# WIMP search using the full PandaX-II exposure

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# PandaX-II Experiment for Dark Matter Search

Dark Matter & PandaX-II











## Dark Matter (DM)

#### **Galactic rotation curve**



#### **Bullet Cluster**



 Dark matter really exists in the Universe.

#### **Cosmic Microwave Background**



Ordinary matter

accounts for 5%, dark matter makes up 27%.

#### **Dark Matter Candidates**



- Weakly Interacting Massive Particle (WIMP)
- mass ~ 100 GeV, "WIMP miracle"
- WIMP is one of the most promising dark matter candidates!

# **Detection of WIMPs**

- collider search
- direct detection
- indirect detection



direct





## **PandaX Experiment**









PandaX-I	PandaX-II	PandaX-4T	PandaX-III
120kg LXe	580 kg LXe	4 ton LXe	200kg-1T gas
DM	DM	DM	Xe-136
2009-2014	2015-2019	ongoing	0ν2β
		00	future

#### PandaX-II Detector and Dual-Phase TPC



#### PandaX-II Data Sets

- 2019.06 "End-of-Run" completed
- Total exposure: 131.7 ton-day
  - Run 9: 79.6 days
  - Run 10: 77.1 days
  - Run 11, span 1: 96.4 days
  - Run 11, span 2: 147.9 days
- Refined algorithms
  - Position reconstruction
  - Detector response model
  - Improved background evaluation



## **New Position Reconstruction**

- Trained with evenly distributed <sup>83m</sup>Kr calibration events
- Turn off 7 malfunctioned PMTs
  - 5 top and 2 bottom
- Data-driven position reconstruction: photon acceptance function
  - Analytically parameterized PAF (old)
  - Simulation-based PAF: optical simulation of the detector (new)





#### **New Response Model**

- Calibration data
  - ER events: tritium and <sup>220</sup>Rn
  - NR events: AmBe
- NEST 2.0 based response model
  - · with data quality cut efficiency



ER Run 9 ER Run 10/11 NR Run 9 NR Run 10/11



# **Background Sources**

Source	Evaluation		
material ER	from MC simulation, benchmarked by high energy spec		
<sup>127</sup> Xe	35.5 day lifetime, decay away in Run 11		
<sup>3</sup> Н	Introduced after Run 9, fitted from data		
<sup>222</sup> Rn	Depletion effect from measurement		
<sup>85</sup> Kr	Not a constant due to air leakage in Run 11		
neutrons	Data-driven estimation		
surface events	Data-driven extrapolation		
accidental events	vents Newly trained BDT discriminator		

# <sup>222</sup>Rn Background

- Major ER contribution from <sup>214</sup>Pb
  - Charged Rn progenies attracted to the cathode with negative HV
  - Less contribution in fiducial volume: "depletion effect"
- New method to evaluate ER event rate from <sup>214</sup>Pb
  - The depletion ratio measured from <sup>222</sup>Rn calibration (end-of-run)
  - Interpolation from <sup>218</sup>Po and <sup>214</sup>Bi
- PandaX-II  $^{214}$ Pb level: 10µBq/kg



Activity [Bq]

## Surface background

- Surface events
  - Mostly ER events from Rn plate-out
  - Losing S2 on the surface, shifting below ER region
- Data-driven extrapolation from outside FV region

#### JINST 14 (10): C10039, 2019



3.5

2.5

0.5

20

40

**ER** region

NR region

**Surface events** 

80

100

60

log<sub>10</sub>(S2/S1)

#### **Neutron Background**

- New evaluation based on high energy gammas (HEGs)
  - Neutron events associated with HEGs (neutron capture, nuclear de-exciation)
  - Scale factor (neutron events / HEGs) from MC simulation with HEGs included
  - Tested in AmBe calibration data



SCIENCE CHINA Physics, Mechanics & Astronomy (2019)

• PandaX-II full exposure: 3.0±1.5 events in WIMP signal region

### **Background Budget for Low Energy Events**

• Compared with Run 10, more background contributions in Run 11

Item		Run 9	Run 10	Run 11, span 1	Run 11, span 2	
	$^{85}$ Kr	$1.19\pm0.2$	$0.18\pm0.05$	$0.20\pm0.06$	$0.40\pm0.07$	
Flat ER	$^{222}$ Rn	$0.19\pm0.10$	$0.17\pm0.02$	$0.19\pm0.02$	$0.19\pm0.02$	
Components	$^{220}$ Rn	$0.01\pm0.01$	$0.01\pm0.01$	$0.01\pm0.01$	$0.01\pm0.01$	
(mDRU)	ER (material)	$0.20\pm0.10$	$0.20\pm0.10$	$0.20\pm0.10$	$0.20\pm0.10$	
	Solar $\nu$	0.01	0.01	0.01	0.01	
	$^{136}\mathrm{Xe}$	0.0022	0.0022	0.0022	0.0022	
Total flat ER (mDRU)		$1.61\pm0.24$	$0.57\pm0.11$	$0.73\pm0.08$	$1.03\pm0.08$	
127Xe (mDRU)		$0.14\pm0.03$	$0.0069 \pm 0.0017$ < 0.0001			
<sup>3</sup> H (mDRU)		0	0.17			
Neutron (mDRU)		$0.0022 \pm 0.0011$				
Accidental (event/day)		$0.014\pm0.004$				
Surface (event/day)		$0.041\pm0.008$		$0.063 \pm 0.0013$		

# **Unblinding Data and Results of the WIMP Search**

- WIMP
  - NRs, separated from the ER band
- Searching window
  - S1 [3, 45] PE
  - Fiducial volume 329 kg
- Blind analysis for Run 11
- Total 1220 events, 38 below\_ NR median
  - Consistent with background expectation (best fit with)

dR/dE example with different WIMP masses,  $\sigma = 1 \times 10^{-31} cm^2$ 



	ER	Accidental	Neutron	Surface	Total fitted	Total observed
Run 9	381.1	2.20	0.77	2.13	$387 \pm 23$	384
below NR median	2.7	0.46	0.37	2.12	$5.6\pm0.5$	4
Run 10	141.7	1.08	0.48	2.66	$145.9 \pm 16$	143
below NR median	1.7	0.24	0.22	2.65	$4.8\pm0.6$	0
Run 11, span 1	216.5	1.04	0.60	6.24	$224 \pm 22$	224
below NR median	4.2	0.32	0.32	6.22	$11.1 \pm 1.1$	13
Run 11, span 2	448.2	1.60	0.92	9.58	$460 \pm 35$	469
below NR median	8.26	0.50	0.50	9.54	$18.8 \pm 1.7$	21
Total	1187.9	5.9	2.77	20.6	$1217 \pm 60$	1220
below NR median	16.8	1.52	1.42	20.5	$40.3 \pm 3.1$	38

#### The best fitting of a 400 GeV WIMP

#### **Event Distributions**

- Distribution of events with high WIMP hypothesis likelihood (400 GeV)
  - 3 events in Run 9 and 7 events in Run 11





 Best-fit for m<sub>χ</sub>=400 GeV 5.7 WIMP events -> σ<sub>χn</sub> =4.4x10<sup>-46</sup> cm<sup>2</sup>
Test with a background-only scenario, p-value of 0.17 -> 0.96σ

## **Constraints on WIMP Model**

- Spin-independent Interaction
- Exclusion limits on SI
  - for 30 GeV, 2.2x10<sup>-46</sup> cm<sup>2</sup>, 1.7 WIMPs
  - for 40 GeV, 2.5x10<sup>-46</sup> cm<sup>2</sup>, 11.6 WIMPs
  - for 400 GeV, 1.6x10<sup>-45</sup> cm<sup>2</sup>, 18.4 WIMPs
- 54 ton-day exposure data generated a best exclusion curve for DM detection in 2017;
- The no-downward fluctuation of DM candidates leads to the worse limit in final analysis.



# **Summary of PandaX-II Experiment**

 We established a data model for the analysis of PandaX-II which yields a good performance.

• PandaX reached to the forefront of DM search in recent years!

 No WIMP candidate was observed in the published data of PandaX-II.

More DM candidates are being searched with PandaX-II now!