Progress of double-weak decays and solar pp neutrinos in PandaX-4T experiment

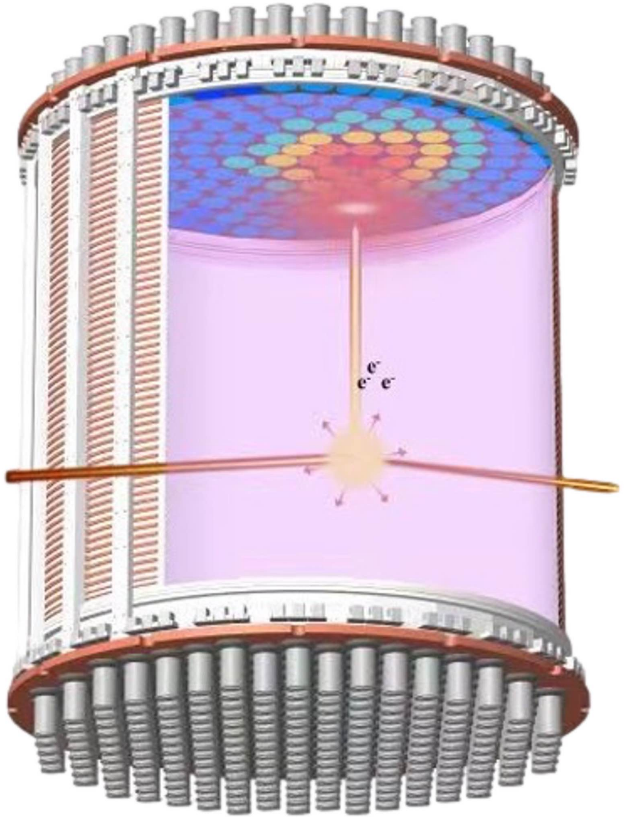
Xiang Xiao (Sun Yat-sen University)
on behalf of the PandaX Collaboration

August 29, 2023

TAUP2023 @ Vienna

PandaX-4T experiment

- Third generation of the PandaX experiments located at CJPL-II
- Dual-phase Xe TPC: 1.2 m (D) ×1.2 m (H)
- Sensitive volume: 3.7 ton LXe
- Total volume: 5.6 ton LXe
- 3-inch PMTs: 169 top / 199 bottom
- Water shielding: 10 m (D) ×13 m (H)



- ER/NR identification
- 3D position reconstruction and fiducialization
- Monolithic and scalable
- **Calorimeter from sub keV to a few MeV**

Multiple physics in a wide energy range

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

	Sub-keV	1 keV	10 keV	100 keV	1 MeV	10 MeV
Xe-136 (~9%)				2νββ / 0νββ		
Xe-134 (~10%)				2νββ / 0νββ		
Xe-124 (~0.1%)			2νECEC			
Xe all isotopes	^{8}B solar ν and light DM	WIMP and other DM models		solar pp ν		Alphas, muons and other physics

see Qing Lin's talk (^{8}B solar ν and light DM)

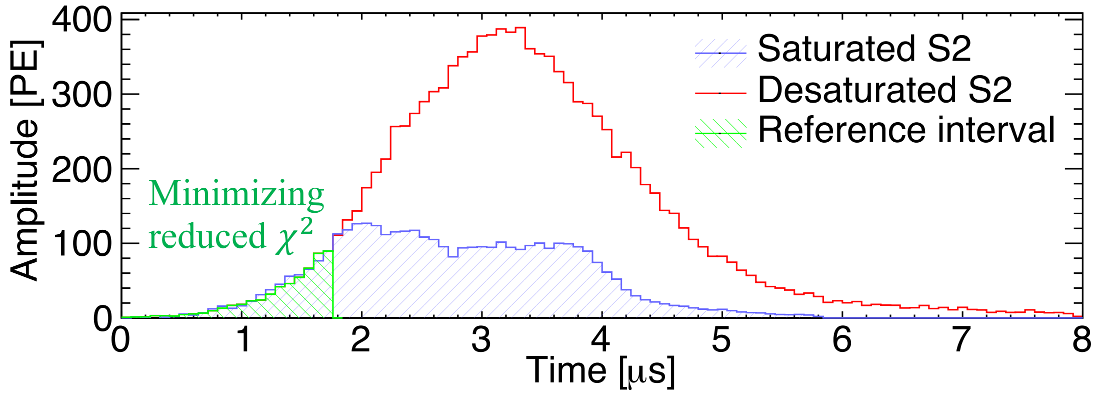
see Ning Zhou's talk (WIMP and other DM models)

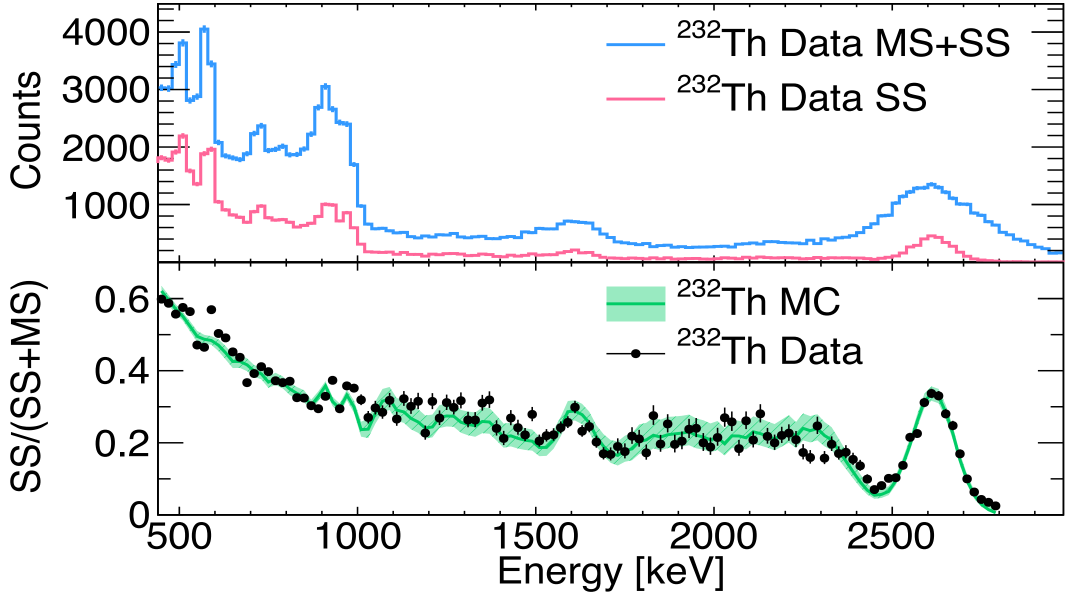
this talk (solar pp ν, 2νECEC, 2νββ / 0νββ)

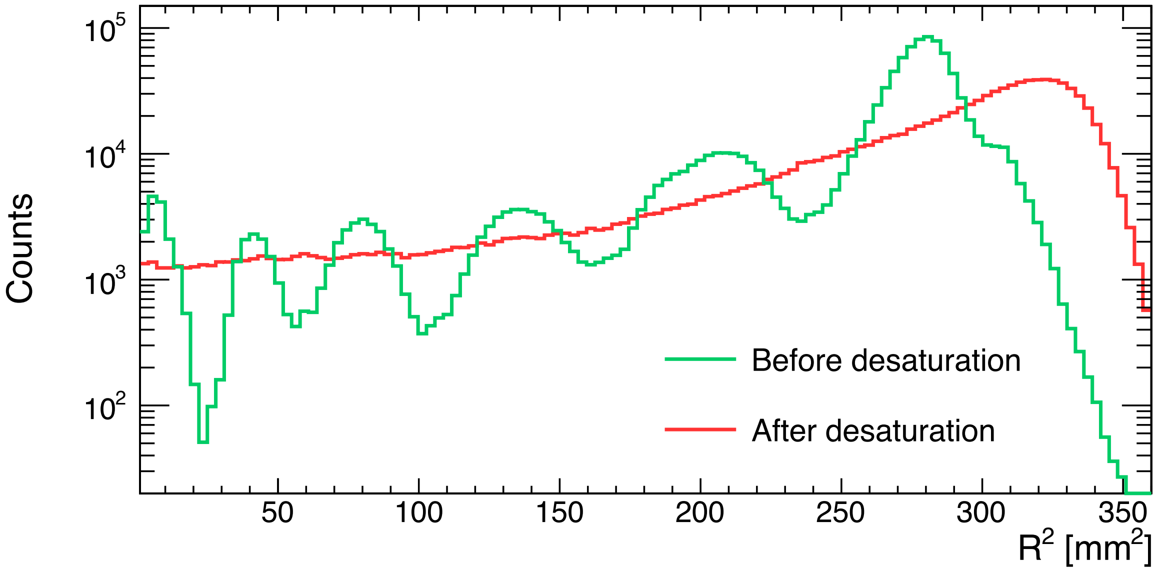
Extending from keV to MeV

Dedicated data analysis pipeline is developed for O(100 keV) – O(MeV) energy range

- Improved single site (SS) and multiple site (MS) identification: calibration data/MC SS ratio consistent within 1.7%
- Desaturation algorithm: X-Y position reconstruction, energy linearity and resolution significantly improved

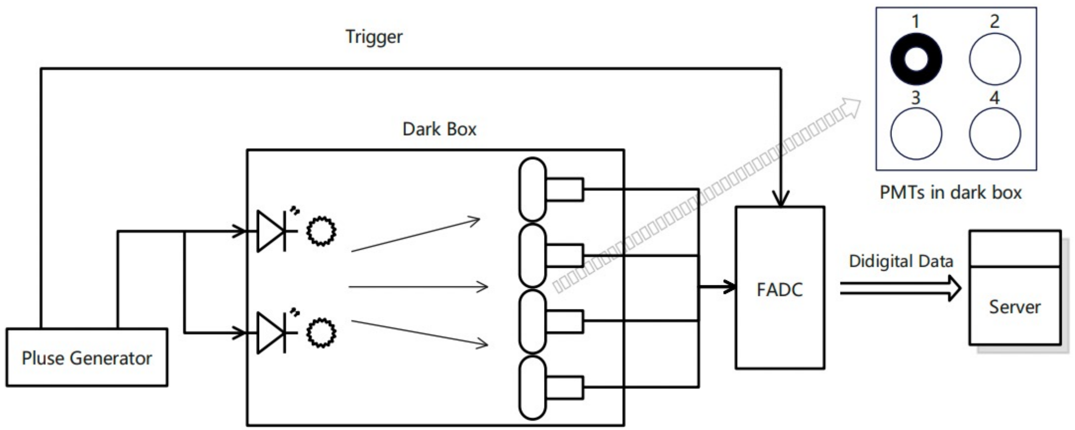


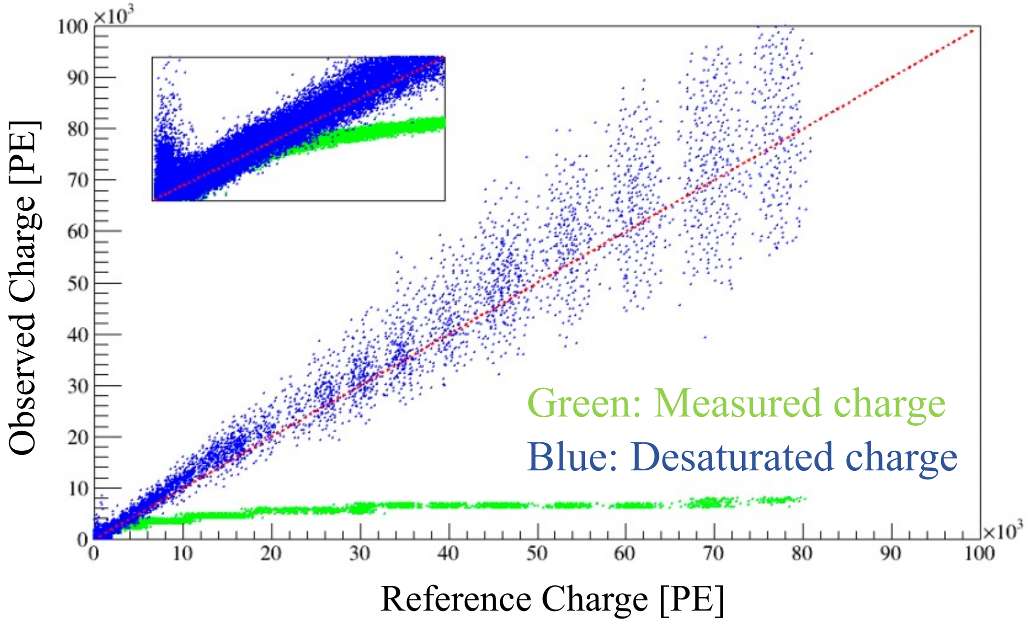




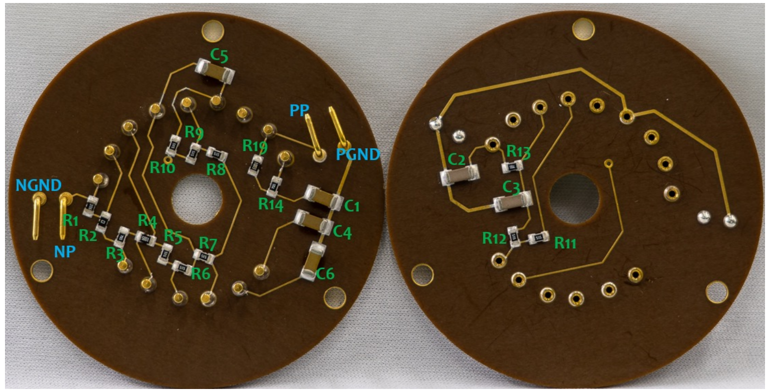
Bench test for saturation and new PMT base design

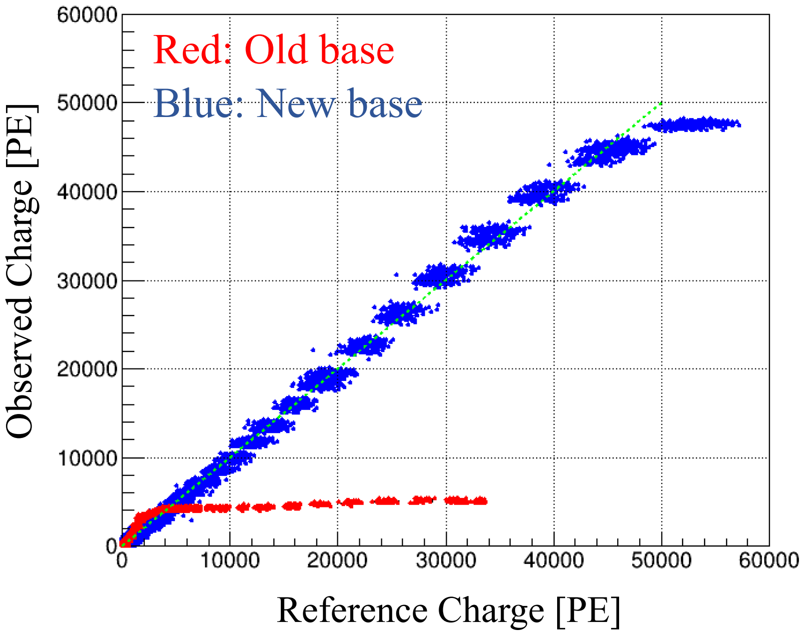
- PMT waveform saturation is studied by independent bench tests
- Desaturation algorithm is checked and verified





- New PMT base design with much improved linearity
- All PMT bases have been changed for the upcoming Run2

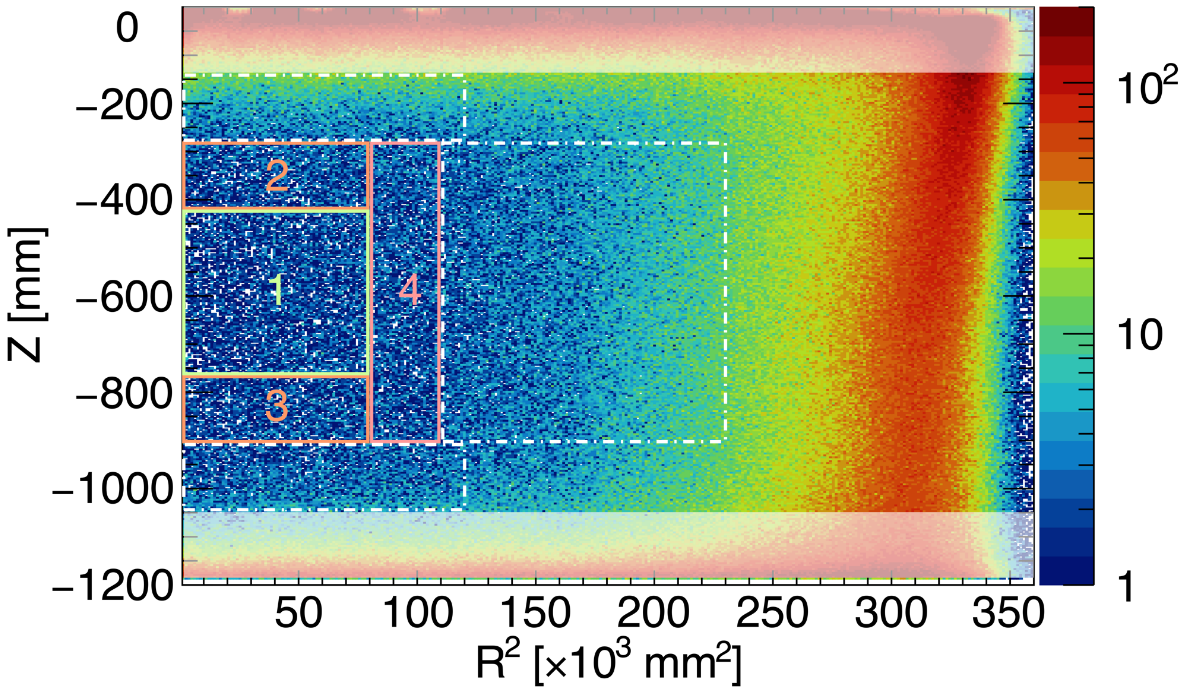


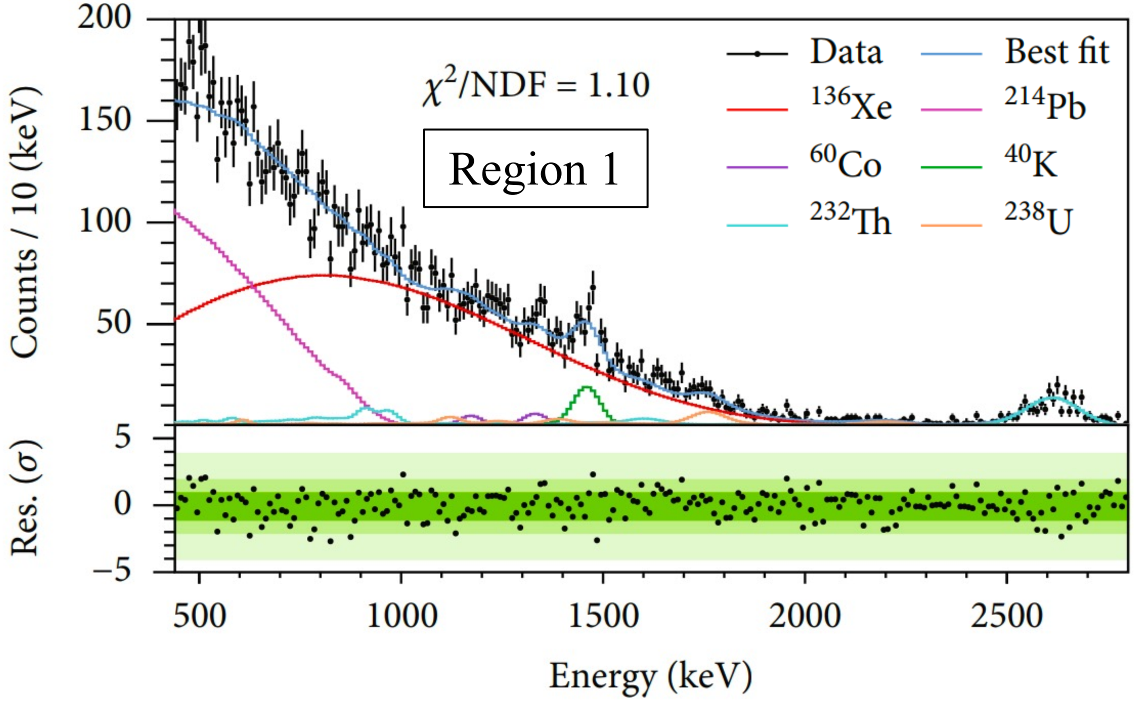


Segmented FV and simultaneous

- Material components are grouped into Top, Bottom and Side categories, each with ^{60}Co, ^{40}K, ^{238}U and ^{232}Th.
- FV is optimized based on both background level and position reconstruction non-linearity, then segmented into four regions.
- Binned Poisson likelihood fitting on SS energy spectrum is performed simultaneously in four regions.
- Outer regions are used to check material background model, and data-MC is consistent at 1% level.

$$L = \prod_{i=1}^{N_{\mathrm{R}}} \prod_{j=1}^{N_{\mathrm{bins}}} \frac{(N_{ij})^{N_{ij}^{\mathrm{obs}}}}{N_{ij}^{\mathrm{obs}}!} e^{-N_{ij}} \prod_{k=1}^{N_{\mathrm{bkgs}}} \frac{1}{\sqrt{2\pi}\sigma_k} e^{-\frac{1}{2}\left(\frac{\eta_k}{\sigma_k}\right)^2}, \quad N_{ij} = n_{\mathrm{Xe}} S_{ij}^{\mathrm{Xe}} + \sum_{k=1}^{N_{\mathrm{bkgs}}} (1+\eta_k) n_{ij}^k B_{ij}^k$$



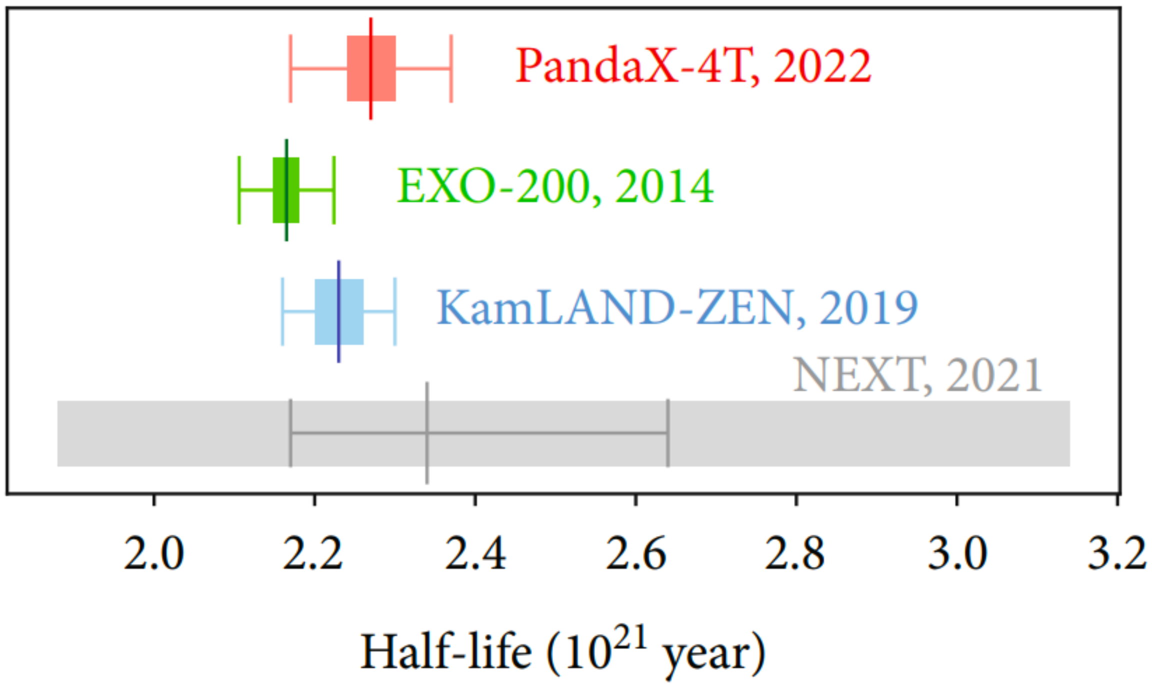


^{136}Xe 2νββ half-life and background model

PandaX — PARTICLE AND ASTROPHYSICAL XENON TPC

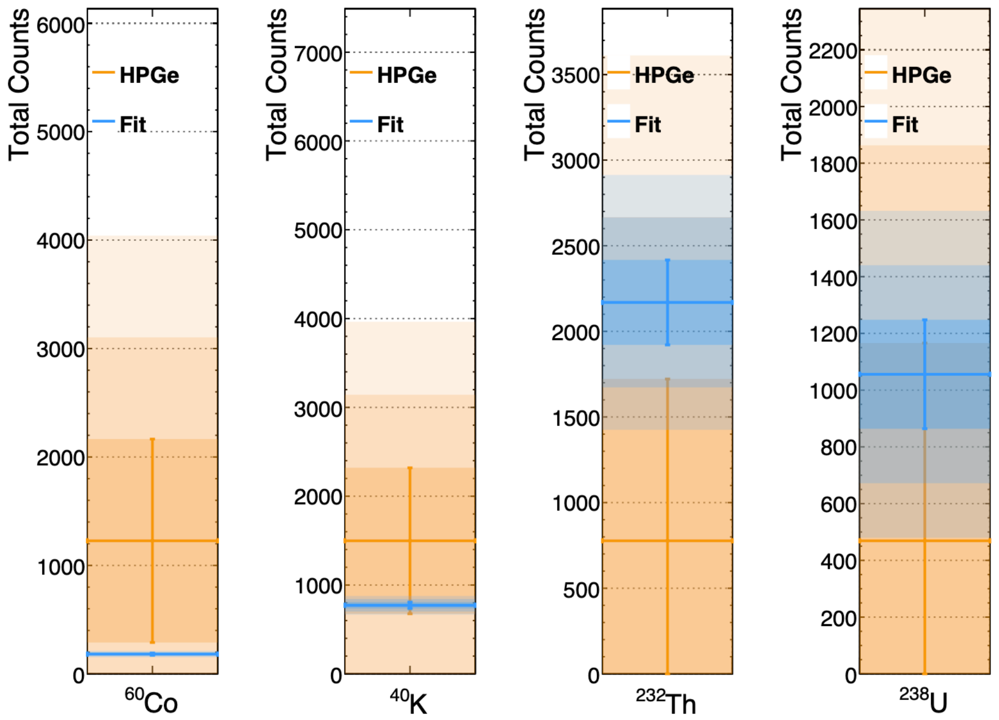
^{136}Xe 2νββ half-life measured as: $2.27 \pm 0.03(\text{stat.}) \pm 0.10(\text{syst.}) \times 10^{21}$ year

- Comparable precision with leading results
- First such measurement from a DM detector with natural xenon
- Much lower analysis threshold compared with previous measurements
- *“in-situ”* material background fitting results compatible and more precise than HPGe assay



Research 2022, 9798721 (2022)

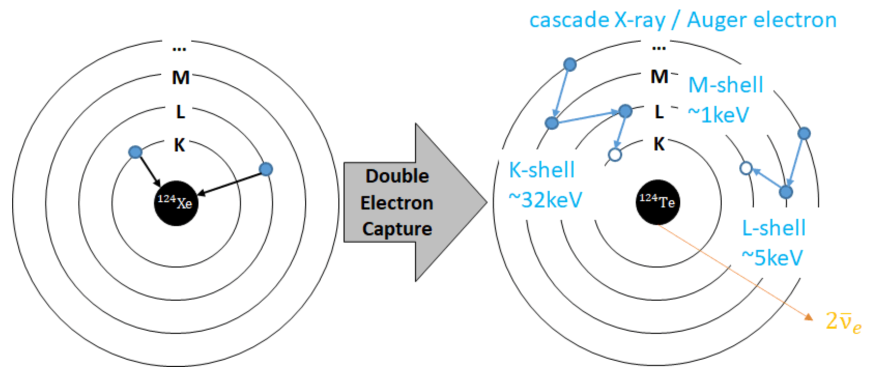
Material, “Side” category



^{124}Xe 2νECEC half-life measurement

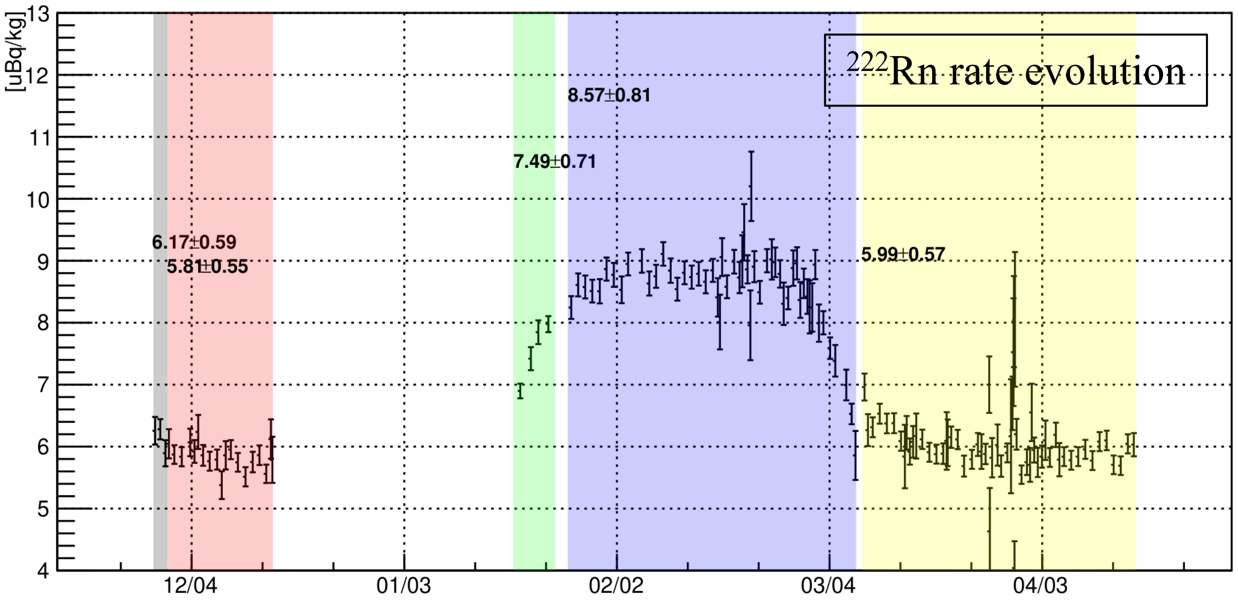
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

$$(A, Z) + 2e^- \rightarrow (A, Z-2) + (2\nu_e)$$

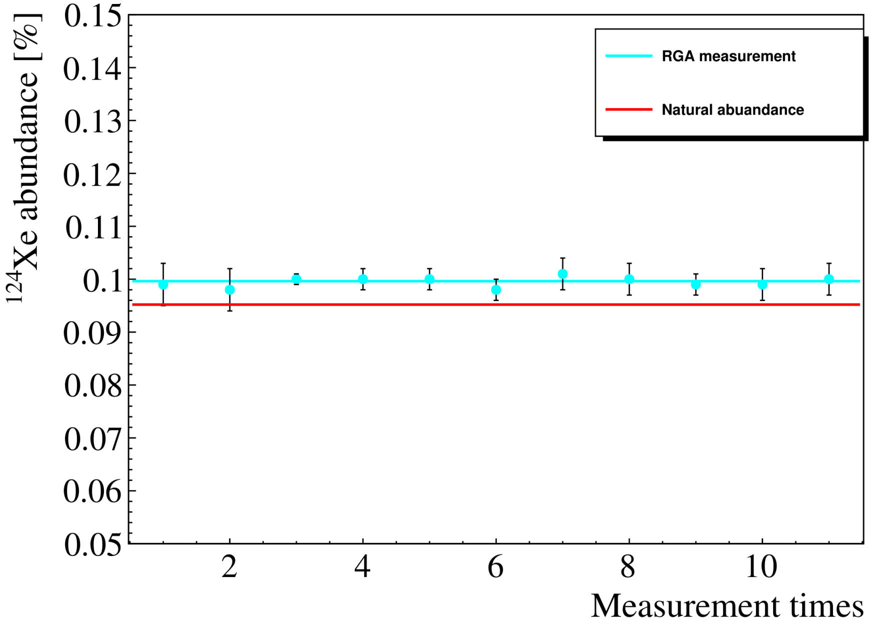


XENONnT recent result: $T_{1/2}$=$(1.18 \pm 0.13_{stat} \pm 0.14_{sys}) \times 10^{22}$ yr

PRL 129, 161805 (2022)



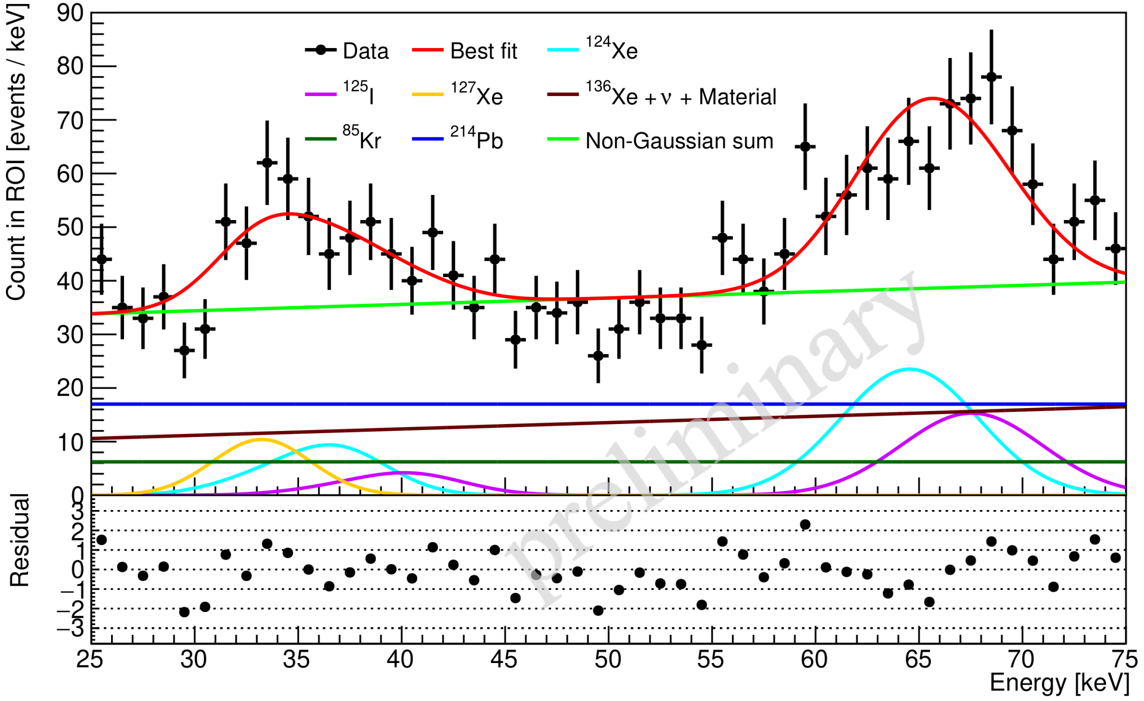
- Background time evolution is modeled and added to likelihood fitting
- Use commissioning Run0 open data to develop the method
- ^{124}Xe abundance measured as (0.100±0.001)%, larger than the natural abundance by ~5%

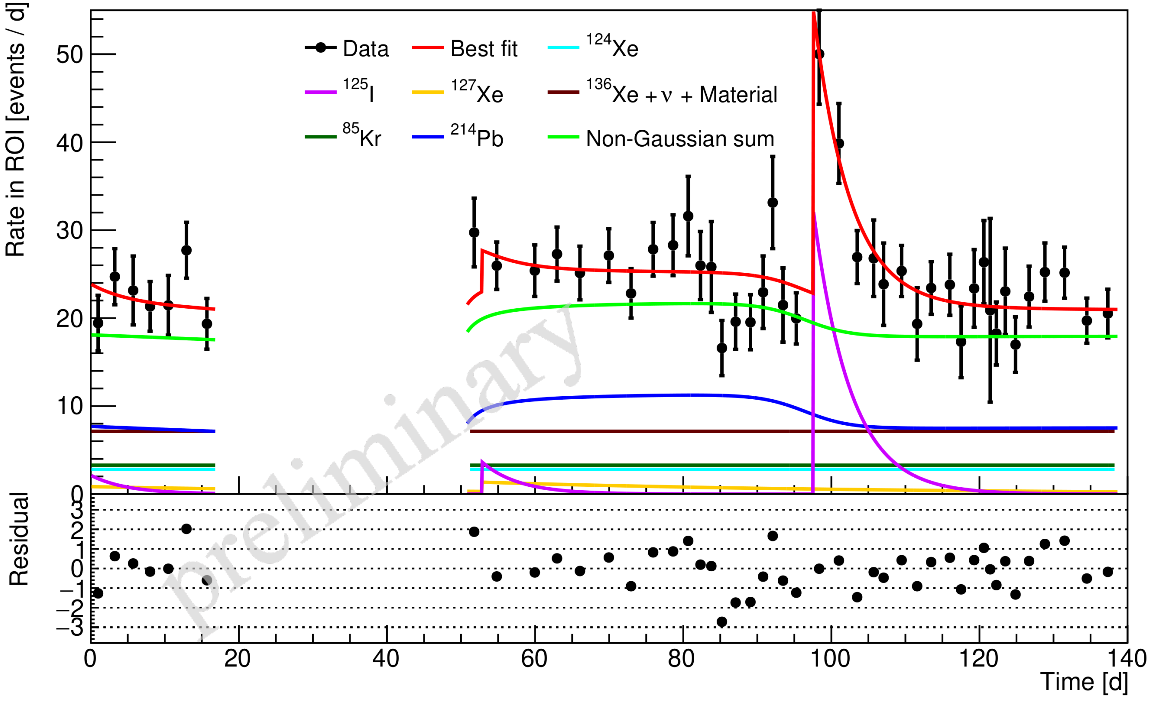


Energy spectrum + time evolution likelihood fit

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

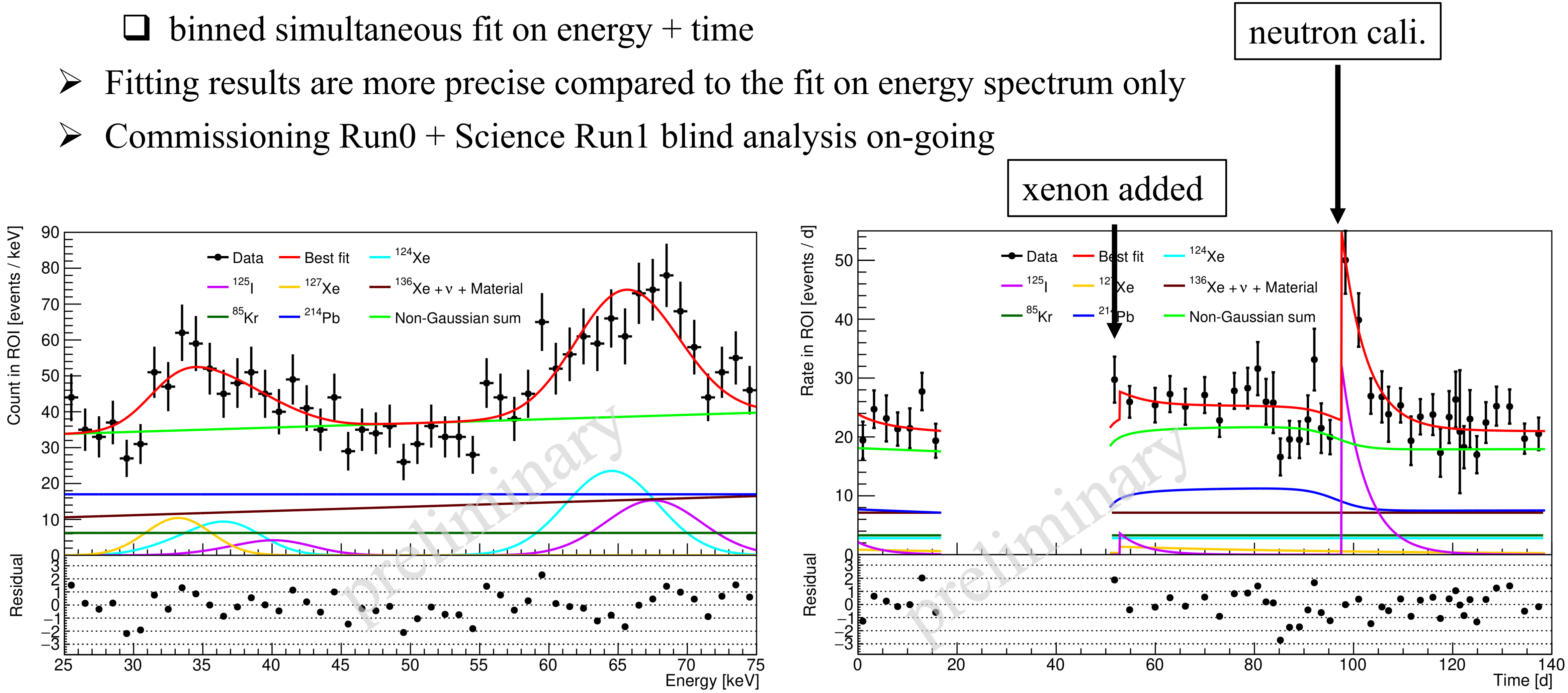
- Two fits were performed on Run0 open data for consistency check:
  - unbinned 2-dimentional fit on parameter space of (energy, time)
  - binned simultaneous fit on energy + time
- Fitting results are more precise compared to the fit on energy spectrum only
- Commissioning Run0 + Science Run1 blind analysis on-going



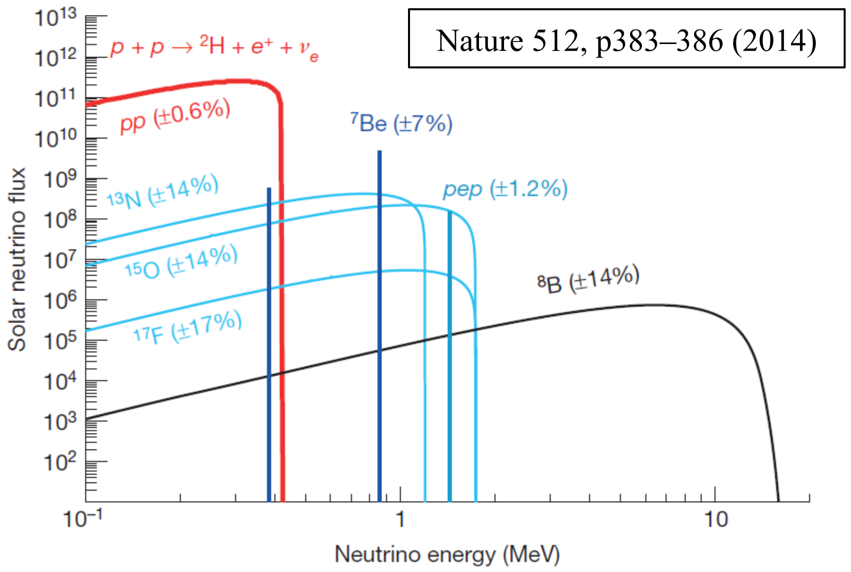


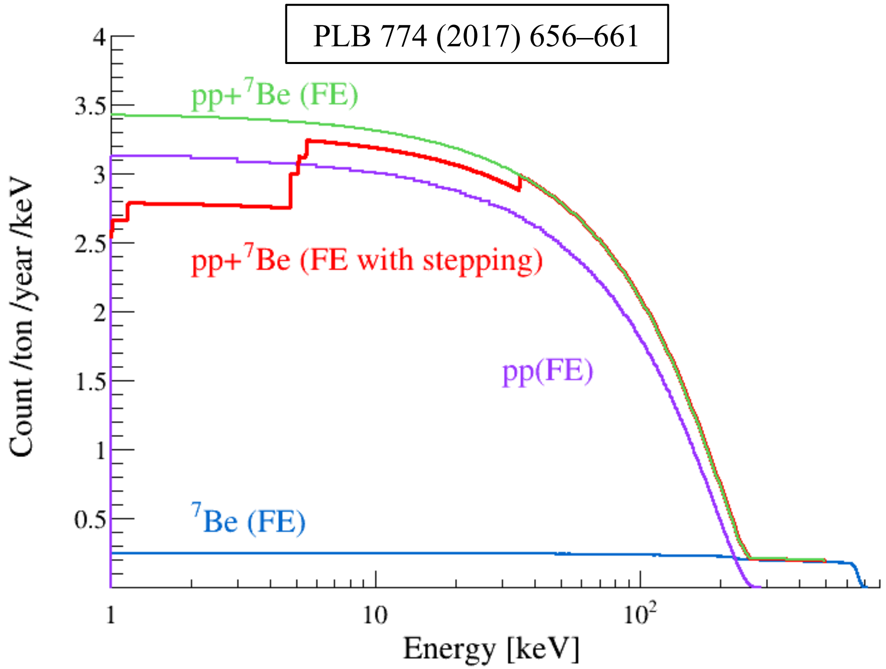
Energy spectrum + time evolution likelihood fit

- Two fits were performed on Run0 open data for consistency check:
  - unbinned 2-dimentional fit on parameter space of (energy, time)
  - binned simultaneous fit on energy + time
- Fitting results are more precise compared to the fit on energy spectrum only
- Commissioning Run0 + Science Run1 blind analysis on-going

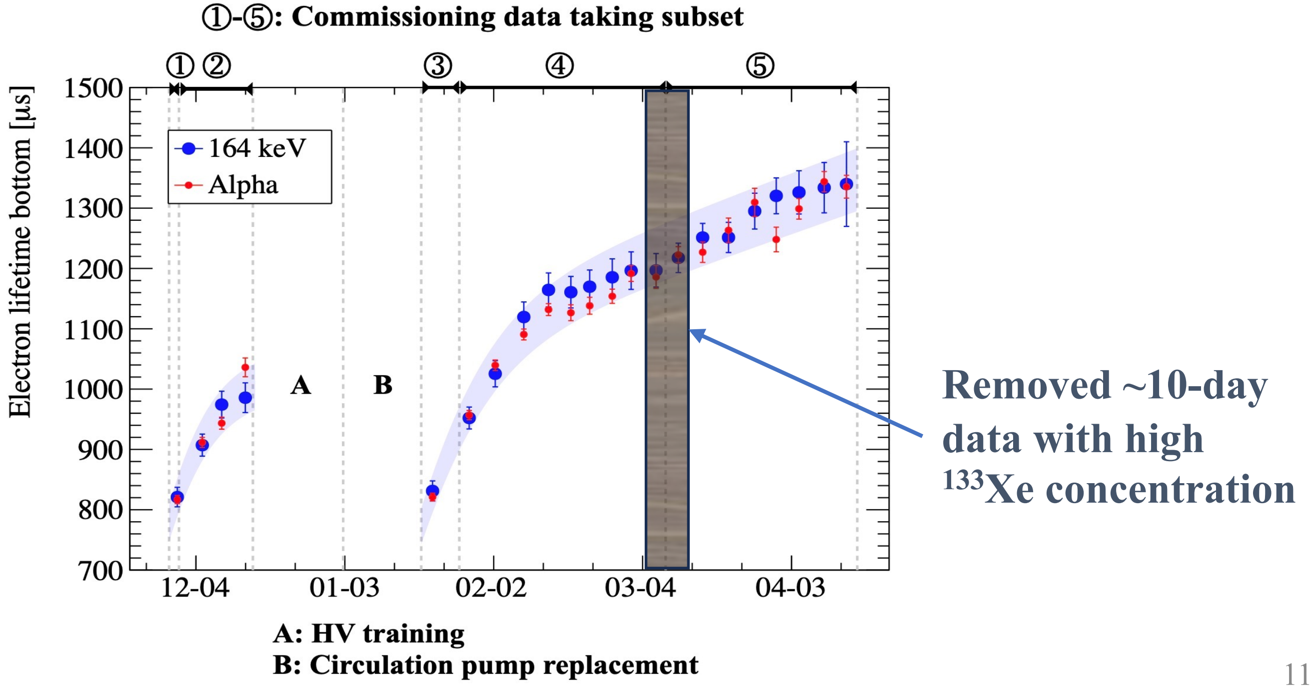


Search for solar pp + ^{7}Be neutrinos

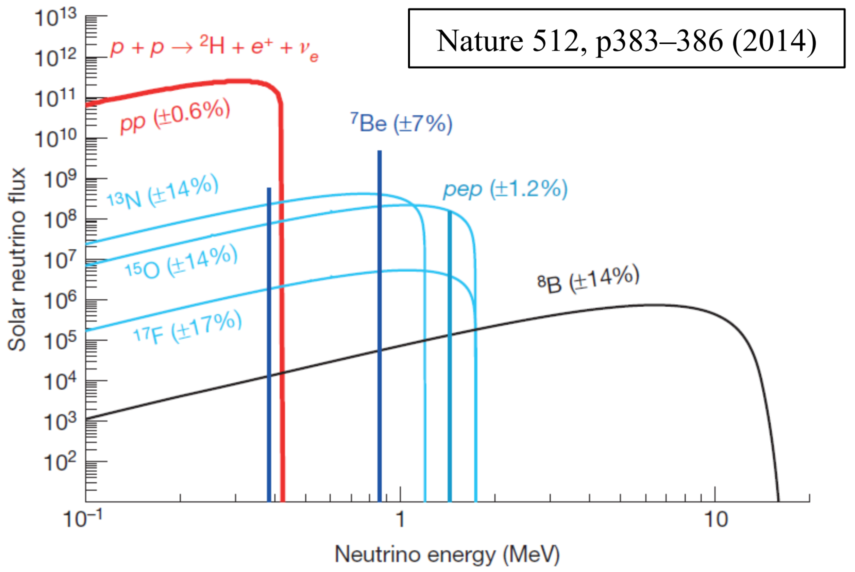




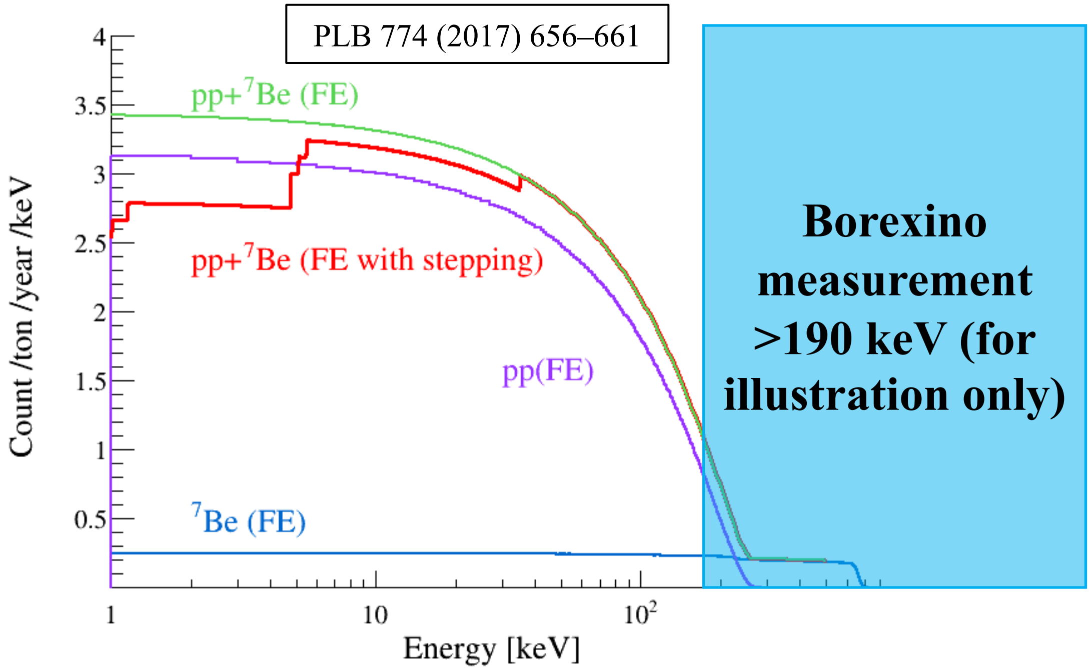
- Binding energy of electron shell of xenon atoms has been taken into account when generating the recoiled electron energy spectrum.
- Commissioning Run0, excluding ~10-day data right after neutron calibrations to avoid high ^{133}Xe concentration.
- Same FV as of our first WIMP search, with optimized energy reconstruction.

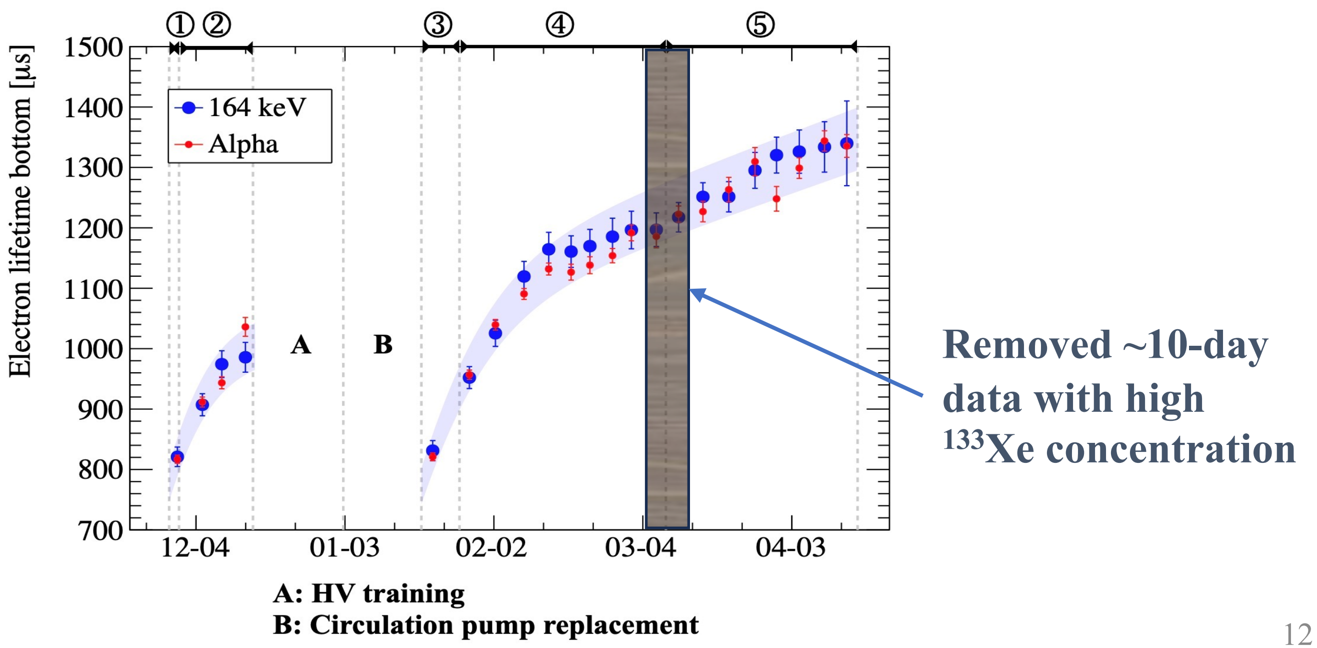


Search for solar pp + ^{7}Be neutrinos



- Binding energy of electron shell of xenon atoms has been taken into account when generating the recoiled electron energy spectrum.
- Commissioning Run0, excluding ~10-day data right after neutron calibrations to avoid high ^{133}Xe concentration.
- Same FV as of our first WIMP search, with optimized energy reconstruction.

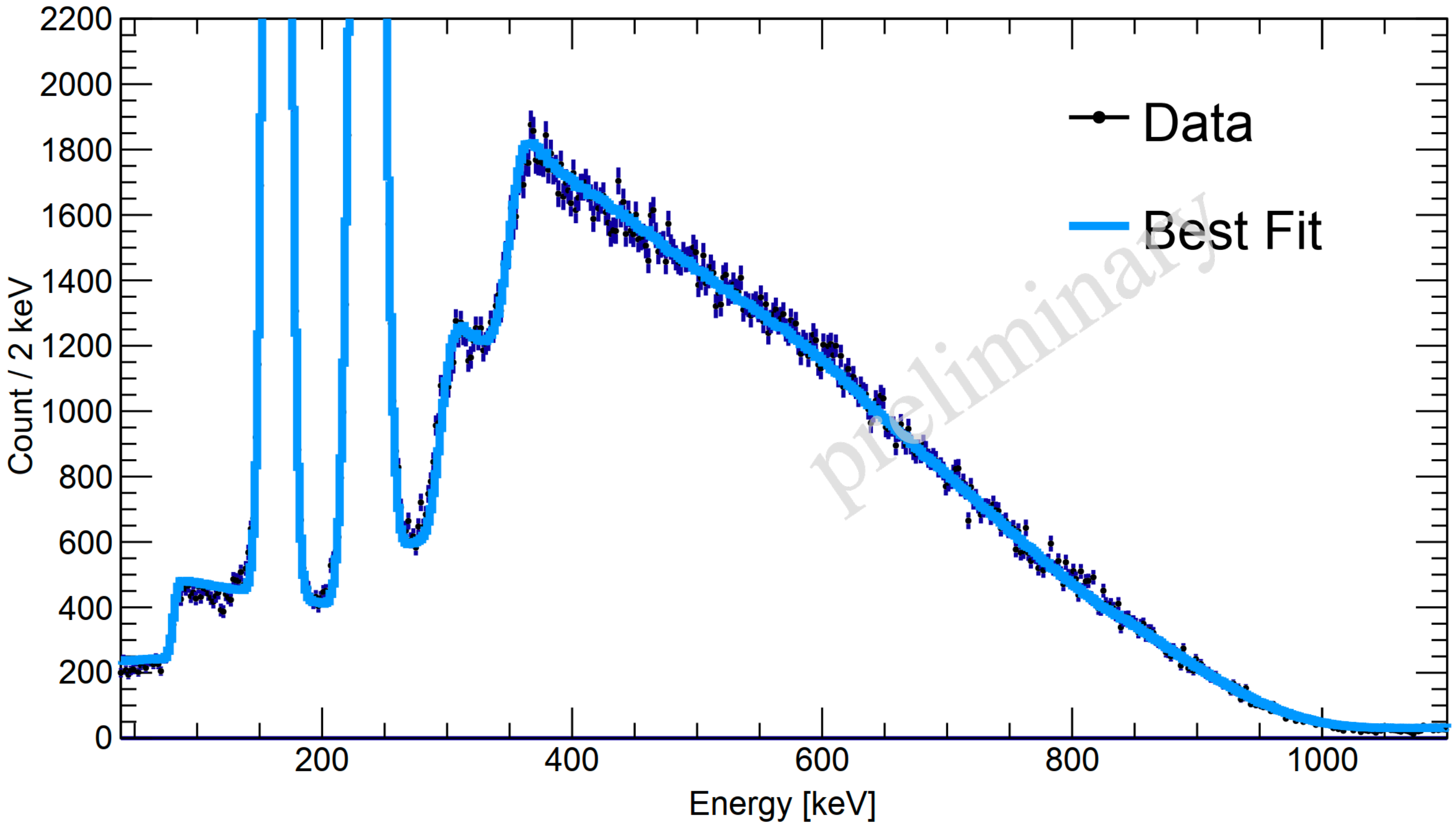




^{214}Pb spectrum fitting on ^{222}Rn calibration data

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

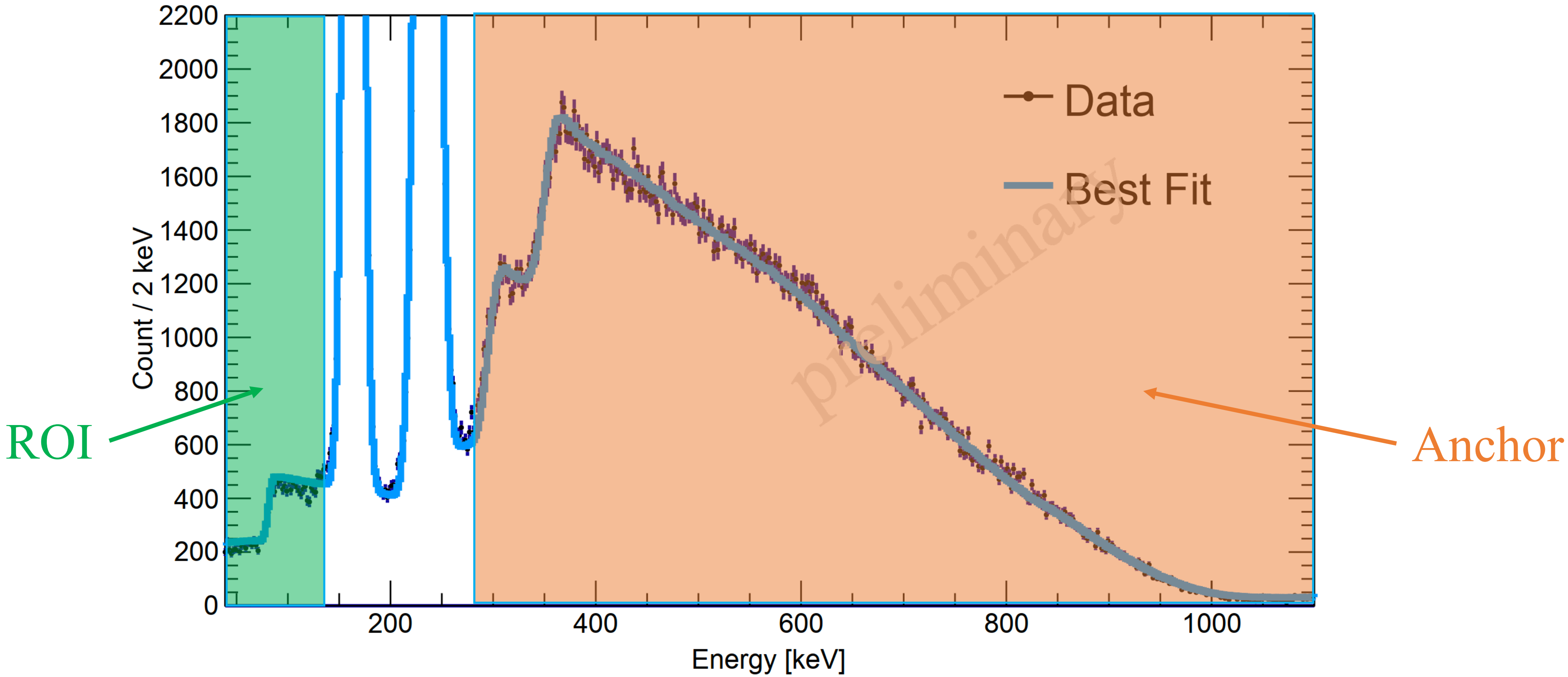
- Dedicated ^{222}Rn calibration campaign was carried out to measure ^{214}Pb spectrum *in-situ*.
- ^{222}Rn activity ~1 mBq/kg, 100x higher than science data.
- Fit was performed with ^{214}Pb decay branching ratios floating.
- Measured ^{214}Pb spectrum is then used in the fit on science data to estimate ^{214}Pb level.



^{214}Pb spectrum fitting on ^{222}Rn calibration data

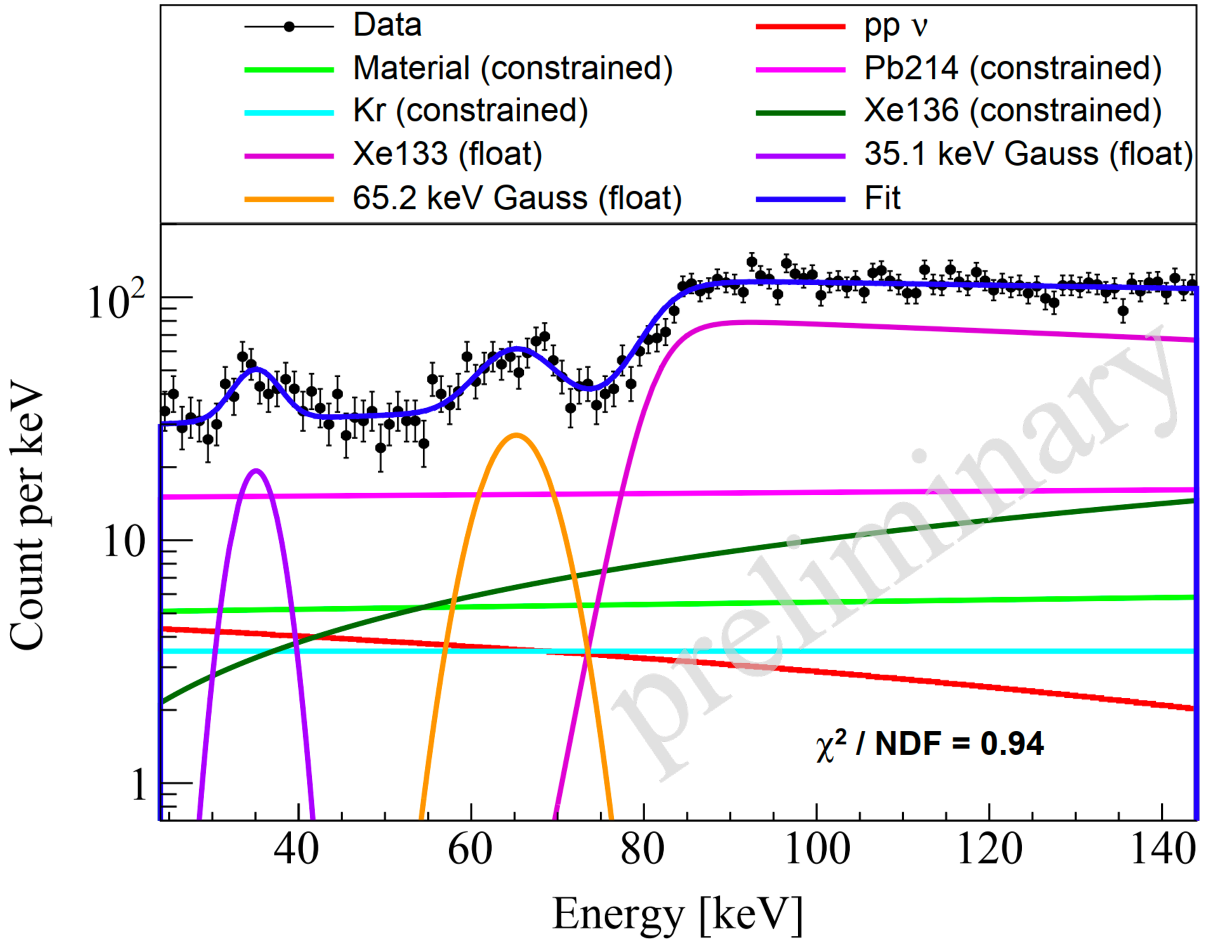
PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- Dedicated ^{222}Rn calibration campaign was carried out to measure ^{214}Pb spectrum *in-situ*.
- ^{222}Rn activity ~1 mBq/kg, 100x higher than science data.
- Fit was performed with ^{214}Pb decay branching ratios floating.
- Measured ^{214}Pb spectrum is then used in the fit on science data to estimate ^{214}Pb level.



Preliminary solar pp + ^{7}Be neutrinos measurement

ROI chosen as [24, 144] keV

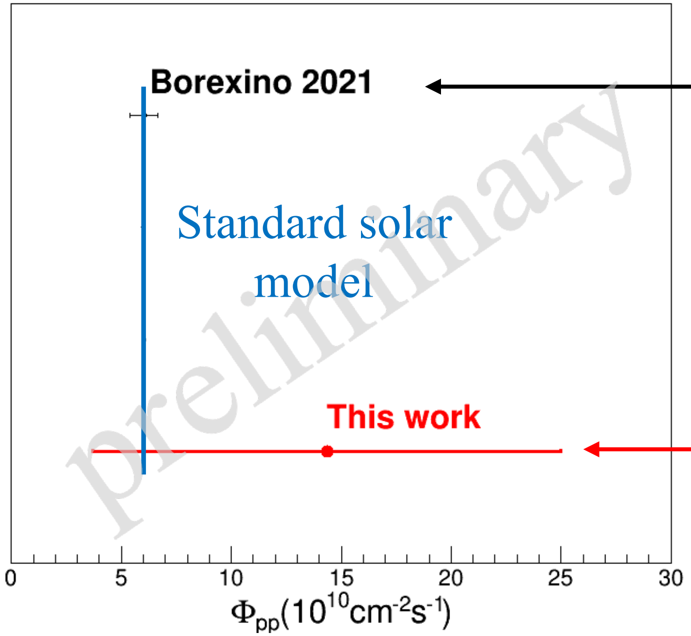


Constrained from higher energy fits or dedicated studies:

- Pb214 (10% constraint)
- Material (12.5% constraint)
- ^{136}Xe $2\nu\beta\beta$ (4.6% constraint)
- ^{85}Kr (51% constraint)

Float:

- 35 keV single gaussian peak (^{127}Xe + ^{124}Xe + ^{125}I)
- 65 keV single gaussian peak (^{124}Xe + ^{125}I)
- ^{133}Xe (simulated spectrum)



The current best measurement with threshold of 190 keV

A first measurement below 190 keV

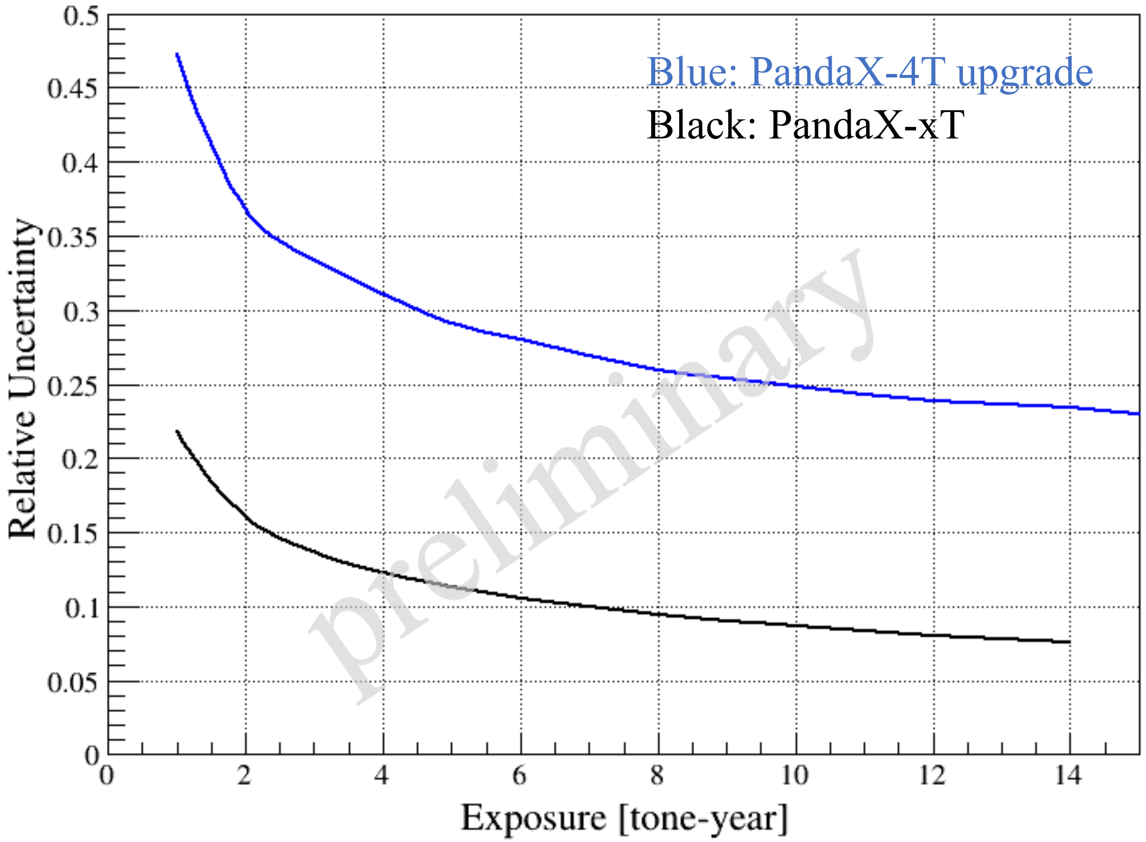
Solar pp + ^{7}Be neutrinos sensitivity for the future

- PandaX-4T: ^{222}Rn ~3.5 uBq/kg, ^{85}Kr ~0.25 ppt, with uncertainty <5%

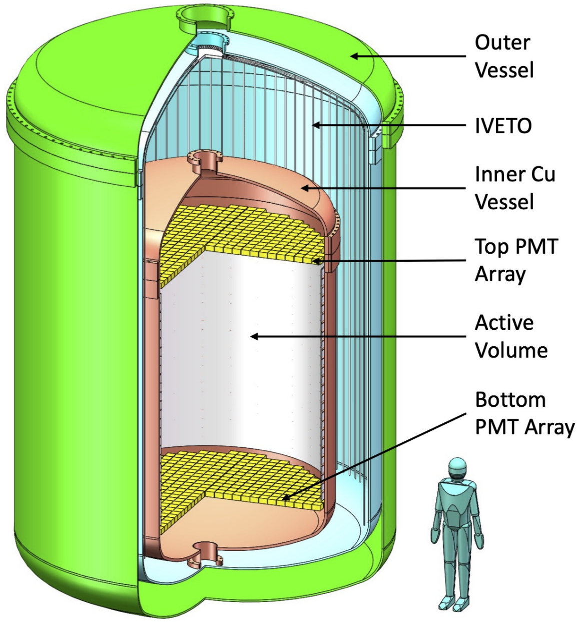
  => pp solar neutrino flux measurement uncertainty: ~28% @ 6 ton·year

- PandaX-xT: ^{222}Rn ~0.5 uBq/kg, ^{85}Kr ~0.01 ppt, with uncertainty <2%

  => pp solar neutrino flux measurement uncertainty: <10% @ 8 ton·year



PandaX-xT:
multi-ten ton liquid xenon project at CJPL-II



Summary

PANDA X
PARTICLE AND ASTROPHYSICAL XENON TPC

- PandaX-4T has extended the energy range from keV to MeV with dedicated analysis pipeline and calibration campaign, and therefore extended the physics reach from DM to neutrino.
- ^{136}Xe 2νββ half-life is precisely measured for the first time by a natural xenon detector, with much lower analysis threshold and robust background control, demonstrating the physics potential of large liquid xenon TPC on multiple fronts.
- pp solar neutrino flux is being measured with recoil energy below 190 keV for the first time.
- On-going analysis of double-weak decays: ^{124}Xe 2νECEC, ^{134}Xe 2νββ / 0νββ, ^{136}Xe 0νββ, etc.

Thank you!

Stay tuned!