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Experimental Study of the $^{13}C(\alpha, n)^{16}O$ Neutron Source Reaction in Stars

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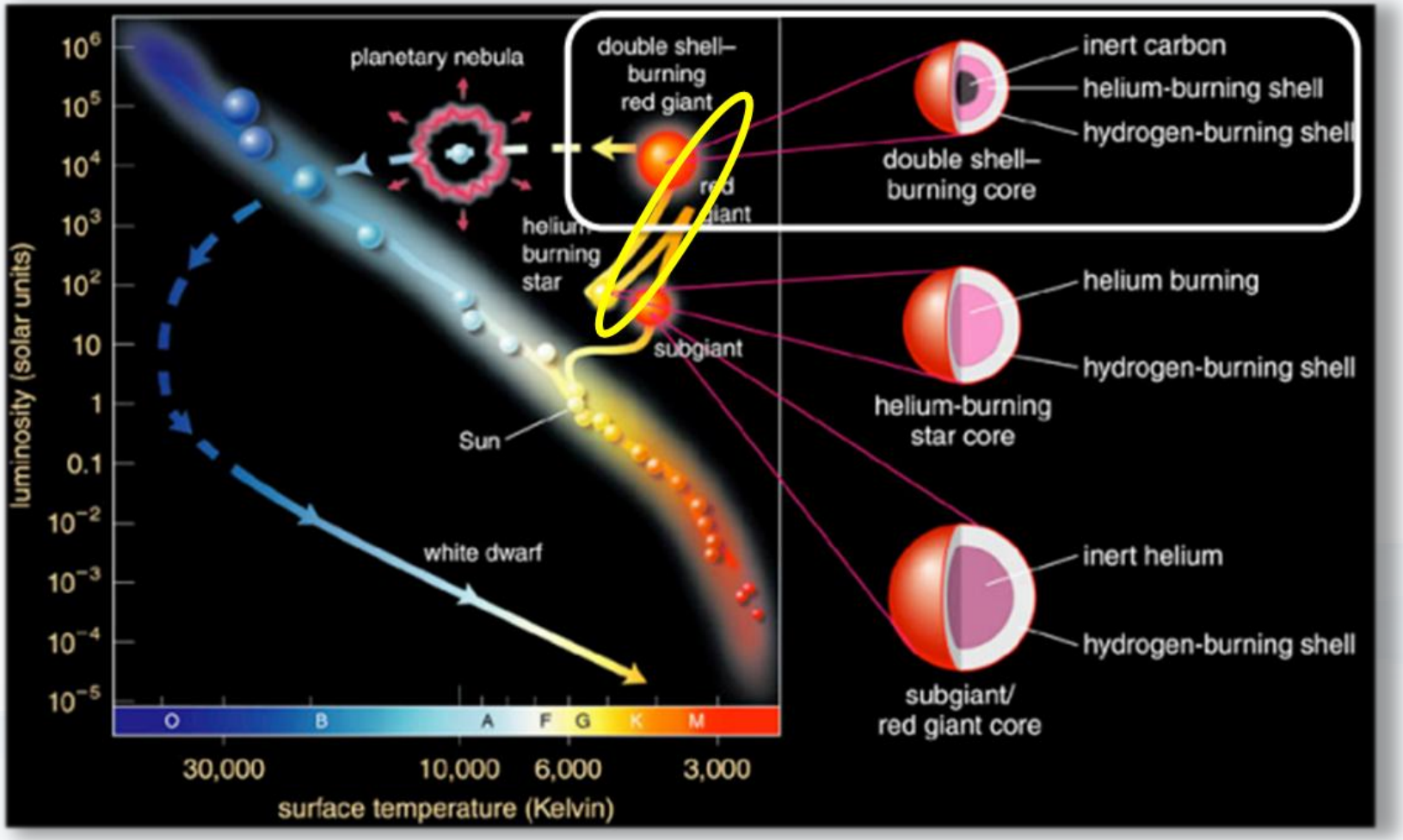
2025/6/23

Heavy element nucleosynthesis



Hertzsprung–Russell diagram

- **Asymptotic Giant Branch（AGB):**

slow neutron capture process (s-process)

- **Carbon-Enriched mental-poor star:**

Intermediate neutron capture process (i-process)

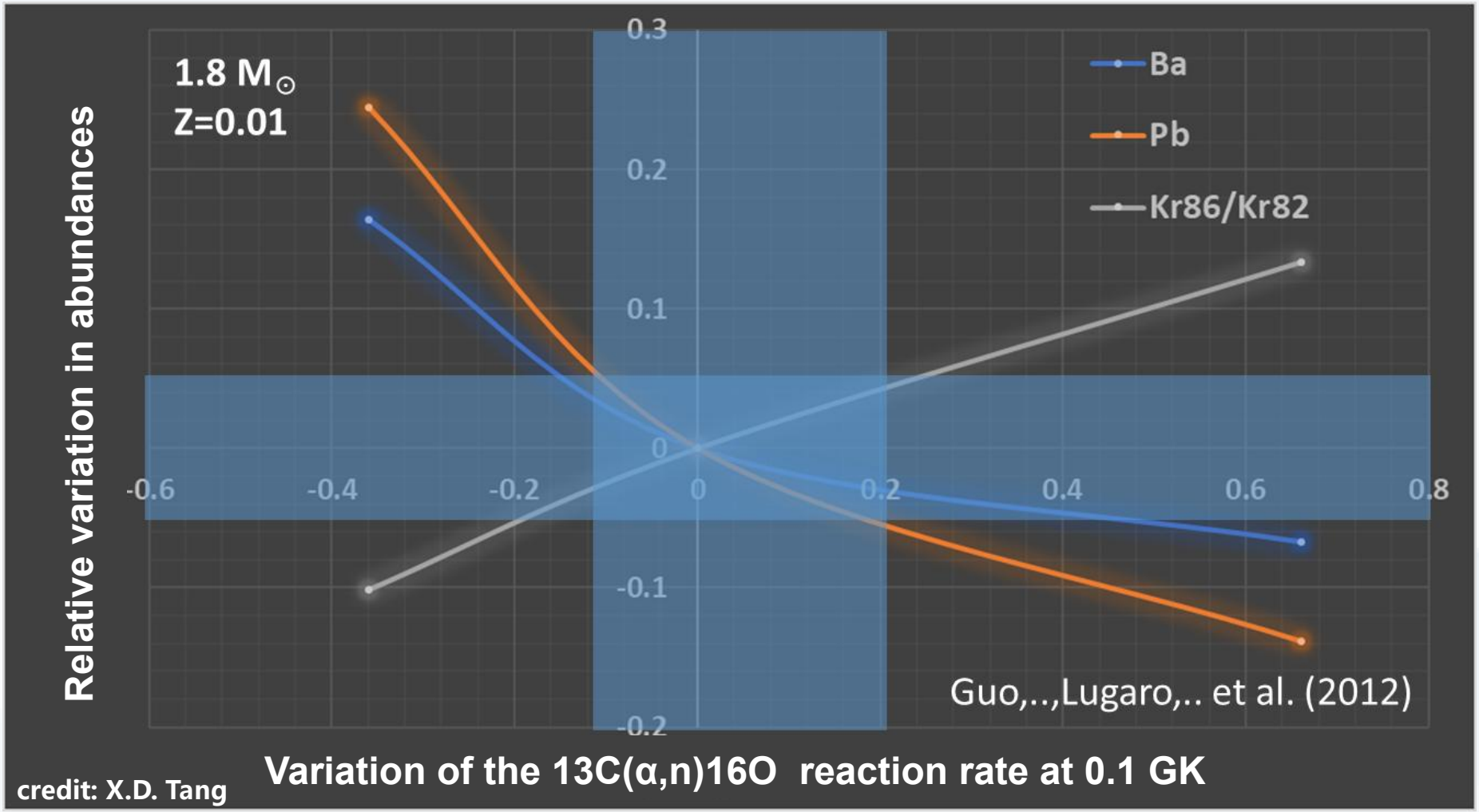
Neutron source reactions：

$^{13}C(\alpha,n)^{16}O$

$^{22}Ne\ (\alpha,n)^{24}Mg$

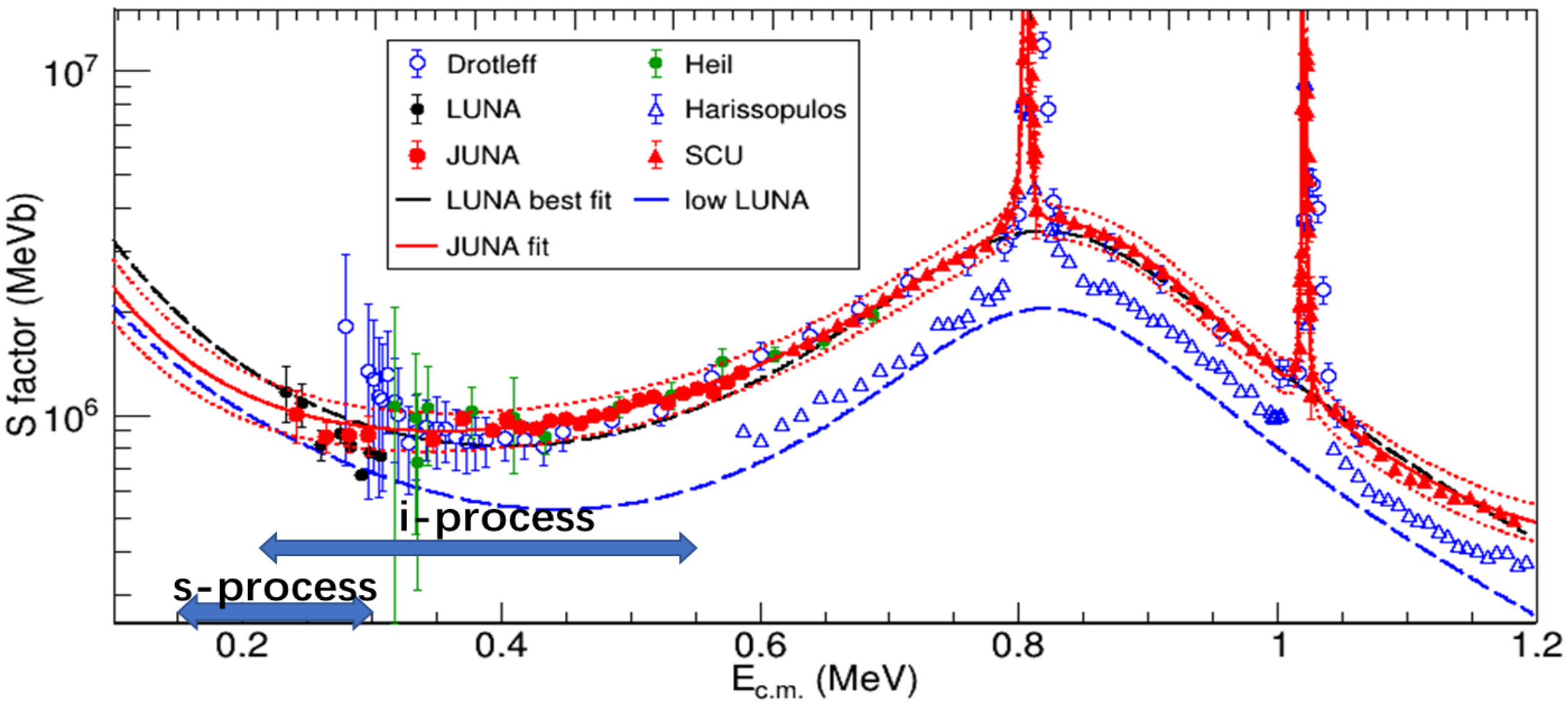
credit: Maria Lugaro

$^{13}C(\alpha,n)^{16}O$ Effects on Elemental Abundances



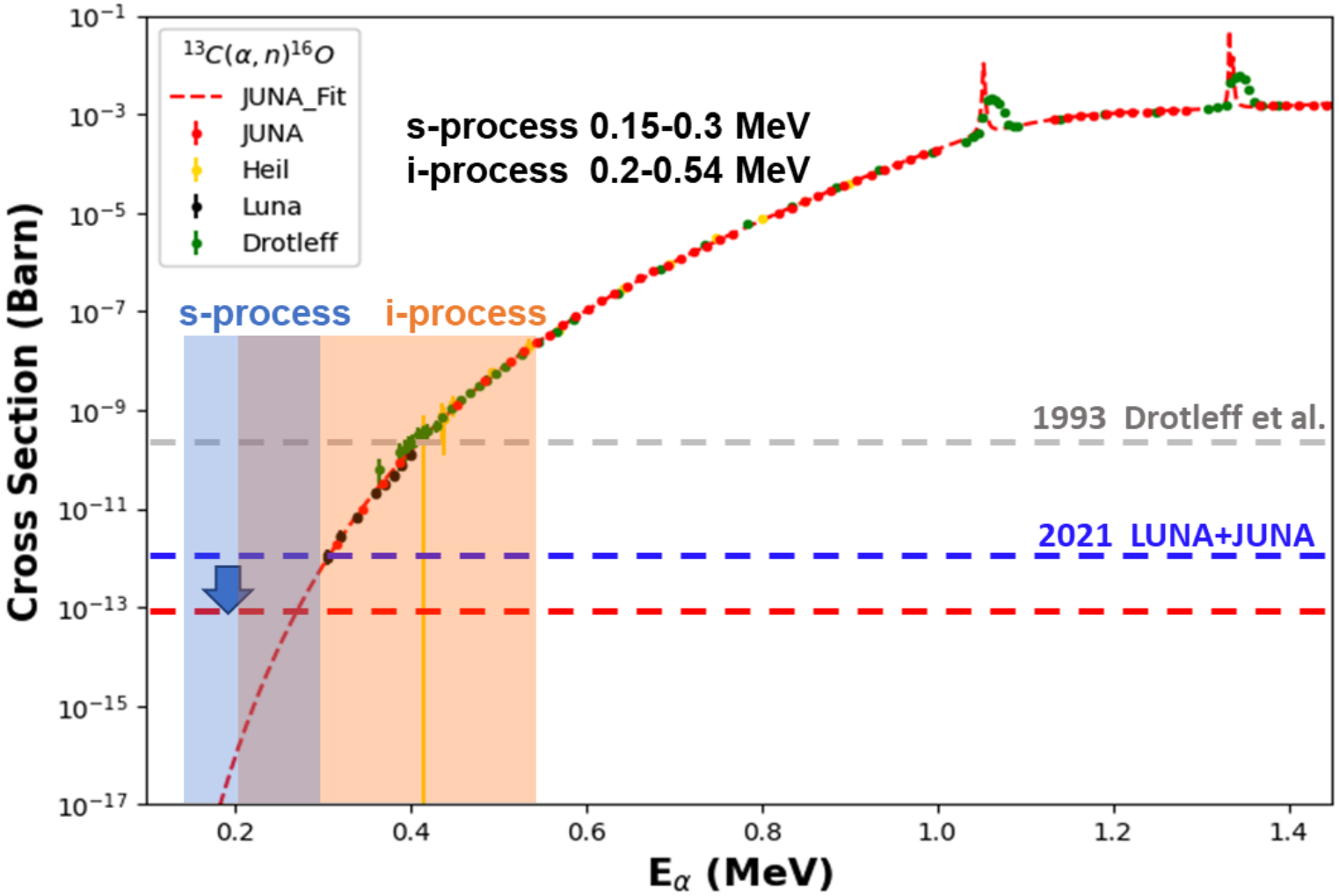
- **Experimental measurement of the reaction rate must achieve an accuracy within +20%/-12% .**

Current study of $^{13}C(\alpha,n)^{16}O$ reaction



- **JUNA(2022): consistent measurement at E_α=0.24-1.9MeV has covered the Gamow window for i-process, reached the high energy region of the Gamow window for s-process.**
- **Challenges: the R-matrix extrapolation toward lower energies carries significant uncertainties.**

Measurement at lower energies



Jinping Underground laboratory for Nuclear Astrophysics experiment(JUNA)

- $E_{c.m.}$ ~0.19MeV: Reaction cross-section is an order of magnitude lower than current measurement
- Count rate from $^{13}C(a,n)$: 0.2 cnts/h

credit: T.Y.Jiao

B. Gao, T. Y. Jiao, Y. T. Li, et al. PRL, 2022, 129: 132701.

Measurement at lower energies

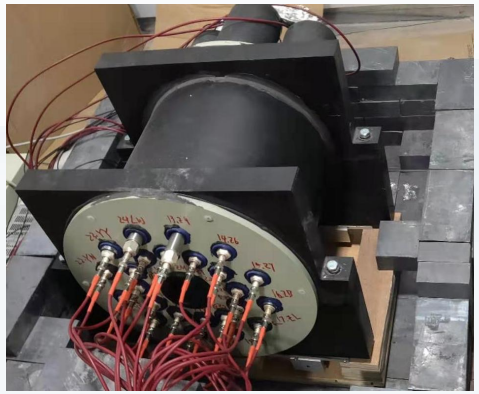
➢ **How to improve the signal to noise(SNR)**

$$SNR = \frac{N_{signal}}{N_{noise}}$$

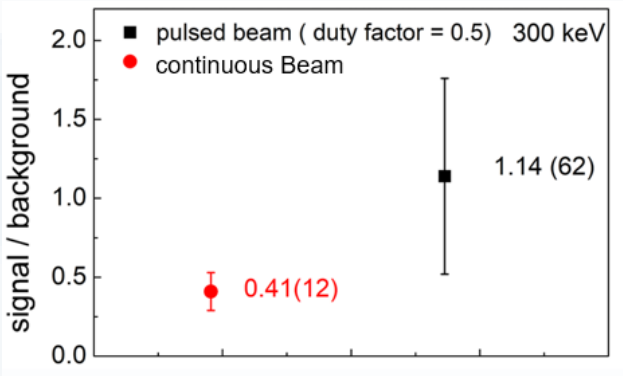
- **Suppress Background** **0.35/h**
  - Beam Background
  - Natural Background
- **Increase beam intensity** **2pmA**
  - Target Broken

- Dipole magnet

- Covered by Rock



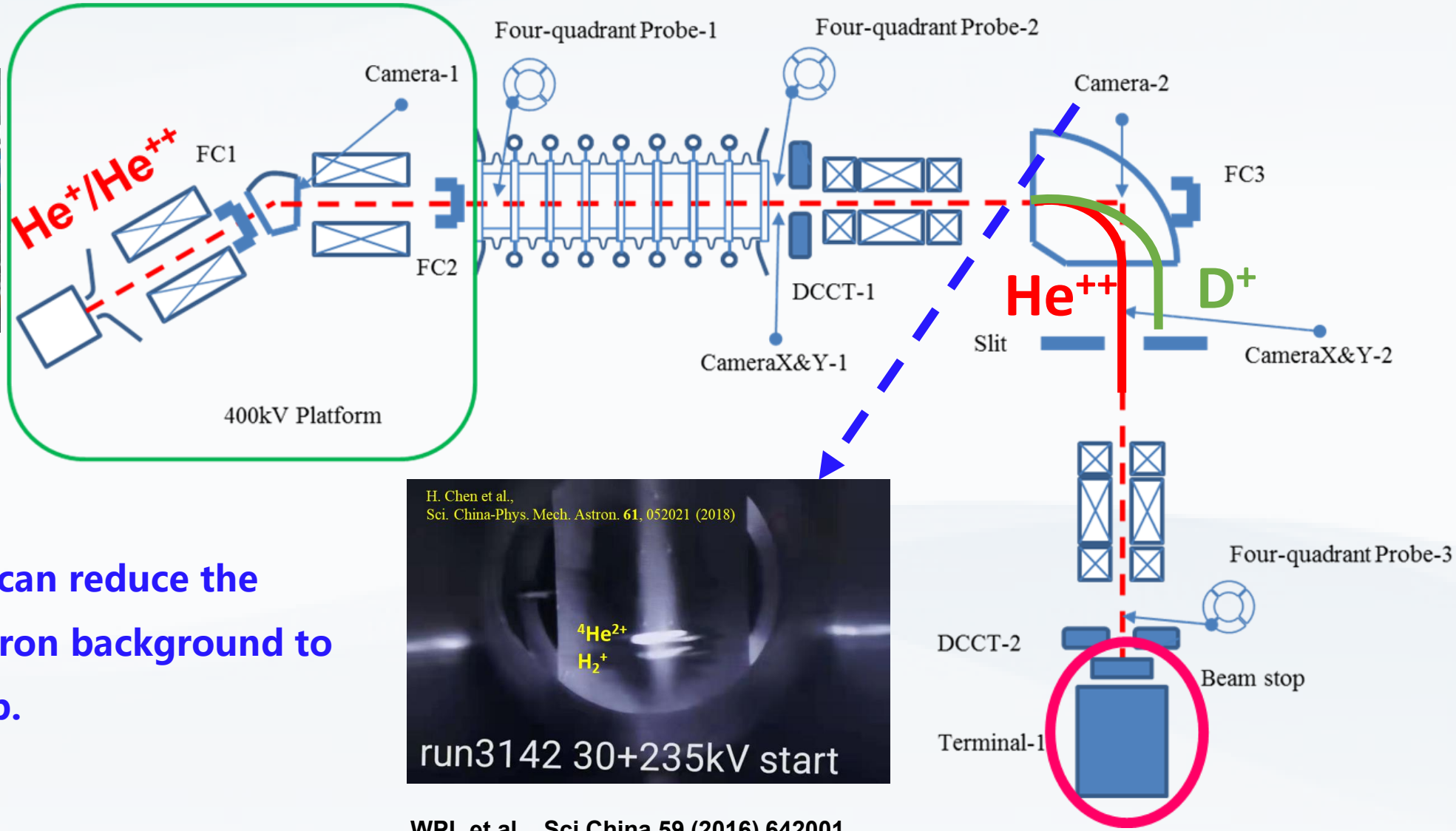
- Coincidence measurement



- Pulsed beam

Beam-induced background

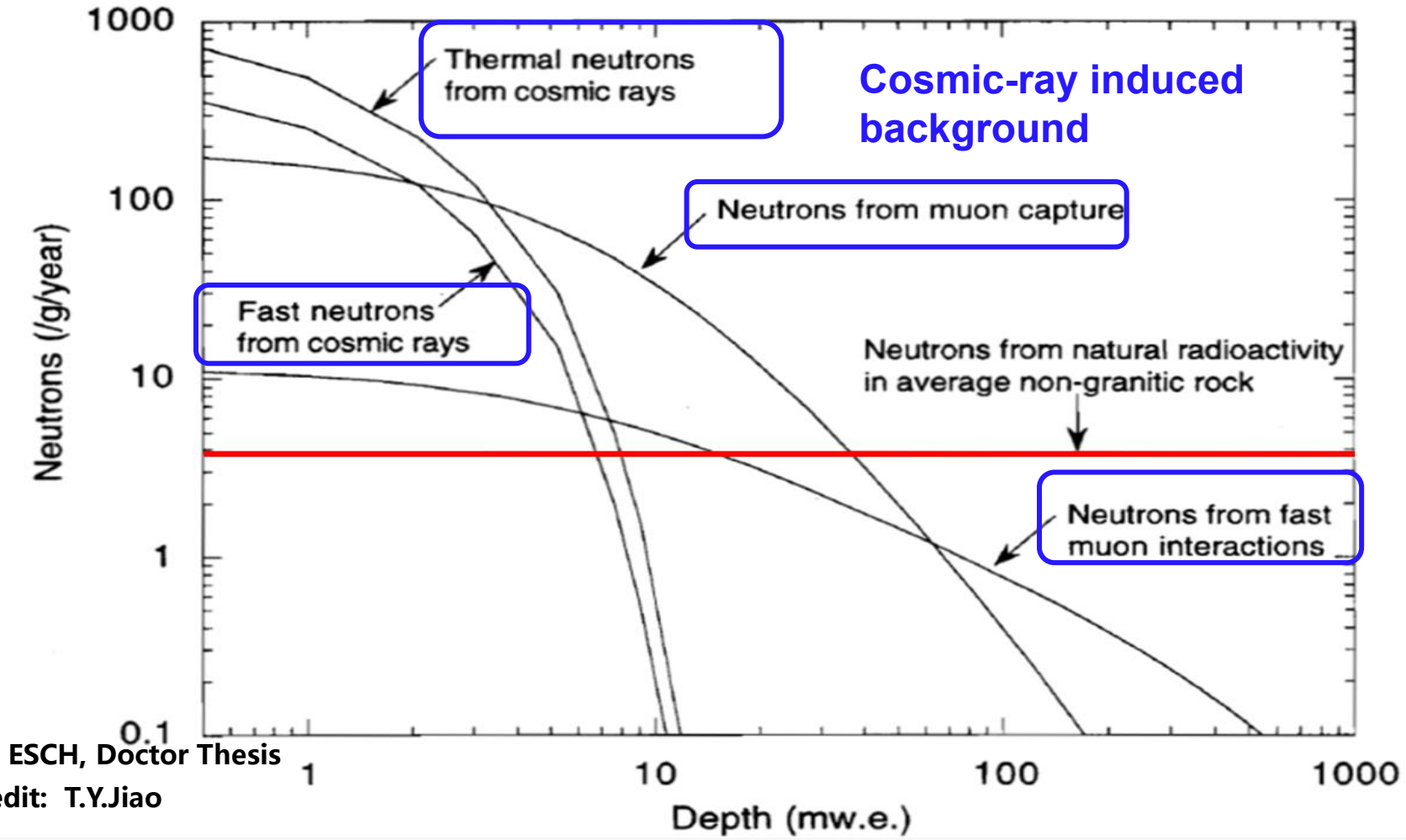
First proton beam of 260 keV and 3 mA in May 2017



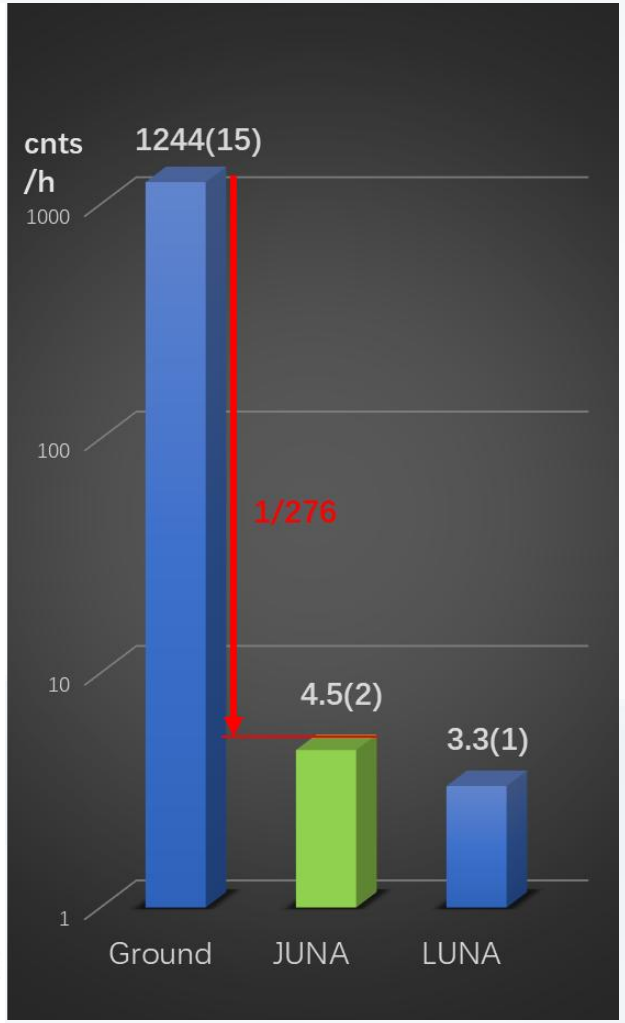
- **The dipole magnet can reduce the beam-induced neutron background to 0.05(8) per coulomb.**

WPL et al., Sci China 59 (2016) 642001
credit: W.P. Liu

Natural background

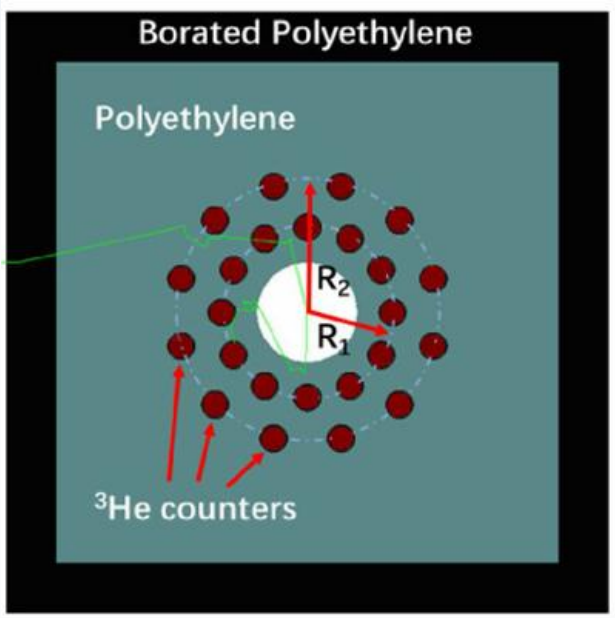


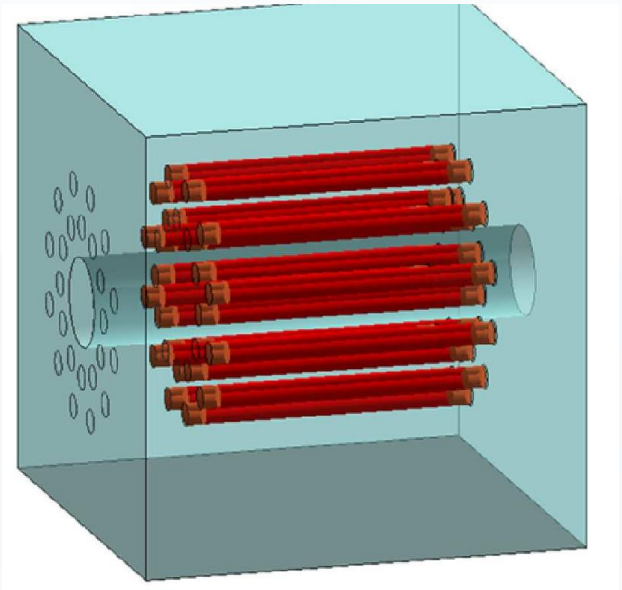
E-I ESCH, Doctor Thesis
credit: T.Y.Jiao



- The background in the surface laboratory is 1244(15) /h, while in the Jinping underground laboratory it is 4.5(2) /h.

Natural background





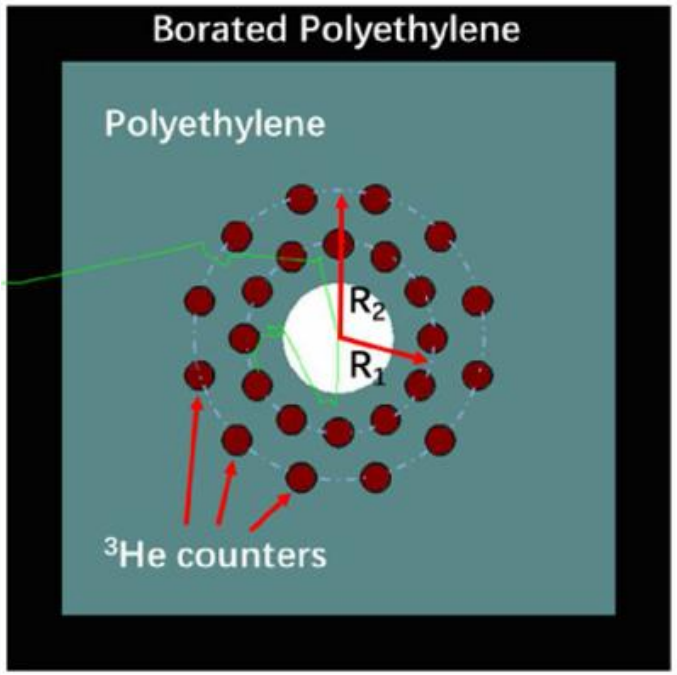
- **Neutron Detector: an array of 24 ^{3}He proportional counters arranged in two concentric circles, surrounded by a polyethylene moderator and a borated polyethylene shields .**

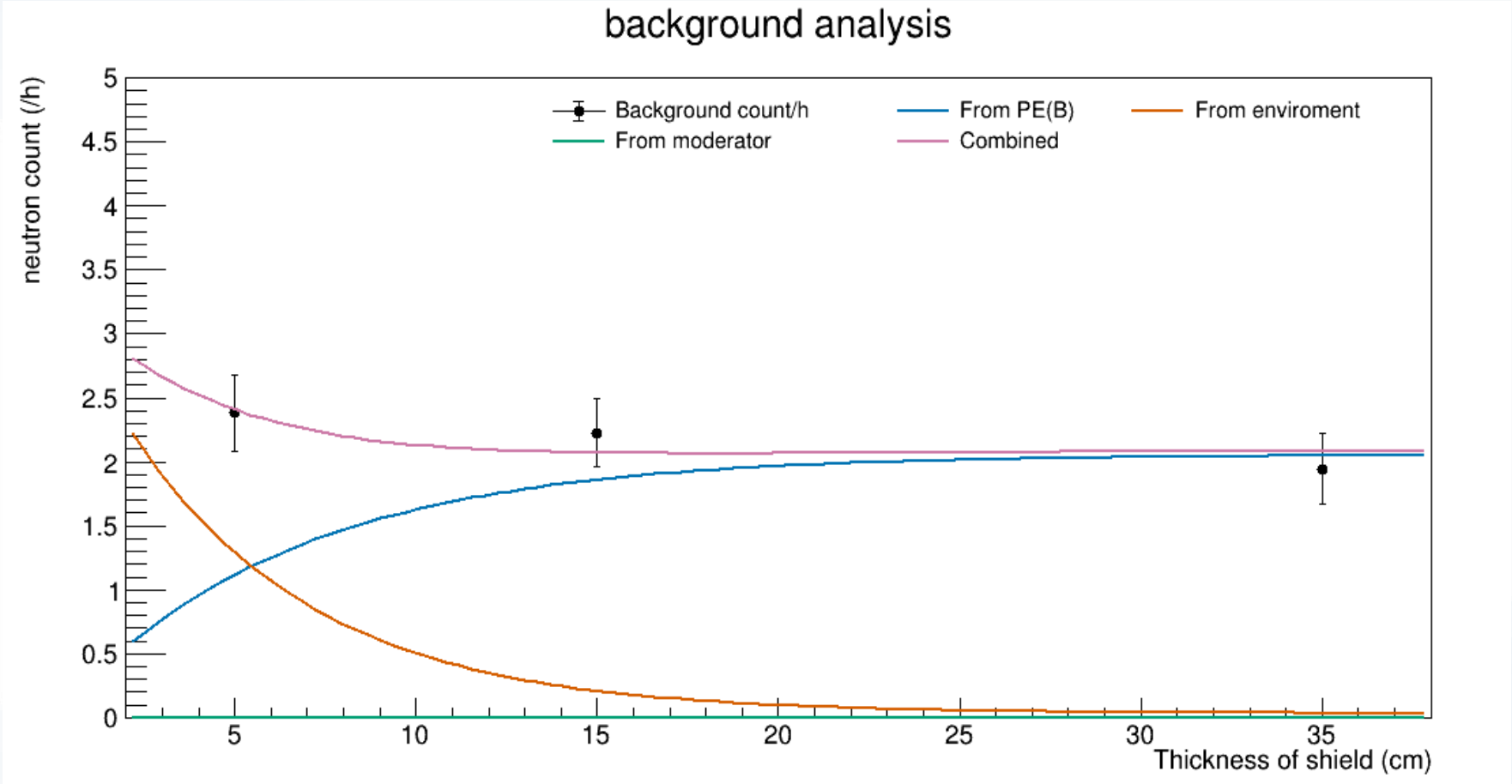
α background is 2 /h. Neutron background is 2.5/h

- **Alpha Background:**
  from the U/Th decay at the surface of 3He tube

- **Natural Neutron Background:**
  from the environment
  or from the material we used as moderator/ as shielding

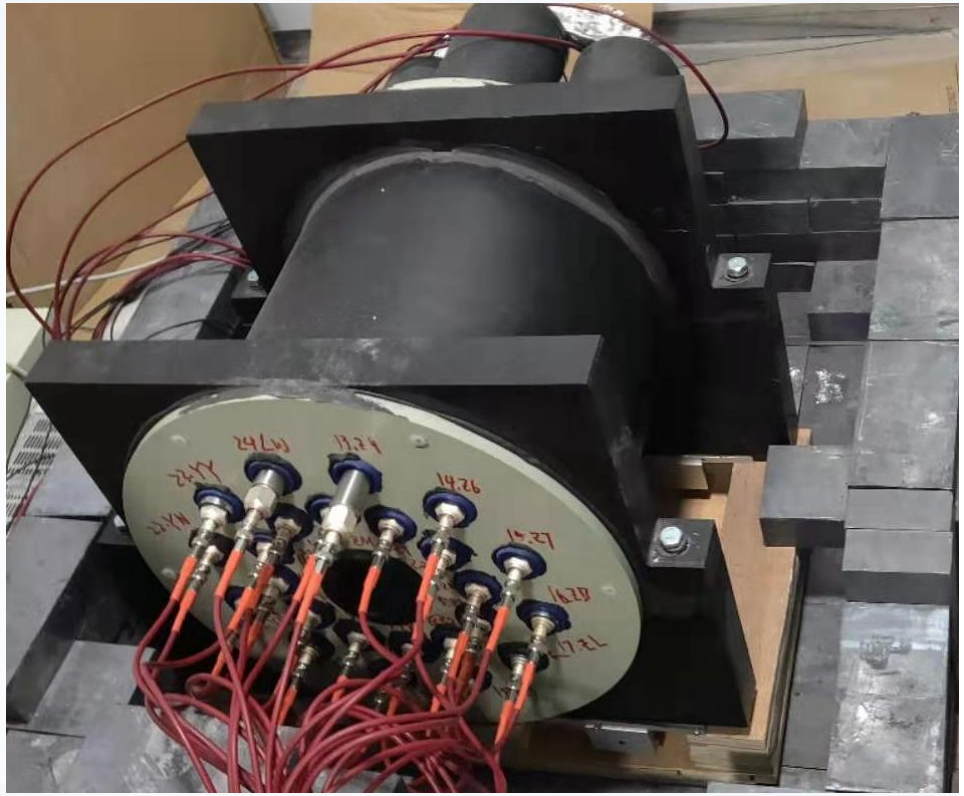
Natural background

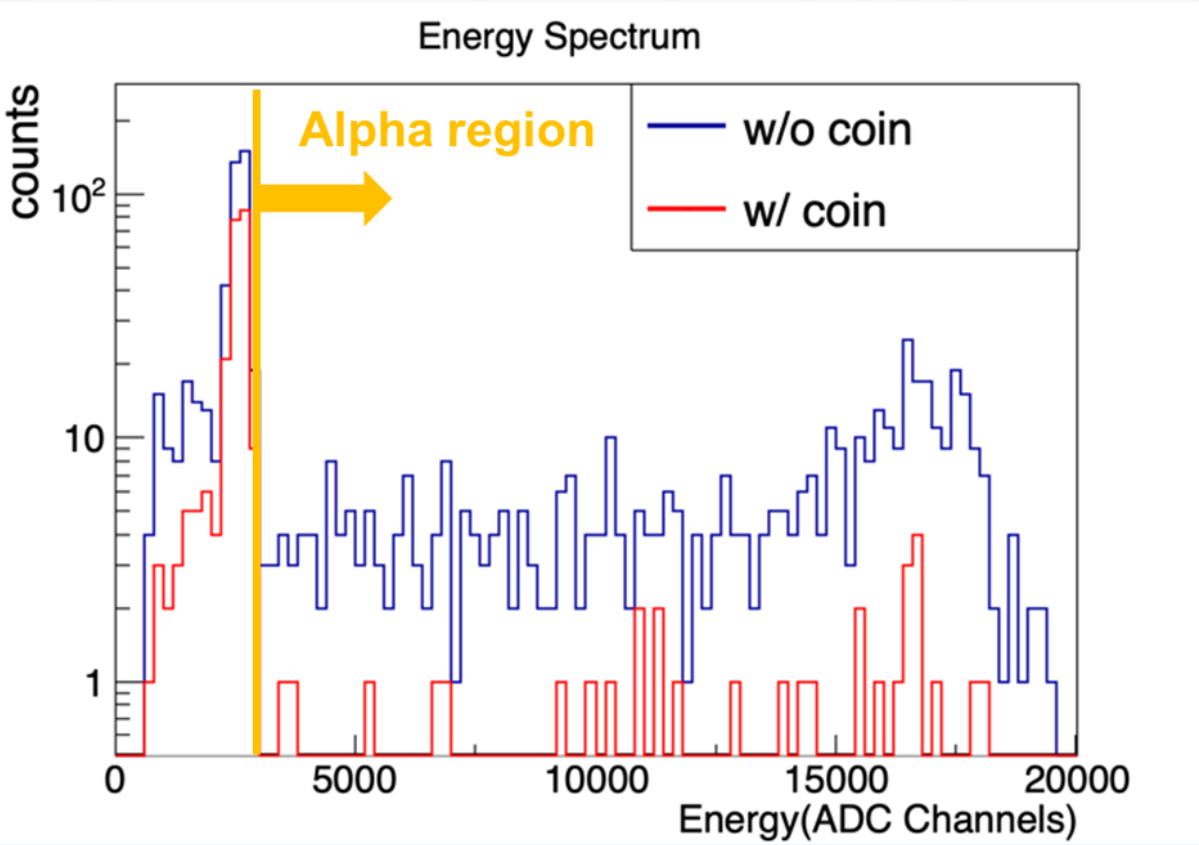




- **Although a relatively scaling factor was required fit the experimental values, the trend suggests that the dominant contribution is the shielding material itself, when the borated polyethylene reaches a thickness of 10 cm or more.**

^{3}He-Plastic scintillation detector array

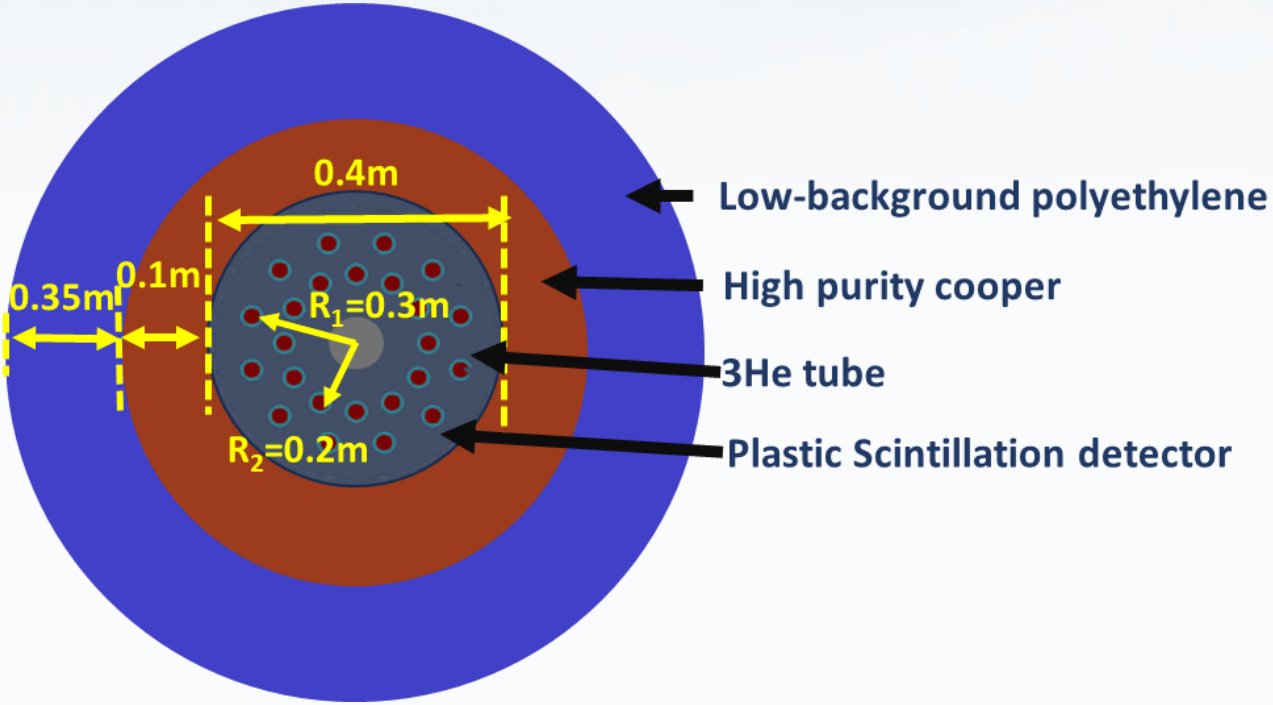




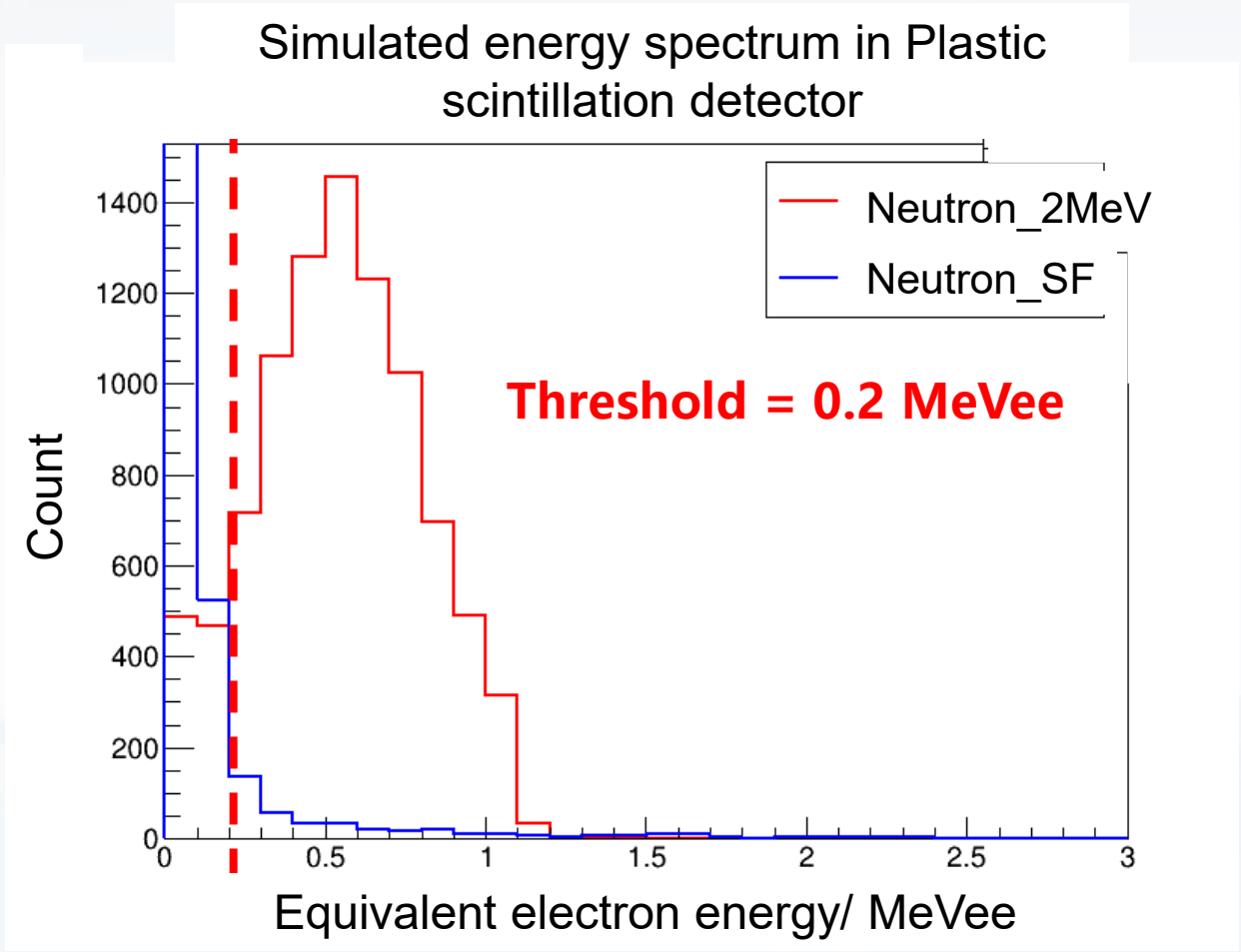
credit: T.Y.Jiao

- **The α-induced background was suppressed to 1/20, while the environmental thermal neutron background was also reduced.**

^{3}He-Plastic scintillation detector

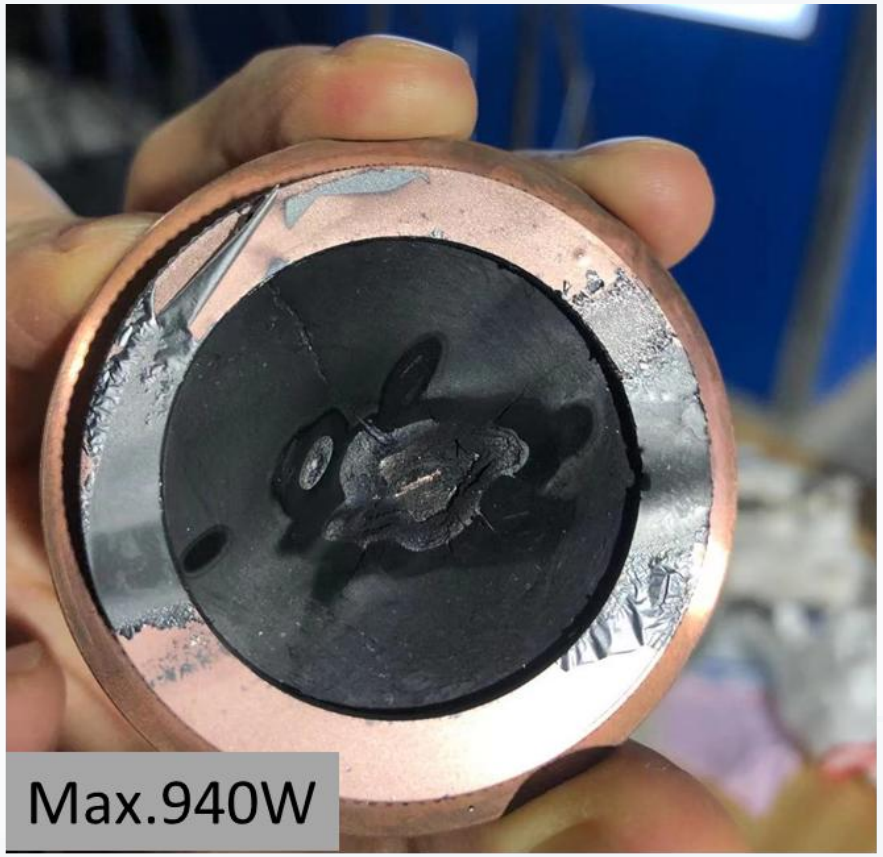


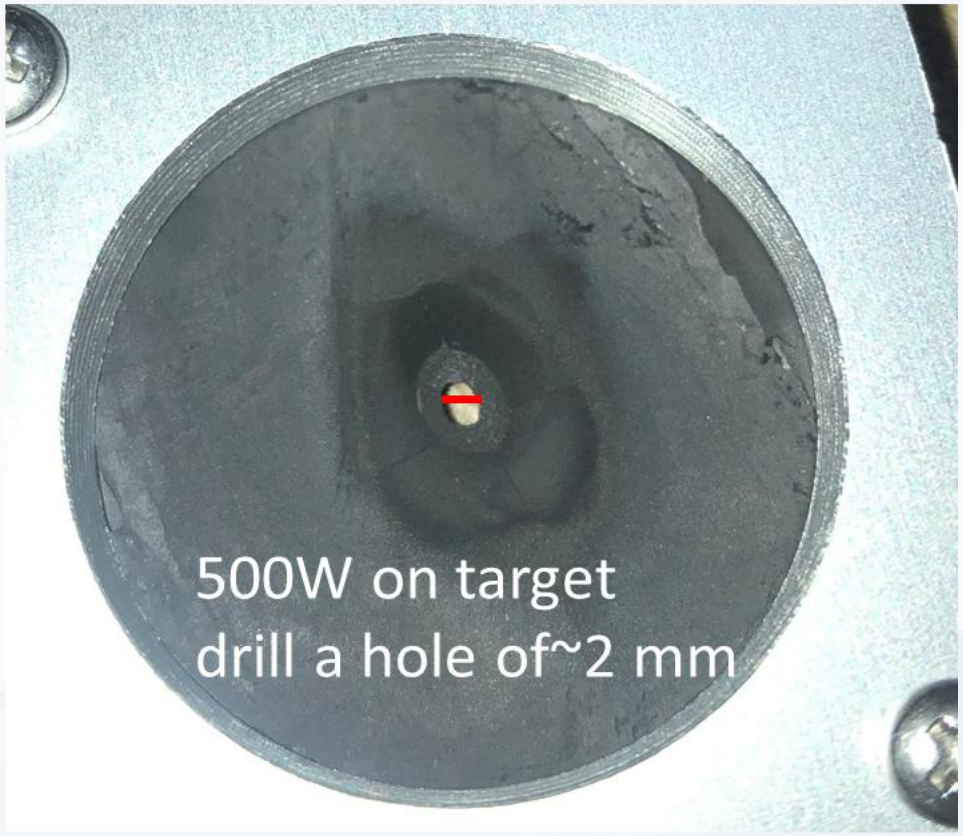
Shielding material	Pb	Cu
thickness(cm)	5	10
238U requirement(ppb)	3.40E+03	1.79E+03



- **By optimizing the shielding materials and setting the plastic scintillator threshold, the natural neutron background wish to be further reduced by an order of magnitude.**

Challenges with high-power beam

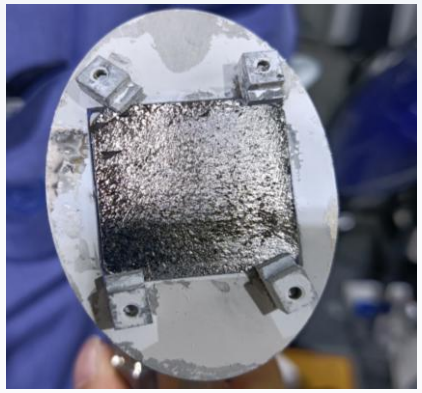




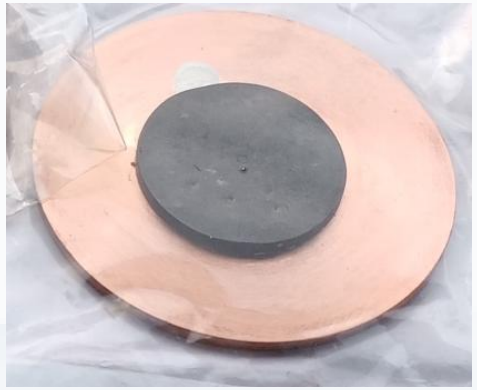
- **Under conditions of high-intensity continuous beam and well-focused beams, target surface damage.**

Challenges with high-power beam

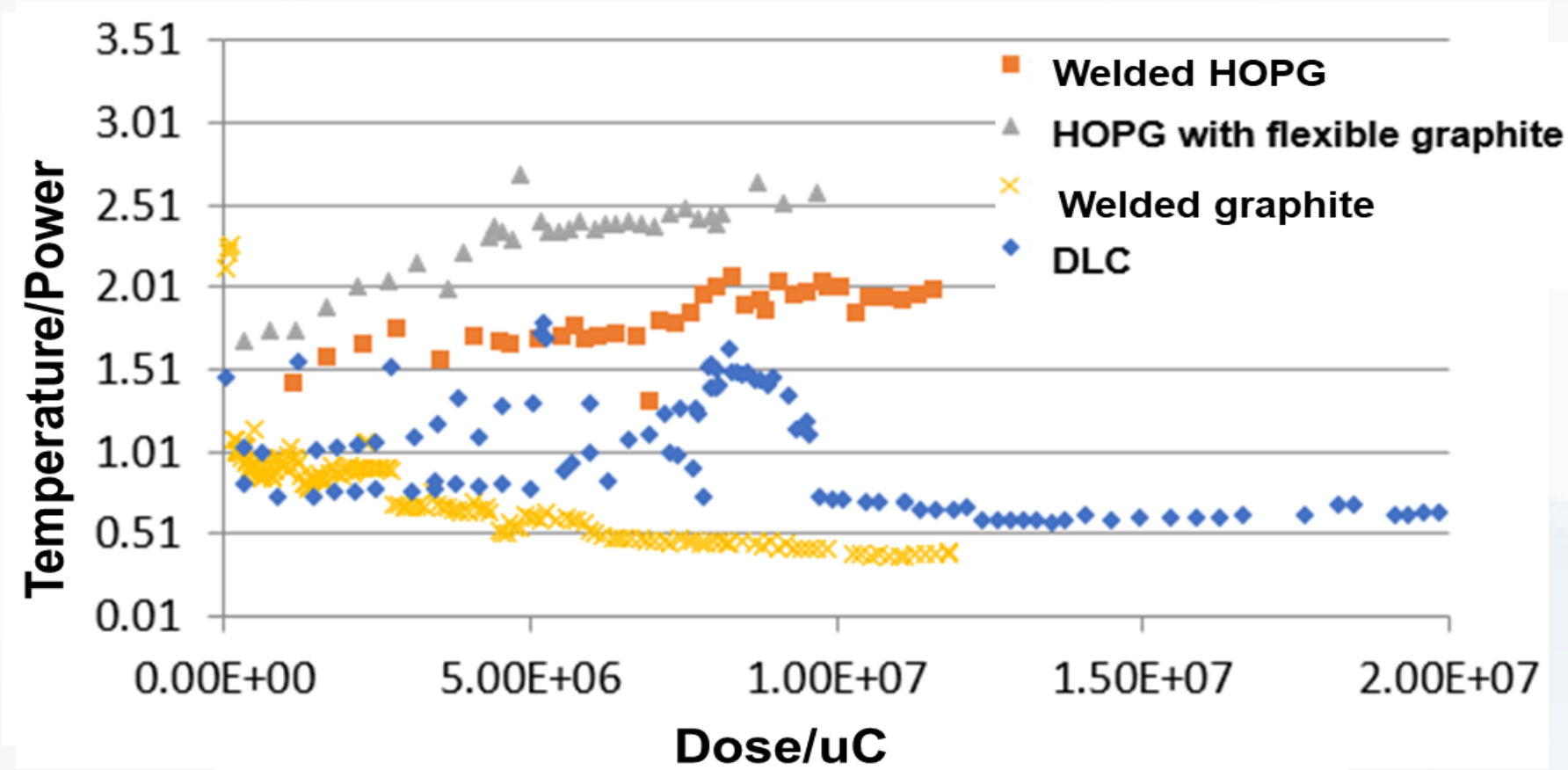
The expected maximum beam power is up to 785 W.



Welded HOPG

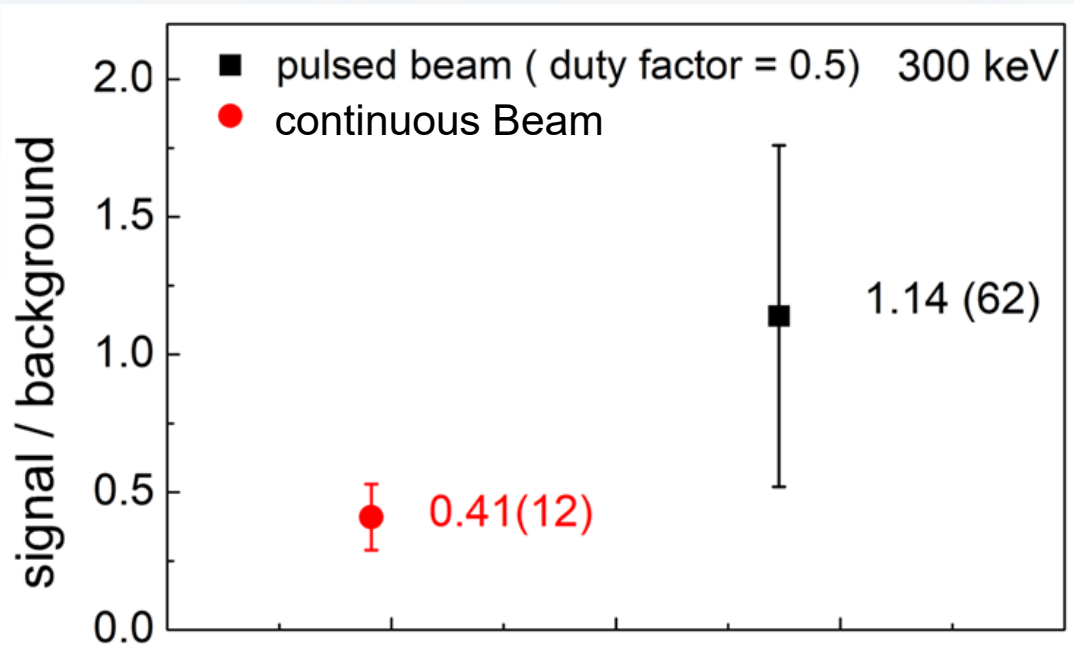


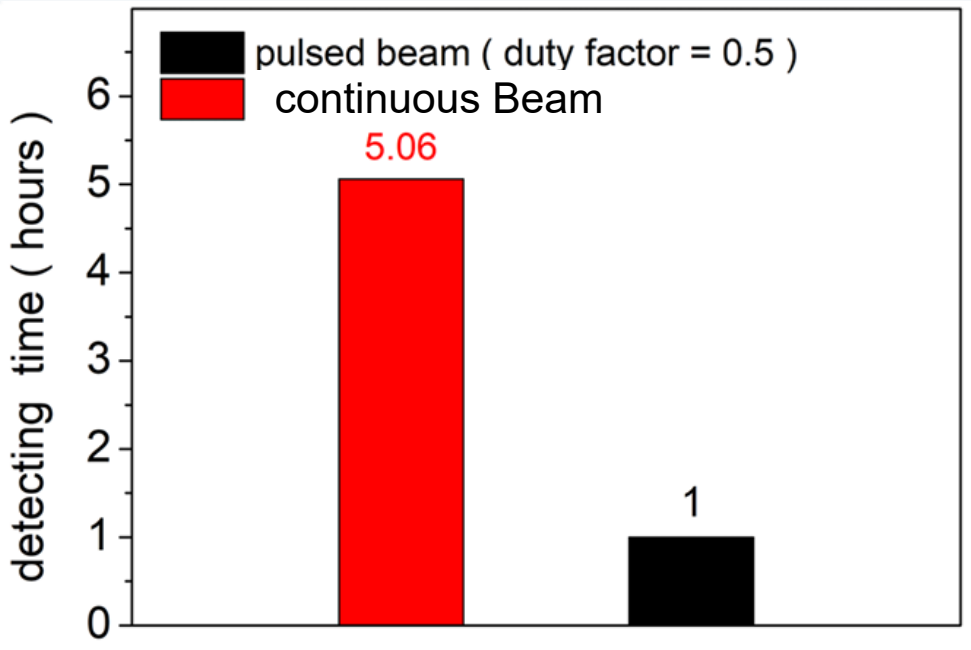
Welded Graphite



- the **welded graphite target** is the most stable one and demonstrate the best performance.

Pulsed beam





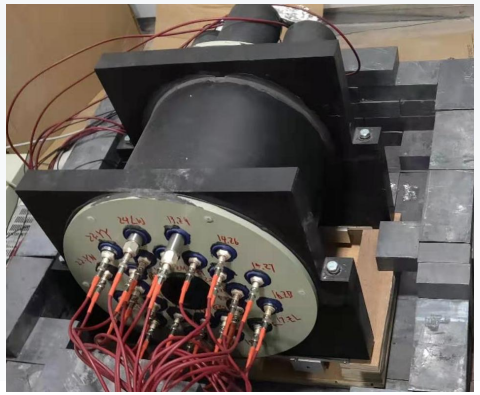
E_{lab} /keV	beam/mA	Intensity/mA	Time/h	net-Cnt/h	BG-Cnt/h	SNR
300	Continuous Beam	0.44	5.06	3.66±1.12	9.01	0.41±0.12
	Pulsed beam	2.25	1	5.12±2.79	4.5	1.14±0.62

- **For the same beam dose, improve the signal-to-noise ratio by improving the maximum withstand beam intensity and reducing the detect time.**

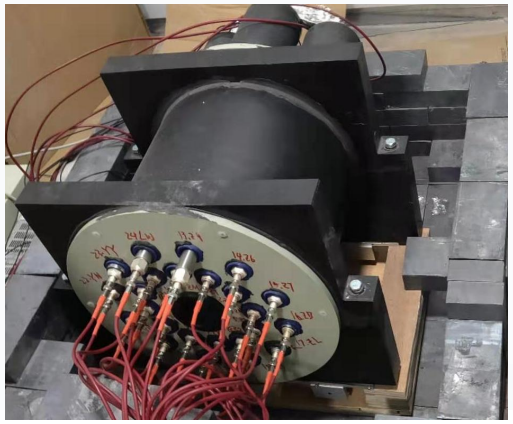
Conclusion

- Dipole magnet

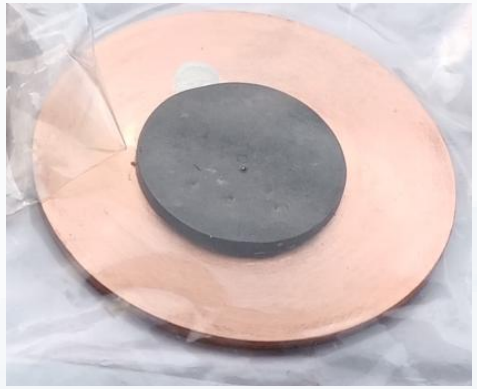
- Covered by Rock



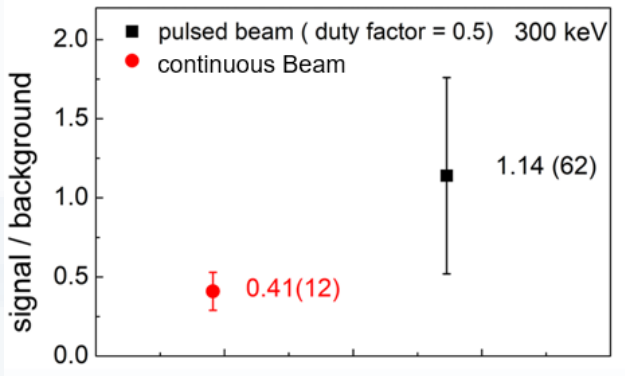
- Coincidence measurement



- Low-background material



- Welded Graphite



- Pulsed beam

- **For $E_{c.m.} = 0.19$MeV, the reaction cross-section will be reduced by an order of magnitude, with the uncertainty lowered to the 10–20% level.**