Progress of underground nuclear astrophysics experiment (JUNA)

Weiping Liu
JUNA chief scientist
CIAE/SUSTech

The ANPhA Symposium
Huizhou, China
Nov. 15-16, 2024

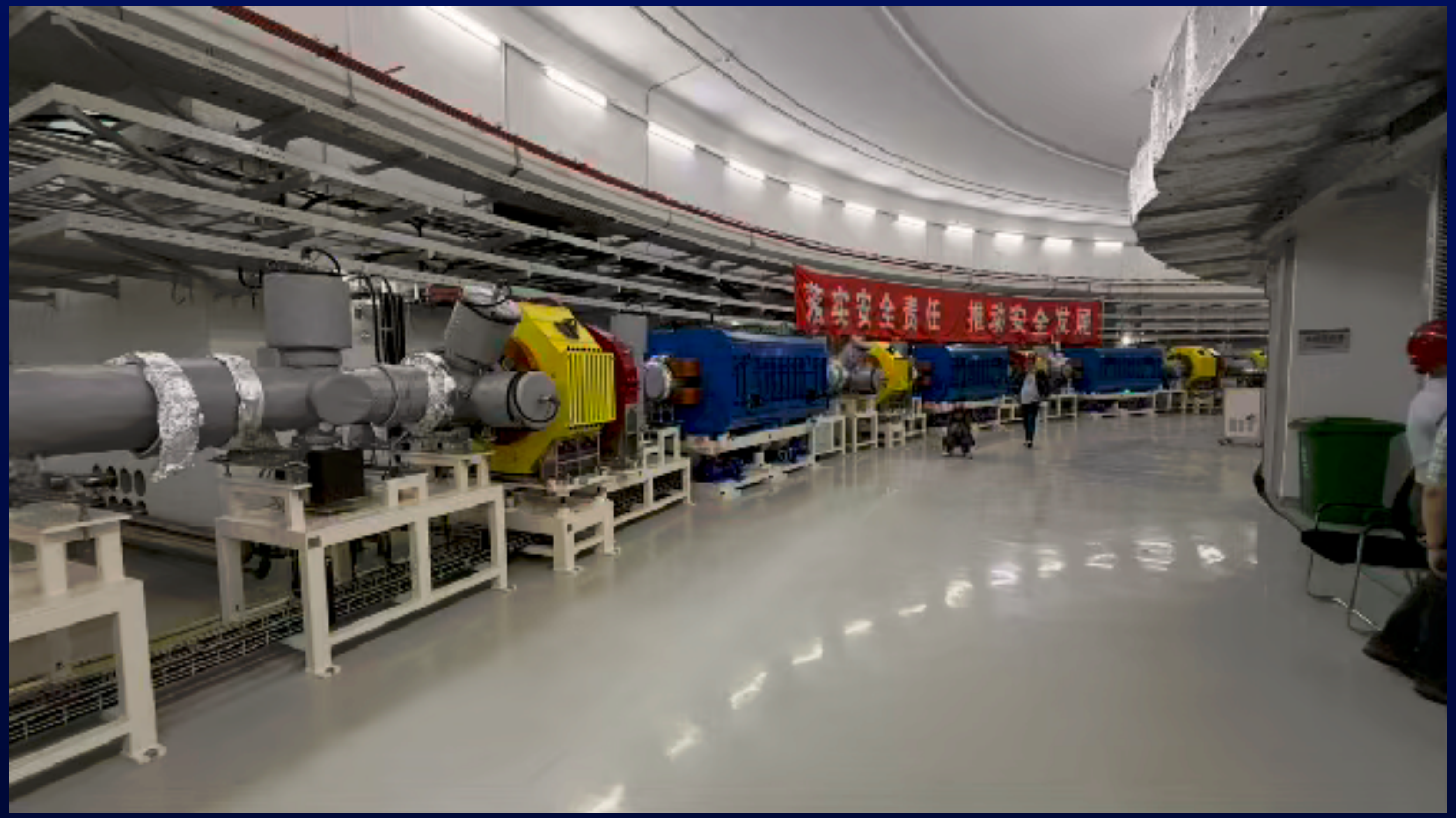
Thanks NSFC, Yalong power, THU, CAS and CNNC

北京師範大學 BEIJING NORMAL UNIVERSITY
中国科学院近代物理研究所 Institute of Modern Physics, Chinese Academy of Sciences
中国原子能科学研究院 中核集团 CHINA INSTITUTE OF ATOMIC ENERGY
雅砻江流域水电开发有限公司 YALONG RIVER HYDROPOWER DEVELEPOMENT COMPANY, LTD.
南方科技大学 SOUTHERN UNIVERSITY OF SCIENCE AND TECHNOLOGY
上海交通大學 SHANGHAI JIAO TONG UNIVERSITY
山东大学 SHANDONG UNIVERSITY
四川大学 SICHUAN UNIVERSITY
深圳大学 SHENZHEN UNIVERSITY
中山大學 SUN YAT-SEN UNIVERSITY
清華大學

Congratulations to HIAF progress!

ECR ion source

Booster ring



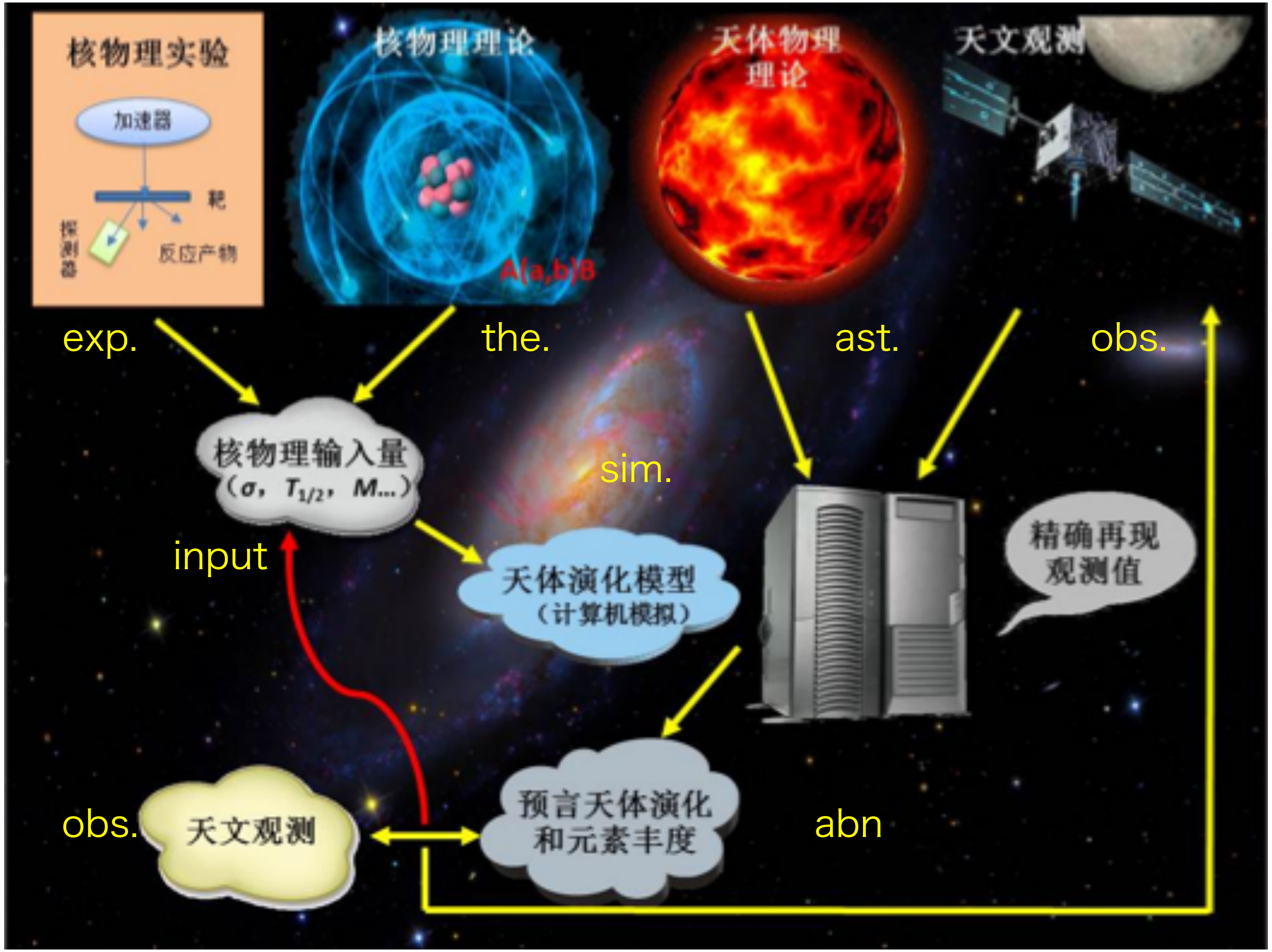
Storage ring

Civil engineering

Photo taken in Nov. 14

W. P. Liu, 2024

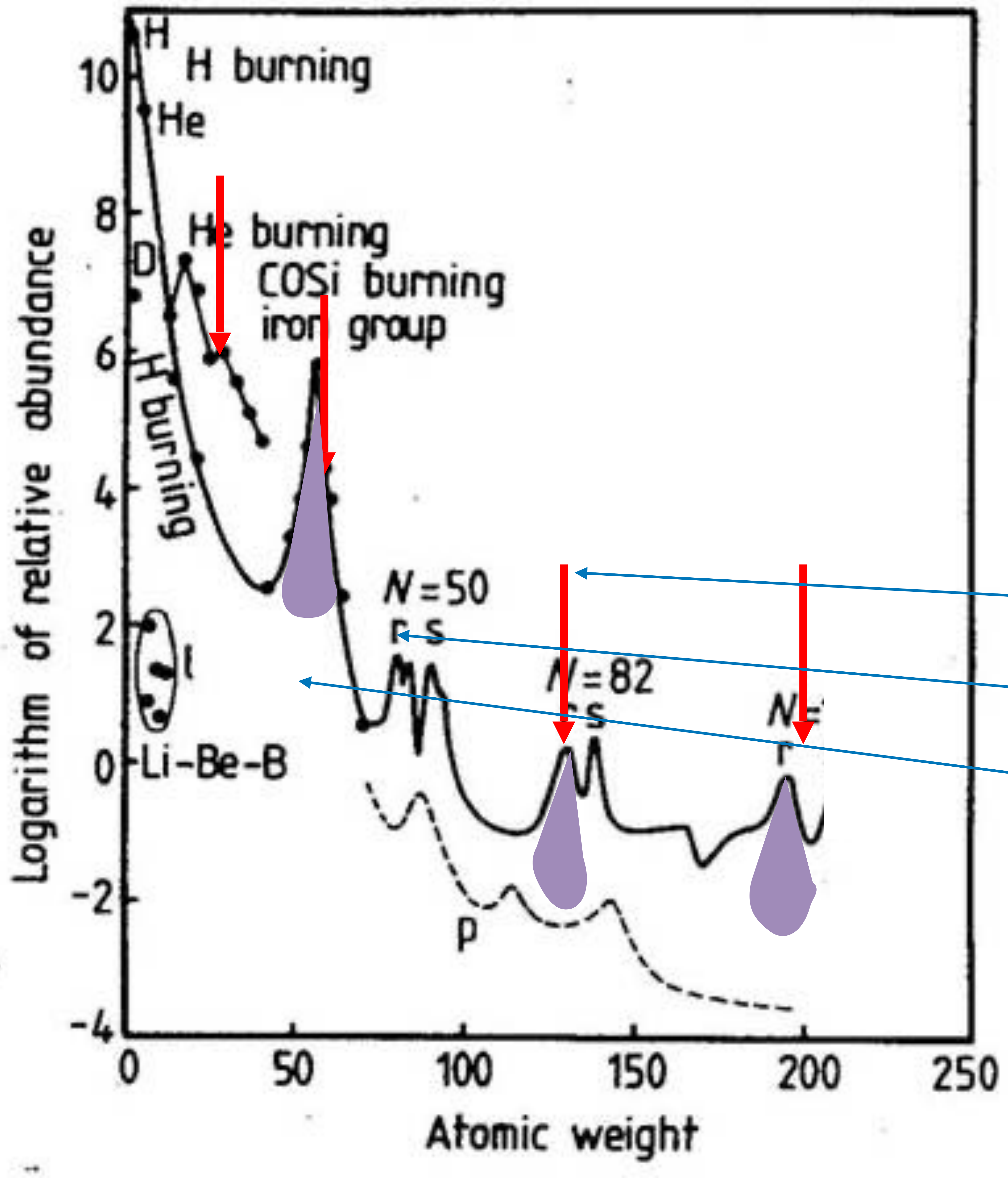
nuclear astrophysics

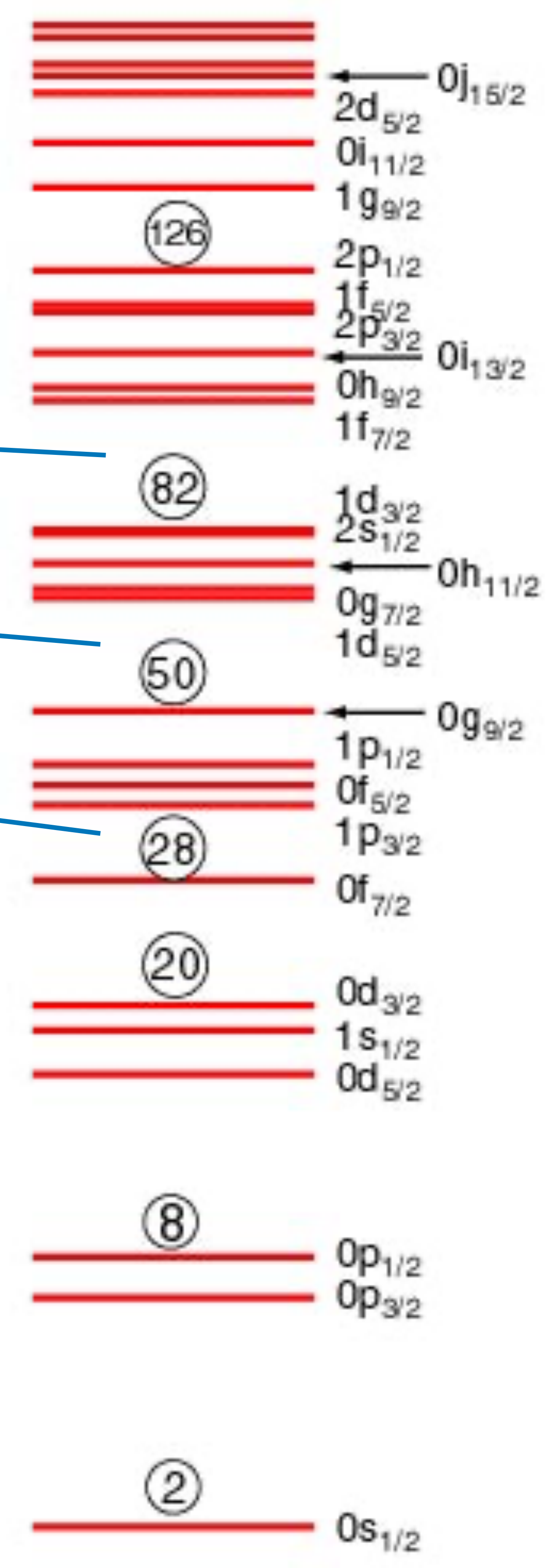


- NP, microscopic, 10^{-15} m, —>observation, cosmic, 10^{14} m, truly interdisciplinary
- For energy production and element synthesis in star

Nuclear Reactions: Alchemists in the Universe

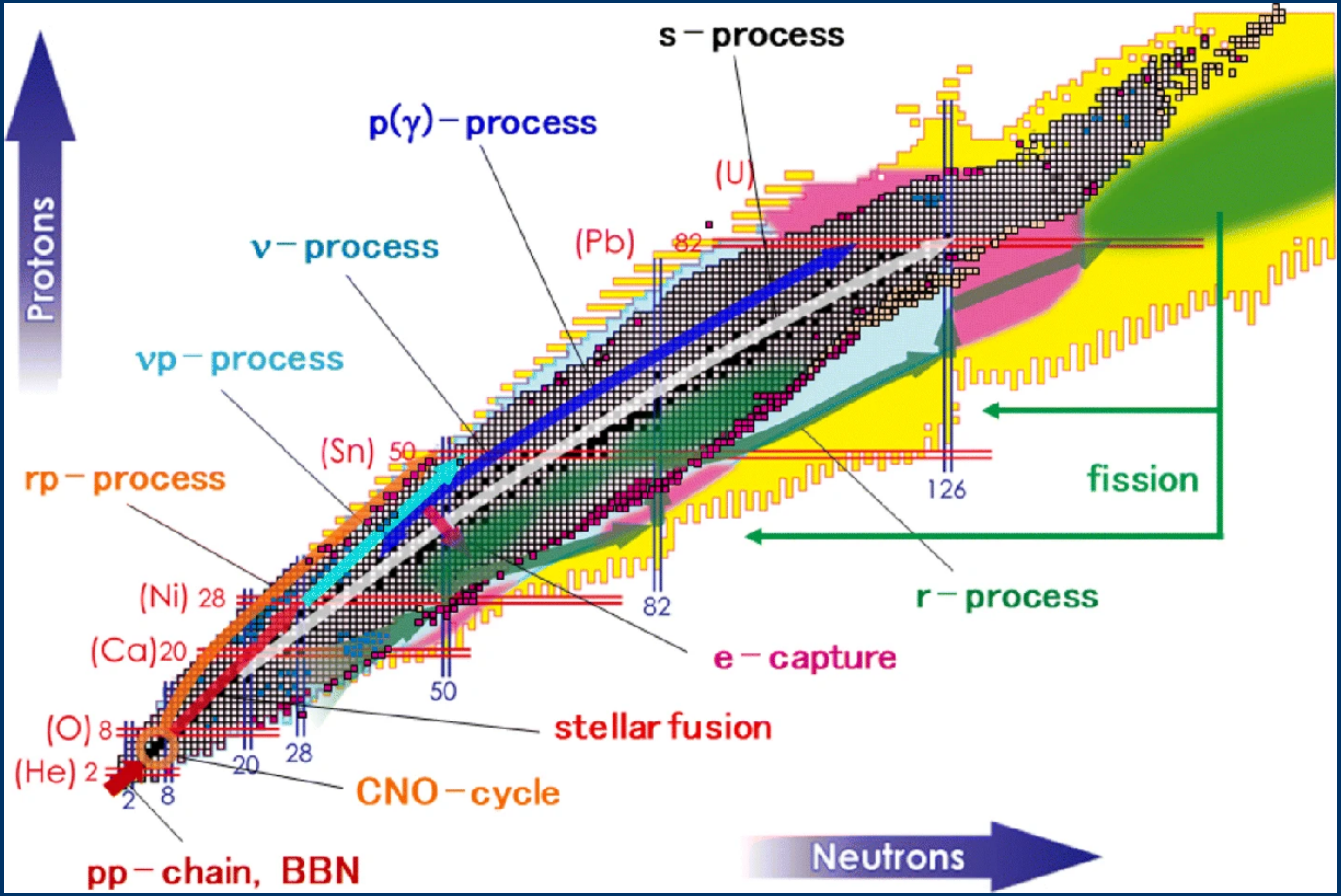
Peaks are the birthmark of nuclear physics: the magic number of the nuclear shell model





Shell Model of Nuclei

Major astrophysics process



- **Bench mark:** $^{7}Be(p,\gamma)^{8}B$, $^{19}F(p,\gamma)^{20}Ne$
- **Bottle neck:** $^{12}C(\alpha,\gamma)^{16}O$, $^{12}C+^{12}C$
- **Neutron source:** $^{13}C(\alpha,n)^{16}O$, $^{22}Ne(\alpha,n)^{25}Mg$
- **Many more:** by sensitivity

- Progress in nuclear astrophysics of east and southeast Asia…Toshitaka Kajino*, …, WPL*, …, Xiaodong Tang*,… et al., AAPPSBulletin (2021) 31:18

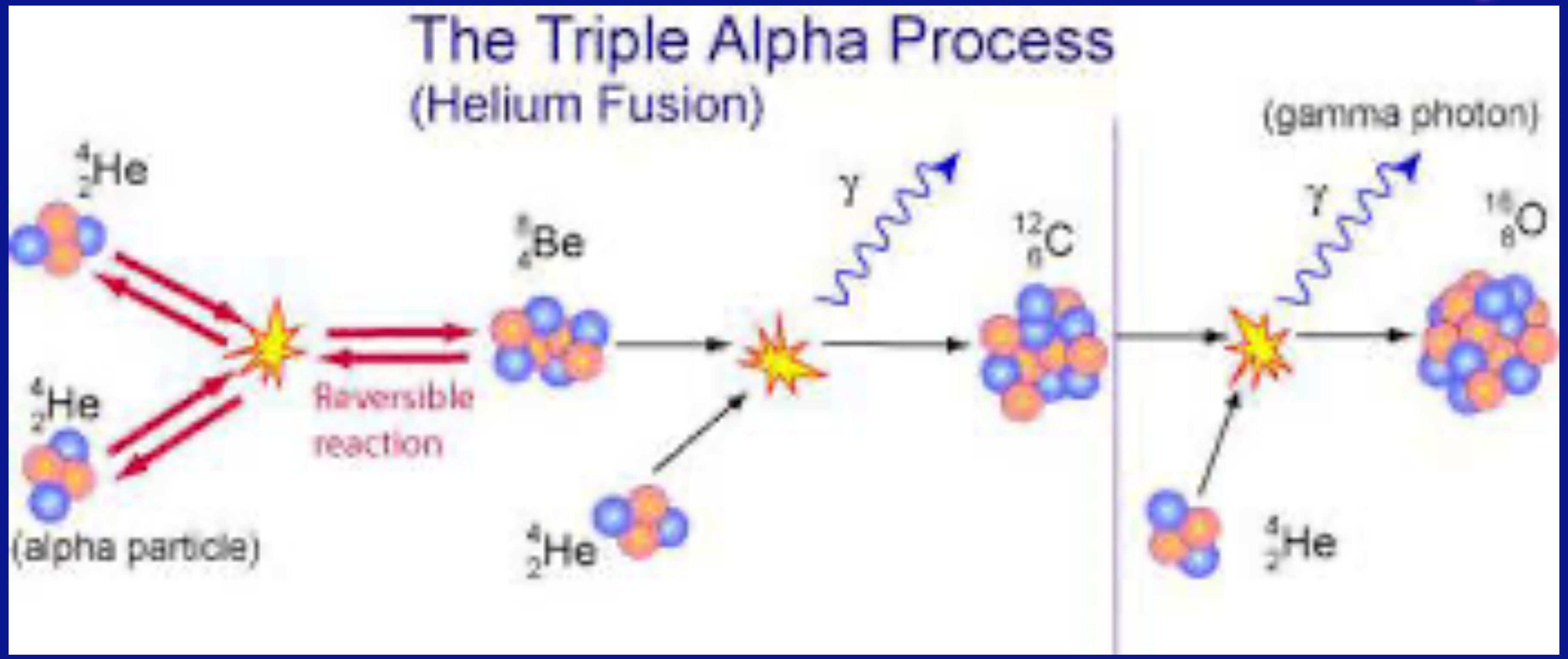
State of nuclei, fate of star

α 0+ α 7.65 0+

^{4}He ^{8}Be 3α reaction bridge

1954, Hoyle state, large amount of Carbon

Fred Hoyle (1915-2001)
APJS 1(1954)121



William A. Fowler (1911–1995)
Rev.Mod.Phys. 56 (1984) 149-179

8.87 2-

regulator

α

7.12 1-

^{12}C

$^{12}C(\alpha,\gamma)^{16}O$

Holy grail reaction

^{16}O

Adequate amount: for sun burn long, for human live

from “Claudon in the universe”

Nuclear astrophysics in China

JUNA experiment

Direct in Gamow window (underground)

RIBLL and LEAF experiment

Direct in higher energy

CIAE experiment

In-direct measurements

theoretical study

Nuclear astrophysics and sensitivity study

theoretical study

Nuclear astrophysics network calculation

theoretical study

Shell model and mean field calculation

Reaction rate database

Nuclear input database

BRIF, CSR experiment

Nuclear decay

CSR experiment

Nuclear mass

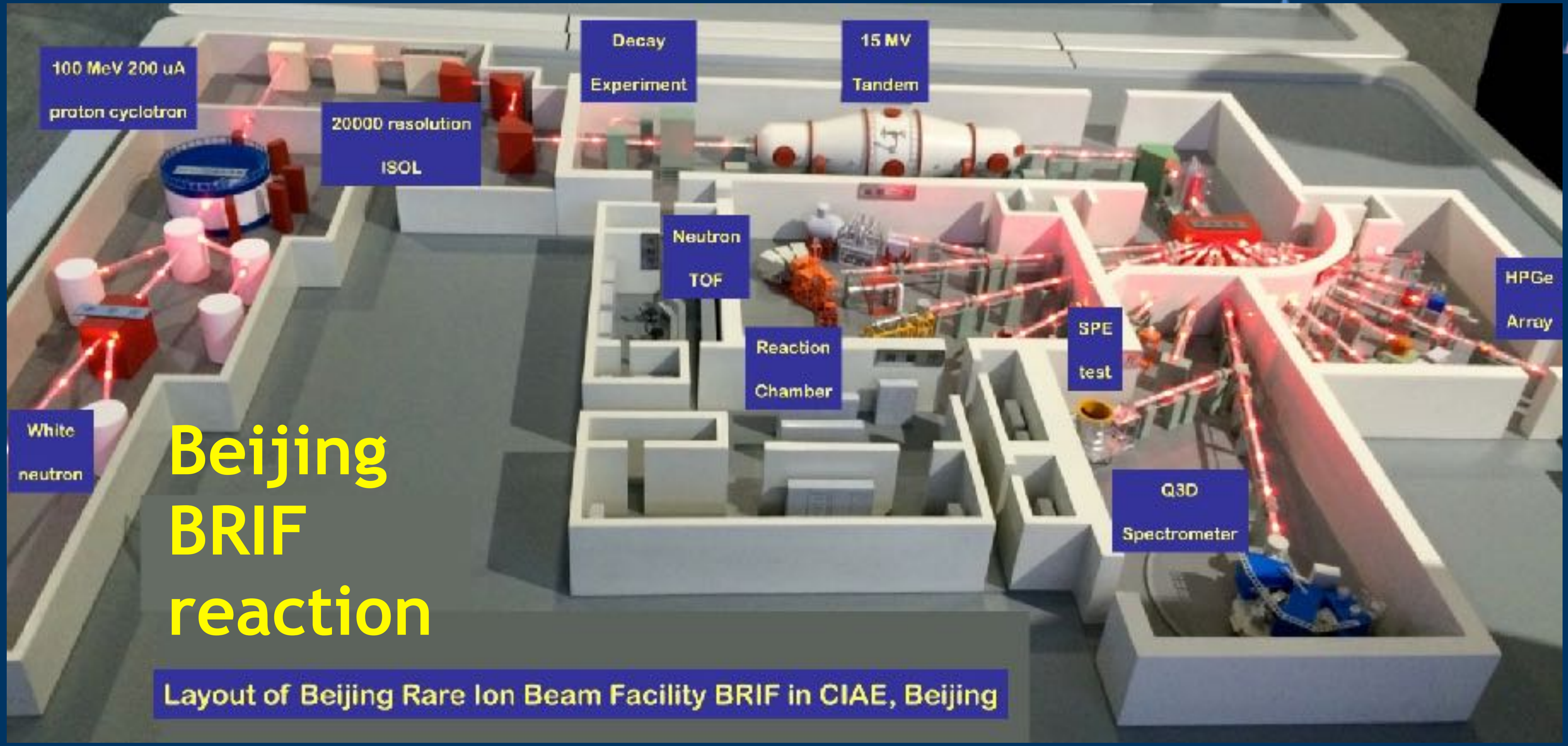
Shell model and mean field calculation

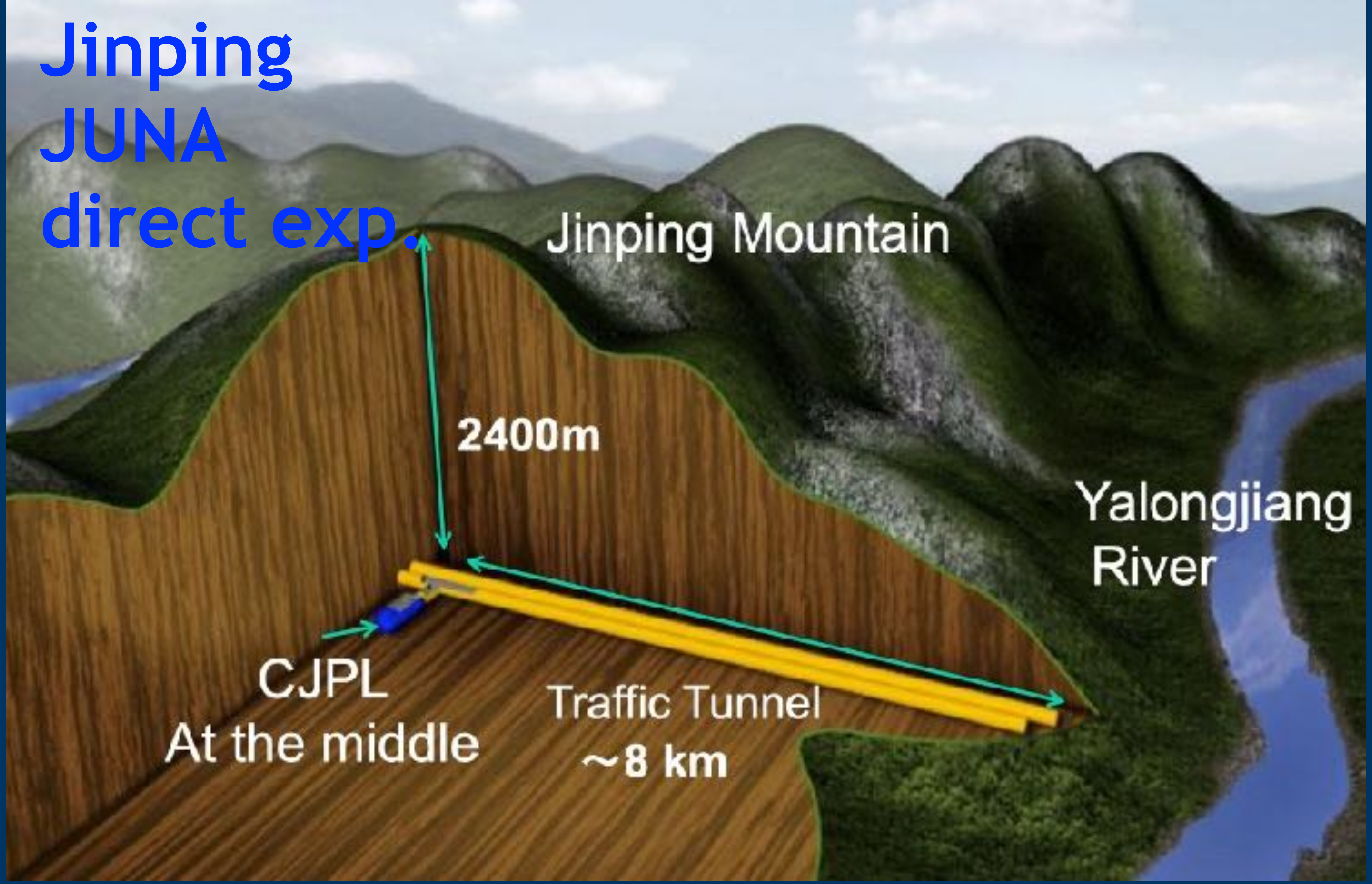
theoretical study

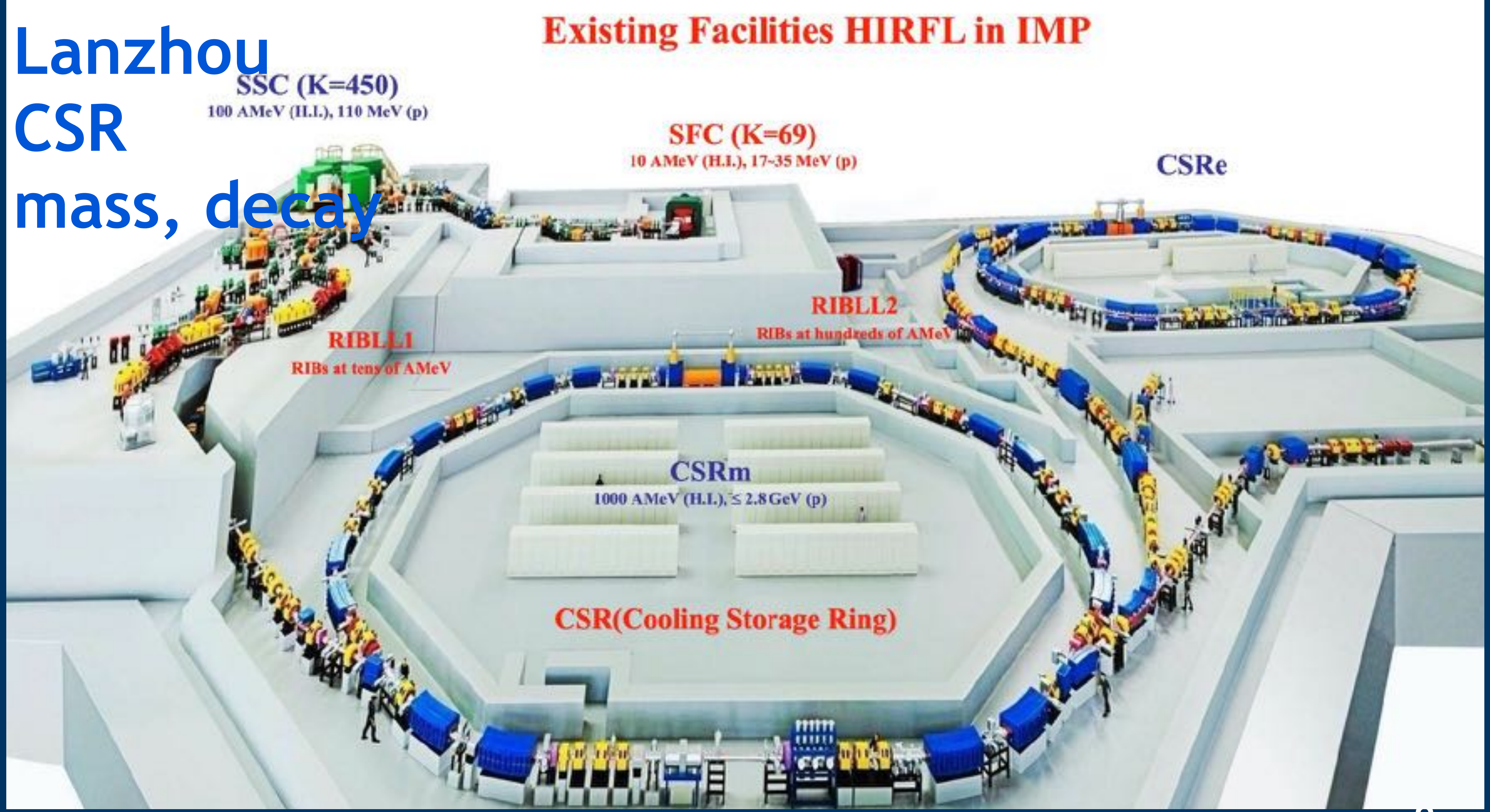
Mass data compilation in China

Mass and decay rate database

Major facilities in China





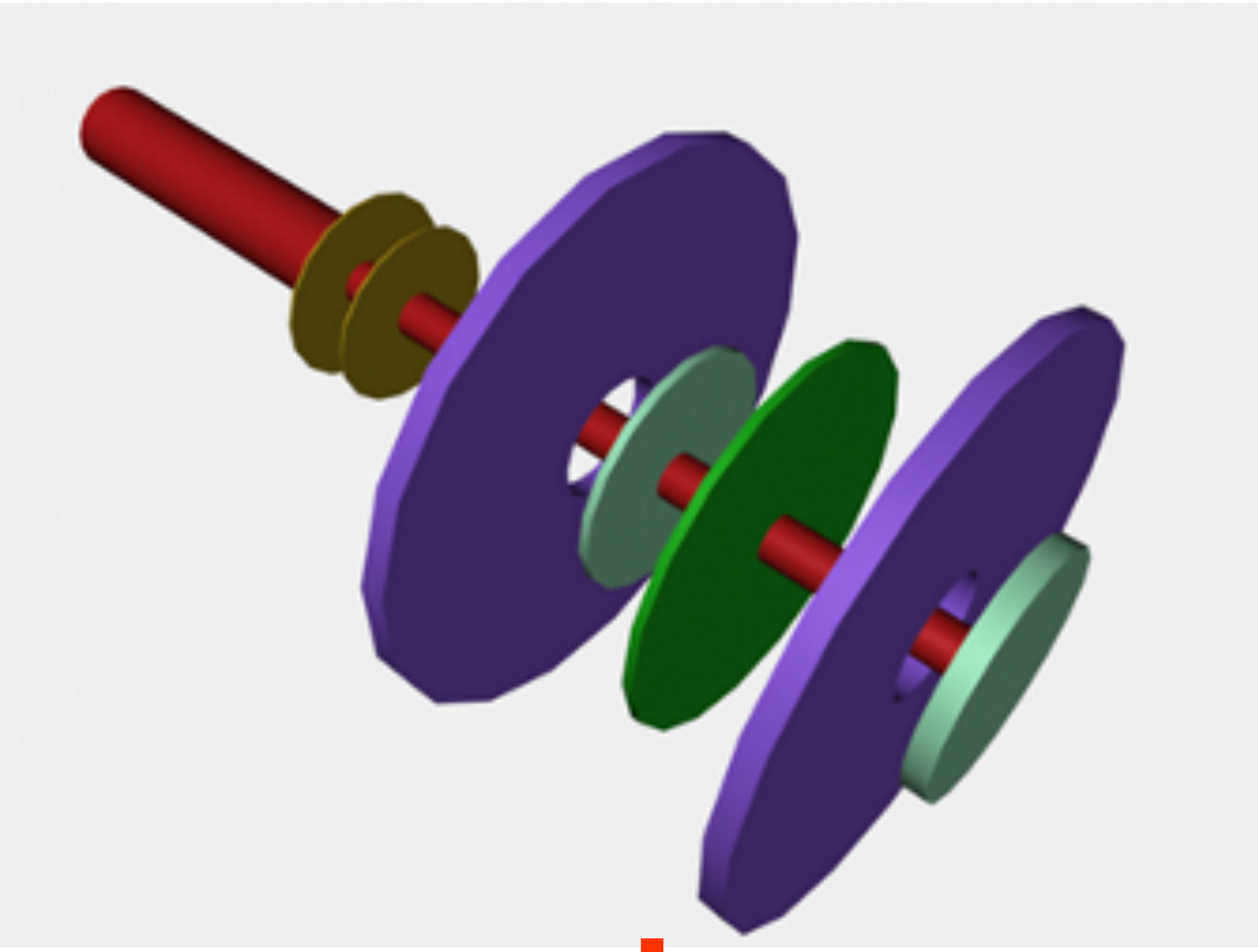


1996: new method for ^{8}B solar neutrino cross section

RIB production

X. X. Bai, WPL et al., NP A588(1995)273c

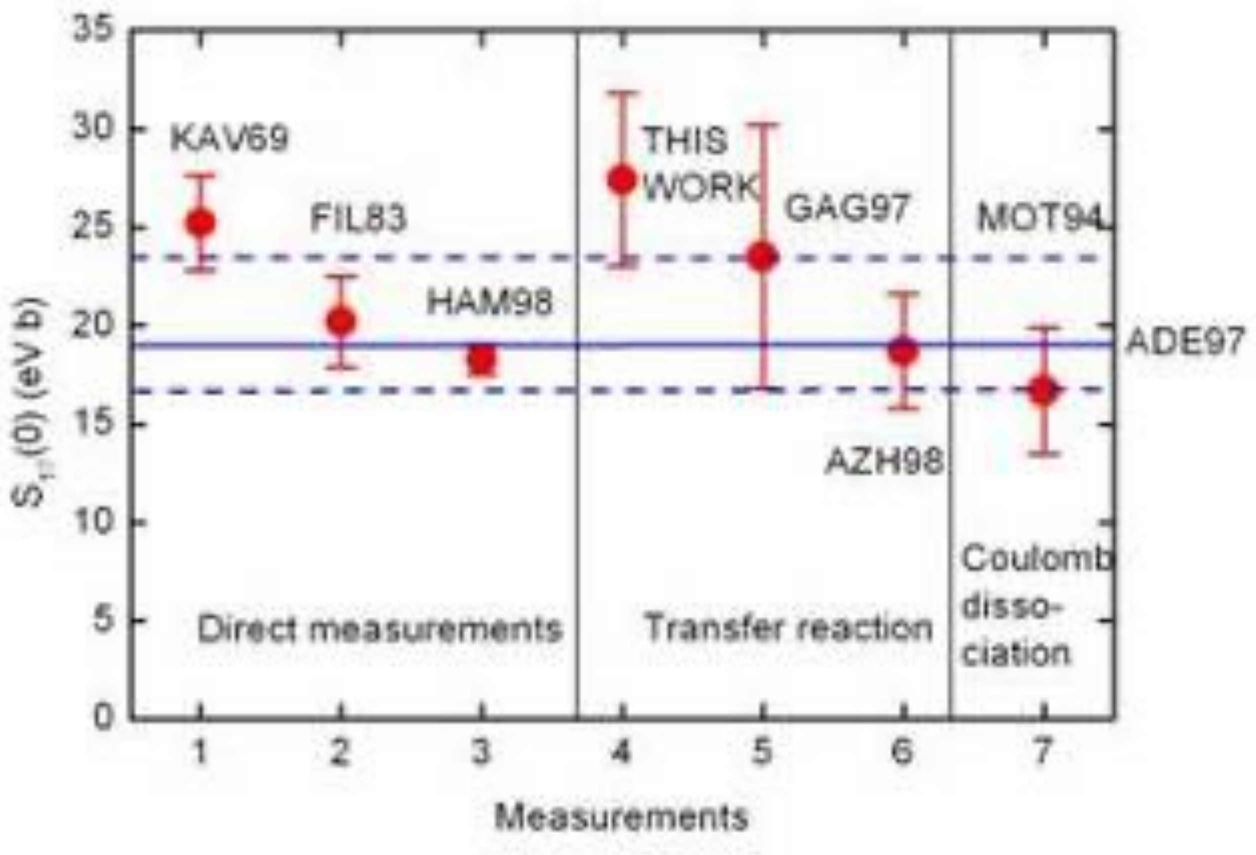
(d,n) or (d,p) measurement



$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} - \left(\frac{d\sigma}{d\Omega}\right)_{CN} = \sum_{j_i j_f} (C^{d}_{l_i j_i})^2 (C^{^{12}N}_{l_f j_f})^2 \frac{d\sigma^{DW}_{l_f j_f l_i j_i}/d\Omega}{b^2_{l_i j_i} b^2_{l_f j_f}},$$

$$\sigma_t = \frac{16\pi}{9}\left(\frac{E_\gamma}{\hbar c}\right)^3 \frac{1}{\hbar v}\frac{e^2_{eff}}{k^2}\frac{(2j_f+1)}{(2I_1+1)(2I_2+1)} C^2_{\ell_f j_f} \times \left|\int_{R_N}^{\infty} r^2 dr\, f_{\ell j}(kr) W_{\eta,\ell_f+1/2}(2\kappa r)\right|^2,$$

ANC or Spec factor



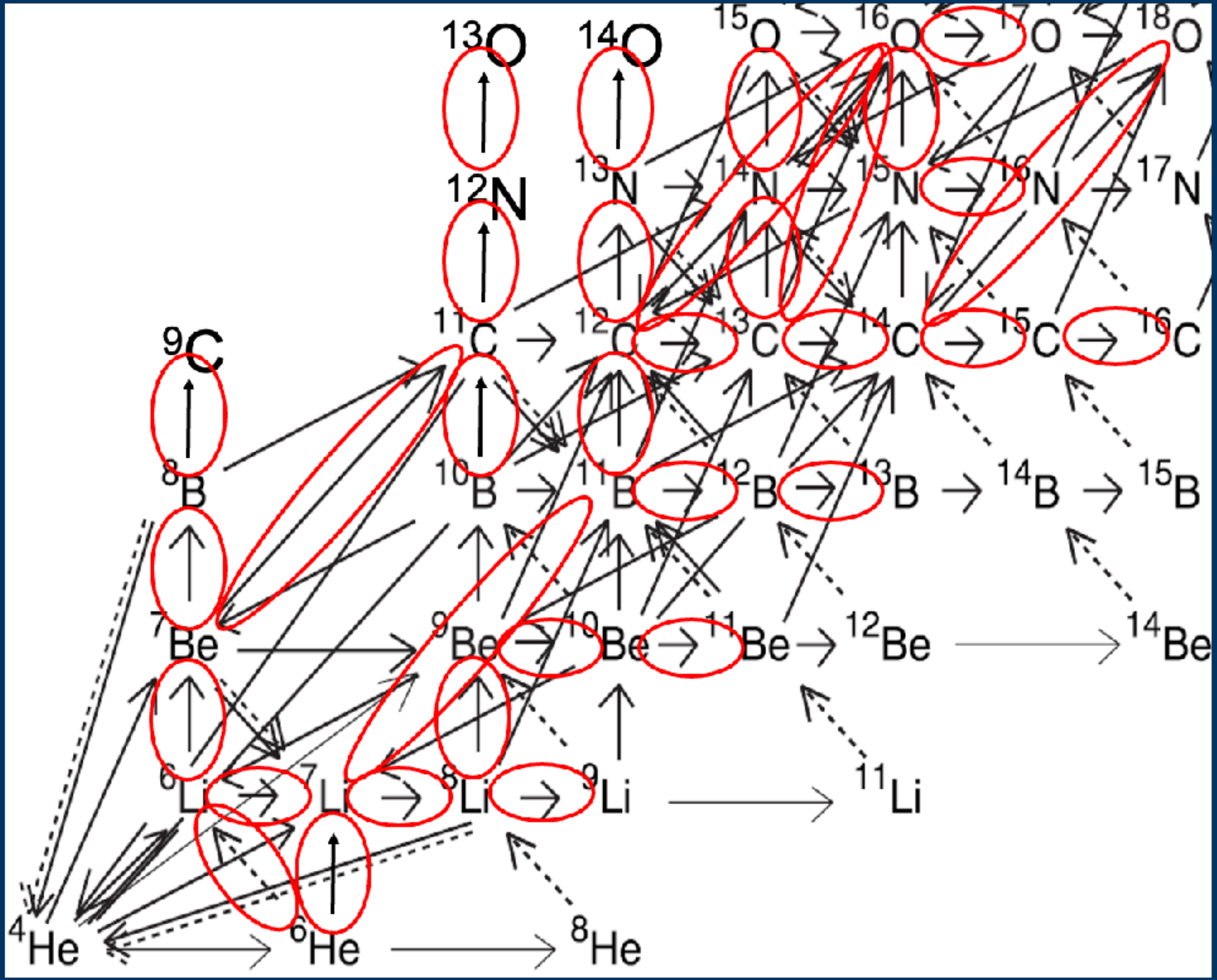
Astrophysical reaction rates

This paper describes an excellent experiment, one of the first examples where a radioactive ion beam has been used in inverse transfer reaction studies.

The topic is sufficient important that this paper should see timely and widespread exposure to the physics community in order to stimulate a board-based dialog.

WPL et al., PRL77(1996)611, 1st NP exp. paper in PRL in China

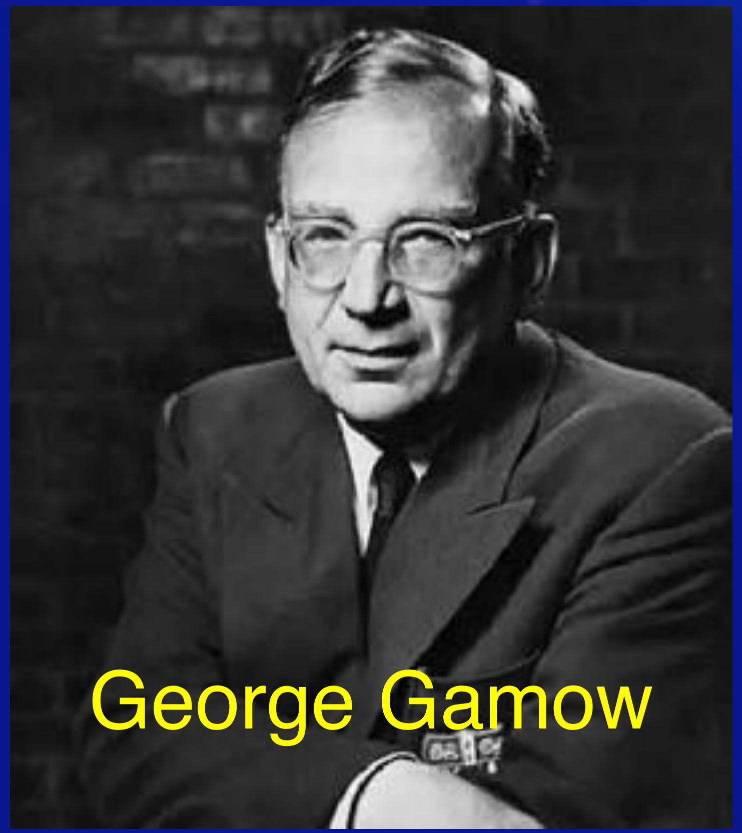
Systematic studies via in-direct approach



$^{13}C(\alpha,n)$, ApJ 756, 193 (2012).
$^{8}Li(p,\gamma)$, PRC 87, 017601 (2013).
$^{22}Na(p,\gamma)$, PRC 88, 035801 (2013).
$^{12}N(p,\gamma)$, PRC 87, 015803 (2013).
$^{15}N(n,\gamma)$, PRC 89, 012801(R) (2014).
^{16}F width, PRC 89, 054315 (2014).
IMME, PLB 756, 323 (2016).
$^{93}Zr(n,\gamma)$, PRC 94, 015804 (2016).
$^{95}Zr(n,\gamma)$, ApJ 848, 98 (2017).
$^{16}O(d,p)$, NPA 986, 26 (2019).
$^{12}C(\alpha,\gamma)$, PRC 99, 025805 (2019).
$^{7}Li(^{6}Li,d)$, PLB 797, 134820 (2019).
$^{12}C(\alpha,\gamma)$, PRL 124, 162701 (2020).
$^{74}Ge(p,\gamma)$, PLB 805, 135431 (2020).

W. P. Liu, 2022, NuSYS

Gamow window



coulomb term

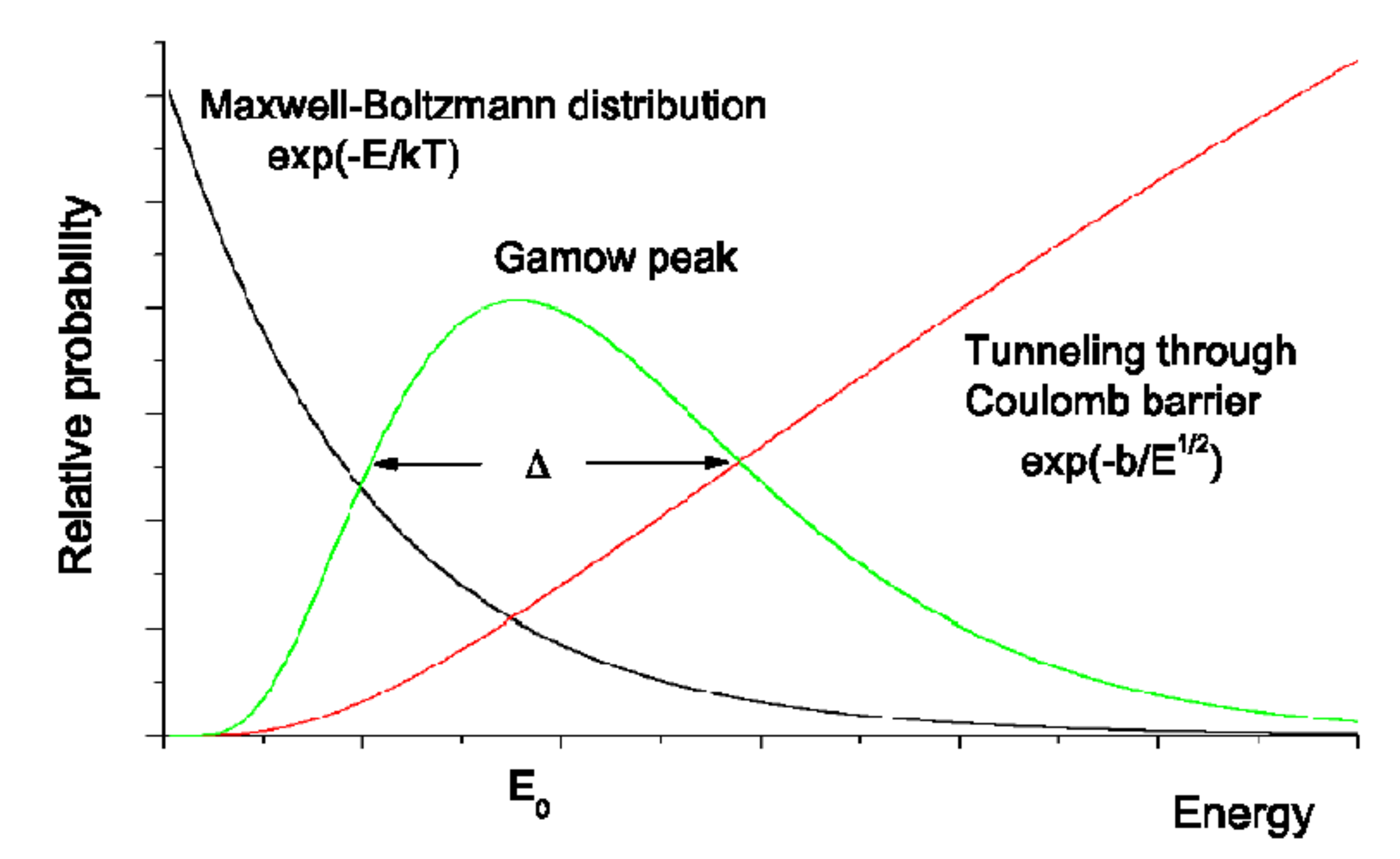
$$\sigma(E) = S(E)e^{-2\pi\eta}\frac{1}{E}$$

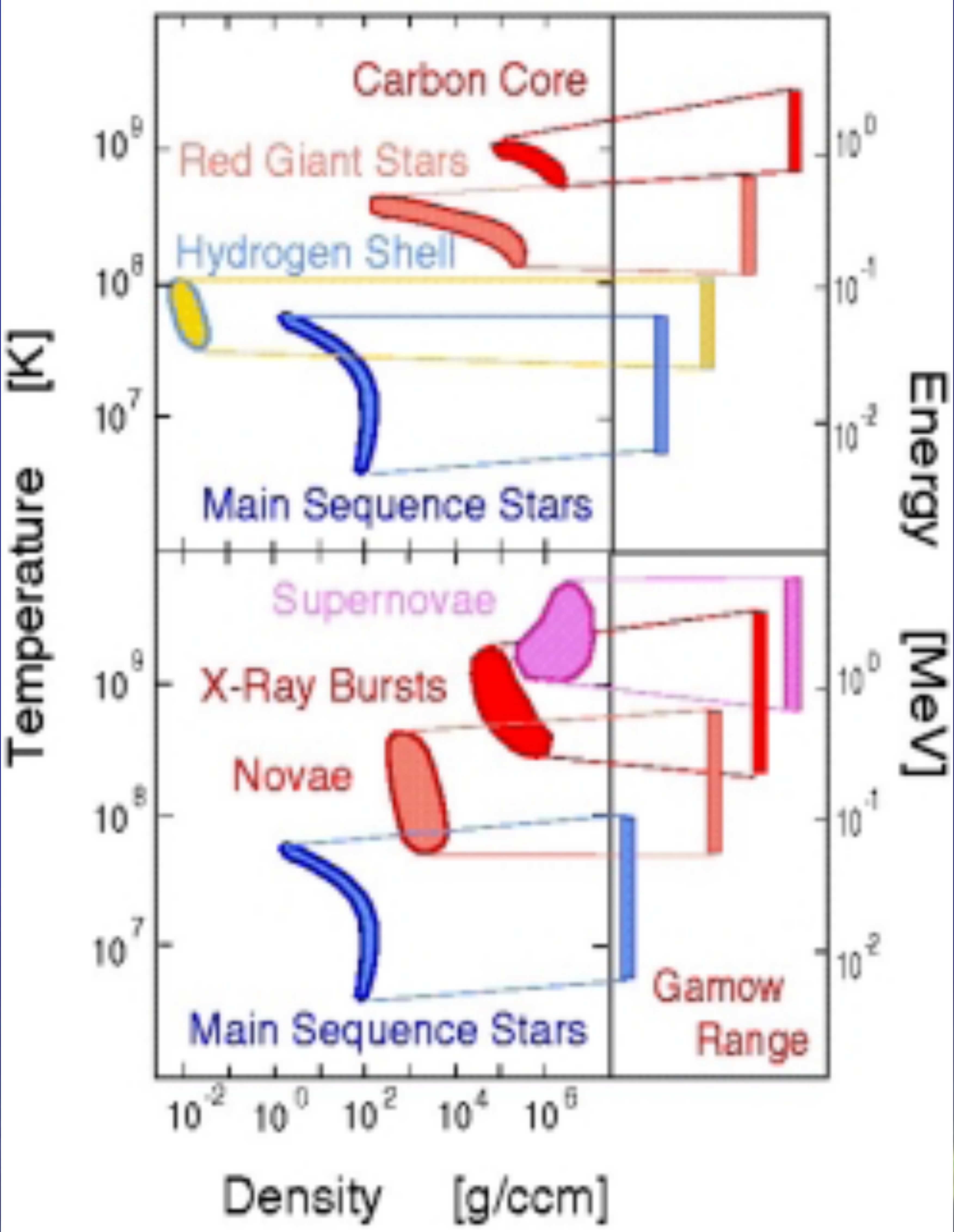
astrophysical s factor

$$\eta = 0.1575 Z_1 Z_2 \sqrt{M/E}$$

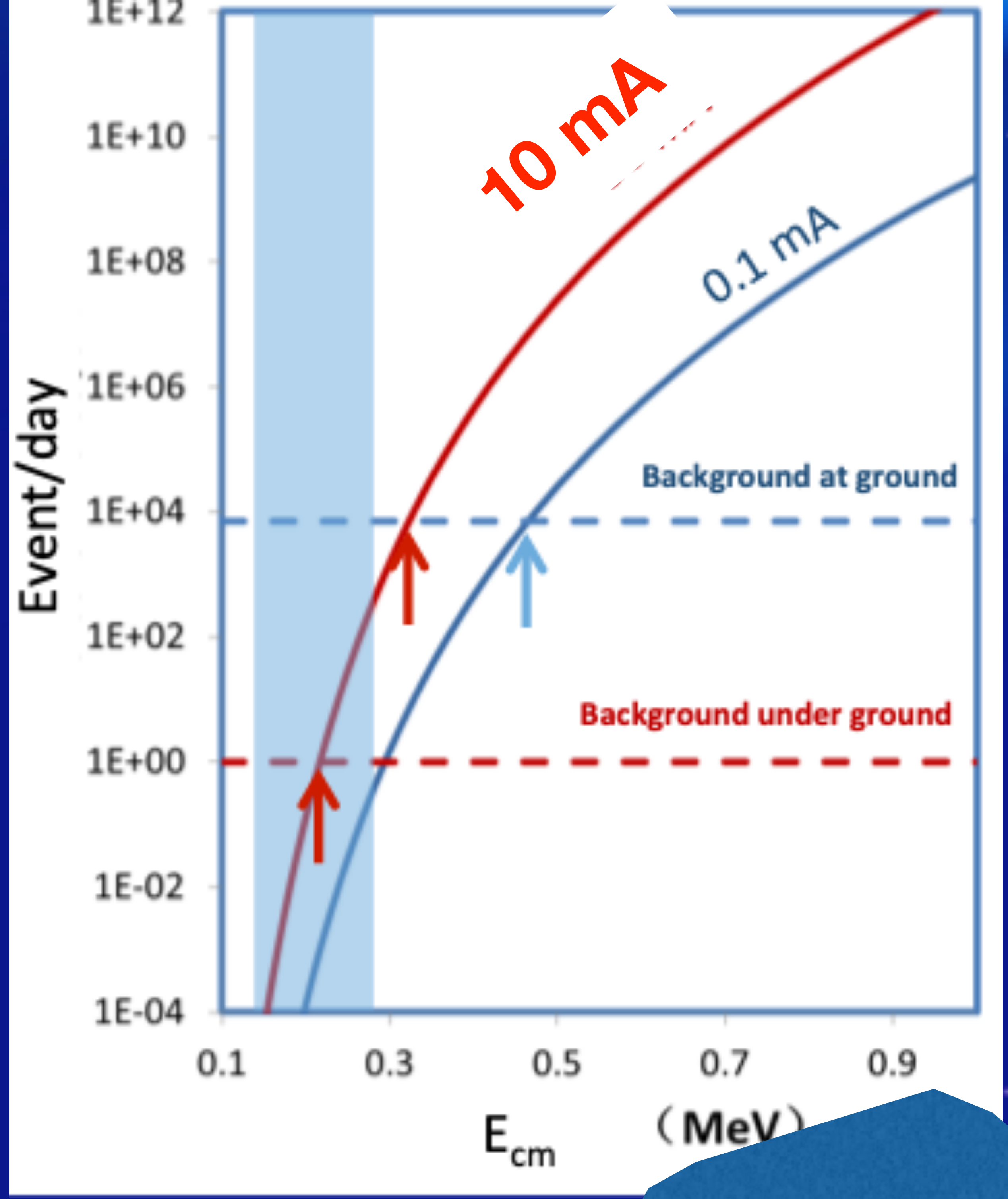
$$E_0 = 1.22(Z_1^2 Z_2^2 M T_6^2)^{1/3}\mathrm{keV}$$

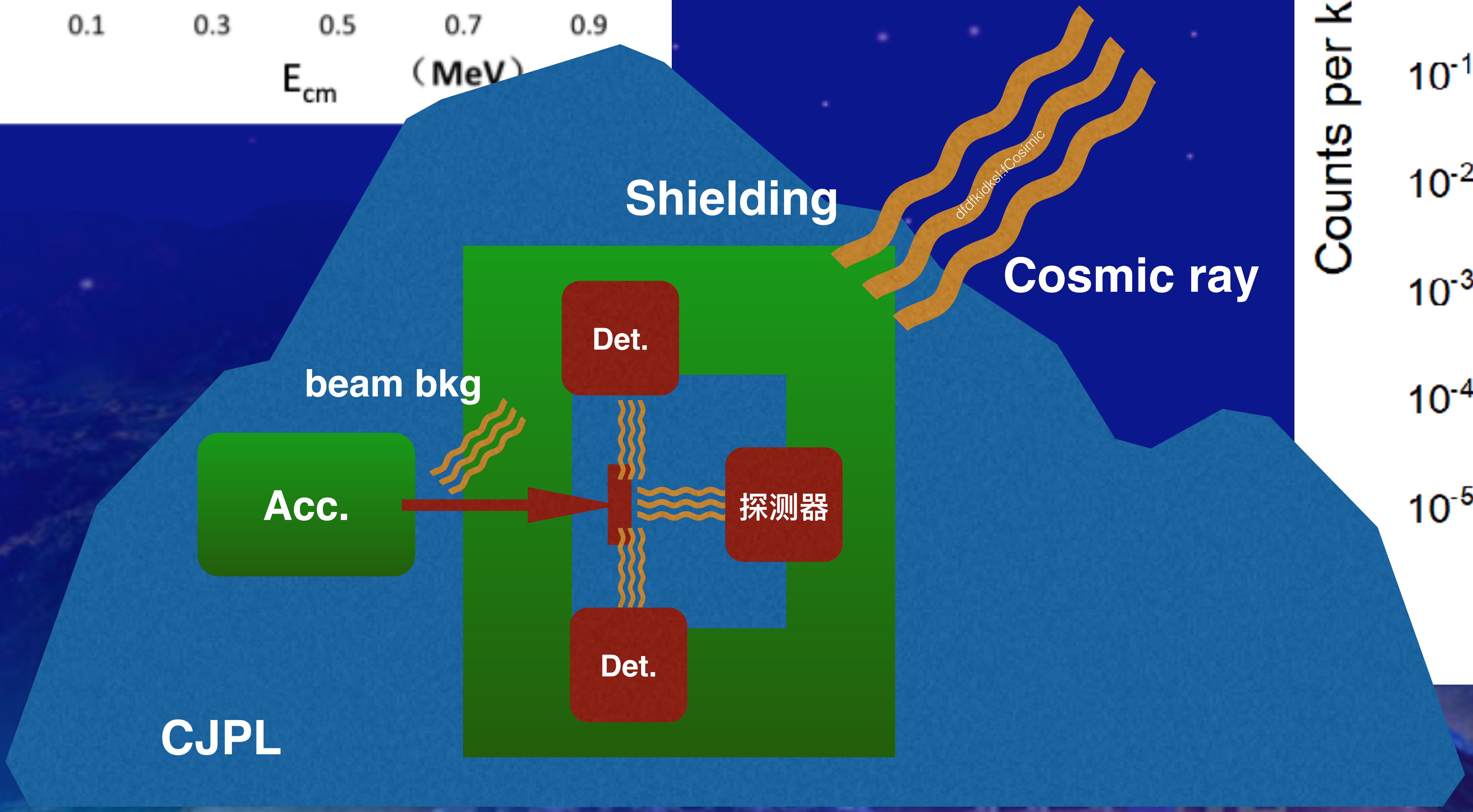
Gamow window

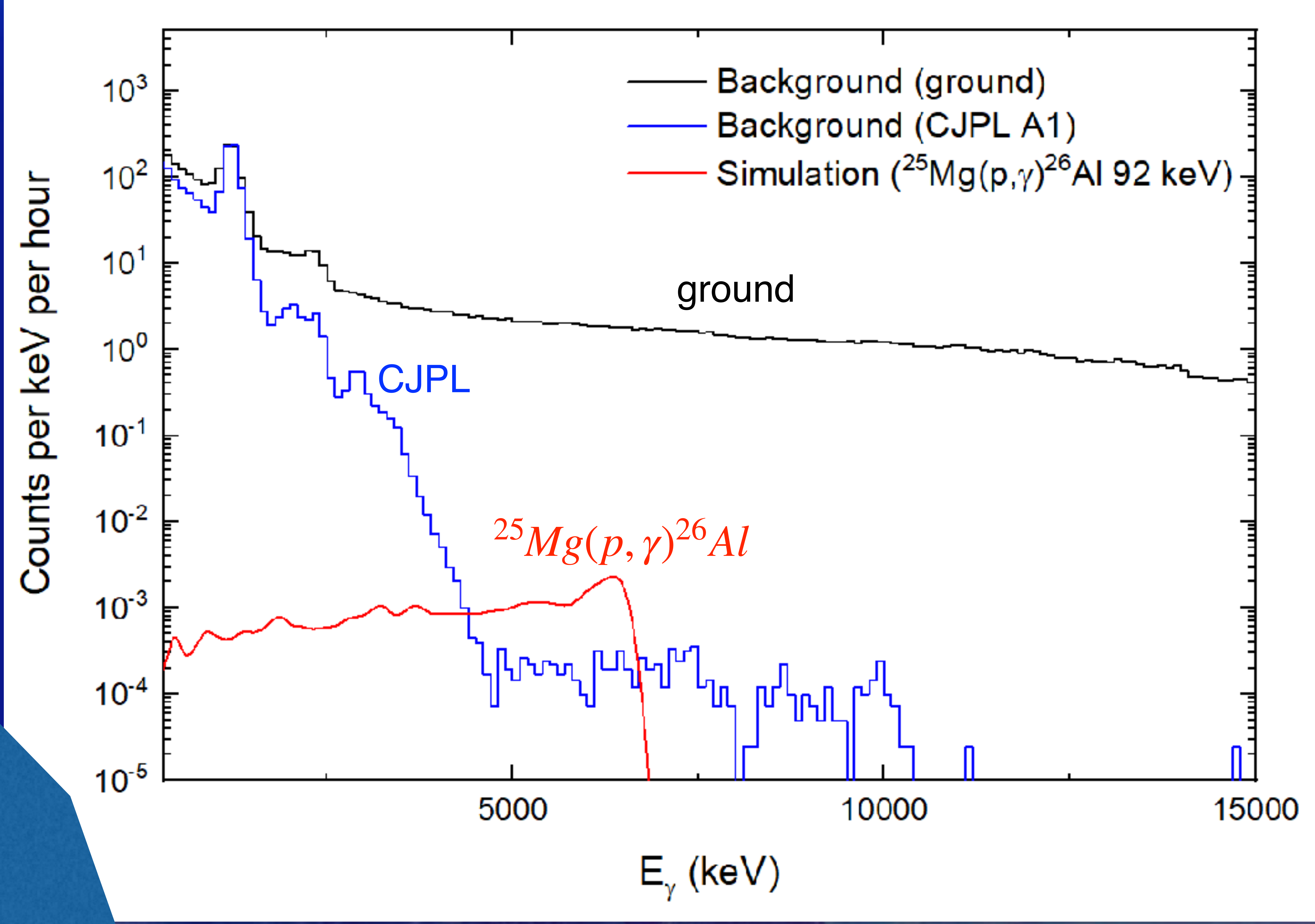




low bkg+high intensity

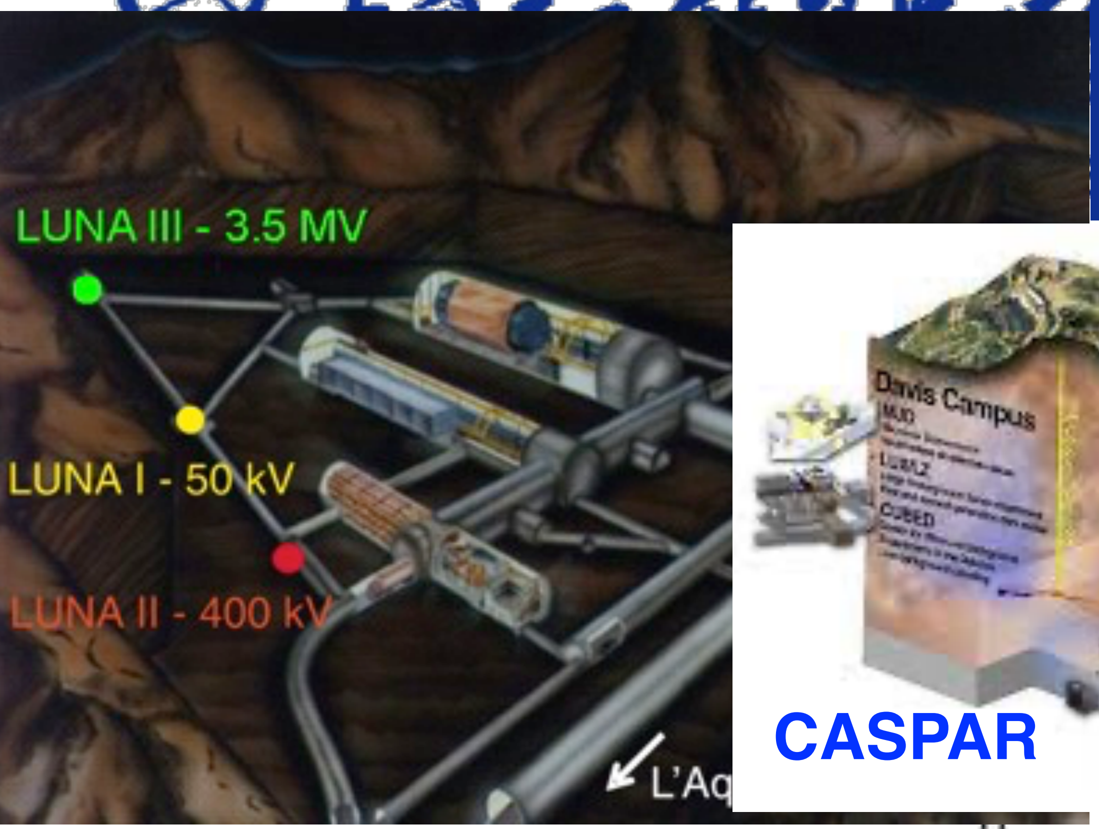


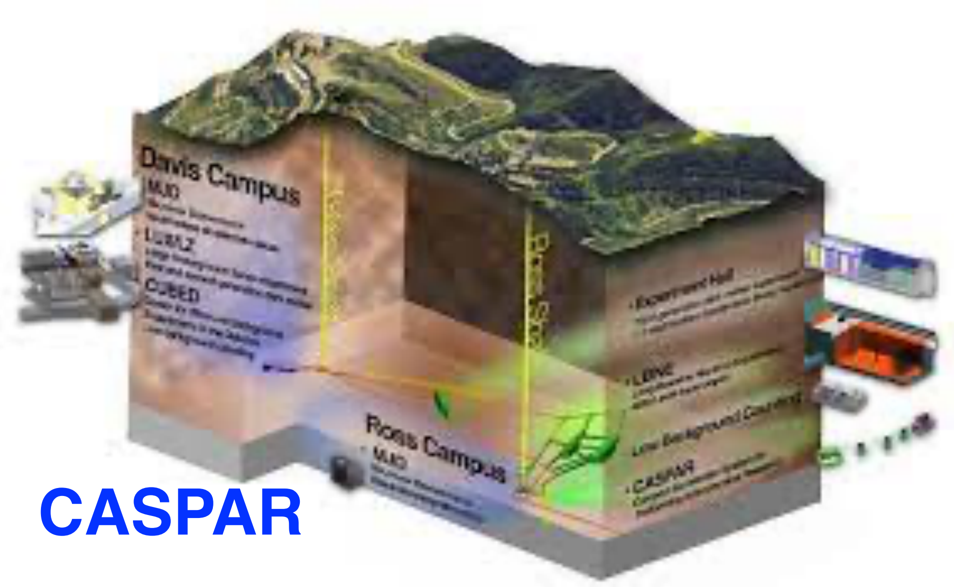




WPL et al., Sci. China 59(2016)2

LUNA, CASPAR and Felsenkeller





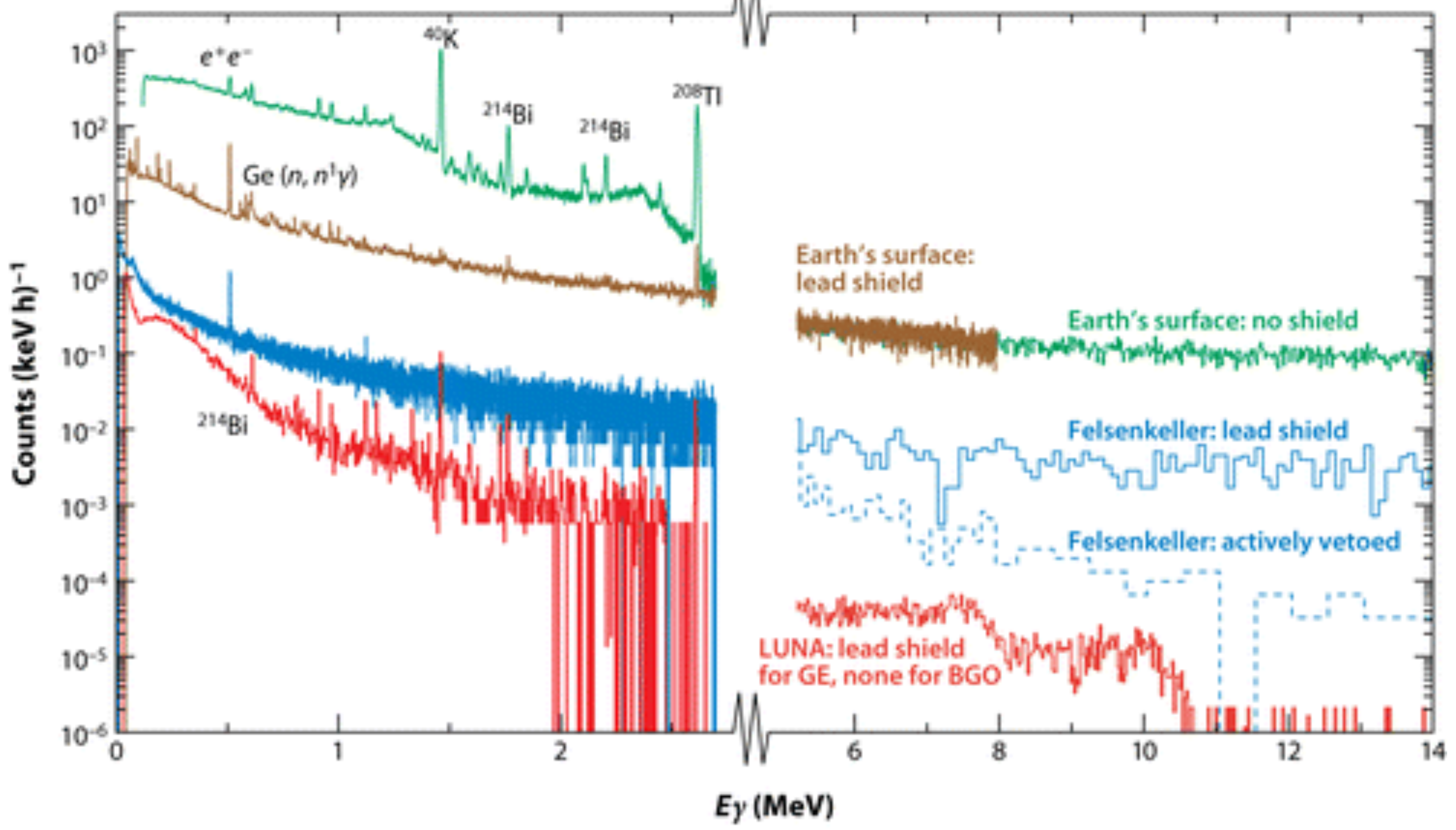
CASPAR

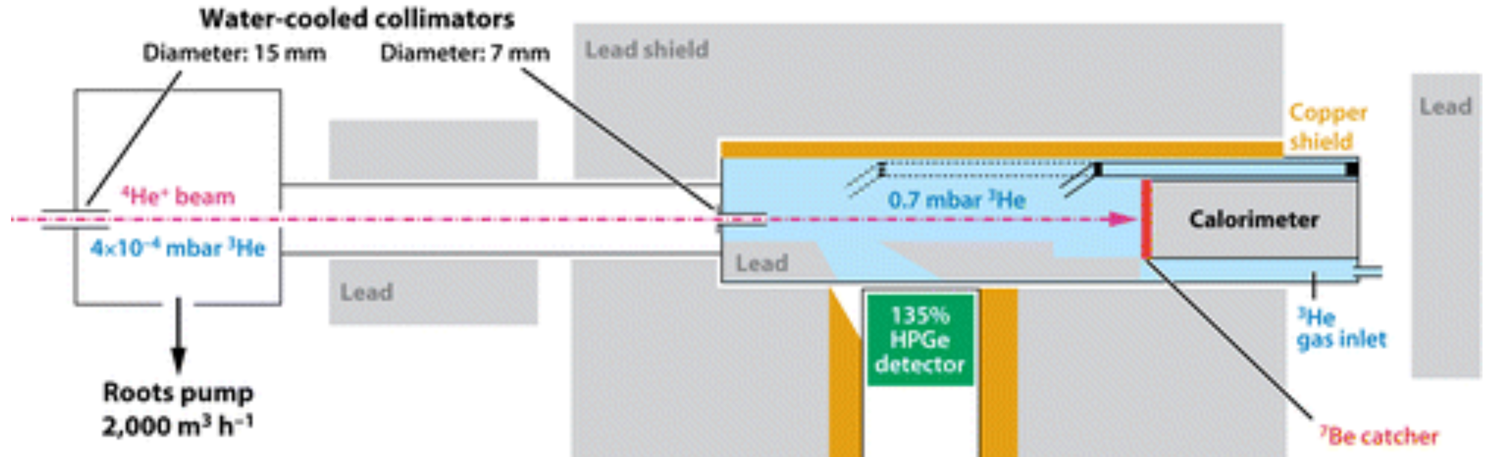
F. Cavanna et al., PRL 115(2015)252501, $^{22}Ne(p,\gamma)^{23}Na$.

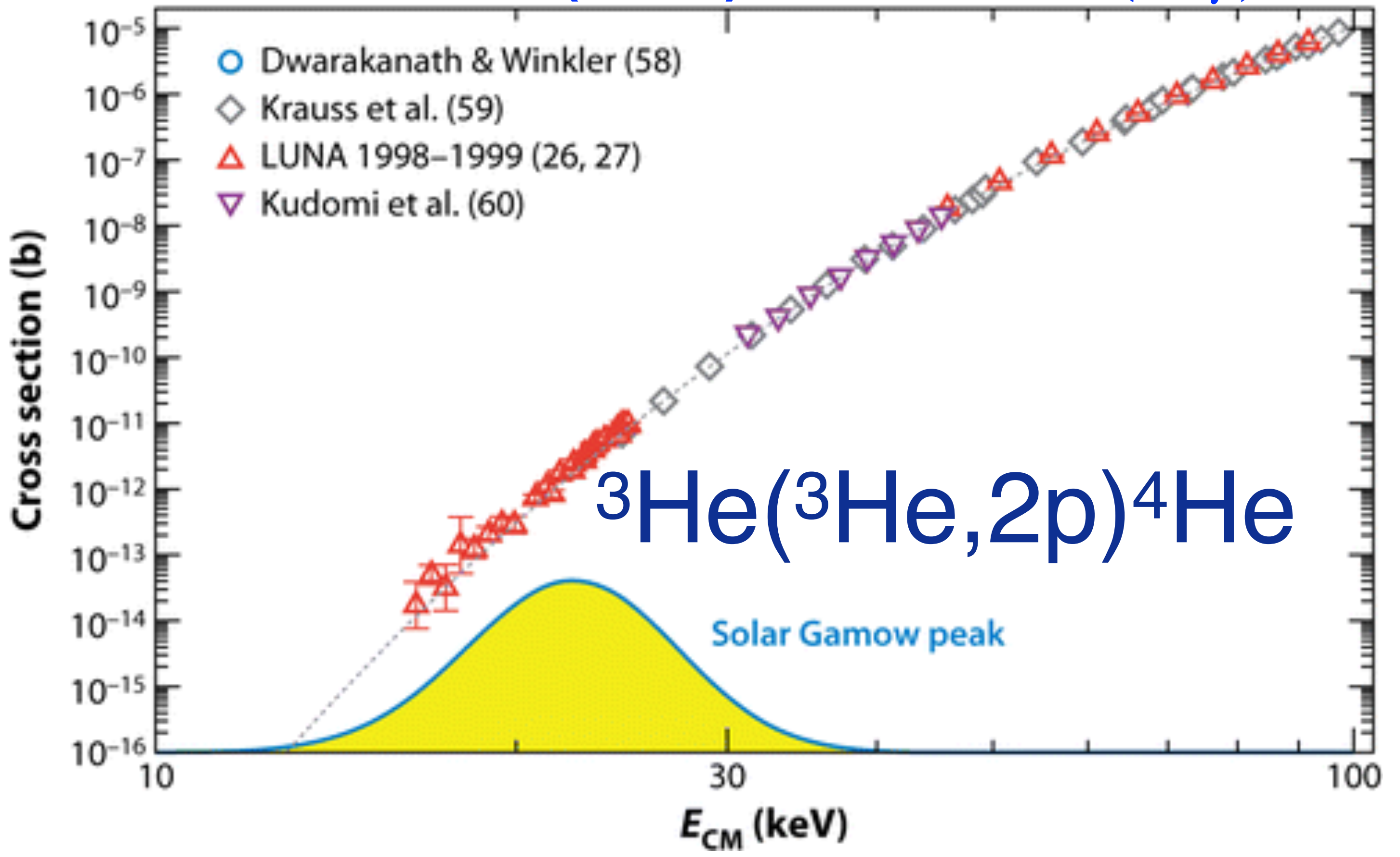
F. Ciani et al. PRL 127(2021)152701, $^{13}C(\alpha,n)^{16}O$

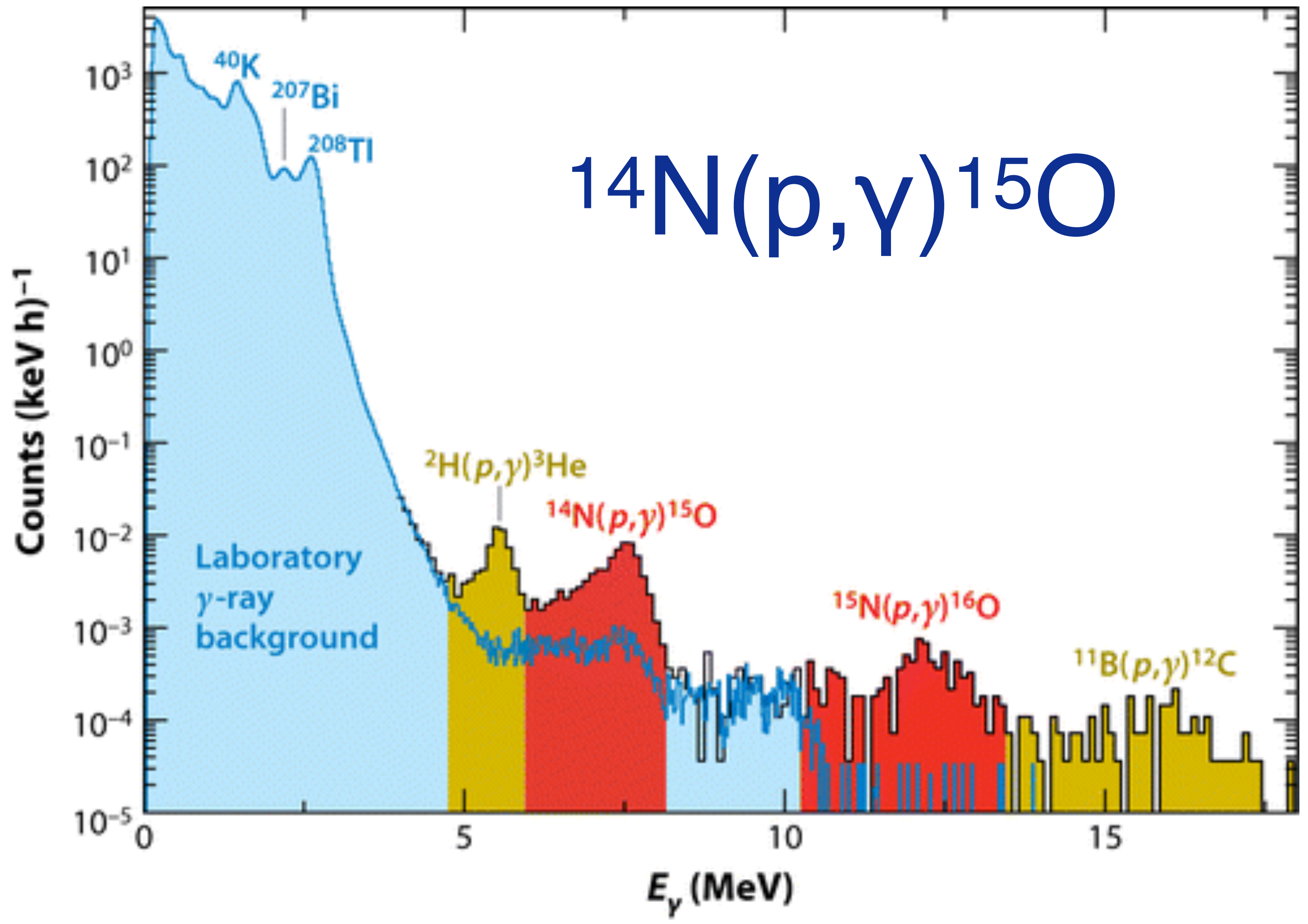
V. Mossa et al., Nature 587(2020)210 , $D(p,\gamma)^{3}He$

A. C. Dombos et al., PRL 128(2022)162701, $^{18}O(\alpha,\gamma)^{22}Ne$









LUNA

$^{3}He(^{3}He,2p)^{4}He$ PRL82(1999)5205
$^{2}H(^{3}He,p)^{4}He$ PLB482(2000)43
$^{2}H(p,\gamma)^{3}He$ NPA 706(2002)203
$^{3}He(\alpha,\gamma)^{7}Be$ PRL 97(2006)122502
$^{14}N(p,\gamma)^{15}O$ PLB 591(2004)61
$^{15}N(p,\gamma)^{16}O$ PRC82, 055804(2010)
$^{17}O(p,\gamma)^{18}F$ PRL 109, 202601(2012)
$^{25}Mg(p,\gamma)^{26}Al$ PLB 707(2012) 60

R. M. Gesuè et al., PRL 133(2024)052701, $^{17}O(p,\gamma)^{18}F$

Felsenkeller

$^{3}He(\alpha,\gamma)^{7}Be$, progress

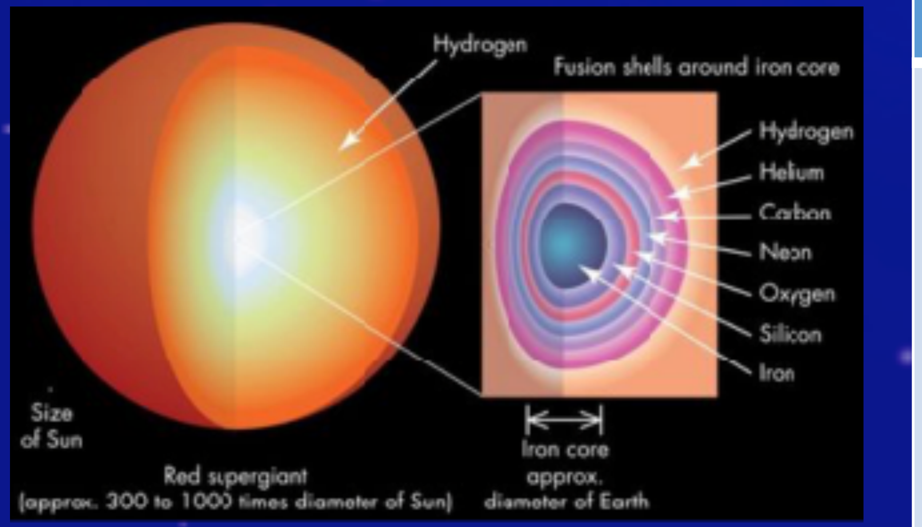
$^{2}H(p,\gamma)^{3}He$, progress

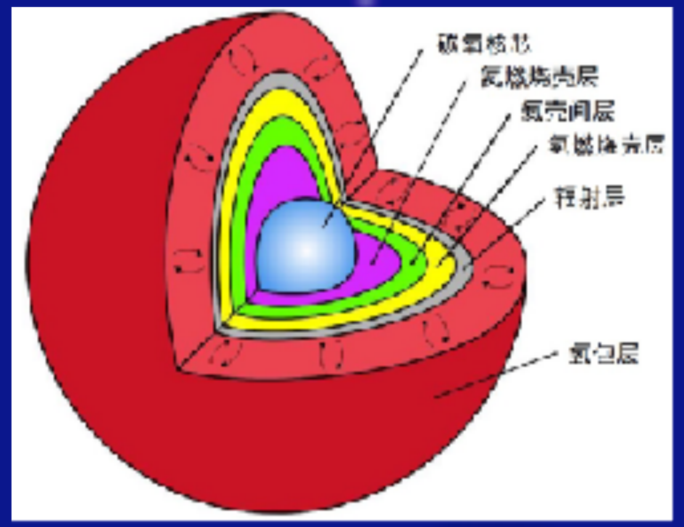
$^{12}C(p,\gamma)^{13}N$, progress

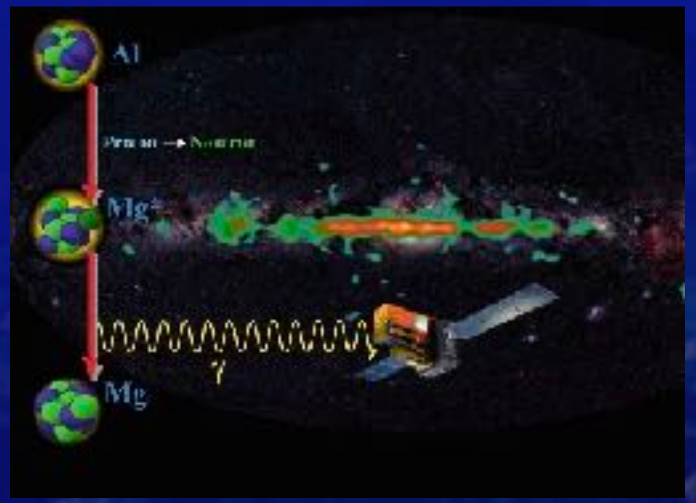
$^{12}C(\alpha,\gamma)^{16}O$, plan

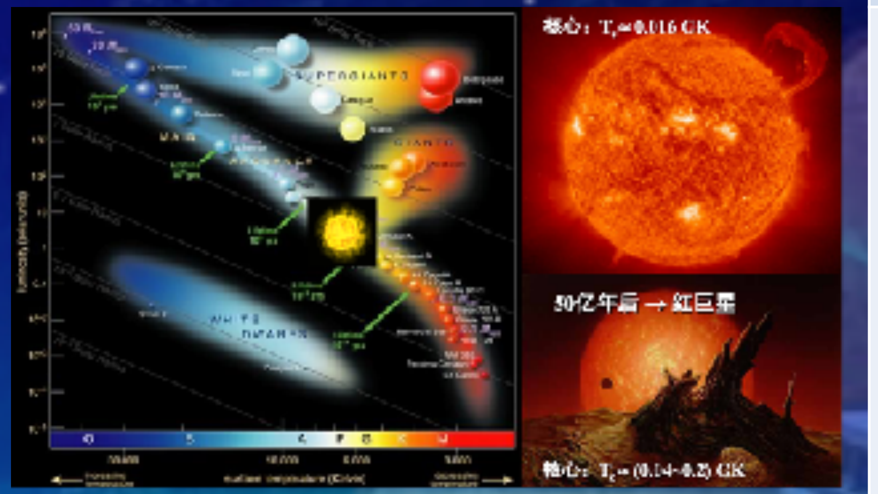
Broggini C, et al. 2010.
Annu. Rev. Nucl. Part. Sci. 60:53–73

Uncertainty remained for key reactions

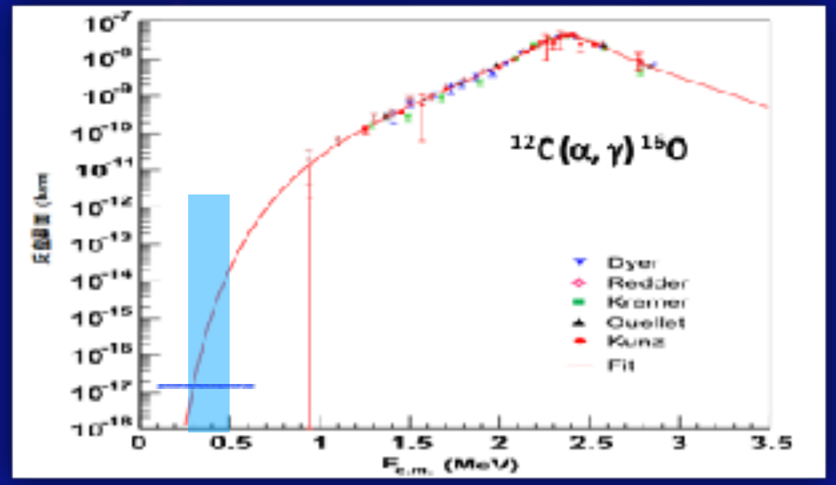




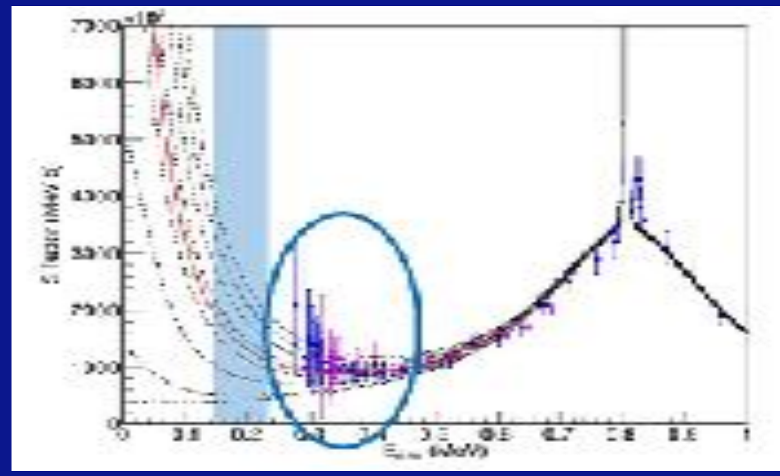




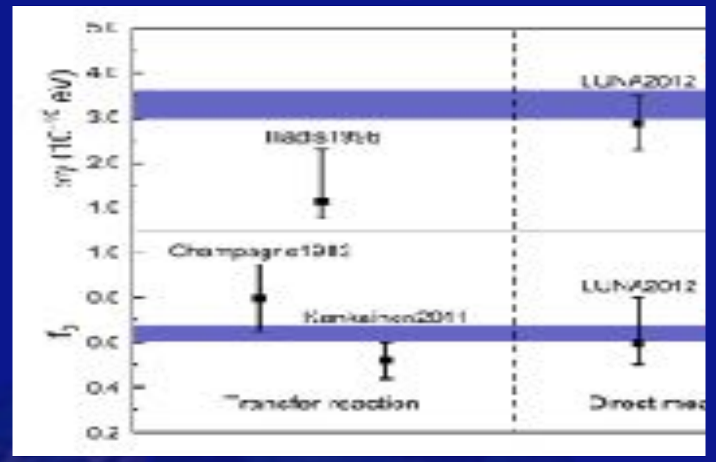
Physics	Reaction	Current	Desired
Massive star	$^{12}C(\alpha,\gamma)^{16}O$	60% 890 keV	20% 220-380 keV
s-process neutron source	$^{13}C(\alpha,n)^{16}O$	60% 230 keV	10% 140-230 keV
Galaxy ^{26}Al source	$^{25}Mg(p,\gamma)^{26}Al$	20% 92 keV	5% 50-300 keV
F aboundace	$^{19}F(p,\alpha)^{16}O$	80 % 189 keV	5 % 50-250 keV



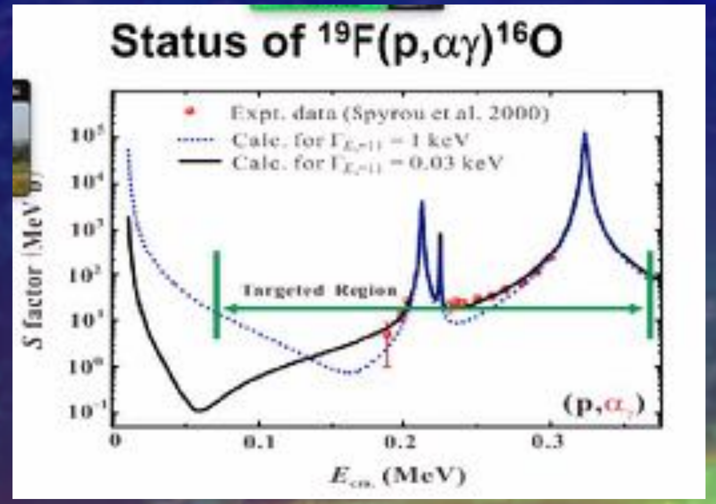
R. J. deBoer et al., RMP vol. 89, 2017



Y. P. Shen, B. Guo, WPL, PPNP 119(2021)103857



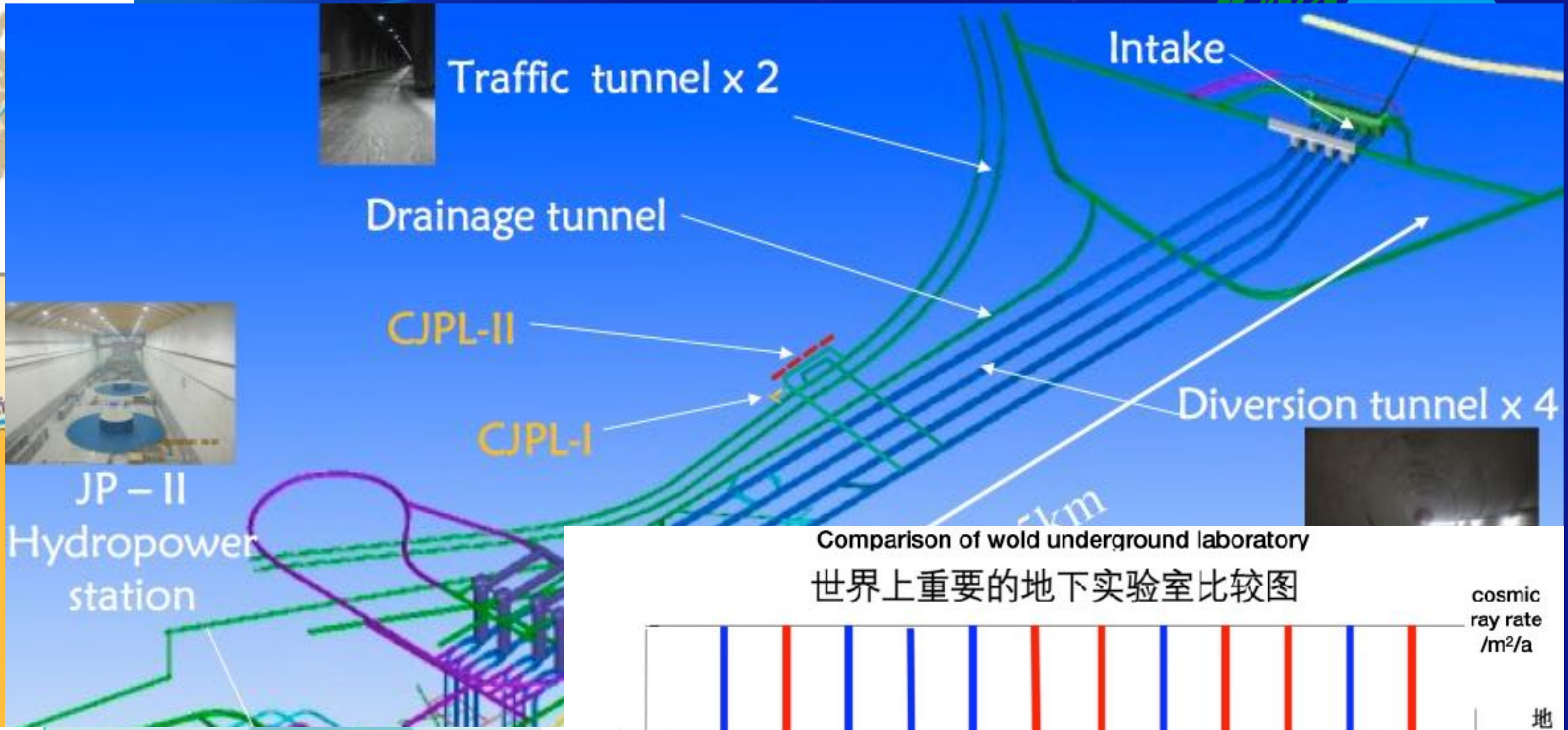
G.F. Ciani et al. PRL 127(2021)152701

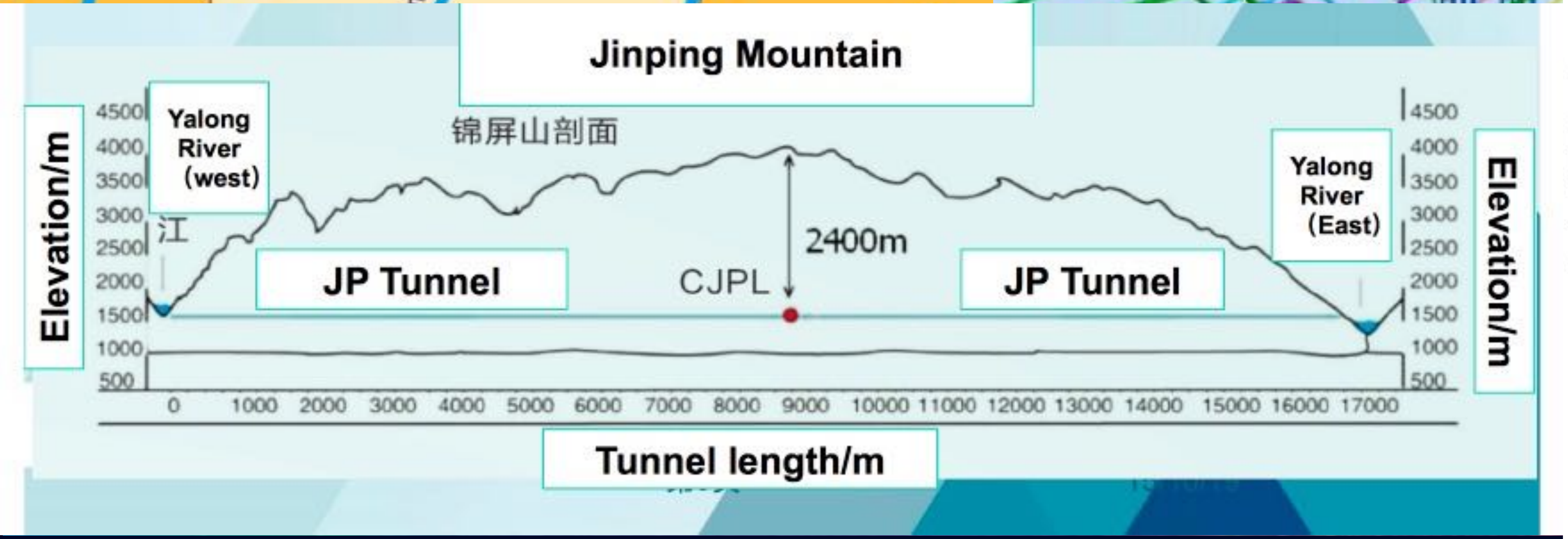


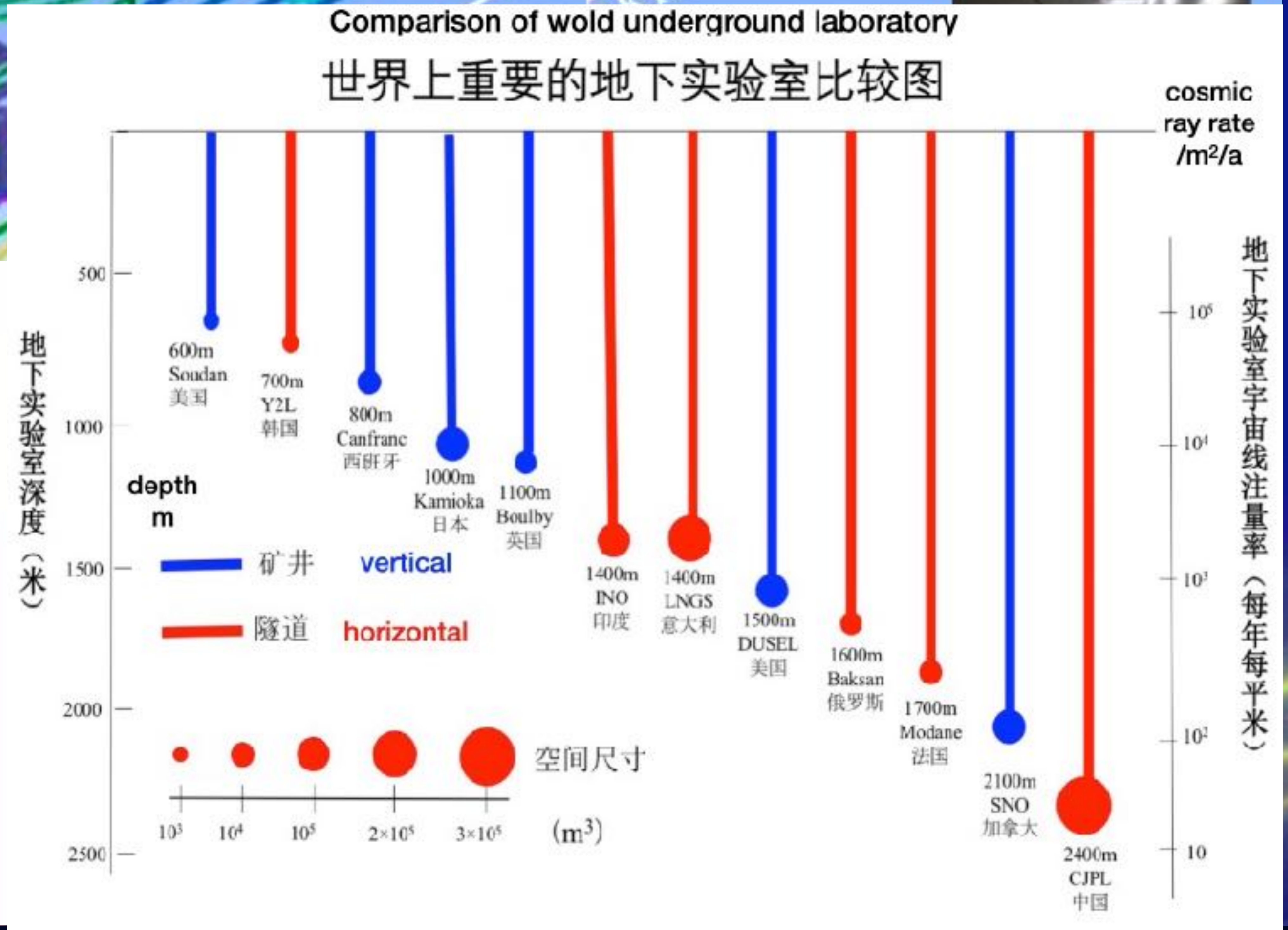
J. J. He et al., Sci. China Phys 59 (2016) 652001

WPL et al., Sci. China 59(2016)2

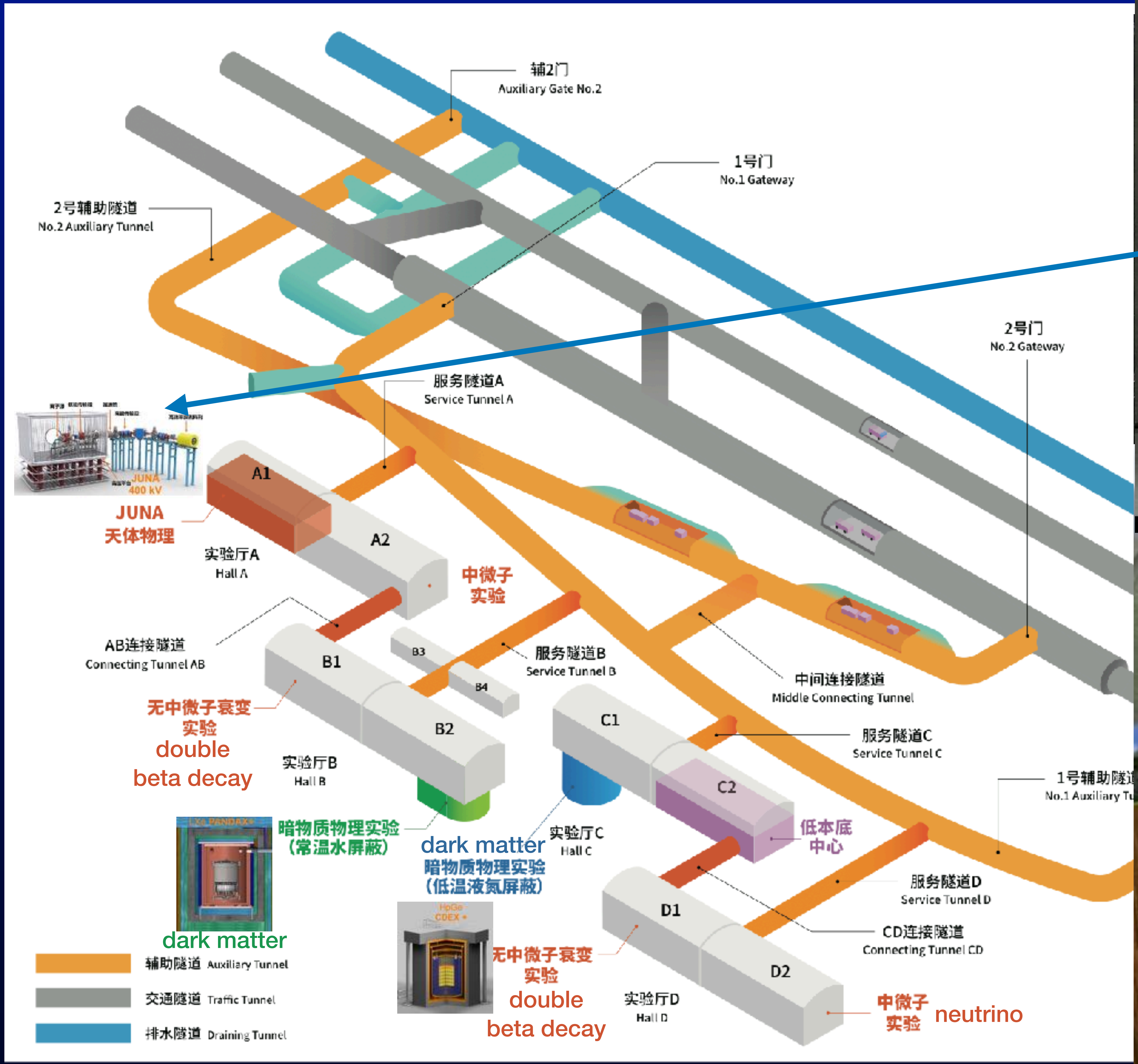
China Jinping: CJPL

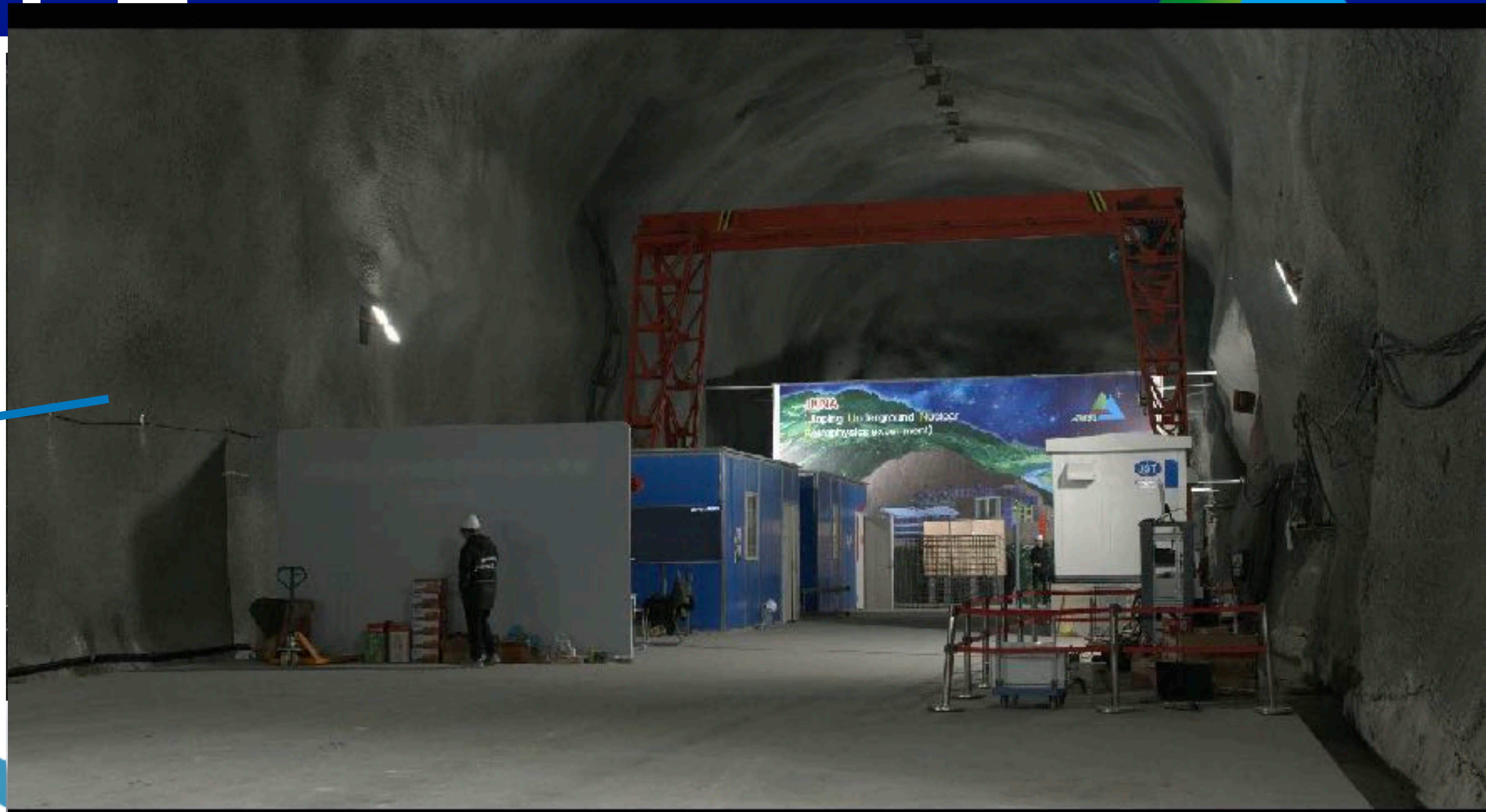






Most silent location: CJPL



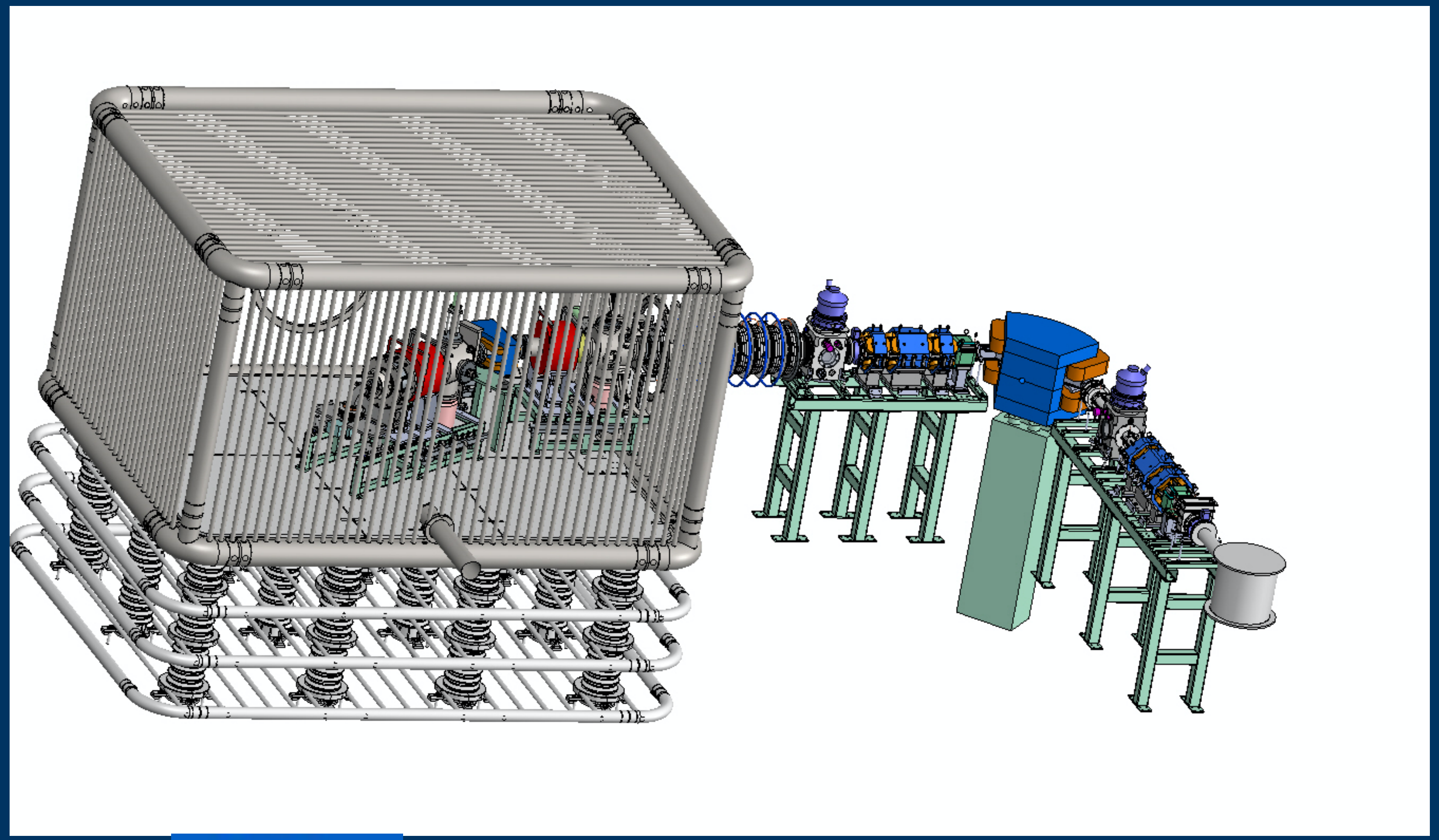


JUNA dream team

JUNA

Group leader

Weiping Liu
$^{12}C(\alpha,\gamma)^{16}O$
Yangping Shen, CIAE
Jun Su, BNU
PI



Bing Guo
$^{22}Ne(\alpha,n)^{25}Mg$
CIAE

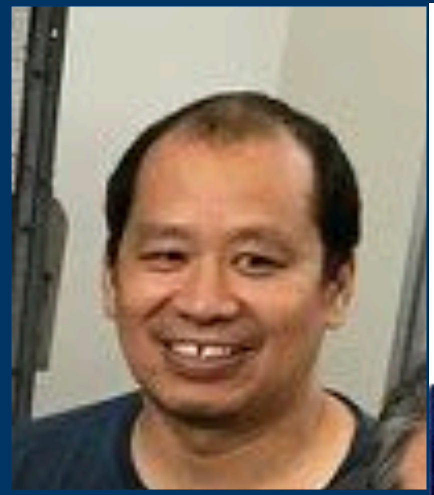
Shuo Wang
$^{14}N(p,\gamma)^{15}O$
SDU

Xiaodong Tang
$^{13}C(\alpha,n)^{16}O$
Ion source IMP

Zhihong Li
$^{25}Mg(p,\gamma)^{26}Al$
CIAE
Jun Su, BNU

Jianjun He
$^{19}F(p,\alpha)^{16}O$
BNU

Gang Lian
Lab. exp. sup.
CIAE



Bao Quncui,CIAE
Liangting Sun, IMP
Ion source and acc.

Acc. installation
Arjun Li

A1 construction
Hongwei Yang

Site support
Xiaopan Cheng

Acc. operation
Long Zhang

Supported by the National Natural Science Foundation of China, Grant No. 11490560, 2015

WPL et al., Sci. China 59(2016)2

JUNA Milestone

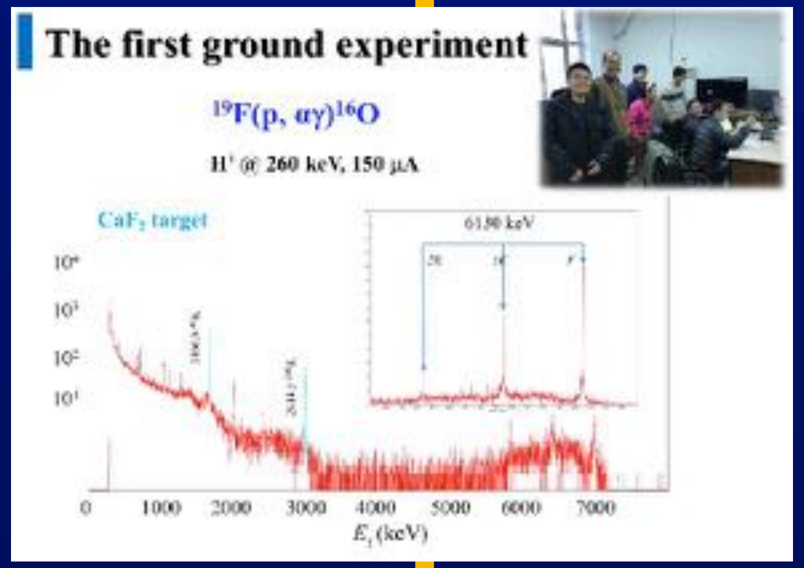
Aug. 2013
Startup meeting

Jan. 2015
Project inauguration

Mar. 2016
On site start

May 2017
Beam on ground

Dec. 2017
3 mA on ground



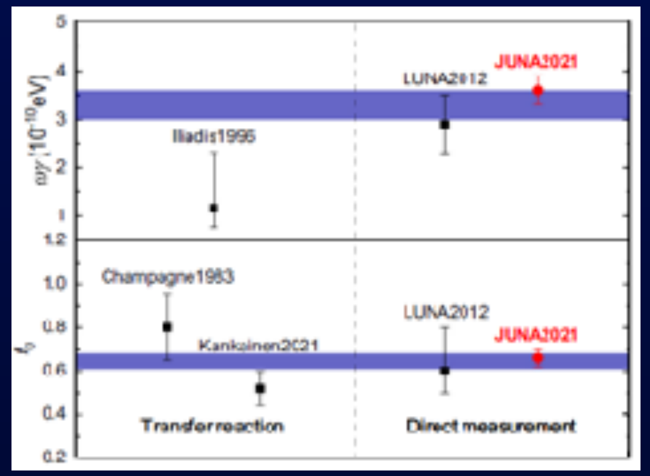
Dec. 2018
Der. Ready
Beam 10 mA

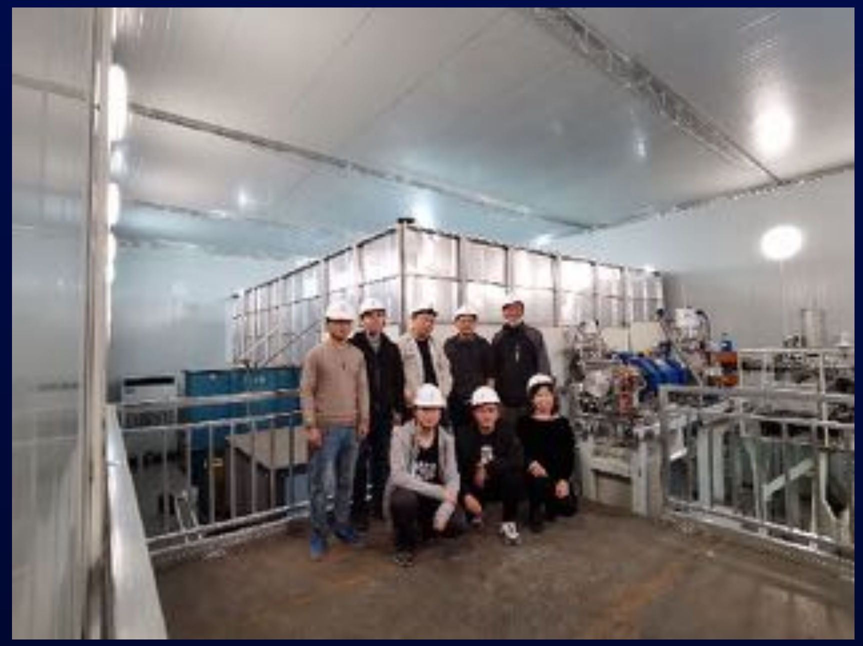
April 2019
Target ready
Acc. Ready

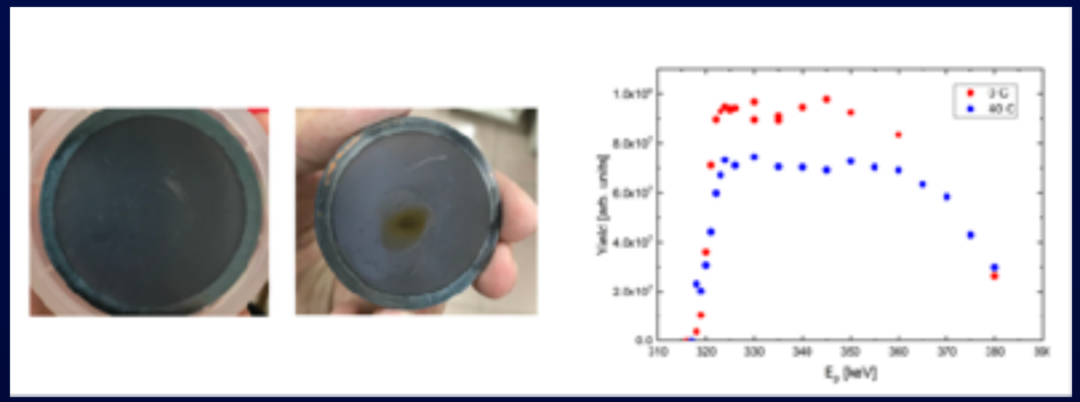
Dec. 2020
Beam underground

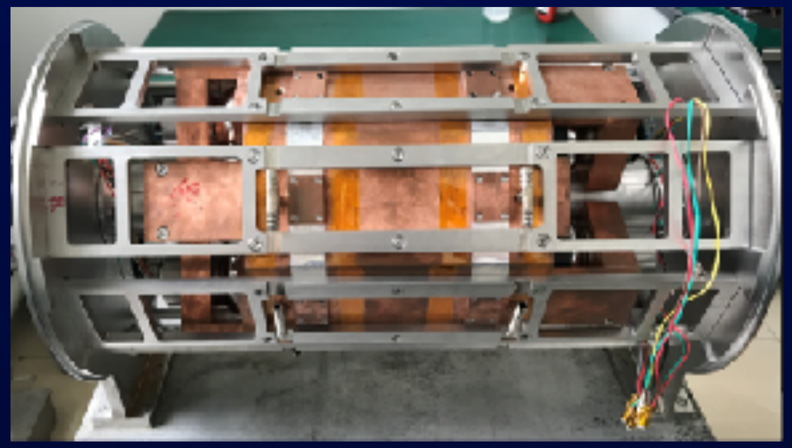
April 2021
^{25}Mg, ^{19}F and ^{13}C etc ready

Oct. 2024
Upgrading commission





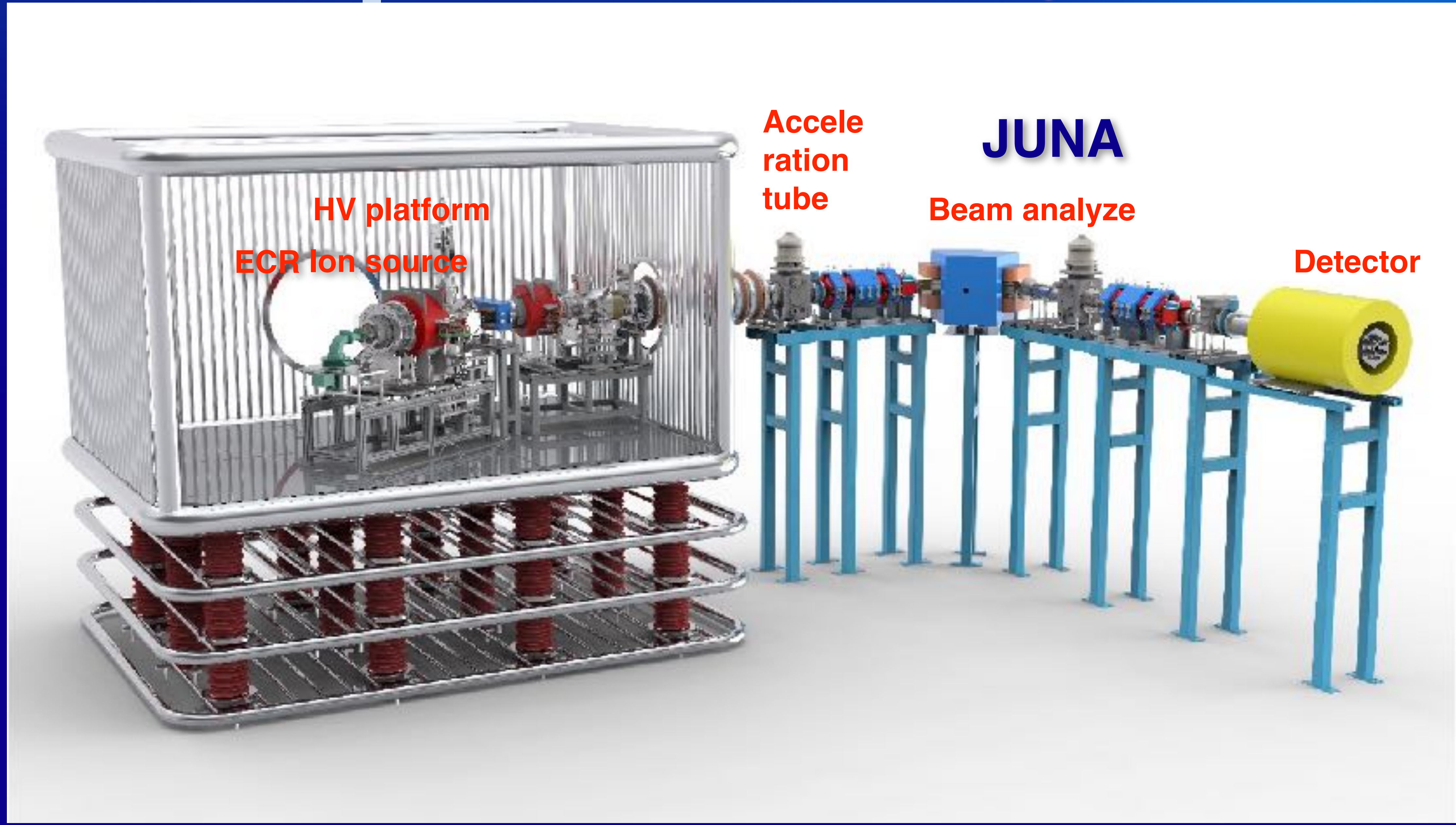




WPL et al., Sci. China 59(2016)2

JUNA accelarator

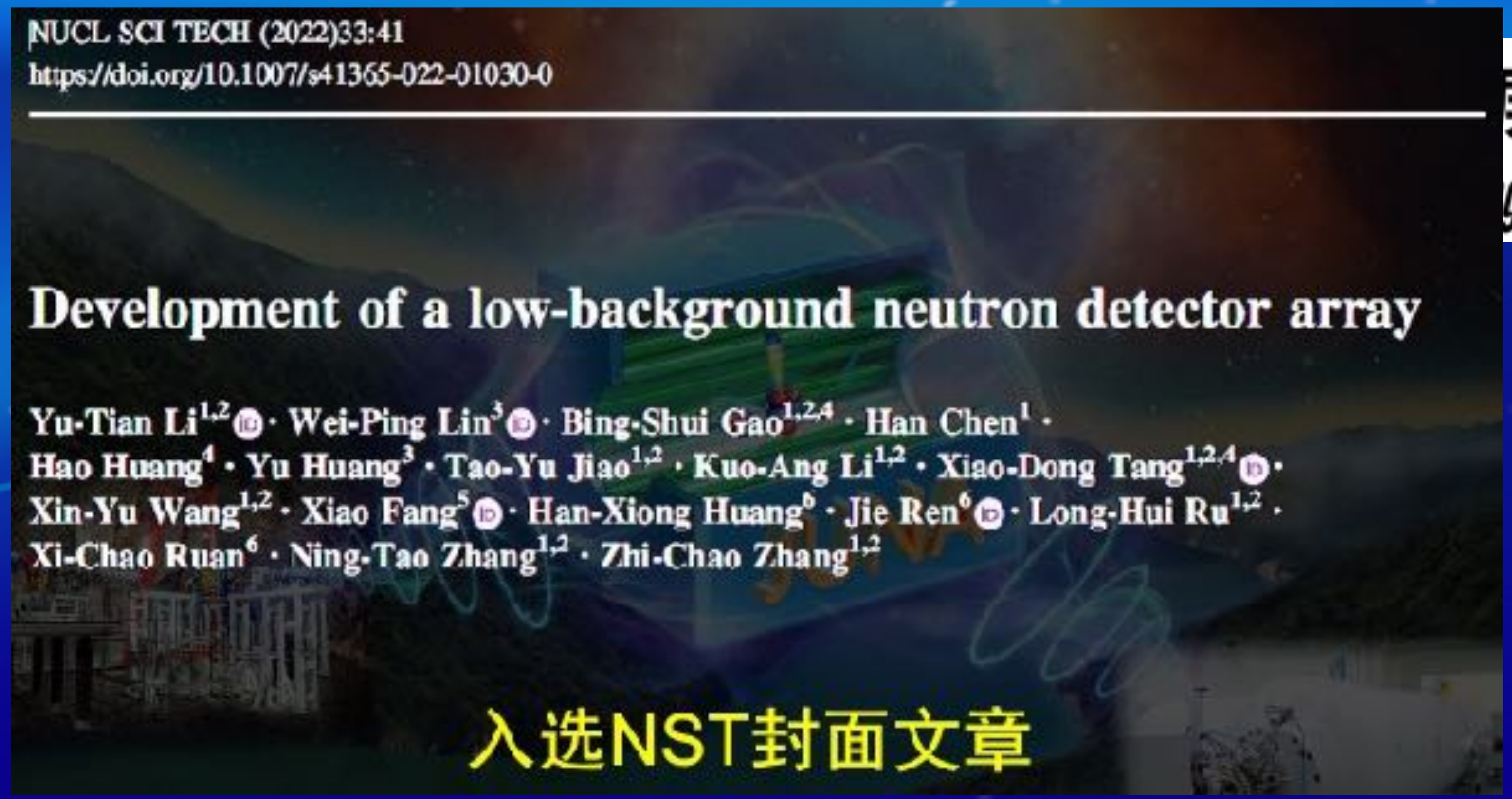
锦屏深地核天体物理实验
Jinping Underground Nuclear Astrophysics Experiment

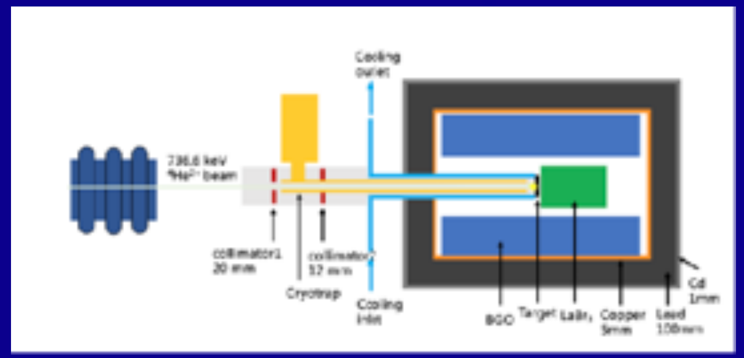


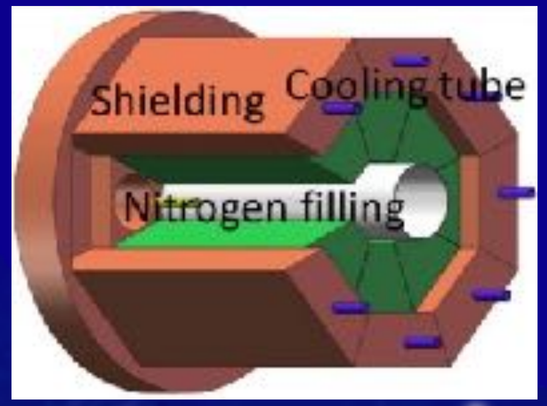
	lab depth m	cosmic μ bkg ($cm^{-2} s^{-1}$)	beam energy (keV)			beam intensity (emA)			energy stability
			H^+	He^+	He^{2+}	H^+	He^+	He^{2+}	
LUNA	1400	2×10^{-8}	50-400	50-400	3.5 MV	0.3~1	0.3~0.8	---	0.05%
CASPAR	1500	4×10^{-9}	100-1000	100-1000	1 MV	0.1	0.1	---	0.05%
JUNA	2400	2×10^{-10}	50-400	50-400	100-800	2-10	2-10	1-2	0.04%
Felsenkeller	45	$\sim10^{-7}$			5 MV		30 uA		

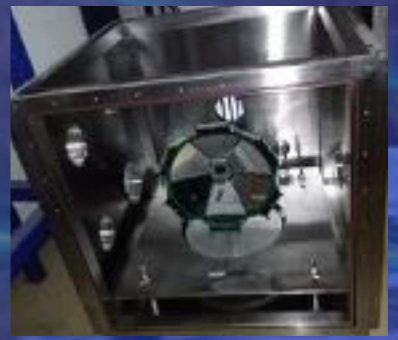
WPL et al., Sci. China 59(2016)2

Detector tech.









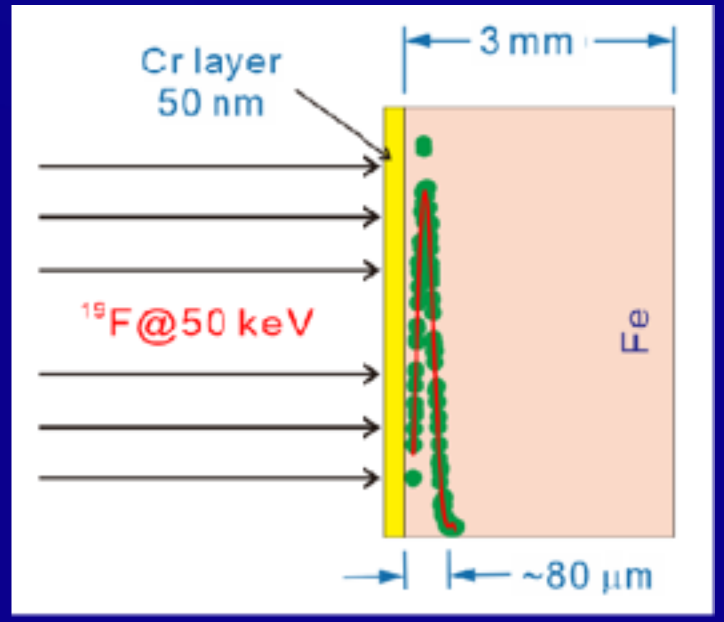
reaction	technology	publication	world best	JUNA
^{12}C	BGO+LaBr		down to 891 keV	down to 552 keV
^{25}Mg	BGO array X8	Atomic ST 52(2018)140	resolution17 %	11 %
^{13}C	^{3}He array X24	NST33(2022) 41, cover story	Exptripolation	Self consisitent
^{19}F	Charged particle array		170 keV	down to 100 keV

High durability target

3-10 times better than previous targets

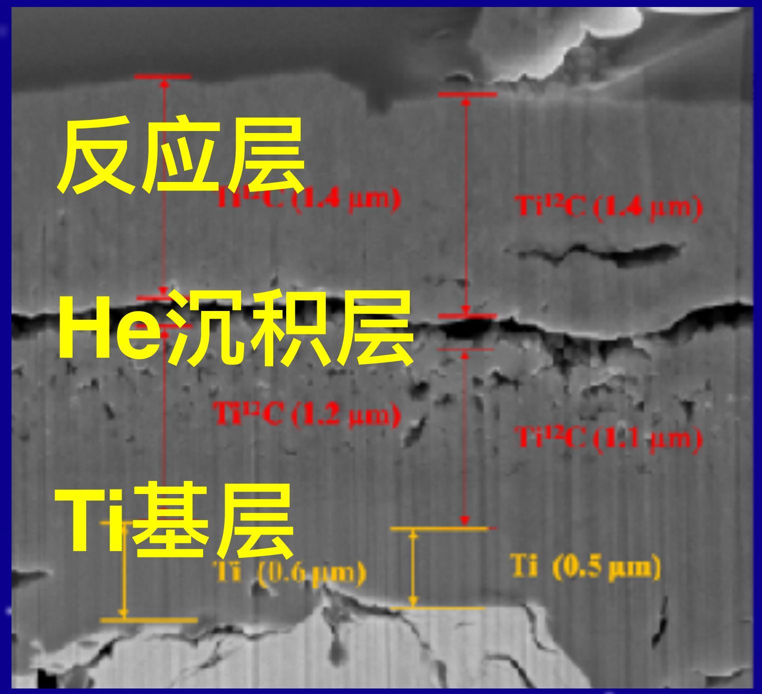
^{19}F Implantation

- High-purity iron substrate
- Magnetron chrome plating
- 100 C



^{12}C Deposit target

- FCVA
- 12C 99.99%
- 400 C

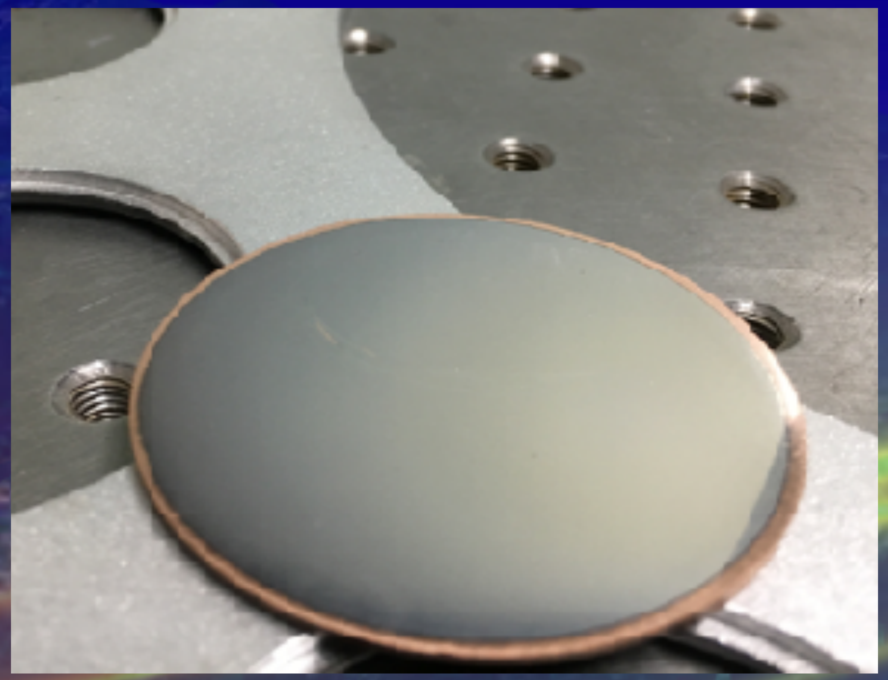


^{13}C Thick target

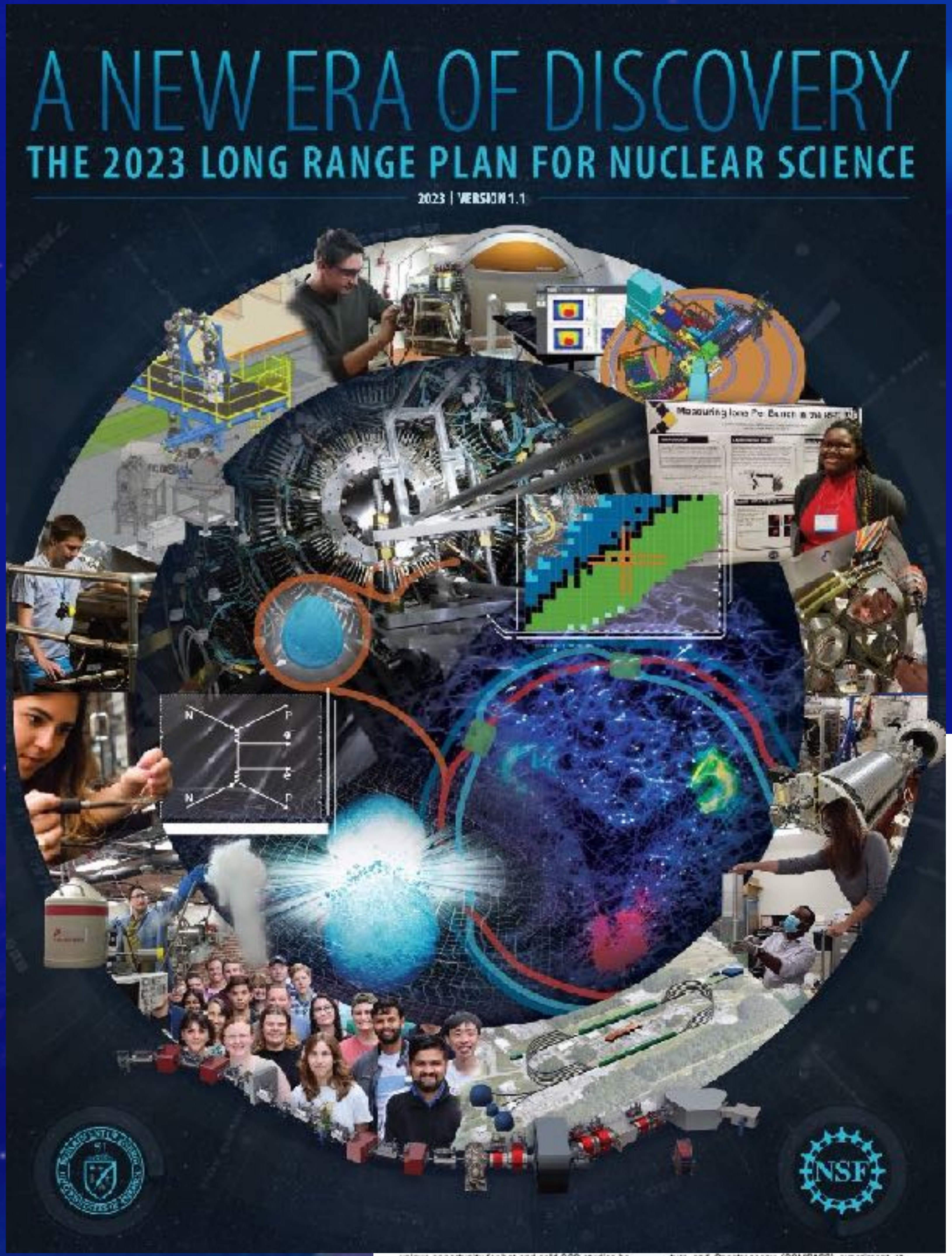
- High-temperature and high-pressure sintering
- 3550°C
- 0.5kW/cm^2

^{25}Mg Hybrid layers

- Cr+Mg+Cr
- rotating coating
- 300 C



JUNA in DOE long range plan 2023

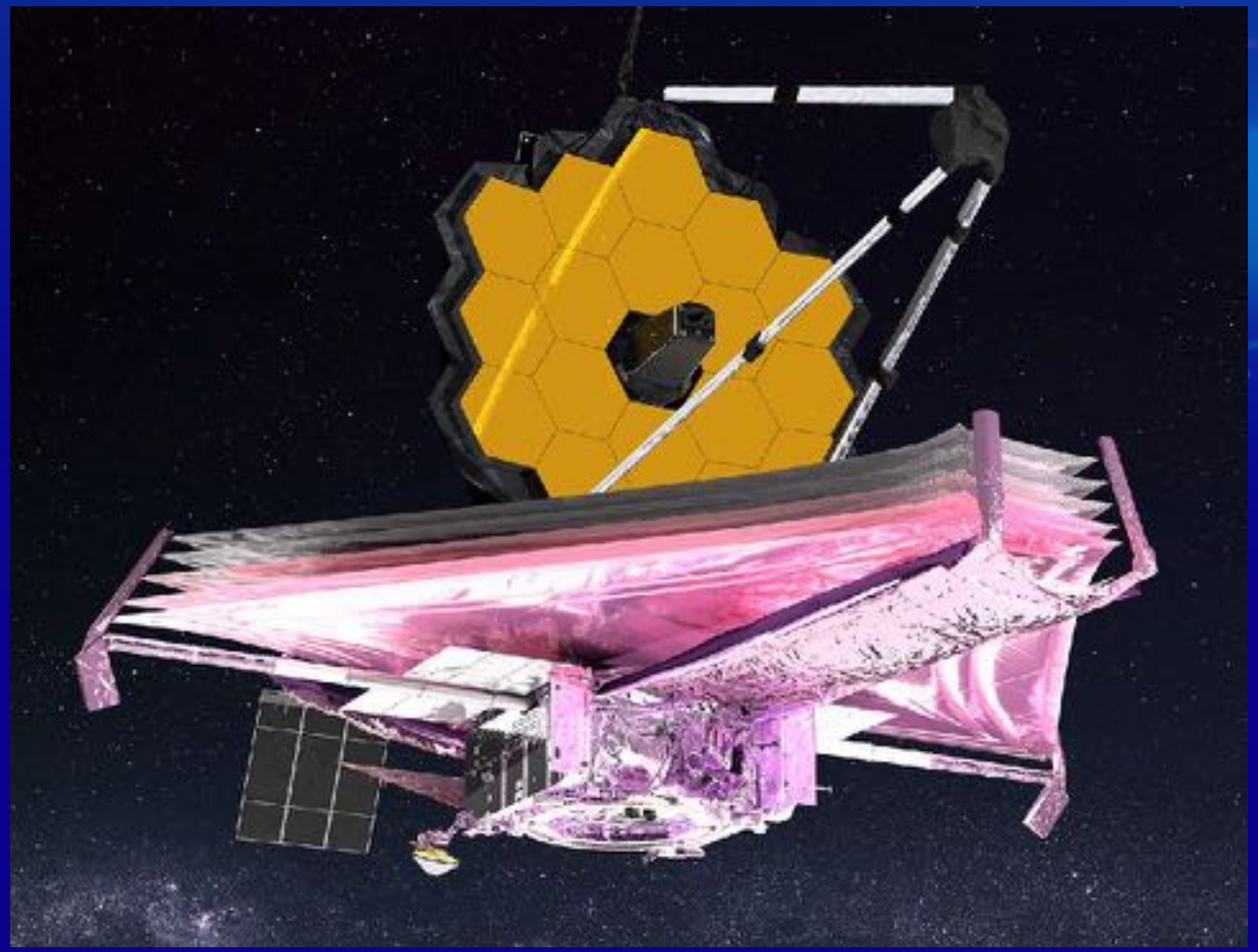


A NEW ERA OF DISCOVERY THE 2023 LONG RANGE PLAN FOR NUCLEAR SCIENCE

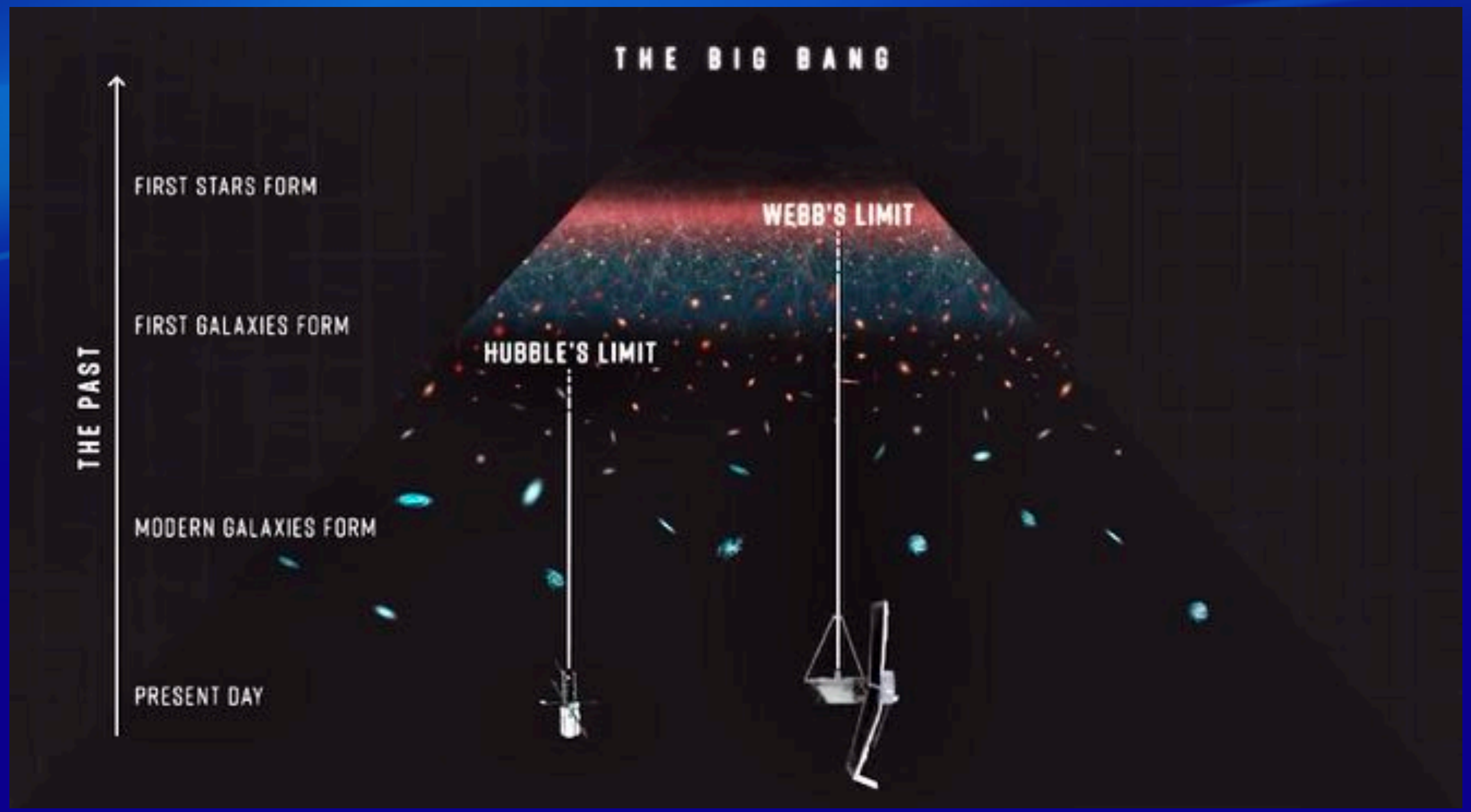
Various experimental facilities in Asia are involved in all areas of experimental nuclear physics, including those under construction. These facilities include the new Yemilab underground laboratory and the Rare Isotope Accelerator Complex for Online Experiment (RAON) in Korea; the Stawell Underground Physics Laboratory (SUPL) in Australia; and the Jinping Underground Laboratory for Nuclear Astrophysics (JUNA) facility, the Beijing Radioactive Ion Beam Facility (BRIF), the Heavy Ion Accelerator Facility (HAIF), and CJPL-II Underground Laboratory in China. All these international facilities are shown in Figure 9.8.

$^{19}F(p,\gamma)^{20}Ne$： confirm CNO break，explain Ca in oldest star

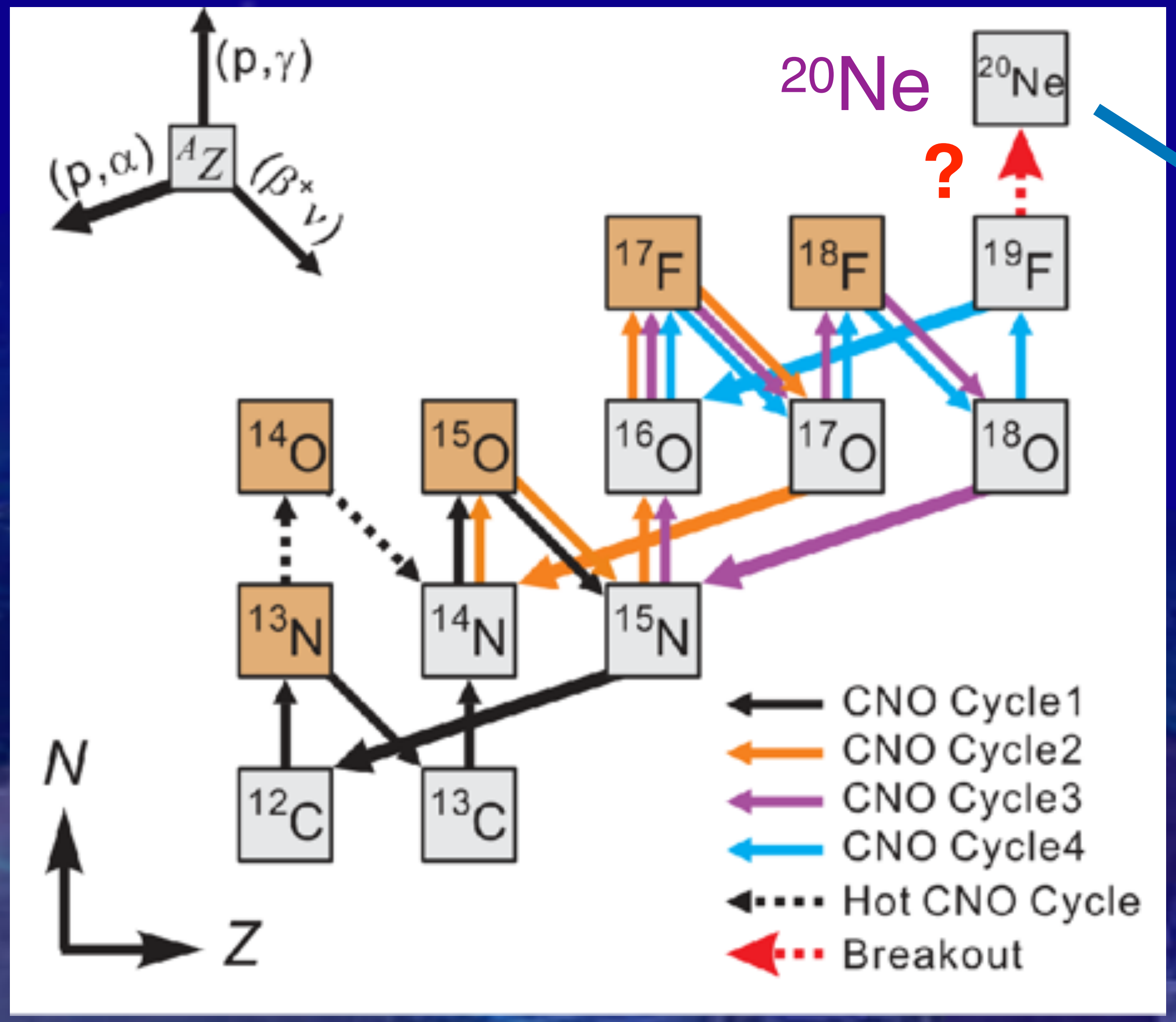
锦屏深地核天体物理实验
Jinping Underground Nuclear Astrophysics Experiment

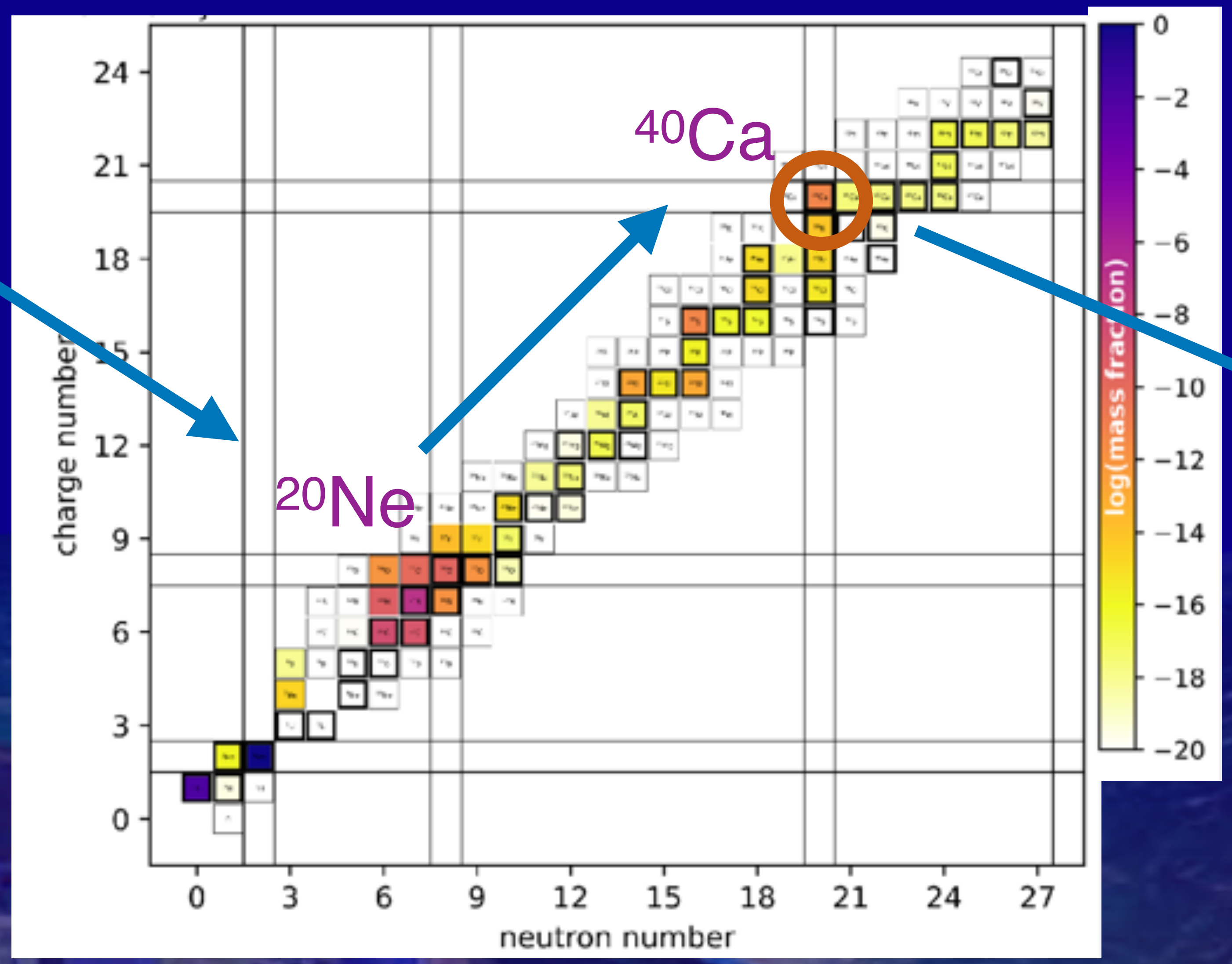


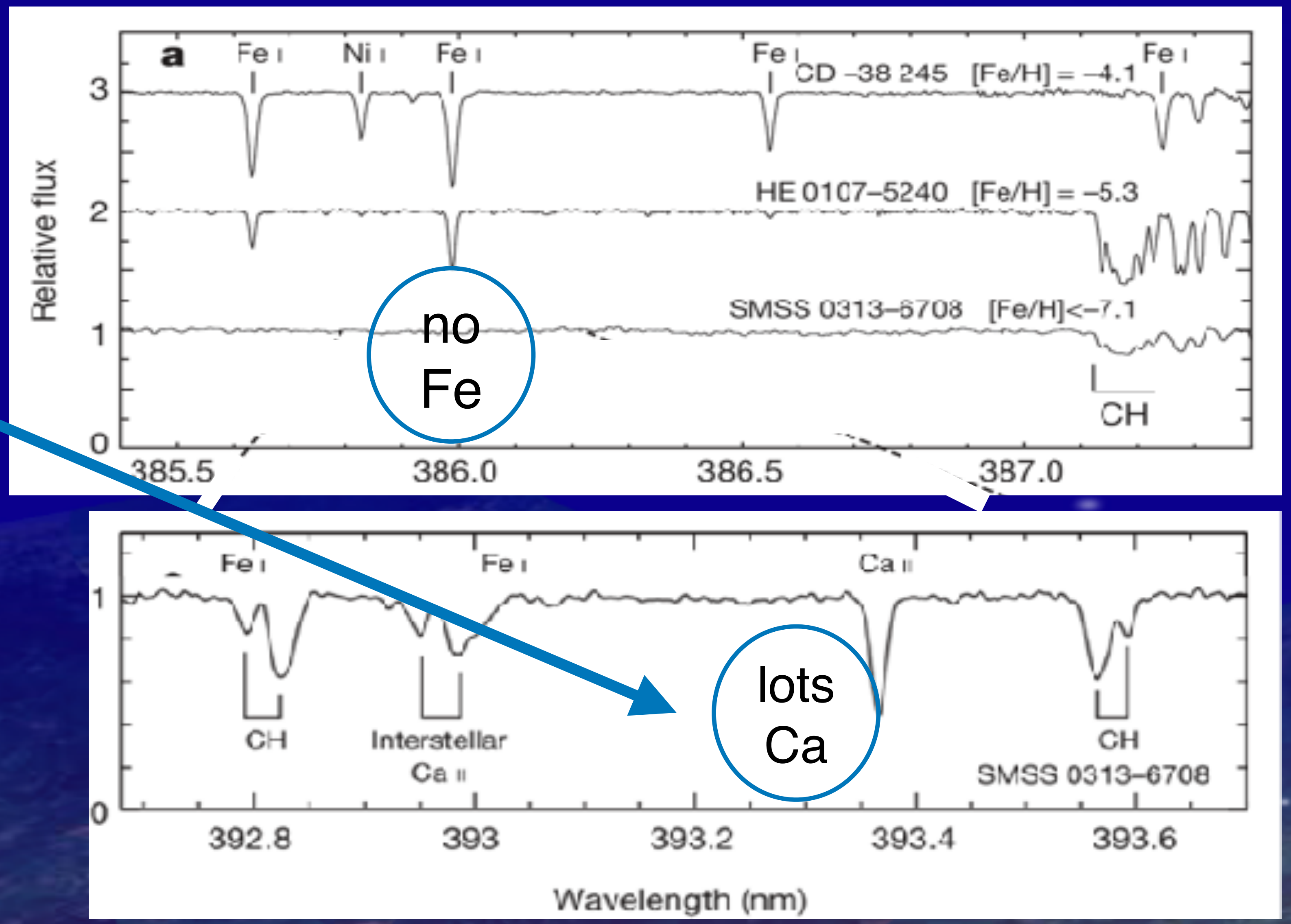
JWST



S.C. Keller et al., Nature 506 (2014) 463







Solution: $^{19}F(p,g)^{20}Ne$ rate one order large?

SMSS 0313-6708：lots of Ca, but no Fe?

NIC, 2023

Experiment setup

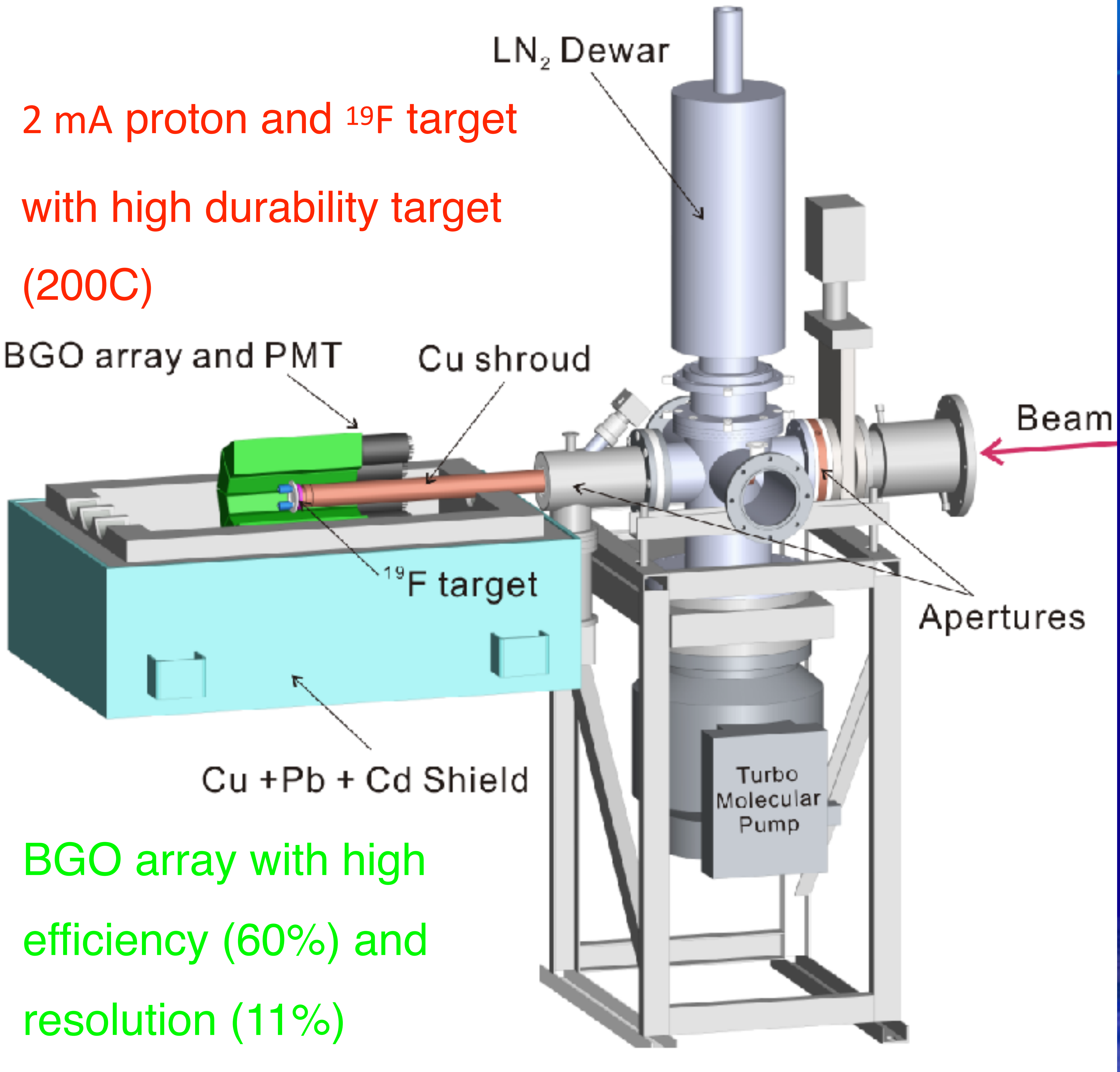
PI: J. J. He, BNU
with L. Y. Zhang, BNU

锦屏深地核天体物理实验
Jinping Underground Nuclear Astrophysics Experiment

2 mA proton and ^{19}F target

with high durability target

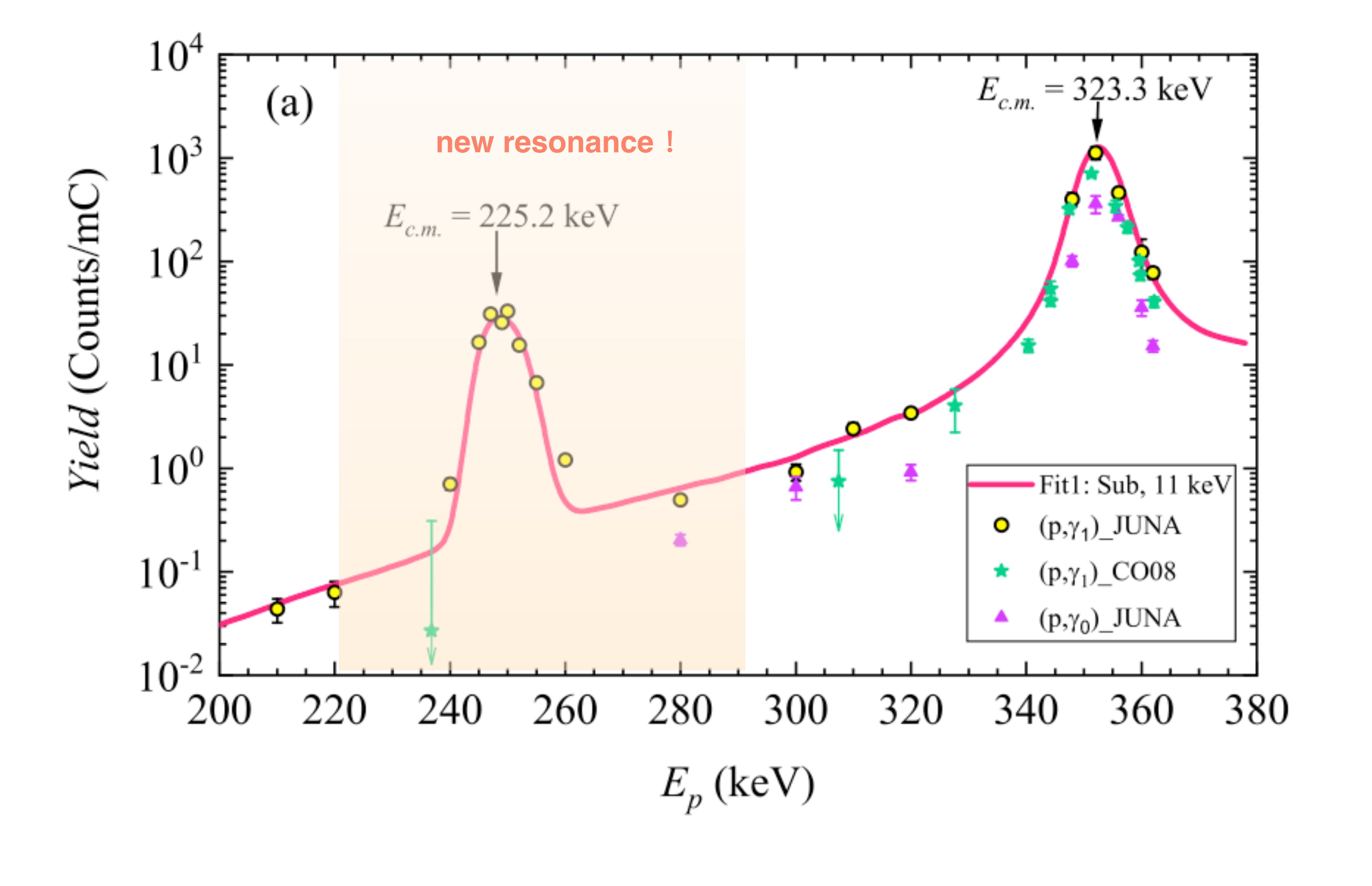
(200C)



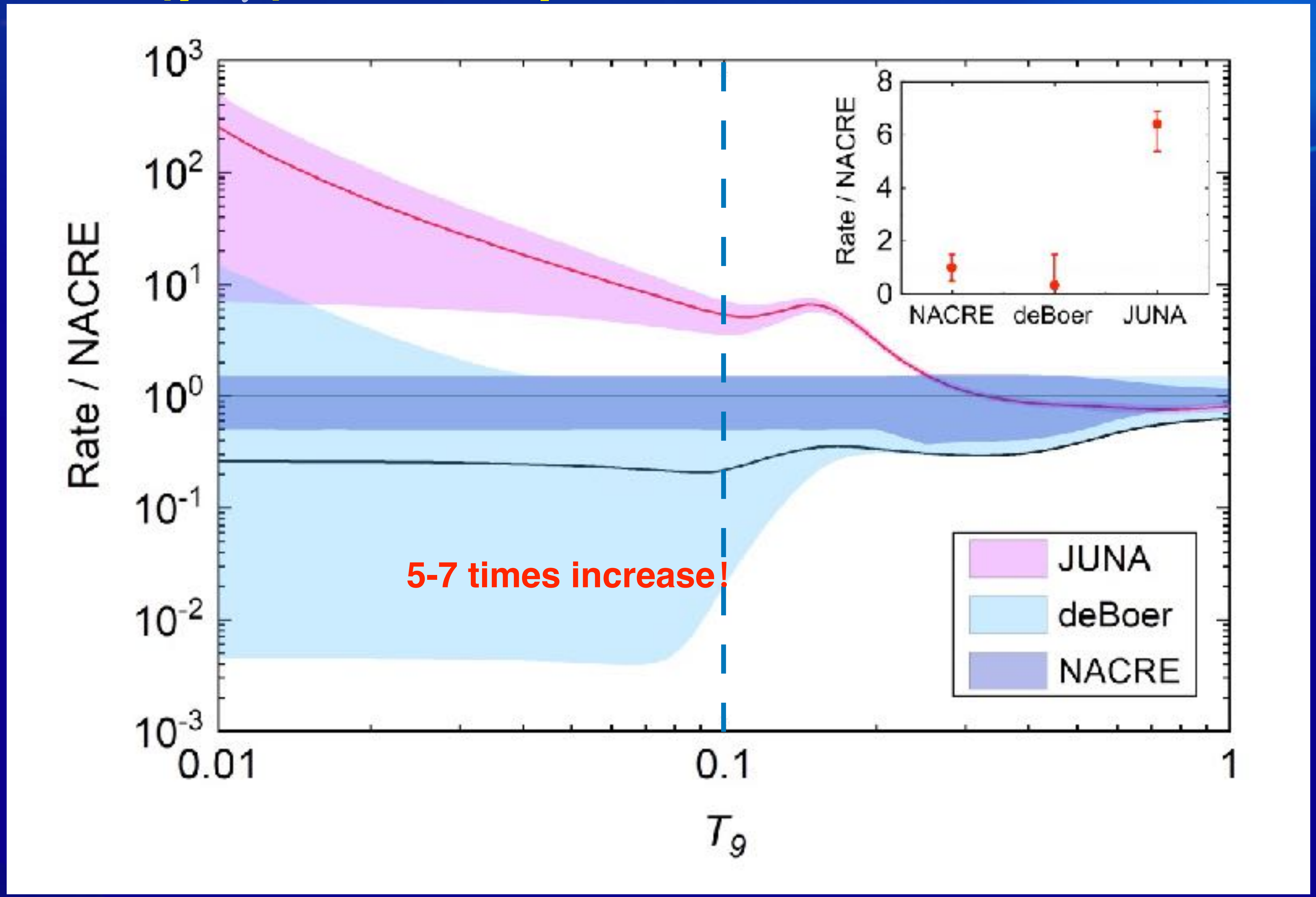
BGO array with high

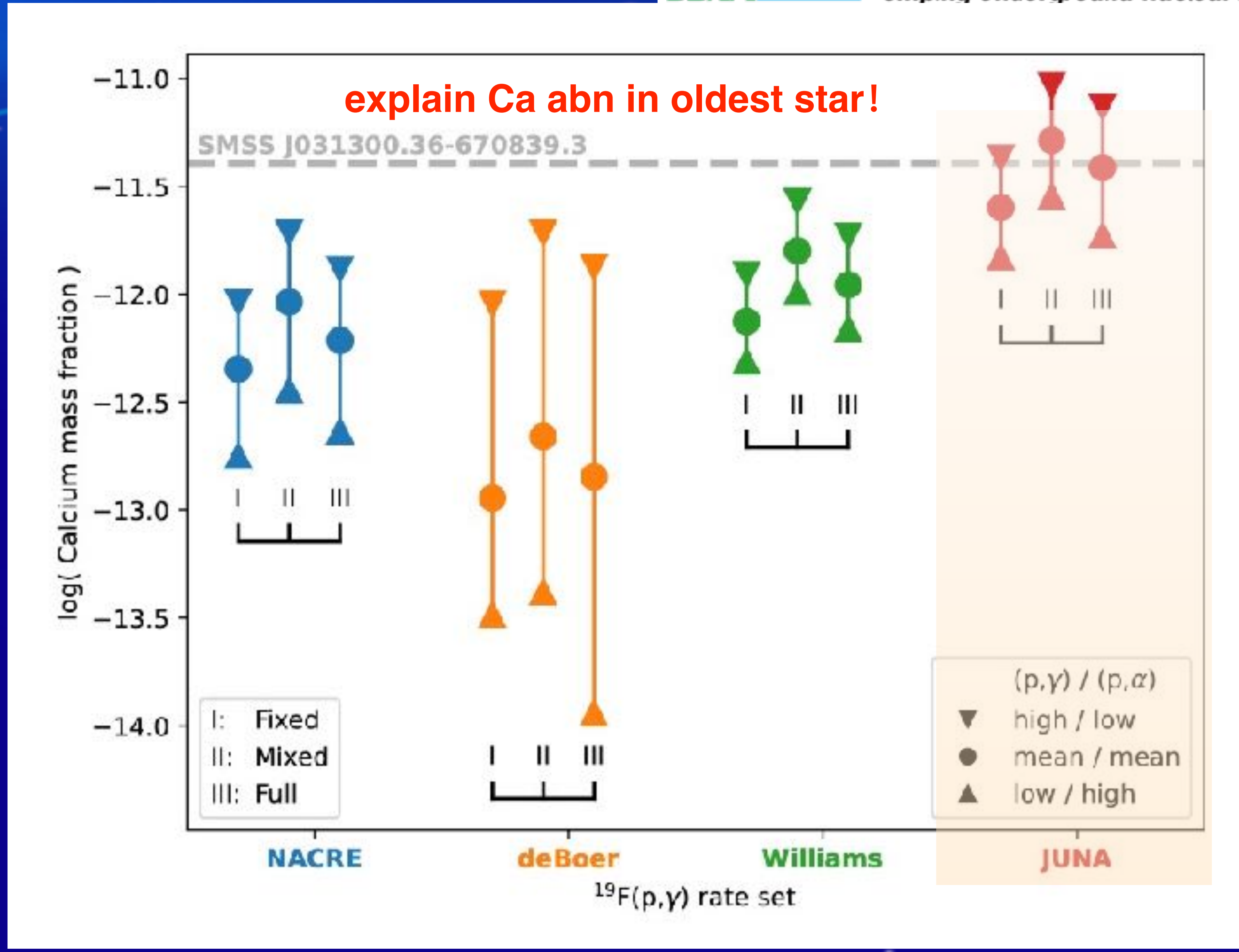
efficiency (60%) and

resolution (11%)



$^{19}F(p,\gamma)^{20}Ne$ implications





Article

Measurement of $^{19}F(p,\gamma)^{20}Ne$ reaction suggests CNO breakout in first stars

https://doi.org/10.1038/s41586-022-05230-x
Received: 28 February 2022
Accepted: 11 August 2022

Liyong Zhang[1], Jianjun He[1✉], Richard J. deBoer[2], Michael Wiescher[2✉], Alexander Heger[3], Daid Kahl[4], Jun Su[1], Daniel Odell[5], Yinji Chen[1], Xinyue Li[1], Jianguo Wang[6], Long Zhang[7], Fuqiang Cao[7], Hao Zhang[1], Zhicheng Zhang[8], Xinzhi Jiang[1], Luohuan Wang[1], Ziming Li[1], Luyang Song[1], Hongwei Zhao[6], Liangting Sun[6], Qi Wu[6], Jiaqing Li[6], Baoqun Cui[7], Lihua Chen[7], Ruigang Ma[7], Ertao Li[8], Gang Lian[7], Yaode Sheng[1], Zhihong Li[7], Bing Guo[7], Xiaohong Zhou[6], Yuhu Zhang[6], Hushan Xu[6], Jianping Cheng[1] & Weiping Liu[7✉]

Check for updates

Nuclear astrophysics

Underground route to grasping the oldest stars

Marco Pignatari & Athanasios Psaltis

Nuclear-fusion experiments performed deep under Earth's surface reveal one possible scenario that could have resulted in the chemical abundances found in an ancient star in the Milky Way. See p.656

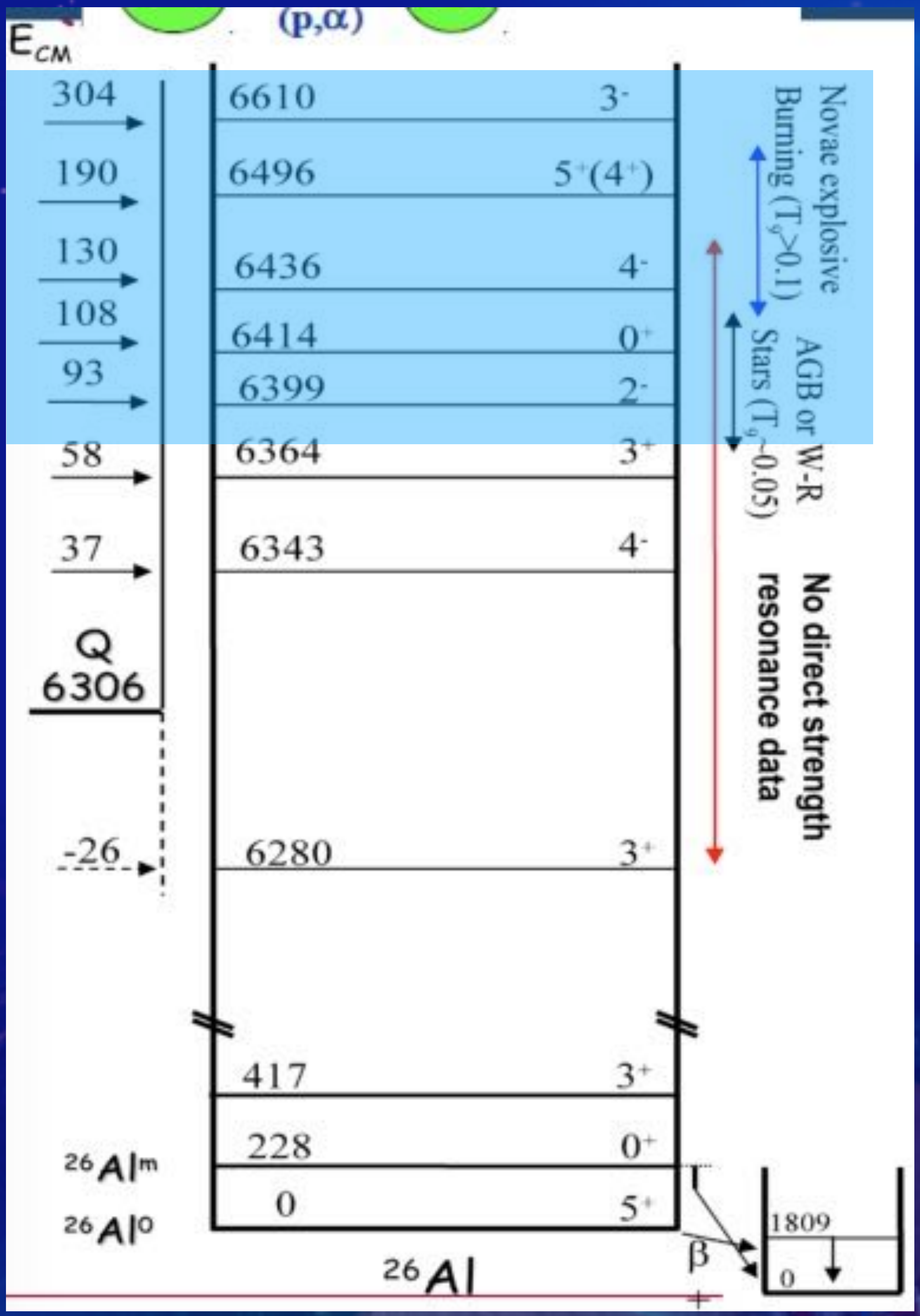
L. Y. Zhang, J. J. He*, ..., WPL*, Nature 610(2022)656, Selected as news and views

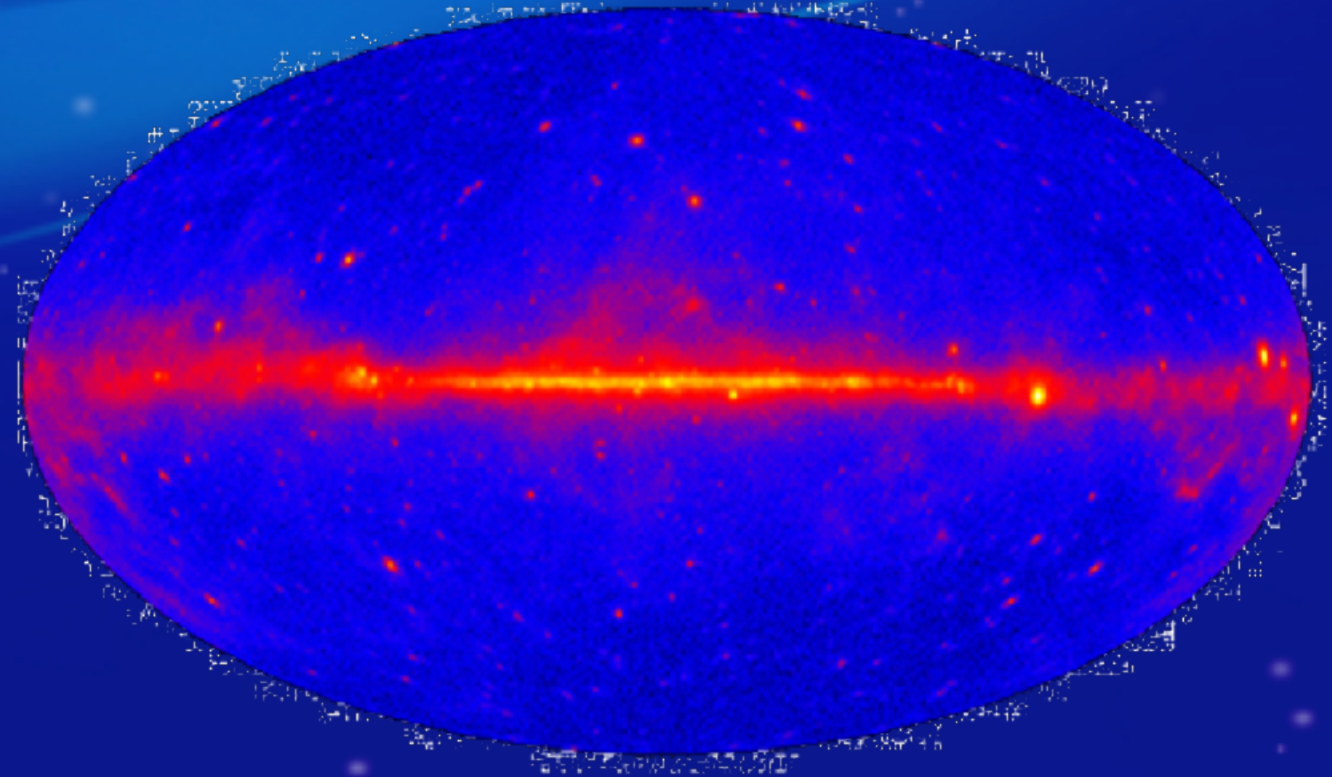
$^{25}Mg(p,\gamma)^{26}Al$： gamma astronomy

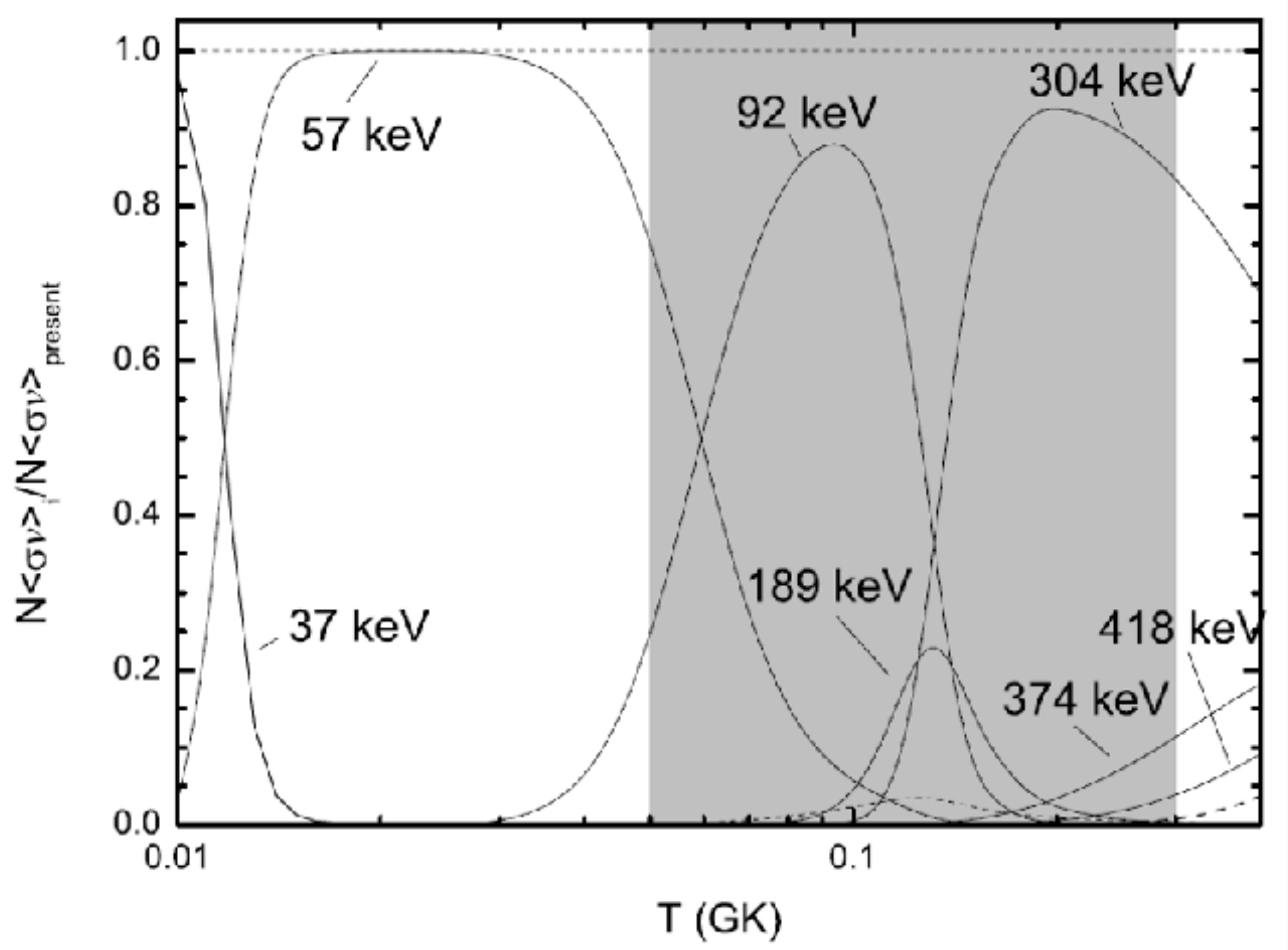
PI: Z. H. Li, CIAE

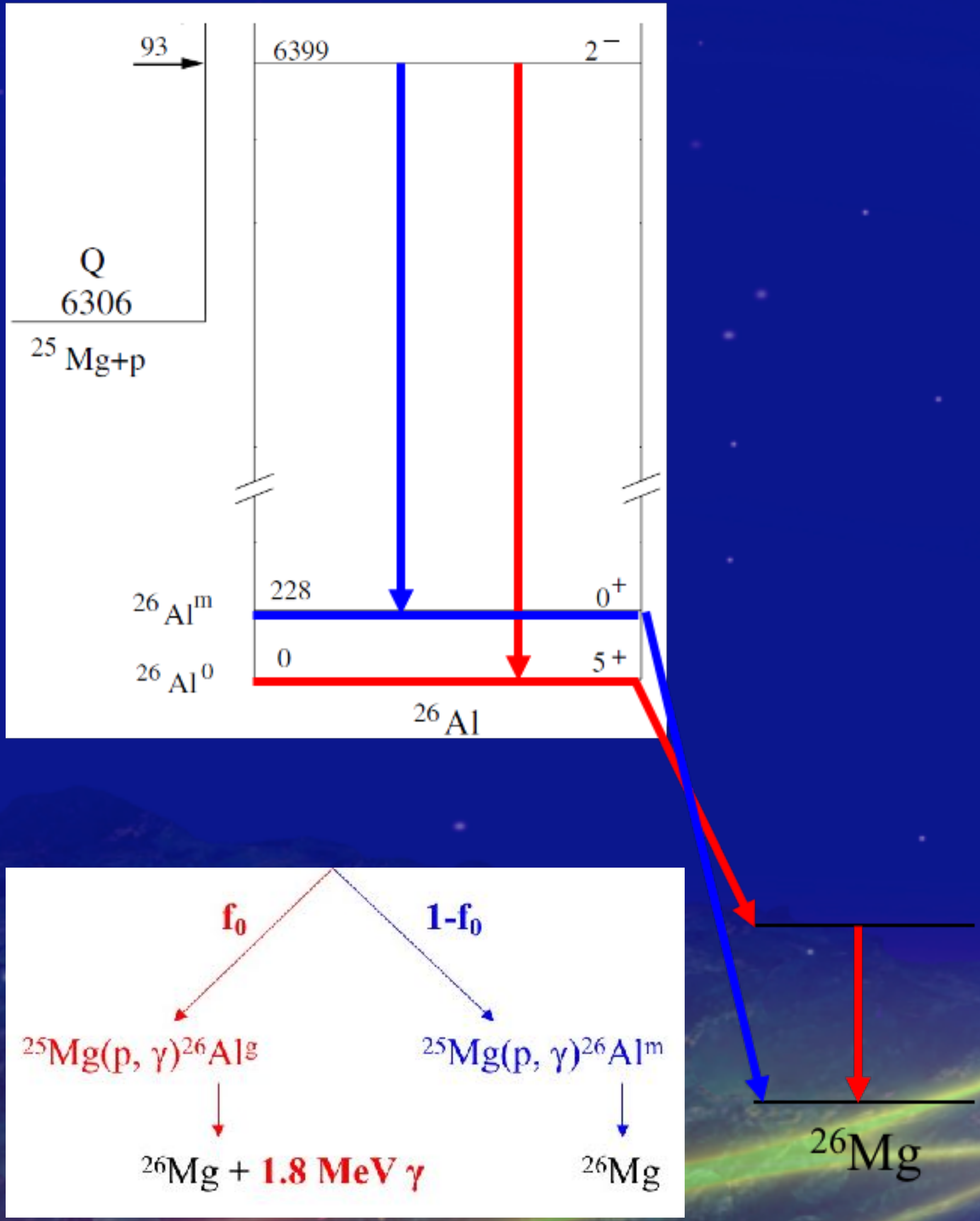
J. Su, CIAE/BNU

Exp.: Jan. 1-15, 2021





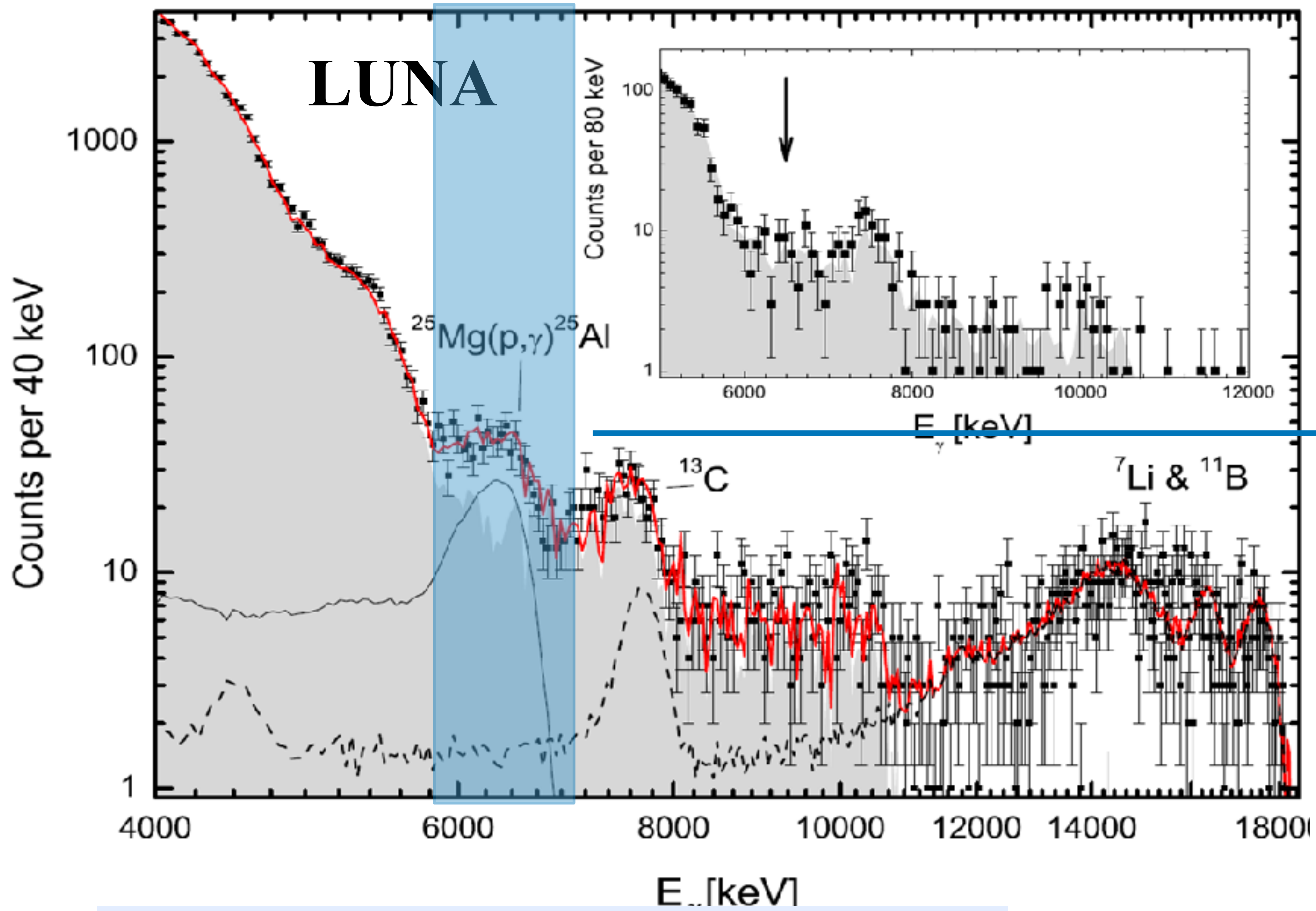


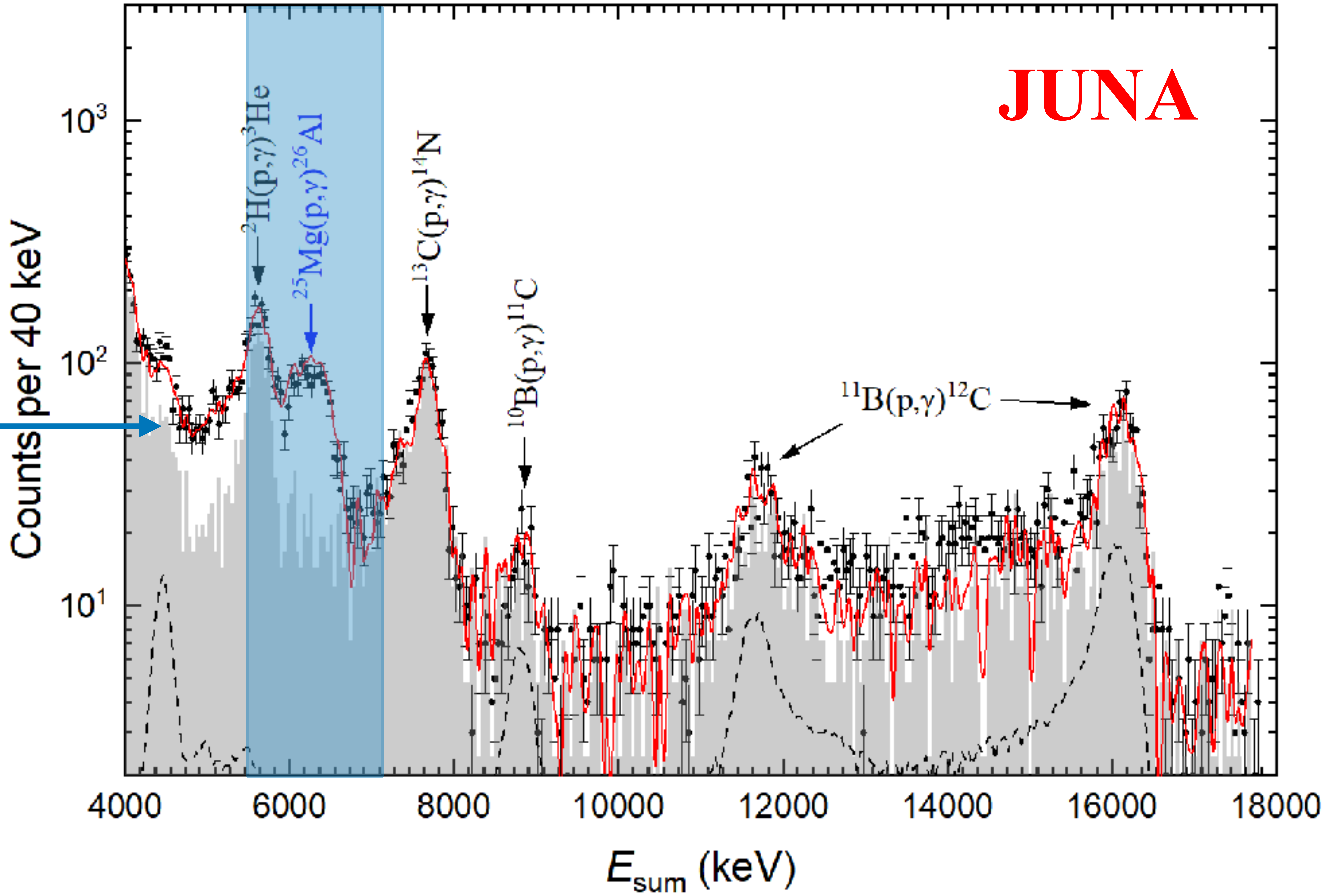


Z. H. Li et al., Sci. China Phys 58. 082002(2015), J. Su et al., Science Bulletin, 67(2022)2（封面文章）

中国原子能科学研究院
China Institute of Atomic Energy
中核集团

JUNA vs. LUNA



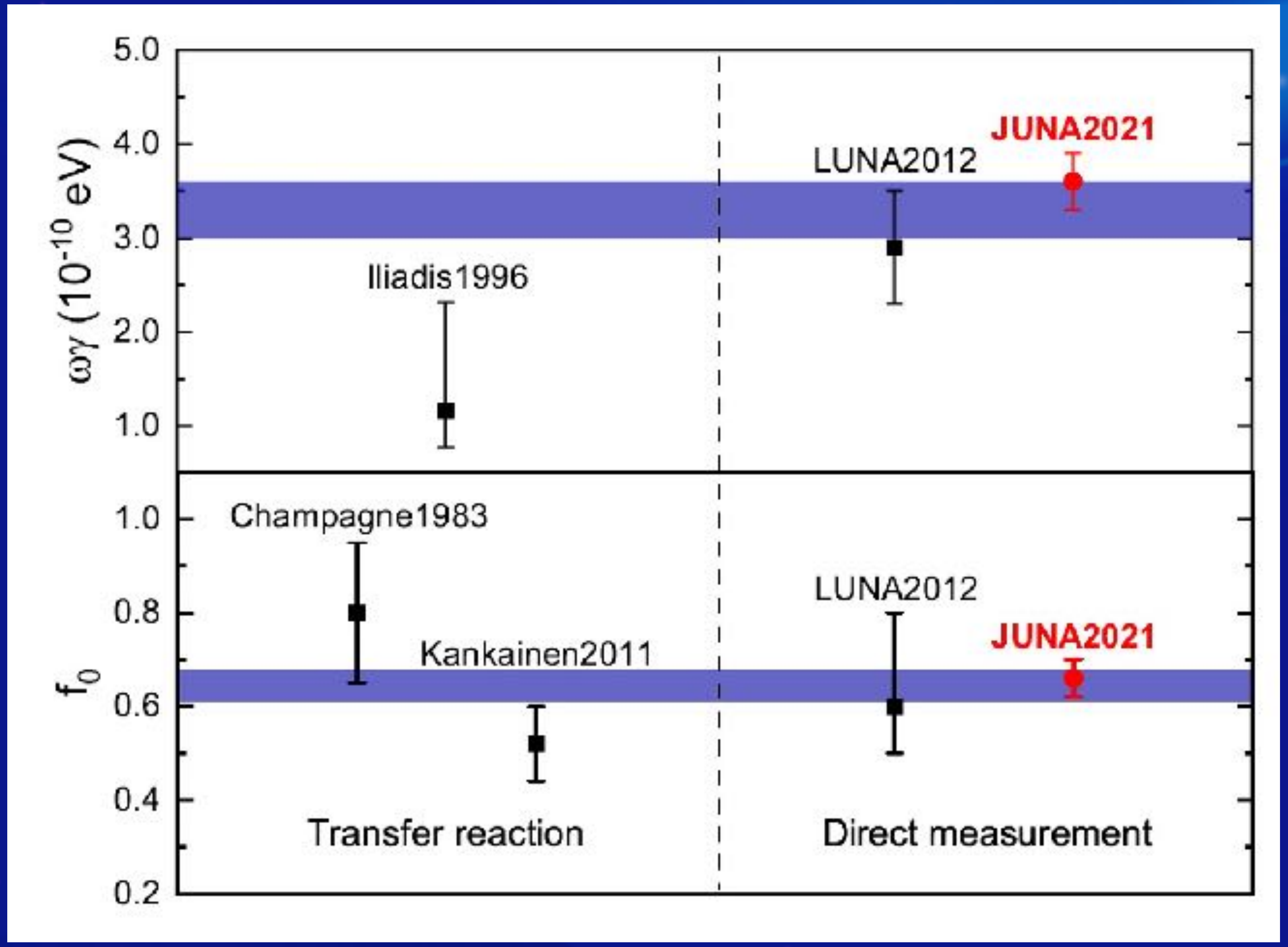


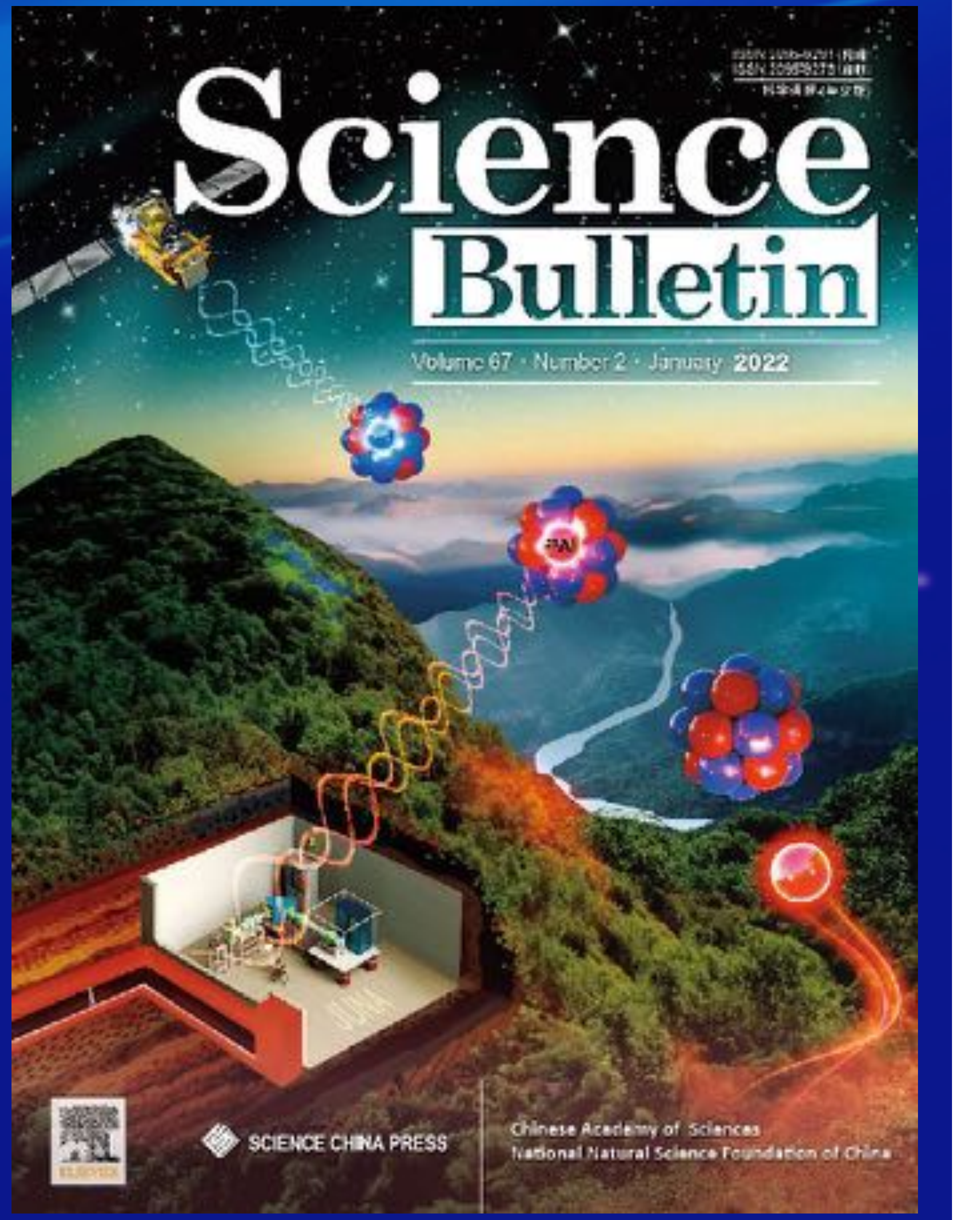
52 days, 370 C
signal: 410
strength: 2.9±0.6×10^{-10} eV

15days, 1008 C
signal: 1225
strength: 3.8±0.4×10^{-10} eV

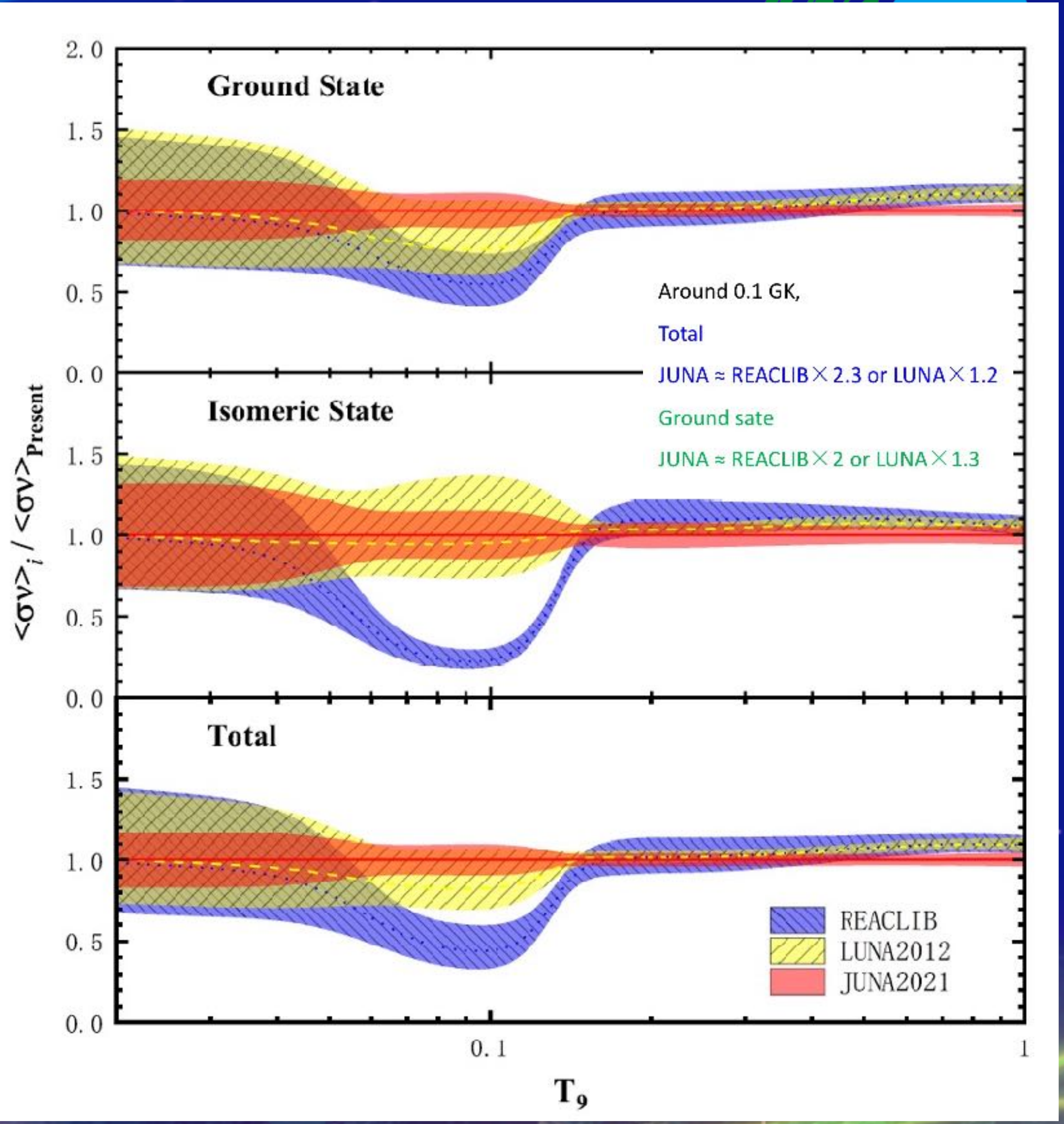
J. Su, Z. H. Li*,...., WPL*, Science Bulletin, 67(2022)2, cover paper

JUNA result of $^{25}Mg(p,\gamma)^{26}Al$





IF>20



BRIF in-direct

Y. J. Li, Z. H. Li, E. T. Li, X. Y. Li, T. L. Ma, Y. P. Shen, J. C. Liu, L. Gan, Y. Su, L.-H. Qiao, *et al.*, Phys. Rev. C **102**, 025804 (2020).

E_x (keV)[a]	$\omega\gamma$ (eV)	f_0
37.1 ± 0.1	$(4.5 \pm 1.8) \times 10^{-22}$[b]	0.79 ± 0.05[b]
57.7 ± 0.1	$(2.9 \pm 0.5) \times 10^{-13}$[c]	0.81 ± 0.05[b]
92.1 ± 0.2	$(3.8 \pm 0.3) \times 10^{-10}$[d]	0.66 ± 0.04[d]
189.6 ± 0.1	$(9.0 \pm 0.6) \times 10^{-7}$[b]	0.75 ± 0.02[b]
304.1 ± 0.1	$(3.1 \pm 0.1) \times 10^{-2}$[e]	0.859 ± 0.01[e]

JUNA underground

JUNA ground

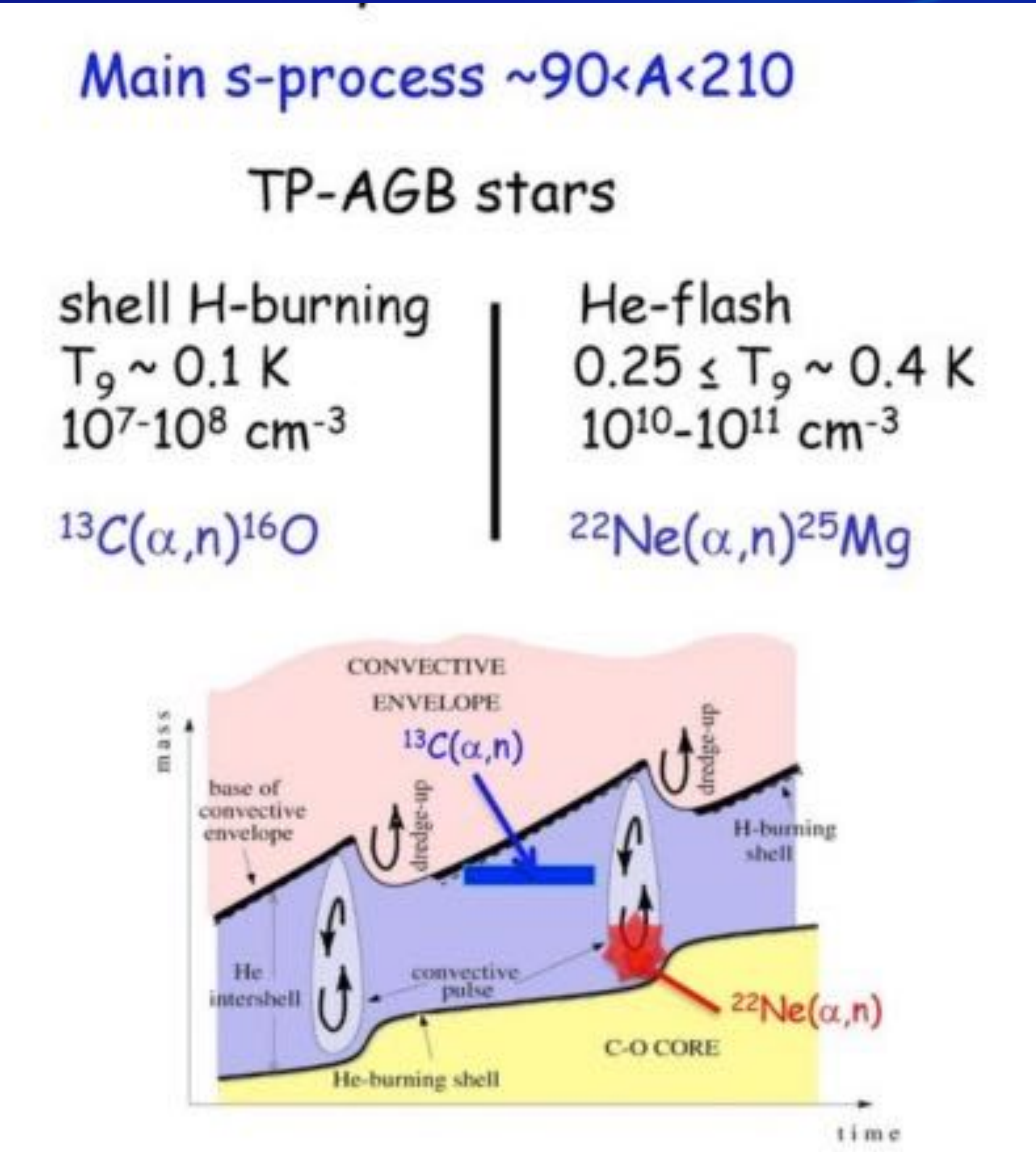
J. Su, Z. H. Li*,…., WPL*, Science Bulletin, 67(2022)2,cover paper

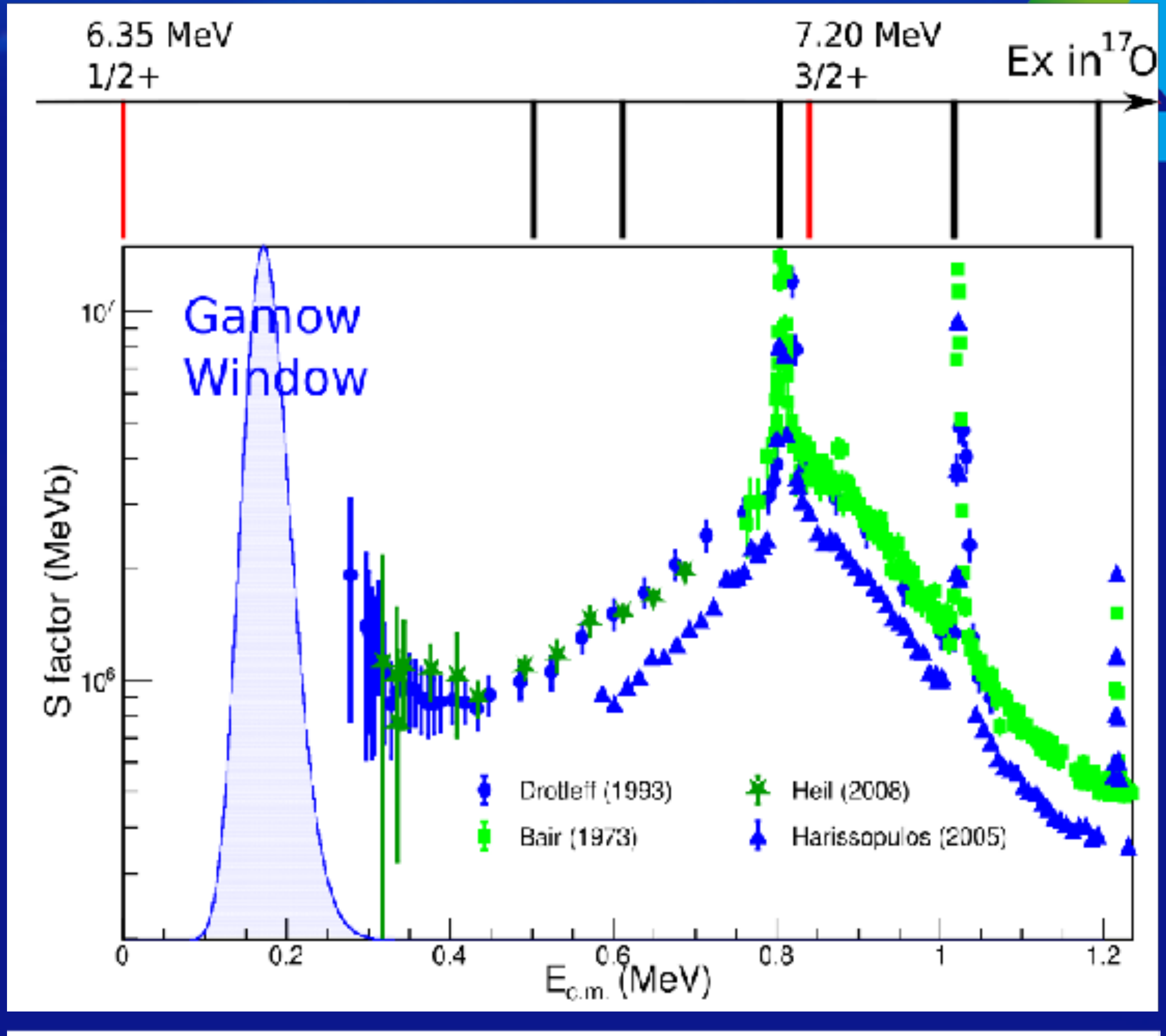
$^{13}C(a,n)^{16}O$ neutron source reaction for heavy elements

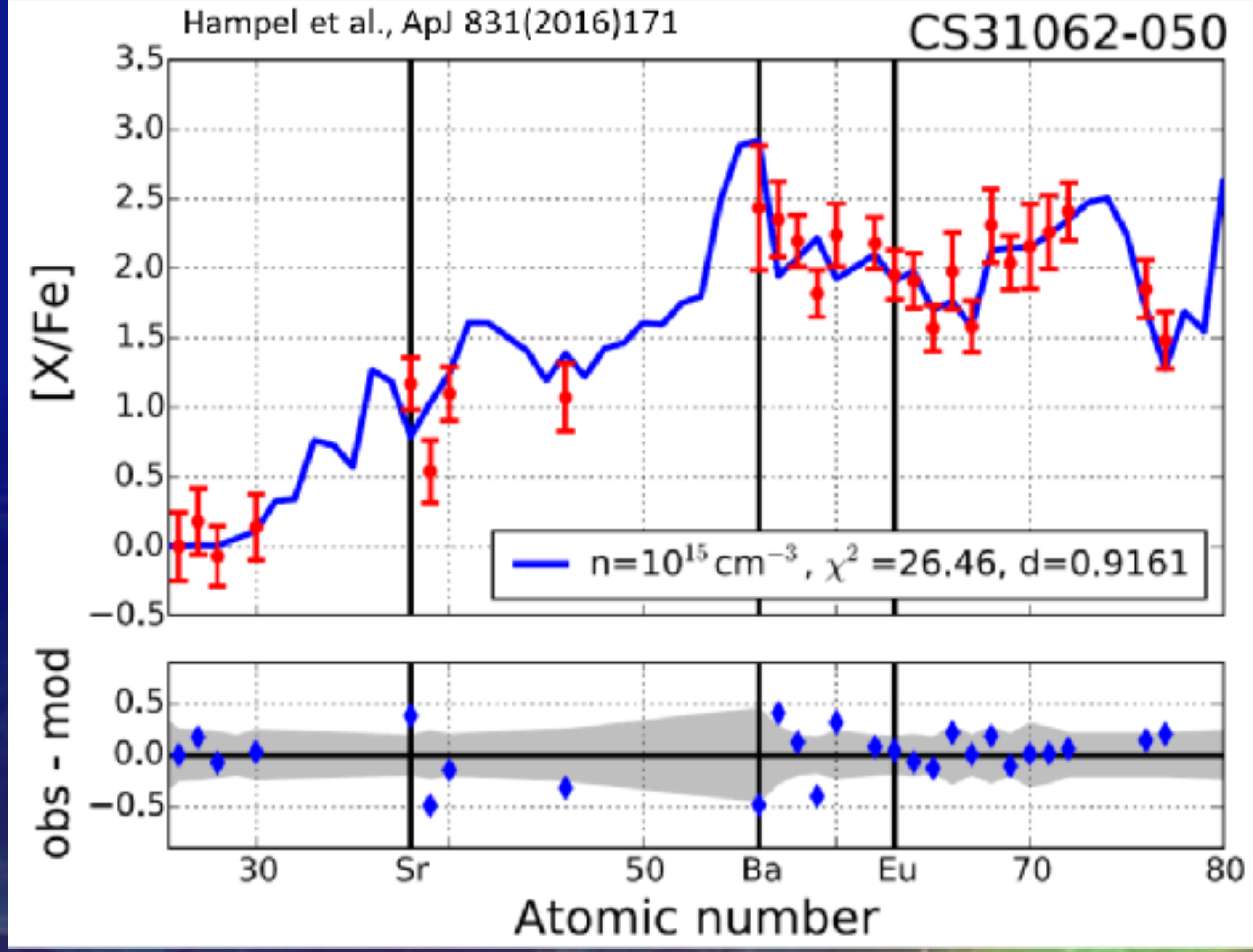
PI: X. D. Tang, IMP

B. Gao, IMP

Exp.: Jan. 27-Feb. 16, 2021



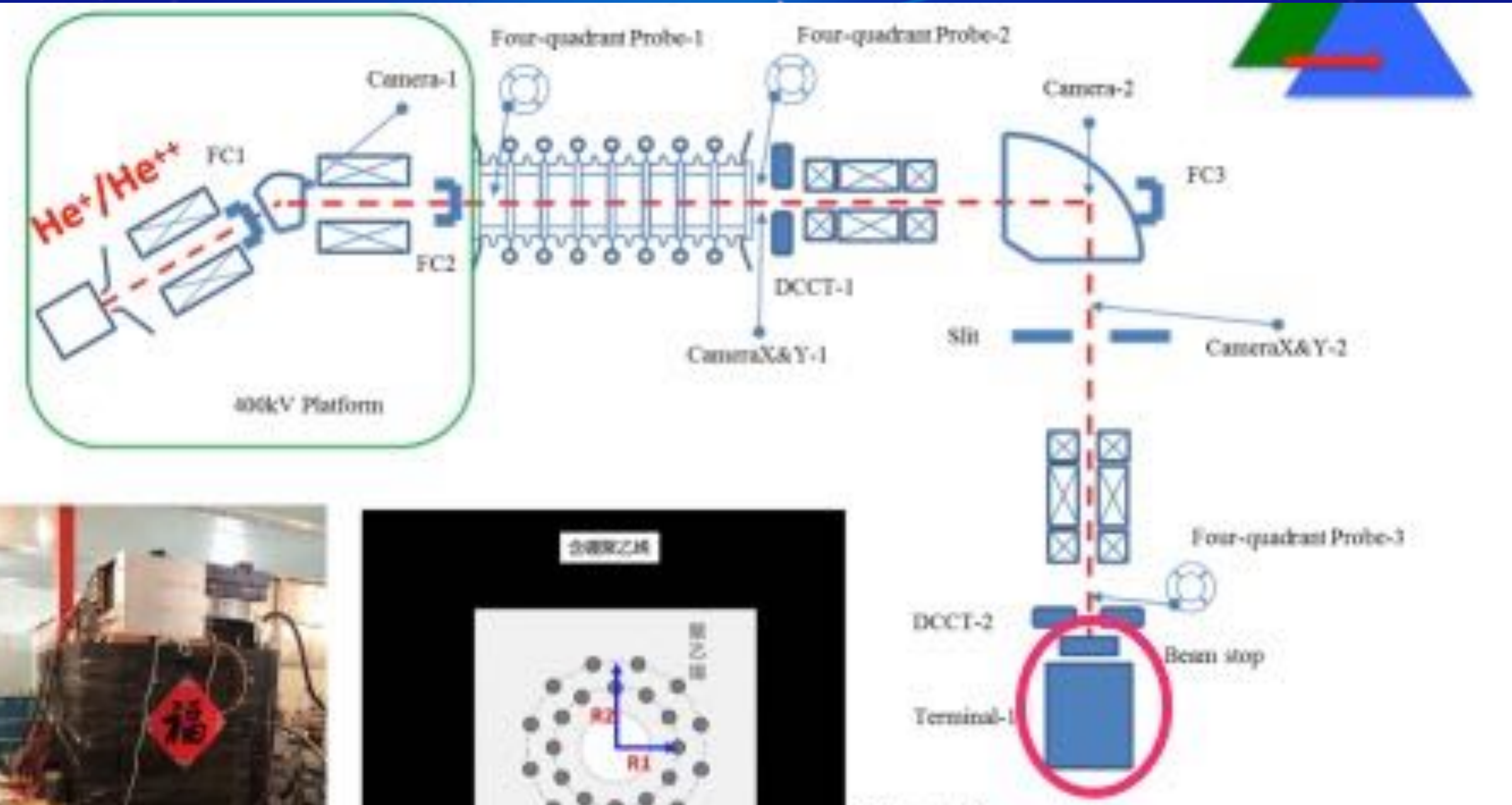




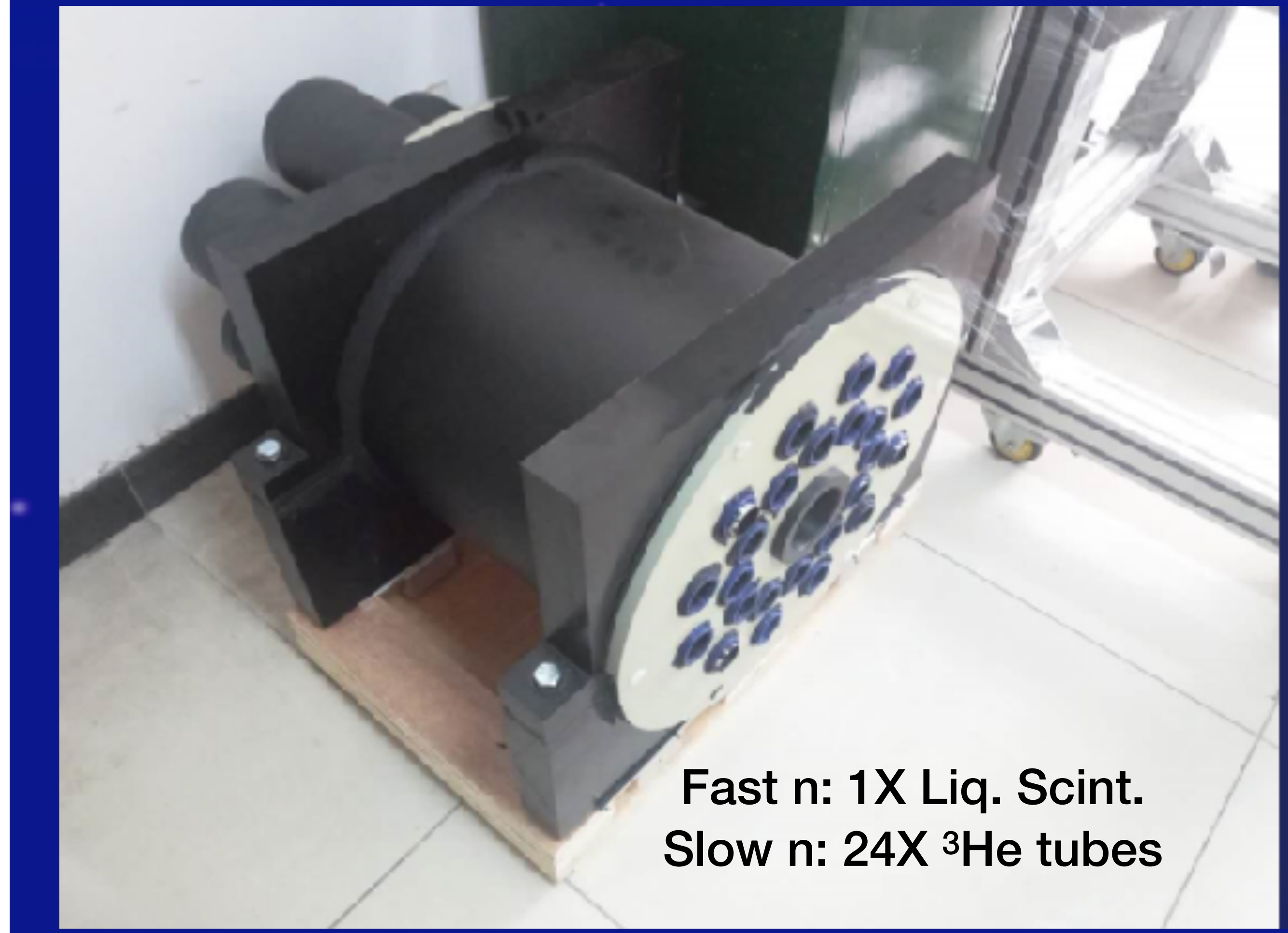
B. Gao, …, Y. D. Tang*,…, WPL*, $^{13}C(\alpha,n)^{16}O$, PRL 129(2022)132701

Lin, Nov. 3, 11:10-11:35
this workshop

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

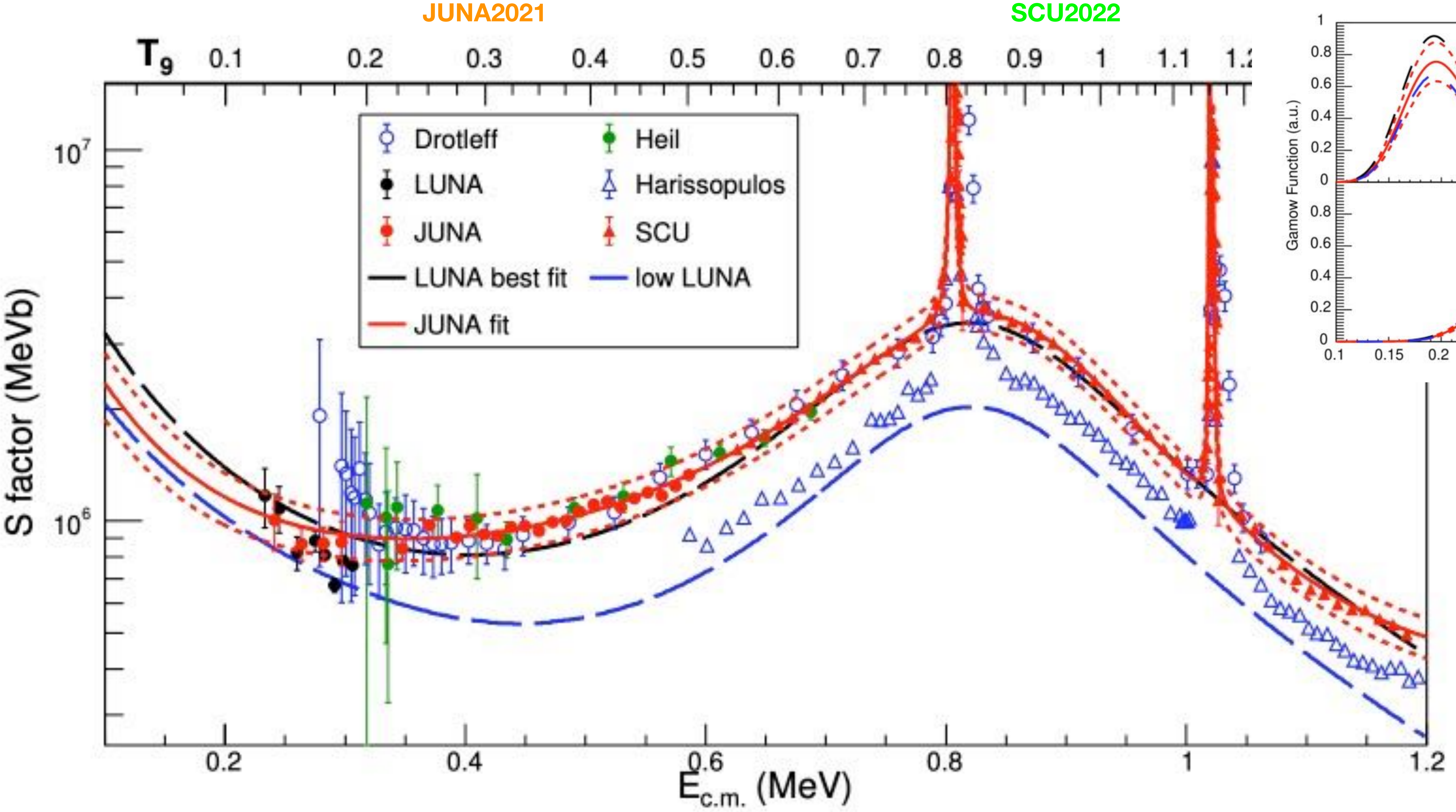


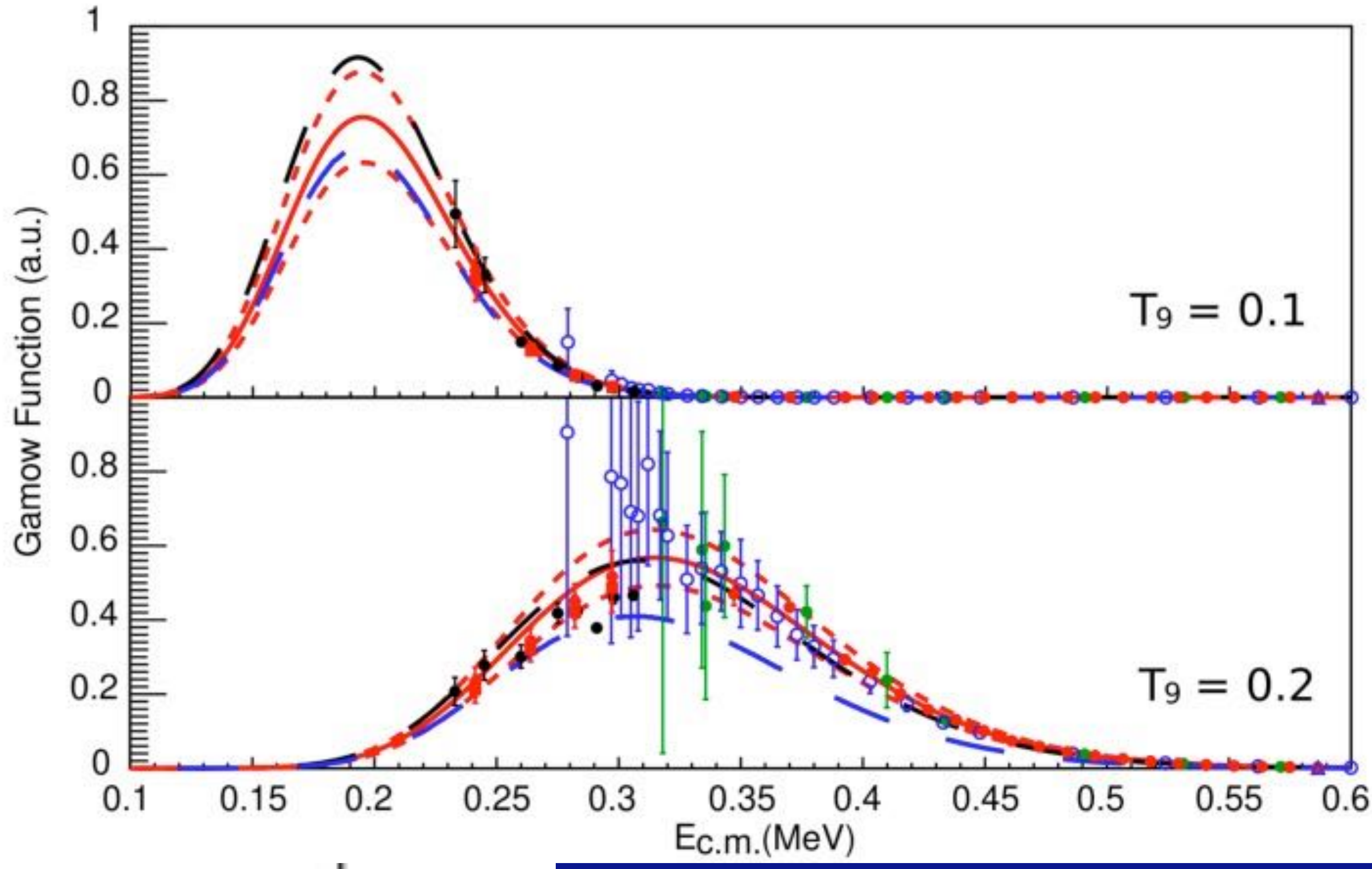
He^{++}: 1pmA
He^{+}: 1pmA,
^{13}C thick target (2mm) x 3



B. Gao, …, Y. D. Tang*,…, WPL*, $^{13}C(\alpha,n)^{16}O$, PRL 129(2022)132701

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





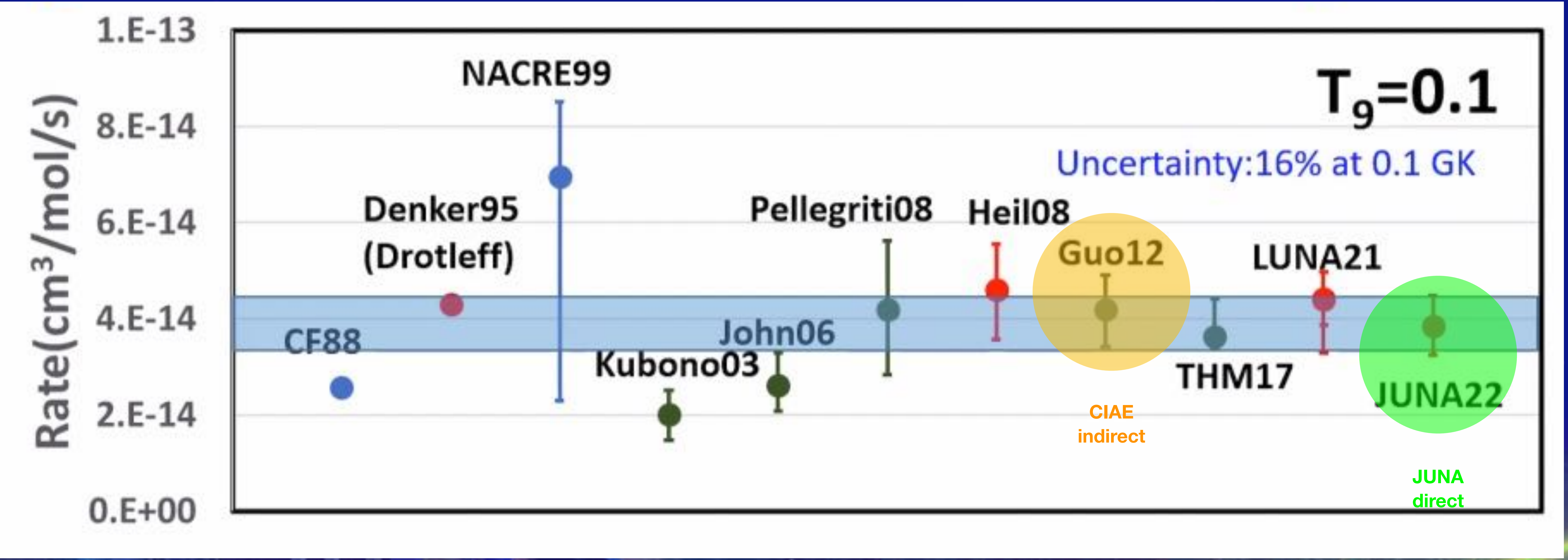
- **mA thick target, differential method to pin down thickness**
- **magnetic removal of He^{2+}, cover 0.4 MeV to 0.8 MeV (JUNA), cover i-process; to 1.2 MeV tandem, calibration of eff. , cross check other date**
- **n background 5/ hour, 2.5 MeV eff. 25%, good S/N**

B. Gao, …, Y. D. Tang*,…, WPL*, $^{13}C(\alpha,n)^{16}O$, PRL 129(2022)132701

Resolve conflict in30 years research

Annu. Rev. Nucl. Part. Sci. 2023. 73:315–40

Recent studies of the low-energy range of the $^{13}C(\alpha,n)^{16}O$ reaction rate at the deep underground accelerator facilities of LUNA in Italy (83) and JUNA in China (84) have removed most of the uncertainties in the extrapolation of the previous higher-energy data [the NACRE II compilation (85)]. The low-energy data match well the prediction of a recent R-matrix analysis (86)



B. Gao, …, Y. D. Tang*,…, WPL*, $^{13}C(\alpha,n)^{16}O$, PRL 129(2022)132701

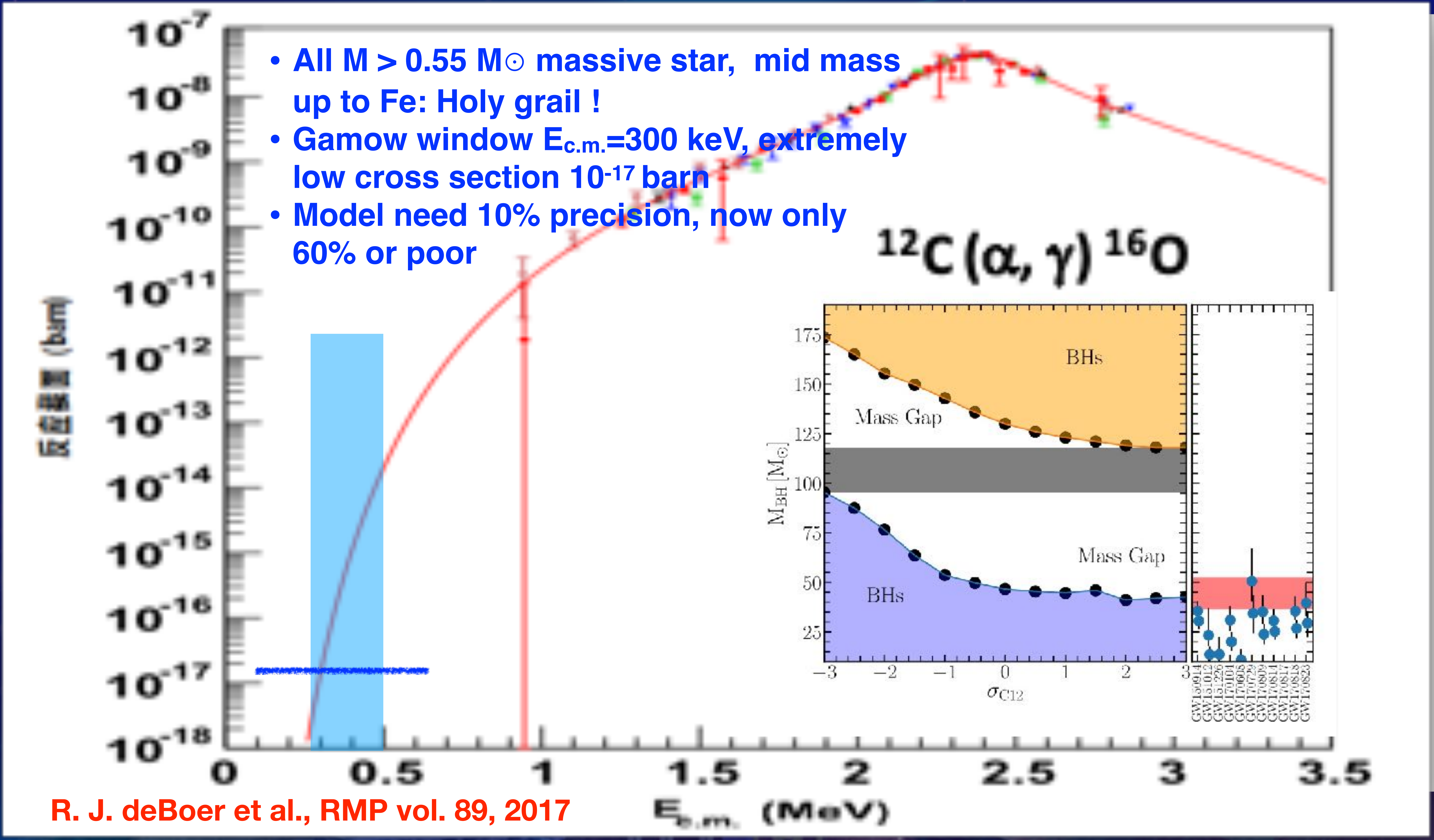
B. Guo*, Z. H. Li,…, WPL*, Astrophys. J. 756(2012)193.

Big question, big impact, big challenge

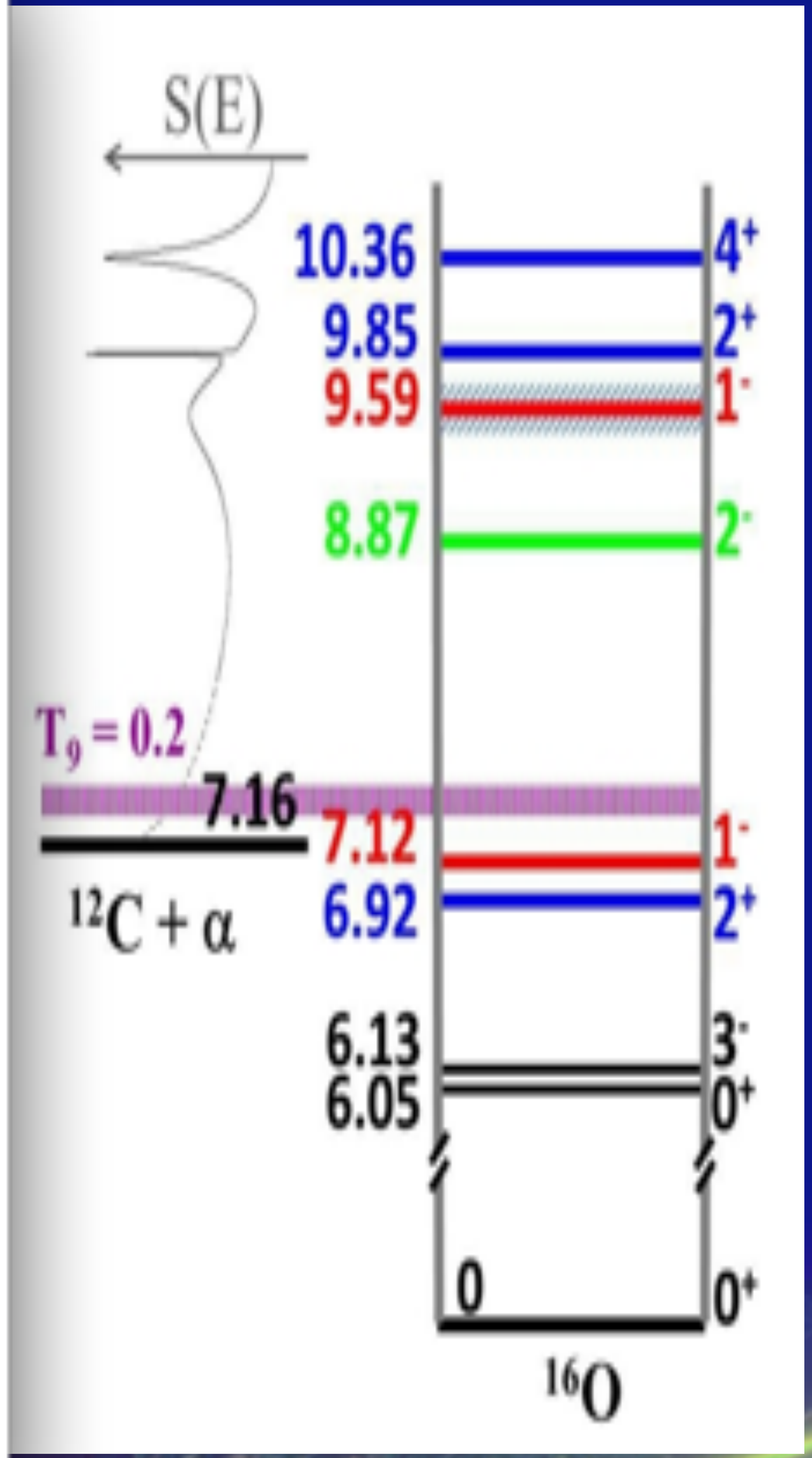
Exp.: Feb. 26-Apr. 18, 2021

PI: WPL/Y. P. Shen, CIAE

- All M > 0.55 M⊙ massive star, mid mass up to Fe: Holy grail !
- Gamow window $E_{c.m.}$=300 keV, extremely low cross section 10^{-17} barn
- Model need 10% precision, now only 60% or poor



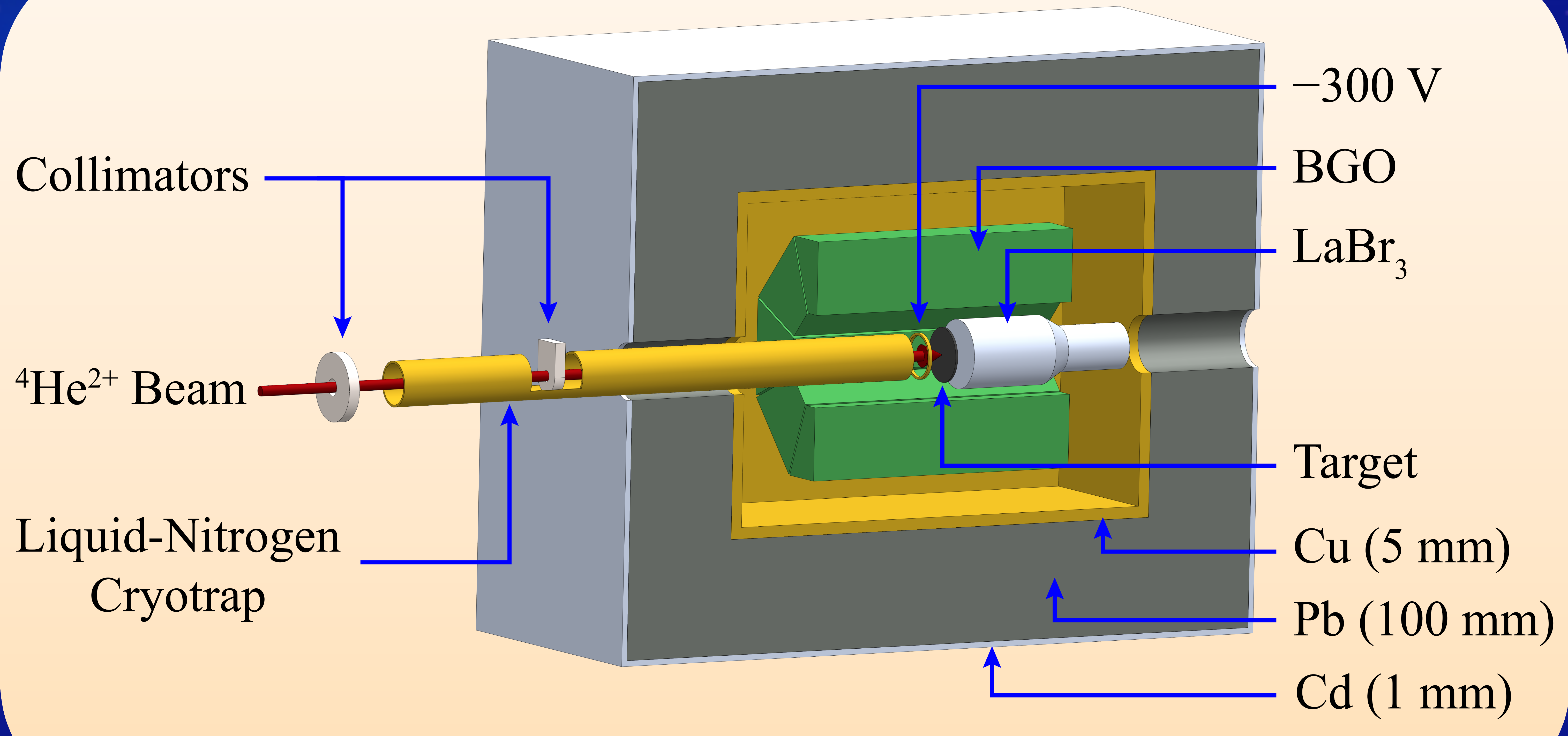
R. J. deBoer et al., RMP vol. 89, 2017



B. Guo, Z. H. Li, …, WPL,, APJ 756, 193 (2012); Y. P. Shen, B. Guo, …, WPL, PRL 124, 162701(2020)

R. Farmer1,2 , M. Renzo3 , S. E. de Mink et al., APJ 902, L36, 2020

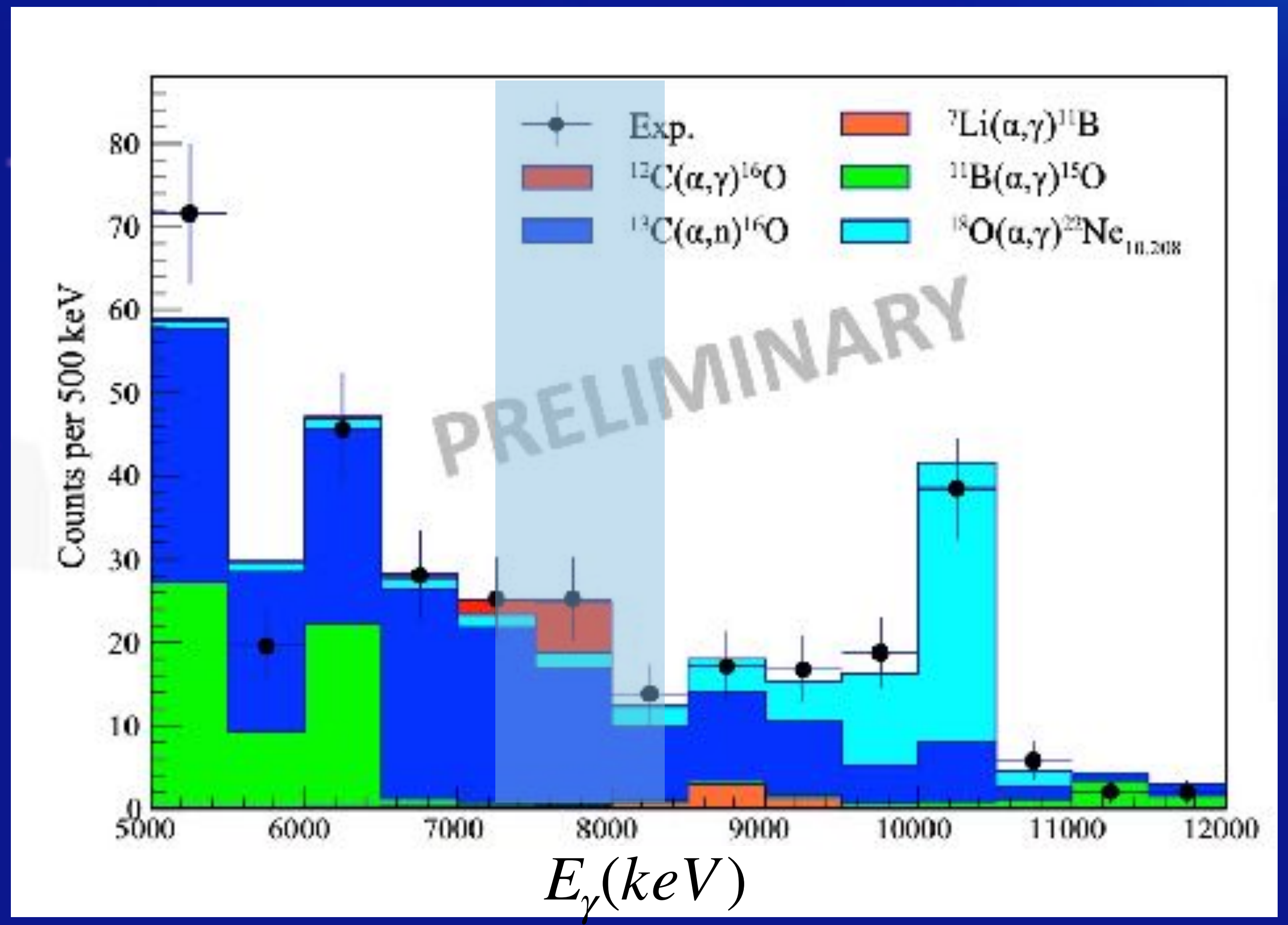
$^{12}C(\alpha,\gamma)^{16}O$ ： more sensitivity



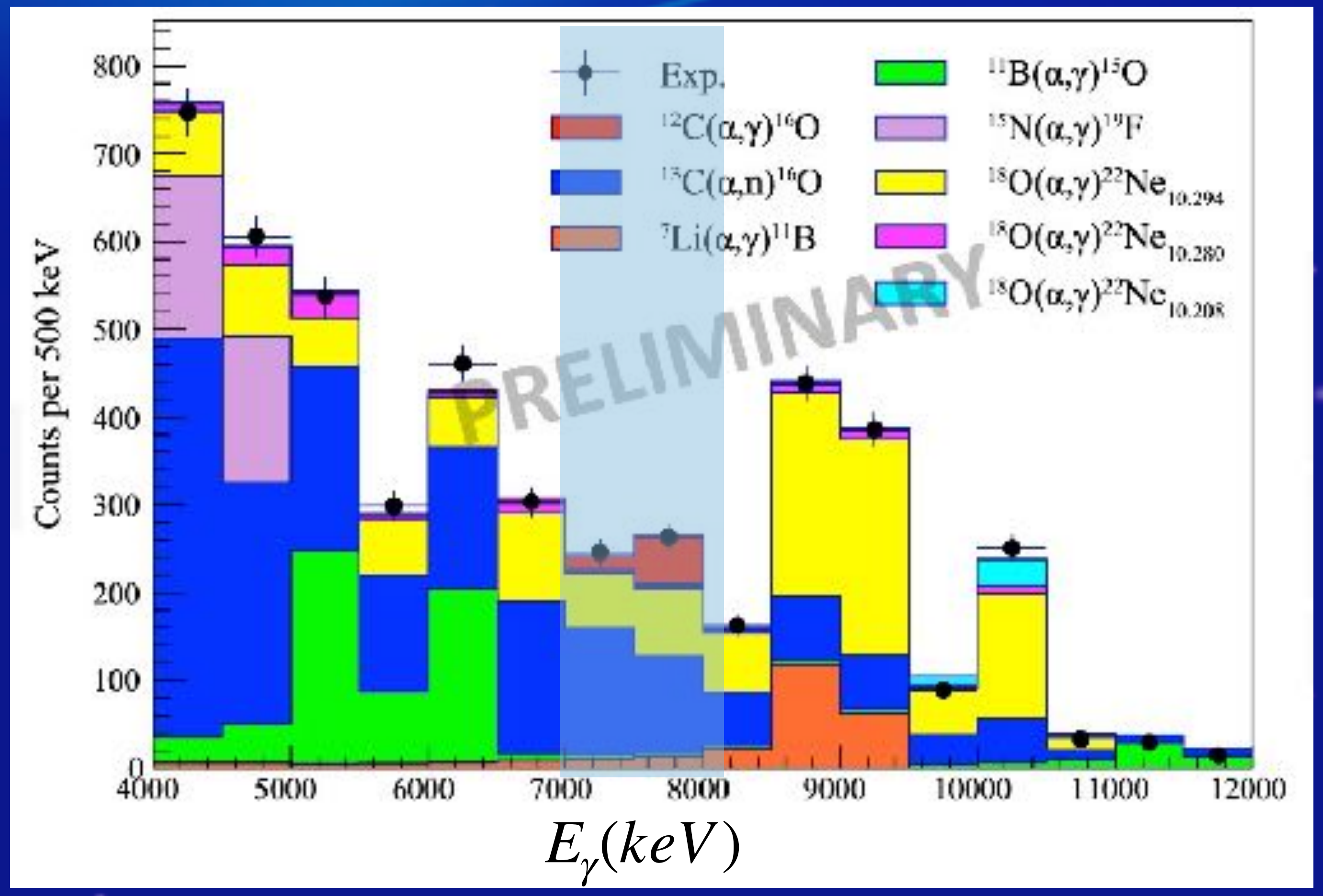
- FCVA implantation CTi thick targets
- durability >280 C @800 keV He^{2+}, with only 25% loss
- $BGO+LaBr_3$ (Lanthanum bromide) veto
- wide energy search for best S/N, 552 keV is best, other suffer from $^{18}O(\alpha,\gamma)^{22}Ne$ contaminations
- sensitivity of 10^{-12} b @$E_{c.m.}$ = 552 keV

$^{12}C(\alpha,\gamma)^{16}O$ ： submitted

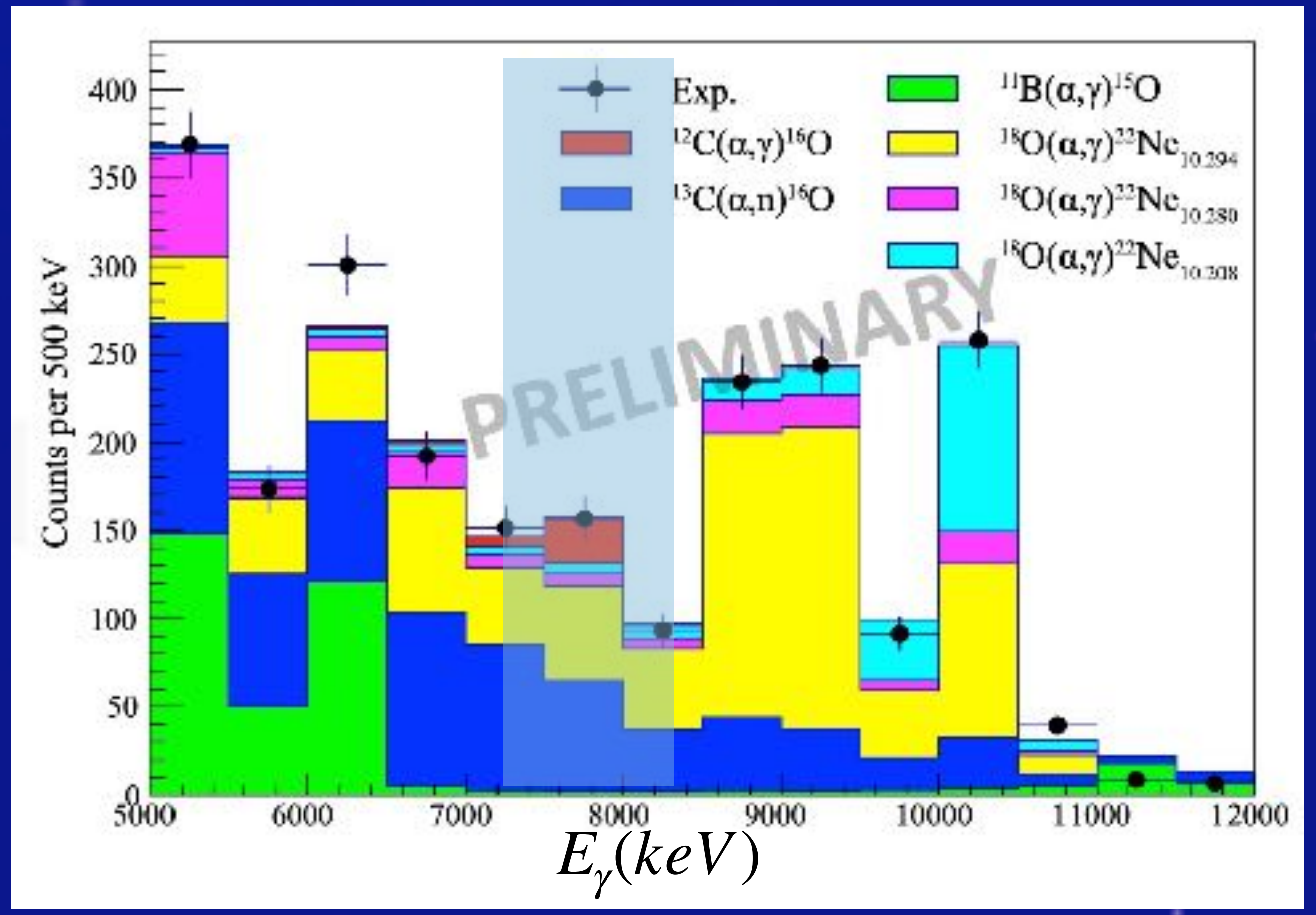
552 keV, 126 C

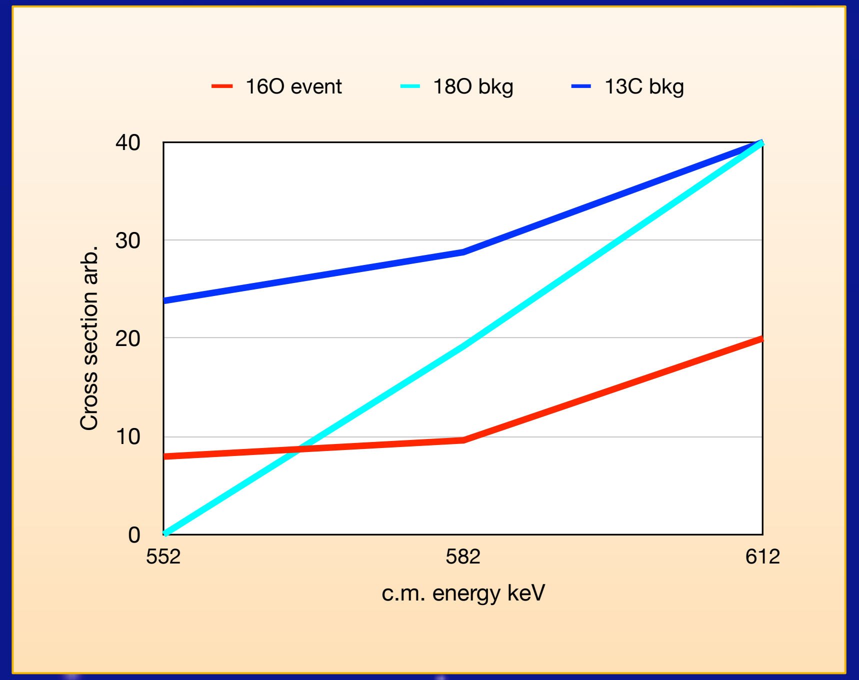


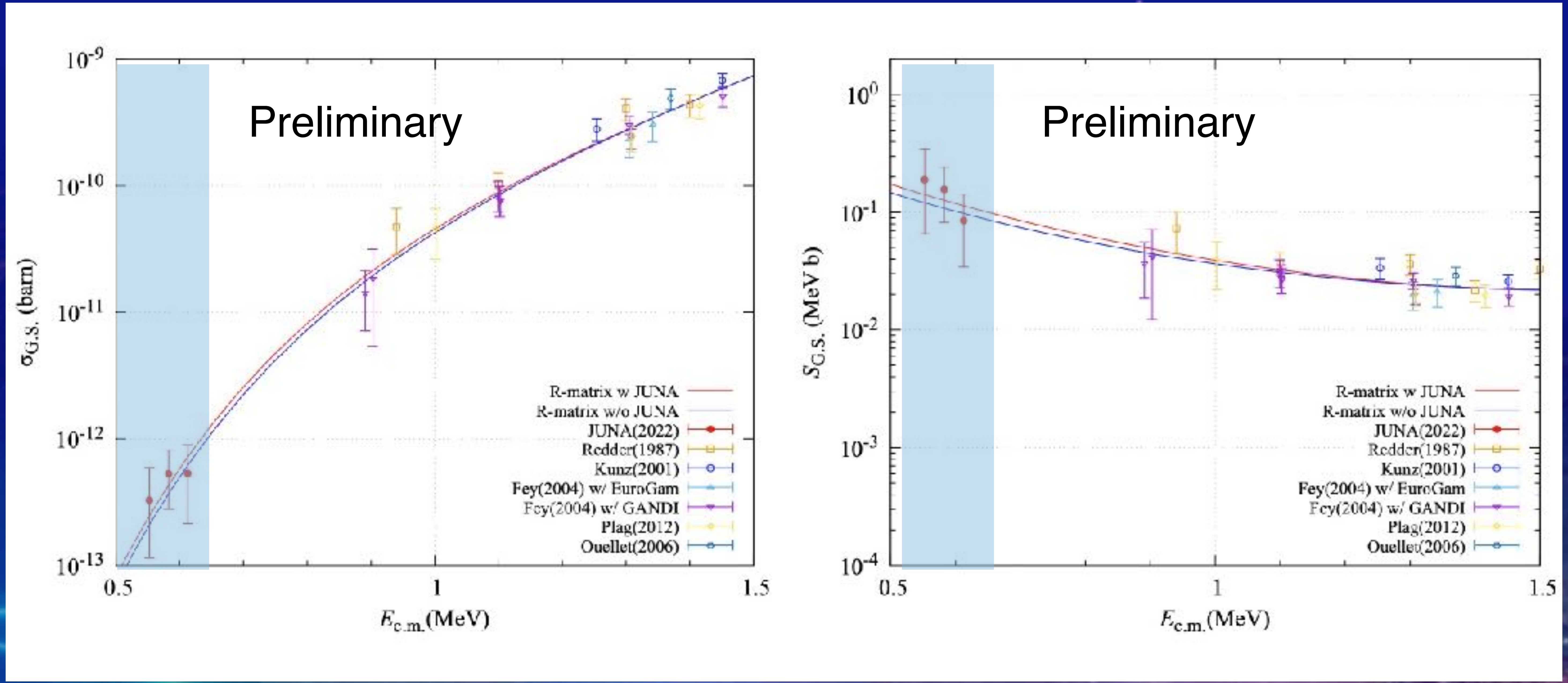
582 keV, 417 C

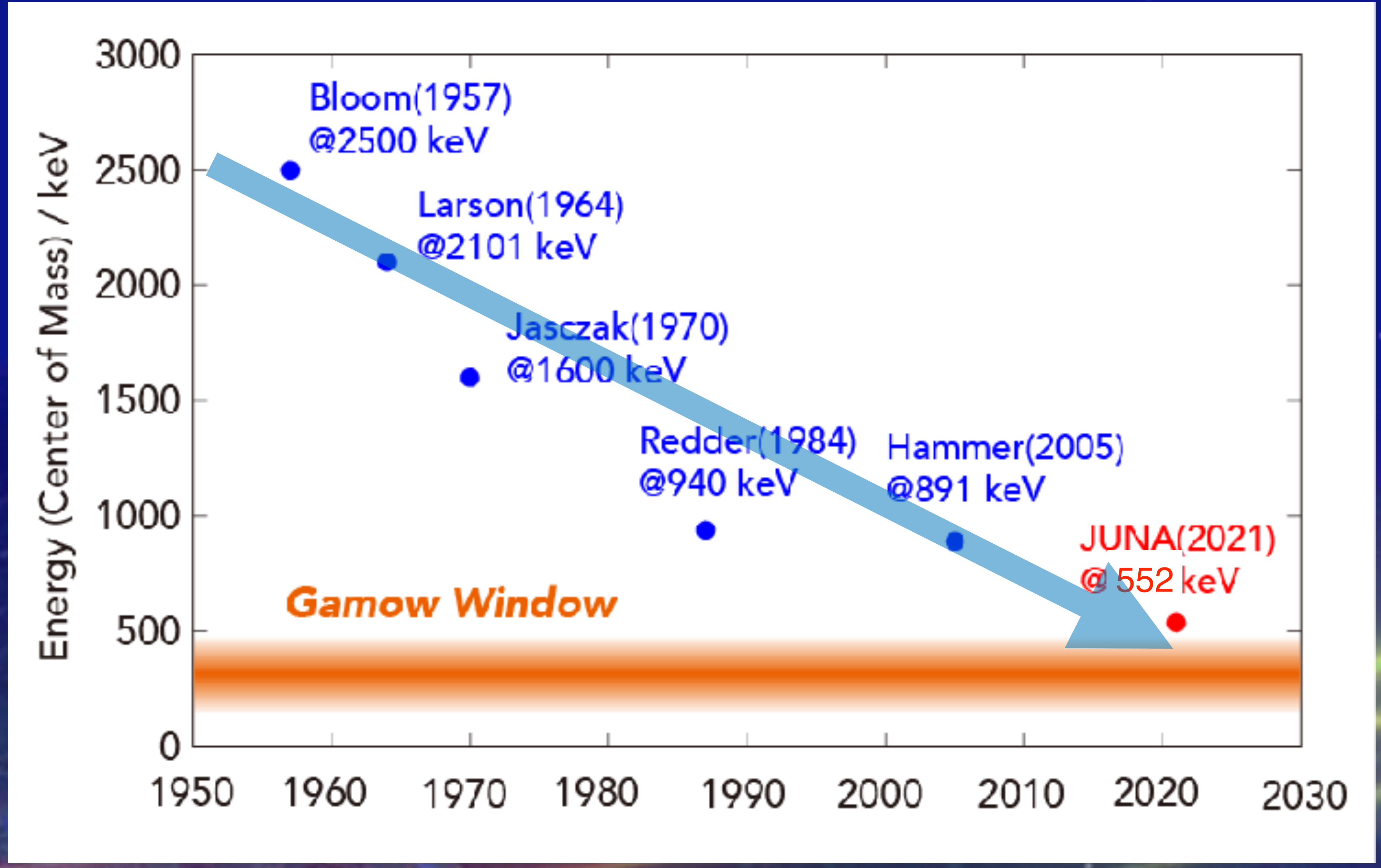


612 keV, 200 C









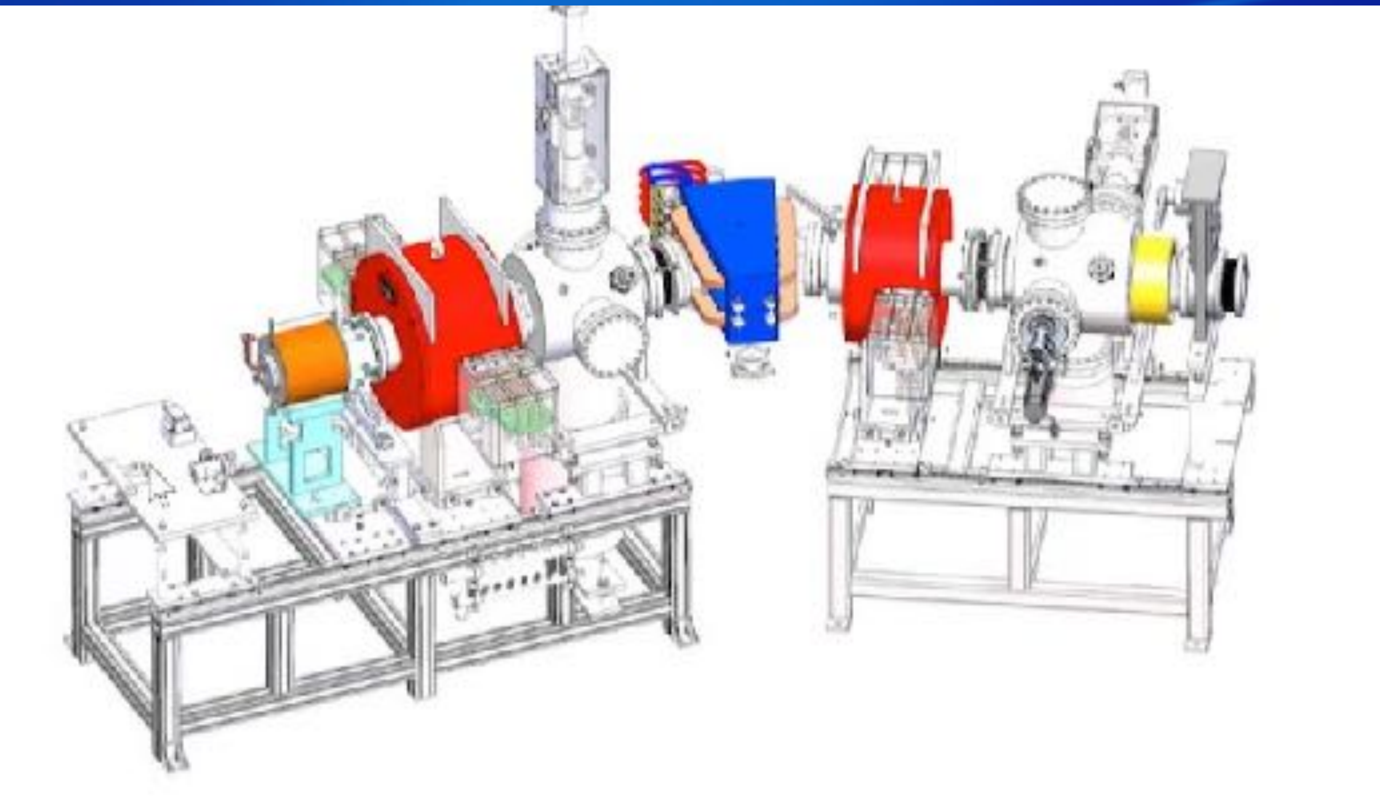
JUNA results from Run-1

Reaction	Quantities	Best data before	JUNA data	Publication
Holy grail $^{12}C(\alpha,\gamma)^{16}O$	Lowest energy/keV	891	**552**	**In preparation**
	Cross section/b	10^{-11}	**10^{-12}**	
Neutron source $^{13}C(\alpha,n)^{16}O$	Energy range/keV	230-300	**240-1900**	**PRL 129(2022)132701**
	s-process	50%	**20%**	
^{26}Al abundance $^{25}Mg(p,\gamma)^{26}Al$	Uncertainty	21%	**8%**	**Science Bulletin 67(2022)2 cover paper**
F abundance $^{19}F(p,\alpha\gamma)^{16}O$	Lowest energy/keV	189	**72**	**PRL 127(2021)152702 Editor suggestion**
	Uncertainty	80%	**5%**	
Ne isotope ratio $^{18}O(\alpha,\gamma)^{22}Ne$	Uncertainty	472±18 keV	**474.1±1.1 keV**	**PRL 130(2023)092701**
CNO breakout $^{19}F(p,\gamma)^{20}Ne$	Lowest energy/keV	300	**200**	**Nature 610(2022)656 news and views**

Recent development in underground nuclear astrophysics

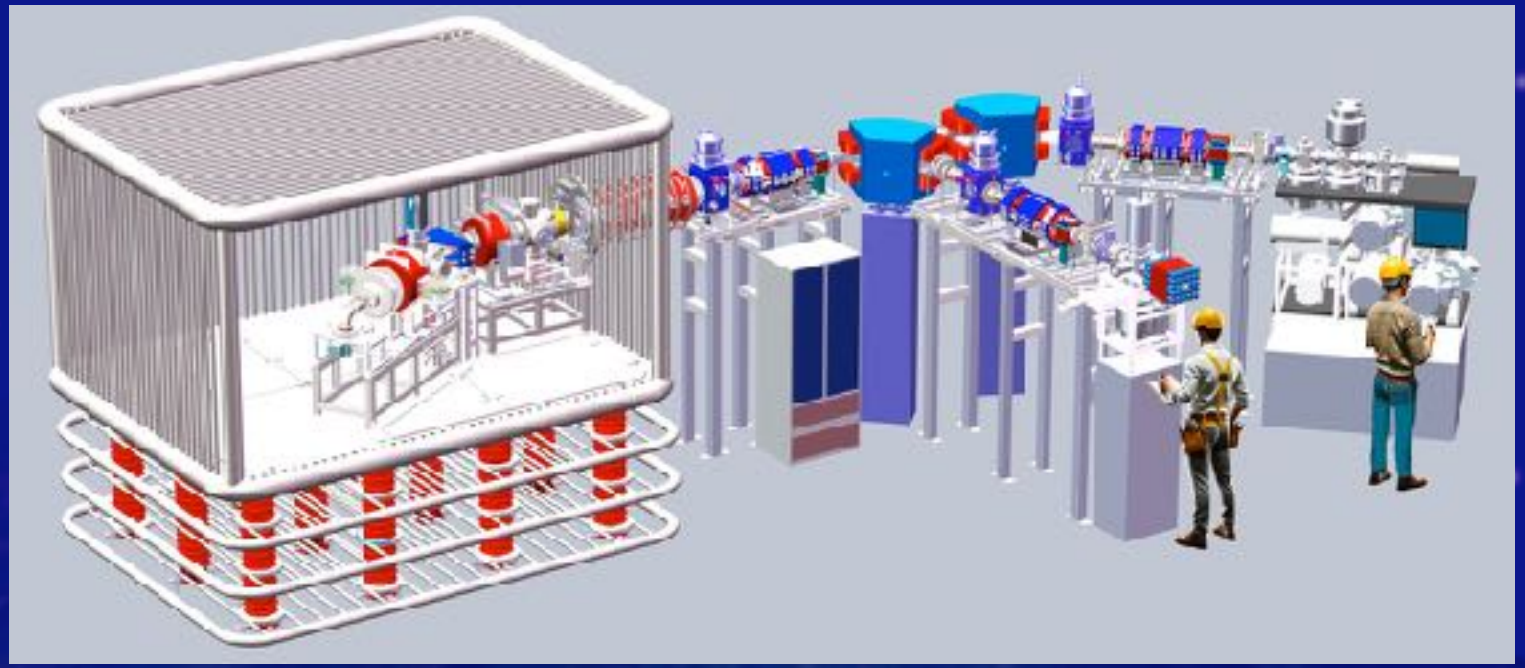
Green lights for JUNA Run-2

- CJPL IAC highly recommend JUNA and gave green lights for next 5 years and support for A1 fine tuning
- High density radiation hard target and gas target
- High resolution and efficiency neutron and gamma detector



Improved ion source

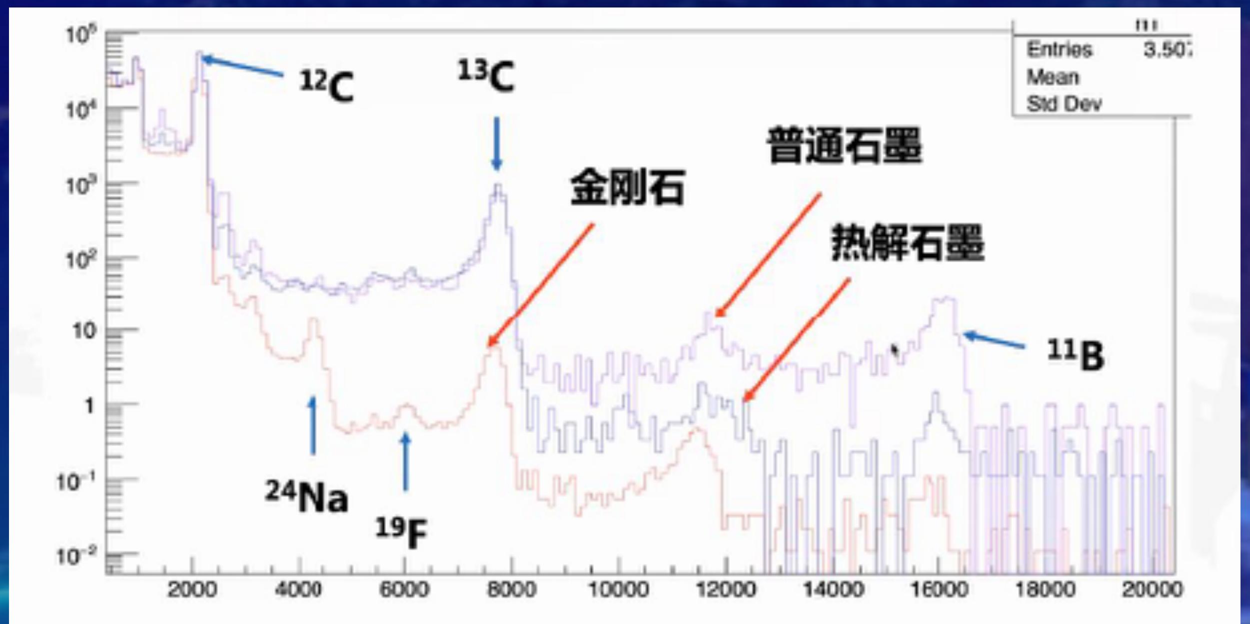
Run-2 kickoff meeting April 24, 2024



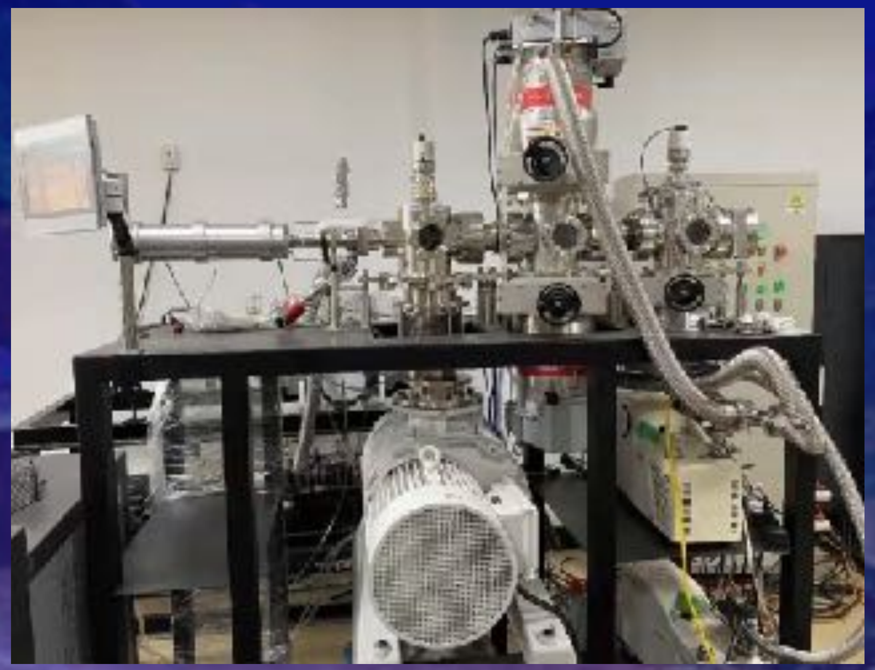
floor plan for JUNA Run-2

CJPL-II A1 for JUNA: March, 2024

CJPL-II A1 for JUNA: October, 2024



test result for diamond target

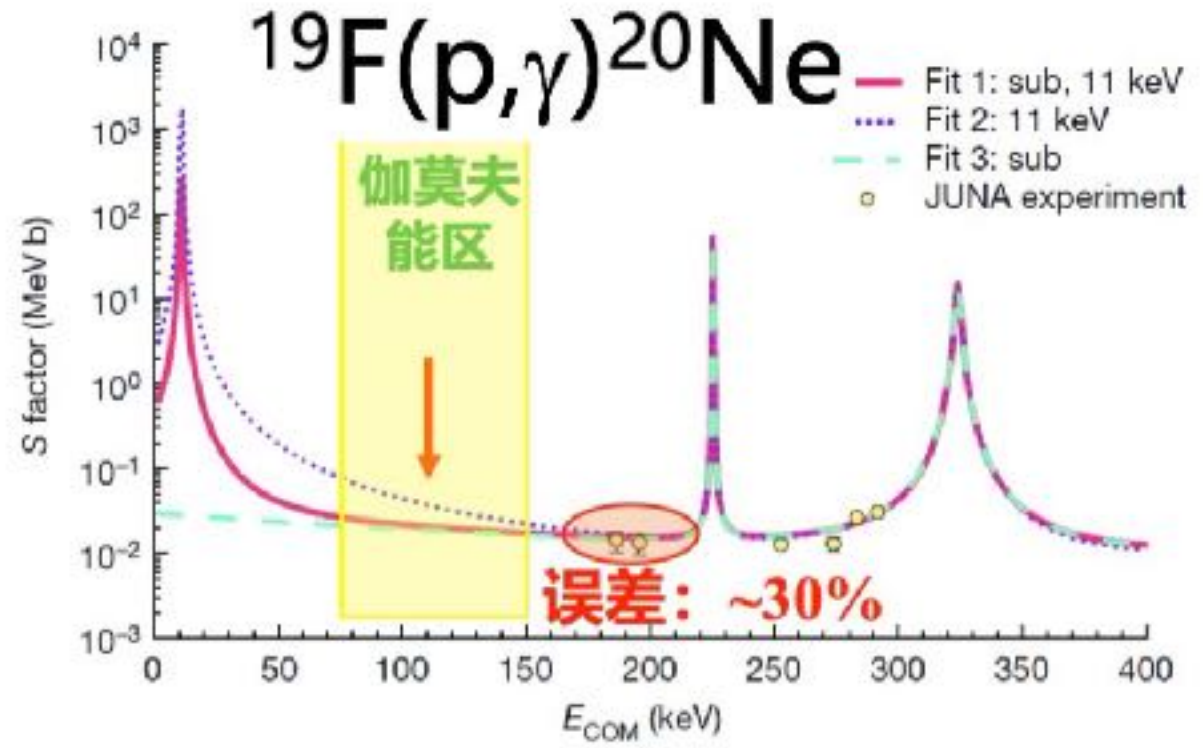


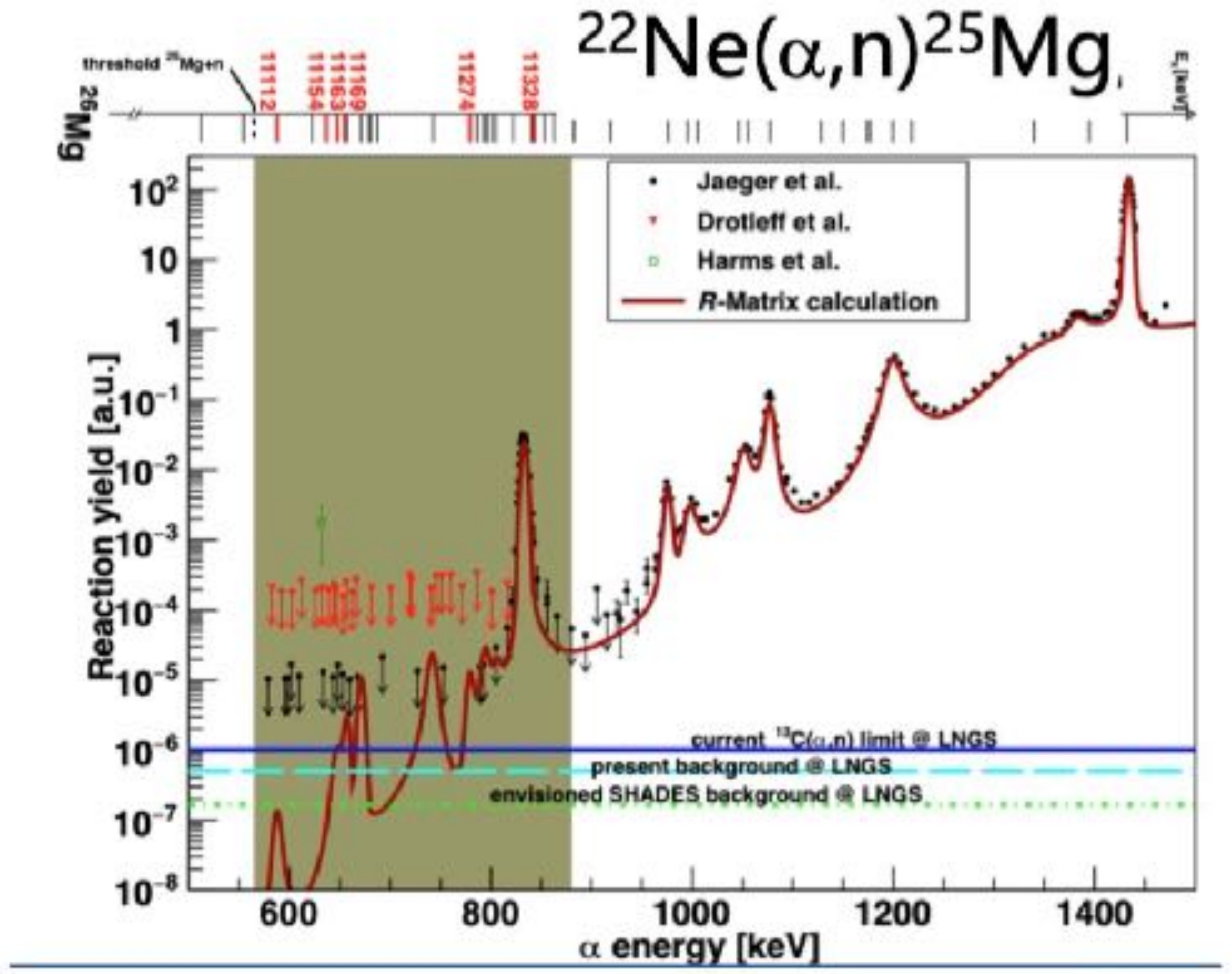
gas jet target

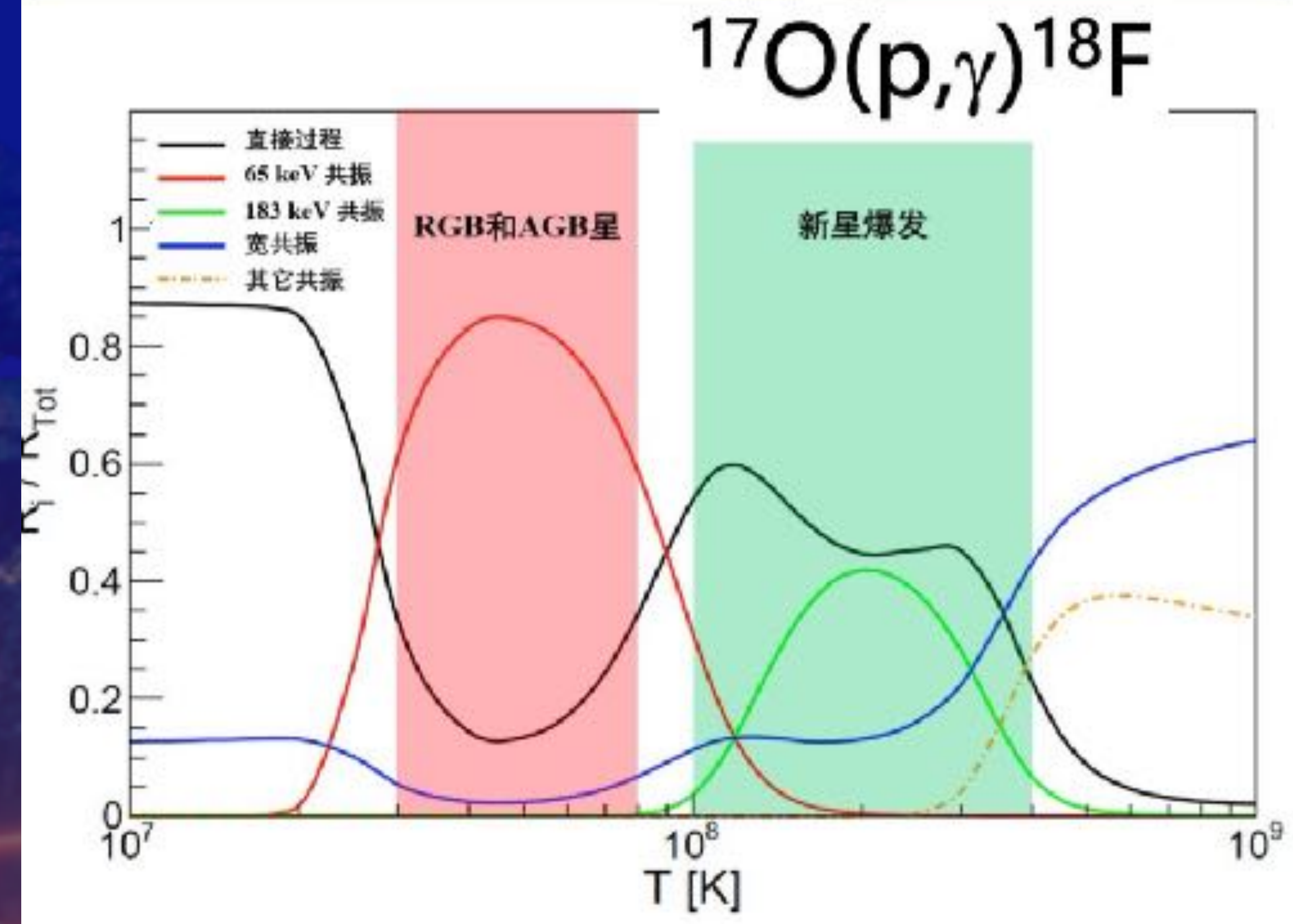
enlarged BGO array

JUNA Run-2 Exp.: 2024-2026

- From Run-1 to lower energy
  - $^{12}C(\alpha,\gamma)^{16}O$, precision from 1s to 3s
  - $^{13}C(\alpha,n)^{16}O$, full coverage of s-process
  - $^{19}F(p,\gamma)^{20}Ne$, cover 80-150 keV with high precision
  - $^{14}N(p,\gamma)^{15}O$, Solar neutrino
- Using gas target
  - $^{22}Ne(\alpha,n)^{25}Mg$, weak s-process n source
  - $^{3}He(\alpha,\gamma)^{7}Be$, solar neutron, Li problem, 80-380 keV
- Others
  - $^{17}O(p,\alpha)^{14}N$, ^{17}O over abundance
  - $^{17}O(p,\gamma)^{18}F$, H isotope ratio，65 keV resonance
  - $^{26}Al(p,\gamma)^{27}Si$, BRIF ISOL ^{26}Al implantation target
  - $^{10}B(\alpha,n)^{13}N$, search for new resonance







JUNA and Super JUNA coverage

H burning	He burning	N source	C\O burning
$^{7}Be(p,\gamma)^{8}B$	$^{12}C(\alpha,\gamma)^{16}O$	$^{13}C(\alpha,n)^{16}O$	$^{12}C+^{12}C$
$^{12}C(p,\gamma)^{13}N$	$^{16}O(\alpha,\gamma)^{20}Ne$	$^{22}Ne(\alpha,n)^{25}Mg$	$^{12}C+^{16}O$
$^{14}N(p,\gamma)^{15}O$	$^{20}Ne(\alpha,\gamma)^{24}Mg$	$^{25}Mg(\alpha,n)^{28}Si$	$^{16}O+^{16}O$
$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$	$^{18}O(\alpha,\gamma)^{22}Ne$	$^{26}Mg(\alpha,n)^{29}Si$	**γ astronomy**
$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$	$^{22}Ne(\alpha,\gamma)^{26}Mg$		$^{25}Mg(p,\gamma)^{26}Al$
$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$	$^{24}Mg(\alpha,\gamma)^{28}Si$		$^{26}Al(p,\gamma)^{27}Si$
$^{19}F(p,\alpha)^{16}O$			
$^{3}He(\alpha,\gamma)^{7}Be$			

JUNA achieved

JUNA and Super JUNA proposed

锦屏深地核天体物理实验
Jinping Underground Nuclear Astrophysics Experiment
JUNA
400 kV
1-10 mA
800 kV
20 mA
Super-JUNA
25
20
15
10
5
0
0.1
1
I(4He) / mA
E(4He) / MeV
12C(α,γ)16O
Super JUNA
JUNA
22Ne(α,n)25Mg
13C(α,n)16O
Intensity
Super JUNA
JUNA
LUNA
LUNA MV
Energy
JUNA
Super JUNA

2024-2030 JUNA and Super-JUNA

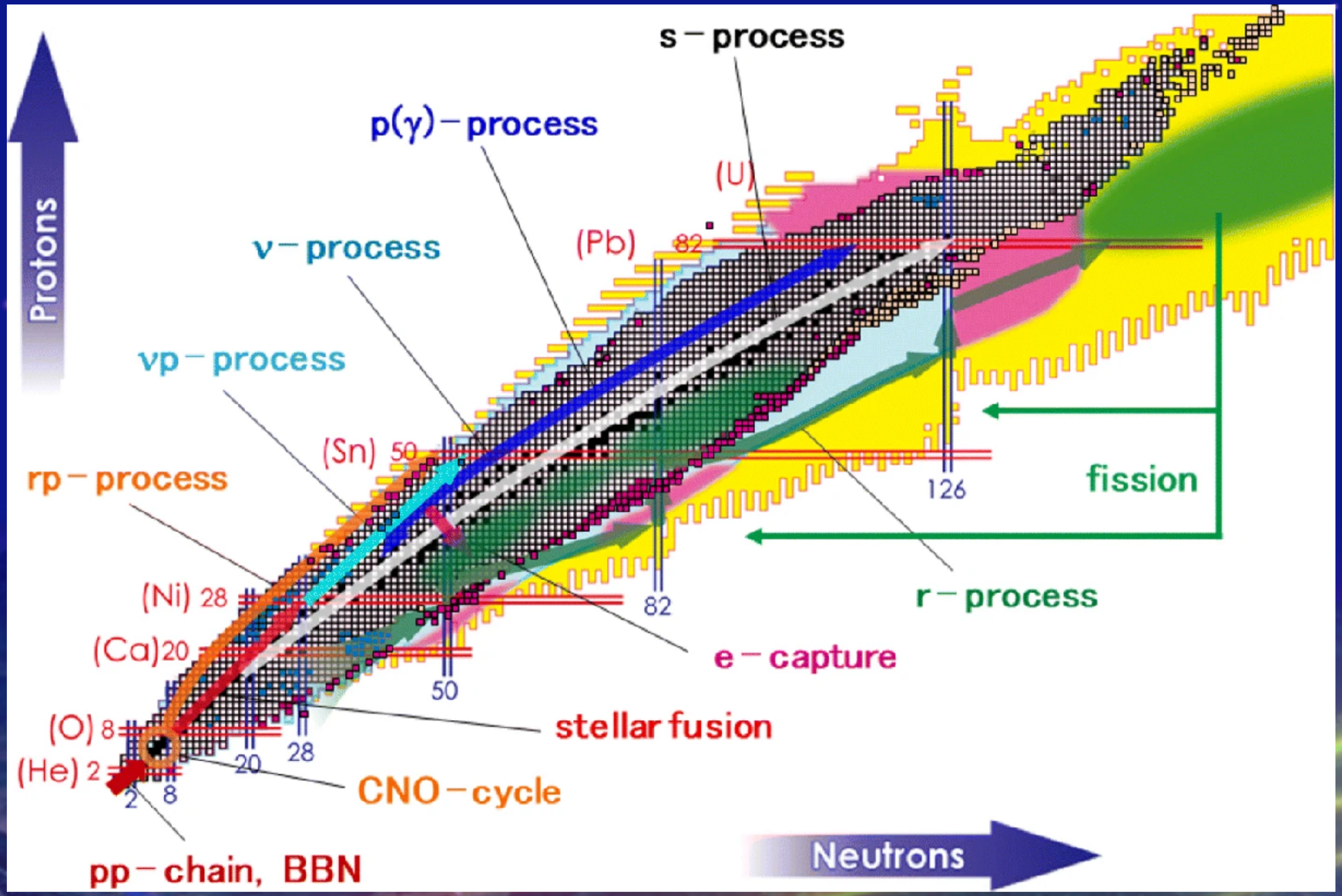
	JUNA	Super-JUNA	JUNA Exp.	Super-JUNA Exp.
2024	ground test run Run-2 exp.	R&D	(p,g)	
2025	Run-2	Ground test and fabrication	(a,n) and (a,g) gas target	
2026	Run-2	Setup and test	cont.	
2027	Upgrade Run-3 exp.	Test run Run-4 exp.	Test run	(p,g) test
2028	Run-3	Run-4	cont.	(a,g), (a,n) Exp.
2029	Run-3	Run-4	cont.	(a,g), (a,n) Exp.
2030	Run-3	Run-4	cont.	(a,g), (a,n) Exp.

Future study of nuclear astrophysics

- Underground, LUNA, CASPAR, JUNA,…
- Explosive process, RIBLL, RIBF, FRIB, TRIUMF, BRIF,…
- Mass, ESR, CSR, RI-Ring,…
- Decay, RIBF, RIBLL, BRIF, ISOLDE,…
- Neutron capture, CERN n-tof, CSNS, ….
- Novel approach, SLEGES, Laser facilities,…
- Theory, simulation, …
- Space based, gamma observatory,…

Future: FRIB, RAON, FAIR, HIAF, ELI-NP, BISOL,…, will open up new opportunities!

Progress in nuclear astrophysics of east and southeast Asia…
Toshitaka Kajino*, …, WPL*, …, Xiaodong Tang*,… et al., AAPPSBulletin (2021) 31:18



JUNA summary

- JUNA is an advanced deep astrophysics platform. China, follow Italy and United States and others, started to carry out direct measurement of key astrophysical reactions, which leading the nuclear astrophysics to the stage of precision numerical simulation stage

- JUNA accurately measured key nuclear astrophysical reactions, compared with previous experiment, beam intensity is higher, detector efficiency, target exposure, sensitivity and energy coverage are greatly improved

- From JUNA Run-1, Gamma-ray astronomical reaction has reached the highest precision, and the astrophysical holy grail reaction has achieved the highest sensitivity, new resonances revealing the origin of heavy element abundance in the oldest stars, and the discrepancies of neutron source reactions was resolved

- JUNA Run-2 will start by the end of 2024, welcome to join JUNA collaboration and submit your proposals deep underground!

JUNA Team

Weiping Liu[1], Zhihong Li[1], Jianjun He[2], Xiaodong Tang[2], Gang Lian[1], Zhu An[4], Qinghao Chen[3], Xiongjun Chen[1], Yangping Chen[1], Zhijun Chen[2], Baoqun Cui[1], Xianchao Du[1], Changbo Fu[5], Lin Gan[1], Bing Guo[1], Guozhu He[1], Alexander Heger[6], Suqing Hou[2], Hanxiong Huang[1], Ning Huang[4], Baolu Jia[2], Liyang Jiang[1], Shigeru Kubono[7], Jianmin Li[3], Kuoang Li[2], Tao Li[2], Yunju Li[1], Maria Lugaro[8], Xiaobing Luo[4], Shaobo Ma[2], Dongming Mei[9], Yongzhong Qian[10], Jiuchang Qin[1], Jie Ren[1], Jun Su[1], Liangting Sun[2], Wanpeng Tan[11], Isao Tanihata[12], Peng Wang[4], Shuo Wang[13], Youbao Wang[1], Qi Wu[2], Shiwei Xu[2], Shengquan Yan[1], Litao Yang[3], Xiangqing Yu[2], Qian Yue[3], Sheng Zeng[1], Huanyu Zhang[1], Hui Zhang[3], Liyong Zhang[2], Ningtao Zhang[2], Qiwei Zhang[1], Tao Zhang[5], Xiaopeng Zhang[5], Xuezhen Zhang[2], Zimin Zhang[2], Wei Zhao[3], Zuo Zhao[1], Chao Zhou[1]

[1]China Institute of Atomic Energy, Beijing, China,
[2]Institute of Modern Physics, Lanzhou, China
[3]Tsinghua University, Beijing, China,
[4]Sichuan University, Chengdu, China
[5]Shanghai Jiaotong University, Shanghai, China,
[6]Monash University, Melbourne, Victoria, Australia,
[7]RIKEN, Institute of Physical and Chemical Research, Wako, Japan,
[8]Konkoly Observatory of the Hungarian Academy of Sciences, Hungary,
[9]South Dakota State University, Brookings, South Dakota, US
[10]Minnesota University, Minneapolis and Saint Paul, Minnesota, US,
[11]University of Notre Dame, Notre Dame, Indiana, US,
[12]Osaka University, Suita, Osaka, Japan
[13]Shangdong University, Beihai , China


JUNA @CIAE 2019


JUNA IAC by M. Wiescher