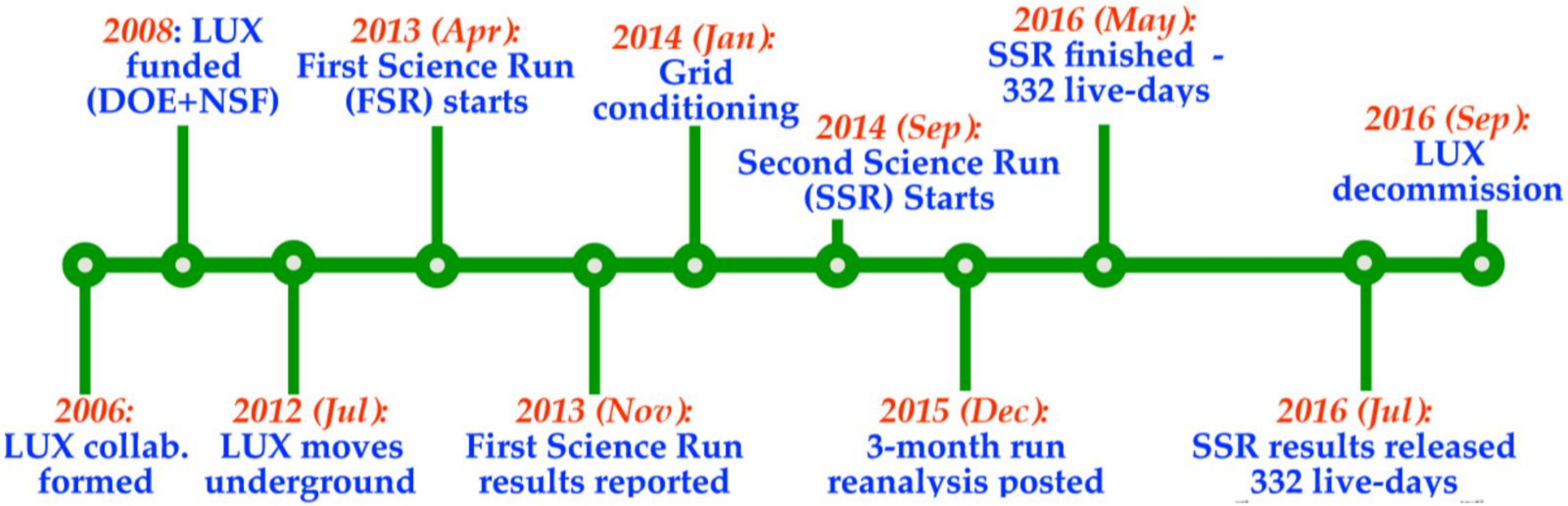
  LUX(250kg), LZ(7ton)

- **PandaX collaboration** (SJTU and coll. Inst., funded by Chinese agencies)

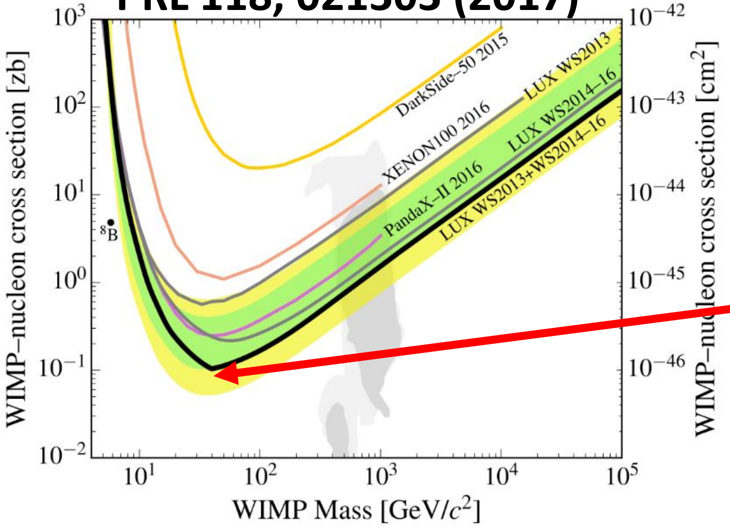
  PandaX-I, PandaX-II, PandaX-4T, PandaX-30T

LUX



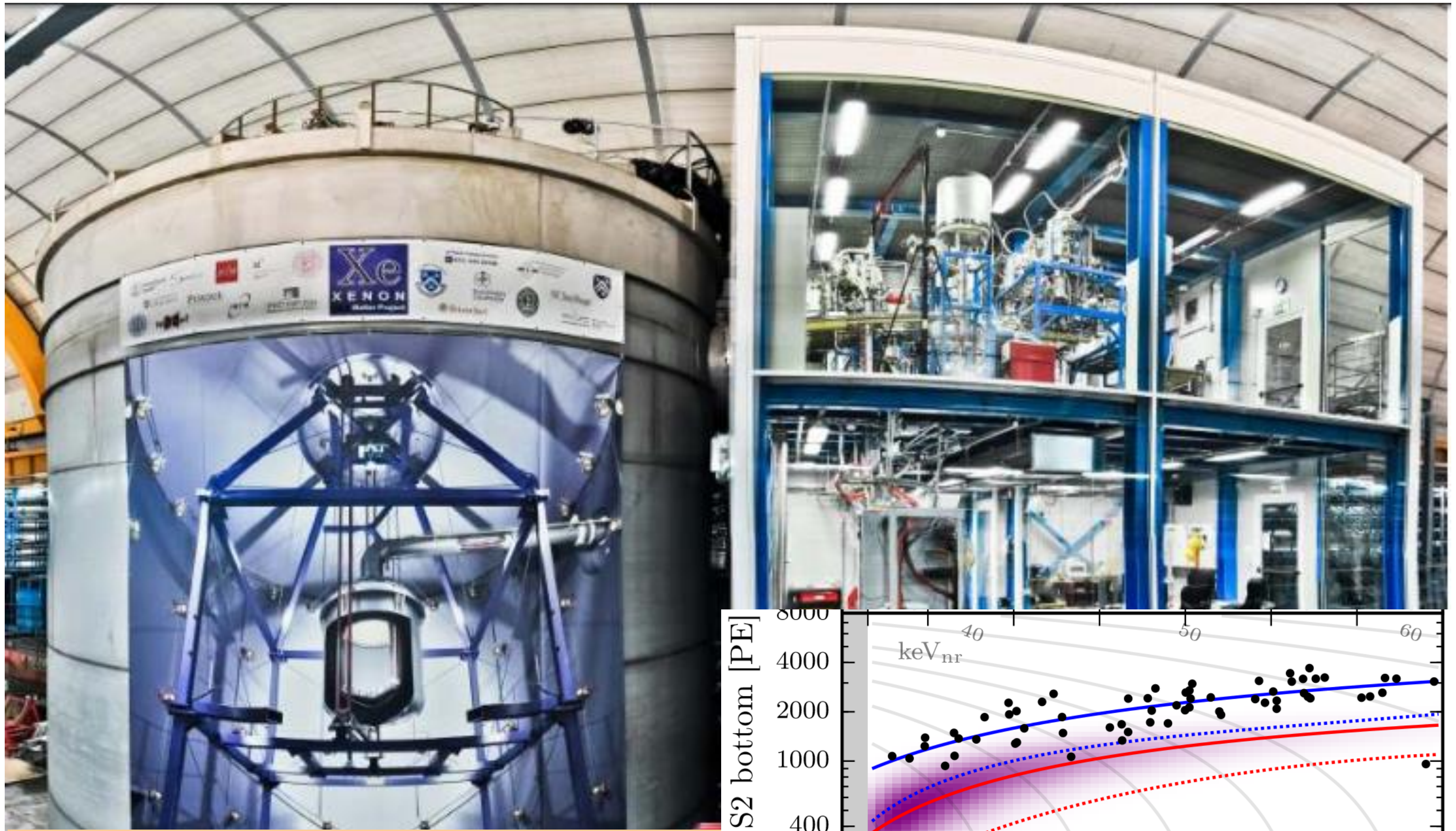


PRL 118, 021303 (2017)



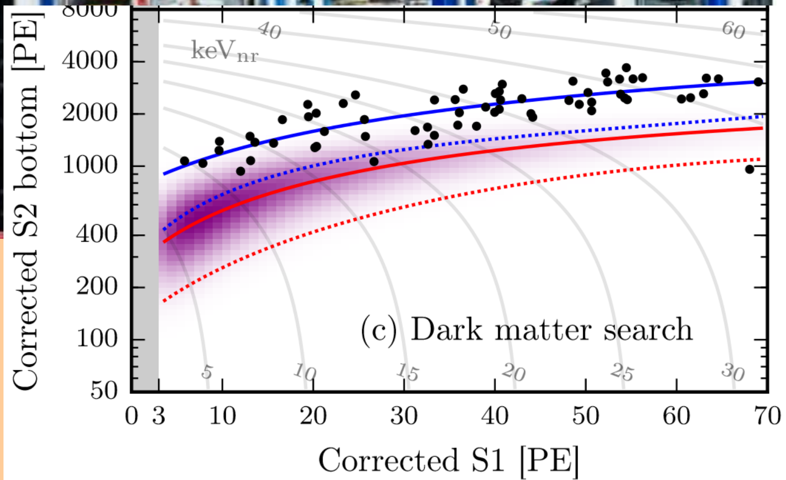
- **Combination of both science runs (95+332 live-days)**
- **SI cross section limit,**
  1.1×10^{-46} cm^2 @ 50 GeV/c^2
- **Currently also leading the SD WIMP-n sensitivity**

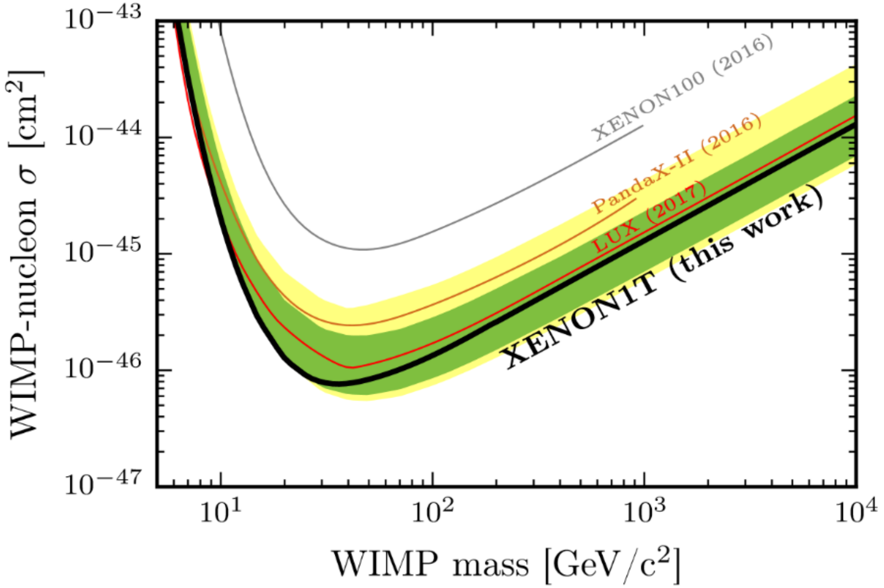
XENON1T First Results (talk tomorrow afternoon)



largest LXe TPC ever built

- cylinder: 96 × 97 cm
- active LXe target: 2.0t (3.2t total)
- 248 PMTs (Hamamatsu R11410-21)





arXiv:1705.06655

- **World leading bkg level: 0.2×10^{-3} evt/day/kg/keV**
- **First SR: 1024 kg x 34.2 day, no candidate found**
- **Minimum limit: 7.7 x 10^{-47} cm^2 @ 35 GeV**

PandaX experiment and Jinping Underground Laboratory

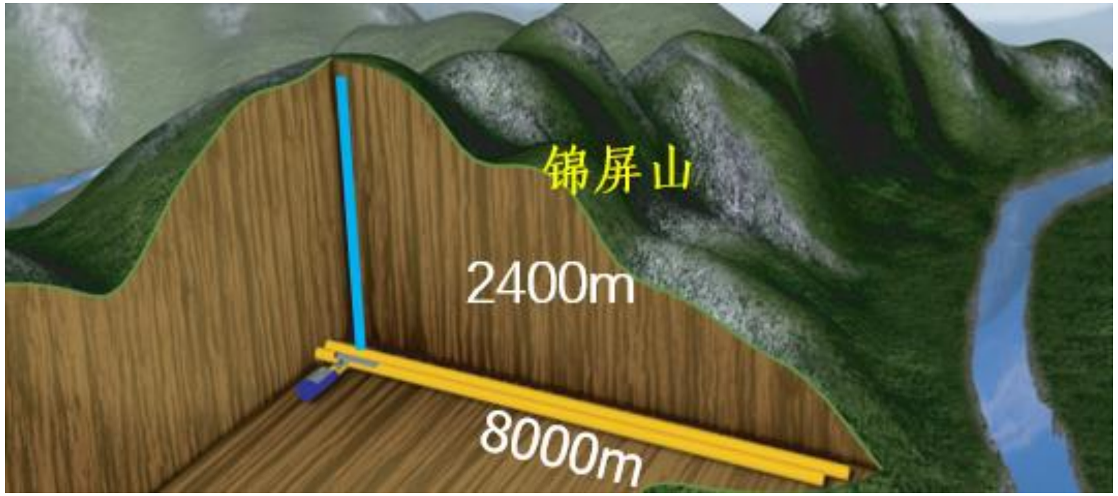
PandaX collaboration

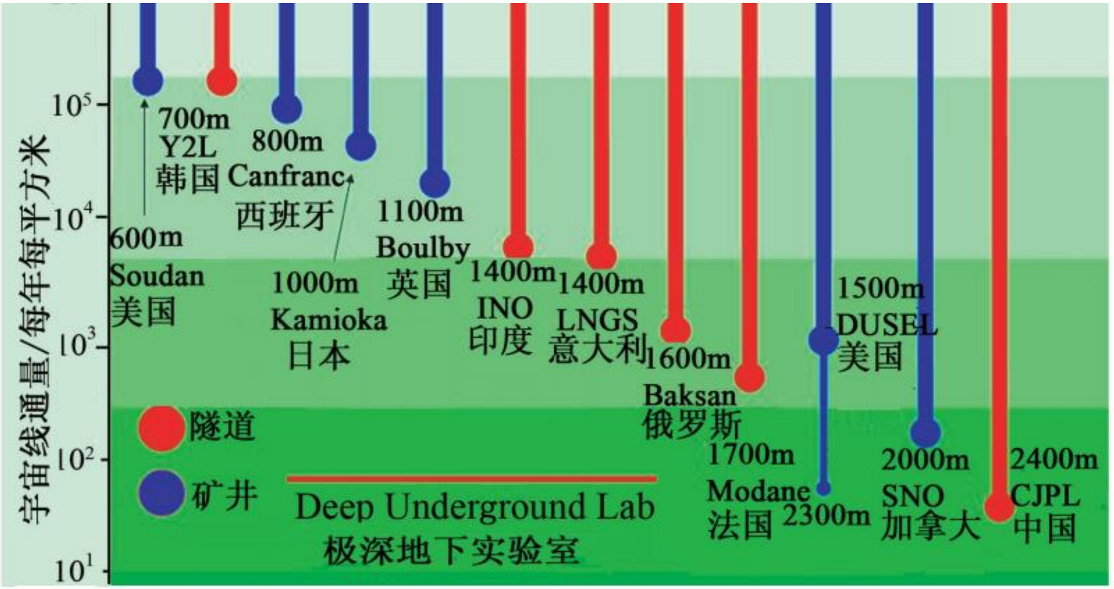
Started in 2009

- Shanghai Jiao Tong University (2009-)
- Peking University (2009-)
- Shandong University (2009-)
- Shanghai Institute of Applied Physics, CAS (2009-)
- University of Science & Technology of China (2015-)
- China Institute of Atomic Energy (2015-)
- Sun Yat-Sen University (2015-)
- Yalong Hydropower Company (2009-)
- University of Maryland (2009-)

China Jinping Underground Laboratory

Deepest in the world (1μ/week/m²)
and Horizontal access!



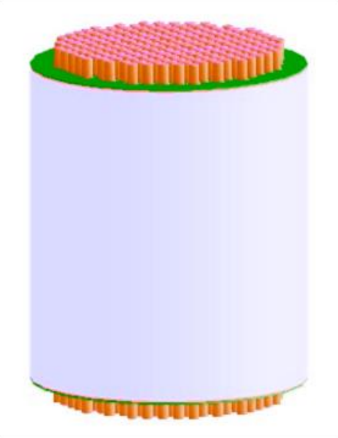


PandaX experiment

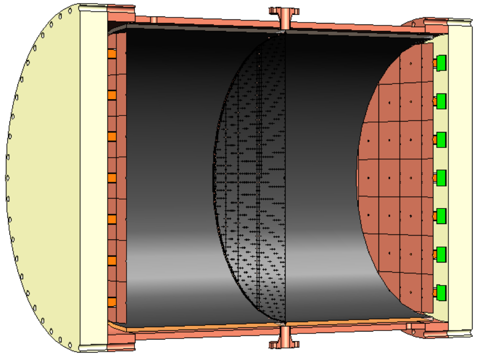
PANDA X = Particle and Astrophysical Xenon Experiments

Phase I:
120 kg DM
2009-2014

Phase II:
500 kg DM
2014-2018



PandaX-xT:
multi-ton
DM
future



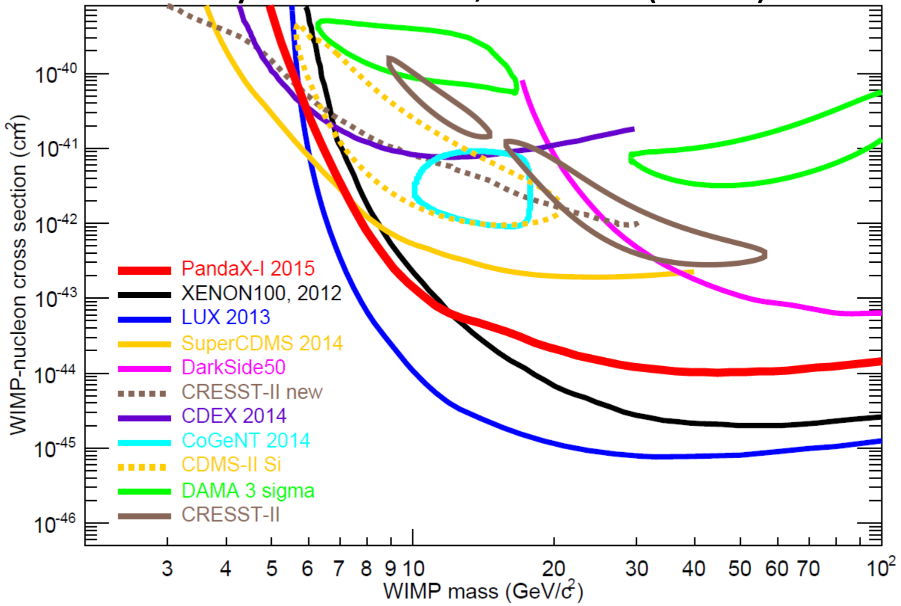
PandaX-III:
200 kg to 1 ton
^{136}Xe 0vDBD
future

First delivery of PandaX equipment to Jinping lab, Aug. 16, 2012

PandaX apparatus

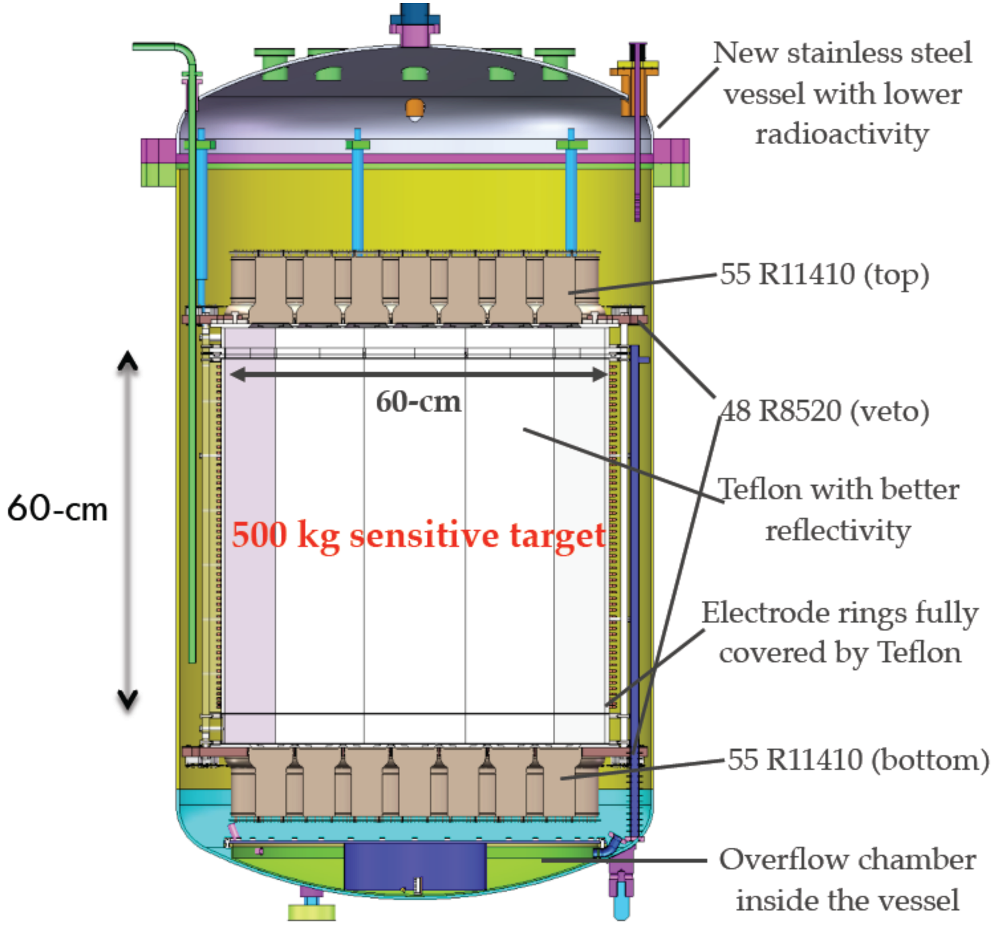
Final Results from PandaX-I

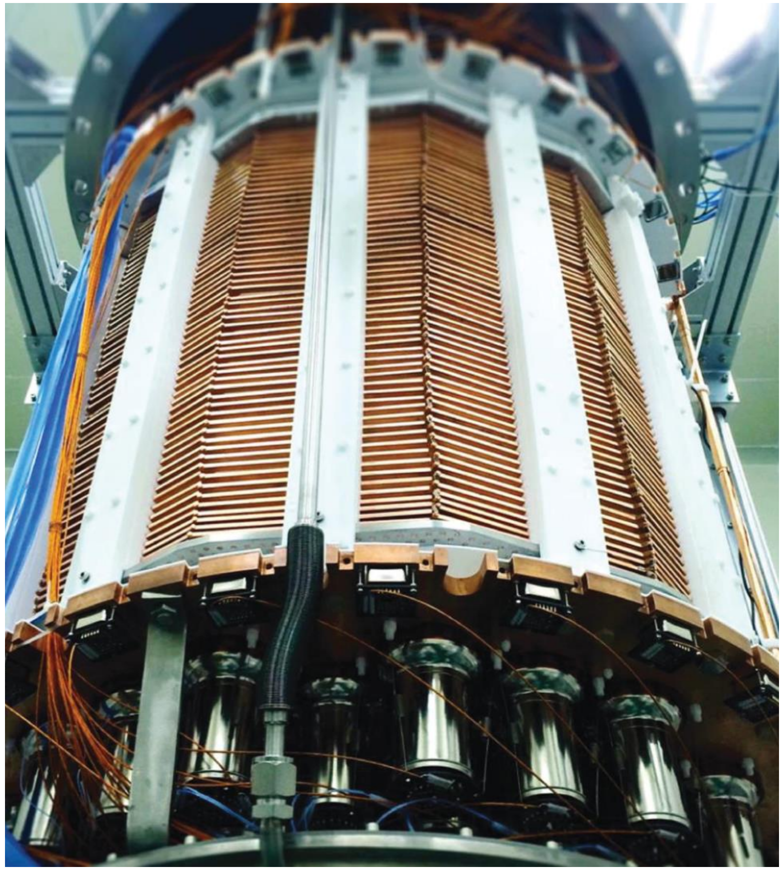
Phys. Rev. D **92**, 052004(2015)



- Completed in Oct. 2014, with 54.0 x 80.1 kg-day exposure
- Data strongly disfavor all previously reported claims
- Competitive upper limits for low mass WIMP in xenon experiments

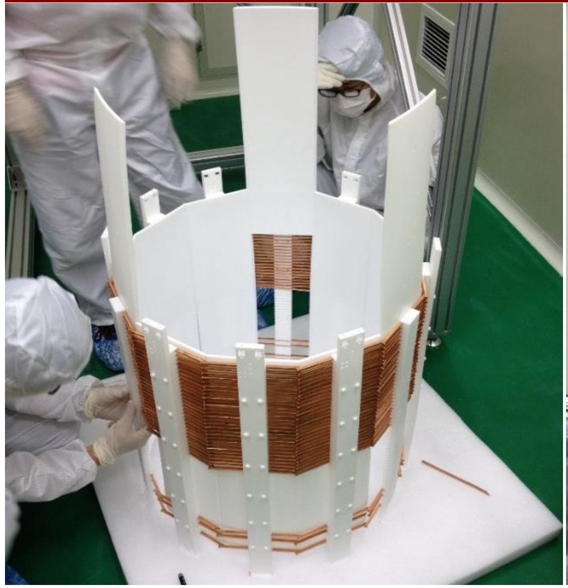
PandaX-II Detector

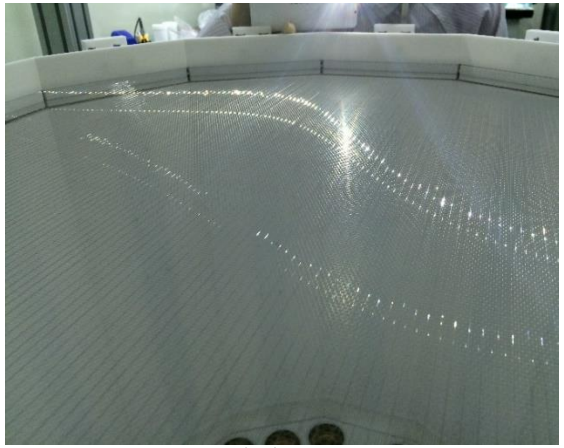


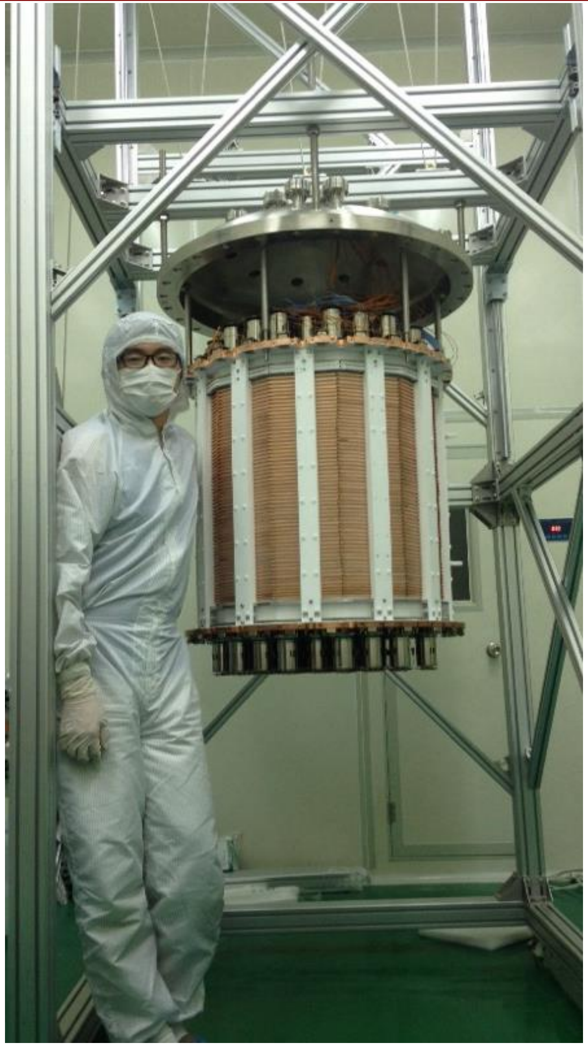


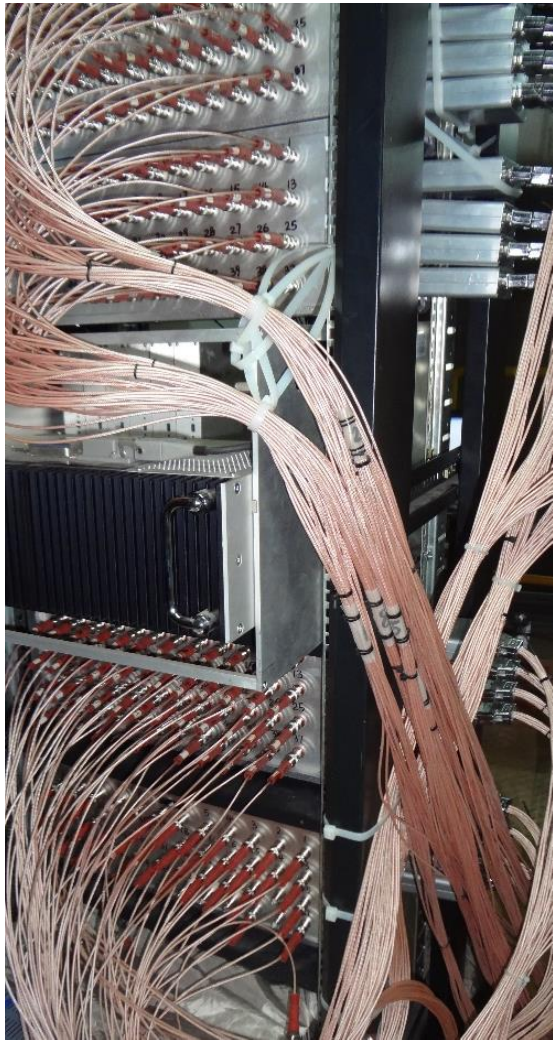
- 60 cm x 60 cm cylindrical TPC
- 580-kg of LXe in sensitive region, 1.2-ton LXe in total
- 55 top + 55 bottom R11410 3” target PMTs (split –ve and +ve HV
- 24 top + 24 bottom R8520 1” VETO PMTs

Assembling the detector

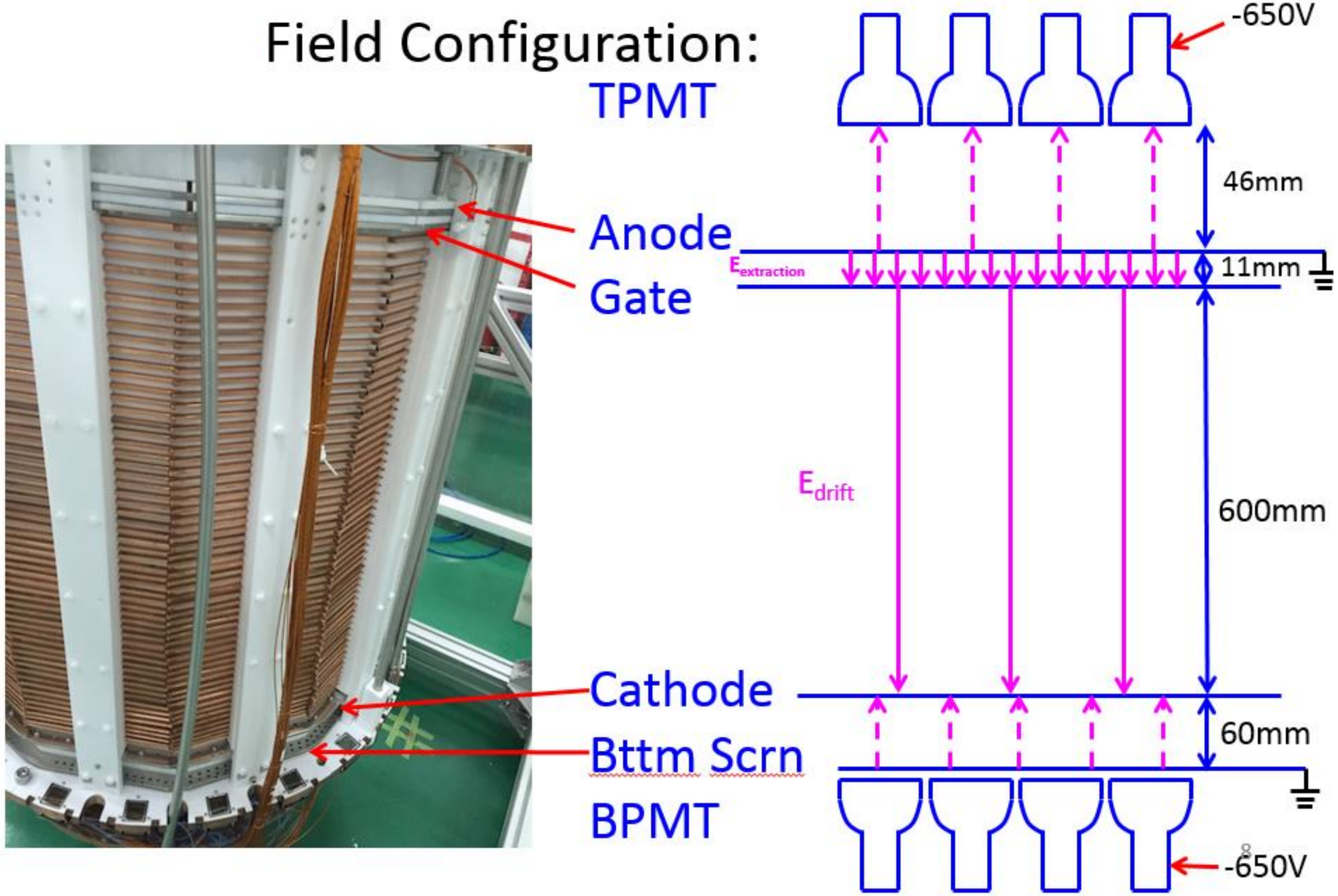








Configuration of fields

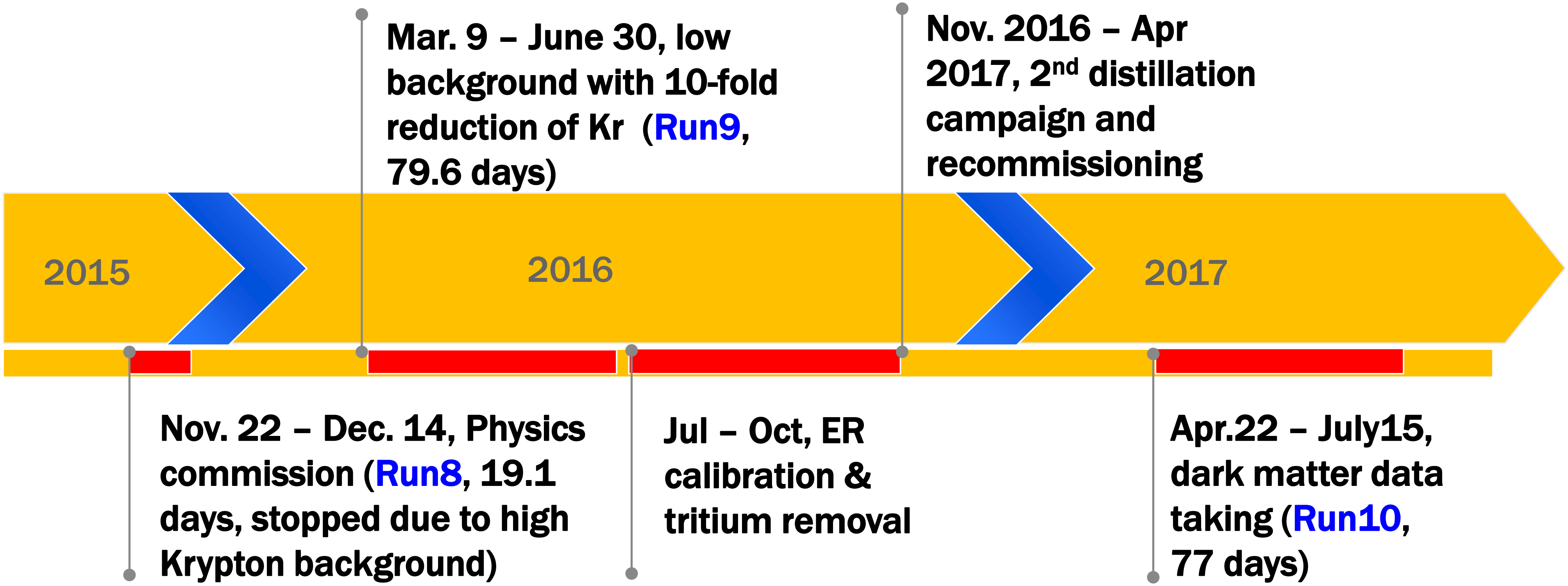


	Cathode (-kV)	Gate (-kV)	Drift field (V/cm)
Run9	-29.3	-4.95	400
Run10	-24.0	-4.95	320

Ref: LUX: 180 V/cm, XENON1T: 120 V/cm

Drift field in Run10 was lowered to avoid spurious discharge from the cathode

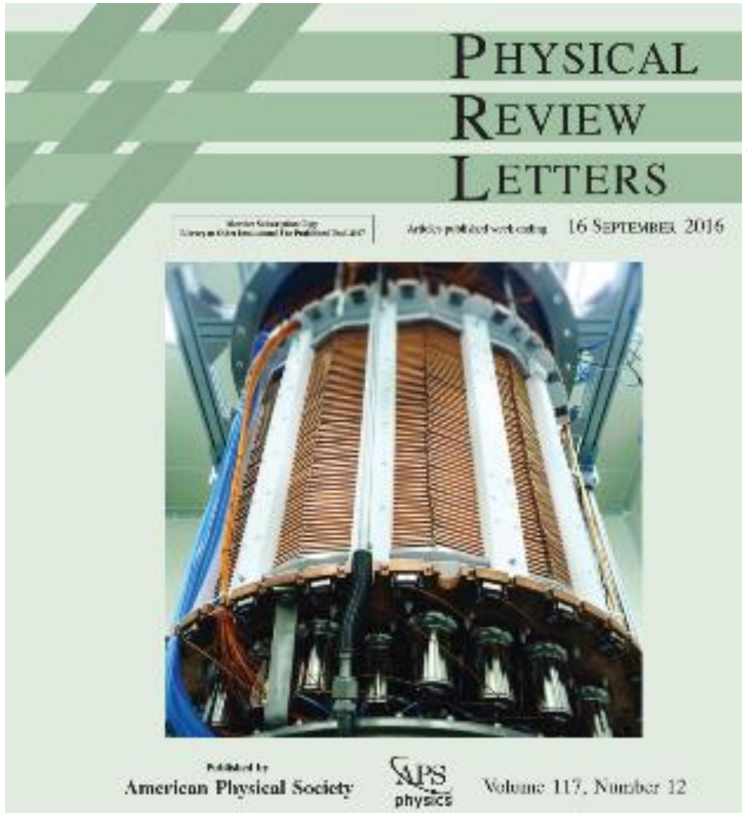
PandaX-II run history



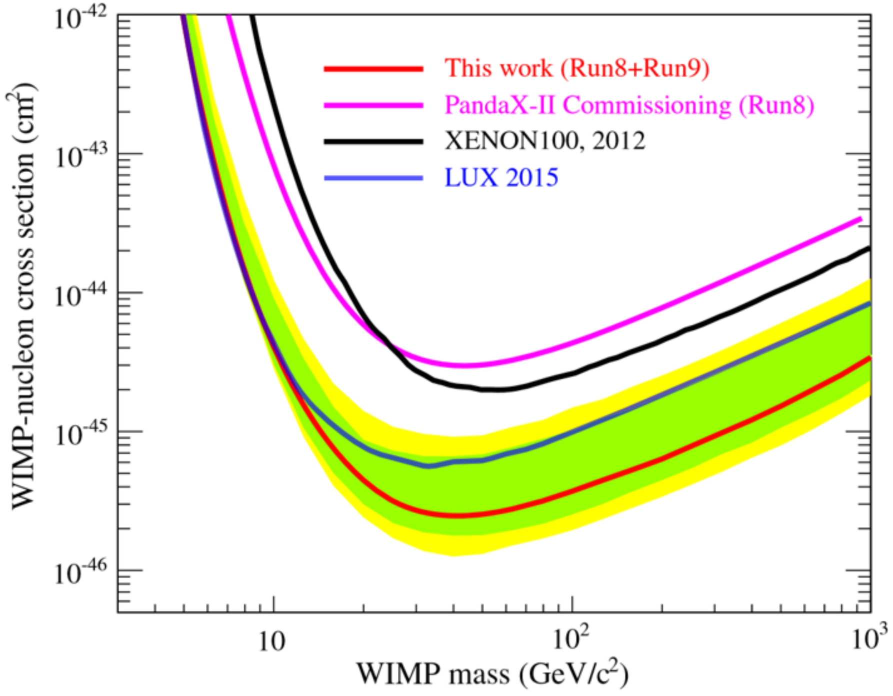
- Run9 =79.8 days, exposure: 26.2 ton-day
- Run10 =77.1 days, exposure: 27.9 ton-day
- Largest reported DM exposure to date

PandaX-II Run8+9 SI and SD results

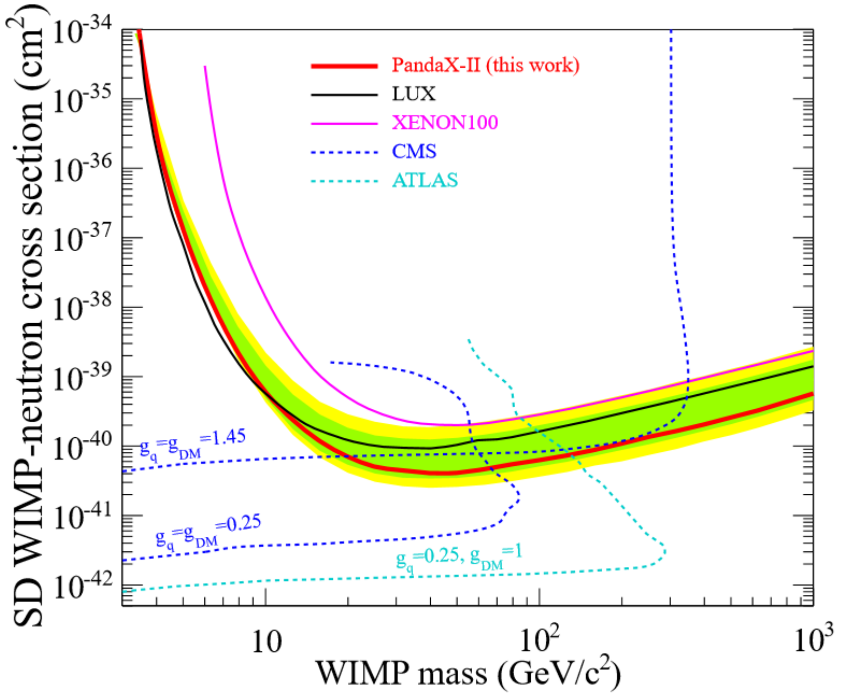
33,000 kg-day exposure



PRL 117, 121303 (2016)



PRL 118, 071301 (2017)



Minimum elastic SI exclusion:

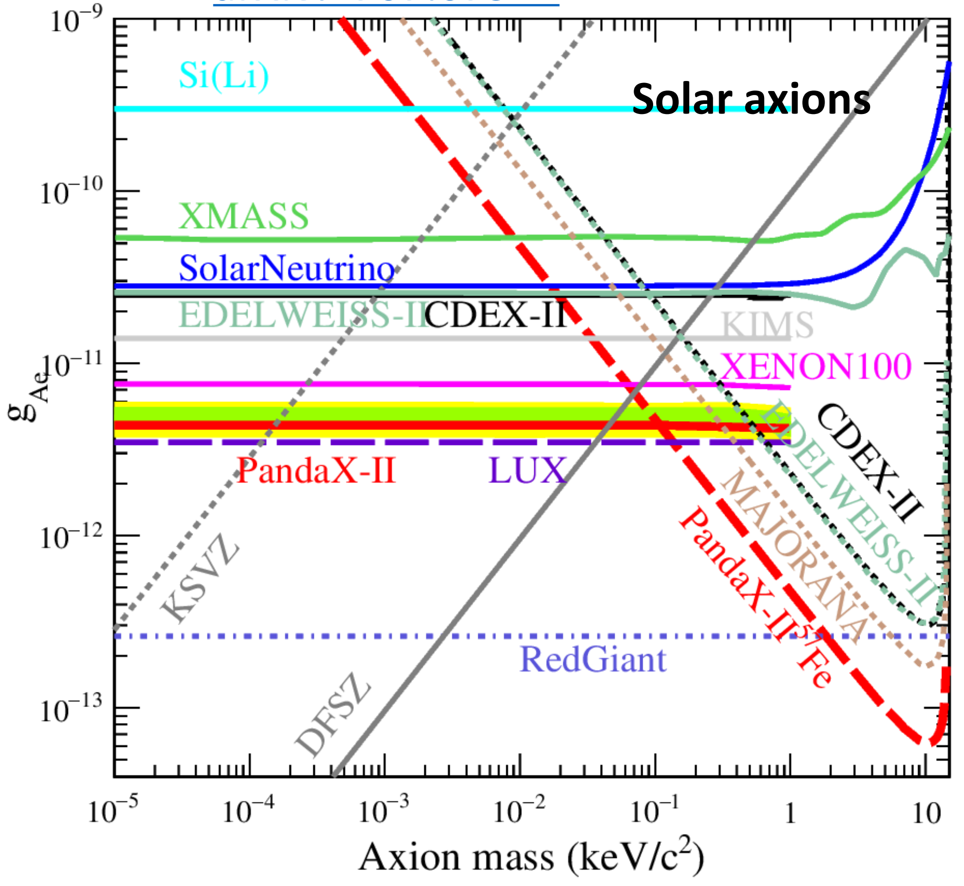
2.5×10^{-46} cm^2 @ 40 GeV/c^2

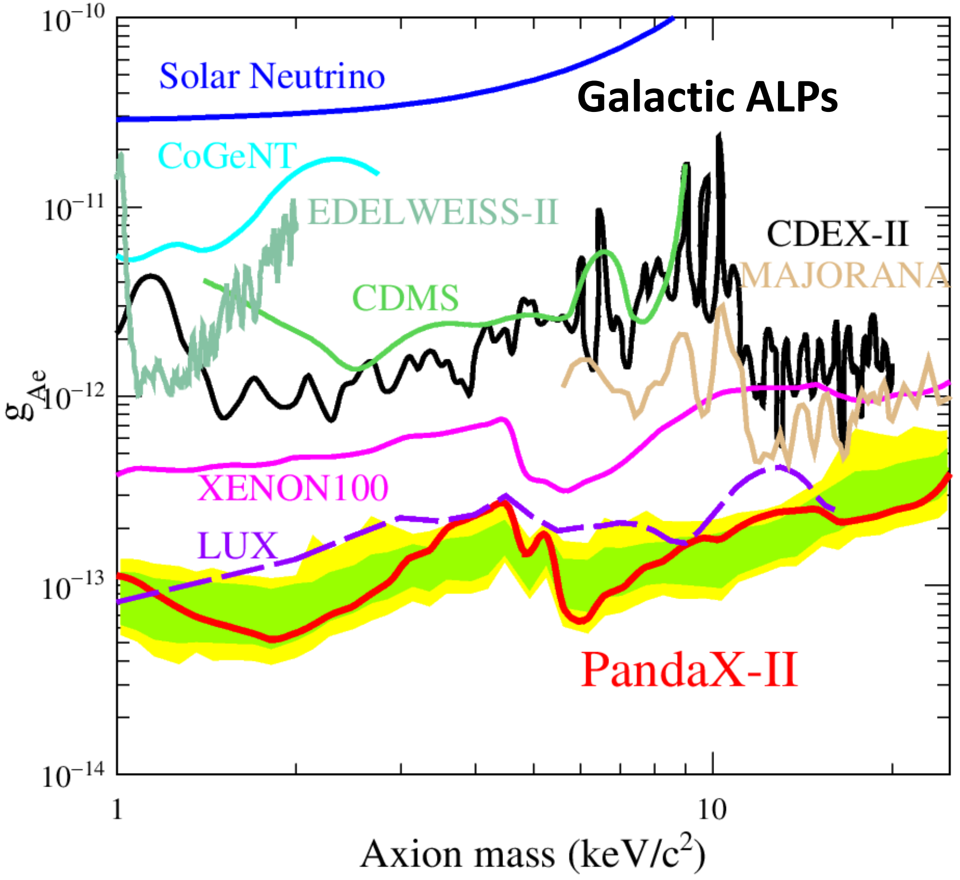
Minimum χ-n SD cross section limit:

4.1×10^{-41} cm^2 at 40 GeV/c^2

Run9 axion search results

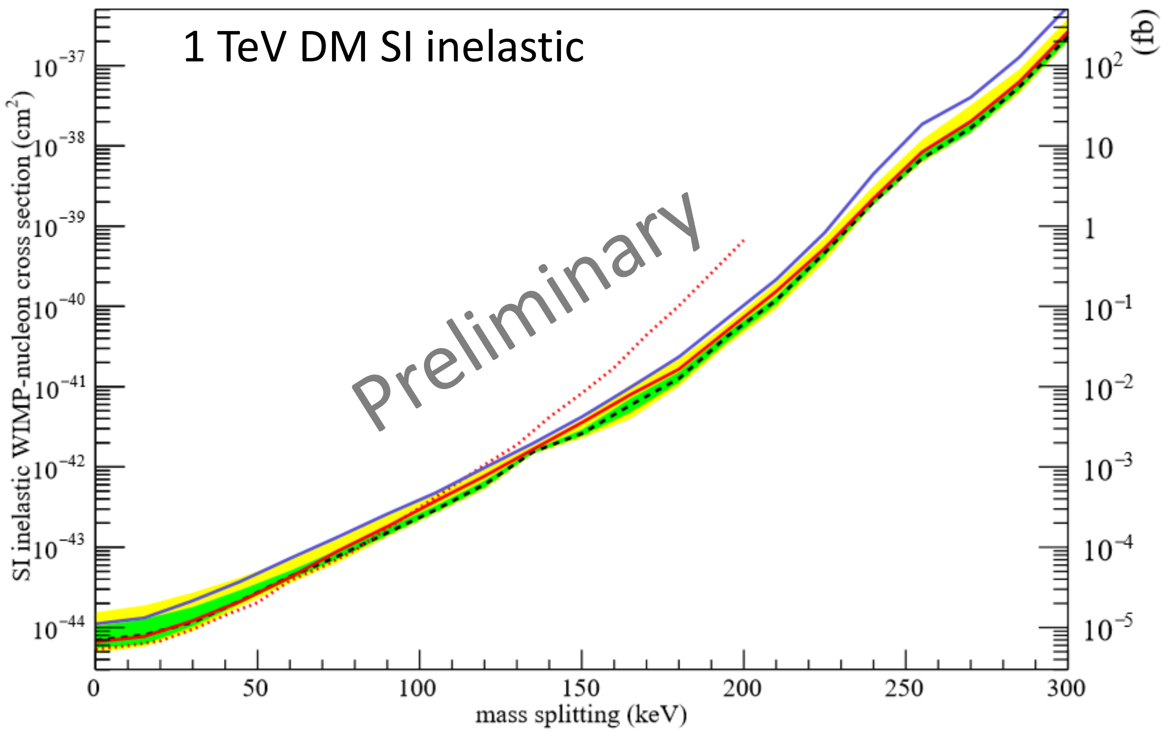
arXiv:1707.07921

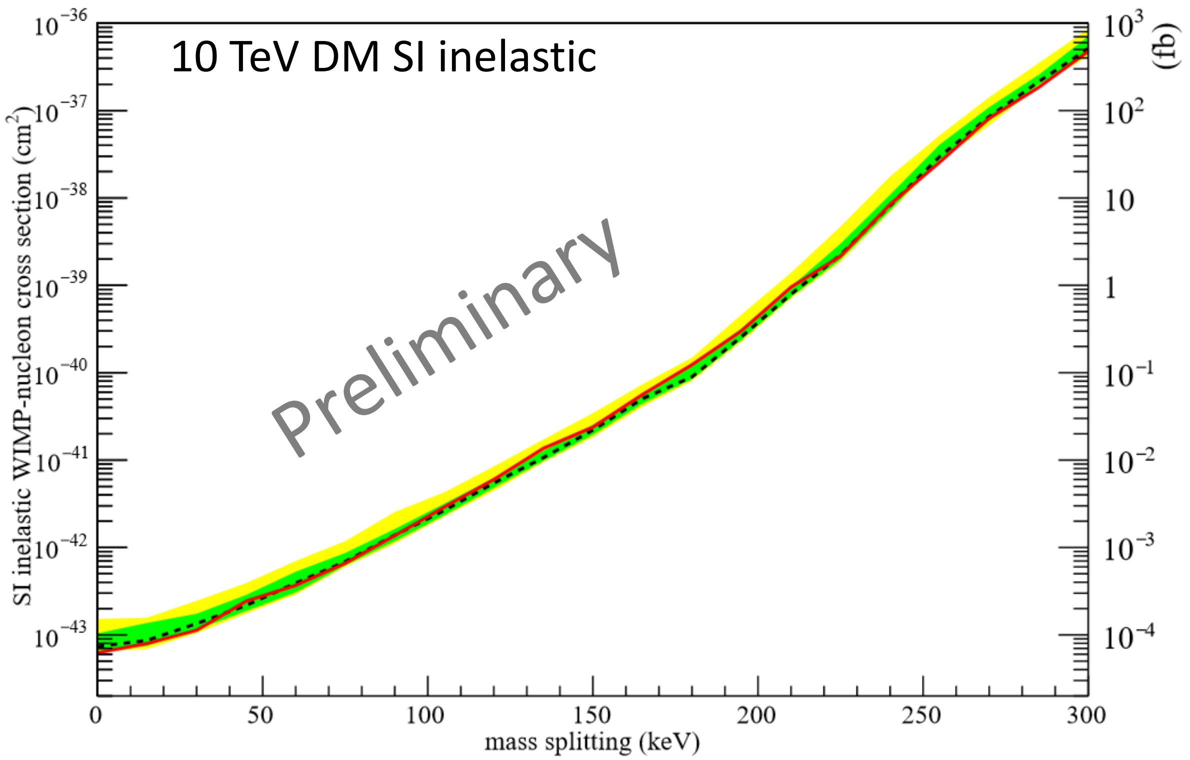




Among the leading axion search on axion-electron coupling using DD experiments

Run9 on inelastic dark matter





- **Opened up energy window to access initial-final mass difference up to 300 keV (high mass DM, ~TeV)**
- **Tightest direct constraint on this to date (to be published)**

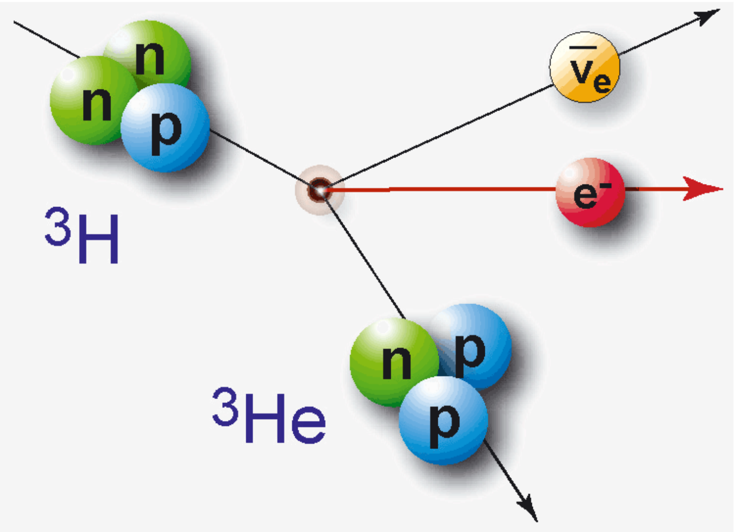
2017 new data and results

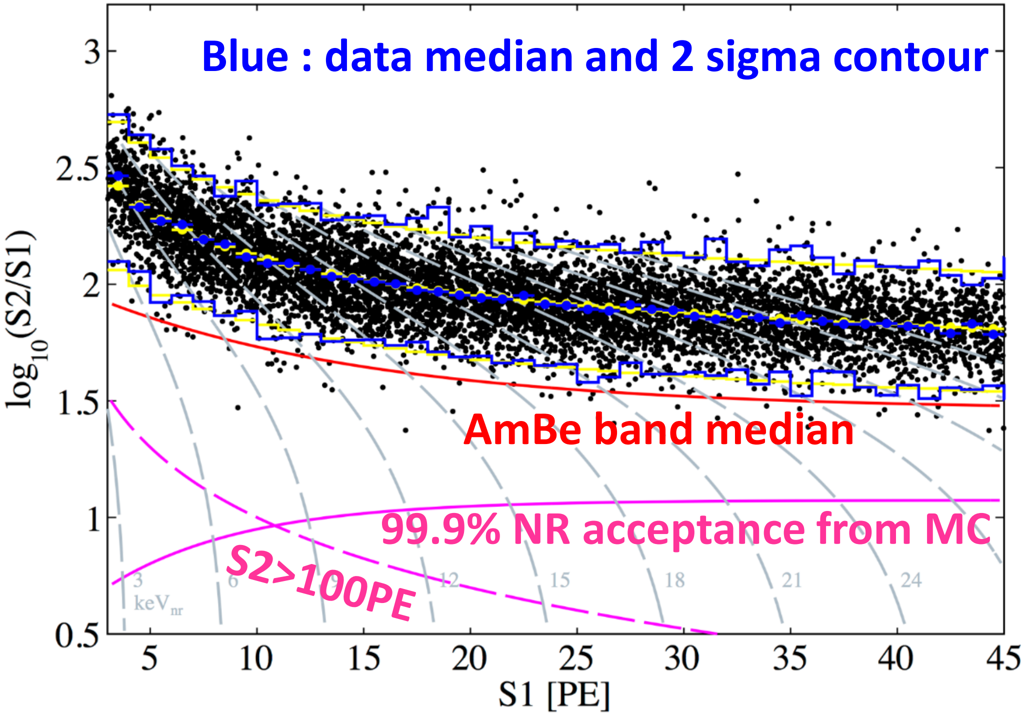
New SI DM search results from Run10

- Improved trigger threshold
- Channel-by-channel SPE efficiency (ε_{ZLE})
- Improved detector ER/NR response model
- 2.5 times reduction in total background
  - Kr85 ↓6 times
  - Accidental ↓ 3 times
  - Xe127 ↓ 13 times

ER calibration

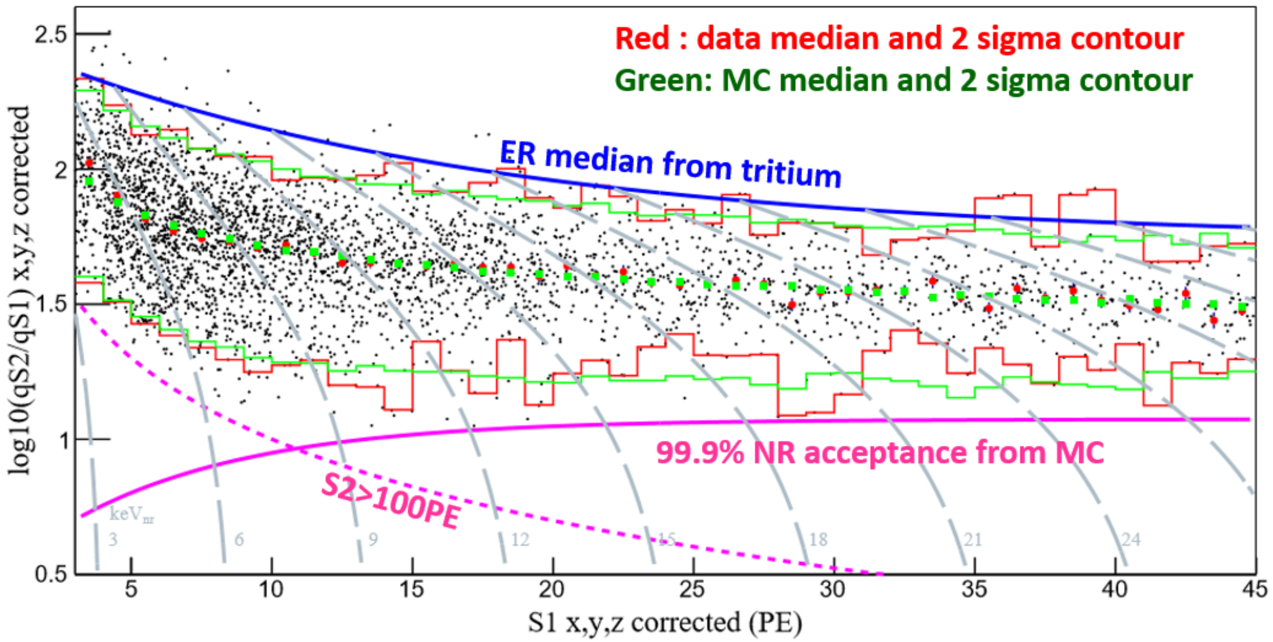
ER calibration using tritiated methane (a technique pioneered by LUX collaboration)

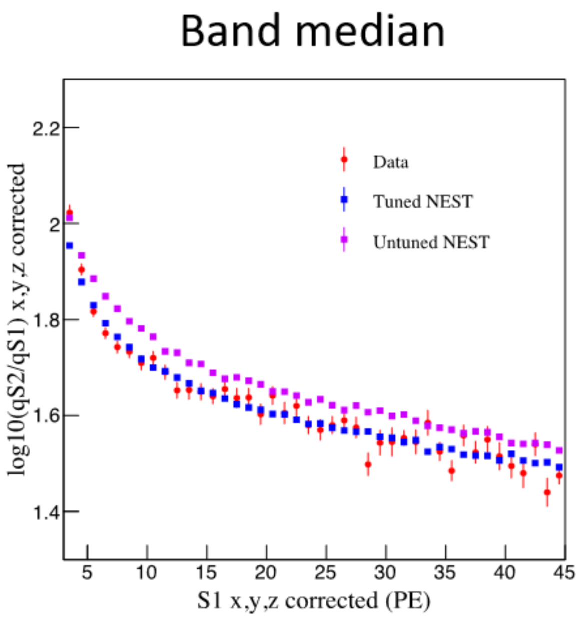


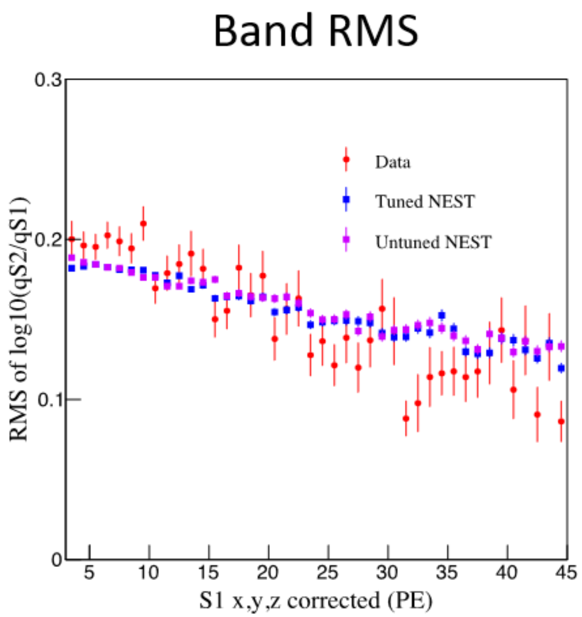


- Selected data with electron lifetime ~700 μs, ~8000 low energy ER events
- Events leaked below the NR median: 0.53(8)%
- Consistent with Gaussian estimate

NR calibration with AmBe data







A tuning of the N_{ex}/N_i (excitation/ionization) parameter was made on the NEST model, after which data and MC yield good agreement

Background level

	Run9 (mDRU)	Run10 (mDRU)
Xe127	0.42	0.033
Tritium	0	0.22
Kr85	1.19	0.20
Rn222	0.13	0.10
Rn220	0.01	0.02
Detector ER	0.20	0.21
Solar neutrino	0.01	0.01
Xe136	0.0022	0.0023
Total	1.95	0.79

1 mDRU = 10^{-3} evts/keV/kg/day

Original ^{127}Xe (cosmogenic, 36-day $\tau_{1/2}$) gone, additional introduced by a fresh "surface" bottle. Down 13 times

Based on best fit to data (later)

Reduced 6 times

These are consistent between Run 9 and Run 10

Reduced 2.5 times

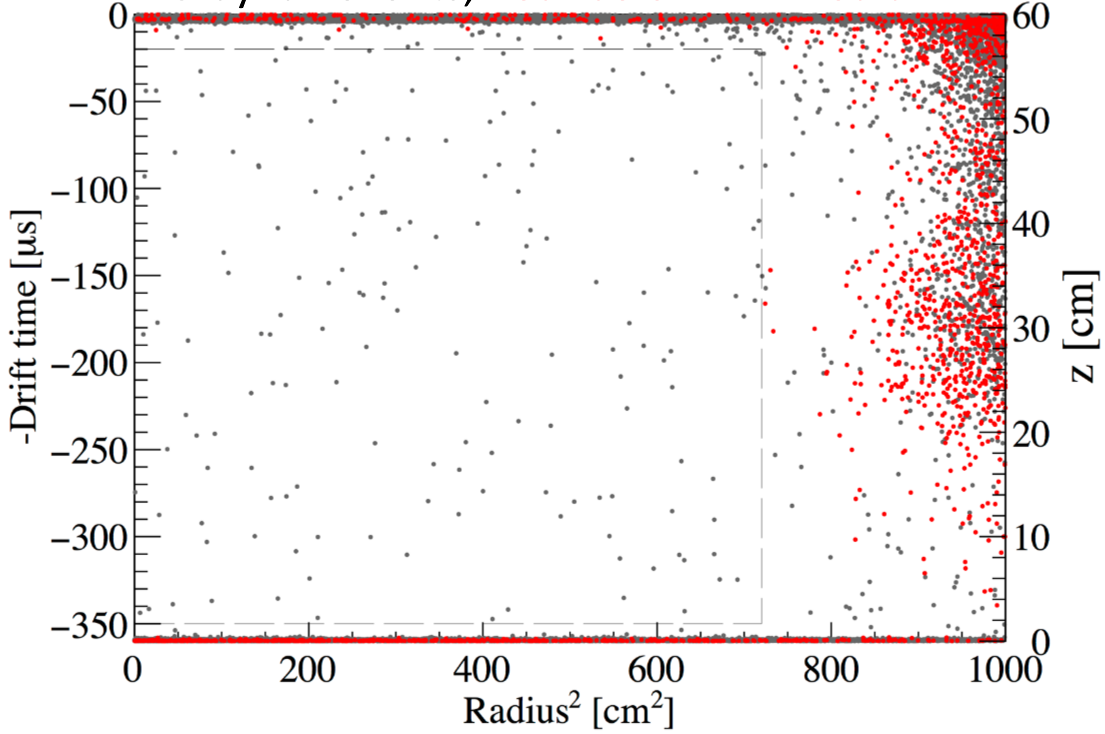
Event reduction after consecutive cuts

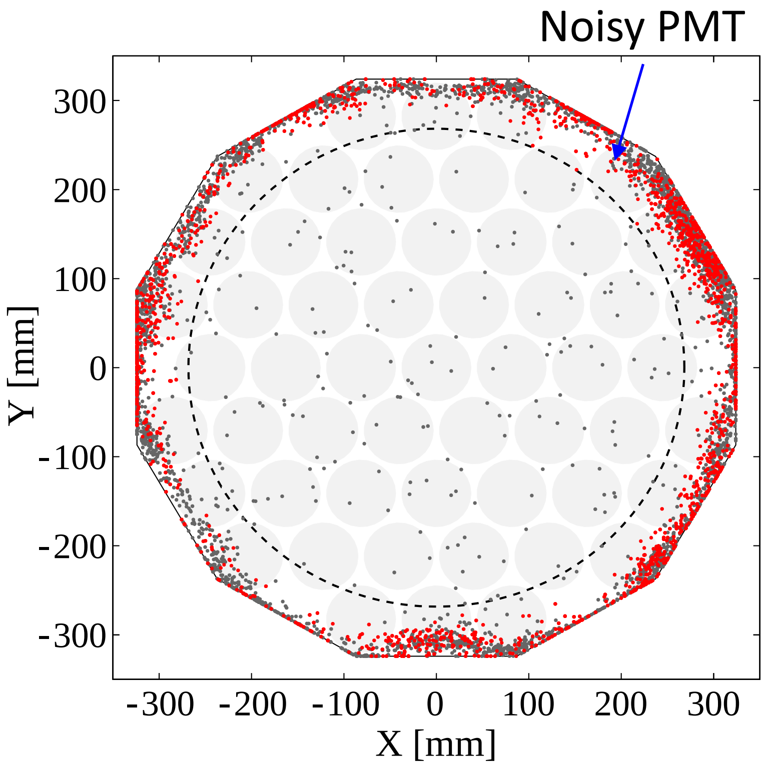
	Run 9	Run 10
All triggers	24502402	18369083
Low E search window	131097	111856
Final candidate in FV	389	177

Run10 background level significantly reduced.

Vertex distribution and FV

Gray: all events, Red: below NR-median



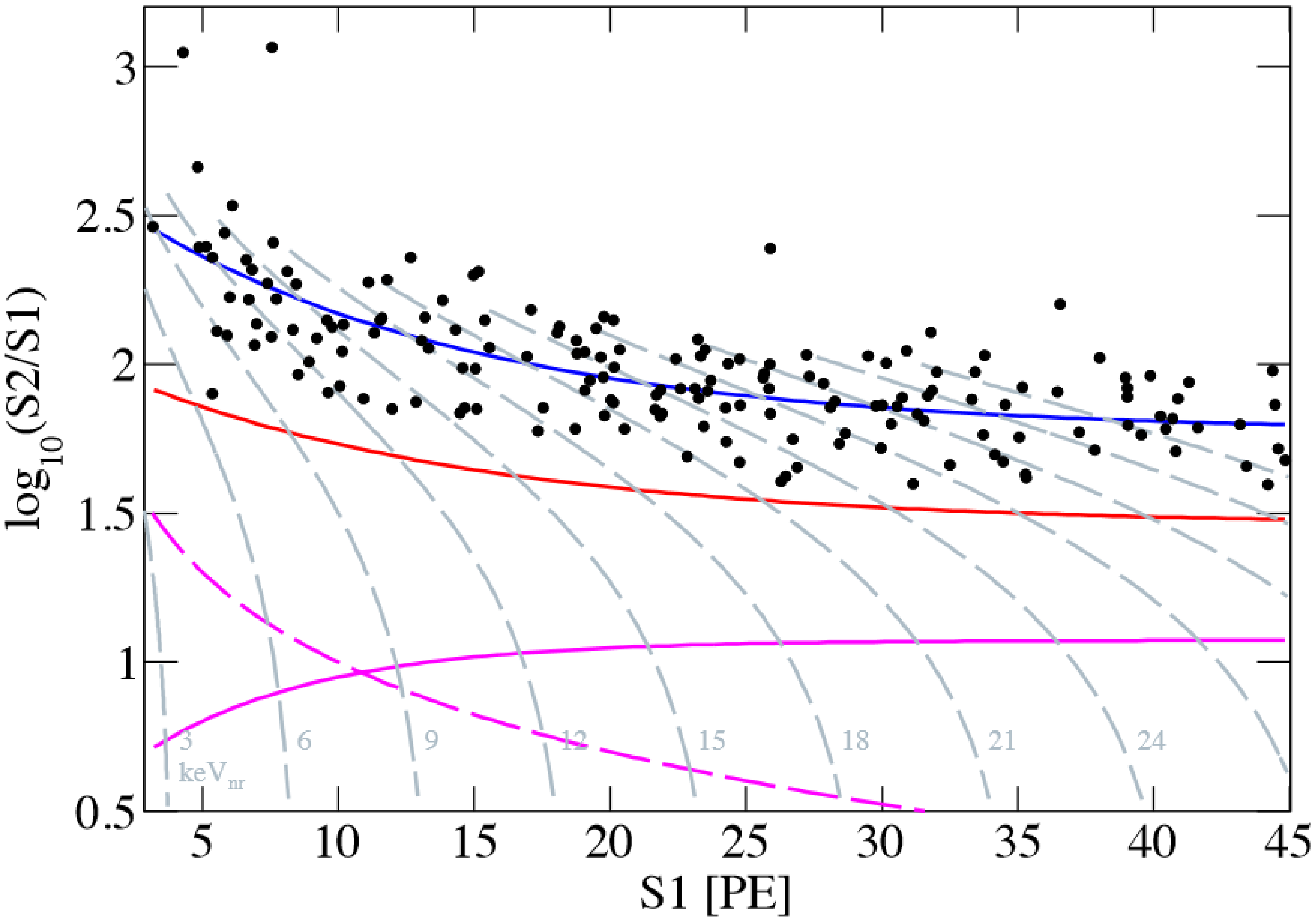


All high level cuts remained identical in Run9 and Run10 except the vertical drift time cut (different drift field)

FV = 361.5 kg of LXe

- Events @ large radius with suppressed S2: electron loss on the wall due to field irregularity
- The noisy outer PMT caused biased reconstructed position, particularly for suppressed S2 (deeper in the TPC)
- Residual events are uniformly distributed in the detector

Distribution of events (run10)

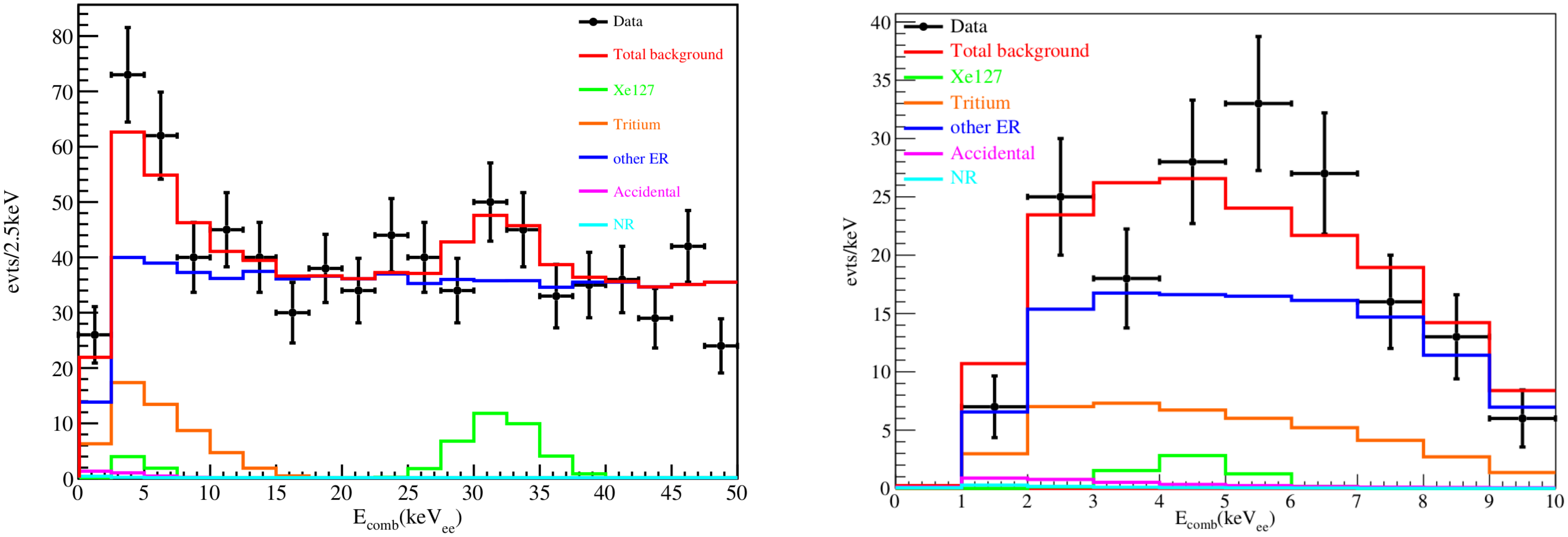


Total events: 177

- Expected background below NR median: 2.05 evts with ~20% uncertainty
- Observed: 0

Appears to have a downward fluctuation of background!

Energy spectrum



- MC: best fit background (fixed shapes). All components agree with expectation with in uncertainties
- Data and expected background in good agreement

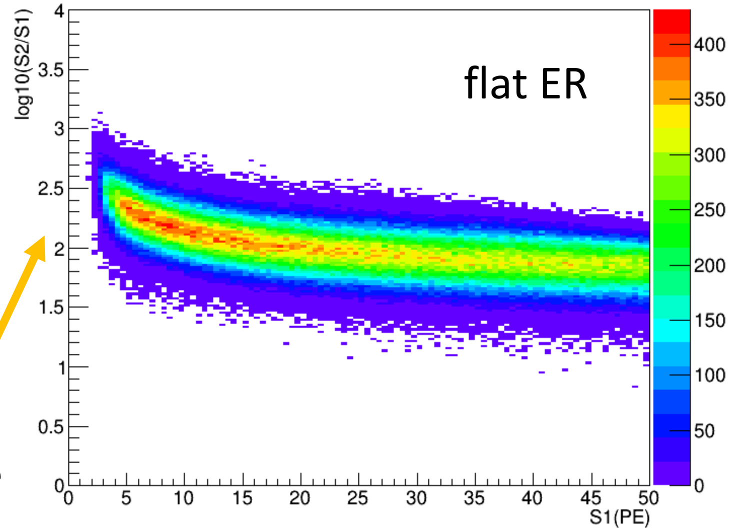
Combined analysis with Run9

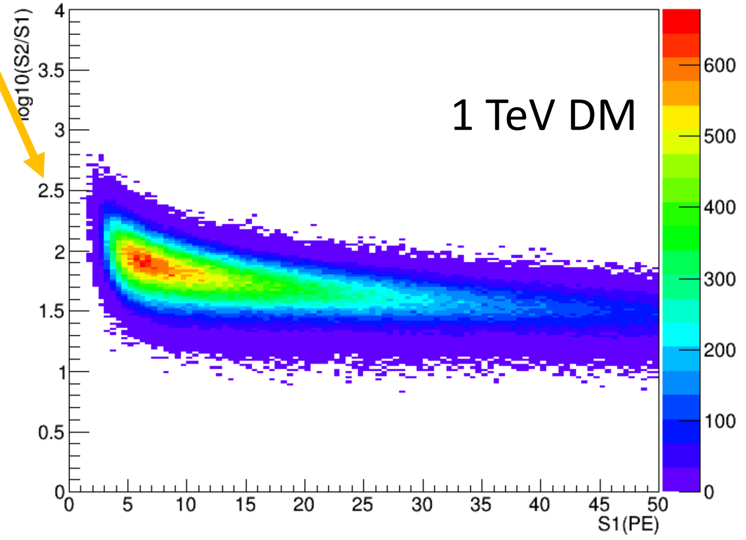
- Total exposure = 54 ton-day (world largest set)
- Background separatedly estimated in two runs but with common systematics
- Combined likelihood function with background: flat ER (^{85}Kr, Rn and others), ^{127}Xe, tritium, accidental, neutron)
- PDFs produced by MC with tuned ER/NR and detector models

$$\mathcal{L}_{\text{pandax}} = \left[\prod_{n=1}^{\text{nset}} \mathcal{L}_n\right] \times \left[G(\delta_{\text{DM}}, \sigma_{\text{DM}}) \prod_b G(\delta_b, \sigma_b)\right],$$

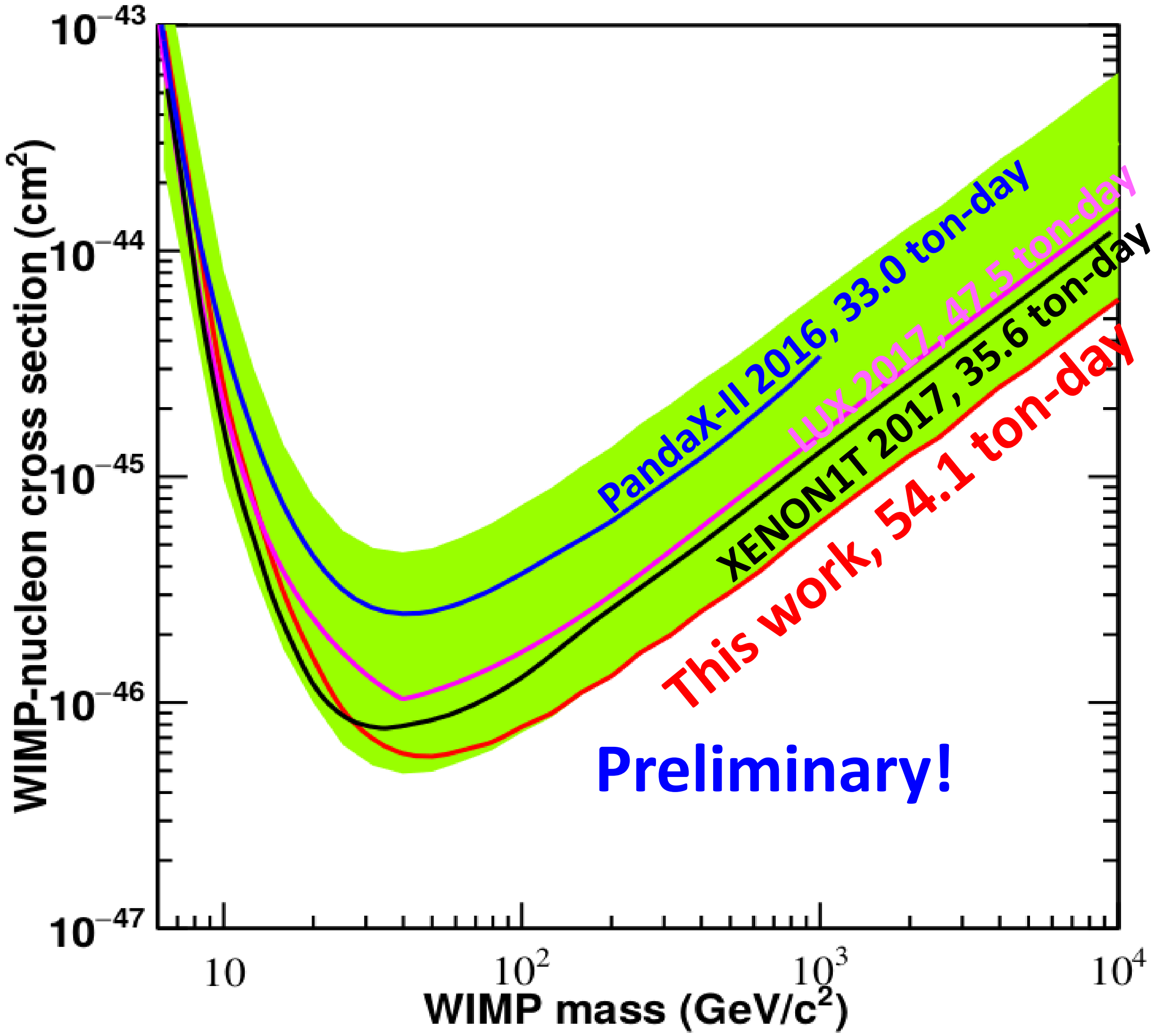
$$\mathcal{L}_n = \text{Poiss}(N^n_{\text{meas}}|N^n_{\text{exp}}) \times \left[\prod_{i=1}^{N^n_{\text{meas}}} \left(\frac{N^n_{\text{DM}}(1+\delta_{\text{DM}})P^n_{\text{DM}}(S^i_1, S^i_2)}{N^n_{\text{exp}}} + \sum_b \frac{N^n_b(1+\delta_b)P^n_b(S^i_1, S^i_2)}{N^n_{\text{exp}}}\right)\right]$$

Example PDFs





Preliminary Results on elastic SI DM-nucleon scattering

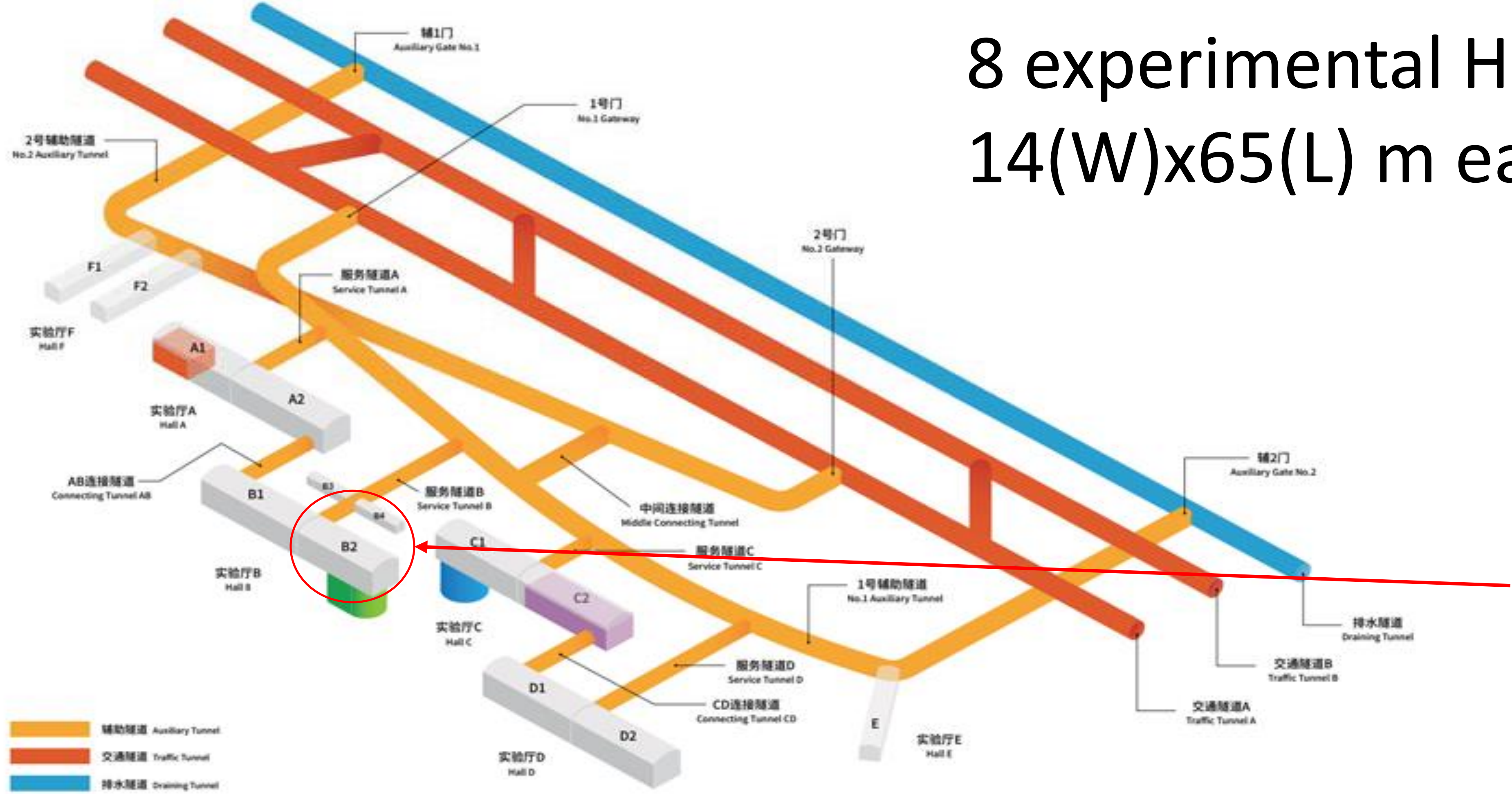


- Profile likelihood fits made to the data in grids of (m_χ, σ_χ).
- 90% upper limits produced comparison of test statistic to toy MC, and power-constrained to -1σ
- Improved from PandaX-II 2016 limit ~4 times for mass>30 GeV.
- More constraining than LUX and XENON1T 2017
- Best limit, is 6×10^{-47} cm^2 at m_χ~45GeV.
- talk by Y. Yang, tomorrow afternoon

PandaX Future

PandaX new home: CJPL-II

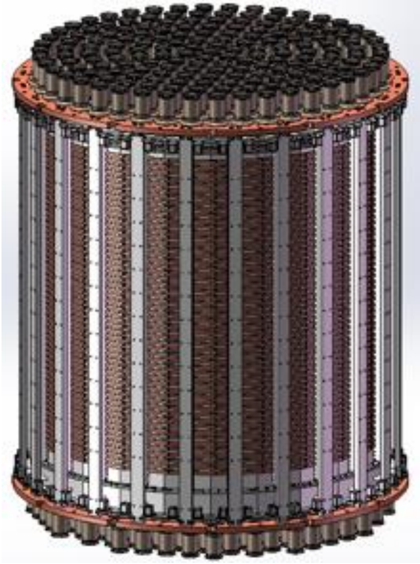
8 experimental Halls, 14(H)x 14(W)x65(L) m each.

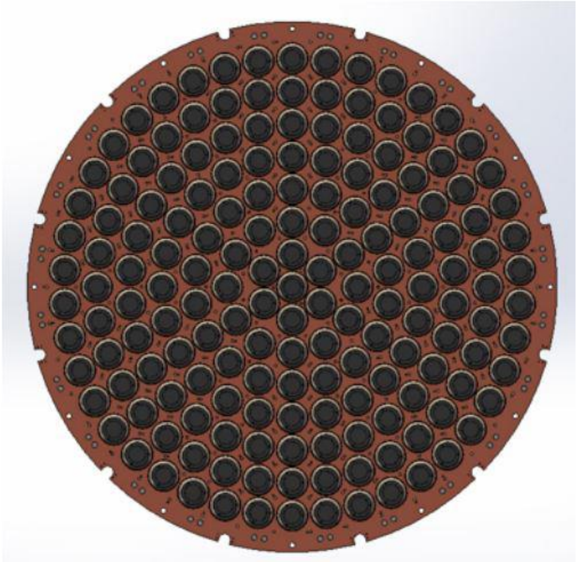


B2, PandaX site!

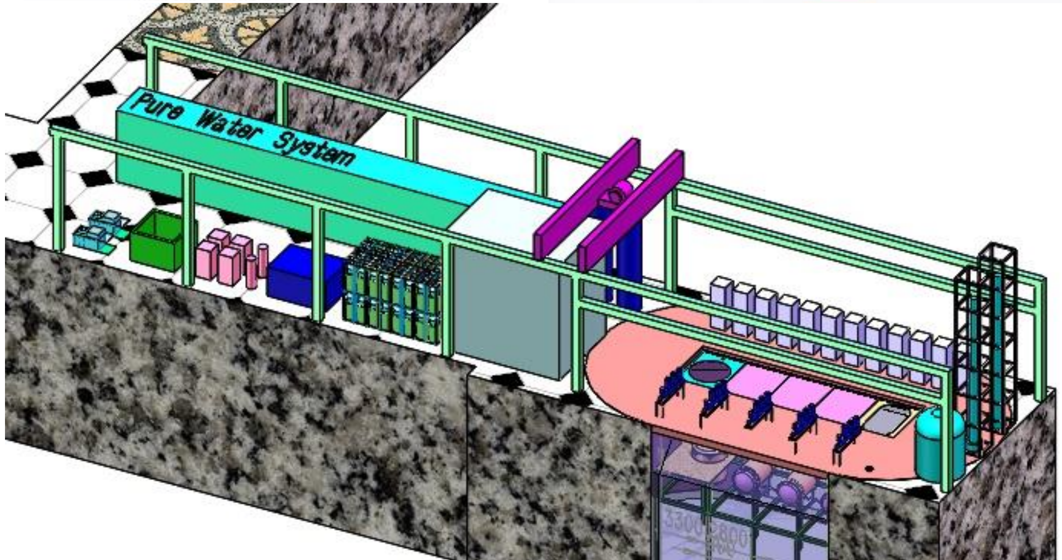
Experimental hall

PandaX-xT Experiment



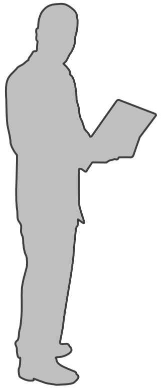


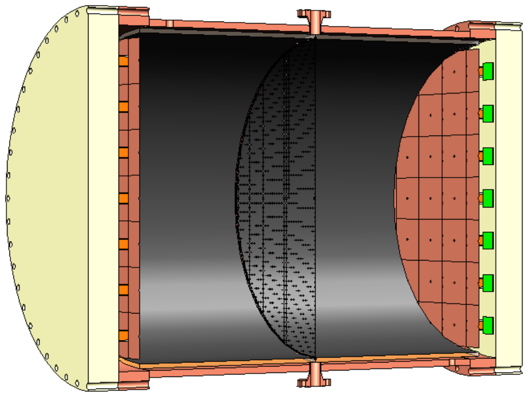
- Preparing new experiments in CJPL-II, hall #B2
- Intermediate stage:
  - ➢PandaX-4T (4-ton target) with SI sensitivity ~10^{-48} cm^2
  - ➢On-site assembly and commissioning: 2019-2020
- Eventual goal: G3 xenon dark matter detector (~30T) in CJPL to “neutrino floor” sensitivity

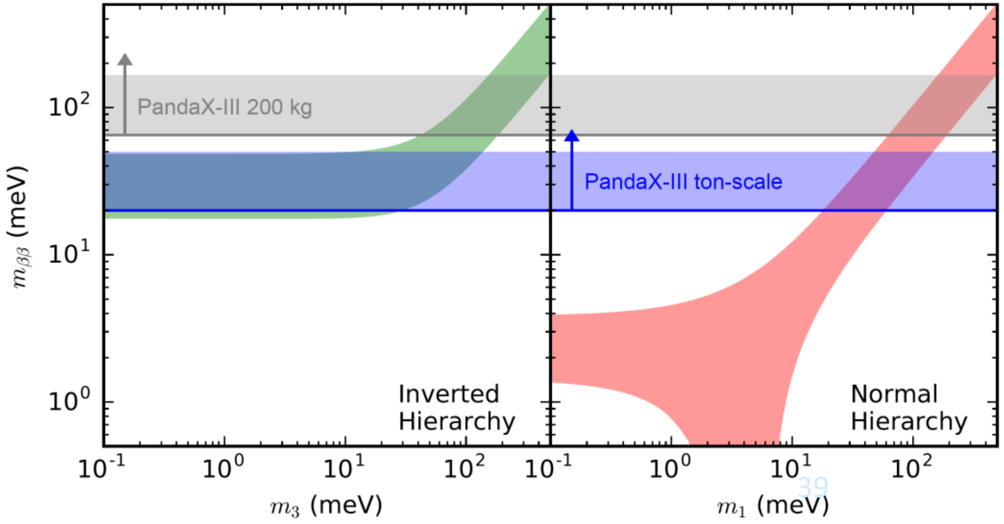


PandaX-III: High pressure ^{136}Xe TPC

- 0νDBD signal: two electrons emitting from the same vertex with a summed energy at the Q value (tracking essential)
- TPC: 200 kg, 10 atm, symmetric, double-ended charge readout plane with micromegas module with cathode in the middle
- Four more upgraded modules for a ton scale experiment
- Published CDR recently: ArXiv:1610.08883







Conclusion

- Searching for WIMPs is far from over.
- PandaX experiment since 2012 has gone through two generations of detectors, improving detection sensitivity by almost three orders of magnitude.
- The most recent result has the world-largest exposure (54 ton-day), setting a currently leading WIMP detection sensitivity, particularly at TeV scale. (The best limit is 6×10^{-47} cm^2 at m_{χ}~45GeV).
- PandaX will continue to develop larger scale detectors.