Reactor Neutrino Energy Spectrum Measurement with a High Pressure Gas TPC Detector

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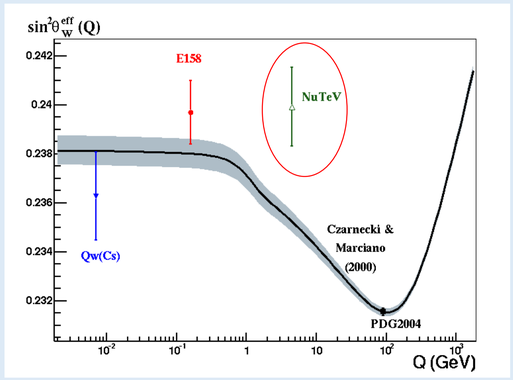
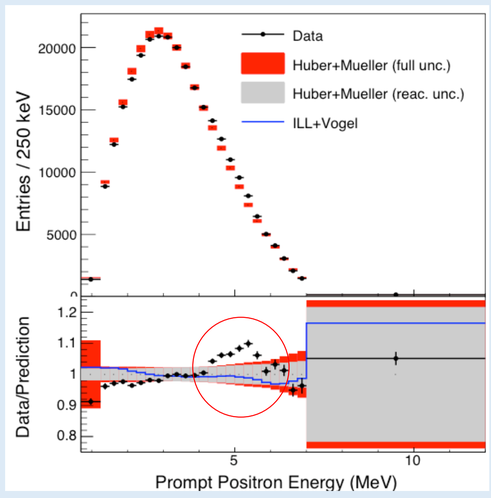
Physics motivation of a short baseline experiment with gas TPC

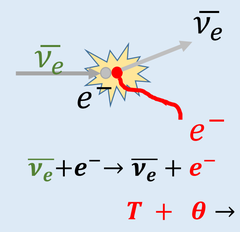
- Precisely measure the energy spectrum of reactor antineutrinos
  - High precision reactor spectrum 1%
  - Input for JUNO Energy resolution： Daya Bay ~8%， JUNO 3%
- Weak mixing angle θw
- Abnormal neutrino magnetic moment
- Sterile neutrino

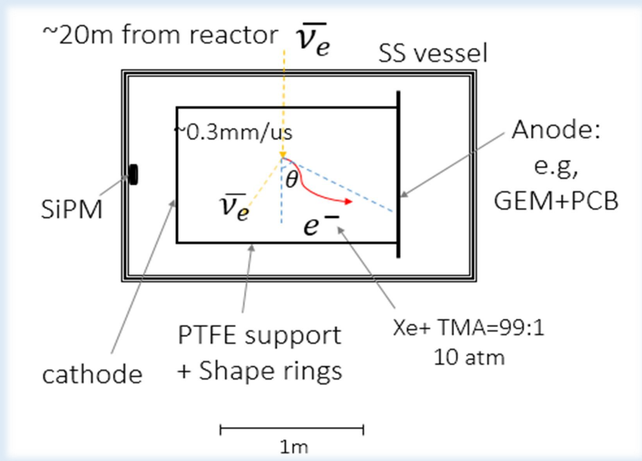




Potential advances of gas TPC:

- Excellent energy resolution
- Good charged-particle tracking with fine charge readout
- Powerful electron/gamma discrimination





Reactor neutrino detection via $\overline{\nu}$-e scattering

- e^- kinetic energy:

Collect all electrons from ionization

- e^- track measurement → reconstruct scattering angle:
  1. XY direction, XY-strip readout
  2. Z direction：

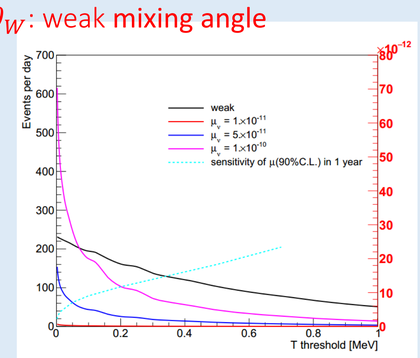
$L = v_{drift} * (t_{anode} - t_{SiPM})$

Cross section formula and event rate calculation :

$$\frac{d\sigma}{dT} = \frac{G_F^2 m_e}{2\pi}\left[(g_V+g_A)^2+(g_V-g_A)^2\left(1-\frac{T}{E_\nu}\right)^2+(g_V^2-g_A^2)\frac{m_e T}{E_\nu^2}\right]+\frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\frac{1-T/E_\nu}{T}$$

- m_e: electron mass
- T: electron kinetic energy
- E_ν: neutrino energy
- G_F: weak interaction constant
- μ_ν: neutrino magnetic moment
- θ_W: weak mixing angle

- $g_V = 2\sin^2\theta_W + \frac{1}{2}, g_A = \begin{cases} \frac{1}{2}\ for\ \nu_e, \\ -\frac{1}{2}\ for\ \overline{\nu_e}, \end{cases}$
- $T_e = \frac{2m_e E_\nu^2\cos^2\theta}{(m_e+E_\nu)^2 - E_\nu^2\cos^2\theta}$

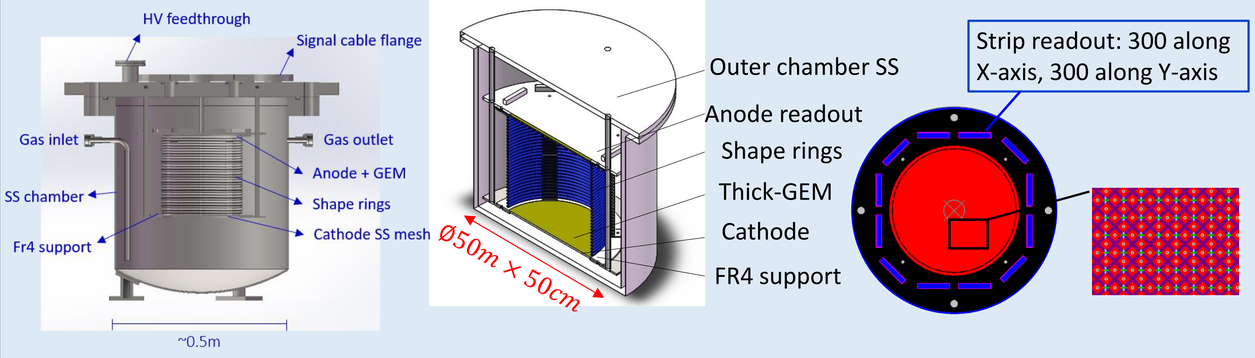


Assumptions

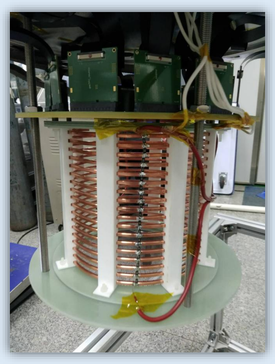
- **Target:** 400kg Xe+TMA gas
- **Distance to reactor:** 20m
- **Reactor power:** 2.9GW
- **Energy threshold:** 200keV e-
- Event rate: 363/day@ $\mu_\nu = 0$

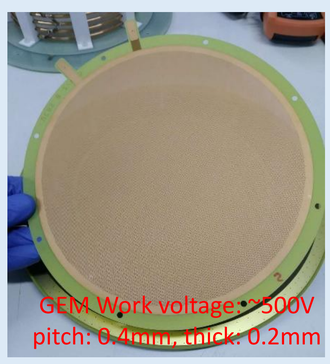
Prototype design and test:

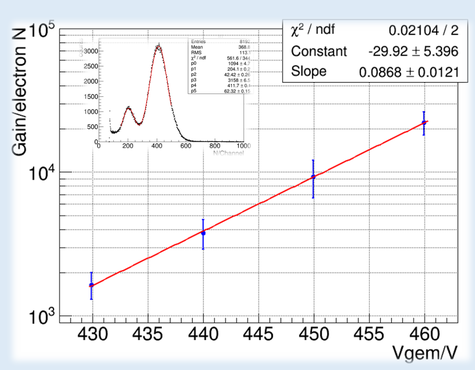
- Detector readout design: Charge and Light
- Study the properties and performances of different gases
- Validate the Monte Carlo simulation
- Develop track reconstruction methods
- Design a large scale (~200 kg) detector based on the prototype



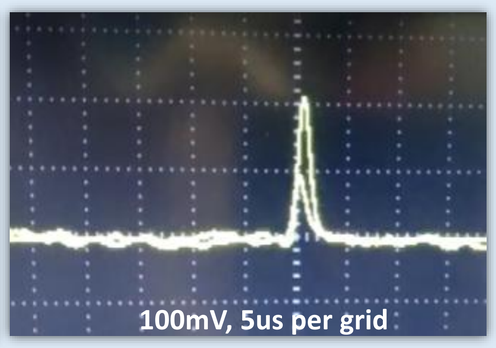
- Detector structure and GEM test







- Gas system and primary test

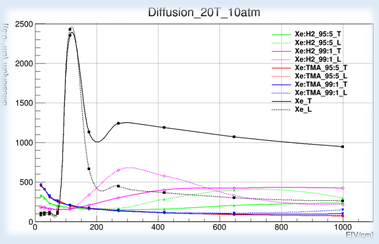


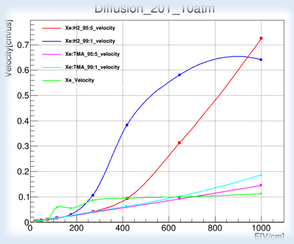
Simulation and reconstruction:

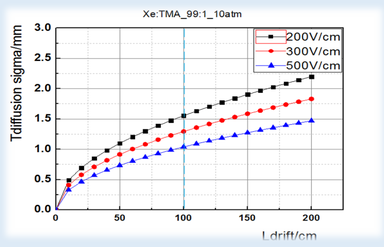
Gas	$^{88}_{42}CF4$	$^{20}_{10}Ne$	$^{40}_{18}Ar$	$^{131}_{54}Xe$
Doping	iC_4H_{10}、TMA、H2（1%-10%）			

Gas selection rules:

- Higher electron density to increase the cross section, no hydrogen atoms to avoid the IBD reaction
- Non-negative gas to improve the energy resolution
- Smaller diffusion and track bending to reconstruction the scattering angle

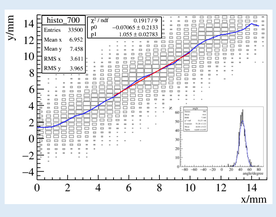


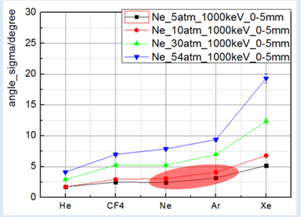




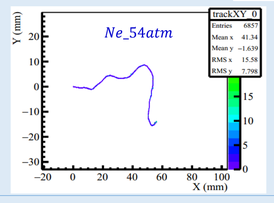
- Scattering angle reconstruction

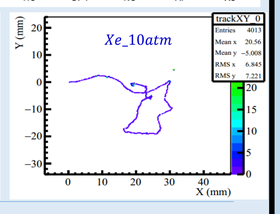
Gas(Z,A)	$^{88}_{42}CF4$	$^{4}_{2}He$	$^{20}_{10}Ne$	$^{40}_{18}Ar$	$^{131}_{54}Xe$
Pressure	12.857atm	270atm	54atm	30atm	10atm@200kg
Pressure	7.143atm	150atm	30atm	16.667atm	5.556atm
Pressure	2.381atm	50atm	10atm	5.556atm	1.852atm
Pressure	1.19atm	25atm	5atm	2.778atm	0.926atm





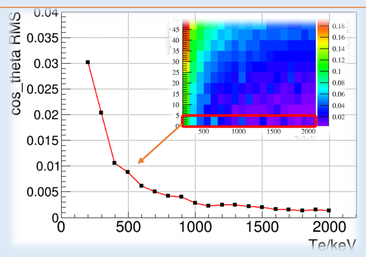
- Xenon gas have the higher target mass on the similar pressure. But it's difficult to precisely reconstruct the scattering angle. Argon and Neon have a greater advantage for reconstructing the scattering angle

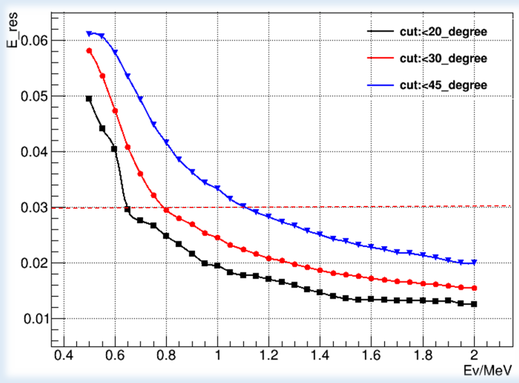




- Neutrino energy reconstruction

Ev energy: 0-2MeV
Te threshold: 200keV
Scattering angle cut: $< 20^\circ, < 30^\circ, < 45^\circ,$





Ne_10atm, drift distance 100cm, Tdif=$\mathbf{0.12}\boldsymbol{mm}$/√cm, fitlength=0-4mm

Conclusion:

- **At present, the design and the assemble of the prototype detector have finished. The primary test has been proceeding, the single signal test of the detector is normal.**
- **The performance of the gas diffusion and attachment efficiency is important parameters for the large detector. And the energy resolution and angle resolution need to verify with the prototype detector, which will provide a more sufficient pre-study for the large detector.**

Ref:

[1] Amsler C, Avenier M, Bagieu G, et al. The MUNU experiment, general description[J]. Nuclear Instruments & Methods in Physics Research, 1997, 396(1–2):115-129.

[2] Collaboration N, Álvarez, V, Borges F I G M, et al. Initial results of NEXT-DEMO, a large-scale prototype of the NEXT-100 experiment[J]. Journal of Instrumentation, 2013, 8(8):59-60.

[3] Chen X, Fu C B, Galan J, et al. PandaX-III: Searching for neutrinoless double beta decay with high pressure 136 Xe gas time projection chambers[J]. Science China(Physics, Mechanics & Astronomy), 2017, 60(6):061011.