MC Simulation with BambooMC in PandaX

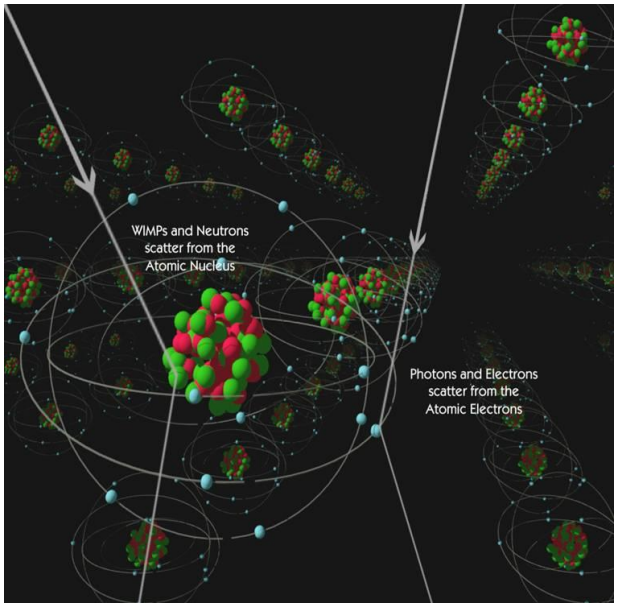
Xun Chen (谌勋)
INPAC, Department of Physics and Astronomy

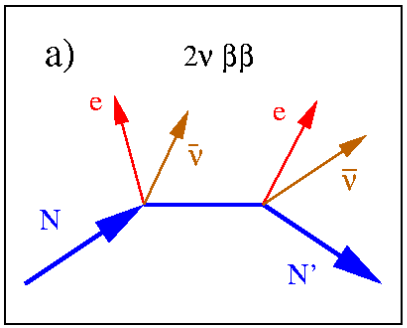
上海交通大學
SHANGHAI JIAO TONG UNIVERSITY

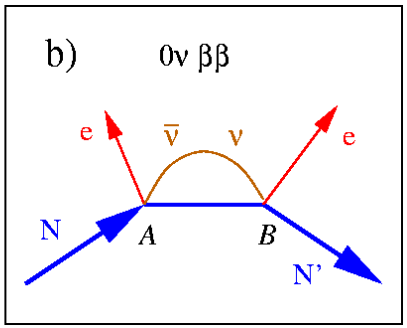
Sep 13, 2016

Searching for Rare Events

- Search for Dark Matter WIMP or 0νββ events
- Need to distinguish the signal from background
- What does the background look like?
- Geant4 based Monte Carlo simulation provide one answer.







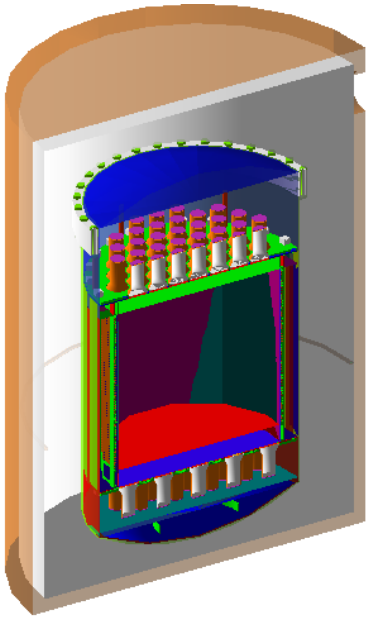
Geant4 based simulation program

- Requirement for the application developer
  - Define of the Detector Geometry
  - Declaration of required Physics Processes
  - Define of the Particle Generator (External or Internal)
  - Define how the data are presented
- One need do it by herself.
- In general, different programs are required for different purpose

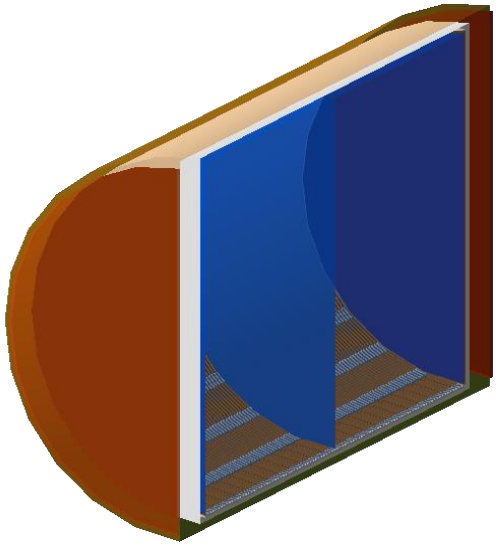
BambooMC

- A modular MC simulation program base on Geant4 used in PandaX experiments.
- Designed to be used as a simple framework for different experiments.
- Modular - It is possible to combine different geometry, physics, generator, analysis in one program.

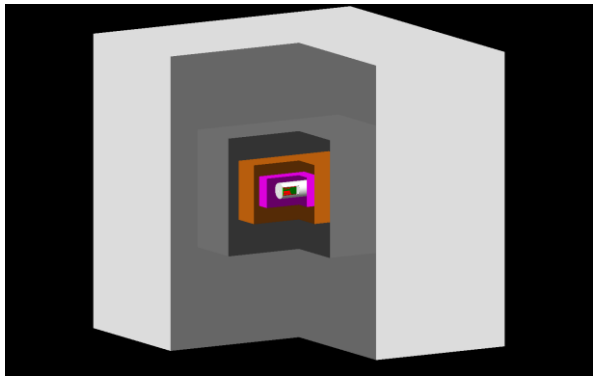
BambooMC for PandaX



PandaX-II detector



PandaX-III detector



PandaX counting station

Organize Components with XML

```xml
<?xml version="1.0" encoding="UTF-8"?>
<BambooMC>
  <run number="9001"/>
  <geometry>
    <material name="PandaXIIIMaterial"/>
    <detector name="SimpleLabWall">
      <parameter name="length" value="20*m"/>
      <parameter name="width" value="15*m"/>
      <parameter name="height" value="12*m"/>
      <parameter name="visible" value="0"/>
    </detector>
    <detector name="WaterShield" parent="PandaXSimpleWaterShield">
      <parameter name="shape" value="1"/>
      <parameter name="length" value="12"/>
      <parameter name="width" value="11.5"/>
      <parameter name="height" value="11.5"/>
      <parameter name="counting_flux_in" value="0"/>
    </detector>
    <detector name="HpXenonGasDetector" parent="WaterShield">
      <parameter name="vessel_inner_radius" value="750*mm"/>
      <parameter name="vessel_inner_height" value="2000*mm"/>
      <parameter name="vessel_barrel_thickness" value="30*mm"/>
      <parameter name="vessel_end_thickness" value="150*mm"/>
    </detector>
  </geometry>
  <physics name="SimpleUnderGroundPhysics">
    <parameter name="cutlength" value="0.1*mm"/>
  </physics>
  <generator name="SimpleGPSGenerator"/>
  <analysis name="PandaXAnalysis">
    <parameter name="EnableEnergyDeposition" value="1"/>
    <parameter name="EnableFlatSurfaceFlux" value="0"/>
    <parameter name="enable_primary_particle" value="1"/>
    <parameter name="save_null_event" value="0"/>
    <parameter name="enable_decay_chain_splitting" value="1"/>
    <parameter name="enable_save_random_seed" value="1"/>
  </analysis>
</BambooMC>
```

Geometry: define material, detectors, and the hierarchy of detectors

Physics: define the physics processes used in simulation

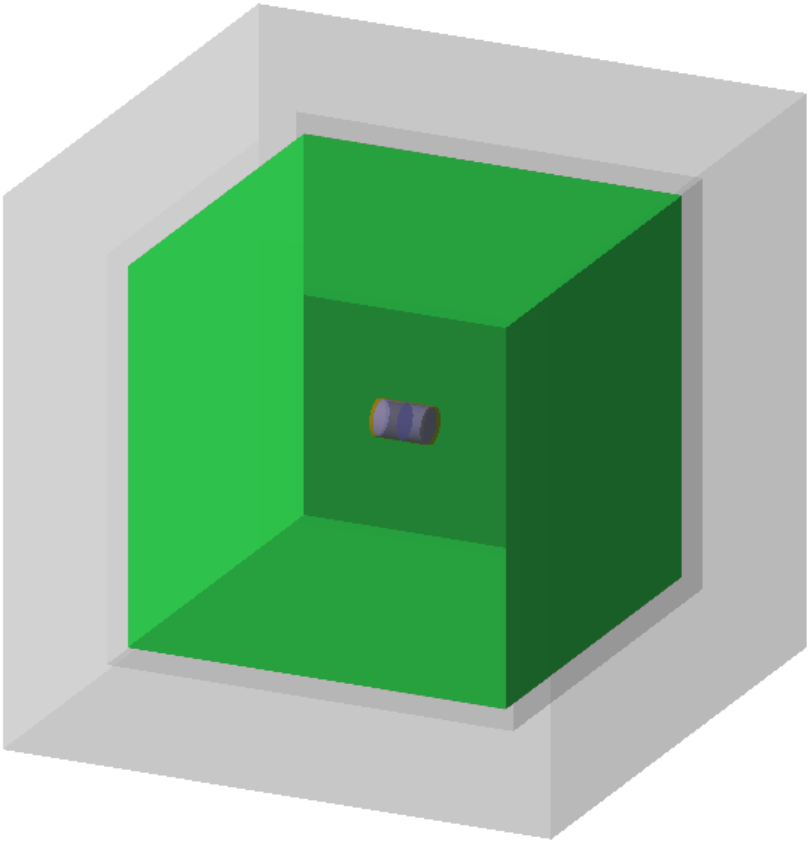
Generator: How do the initial particles be generated.

Analysis: mainly for the organization of output file.

Geometry Definition in BambooMC

- Currently only CSG geometry supported.
- Create a class inherited from BambooDetectorPart
- Implement the construct() function
  - Do things as usual in Geant4: soild - logical volume - physical volume
  - Logical volume may be placed in the parent container logical volume
  - If the detector may have daughters, define the it's own container logical volume

An example of the detector



```
<geometry>
  <material name="PandaXIIIMaterial"/>
  <detector name="SimpleLabWall">
    <parameter name="length" value="20*m"/>
    <parameter name="width" value="15*m"/>
    <parameter name="height" value="12*m"/>
    <parameter name="visible" value="0"/>
  </detector>
  <detector name="WaterShield" parent="PandaXSimpleWa
    <parameter name="shape" value="1"/>
    <parameter name="length" value="12"/>
    <parameter name="width" value="11.5"/>
    <parameter name="height" value="11.5"/>
    <parameter name="counting_flux_in" value="0"/>
  </detector>
  <detector name="HpXenonGasDetector" parent="WaterSh
    <parameter name="vessel_inner_radius" value="750*
    <parameter name="vessel_inner_height" value="2000
    <parameter name="vessel_barrel_thickness" value="
    <parameter name="vessel_end_thickness" value="150
  </detector>
</geometry>
```

Physics Selection

- For PandaX: SimpleUndergroundPhysics
  - Following the suggestion of “Shielding” in http://geant4.cern.ch/support/proc_mod_catalog/physics_lists/useCases.shtml
  - Replace “G4EMStandardPhysics” to “G4EmLivermorePhysics”
  - Other physics processes in this class
    - decay, radioactive decay, hadron elastic, hadron shielding (neutron inelastic process), stopping, interaction between ions
- Geant4 packaged physics can be specified in xml file directly
  - Example: FTFP_BERT

Event Generator

- In collider experiments, we always use events generated by programs from theorists.
  - PYTHIA, WHIZARD …
  - Particle gun is used for simple detector validation.
- In underground experiments, study the backgrounds from the radioactive isotopes in environment and detector components is important.
  - We packed “General Particle Source” in Geant4

General Particle Source

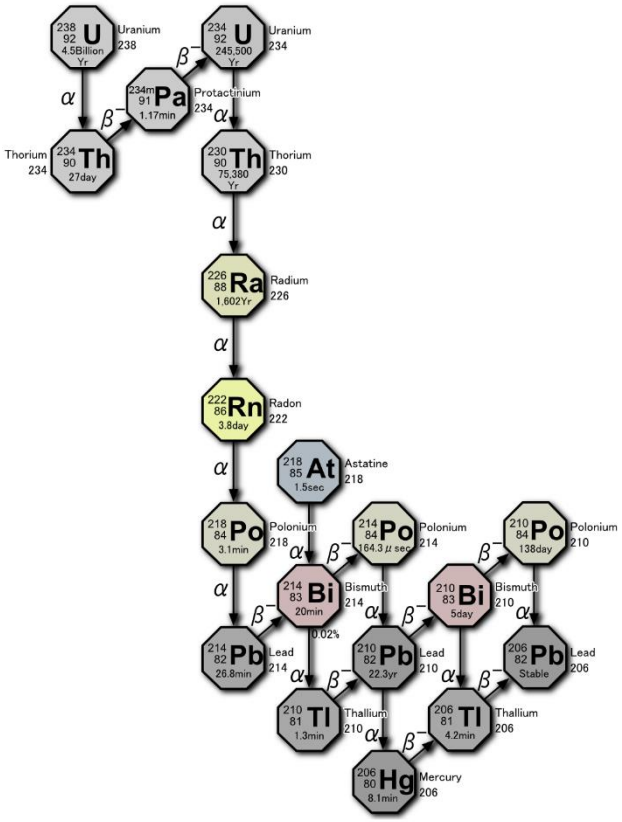
- https://geant4.web.cern.ch/geant4/UserDocumentation/UsersGuides/ForApplicationDeveloper/html/ch02s07.html
- Primary vertex type: point, plane, volume…
- Angular emission: isotropic, cosine law, focused…
- Kinetic energy: mono-energetic, black body, user defined
- Multiple source
- A set of commands provided

Analysis

- PandaXAnalysis
  - ROOT based output
  - Mostly to record the energy depositions details in the sensitive detector
  - Able to record the flux passing through the surface of box shaped geometries.
  - Possible to record the information of primary particles (MCTruth)
- Feature:
  - Splitting the long decay chain into different events

Long decay chain splitting

- Backgrounds from the decay chain from ^{238}U, ^{232}Th are mostly studied.
  - Ions of ^{238}U, ^{232}Th are used as particle source
  - Geant4 will do the rest until stable ^{210}Pb is reached
  - Double precision is not enough to distinguish the different time of the decays in the chain.
  - PandaXAnalysis can put an ion at rest into next saved entry and reset the time.



Water Shielding in PandaX-III

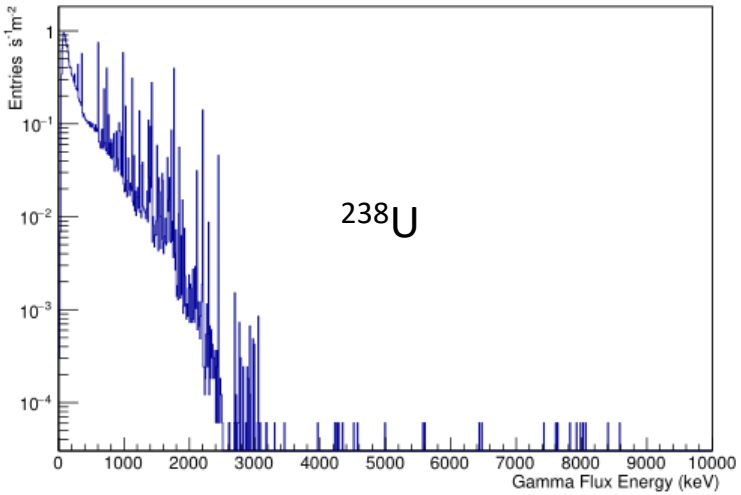
- PandaX-III and PandaX-xT will use a large water pool to shield the radiation from the laboratory (mostly from the concrete wall of 60 cm)

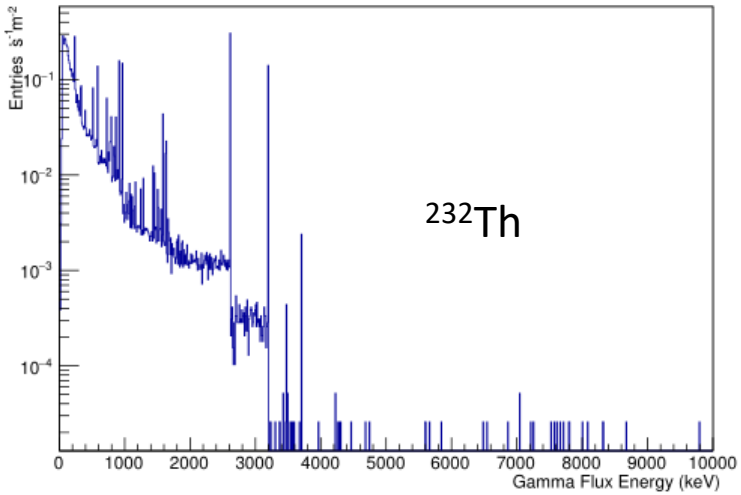
Is the water pool large enough?

You cannot simply generating events in the concrete and count the events inside the detector - very low efficiency!

Flux from the wall

- Gamma Flux from the concrete wall
  - ^{238}U and ^{232}Th in the concrete
  - Record gamma flux entering into the surface of the water pool (with PandaXAnalysis)

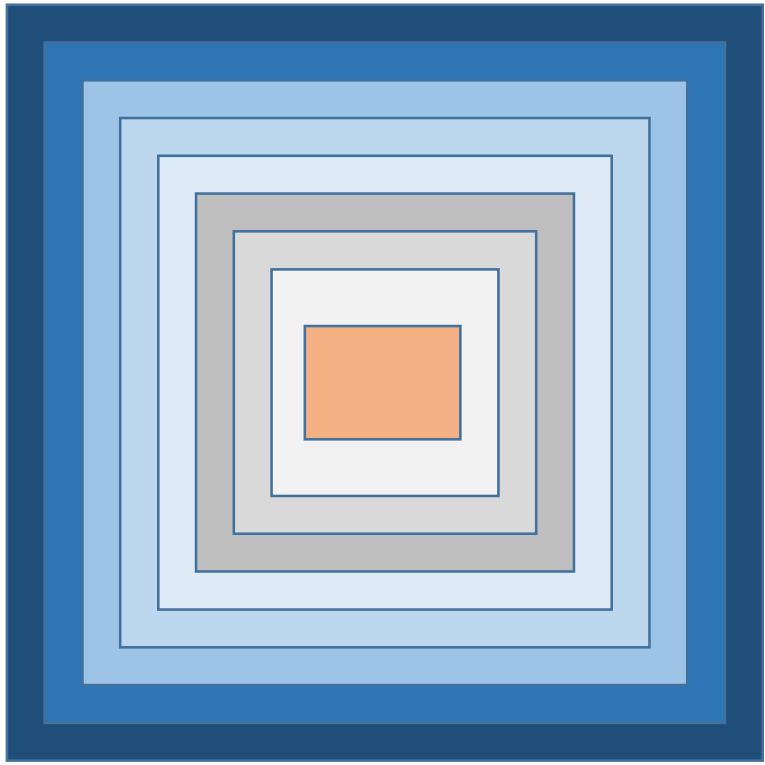




The spectra are used as an input for further simulation.

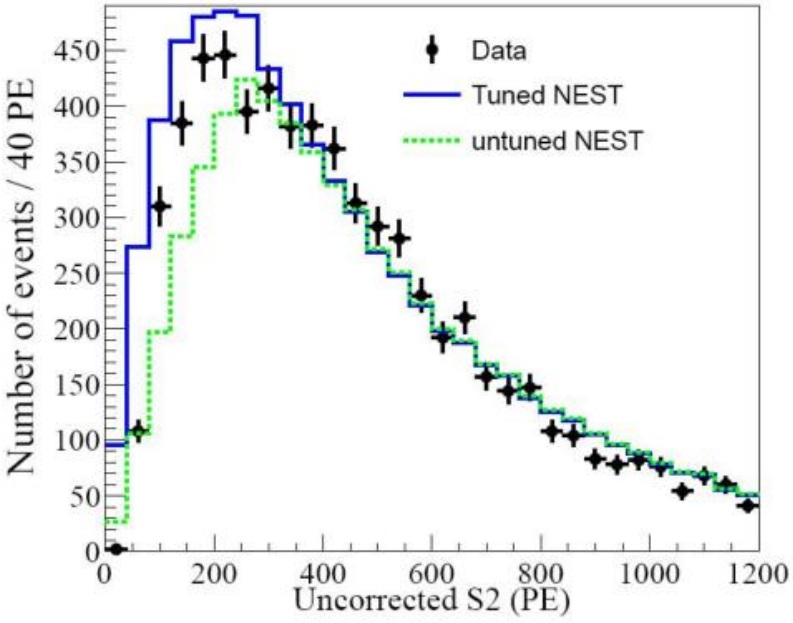
Layer by layer

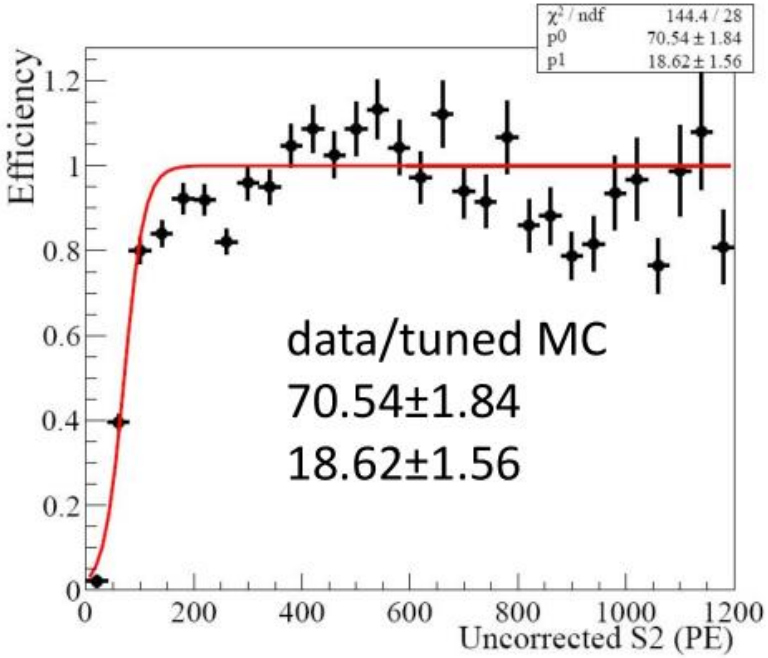
- Iteration from outside to inside
- Flux from outer layer as the input of inner layer
- Sample more flux based on the input
- Record the flux entering the next inner layer
- Simple calculation:
  - 1M at outermost, multiply by 10 for each iteration
  - 7 layers ➔ effective sample size increased by 7 orders



Other topics in PandaX

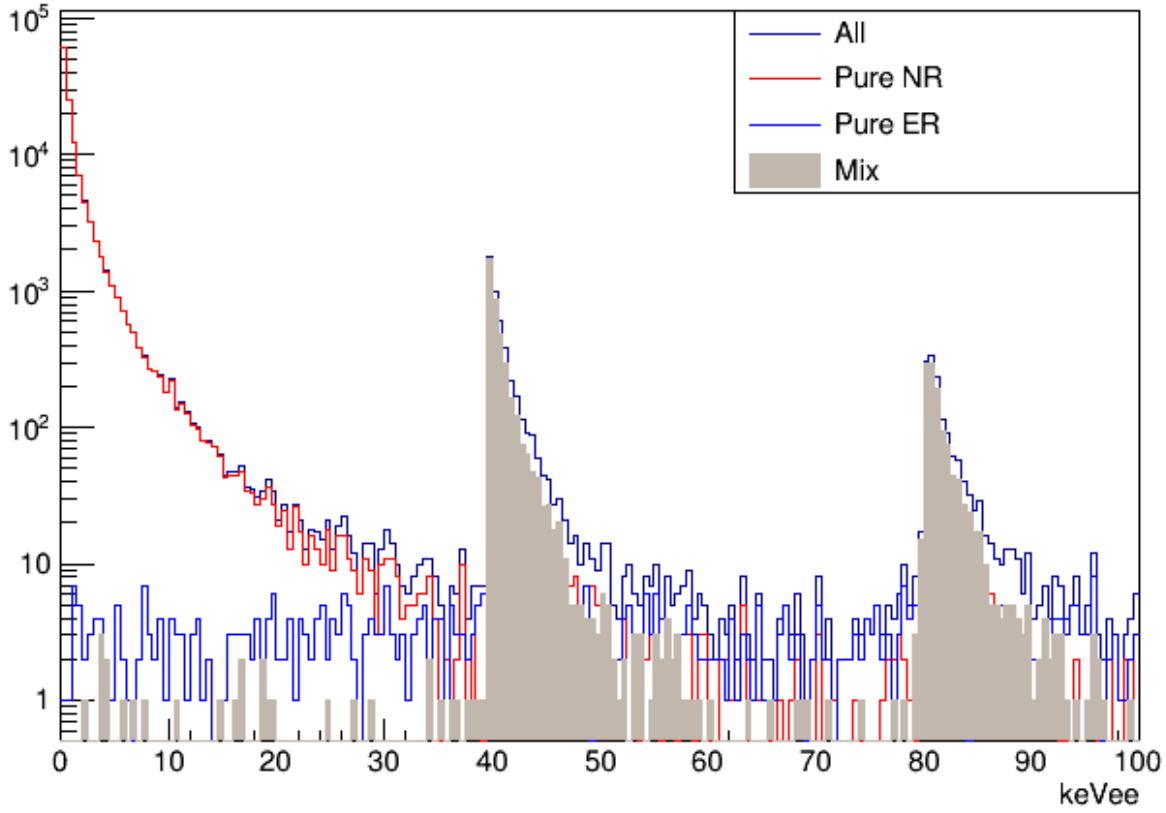
- PandaX-II: detection efficiency





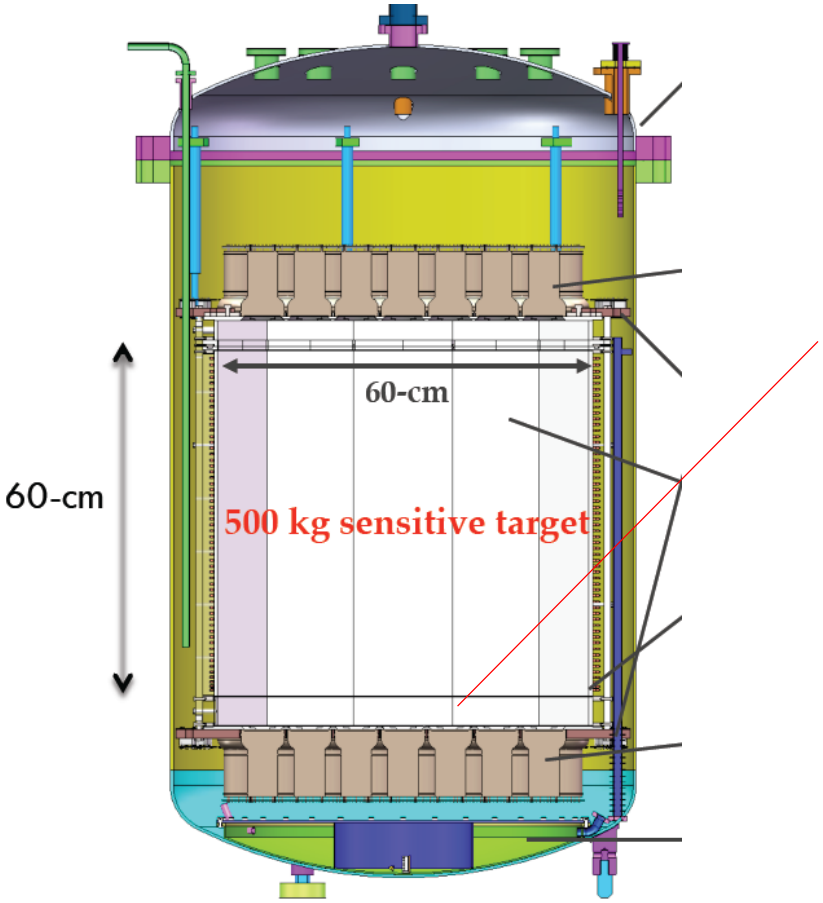
Convert the energy deposition into S1/S2 with additional model.

PandaX dark matter: Understand the detector response



^{252}Cf calibration:
The comparison between MC and calibration data can help use to understand the detector response

X-events



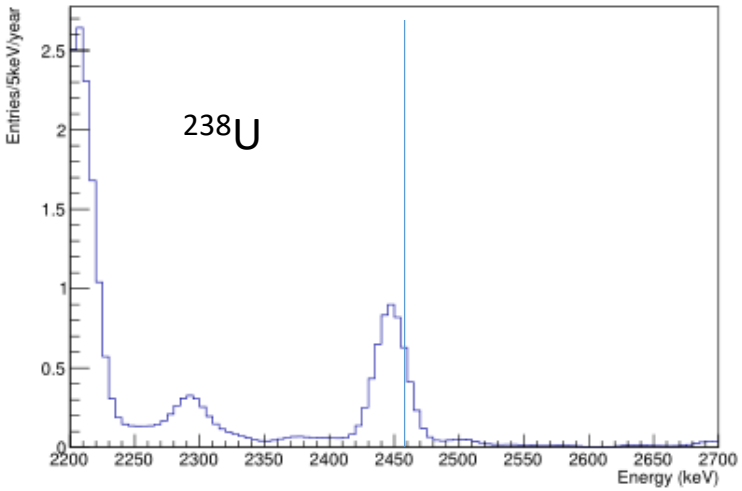
Events below the cathode will only generate S1. If secondary scattering occur in this region, the recorded event may have one S1 and lower S2, looks like a good nuclear recoil event.

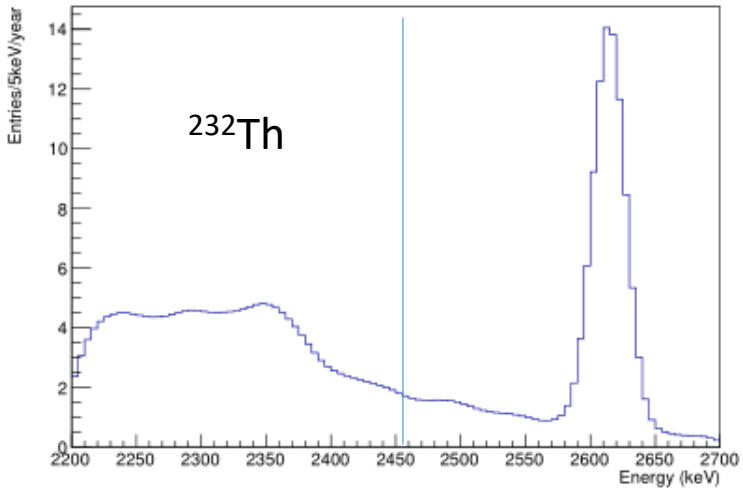
MC can help to understand the effect of “X” events.

PandaX-III: background budget

Understand the background contribution from different parts of the detector.

Signal Q value = 2457.83 keV





Outlook

- BambooMC will be released soon in github.
- Some new features are being considered:
  - Load GDML in geometry definition
  - Multi-threads support (with Geant4.10.p02)
  - Better chain splitting.