Deep Underground Xenon Observatory in China: the PandaX Experiment

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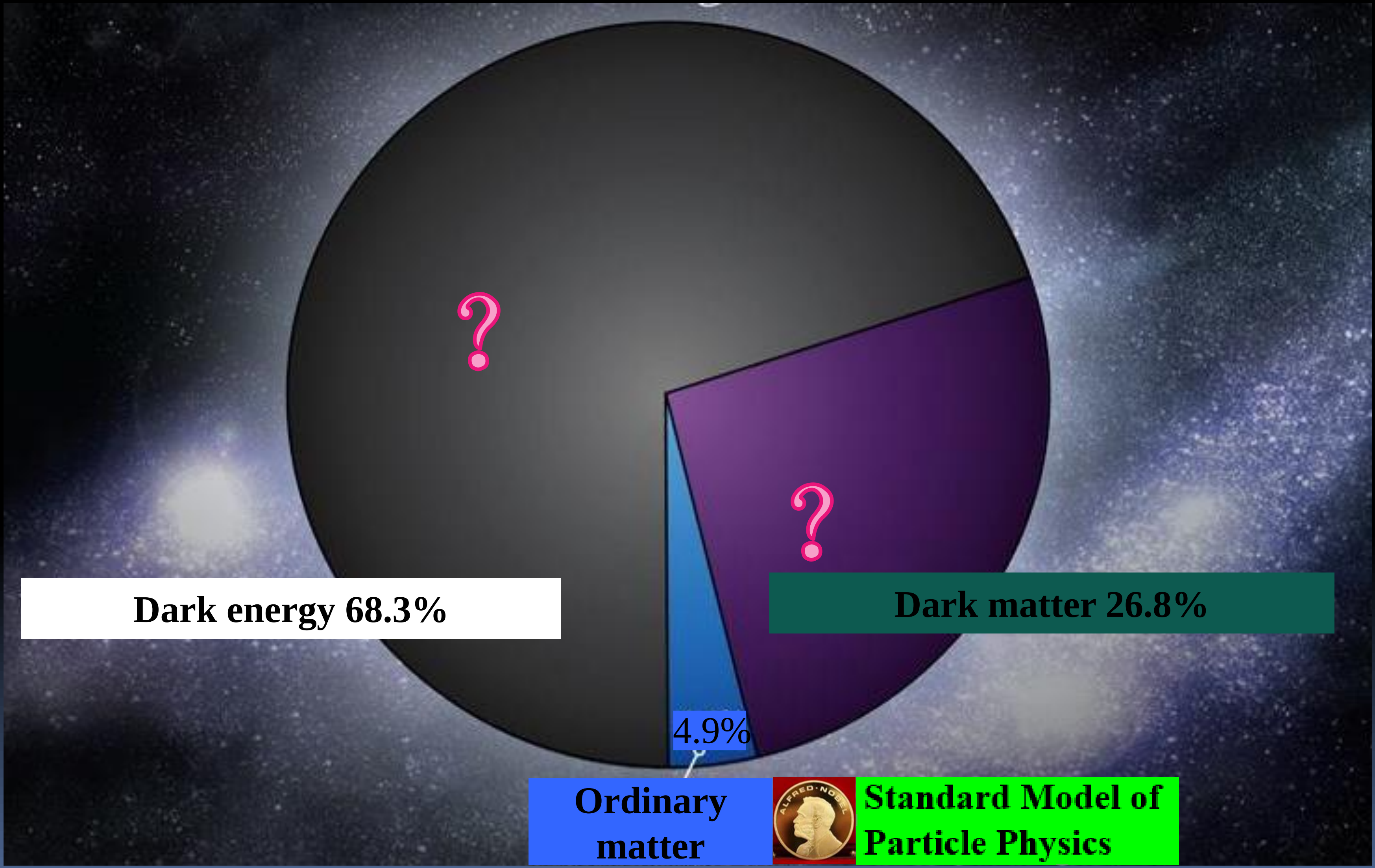
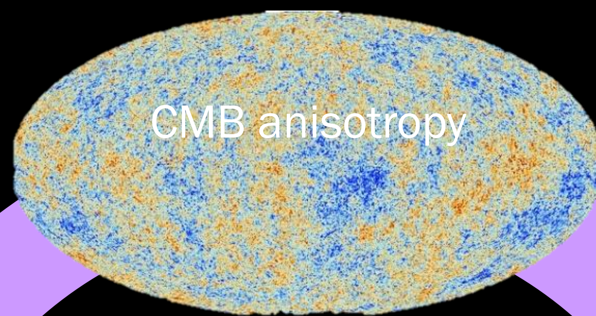
Composition of the universe

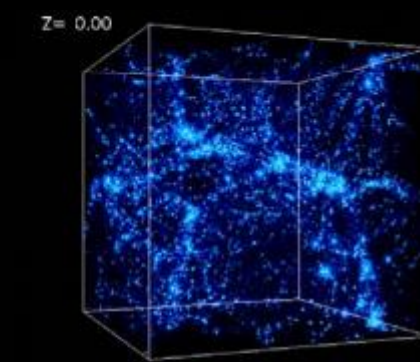


Evidence of dark matter



Galaxy rotational curve

Large structure formation



Gravitational lensing

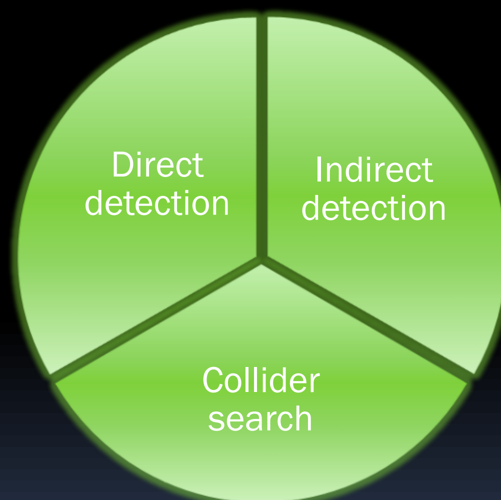
Bullet cluster

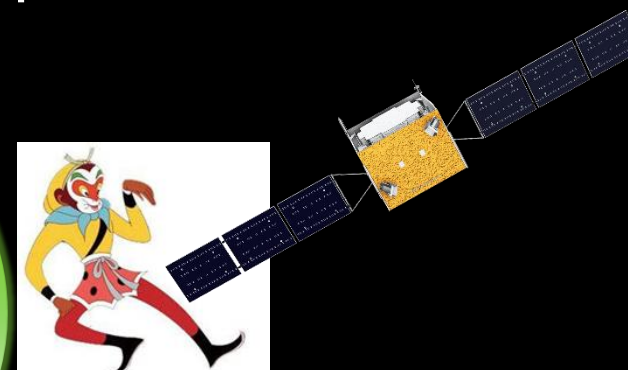
Galactic halo

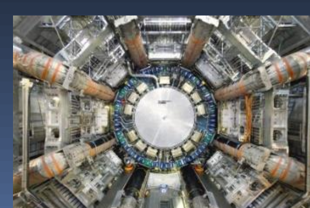
Local density around us: 0.3(0.1) GeV/cm^3

Elementary particles?

- Most "popular": weakly-interacting massive particle = WIMP
- Detectable in laboratory experiment!

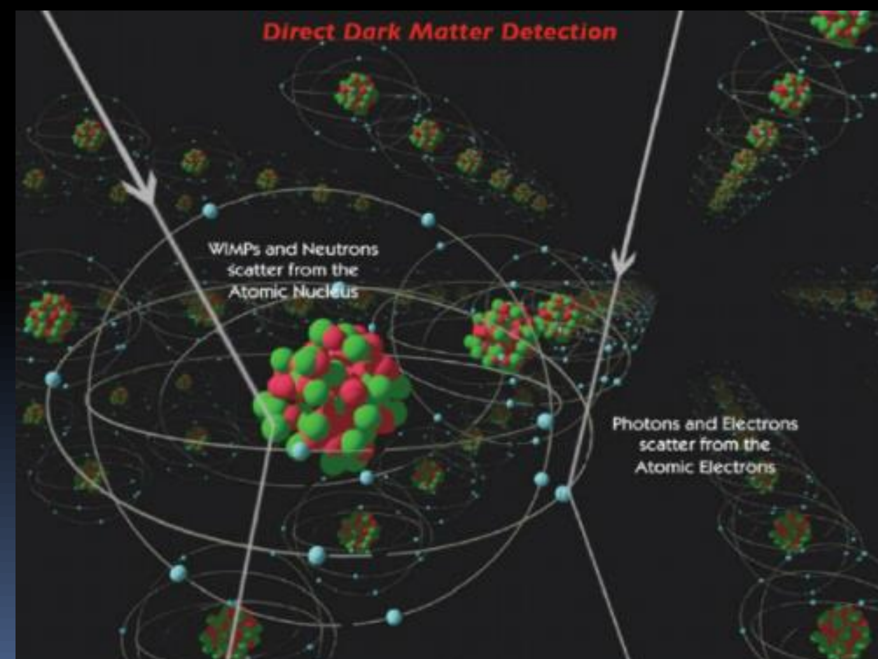




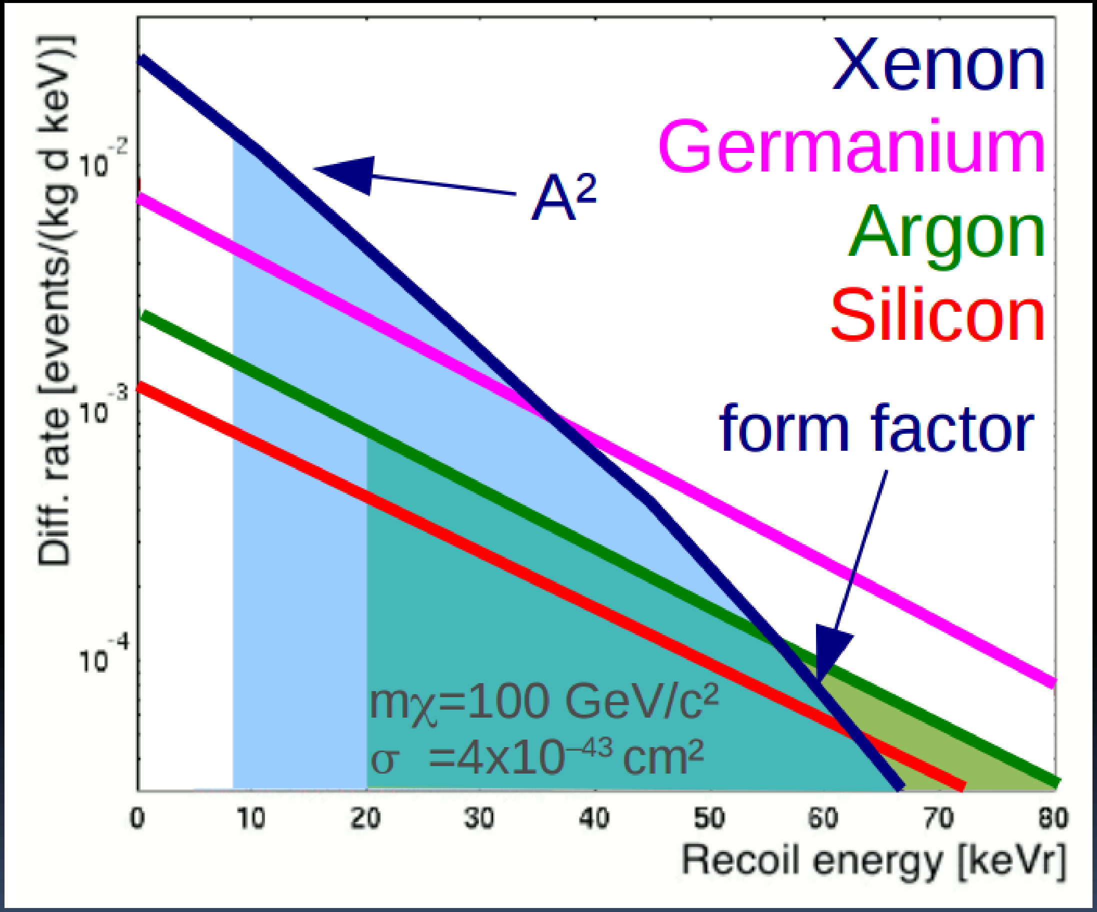


WIMP direct detection

- The solar system is cycling the center of galaxy with 220 km/s speed
- DM direct detection: wait for DM interacting atomic nucleus in the detector, and detect its recoil (Goodman & Witten, 1985)

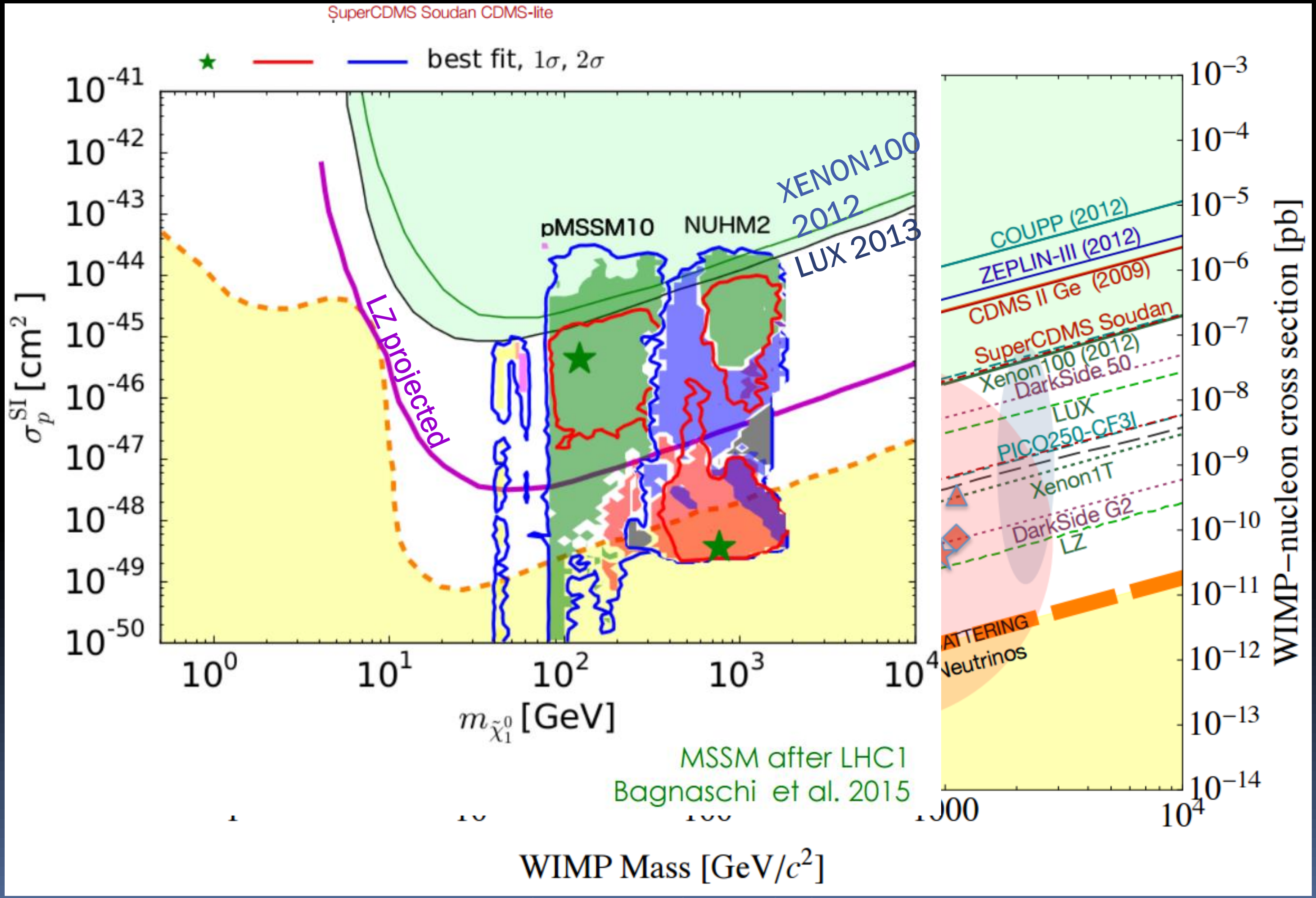


Detection signal

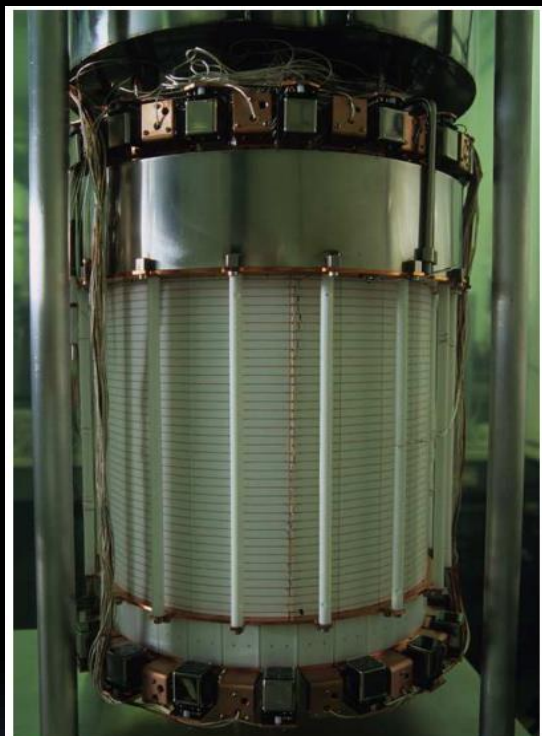


- Up-to 10s of keV of nuclear recoil energy
- Almost exponential spectrum (low threshold ~keV important)
- Most sensitive experiment is approaching 1 evt/100kg/year

Where we are?


SuperCDMS Soudan CDMS-lite
best fit, 1σ, 2σ
pMSSM10
NUHM2
XENON100 2012
LUX 2013
LZ projected
COUPP (2012)
ZEPLIN-III (2012)
CDMS II Ge (2009)
SuperCDMS Soudan
Xenon100 (2012)
DarkSide 50
LUX
PICO250-CF3I
Xenon1T
DarkSide G2
LZ
Neutrinos
MSSM after LHC1
Bagnaschi et al. 2015
WIMP Mass [GeV/c²]
WIMP–nucleon cross section [pb]

Dual phase xenon experiments



XENON100, 60 kg, completed 2012, Gran Sasso
XENON1T commissioning

LUX, 250 kg, running, Sanford Lab
LZ(multi-ton) in preparation

Dual phase xenon detector is

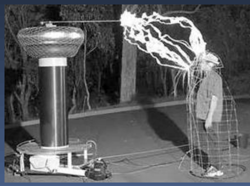
Large target

Low energy calorimeter

3D camera

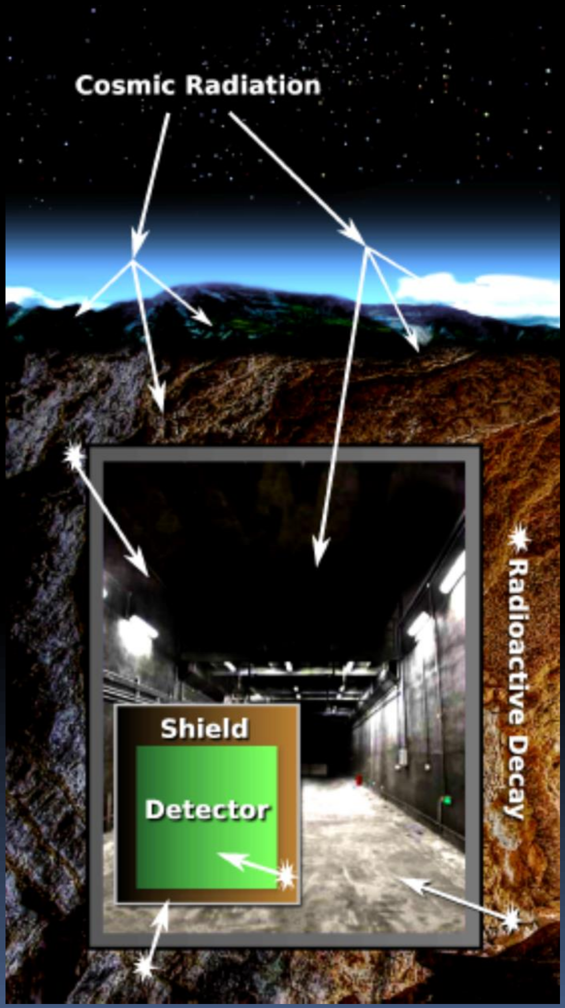
Signal/bkg discriminator

Self-shielding body



Underground experiments

- Every second there are 10^8 dark matter passing through us
- Our body has 10^{29} atoms
- Less <1 nucleus is hit per year!
- But our body is hit 10^8/day by environmental background radiation!
- Hide detector in deep underground lab, and put massive shield



China Jinping Underground Lab

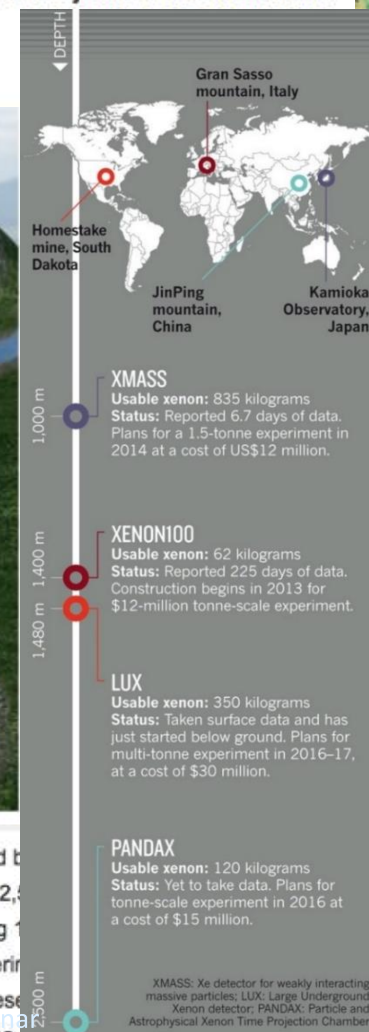
nature International weekly journal of science

Dark-matter hunt gets deep

China launches world's deepest particle-physics experiment — but it joins a crowded field.

Eugenie Samuel Reich

20 February 2013 | Corrected: 21 February 2013

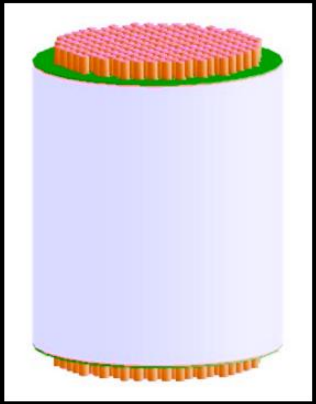


Ongoing experiments in Italy, the United States and Japan are now being joined b
PandaX (see 'Dark and deep'). Installed in the deepest laboratory in the world, 2,
mountain of JinPing in Sichuan province, PandaX will this year begin monitoring
hopes to scale the tank up to 1 tonne by 2016, which would mean that the experi
than any other dark-matter search. "We want to demonstrate that world-class rese
China," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University in China

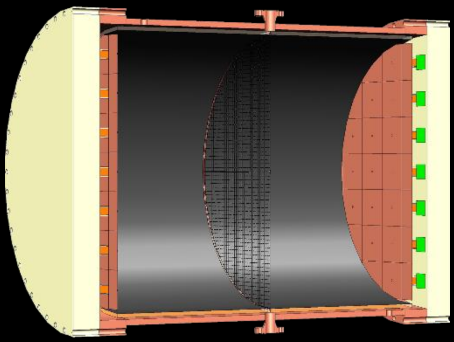
PandaX Experiments

PandaX-I: 120 kg DM experiment 2009-2014

PandaX-II: 500 kg DM experiment 2014-2017



PandaX-xT: multi-ton (~4-T) DM experiment 2017- or 2018-



PandaX-III: 200 kg to 1 ton HP gas ^{136}Xe 0vDBD experiment 2016-

PANDA X = Particle and Astrophysical Xenon Experiments

PandaX collaboration

Started in 2009, ~50 people

- 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-)
- Alternative Energies & Atomic Energy Commission (2015-)
- University of Zaragoza (2015-)
- Suranaree University of Technology(2016-)

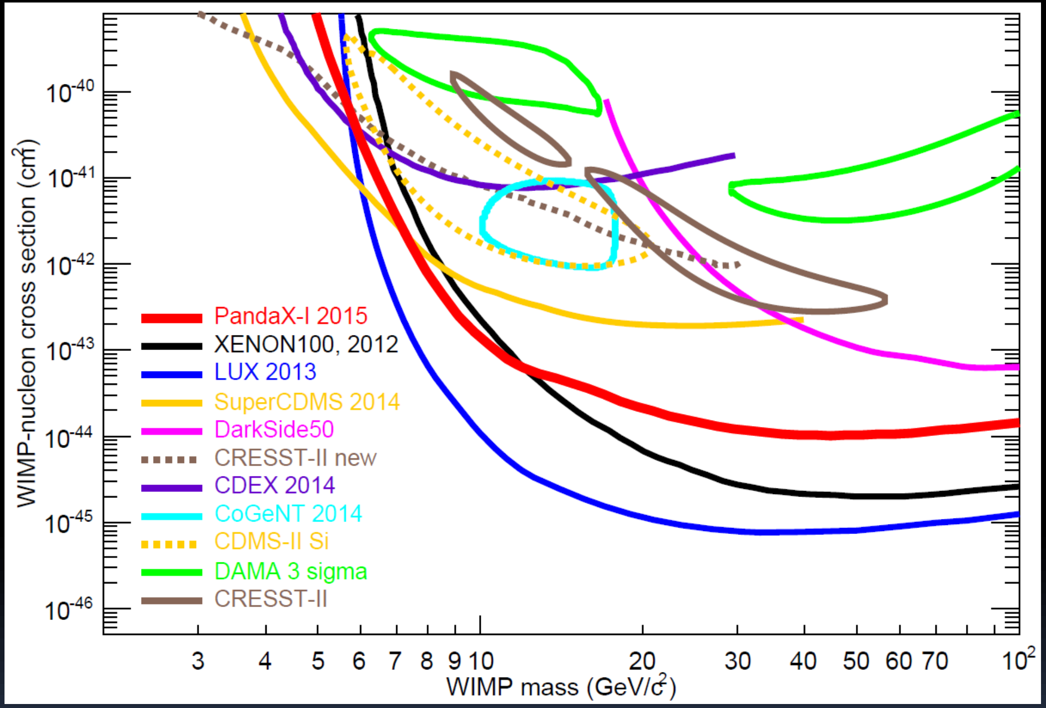
First delivery of PandaX equipment to Jinping

Aug 16, 2012

PandaX apparatus

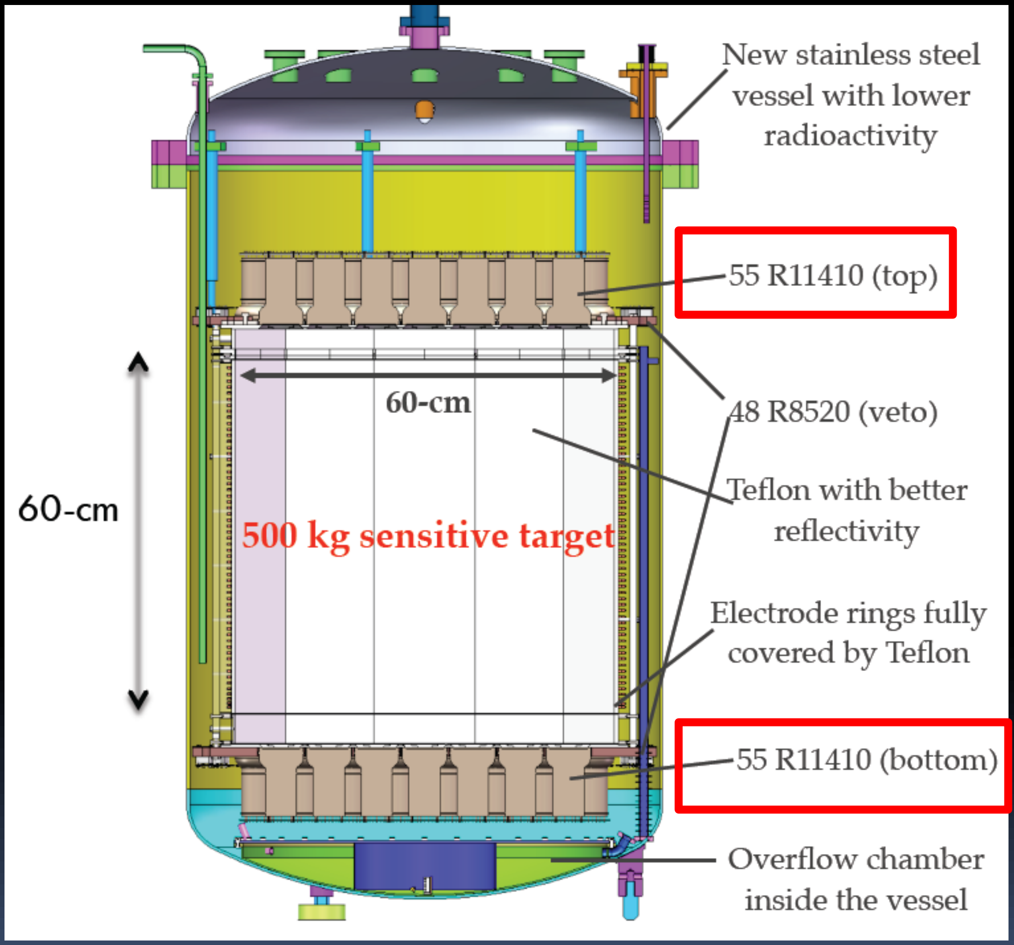
PandaX-I results

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



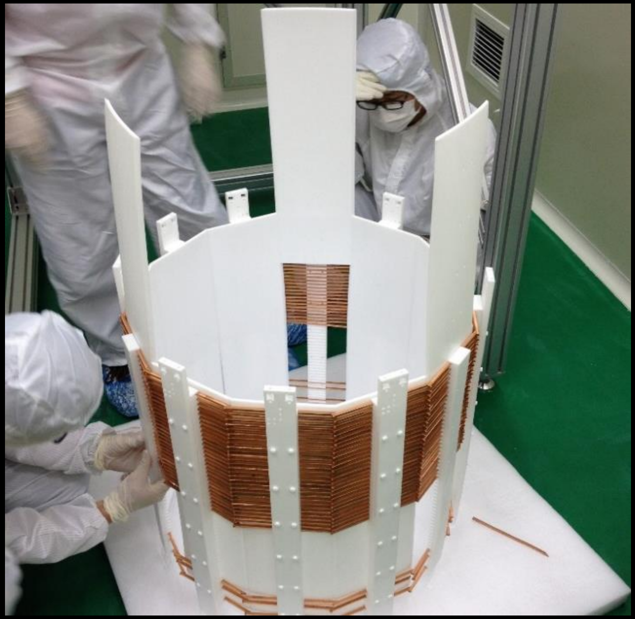
- Completed in Oct. 2014, with 54.0 x 80.1 kg-day exposure
- Data strongly disfavor all previously reported claims
- Competitive upper limit for low mass WIMP among xenon experiments

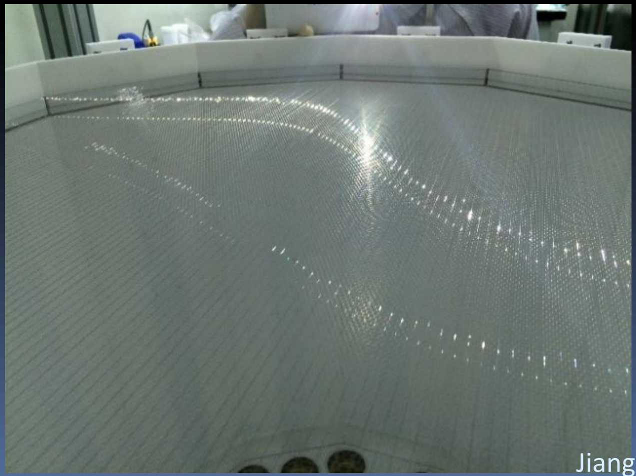
PandaX-II



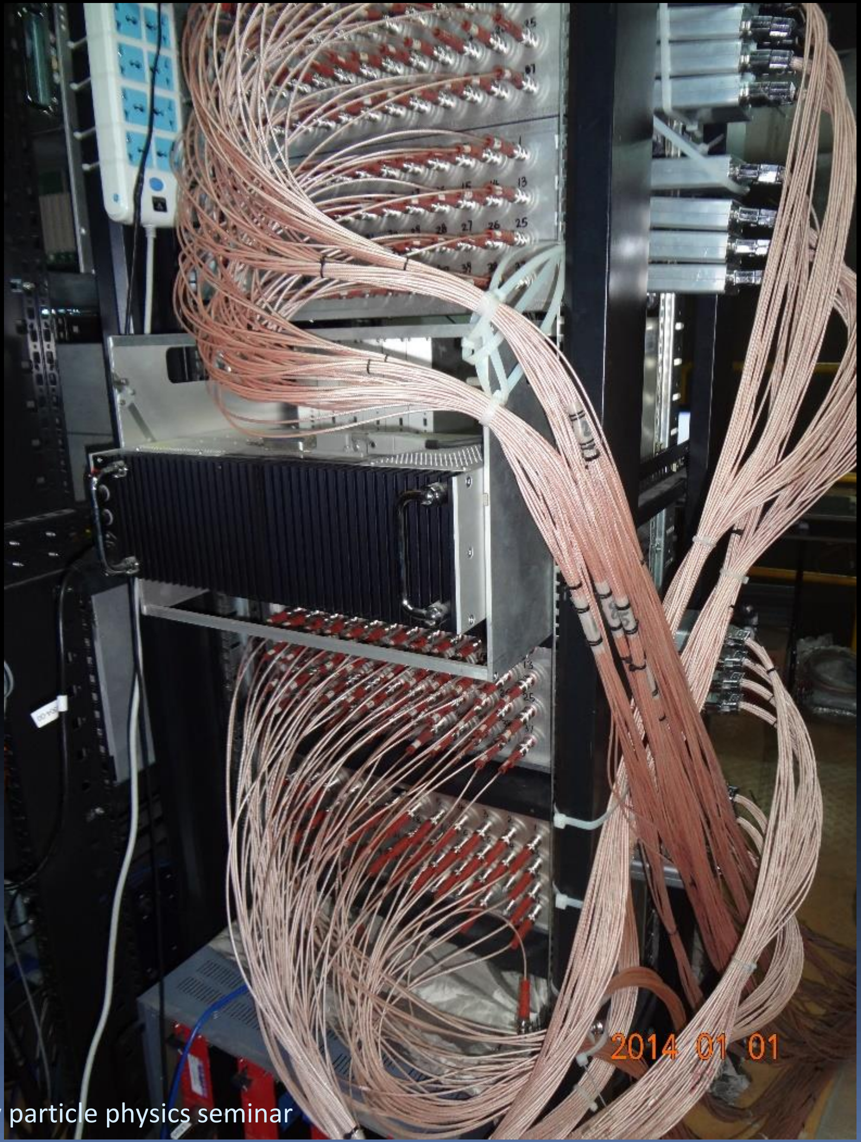
- New inner vessel with clean SS
- New and taller TPC
- More 3” PMTs and improved base design with split –ve and +ve HV
- New isolated skin veto region

Detector construction

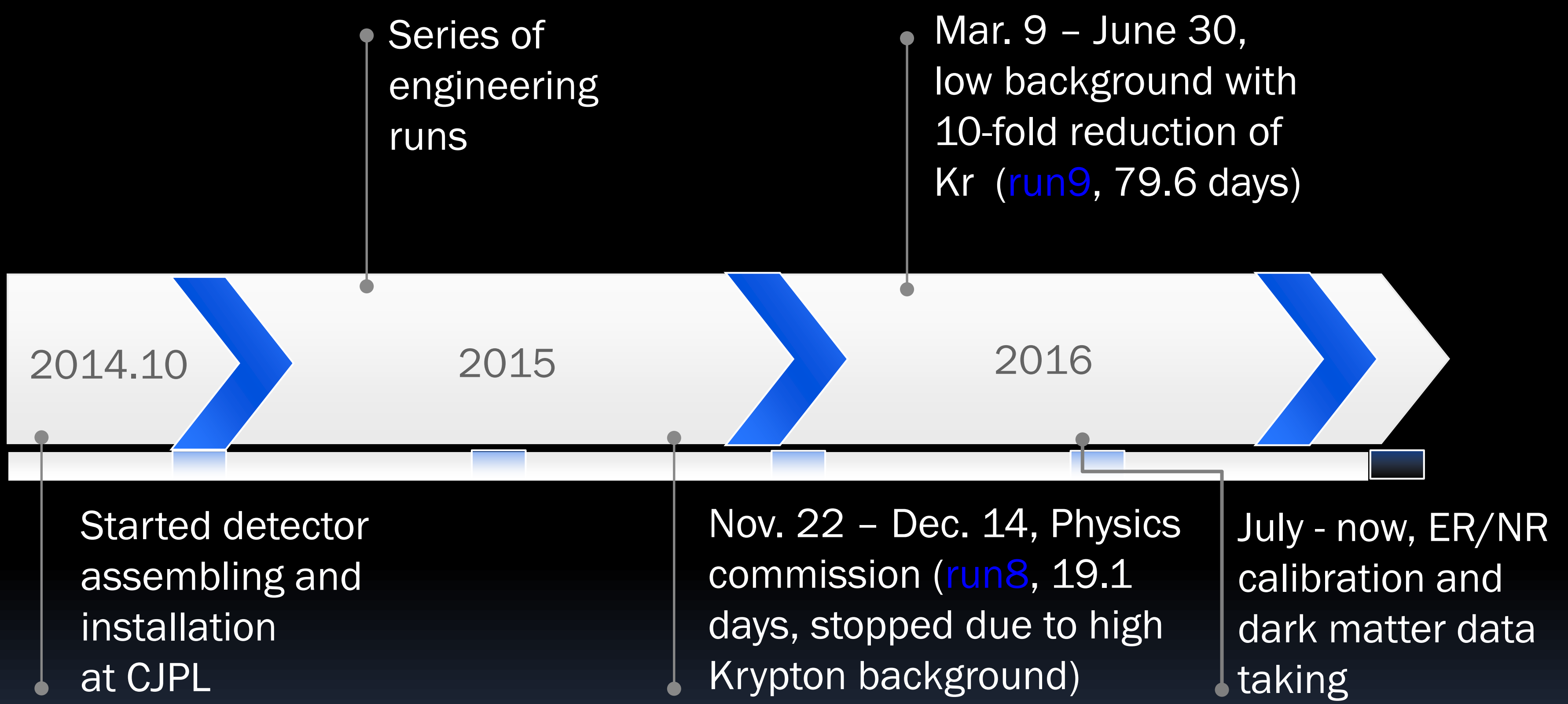




Putting all together



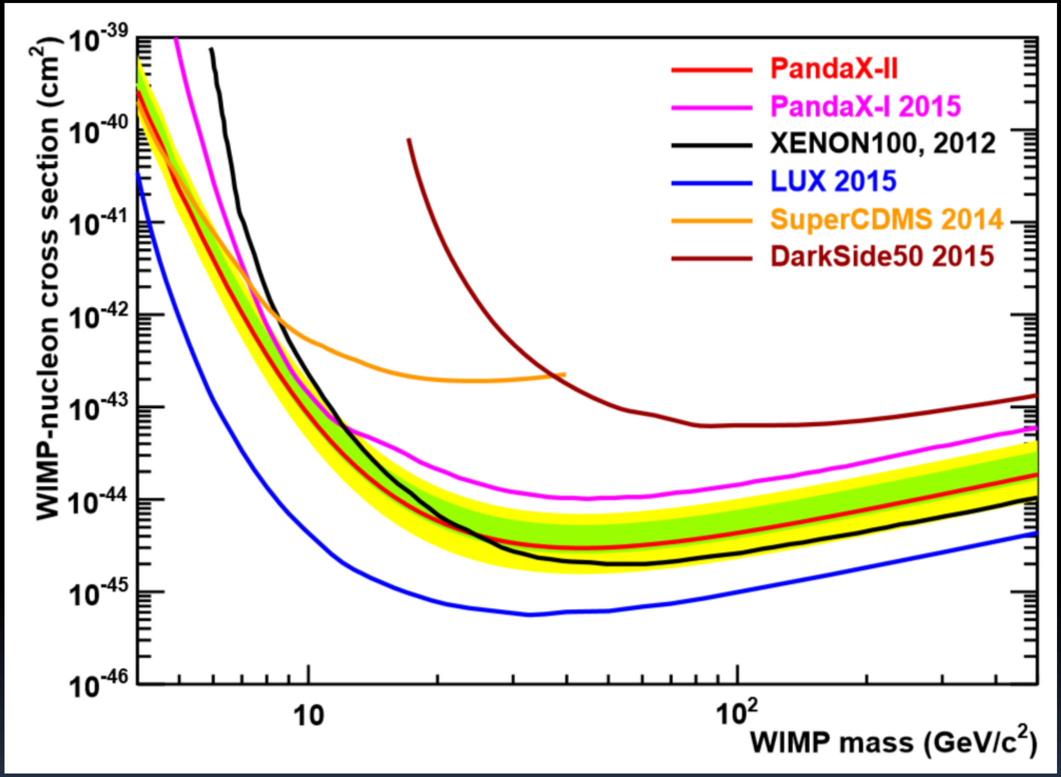
Run history



- Run8+run9=98.7 days, exposure:3.3x10^4 kg-day
- Largest dual phase xenon experiment producing science data

Results from PandaX-II run 8

Phys. Rev. D. 39, 122009 (2016)



306 x 19.1 kg-day

- Cut-and-count analysis with 2 candidates and 3.2(0.7) expected background
- Low mass region: competitive with SuperCDMS 2014
- High mass region: similar exclusion limit as XENON100 225-day

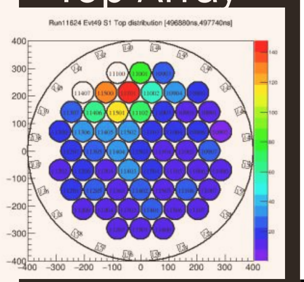
Major upgrade in run 9

Items	Status in Run 9
Krypton level	Reduced by x10
Exposure	Increased x4 (79.6 vs 19.1 day)
ER calibration	Using tritium calibration
NR calibration	Statistics x6
Analysis	Improved position reconstruction
Background	Accidental background suppressed more than x3 using BDT

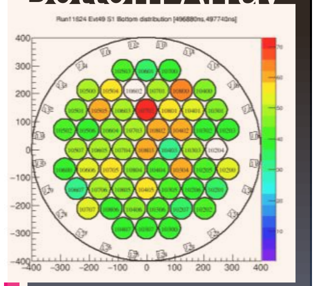
Typical single scattering event

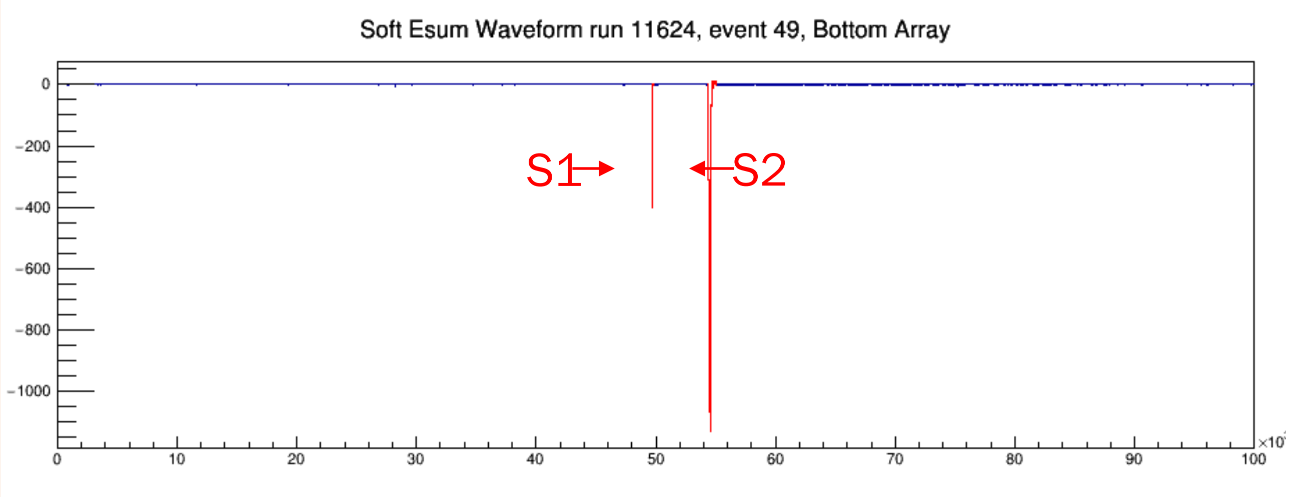
S1

Top Array

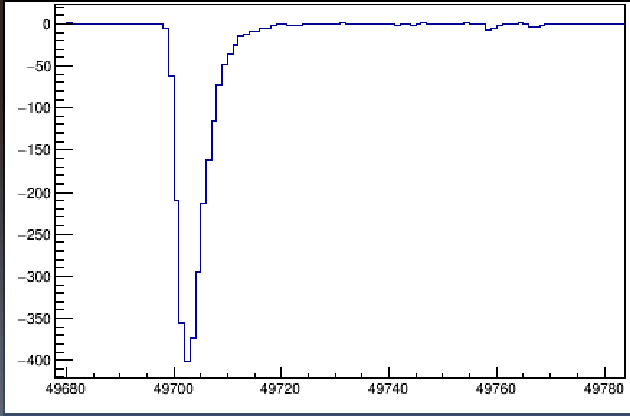


Bottom Array

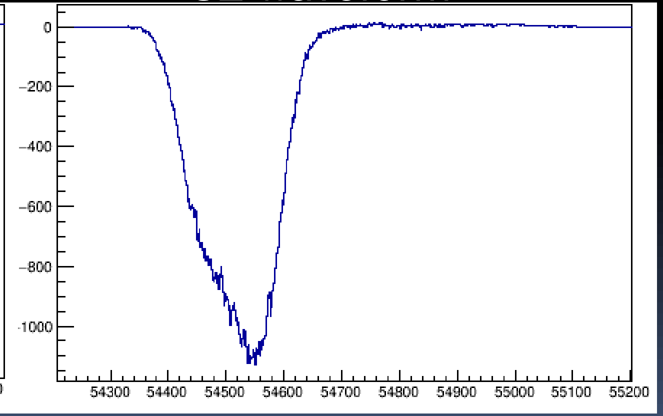




S1 waveform

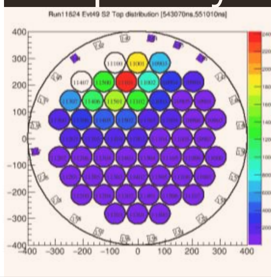


S2 waveform

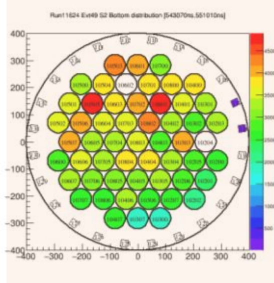


S2

Top Array

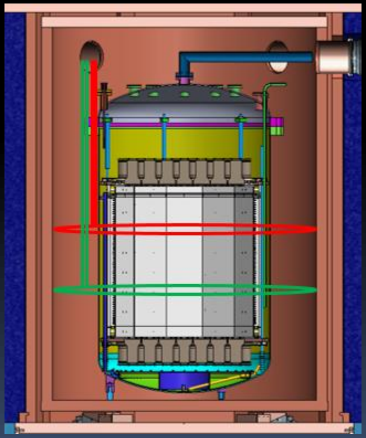


Bottom Array



Extensive calibration program

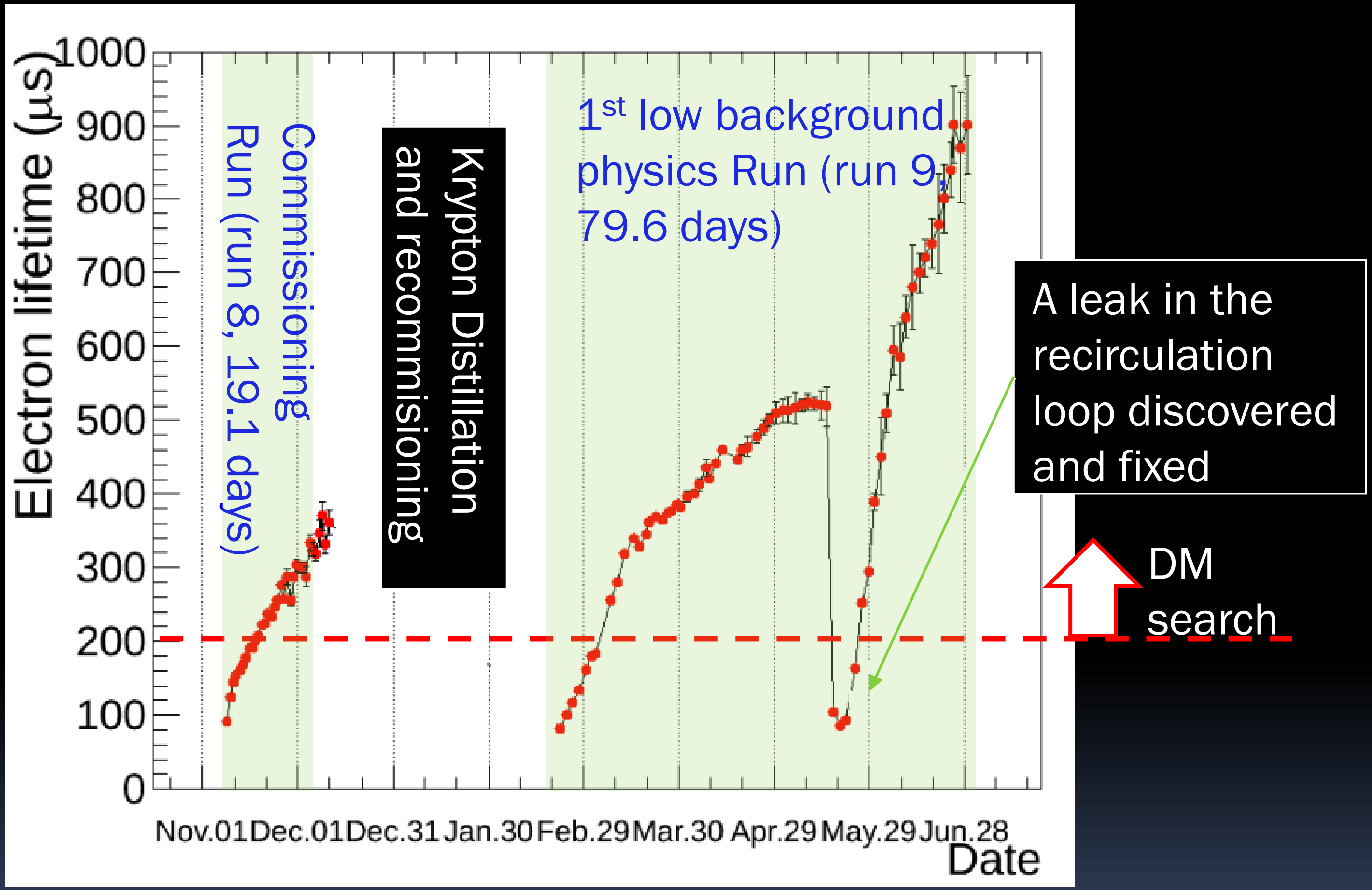
- Internal/external ER peaks:
  - Detector uniformity corrections
  - Light/charge collection parameters



- Low rate AmBe neutron source:
  $\Rightarrow$ Simulate DM NR signal

- CH_3T injection: tritium beta decays
  $\Rightarrow$ Simulate ER background

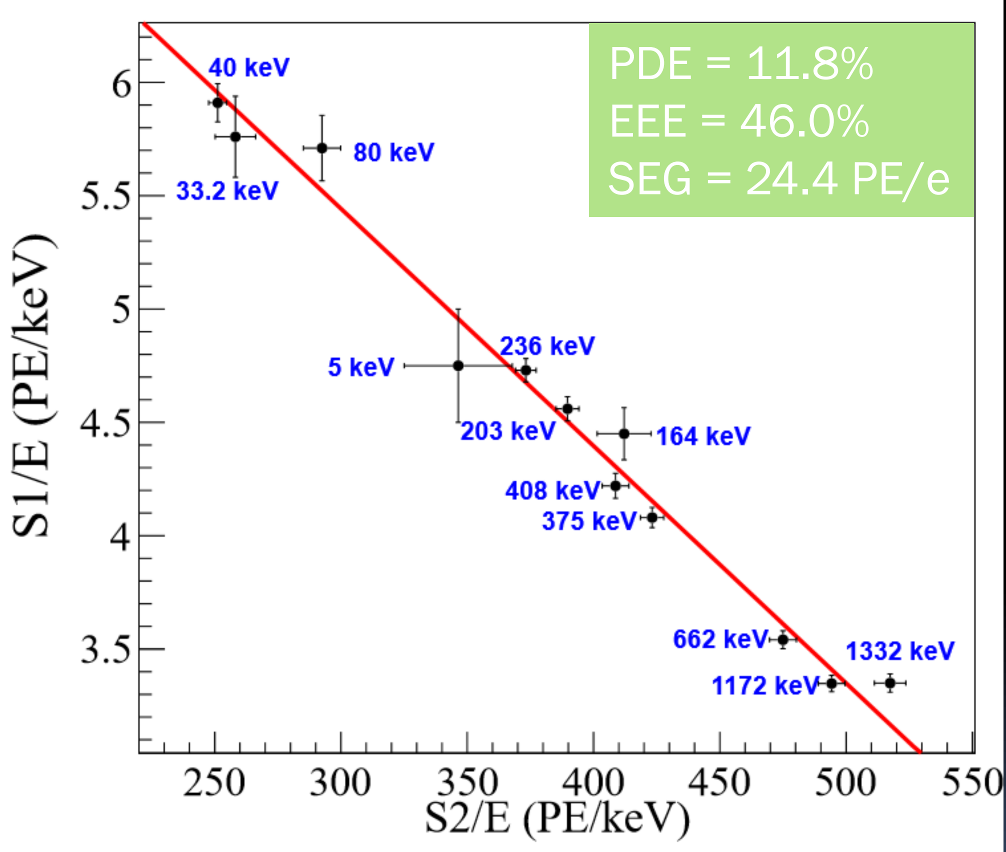
Electron lifetime evolution



- Dominated the uniformity correction (but well self-calibrated)
- Built into the DM and background signal model

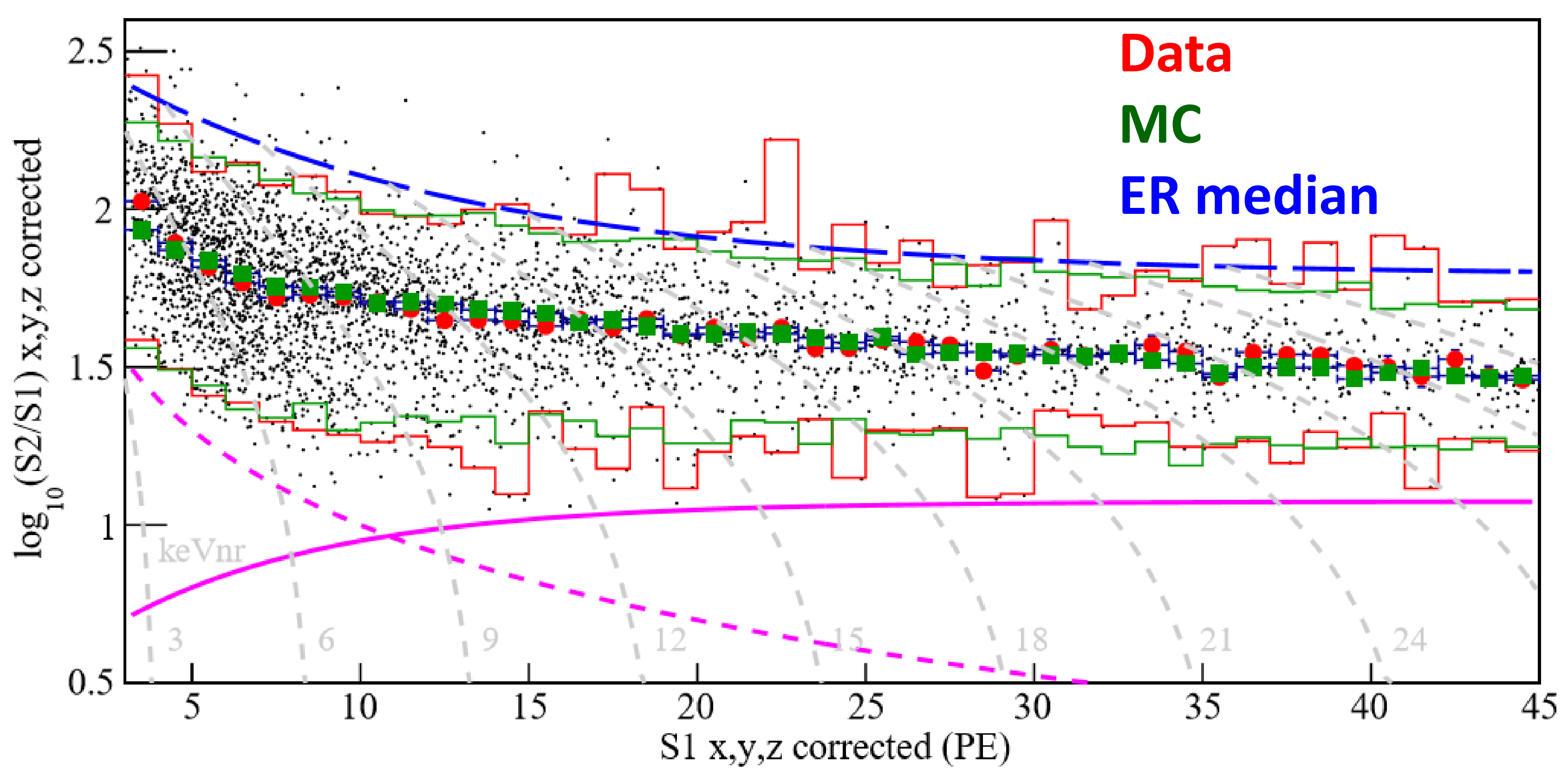
Extraction of detector parameters

$$E_{ee} = W \times \left(\frac{S1}{PDE} + \frac{S2}{EEE \times SEG}\right)$$



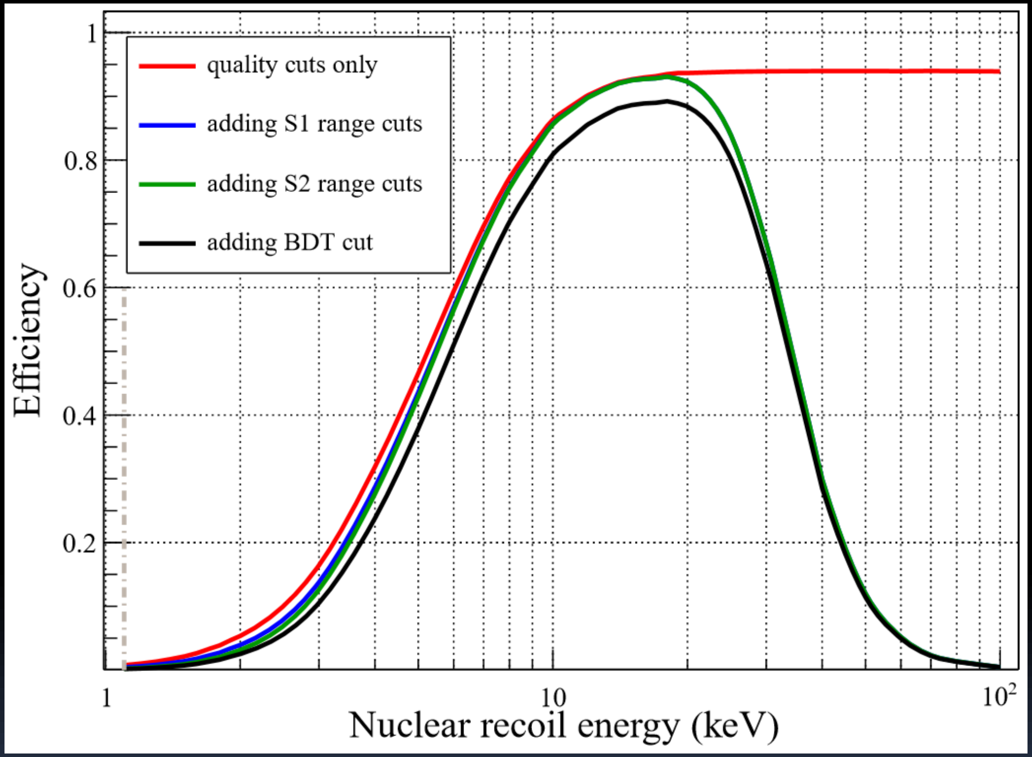
- W = 13.7 eV
- Gaussian fits to all ER peaks in data
- Uncertainty on each data point estimated using energy nonlinearity
- Linear fit in S1/E vs S2/E to extract PDE and EEE

NR calibration



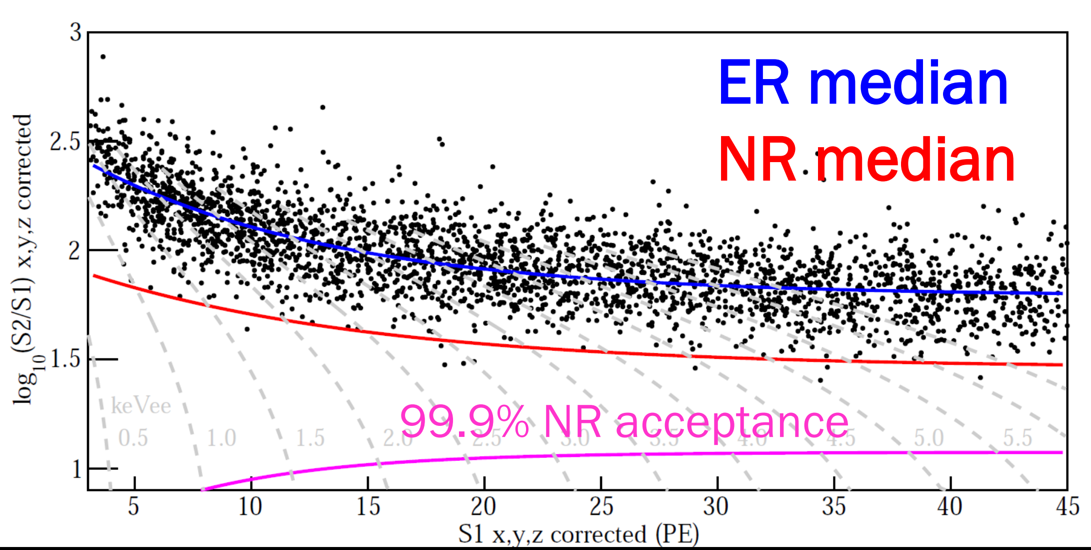
- 162.4 hours of AmBe data taken, with ~3400 low energy single scatter NR events collected
- NR median curve and NR detection efficiency determined

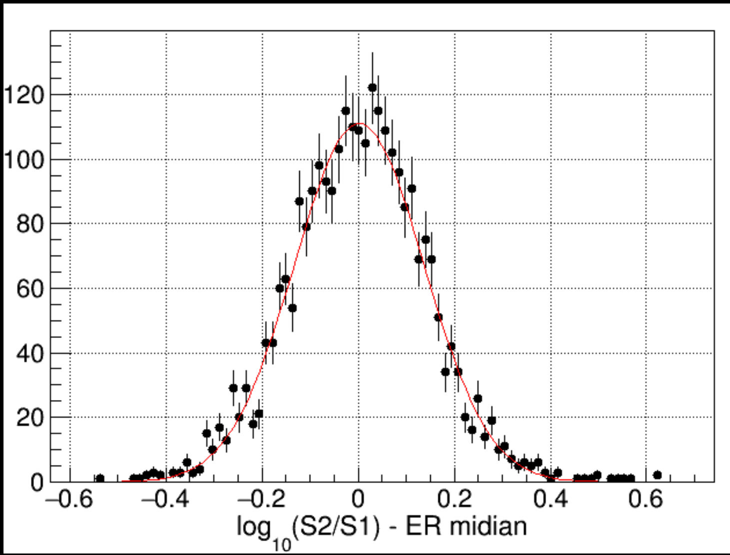
NR detection efficiency



- NR efficiency obtained by data/MC(NEST) ratio
- S1 [3,45] PE, S2 [100_{raw}, 10000_{corr}] PE
- Adopted 1.1 keV_{nr} threshold
- NR efficiency function agrees with that obtained in tritium ER calibration

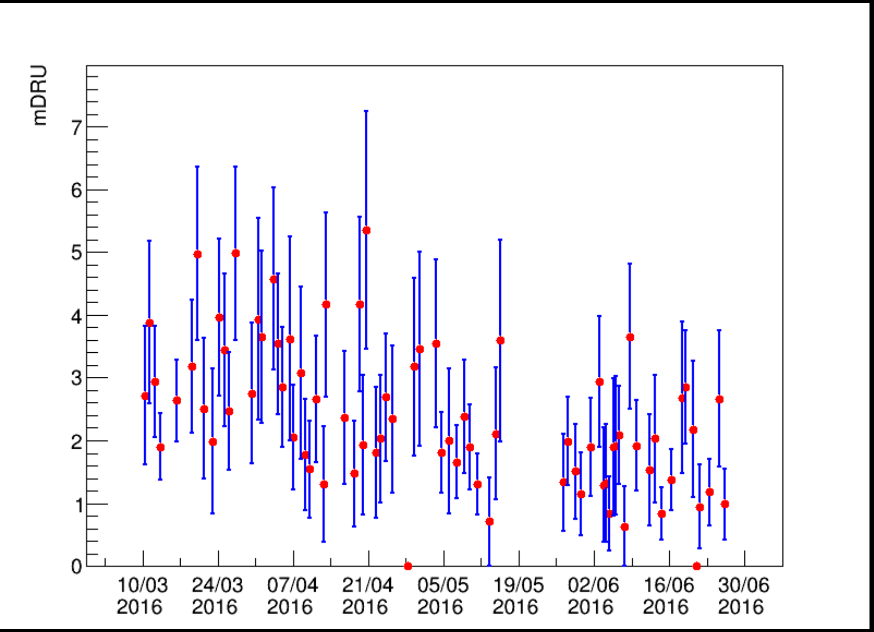
ER calibration with tritium





- 18.0 hours of tritium data taken, with ~2800 low energy ER events collected in the FV
- 9 events leaked below NR median, (0.32 ± 0.11)%
- Consistent with Gaussian expectation

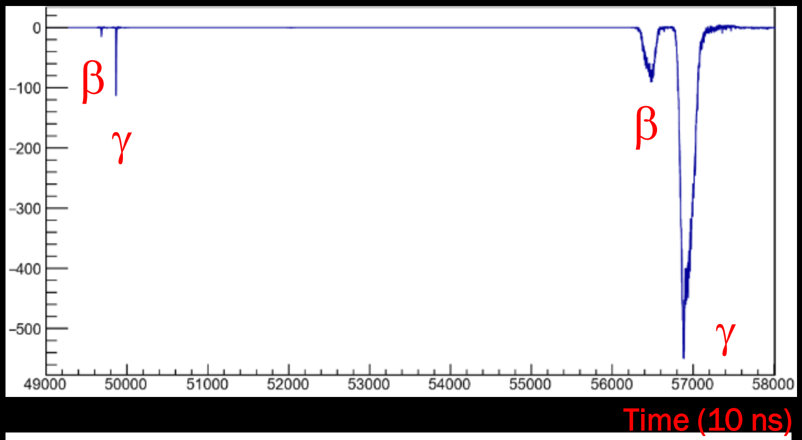
Low energy rate in run 9

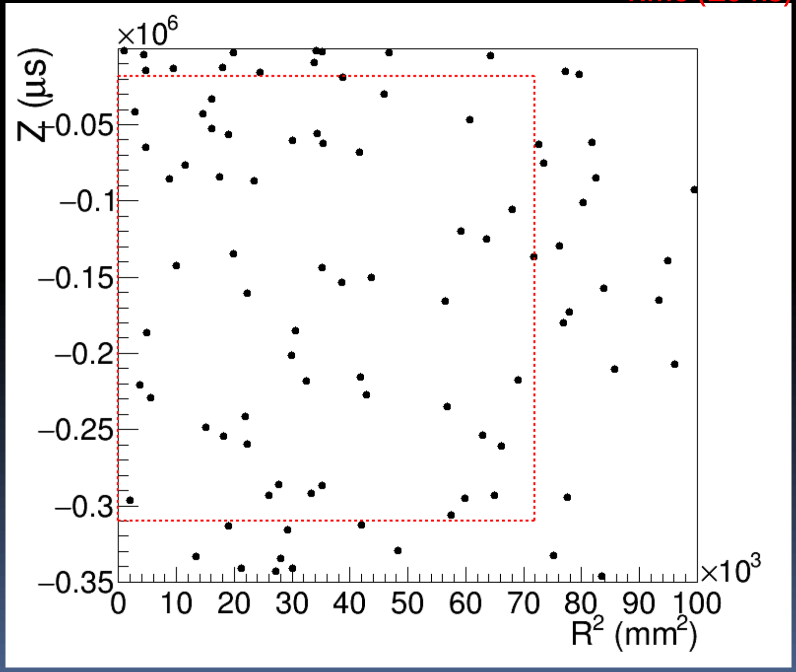


Item	Run 8 (mDRU)	Run 9 (mDRU)
^{85}Kr	11.7	1.19
^{127}Xe	0	0.42
^{222}Rn	0.06	0.13
^{220}Rn	0.02	0.01
Detector material ER	0.20	0.20
Total	12.0	1.95

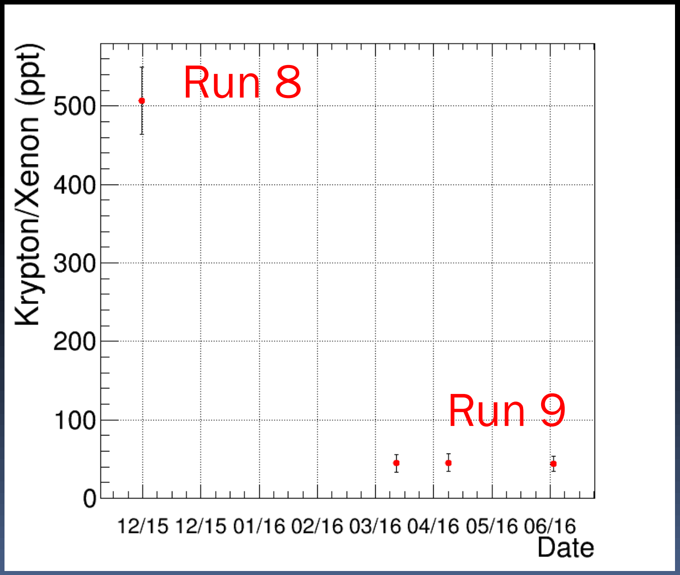
- Events selected in the FV with energy <10 keV_{ee}
- ~2 mDRU in the FV on average, lowest reported background level in dual phase xenon
- Decrease over time due to ^{127}Xe decay

^{85}Kr

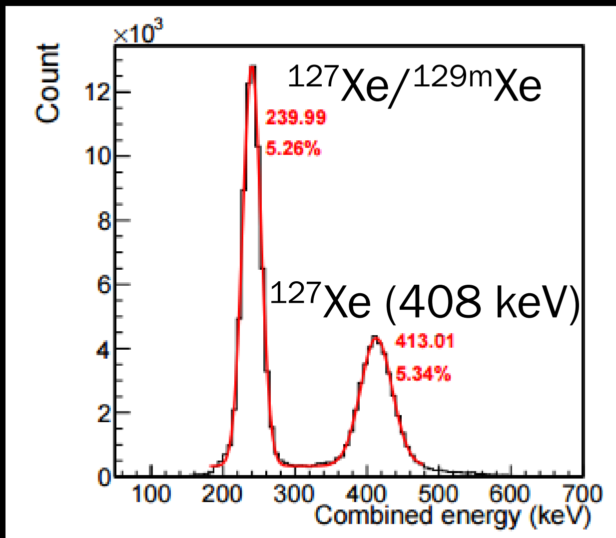


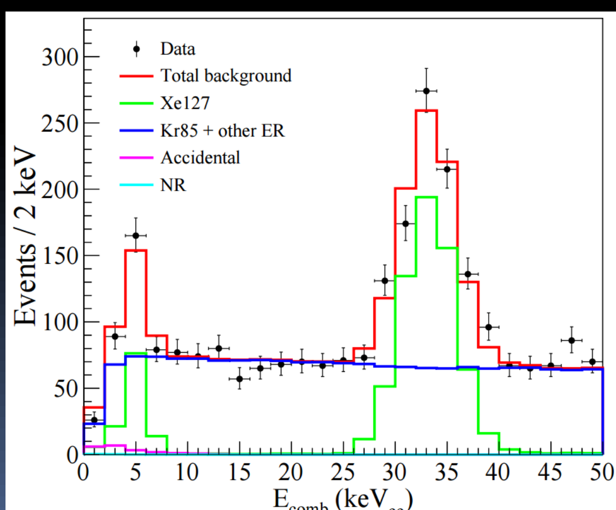


- 0.43% β decay with delayed ^{85m}Rb γ de-excitation
- Uniformly distributed
- Significantly reduced (x10) after the distillation

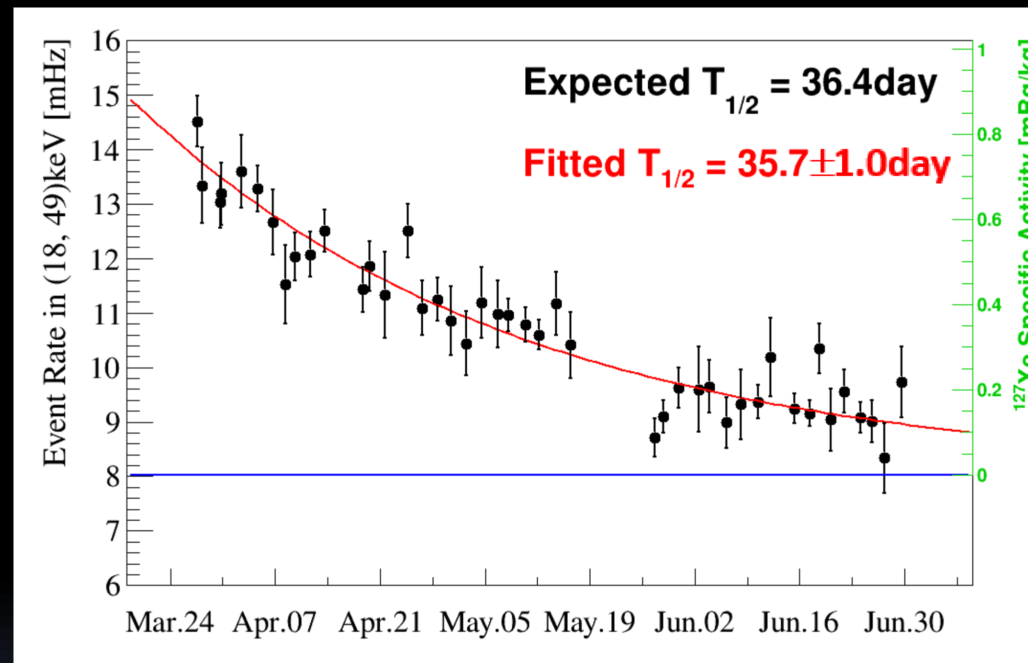


^{127}Xe



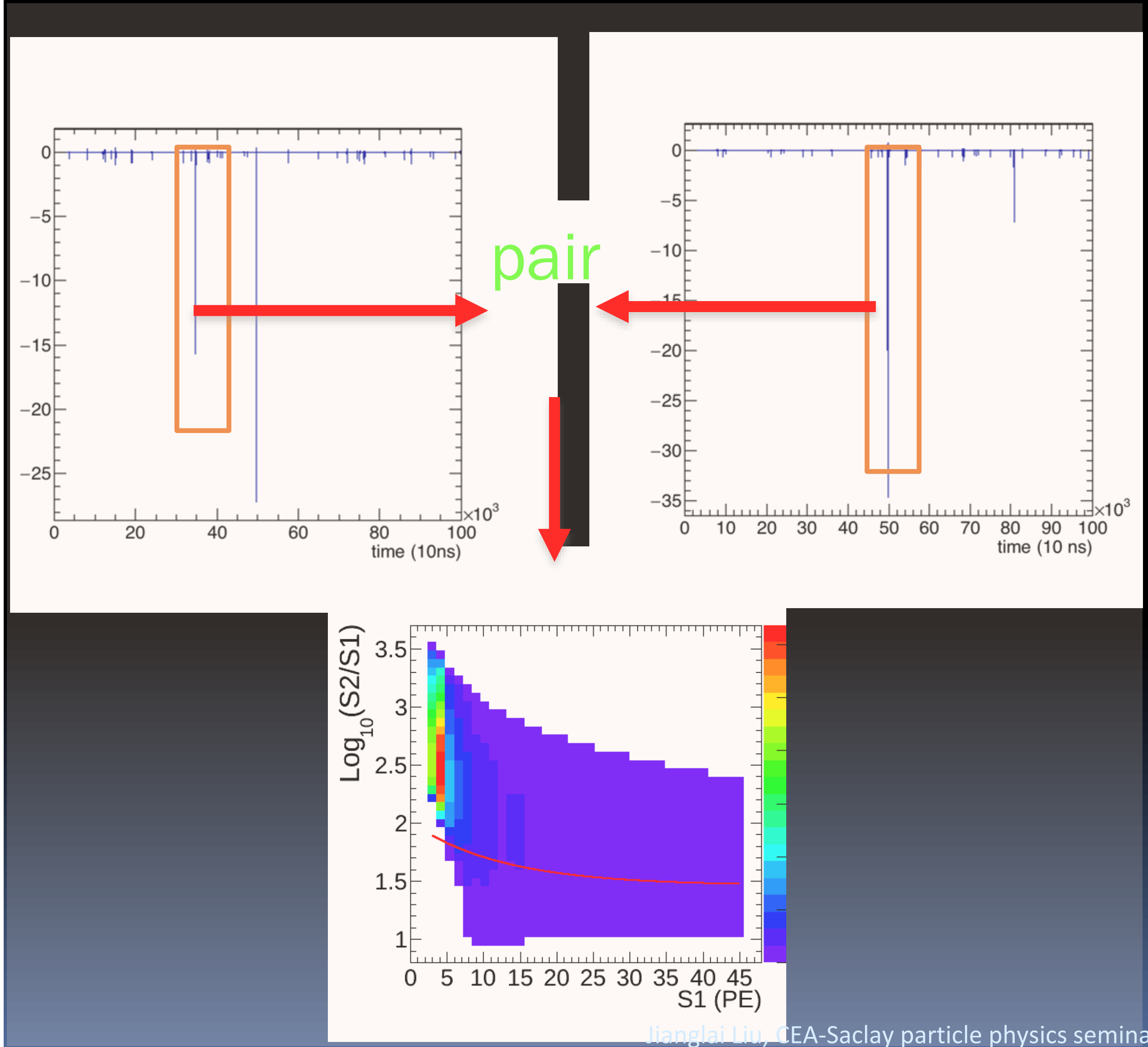


integrated rate around 30 keV_{ee}



Average ^{127}Xe rate in the DM search region: 0.42±0.10 mDRU

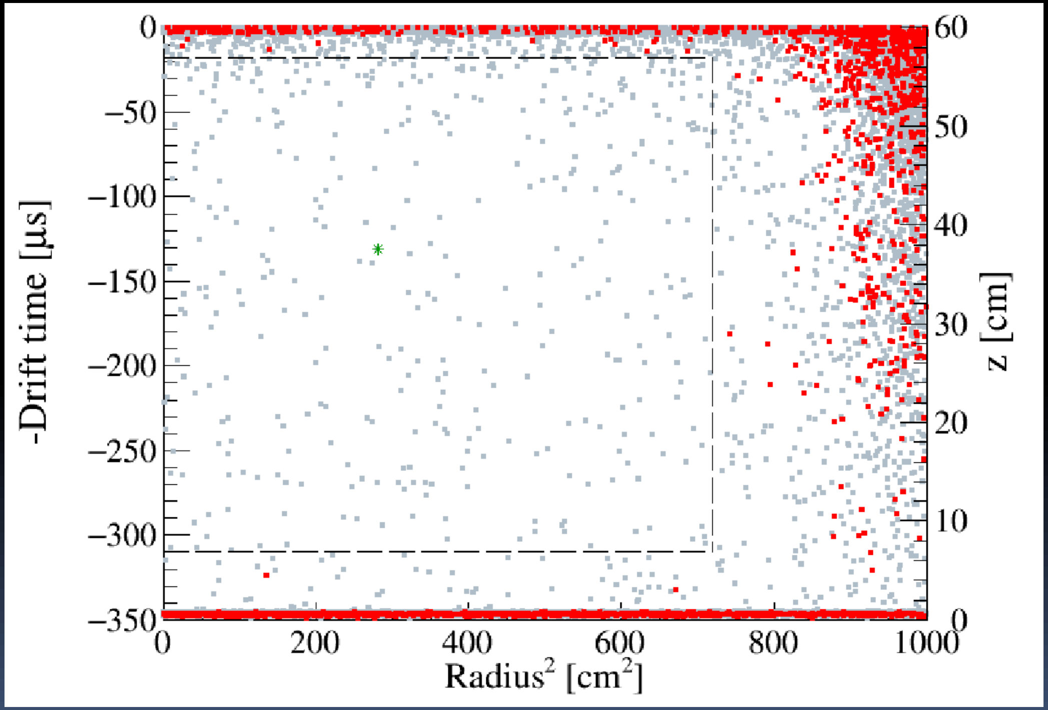
Accidental background



- Isolated S1 and S2 were selected and randomly paired to determine accidental distribution
- Further suppressed this background by x3 using boosted decision tree (BDT) technique

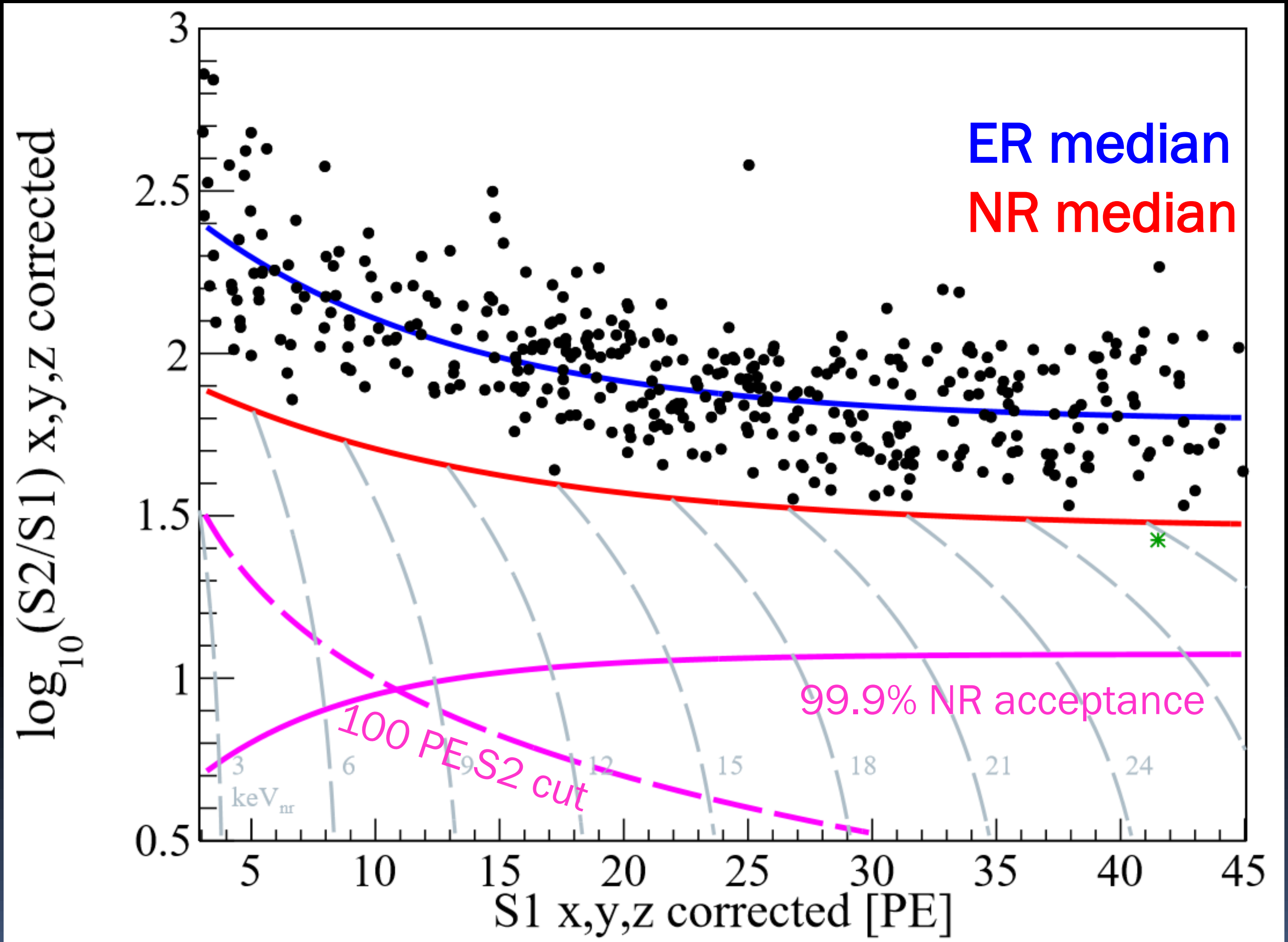
Final candidates (run 9)

Gray: all
Red: below NR median
Green: below NR median and in FV

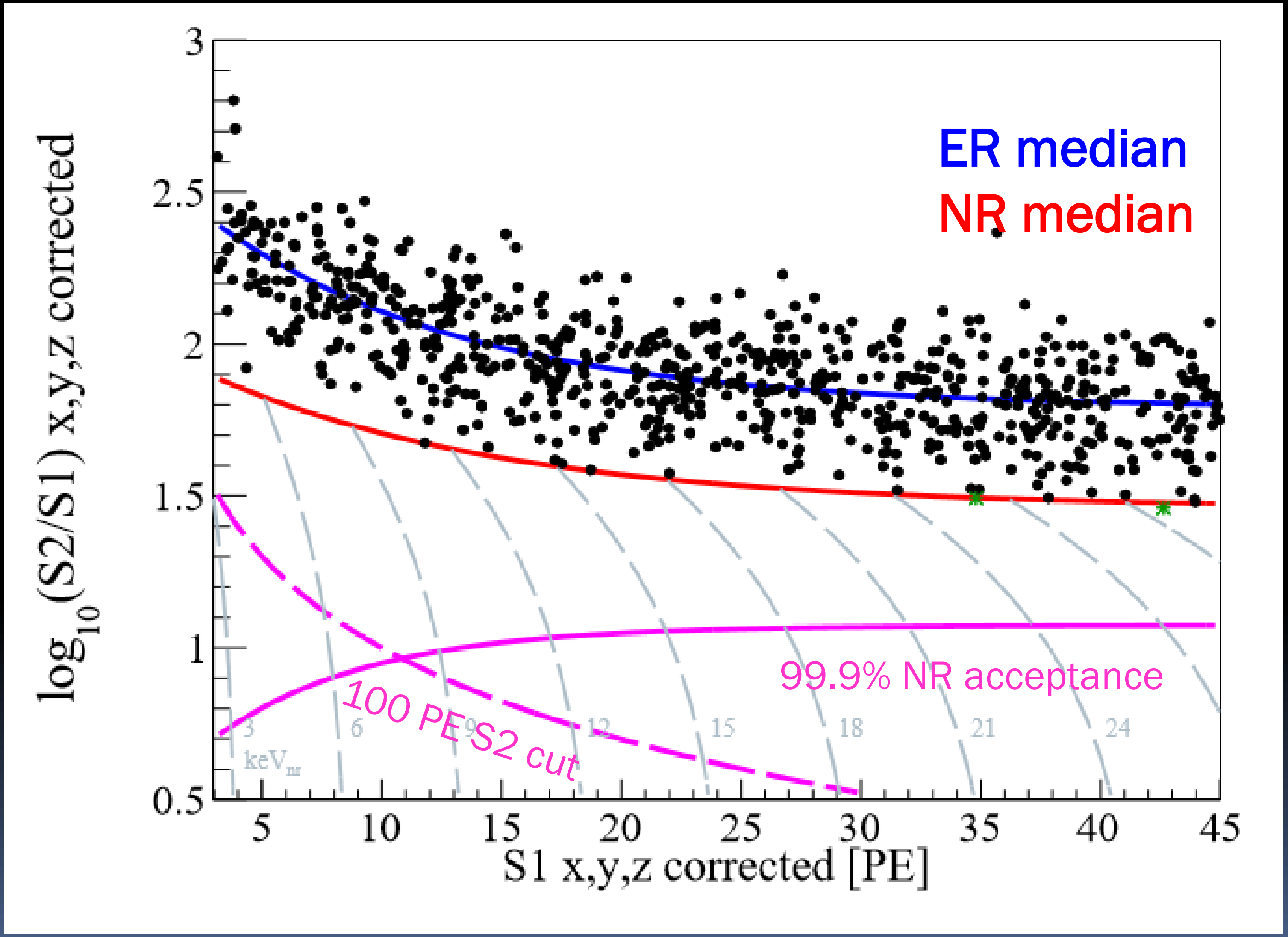


- 389 total candidates found in the FV (329 kg)
- 1 below NR median
- Outside FV, edge events more likely to lose electrons, leading to S2 suppression

Final candidates (run 9)



Final candidate (run 8)



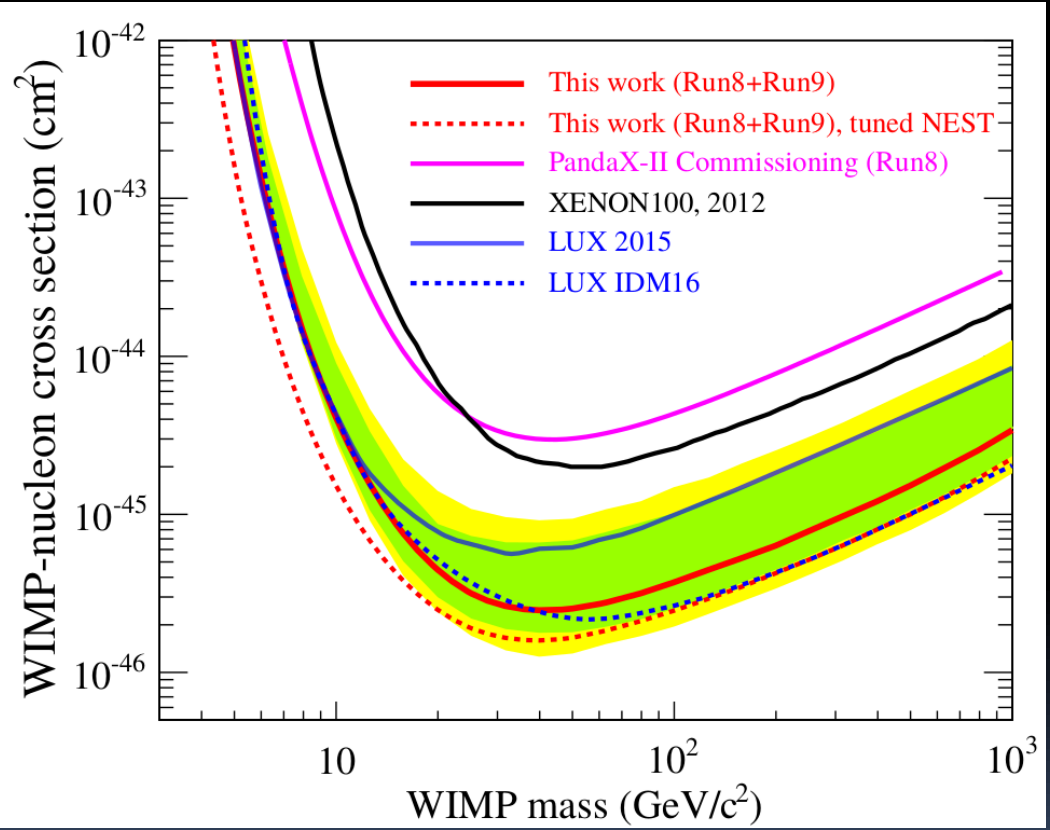
Summary of final candidates

	ER	Accidental	Neutron	Total Expected	Total observed
Run 8	622.8	5.20	0.25	628±106	734
Below NR median	2.0	0.33	0.09	2.4±0.8	2
Run 9	377.9	14.0	0.91	393±46	389
Below NR median	1.2	0.84	0.35	2.4±0.7	1

Combined exposure: 33000 kg-day

SI cross section limit

90% limit (PLL, CL_s), SI isoscalar elastic DM-nucleon

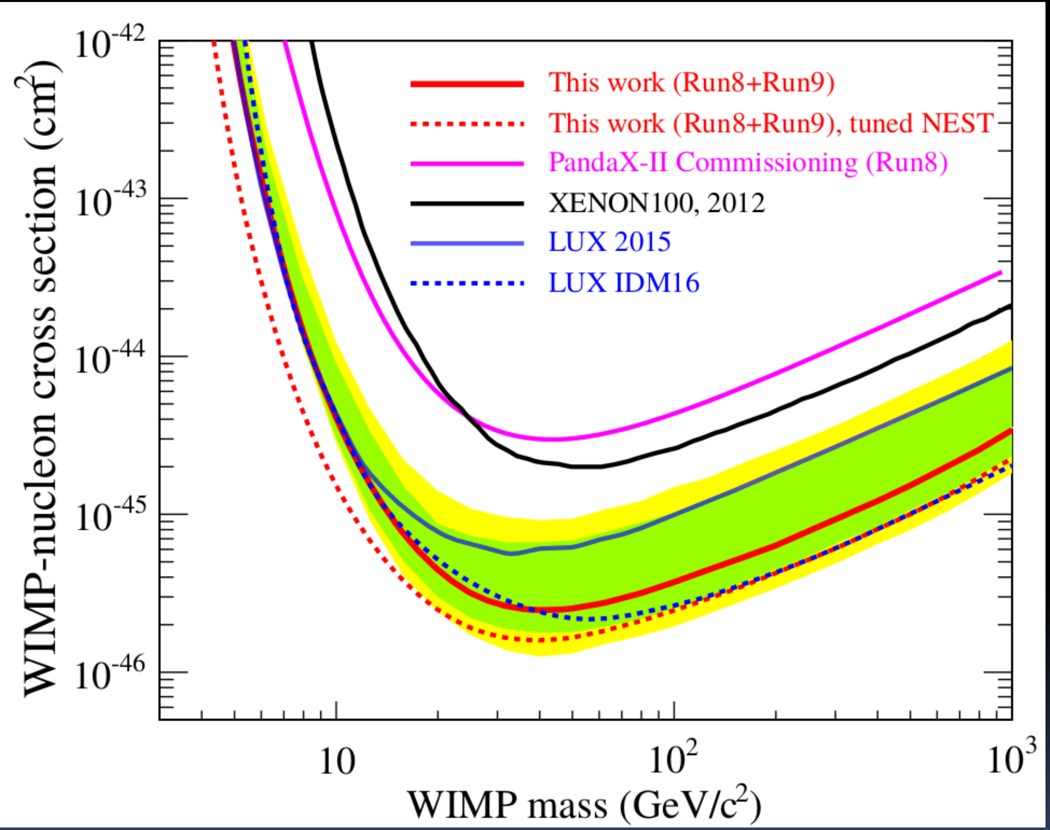


Released at IDM on July 21, arXiv:1607.07400 on July 26, accepted by PRL on Aug. 16

- Minimum exclusion: 2.5×10^{-46} cm^2 @ 40 GeV/c^2, improved x10 from run 8, >x2 from LUX 2015
- More constraining result could be obtained with a tuned NR model (in some aspects agreeing better with NR calibration). Conservatively used NEST model for official results

SI cross section limit

90% limit (PLL, CL_s), SI isoscalar elastic DM-nucleon

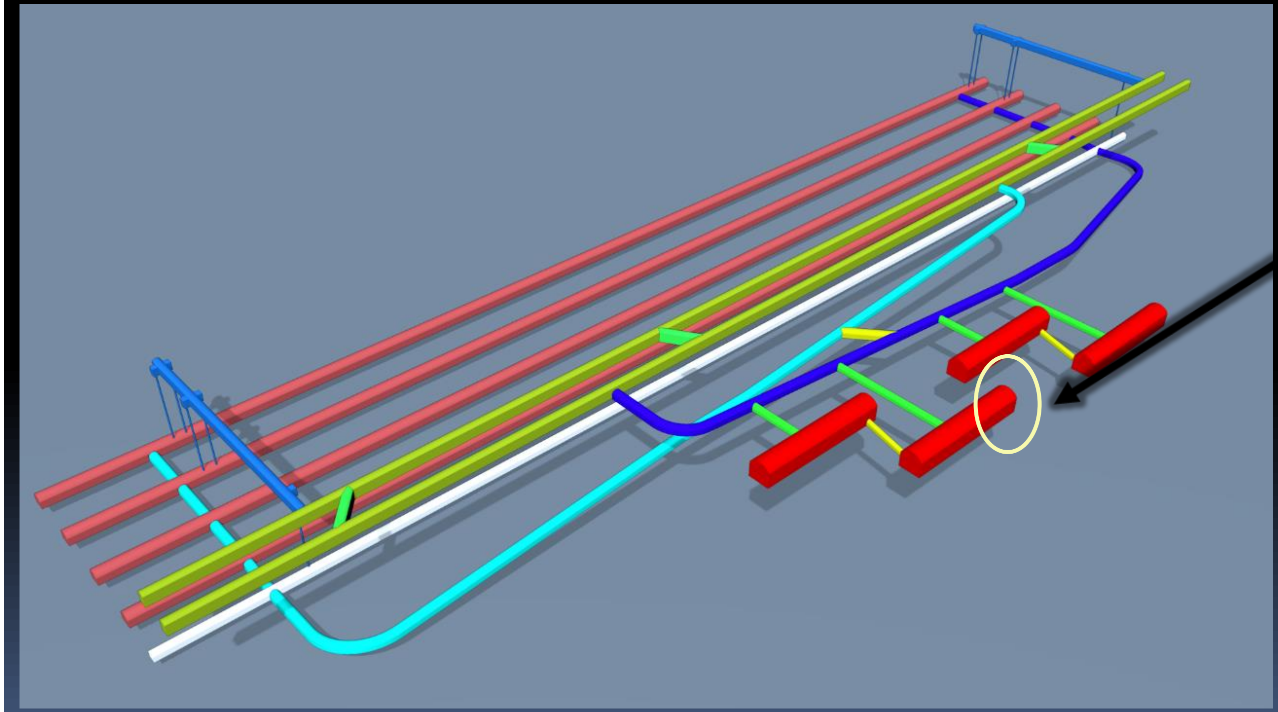


Released at IDM on July 21, arXiv:1607.07400 on July 26, accepted by PRL on Aug. 16

- LUX 332-day results presented at IDM (arxiv:1608.07648) with similar exposure and limit (slightly more constraining than PandaX towards high mass)
- This is the first low background result from PandaX-II, a long life (~500 live-day) ahead of this!

PandaX new home: CJPL-II

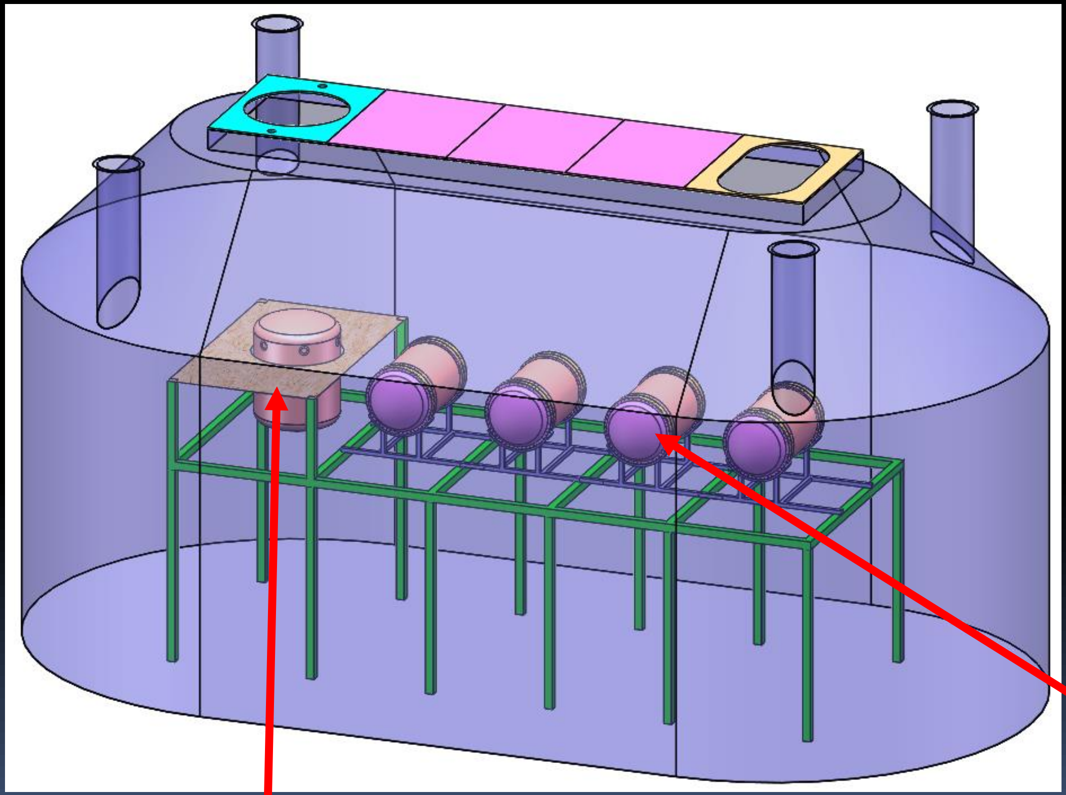
8 experimental Halls, 14(H)x 14(W)x65(L) m each.



B4, PandaX site!

PandaX in CJPL-II

A large experimental infrastructure to host multiple dark matter and double beta detectors



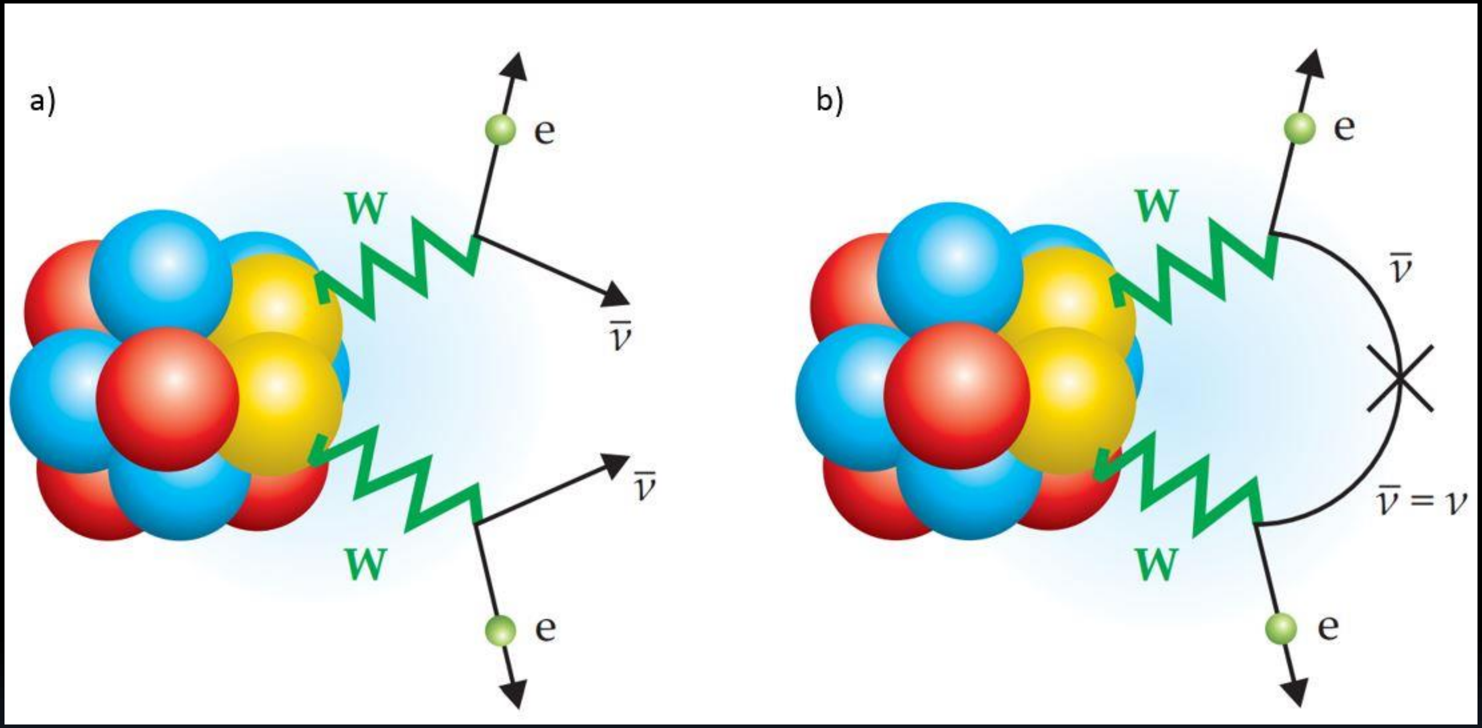
To achieve an extremely low background environment, use ultrapure water contained in a large SS water tank with 25(l)x13(w)x13(h), 3400 ton capacity

3-40 ton LXe DM experiment

HP Xe136 experiment (multiple detectors)

Swimming pool under 2400 m

0vDBD

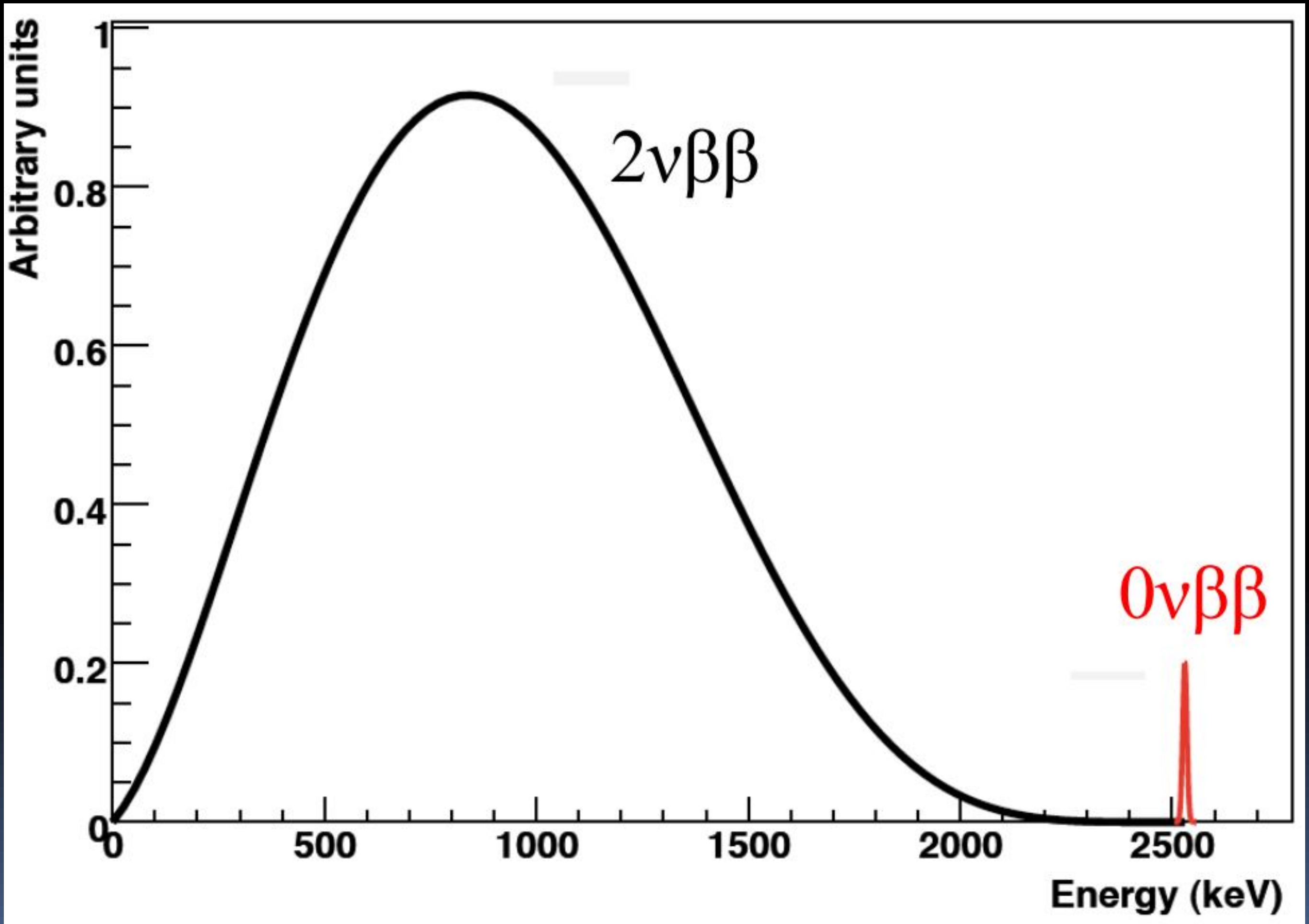


Normal double-β decay: rare but allowed 2nd order standard model process

Zero-neutrino double-β decay:

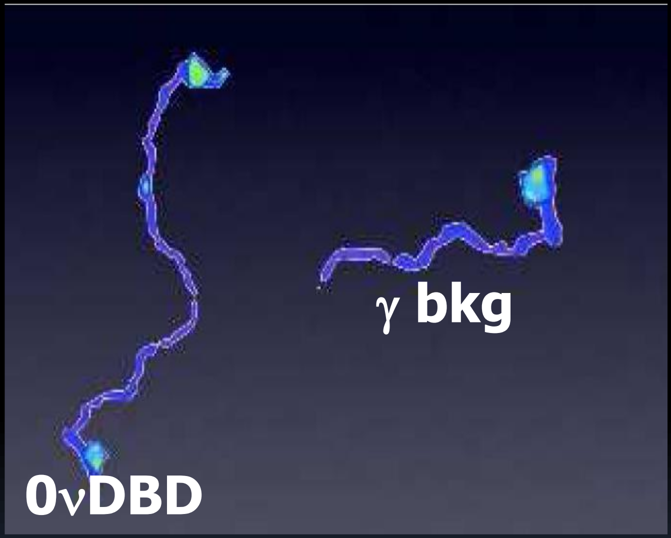
- Neutrino is Majorana
- Lepton number violation
- Neutrino absolute mass

Return of 1920's



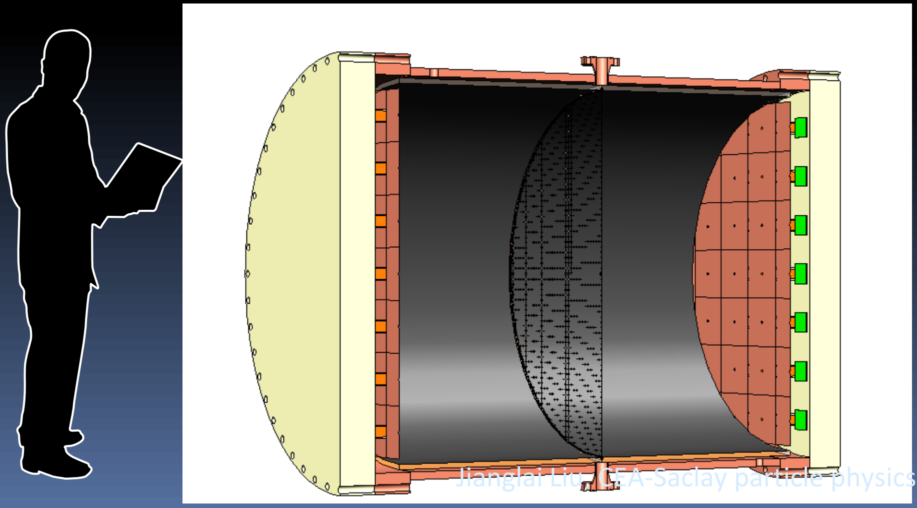
High pressure ^{136}Xe TPC

- 0νDBD signal: two electrons emitting from the same vertex with a summed energy at the Q value
- HP xenon:
  - Excellent energy resolution
  - Tracking ability: at 10 atm, 2-beta track length about 30 cm with two Bragg peaks, discrimination with gamma background⟹ smoking gun for discovery



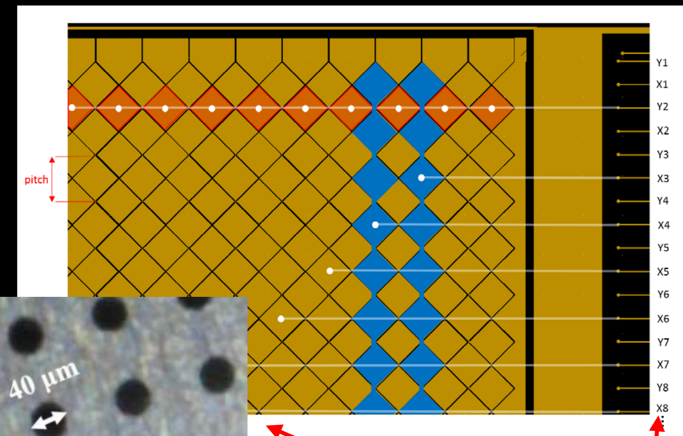
PandaX-III

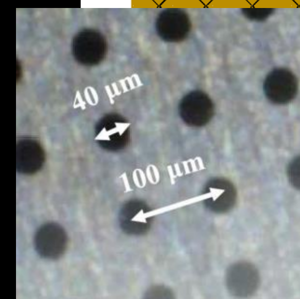
- TPC: 200 kg, 10 atm, symmetric, double-ended charge readout with cathode in the middle
  - Charge readout plane: tiles of square microbulk Micromegas (MM) modules with X, Y strips
  - The largest low-background high pressure TPC
- Four more upgraded modules for a ton scale experiment

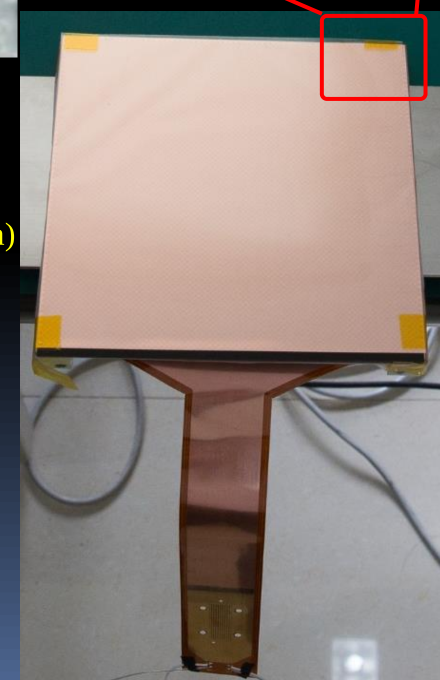


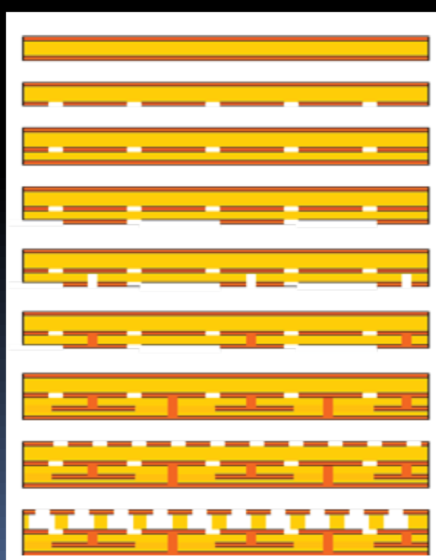
Microbulk micromegas

- Invented at Saclay
- Microbulk MicroMegas films made of Copper and Kapton only (radio-pure)
- 20 cm by 20 cm
- XY strip readout; 3mm pitch size; 128 channel
- 3% energy resolution at 2.5 MeV









Double side Cu-coated (5 μm) Kapton foil (50 μm)

Construction of readout strips/pads (photolithography)

Attachment of a single-side Cu-coated kapton foil (25/5 μm)

Construction of readout lines

Etching of kapton

Vias construction

2nd Layer of Cu-coated kapton

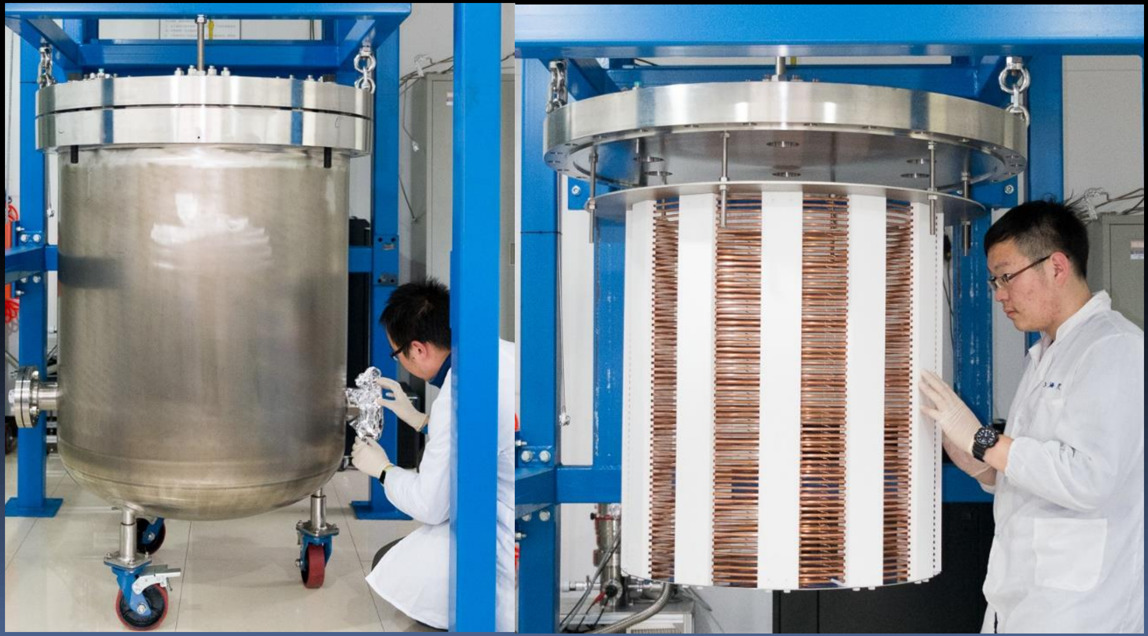
Photochemical production of mesh holes

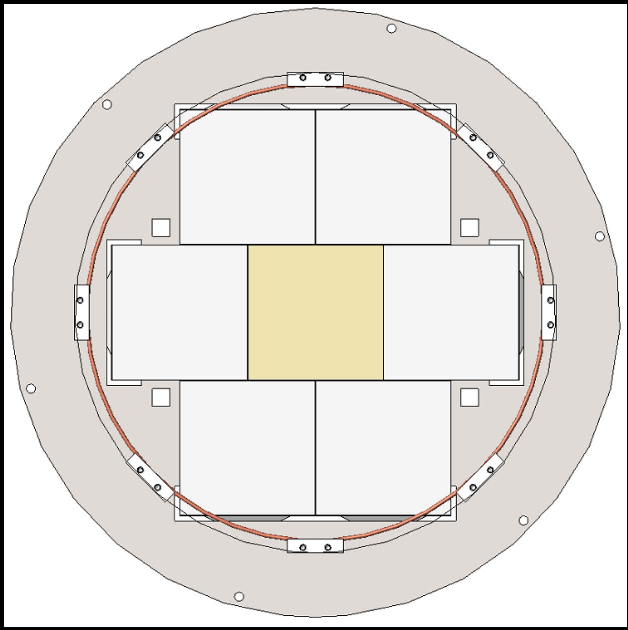
Kapton etching / Cleaning

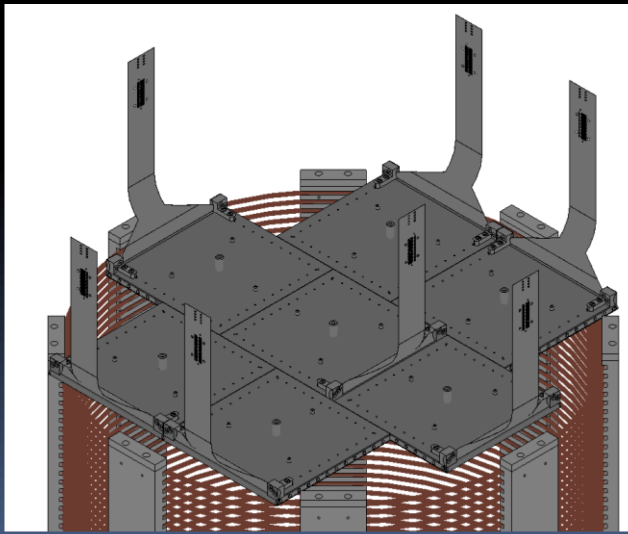
Andriamonje, S. et al. JINST 02 (2010): P02001

Prototype TPC @ SJTU

- 16 kg of Xenon at 10 bar (active mass within TPC) with one readout plane
- Study MM performance in a 0.5 m^2 array
- To study the energy calibration of TPC
- To develop algorithm of 3D electron track reconstruction and topological identification







7 MicroMegas

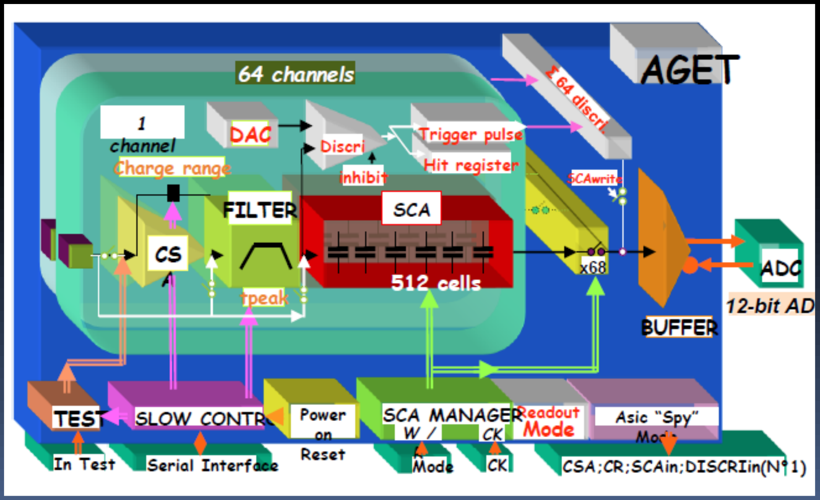
Electronics

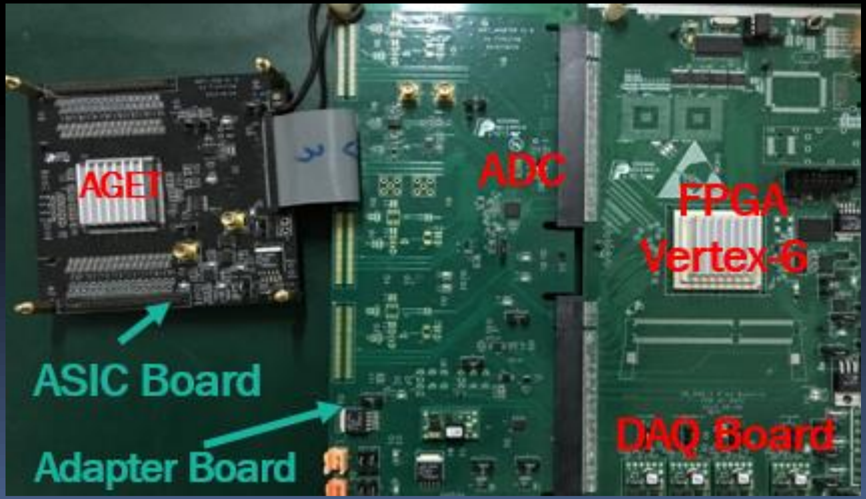
ASIC AGET chips: generic electronics for TPC from CEA-Saclay

- 350 nm CMOS, mature technology
- 64 channel multiplex
- 512 sampling point per channel
- 12 bit ADC
- Dynamic range up to 10 pC
- Sampling rate: 1 MHz to 100 MHz

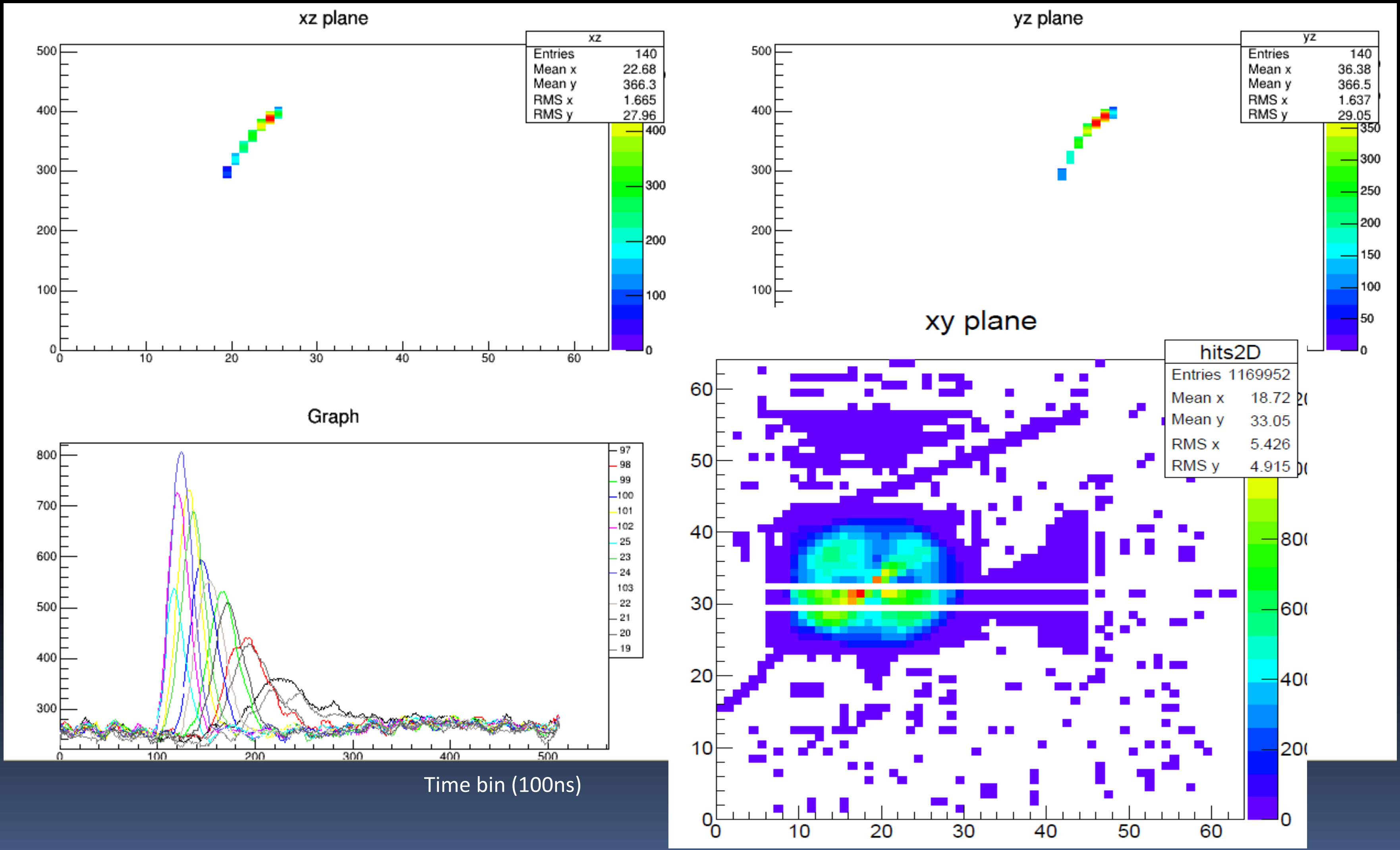
Ensure high energy resolution

AGET-based electronics are being tested and studied at Zaragoza, USTC, and SJTU





α tracks from prototype



Time bin (100ns)

PandaX-III project

- China: Shanghai Jiao Tong University, University of Science and Technology of

Conceptual Design Report

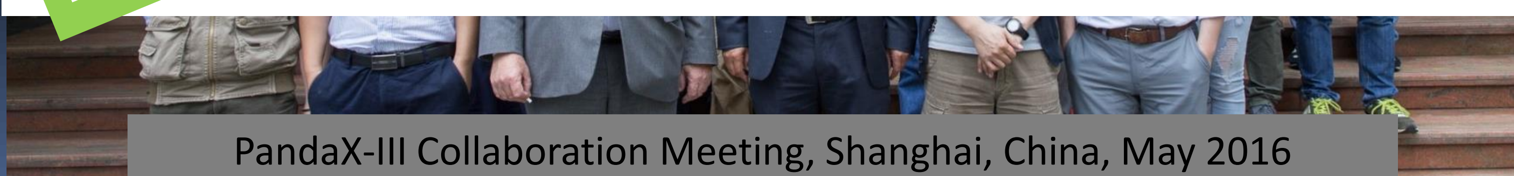
PandaX-III:

Serachi… Double Beta Decay with

… Gas Time Projection Chambers

…daX-III Collaboration

We aim to deploy the first 200 kg detector module in Jinping before the end of 2017!



PandaX-III Collaboration Meeting, Shanghai, China, May 2016

Summary and outlook

- Many exciting physics opportunities in PandaX at the world deepest CJPL
- PandaX-II has reached the forefront of the DM search, and will continue PandaX-II data taking till end of 2017
- The collaboration is going forward in preparation for PandaX-xT and PandaX-III!
- Welcome more collaborators!