Simulation of Low-energy Calibration using Geant4 in Search of Reactor Neutrino Coherent Scattering

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On behalf of the RELICS Collaboration

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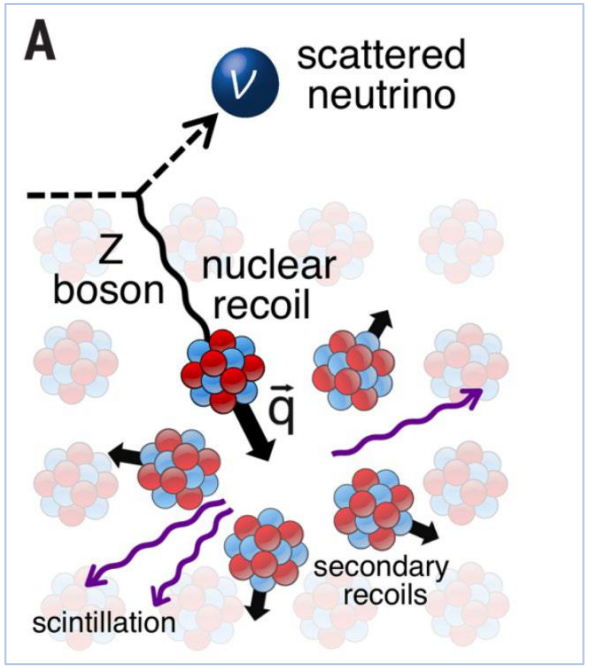
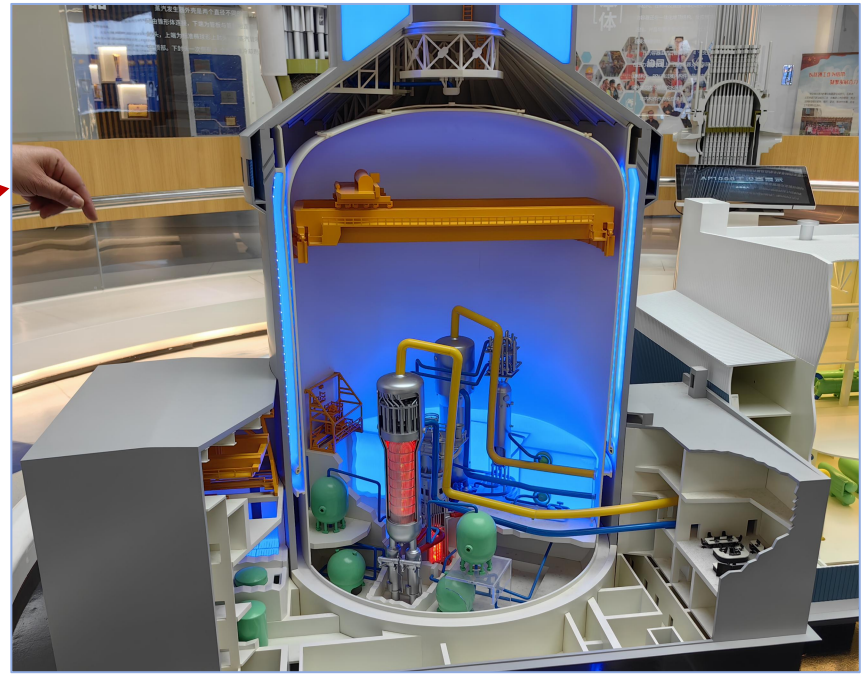
CEvNS &RELICS experiment

REactor neutrino LIquid xenon Coherent Scattering ---- RELICS

Coherent Elastic Neutrino-Nucleus Scattering ---- CEvNS





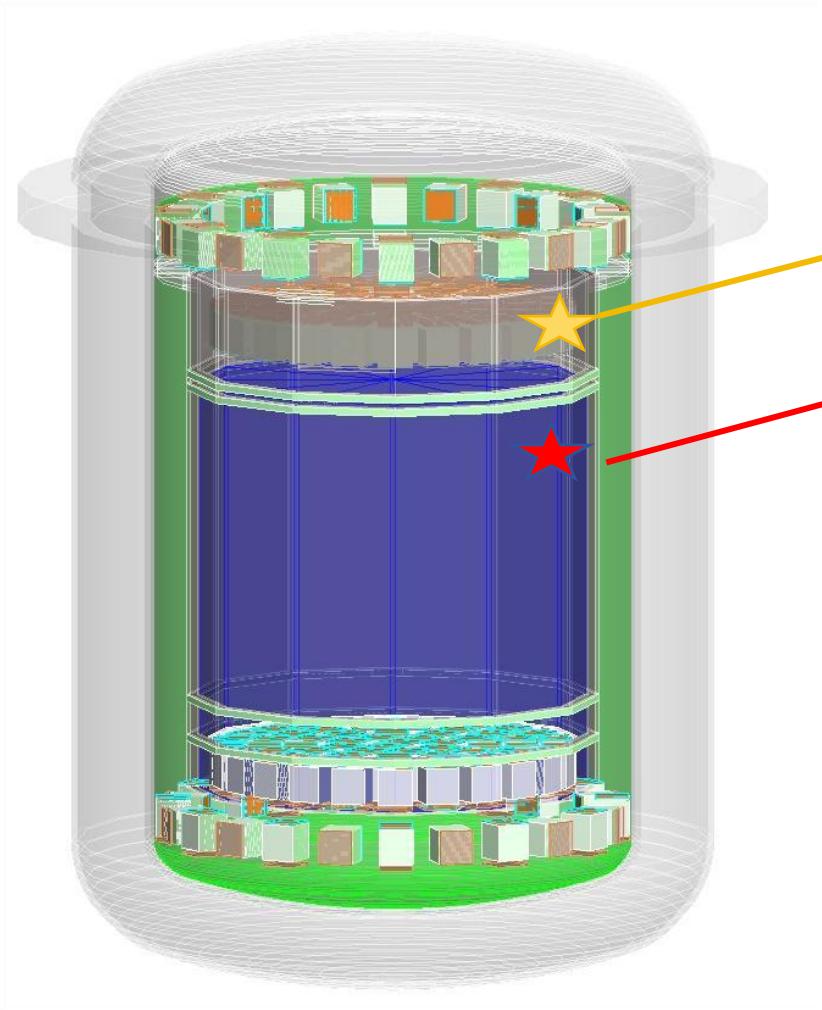
arXiv:1708.01294

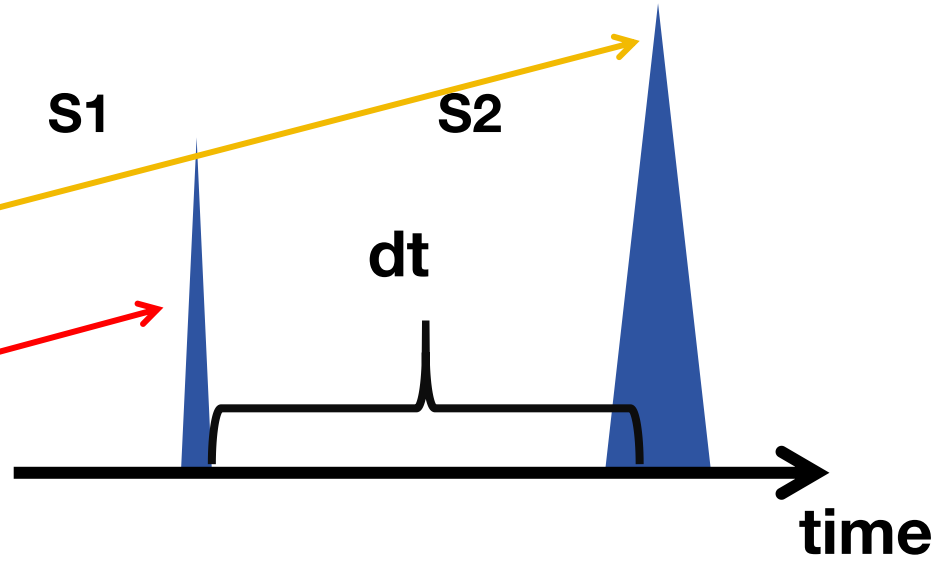
$$\sigma \propto Q_W^2 \propto (N - (1 - 4\sin^2\theta_W)Z)^2$$

$$\Longrightarrow \boxed{\sigma \propto N^2}$$

- Power ~ **3GW**
- Distance to Core ~ **25m**
- Expected ν flux ~ $\mathbf{10^{13}\nu/cm^2/s}$

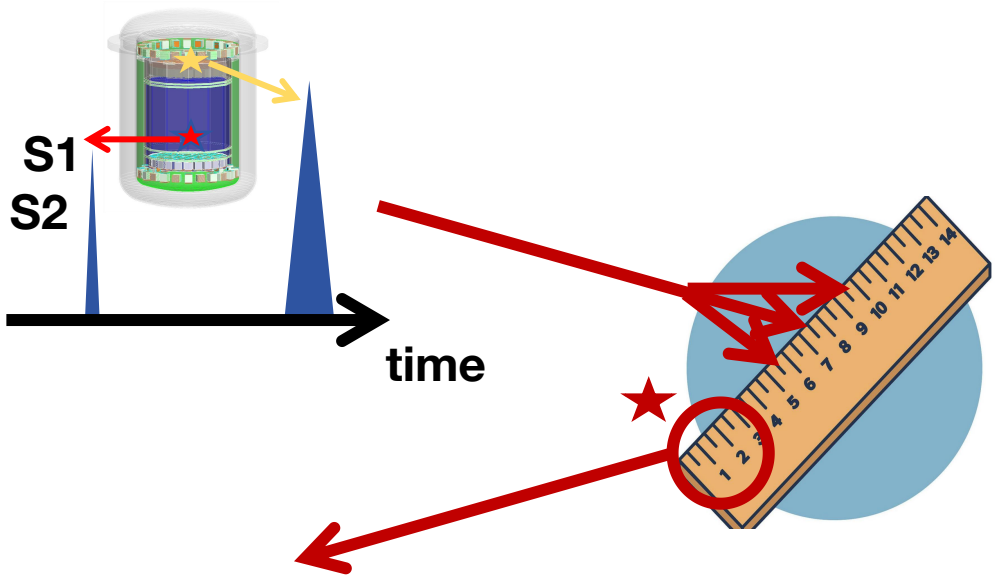
RELICS experiment

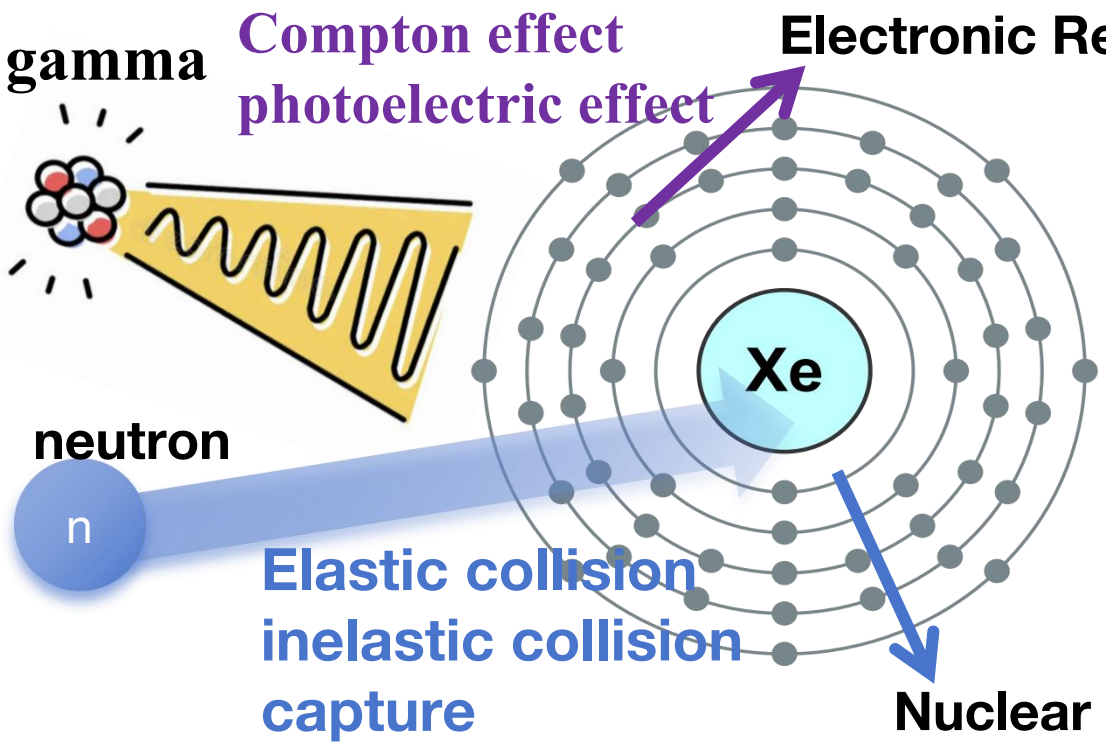


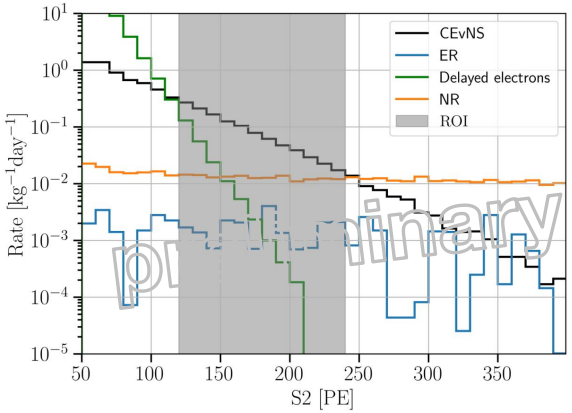


- large sensitive volume
- low-background
- low threshold
- 3D-Reconstruction

Calibration in RELICS



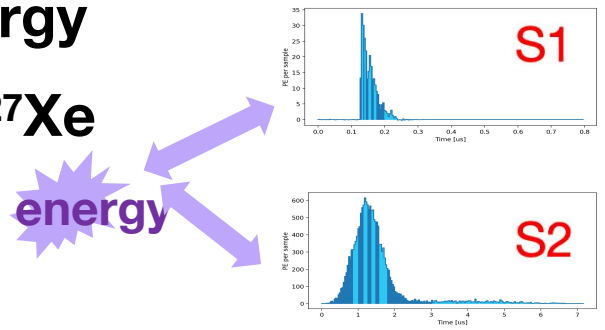




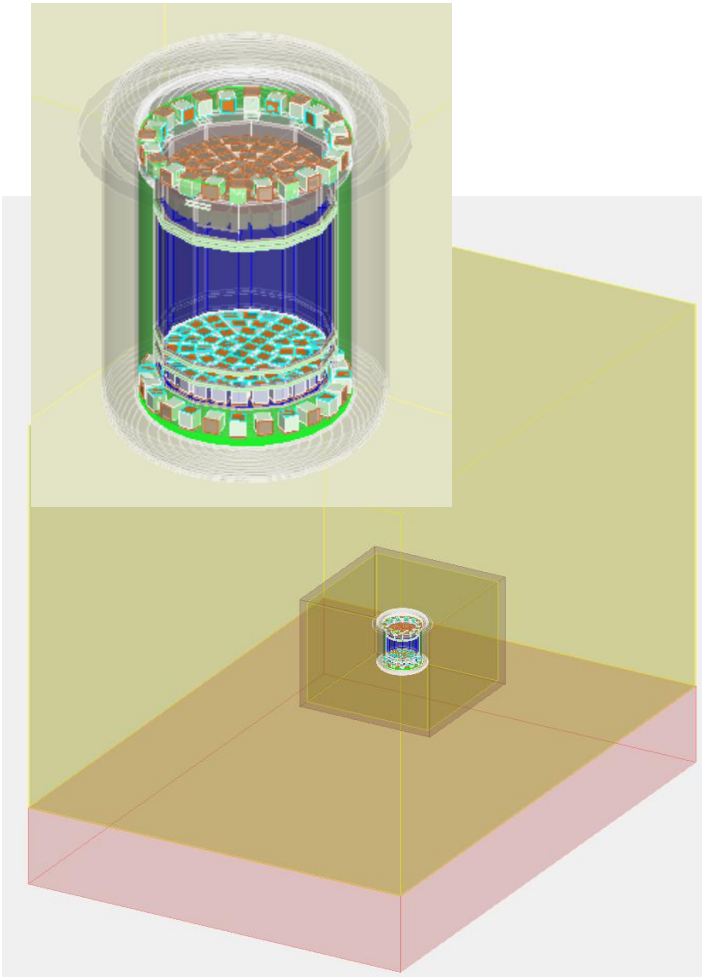
- D-D neutron generator --- > low NR energy
- ^{137}Cs , ^{60}Co , $^{241}AmBe$, ^{129}Xe, ^{131}Xe, ^{127}Xe

  --- > efficiency of S1 & S2

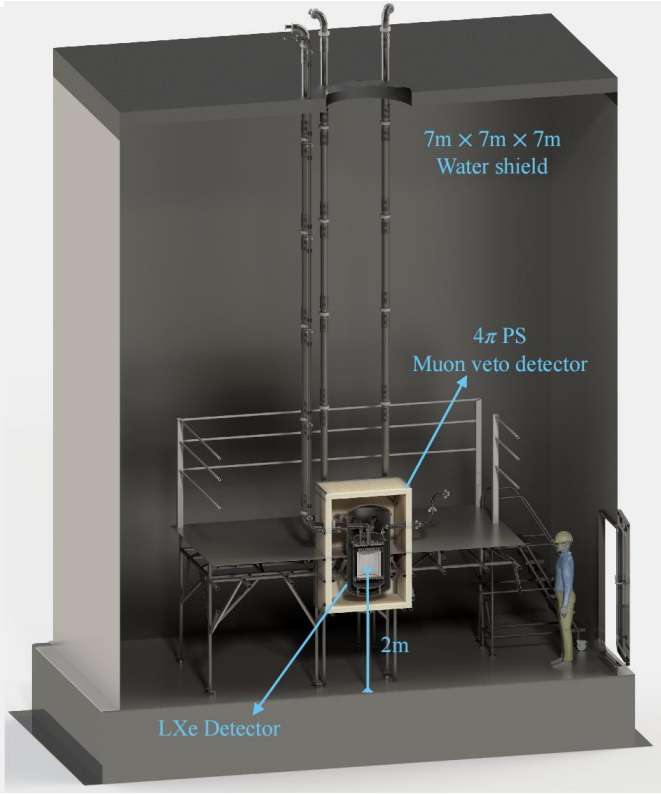
  --- > uniformity of detector



Simulation Configuration



simulation



preliminary design

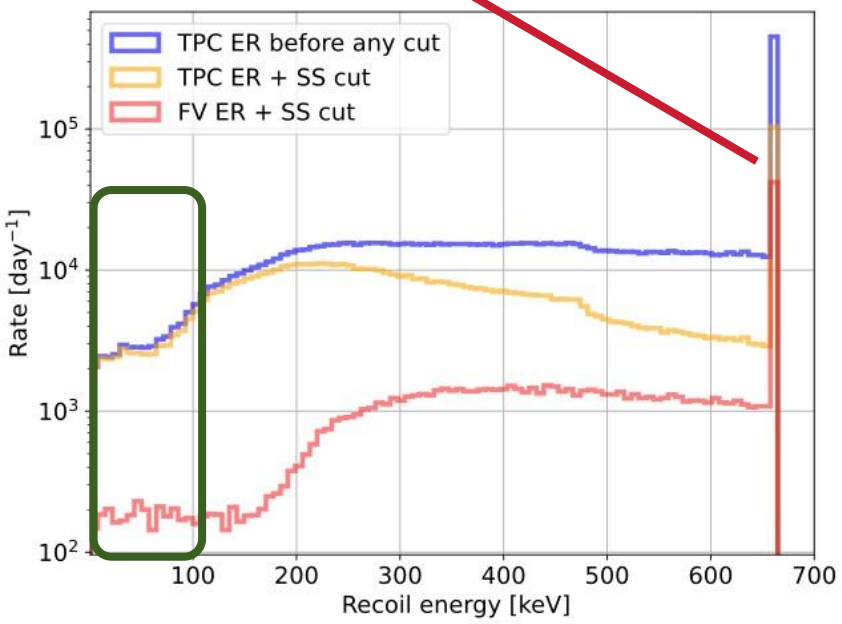
physics list

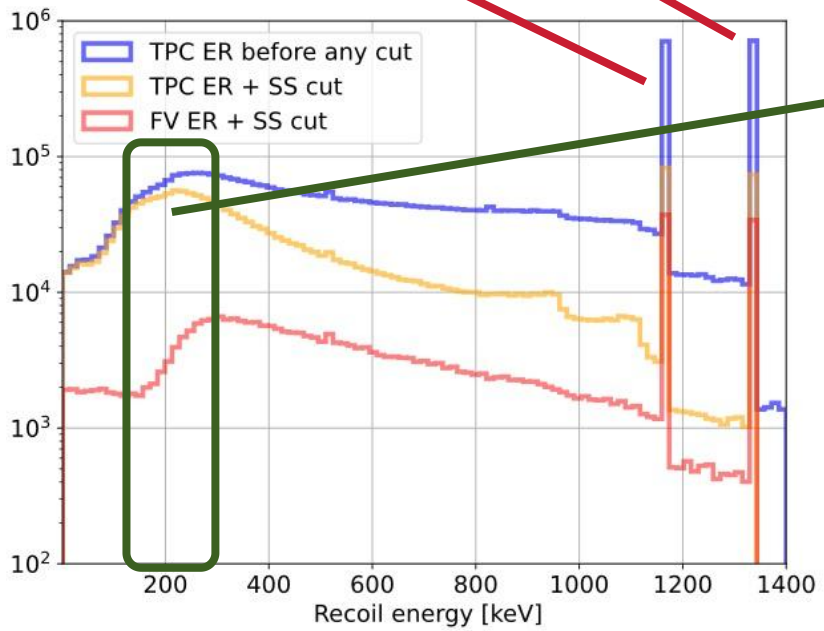
- EM Physics --- G4EmLivermorePhysics
- Decays --- G4DecayPhysics
  G4RadioactiveDecayPhysics
- hadron physics --- G4HadronElasticPhysicsHP
- shielding --- G4HadronPhysicsShielding
- stopping physics ---- G4StoppingPhysics
- ion physics----- G4IonQMDPhysics

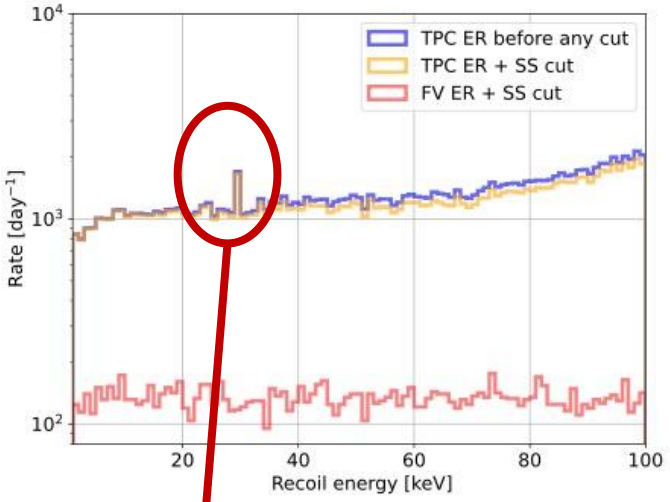
Results of ^{137}Cs & ^{60}Co

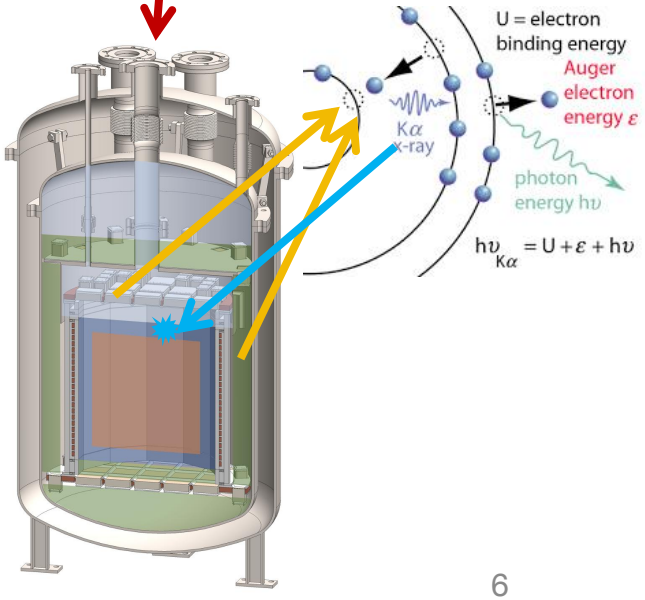
662keV --- > high-energy calibration < --- 1.17MeV & 1.32MeV

29keV -- K shell





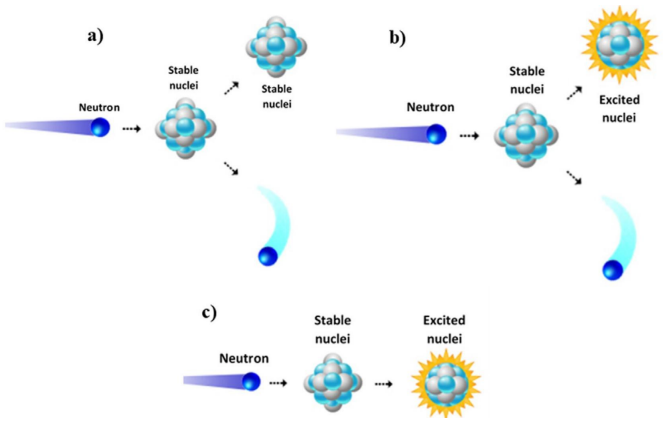




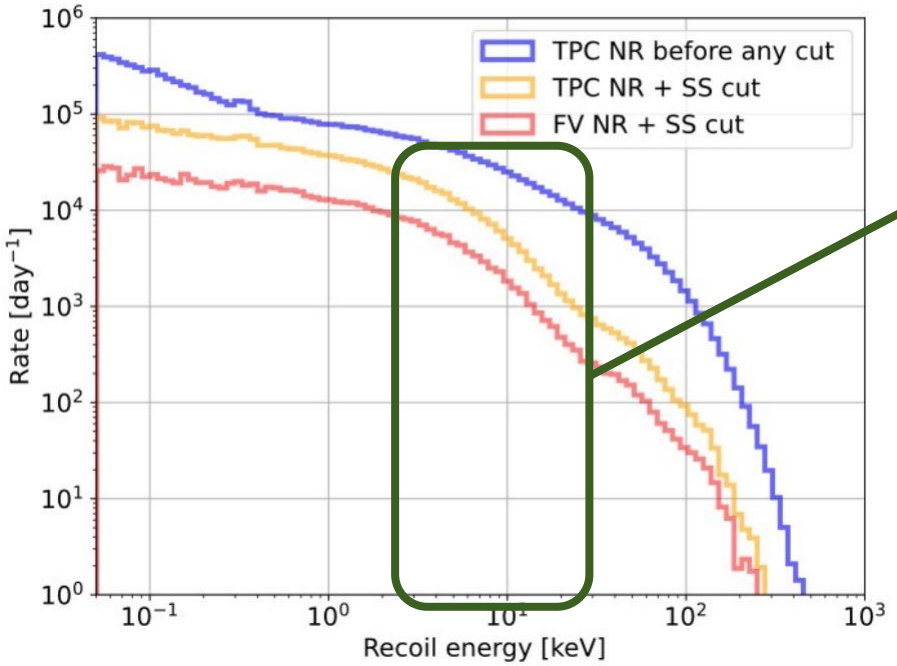
^{137}Cs(left) and ^{60}Co(right) ⟹ **flat spectrum** in low ER energy

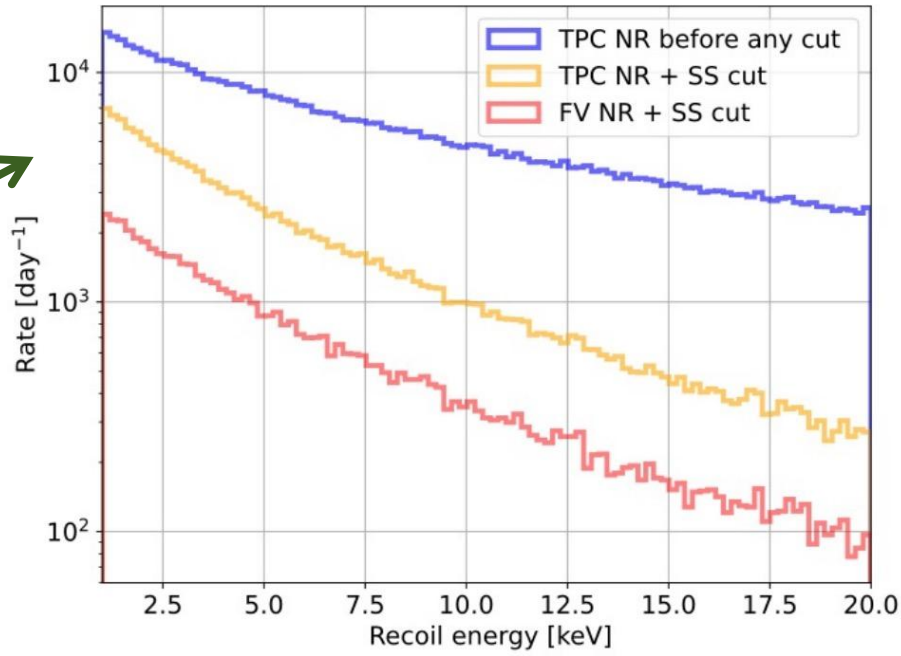
Type of radioactive source	target energy	activity	efficiency	rate	
^{137}Cs	662keV	800Bq	0.0821%	0.66hz	2376/hour
^{60}Co	0-100keV	600Bq	0.0049%	0.0294hz	106/hour

Results of ^{241}AmBe



DOI: 10.1016/B978-0-12-820549-5.00010-3





^{241}AmBe ⟹ **continuous spectrum** in **low NR energy**

Type of radioactive source	target energy	activity	efficiency	rate	
241AmBe	1-20keV	100Bq	0.6516%	0.65hz	2340/hour

Issue of Xe excitation

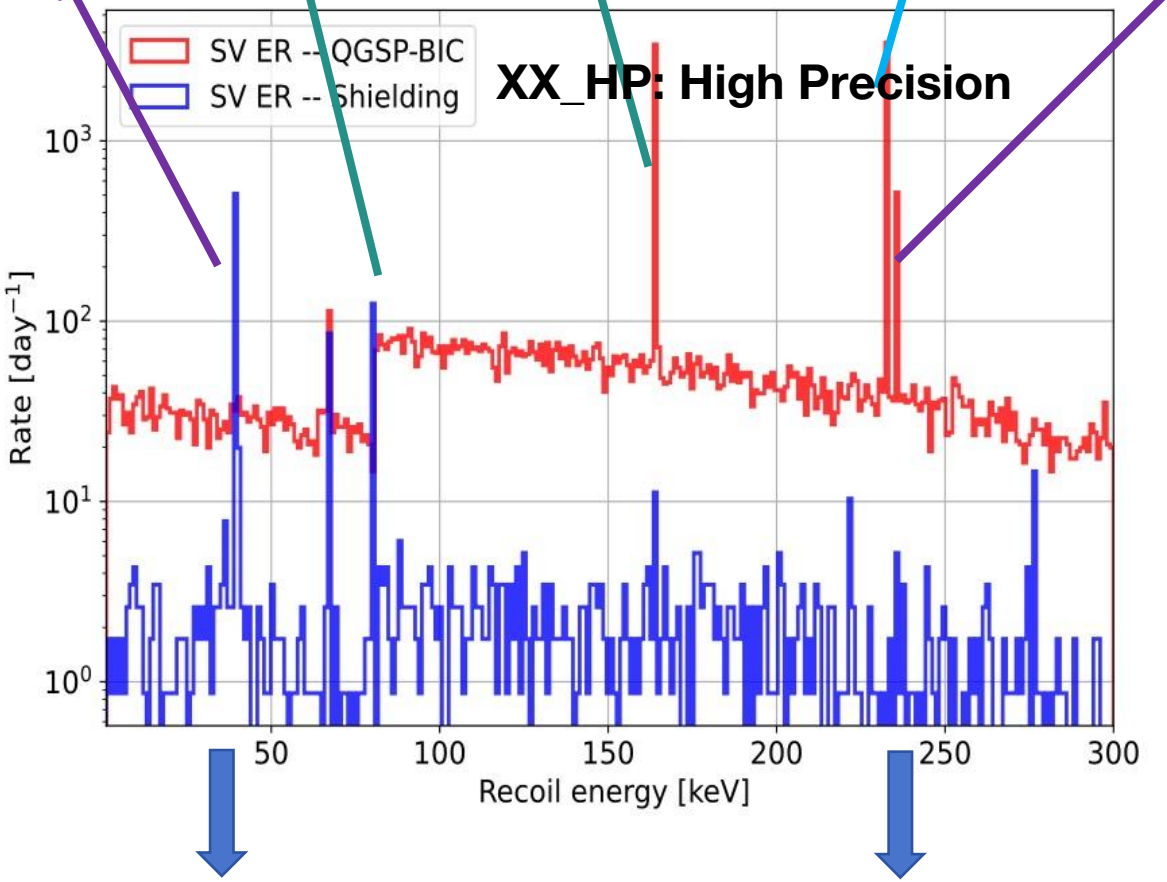
Xe129: 40keV (0.97ns)

Xe131: 80keV (0.48ns)

Xe131: 164keV (11.84 day)

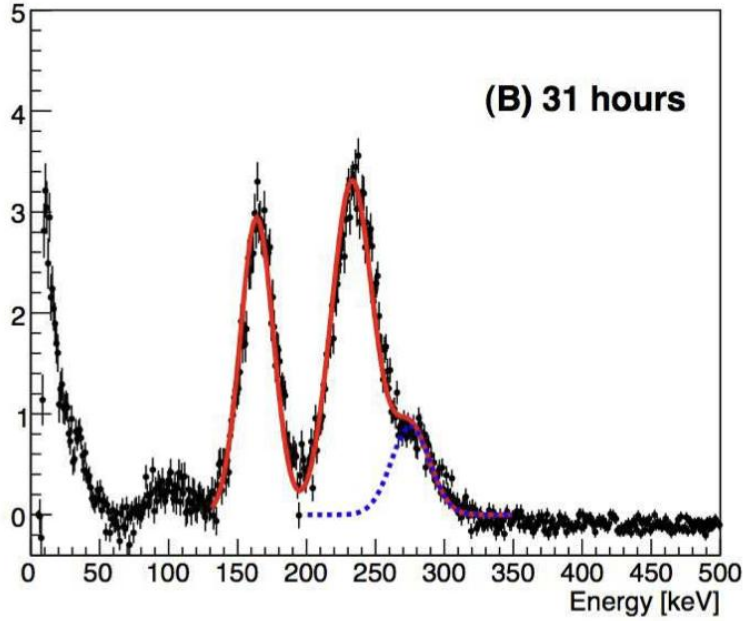
Xe133: 233keV (2.19day)

Xe129: 236keV (8.88 day)



ER calibration

164keV:236keV=1:1

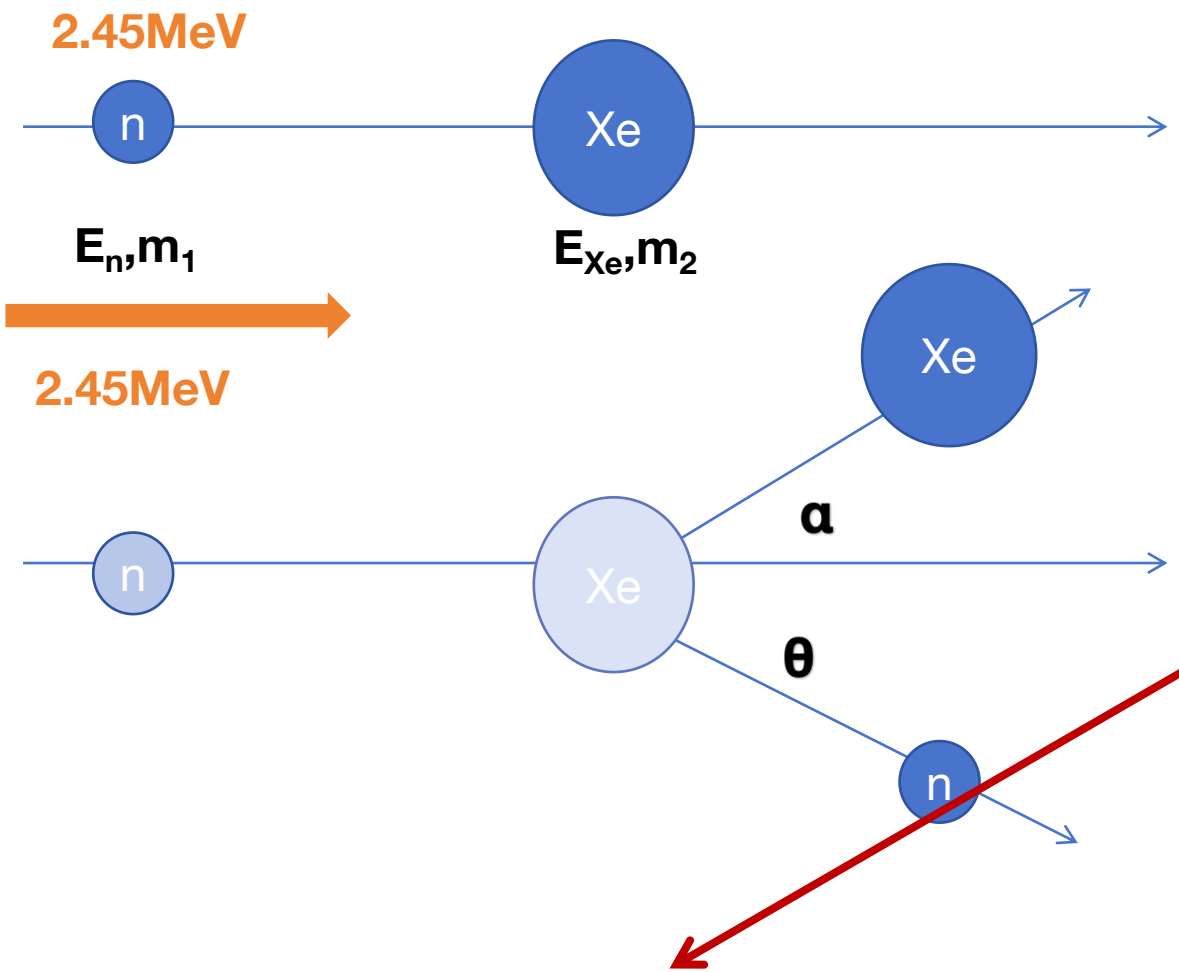


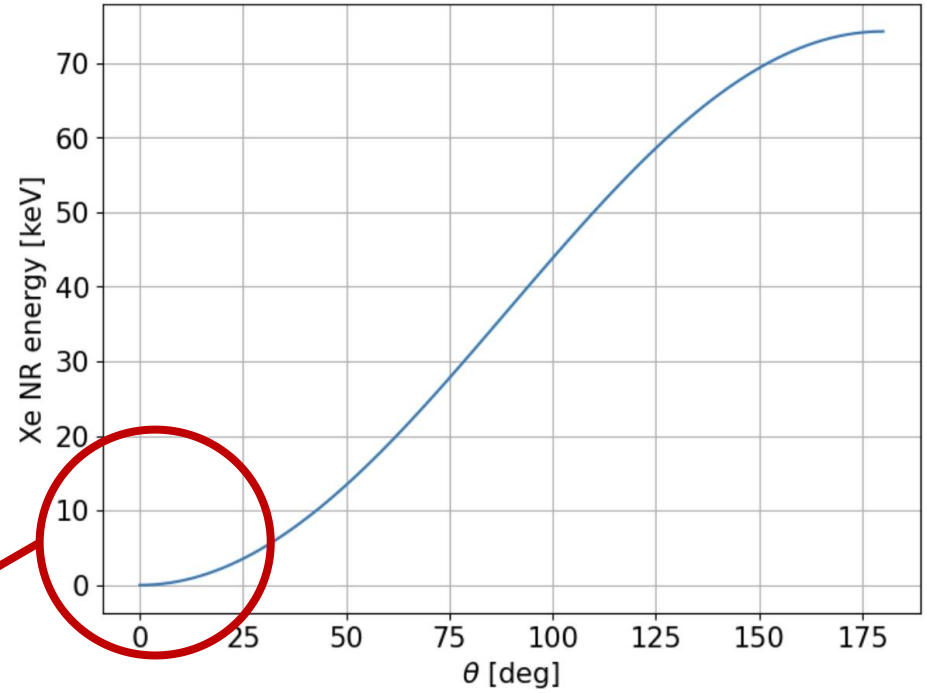
arXiv:0708.1976

simulation ratio -->

164keV:236keV=4:1

Calibration of sub-keV NR by DD neutron generator



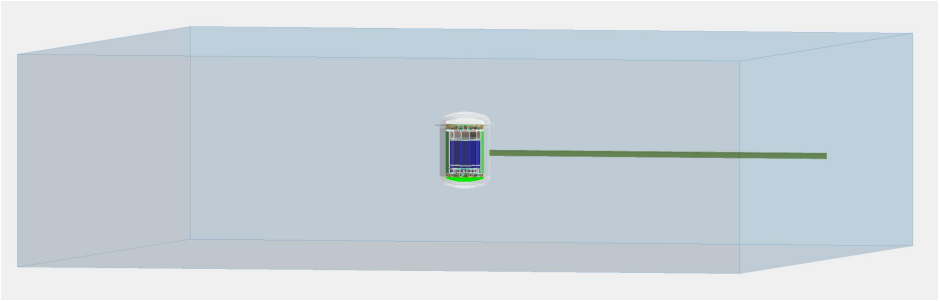


incident neutron energy : 2.45 MeV

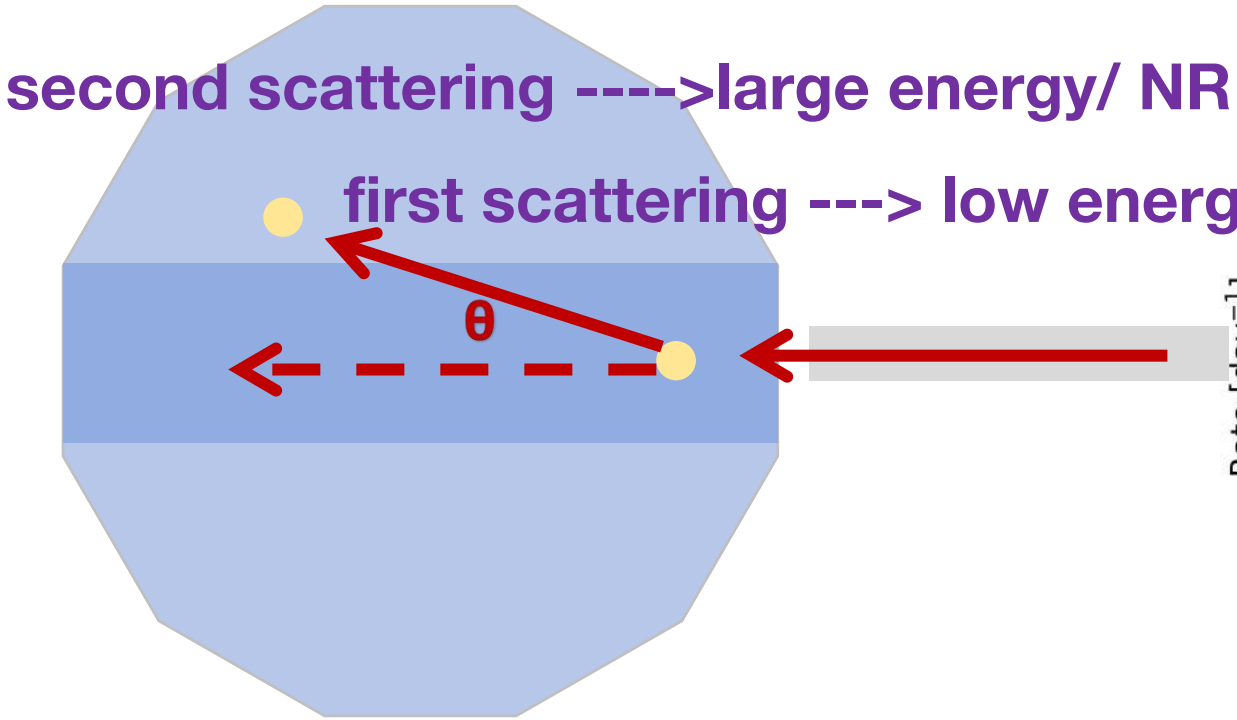
degrees :7 ° -13 ° ---> 0.3keV-1keV

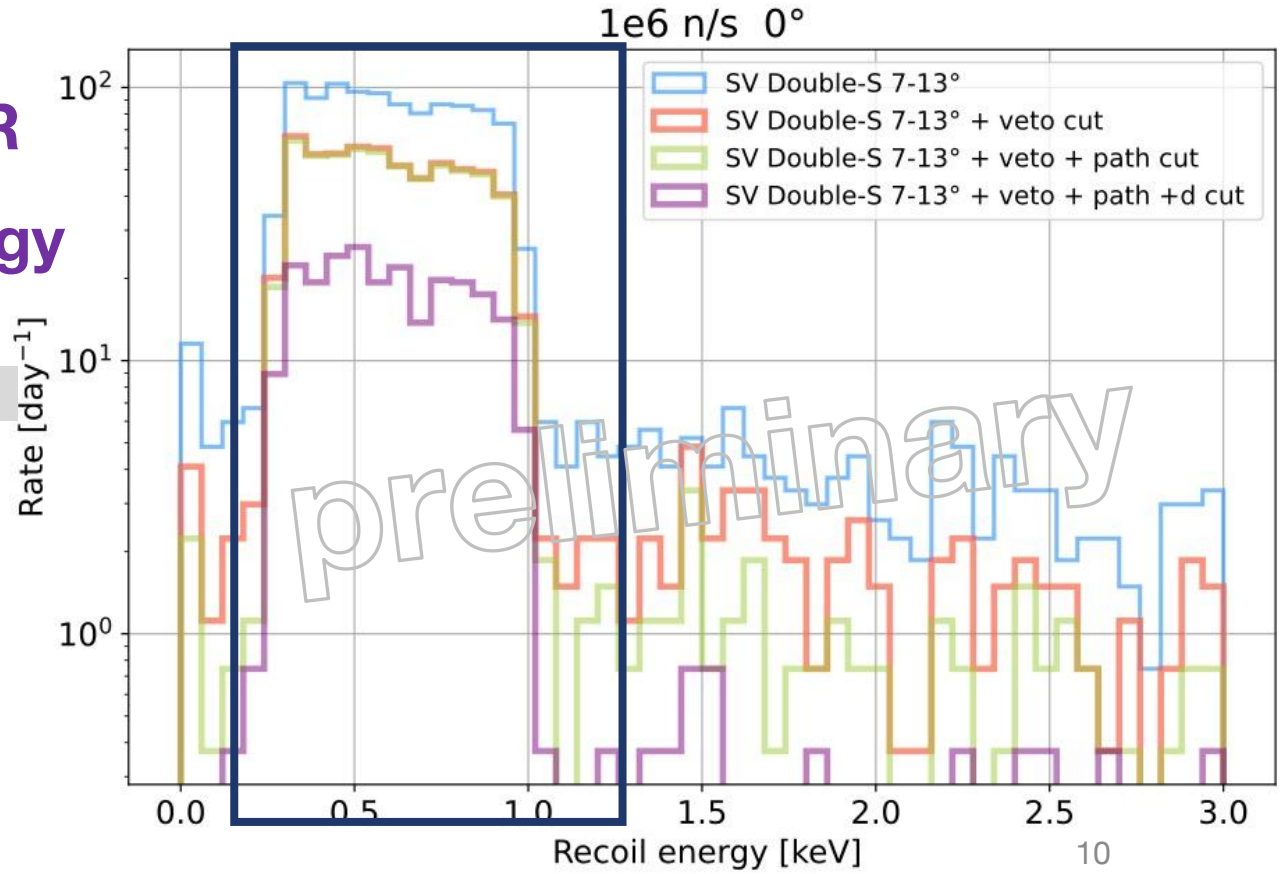
$$E_{Xe} = 4\ m_2\ m_1 \frac{E_n}{(m_1 + m_2)^2} \left(\frac{-cos\theta + 1}{2}\right)$$

Calibration of sub-keV NR by DD neutron generator

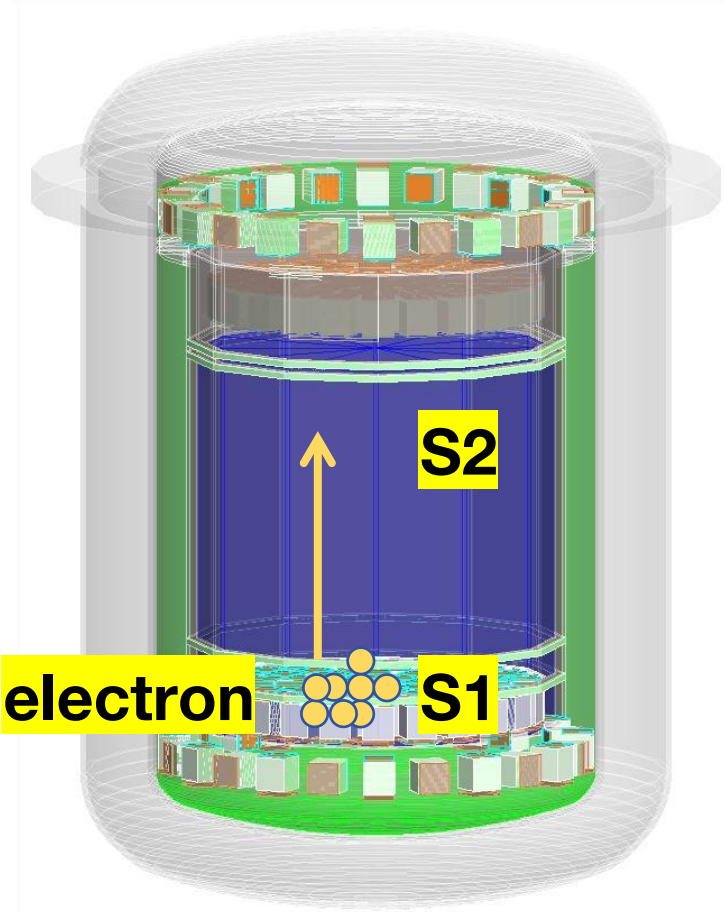


- first scattering --- > maintain direction
- second scattering --- > deposit high energy
- double scattering --- >distance

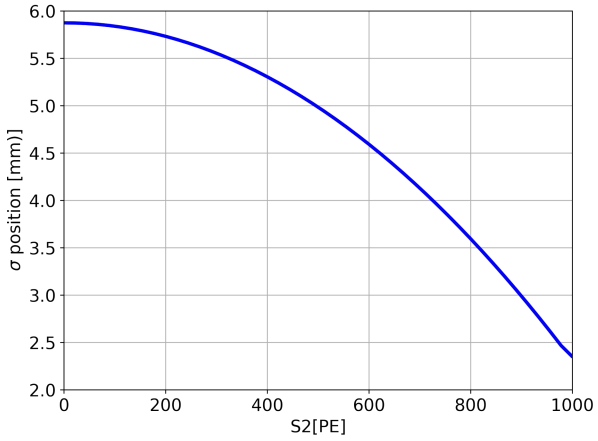


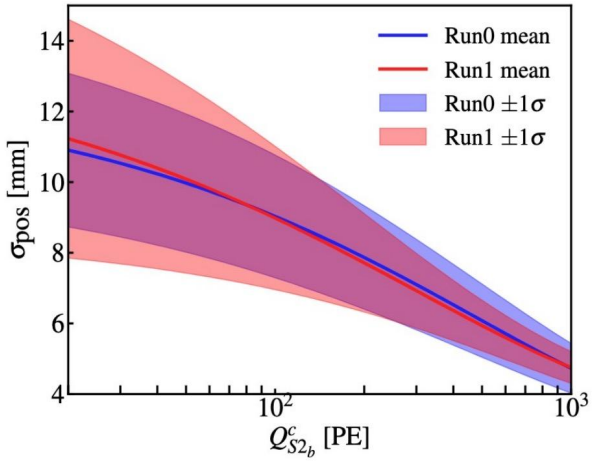


Results of DD Simulation



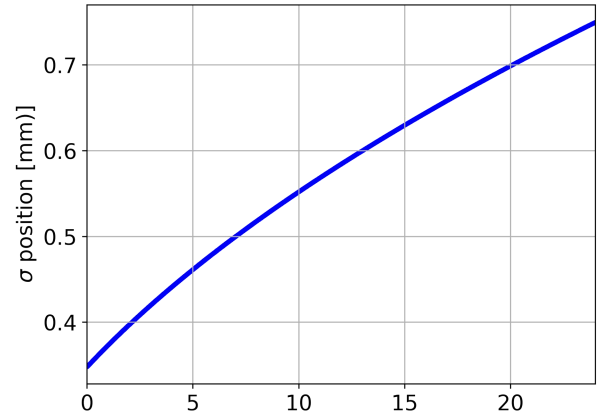
X-Y position
inversely proportional to S2

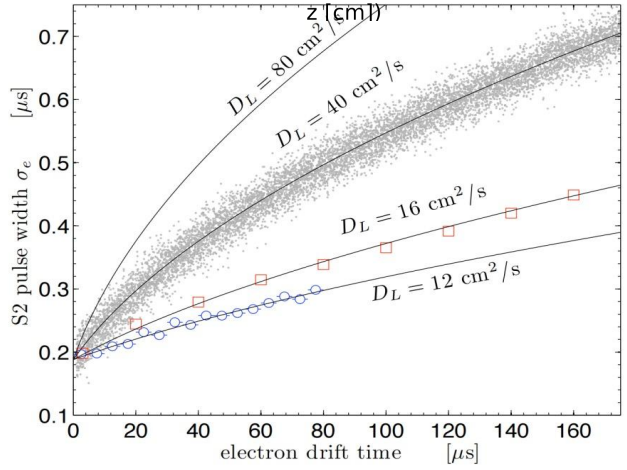




PANDAX : arXiv:2403.04239

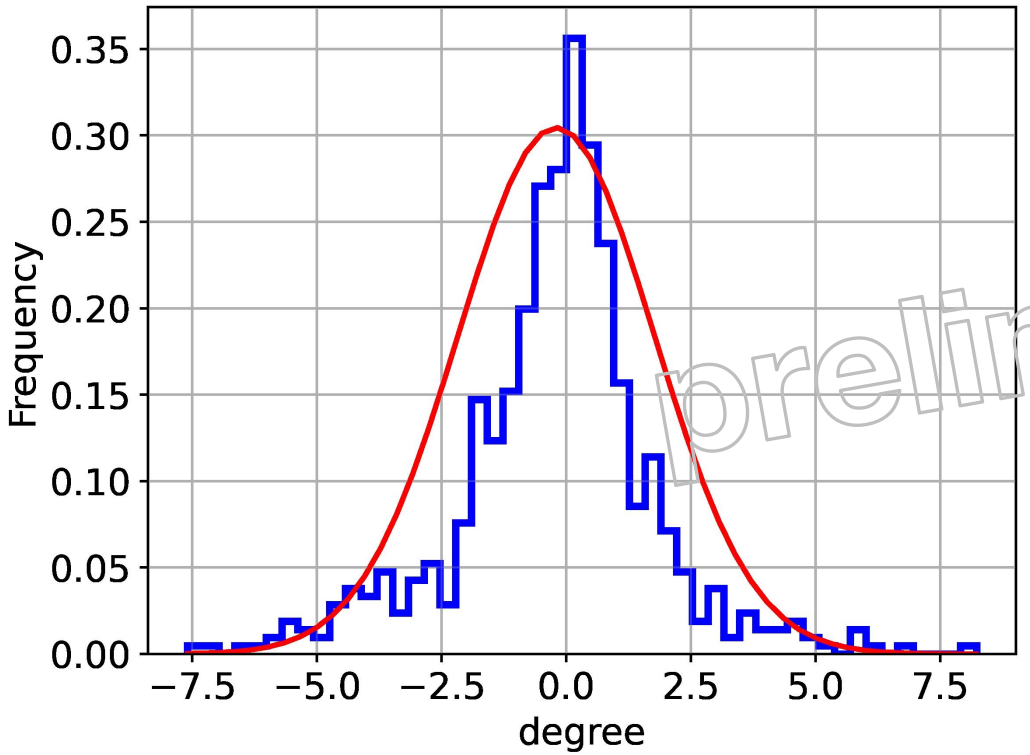
Z position
directly proportional to drift time



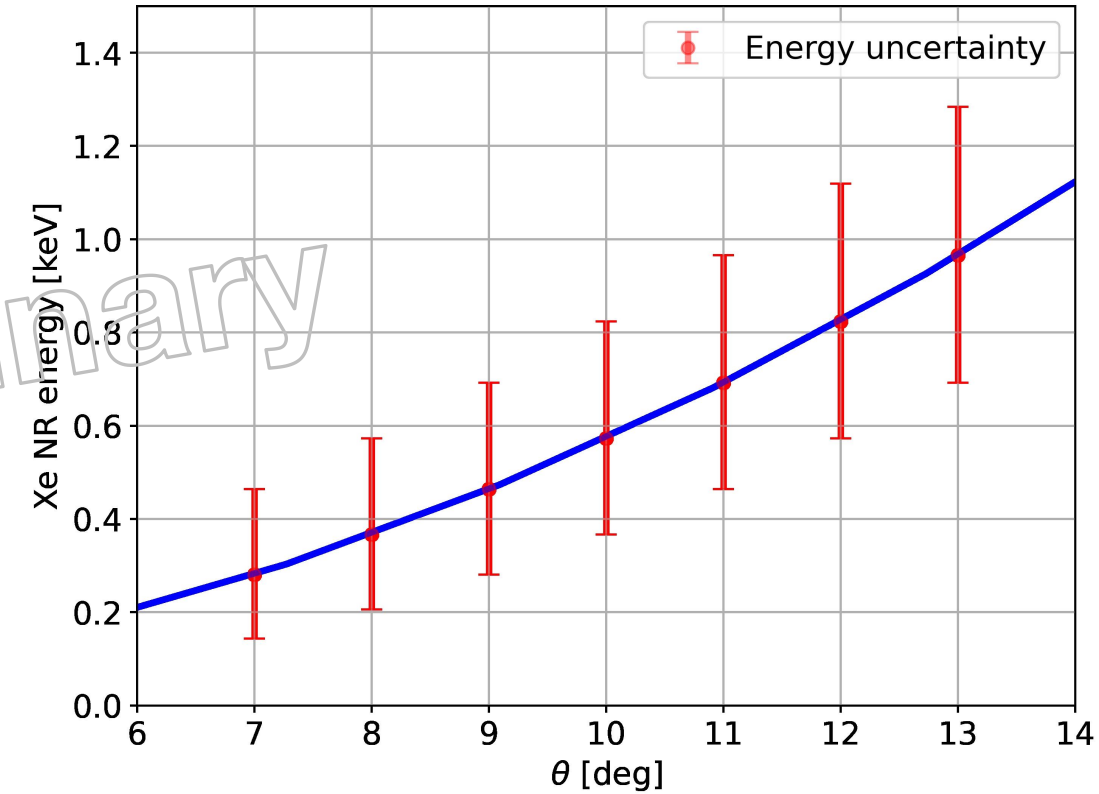


XENON10 : arXiv:1102.2865v2

Results of DD Simulation



1-sigma spread (relative) : 2 degree



13 ° ± 2 ° ---> 1 keV relative error : 32.7%

7 ° ± 2 ° ---> 0.3 keV relative error : 64.2%

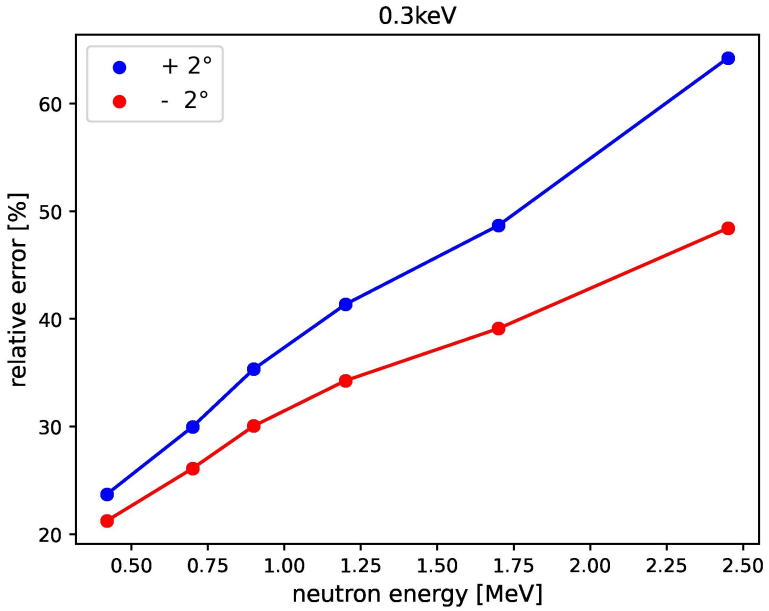
Type of radioactive source	target energy	activity	efficiency	rate/day
DD neutron generator	0.3-1keV	1e6 n/s	5.2 e-9	445 ± 17

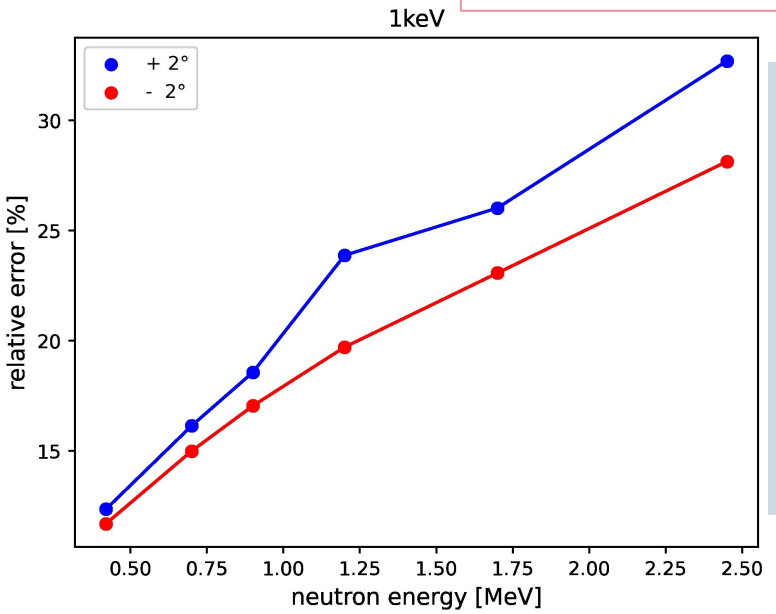
Attempts to reduce energy uncertainty

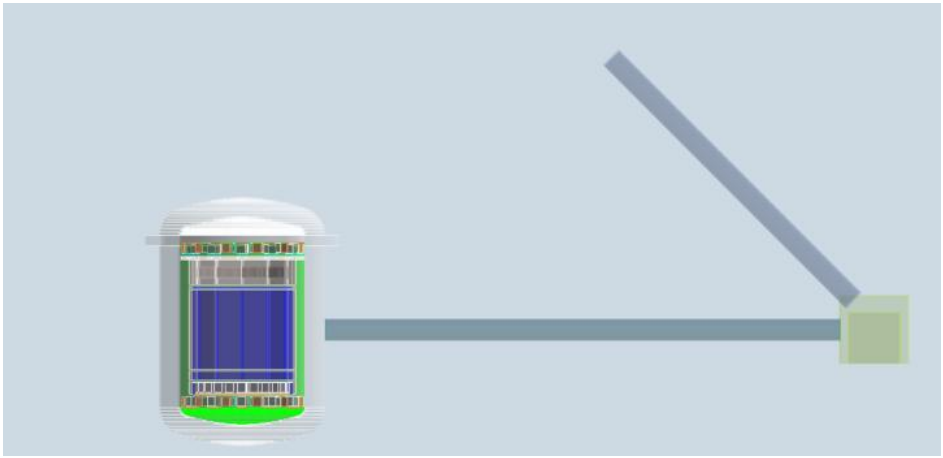
1-sigma spread ： 2 °

- **precision of reconstruction and number of photons**
- **distance between the two scatterings**
- **neutron incident energy**

$$E_{Xe} = 4\ m_2\ m_1 \frac{E_n}{(m_1 + m_2)^2} \left(\frac{-cos\theta + 1}{2}\right)$$





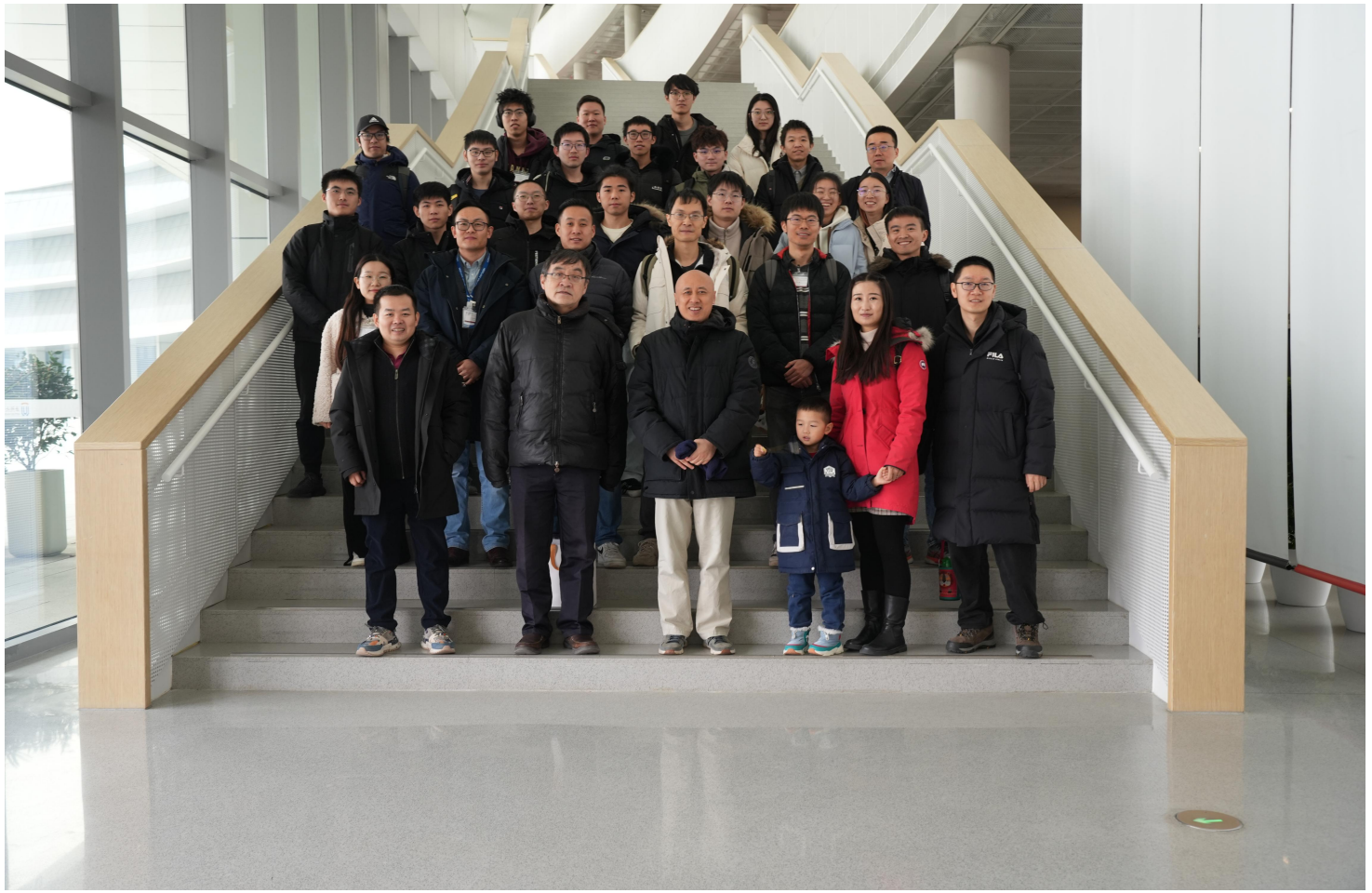


lower energies correspond to smaller relative errors

Summary

- 1) ^{137}Cs ,^{60}Co ,$^{241}AmBe$ can maintain adequate rate within the required activity limits .
- 2) we hope to calibrate sub-keV NR by selecting double scattering events of specific angles .
- 3) There are still some questions in the simulation such as the excitation of xenon .

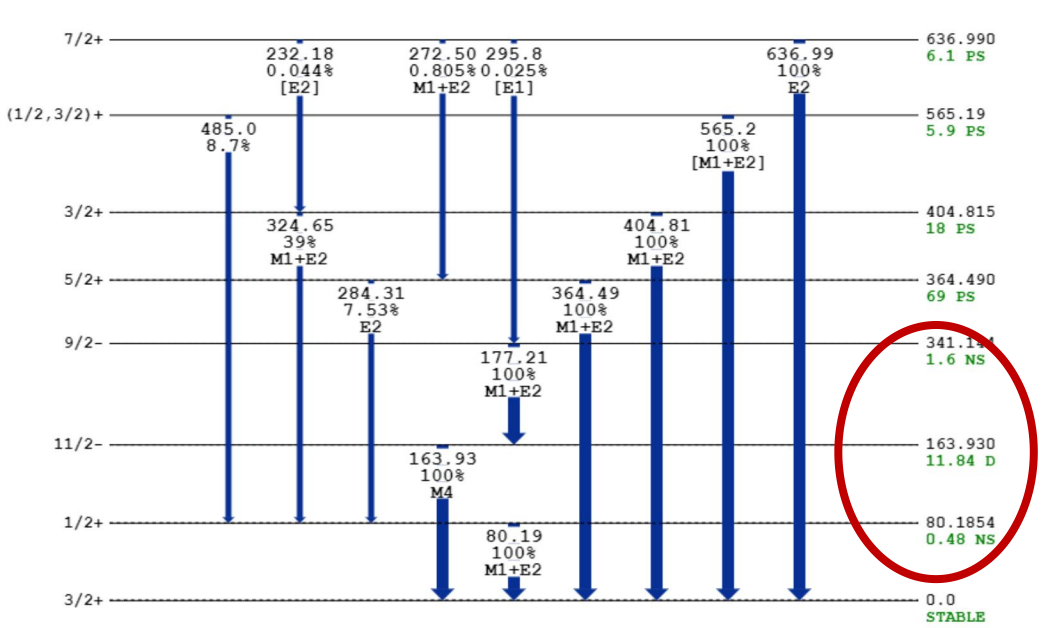
RELICS Collaboration

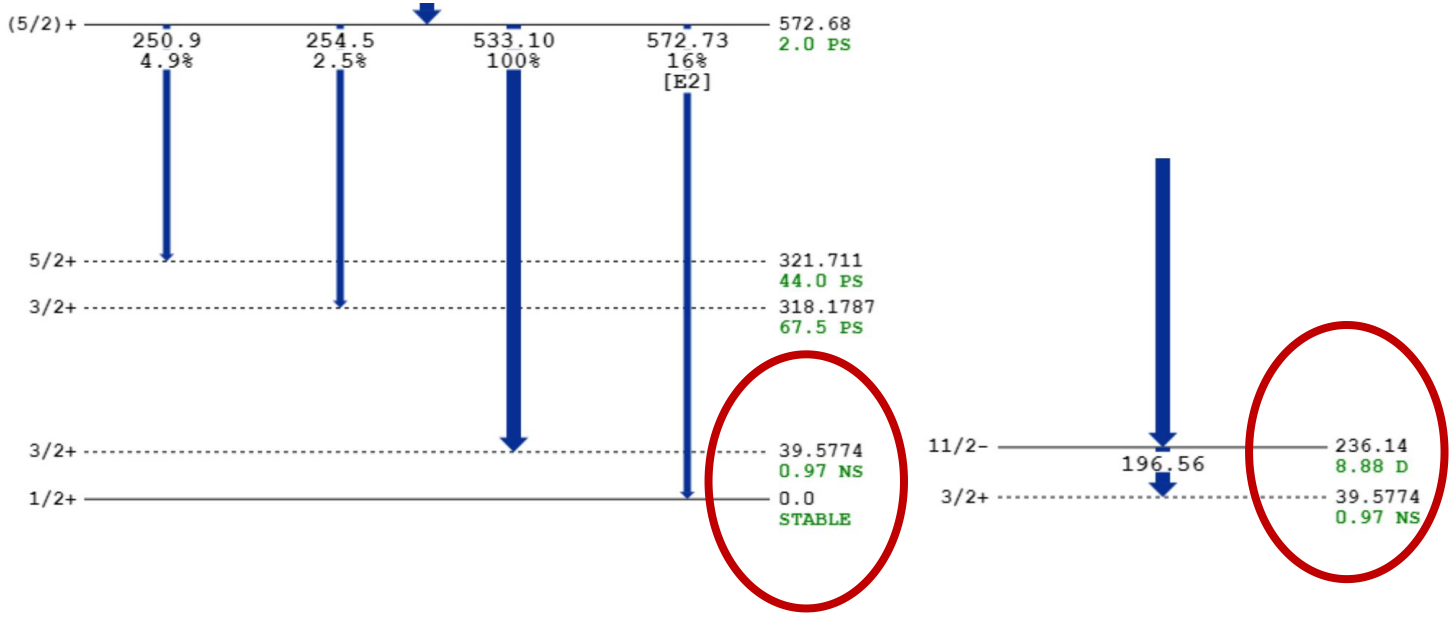


Thanks for your listening !

Issue of Xe excitation

Xenon isotope ：Xe129，Xe131

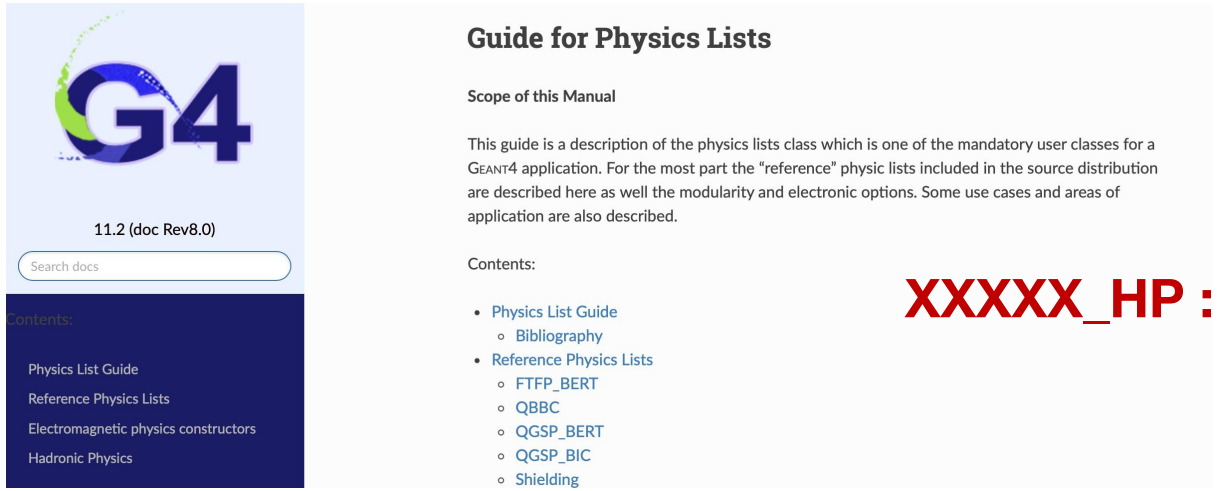




^{131}Xe and ^{129}xe Deexcitation emits specific energy γ rays

^{131}Xe： 80 KeV (0.48 ns) and 164kev (11.84 day)

^{129}xe： 40 KeV (0.97 ns) and 236 keV (8.88 day)



XXXXX_HP : High Precision → **no long-lived excitation**

FTFP_BERT	**consists of elastic, inelastic, capture and fission processes. The inelastic hadron-nucleus processes are implemented by the Fritiof parton model (FTF), Bertini and Precompound models.**
QGSP_BIC	**consists of elastic, inelastic, and capture processes.The inelastic hadron-nucleus processes are implemented by the Quark-gluon String (QGS), the Fritiof parton model (FTF), Bertini, Binary, and Precompound models.**
QGSP_BERT	**consists of elastic, inelastic, capture and fission processes.The inelastic hadron-nucleus processes are implemented by the quark-gluon model (QGS), the Fritiof parton model (FTF), Bertini and Precompound models.**
Shielding	**t is recommended for simulation of deep shielding. Neutrons of 20 MeV and lower use the High Precision neutron models and cross sections to describe elastic and inelastic scattering, capture and fission.**