JUNA

Progress of nuclear astrophysics in China， Beijing facilities and JUNA project

Weiping Liu
ANPhA symposium Oct. 23 - 24, 2015, Kyeongju
China Institute of Atomic Energy (CIAE)
Beijing, China
wpliu@ciae.ac.cn

What will be talk

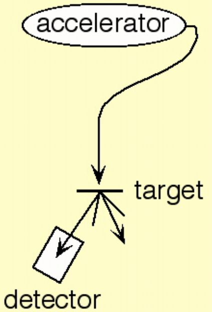
- Nuclear astrophysics now in China
- RI facilities in Beijing
- Underground JUNA project

NA framework

JUNA

Role of Nuclear Science in Studies of the Stars

Nuclear Measurements



$\sigma \sim$ yield of fusion reactions

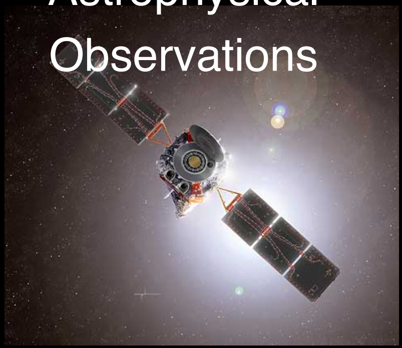
Nuclear Theory

nuclear properties
nuclei in a plasma
reaction rate formalism

Astrophysics Theory

Stellar Structure
Stellar Evolution
Hydrodynamics

Astrophysical Observations

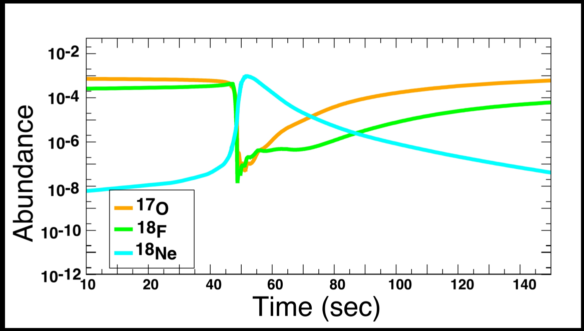


Thermonuclear Reaction Rates

Goal: make simulation accurately represent working of stars

Astrophysics Computer Simulation

Repeat to improve models

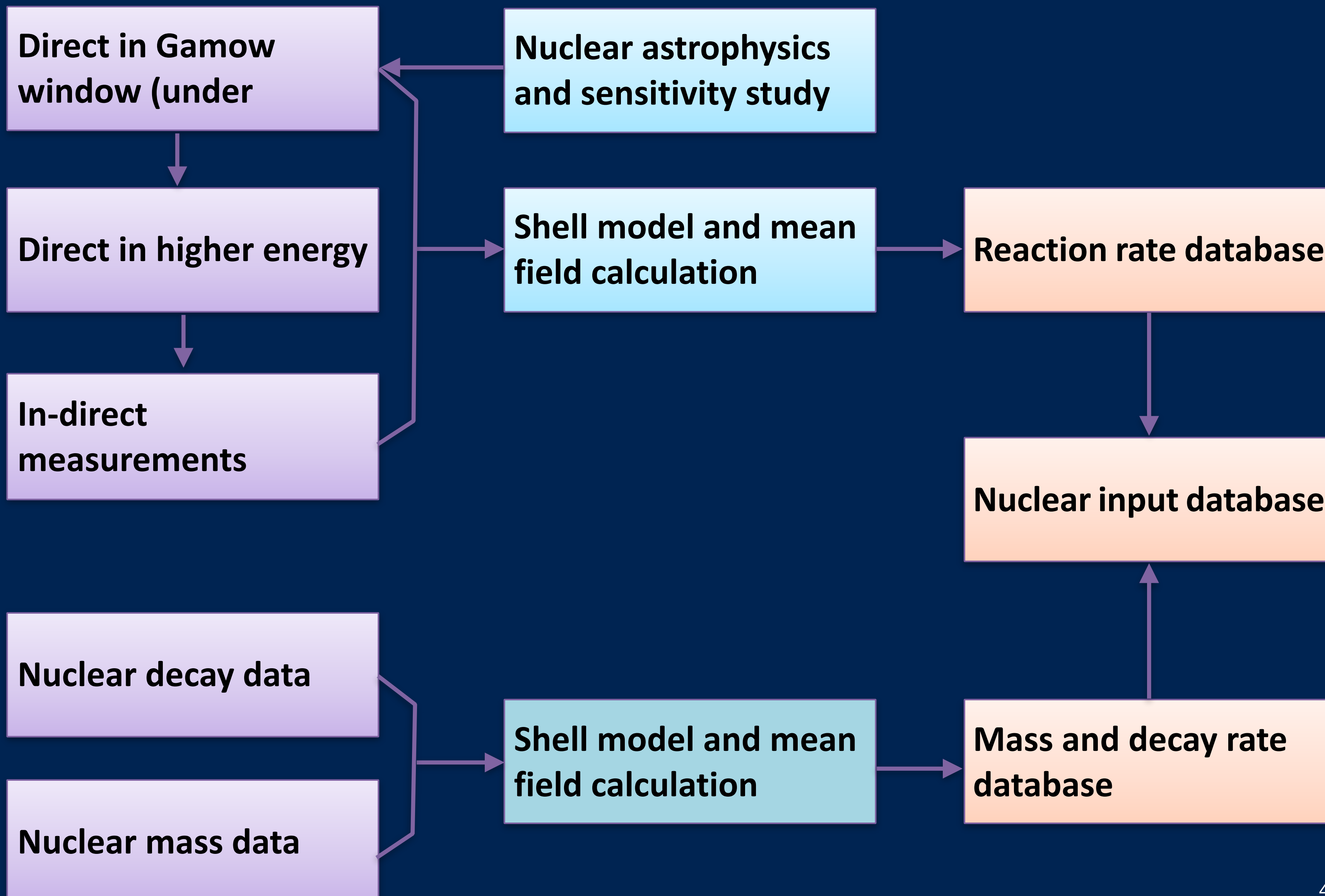


Astrophysical Observations

Predictions

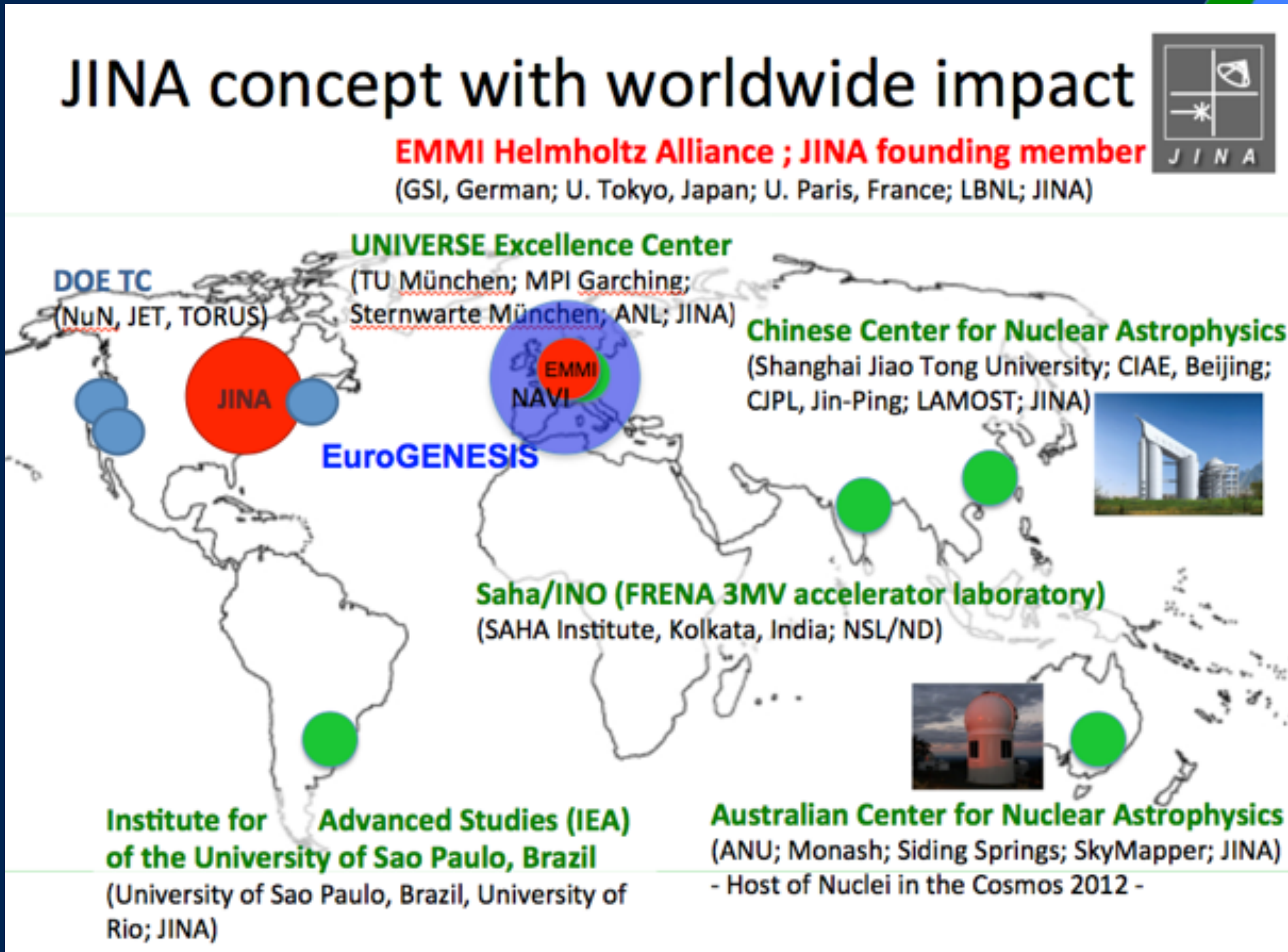
From Michael Smith

Methodology



World wide map

JUNA



From Michael Wiescher

Milestones of NA in China

JUNA

1993, first RI beam line in China

2005, in-direct extended to $^{8}Li(n,\gamma)^{9}Li$

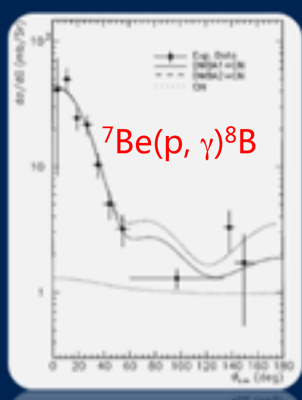
2011, NSFC group fund for NA

2013, direct $^{6}Li(p,\gamma)^{7}Be$ in PLB

2015, NSFC major fund for JUNA

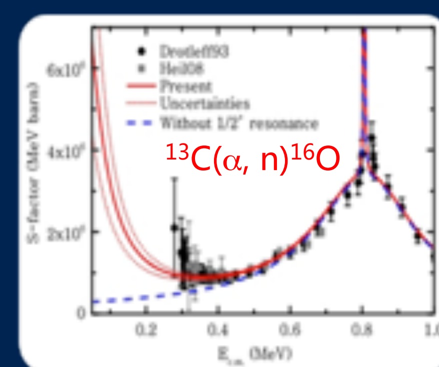
1993 | 1996 | 2005 | 2010 | 2012 | 2014 | 2015

1996, $^{7}Be(p,\gamma)^{8}B$ in-direct in PRL

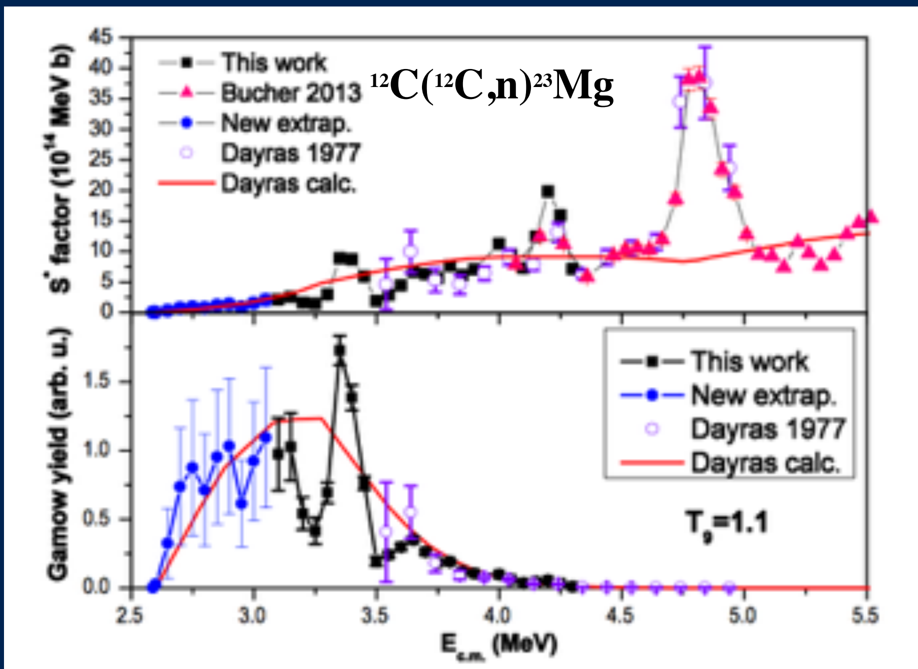


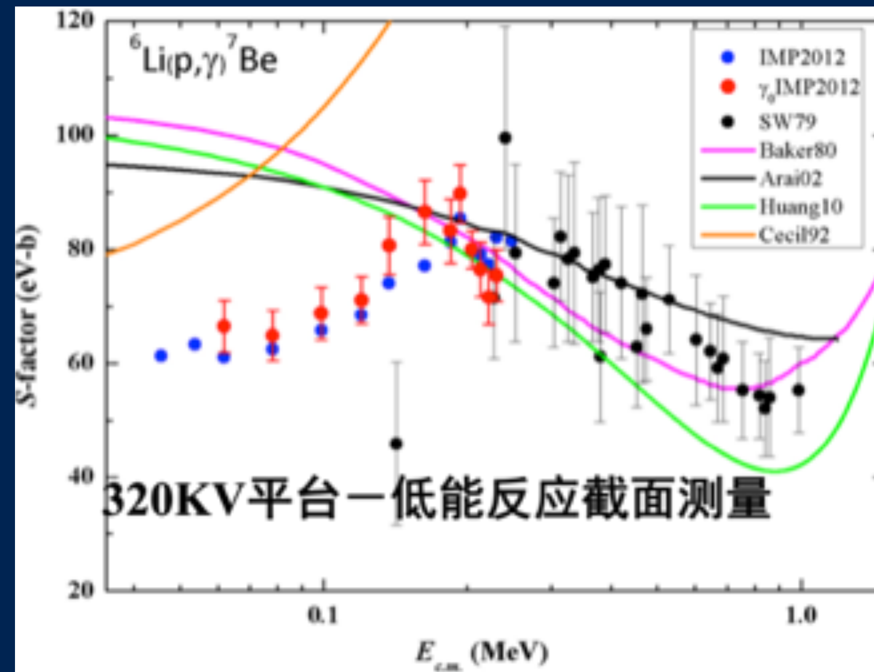
2011, rp mass PRL, APJ

2012, $^{13}C(\alpha,n)^{16}O$ in-direct in APJ



Direct measurement





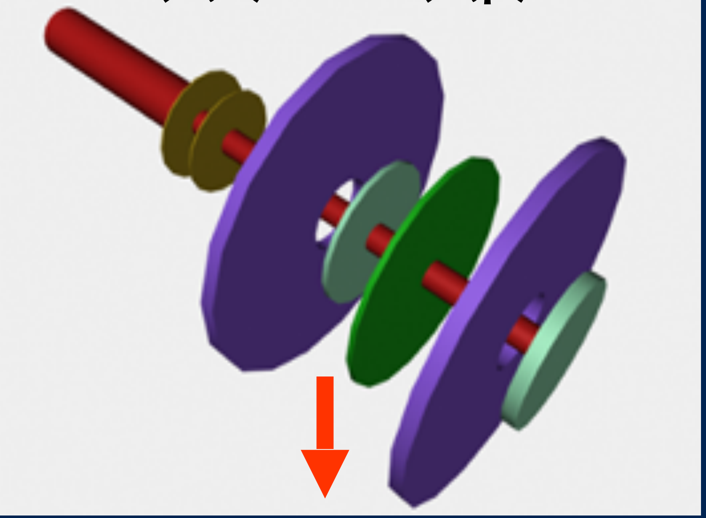
B. Bucher, X. D. Tang* et al., NP and IMP, PRL 114(2015)251102

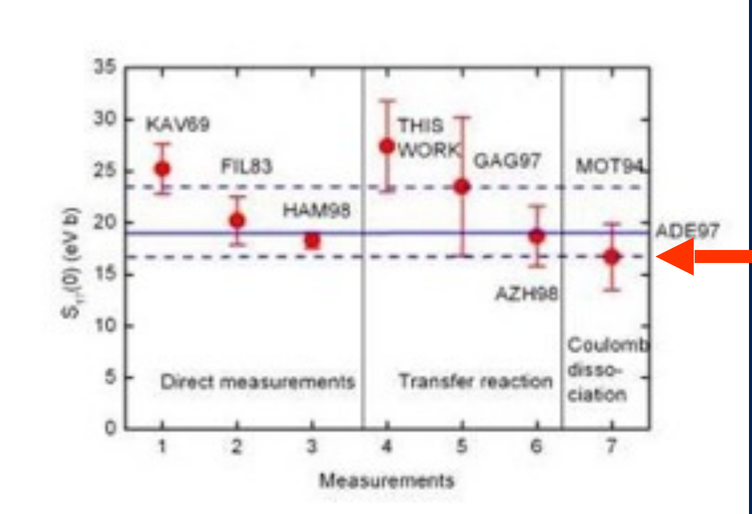
J.J. He, et al., PL B 725 (2013) 287

Indirect measurement

X. X. Bai et al., NP A588(1995)273c
W. P. Liu et al., NIM B204(2003)62

(d,n) and (d,p)





^{7}Be(p, γ)^{8}B S-factor

W.P. Liu et al., CIAE, PRL77(1996)611

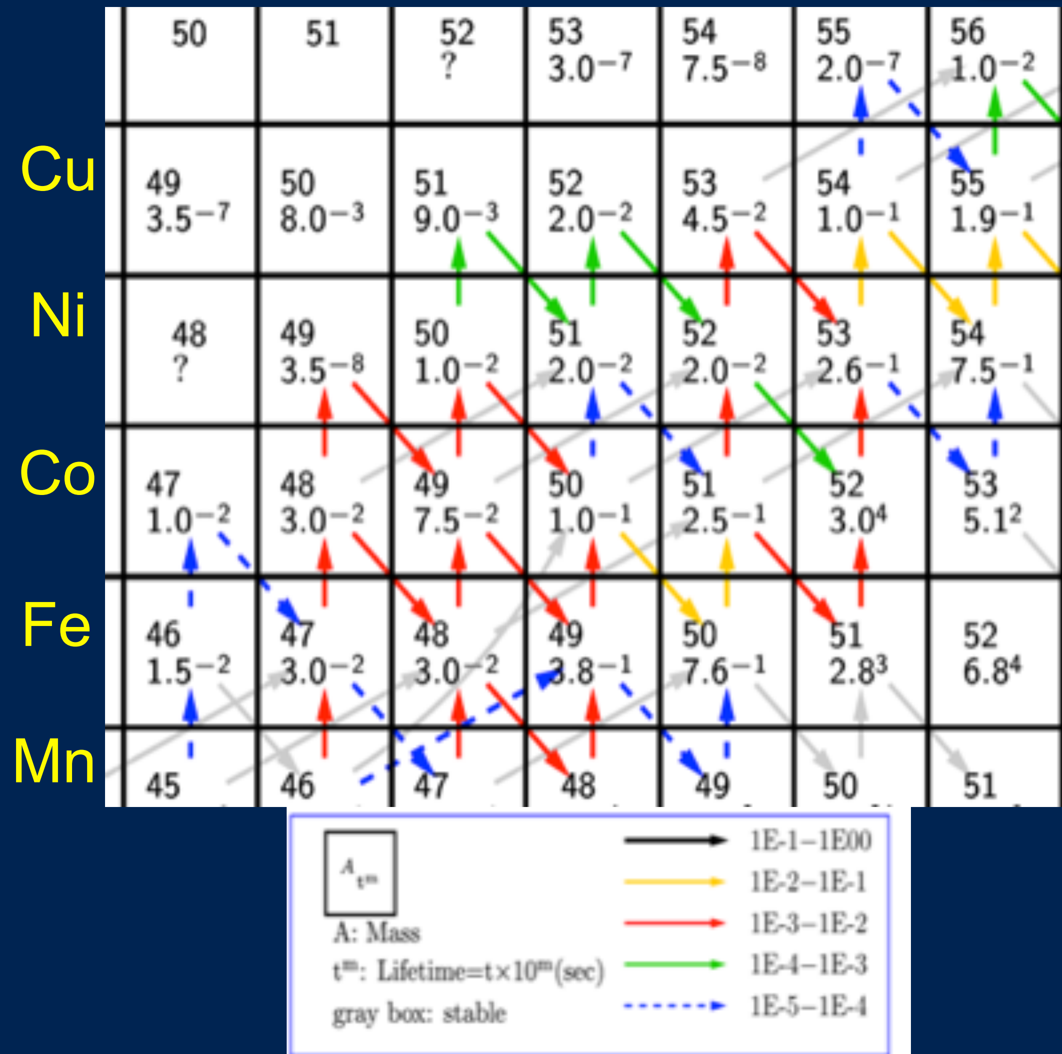
$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} - \left(\frac{d\sigma}{d\Omega}\right)_{CN} = \sum_{j_i j_f} (C^{d}_{l_i j_i})^2 (C^{^{12}N}_{l_f j_f})^2 \frac{d\sigma^{DW}_{l_f j_f l_i j_i}/d\Omega}{b^2_{l_i j_i} b^2_{l_f j_f}},$$

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

ANC method

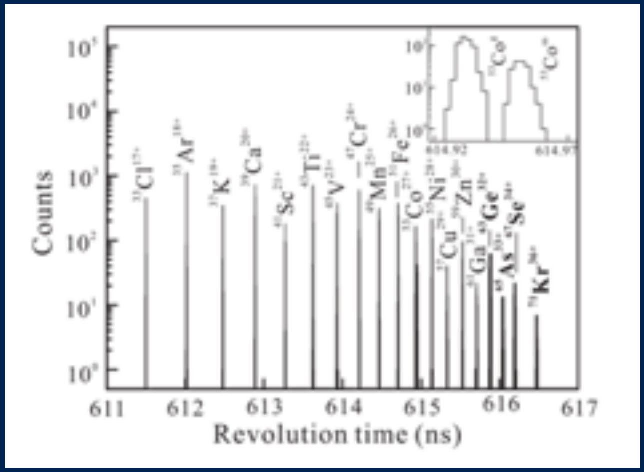
rp process decay

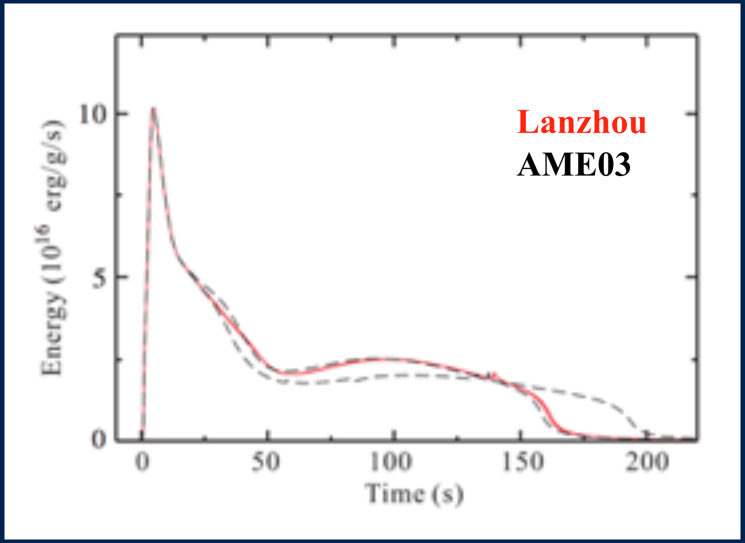
Isotope	$T_{1/2}$(ms)	
	Present Work	NNDC
^{53}Ni	**52±5**	55±0.7
^{54}Ni	**111±6**	104±7
^{52}Co	**108±4**	115±23
^{53}Co	**248±12**	240±9[a] 247±12[b]
^{51}Fe	**298±5**	305±5
^{50}Mn	**286±7**	283.3±0.8

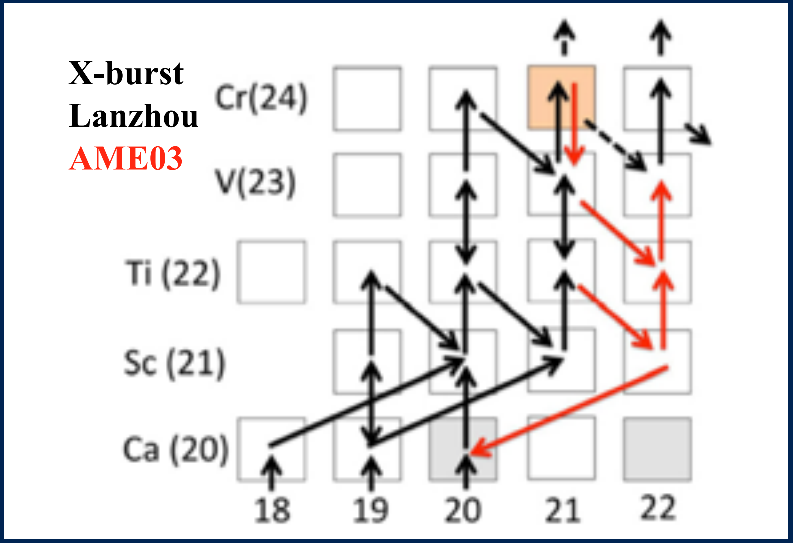


J. su et al., CIAE, Phys. Rev. C 87 ,024312 (2013)

Mass in CSR Lanzhou

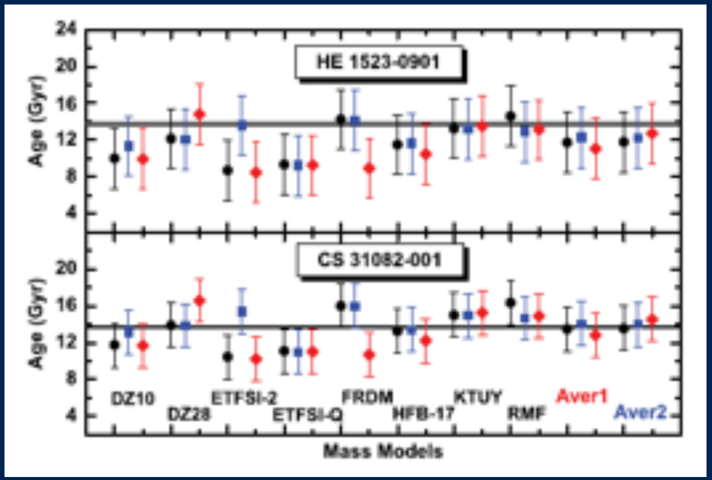




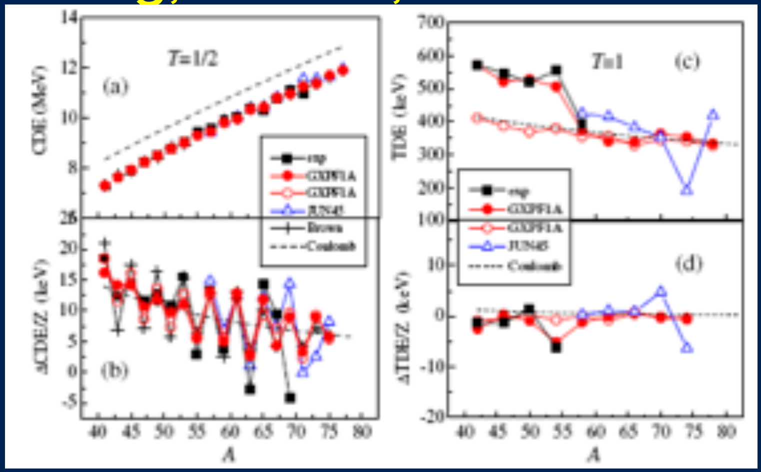


X. L. Tu et al., PRL106(2011)102501; X. L. Yan et al., ApJL 766(2013)8, IMP

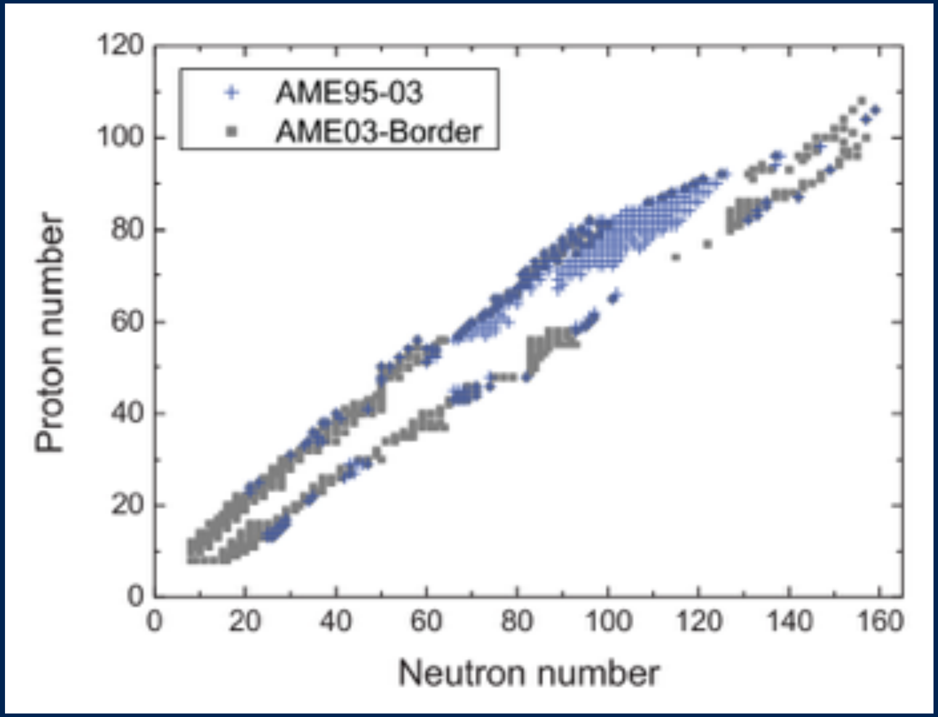
Theory



Z. M. Niu, B. H. Sun, J. Meng, PRC 80, 065806

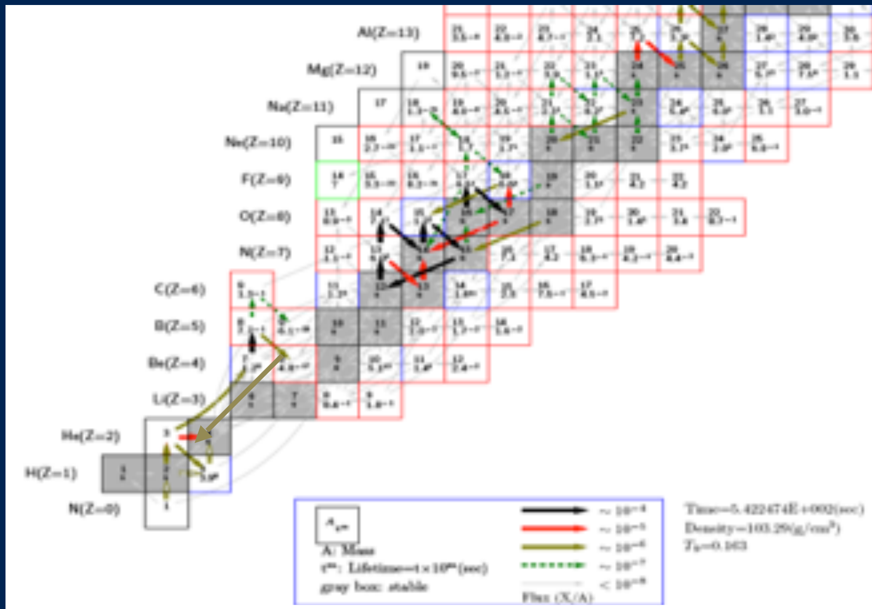


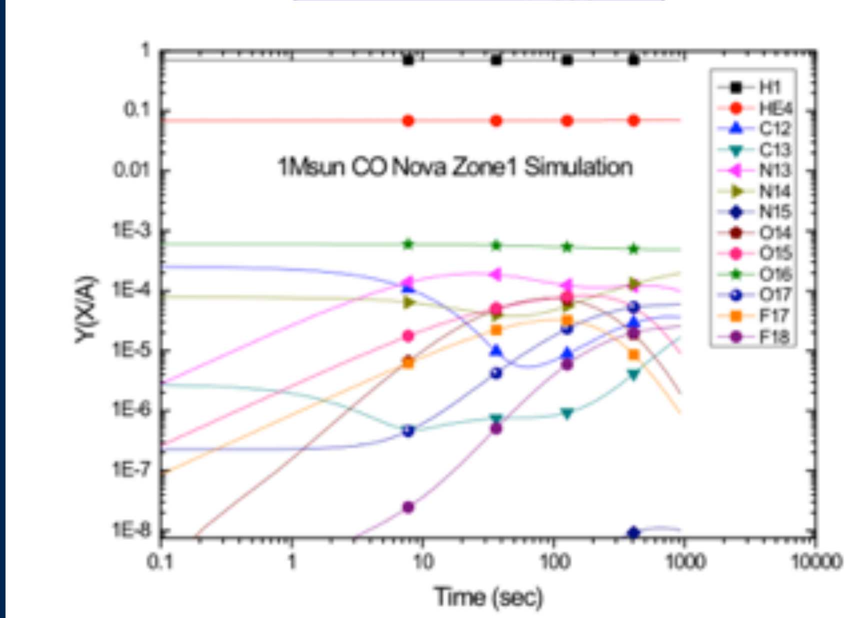
K. Kaneko, Y. Sun, et al.,
PRL 110, 172505 (2013)



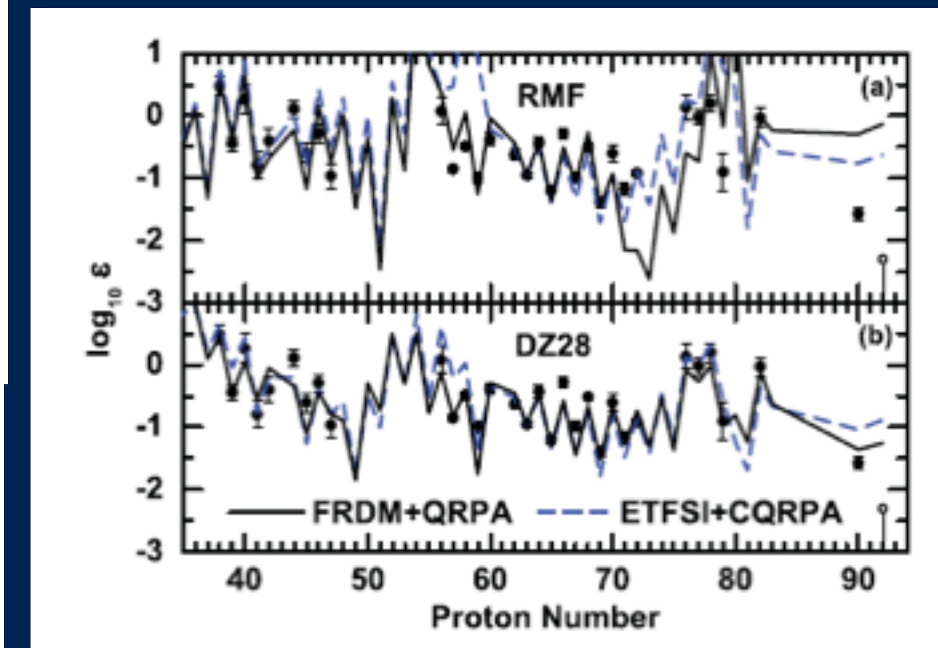
N. Wang, mass, PRC84, 051303R(2011)

Network calc



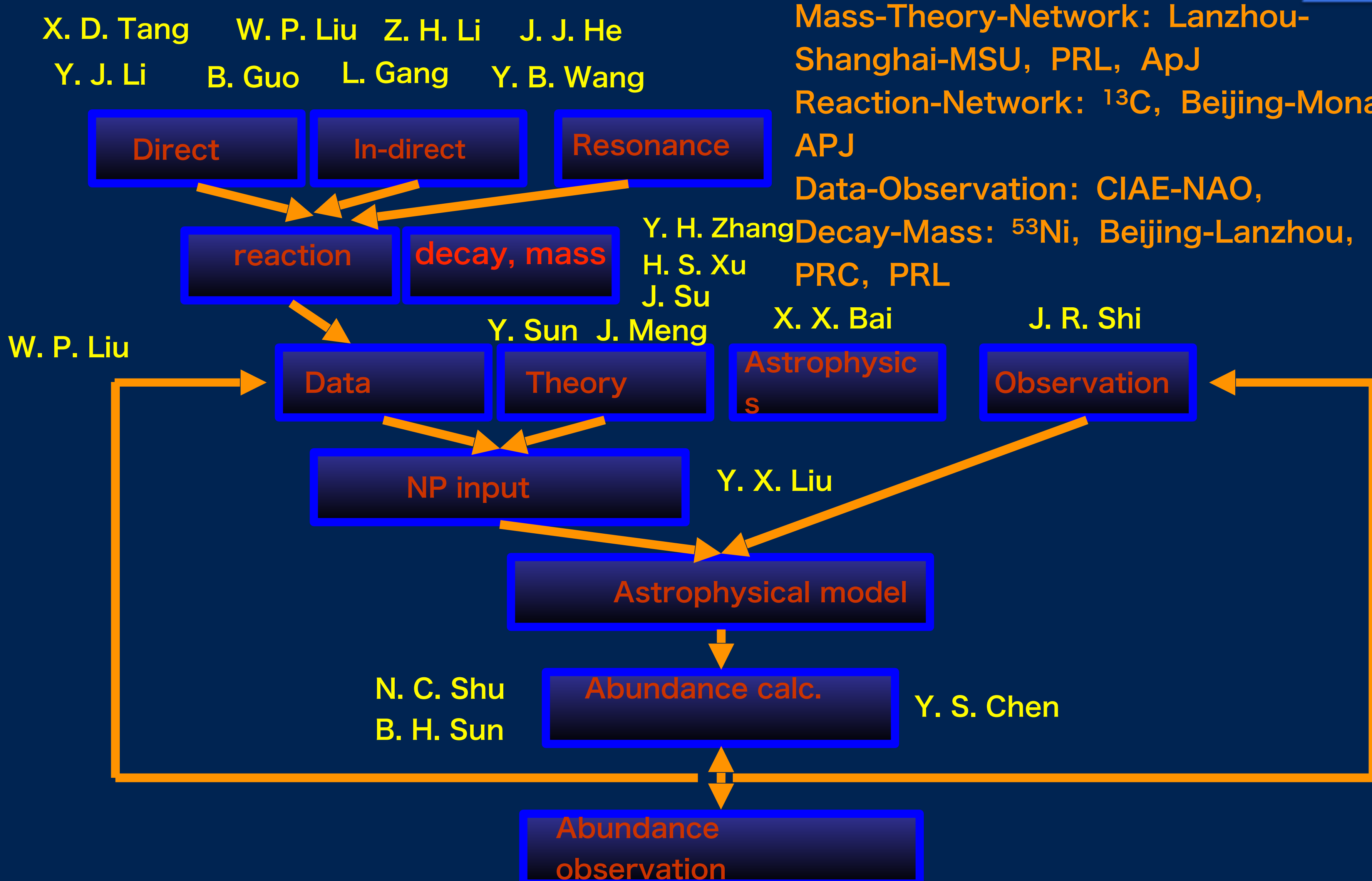


N. C. Shu, Y. S. Chen et al., NPA 758 (2005) 419c



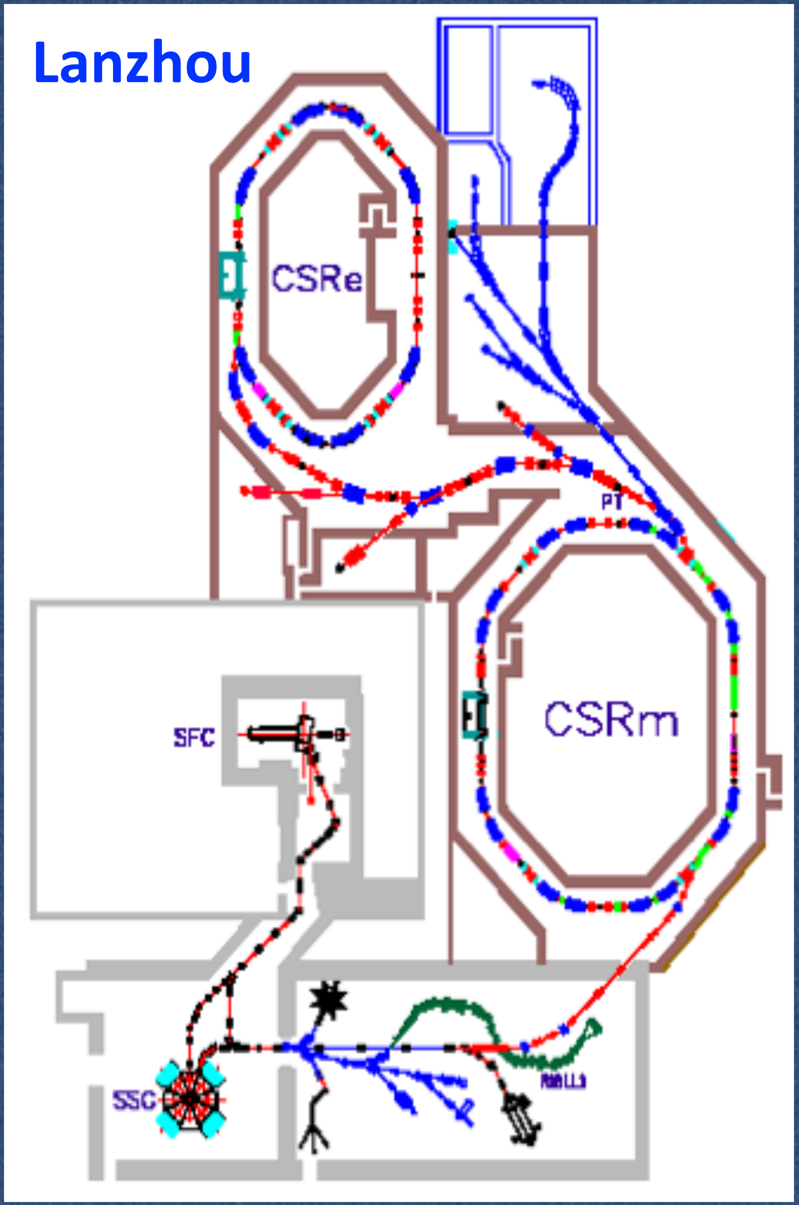
Z. M. Niu, B. H. Sun, J. Meng, PRC 80, 065806 (2009)

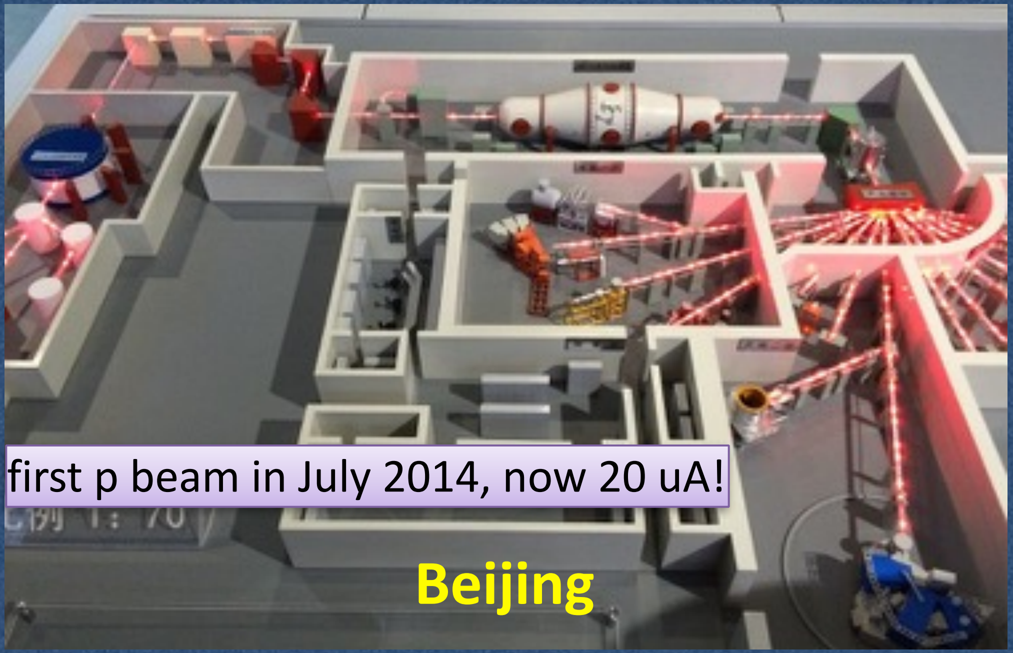
Full coverage of NA



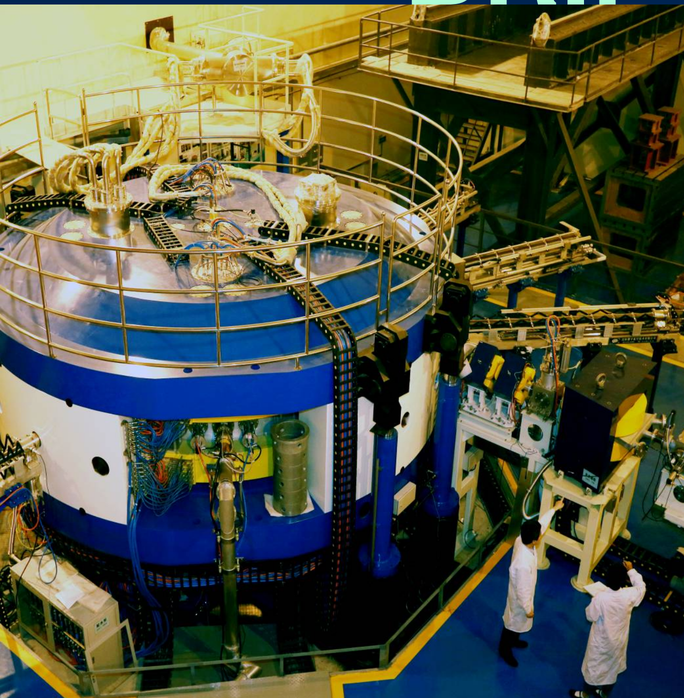
Interaction
Mass-Theory-Network：Lanzhou-Shanghai-MSU，PRL，ApJ
Reaction-Network：^{13}C，Beijing-Monash, APJ
Data-Observation：CIAE-NAO,
Decay-Mass：^{53}Ni，Beijing-Lanzhou, PRC，PRL

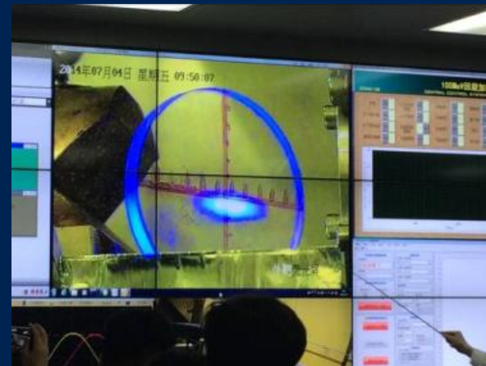
Big platforms in China

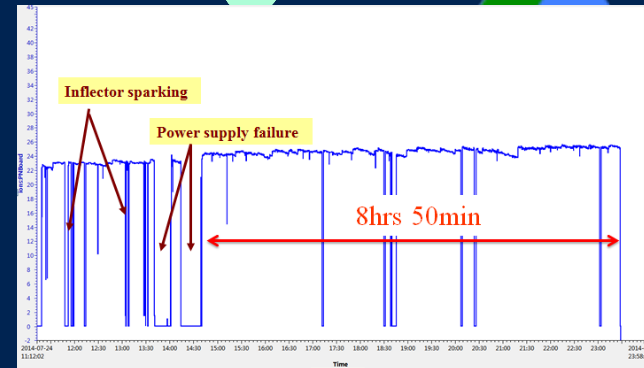




BRIF commissioning

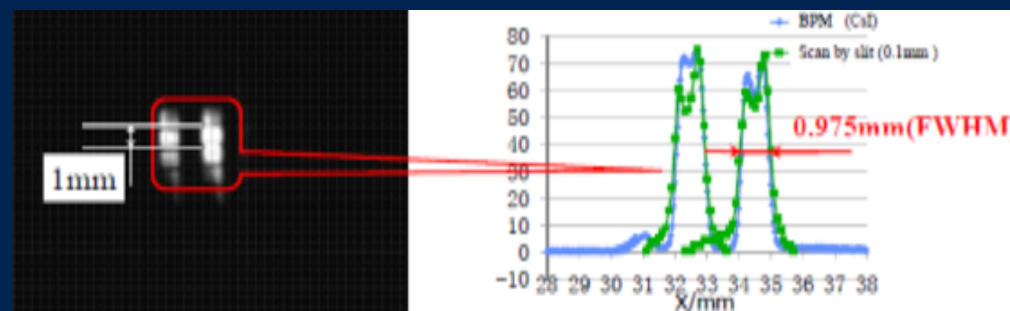




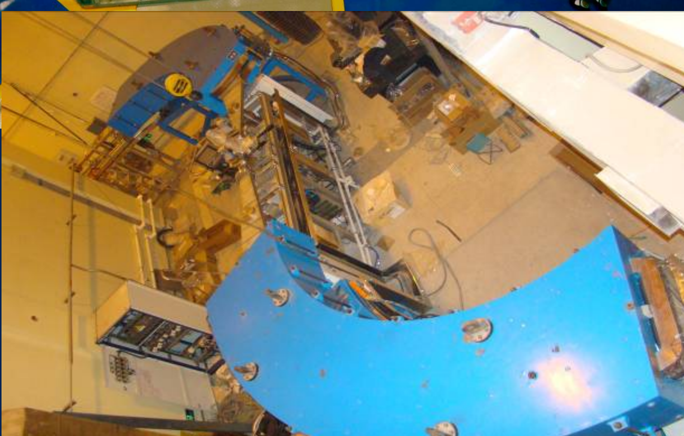


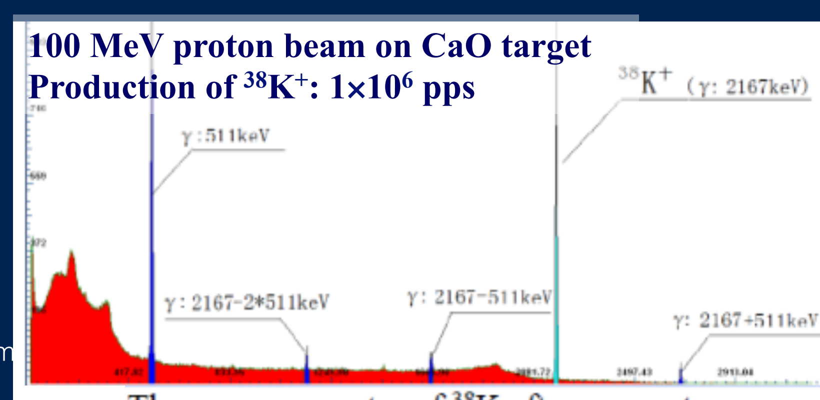
First Beam July 4, 2014

12 hours running with current of 23 μA July 25, 2014

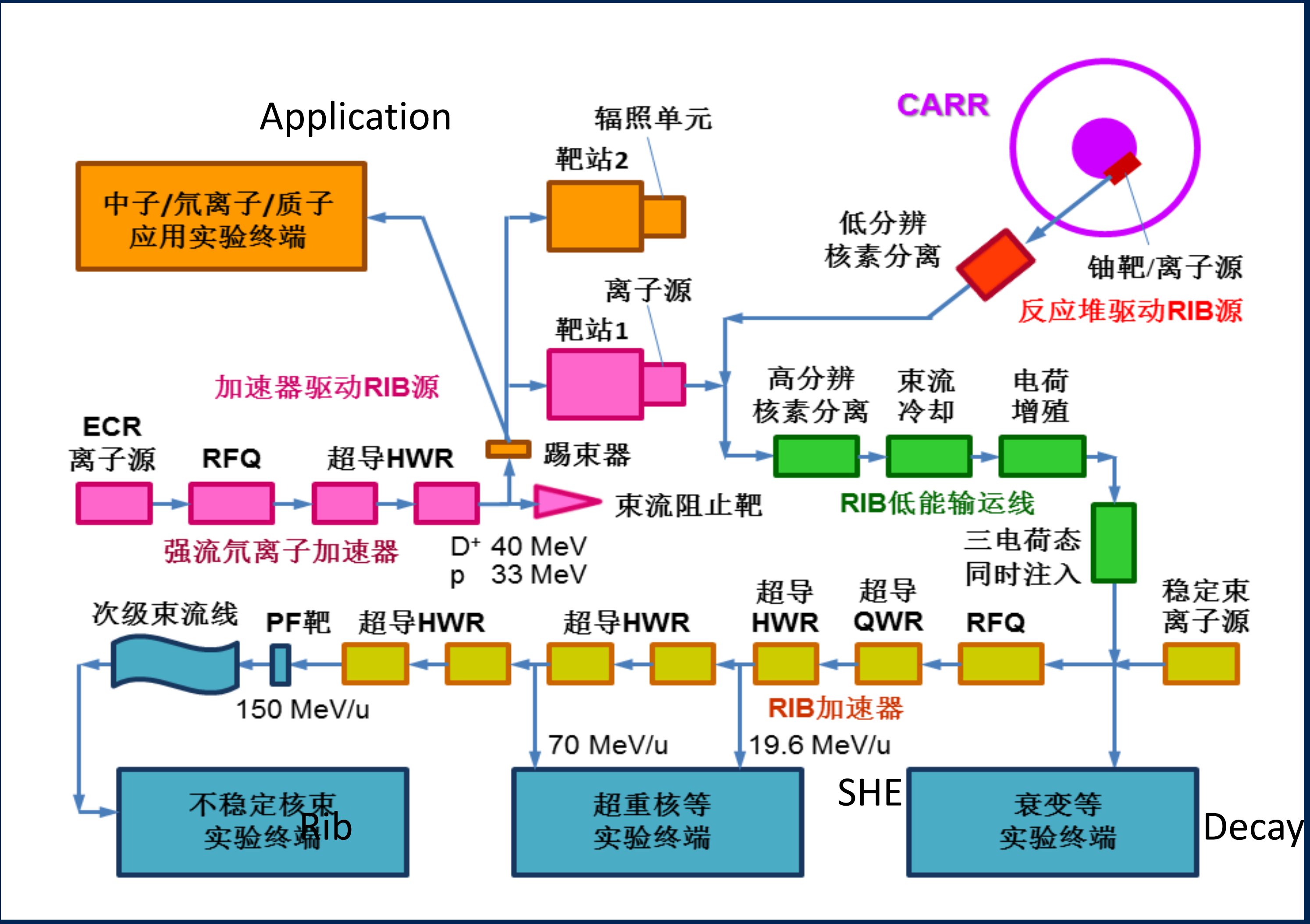


Stable beam mass resolution 14385 Oct 20, 2014

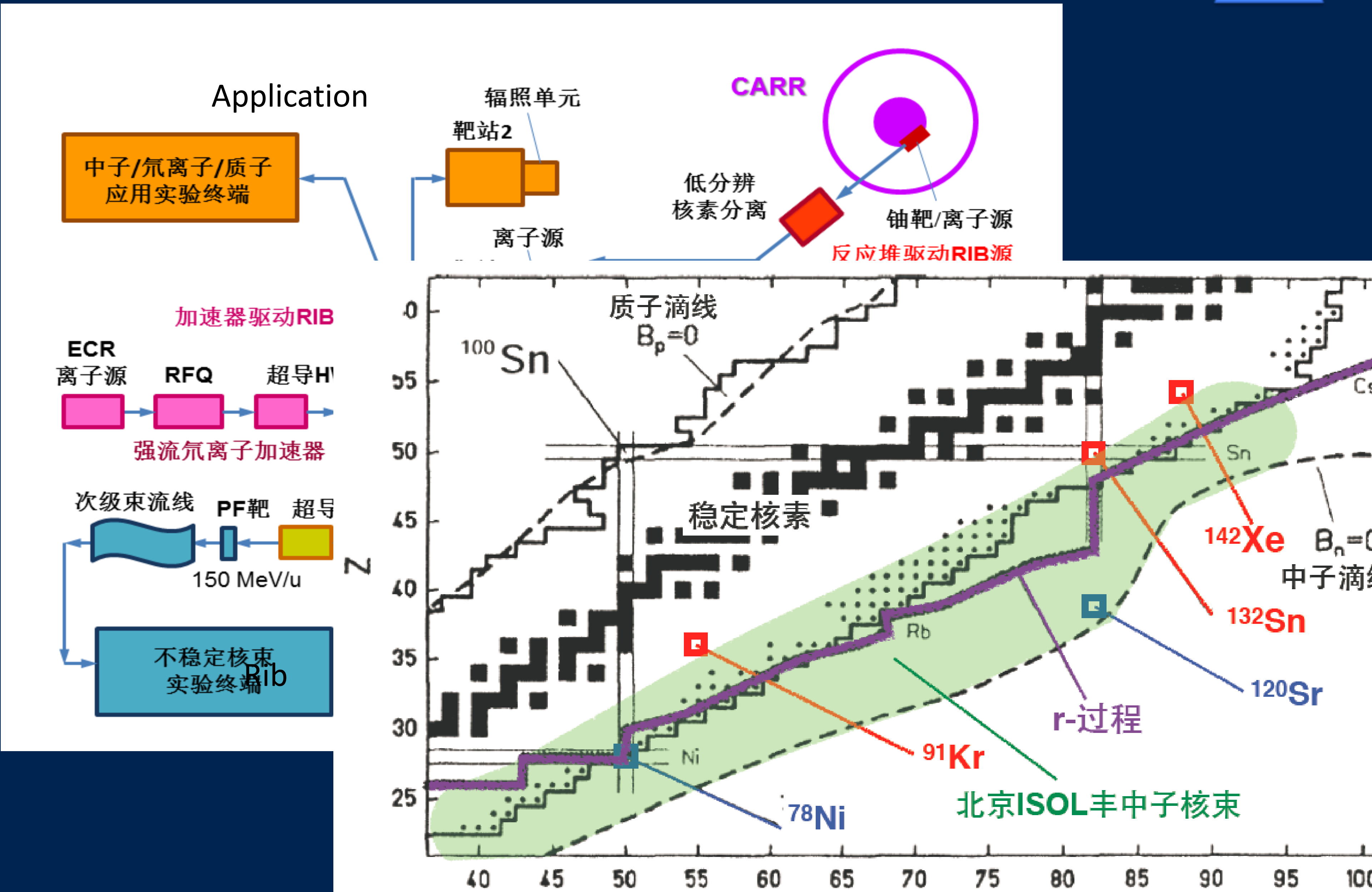




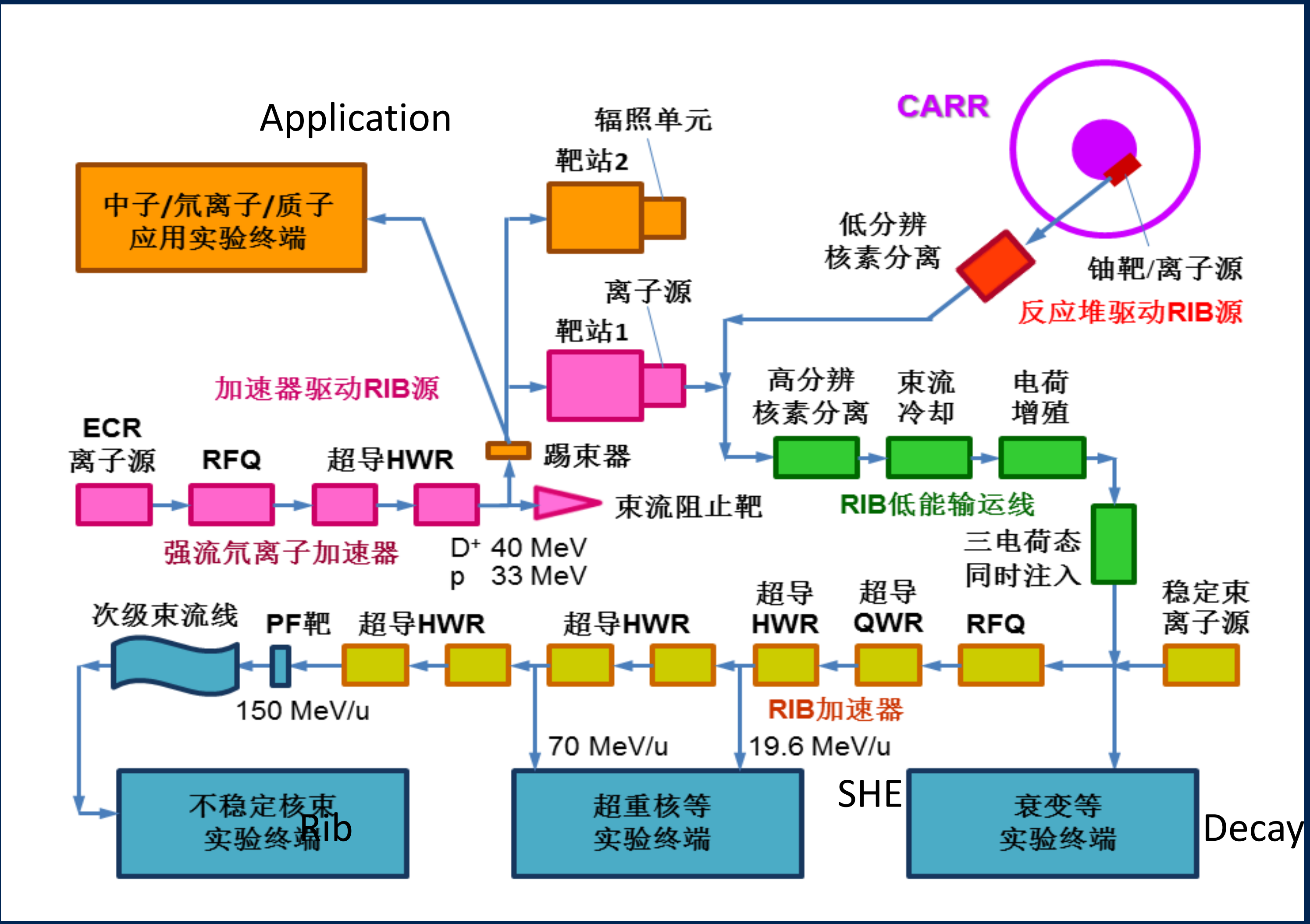
Beijing ISOL



Beijing ISOL



Beijing ISOL



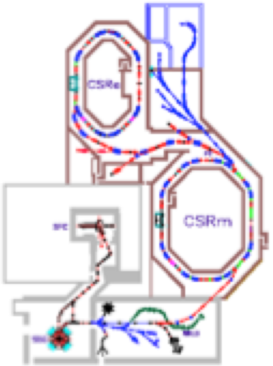
China NP road map

JUNA

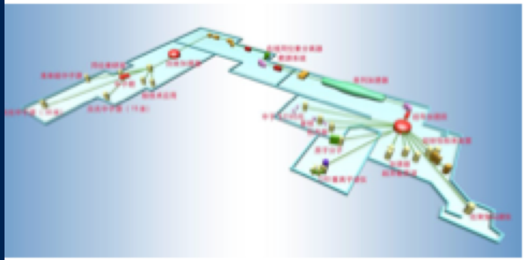
1986
Tandem Beijing
HI-13

1988
Cyclotron Lanzhou
SSC

2008
Storage ring Lanzhou
CSR

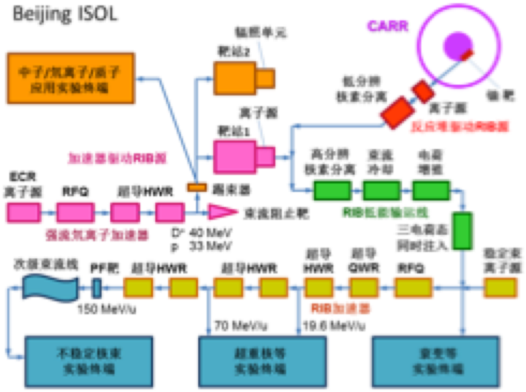


2014
ISOL facility Beijing
BRIF

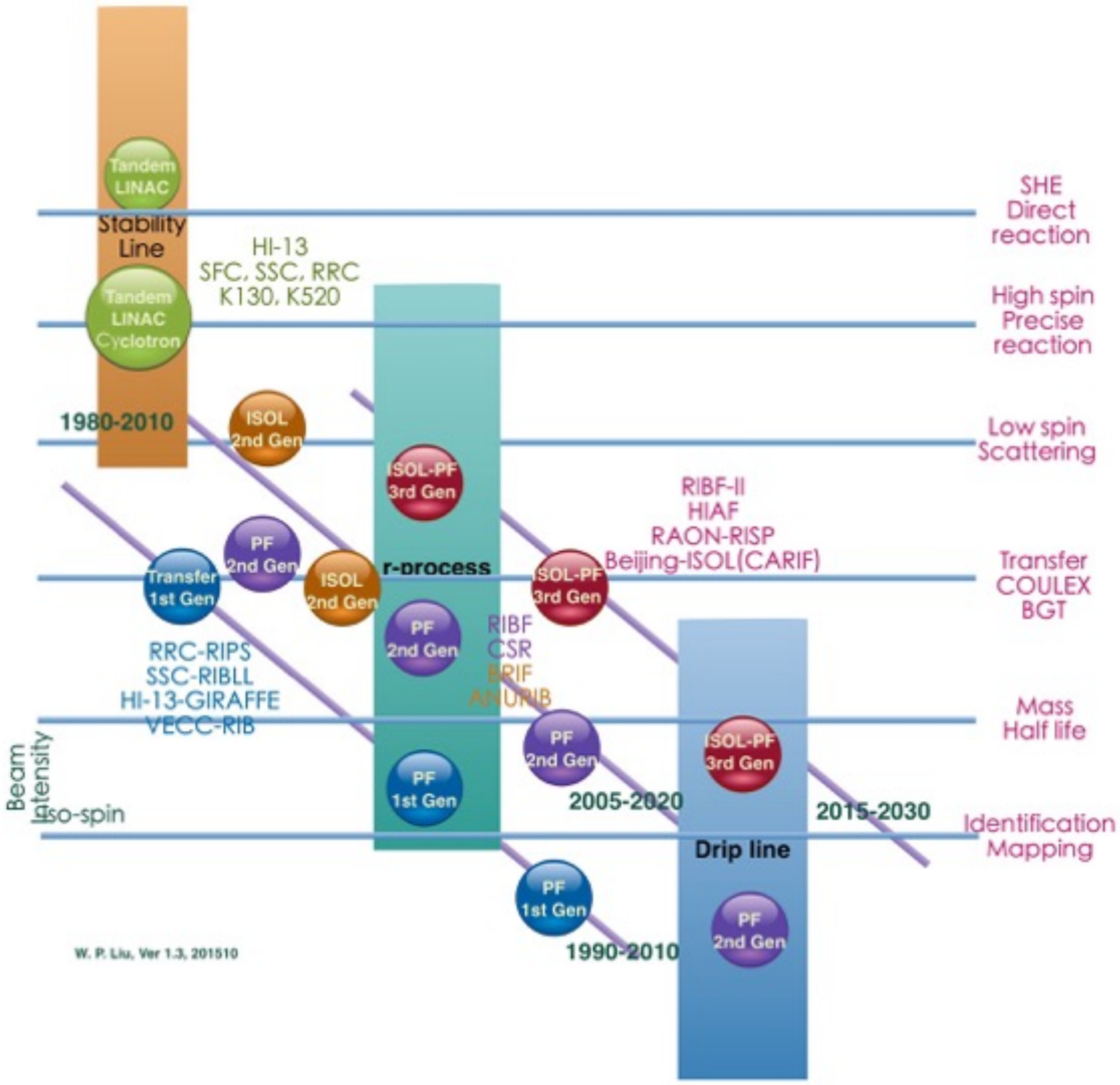


2020
HI facility Dongguan
HIAF

2025
Beijing ISOL facility



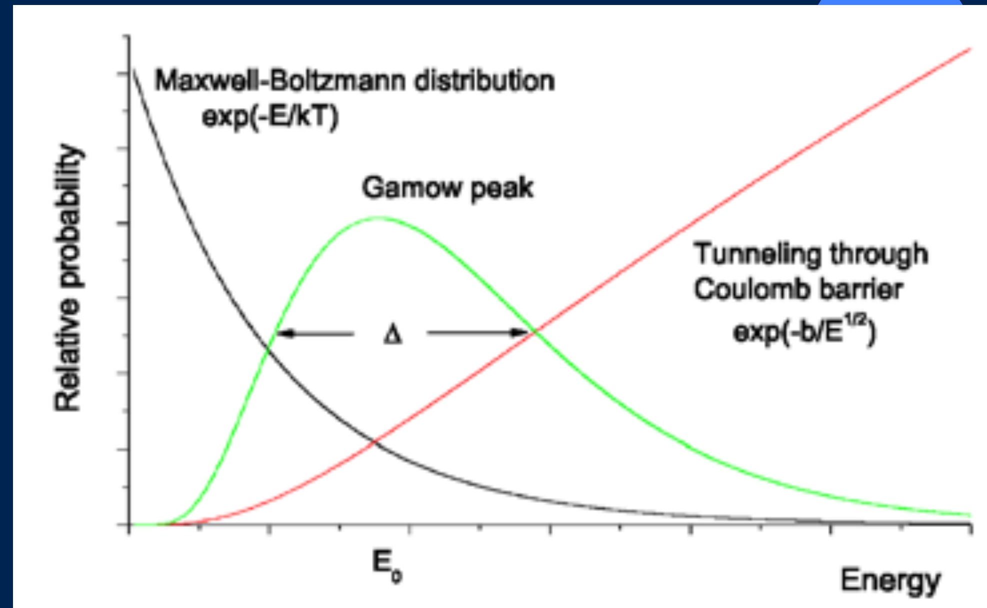
Asia map tech version

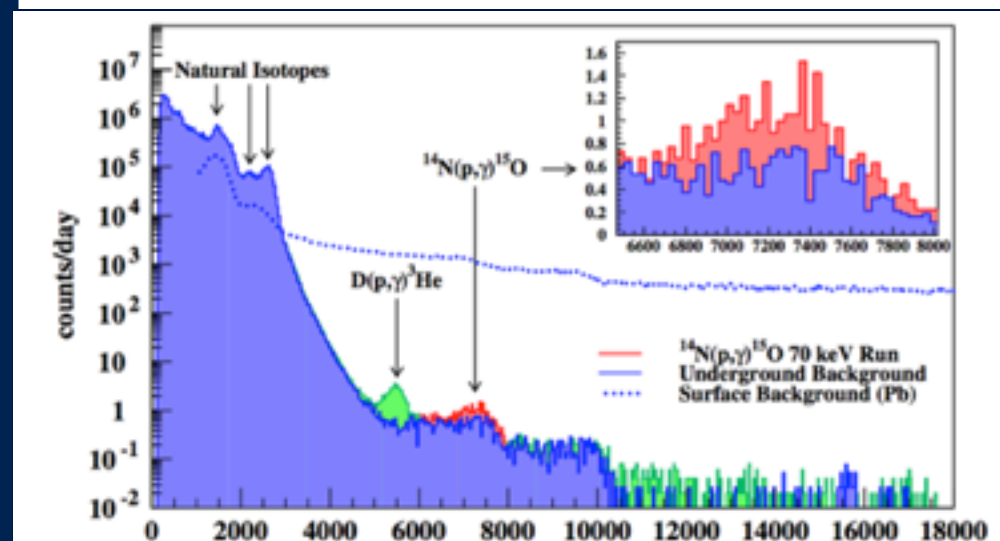


JUNA

Underground nuclear astrophysics

- Direct is the way to get rid of model dependence
- Direct in Gamow window have to go underground
- Underground is list in top priority
- Many world lab planned, with LUNA operational

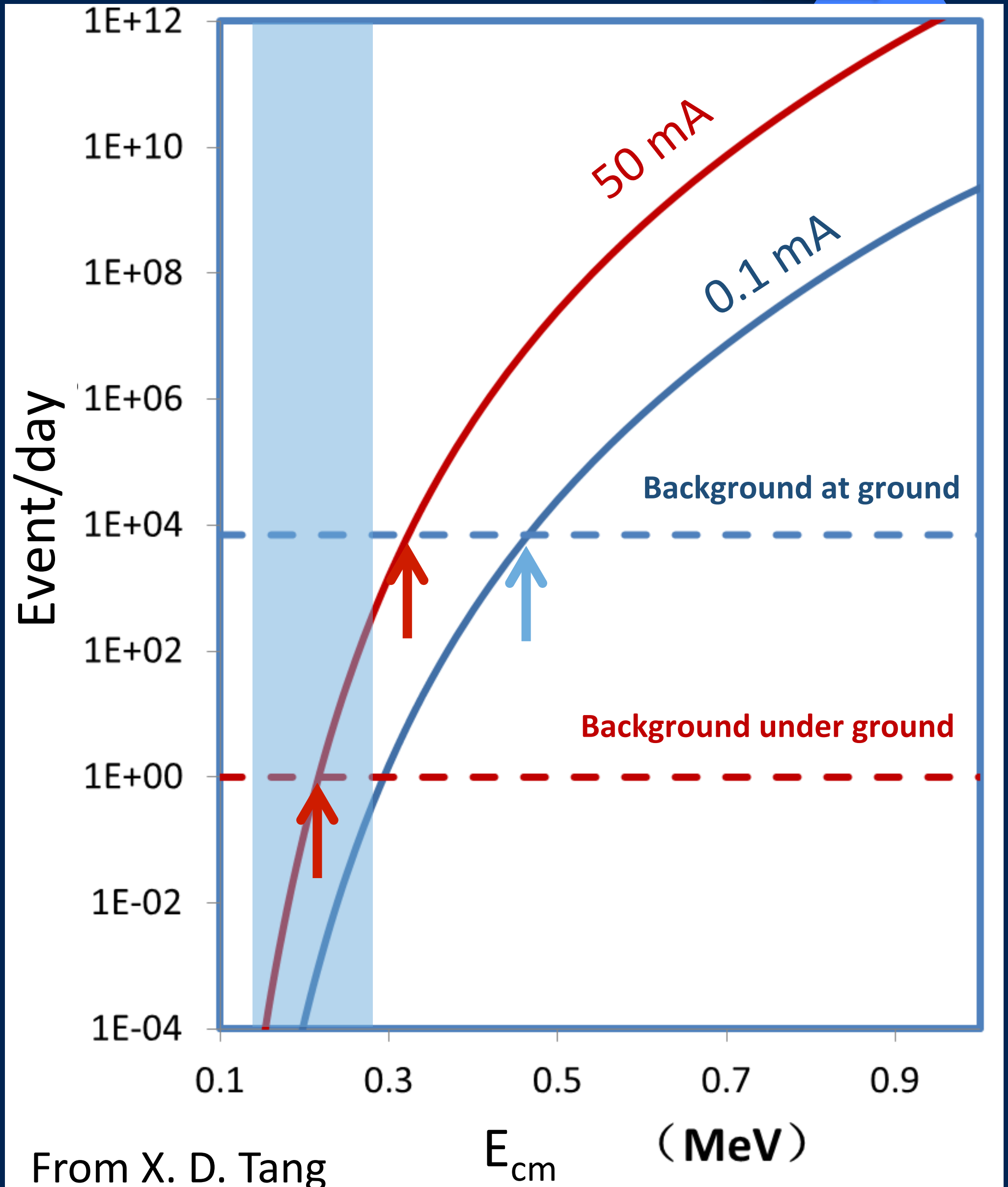




From X. D. Tang

Underground nuclear astrophysics

- Direct is the way to get rid of model dependence
- Direct in Gamow window have to go underground
- Underground is list in top priority
- Many world lab planned, with LUNA operational

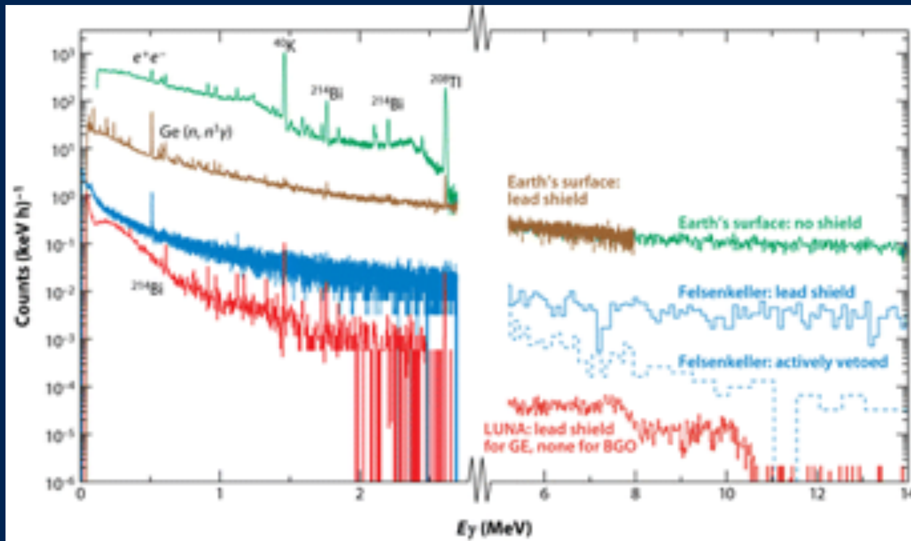


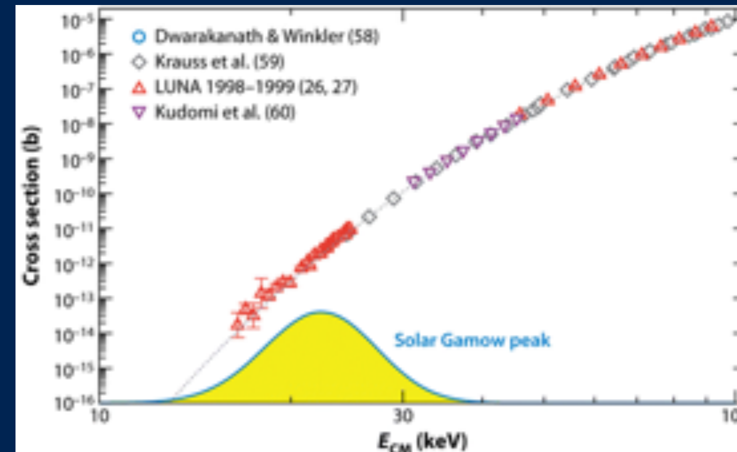
From X. D. Tang

From Paolo Prati

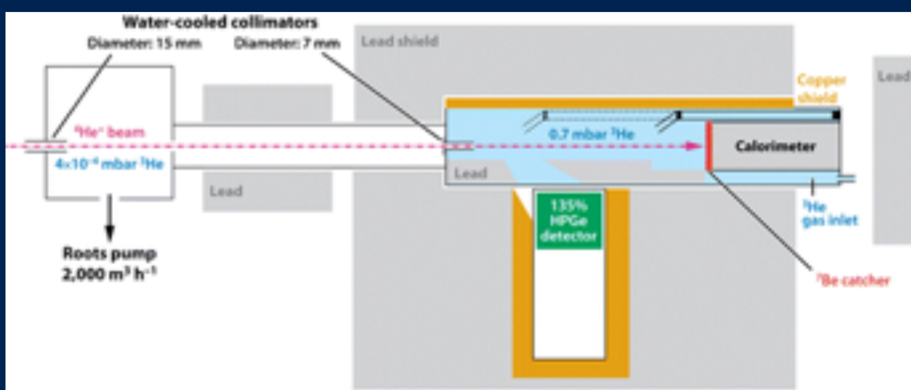
LUNA experiments

JUNA

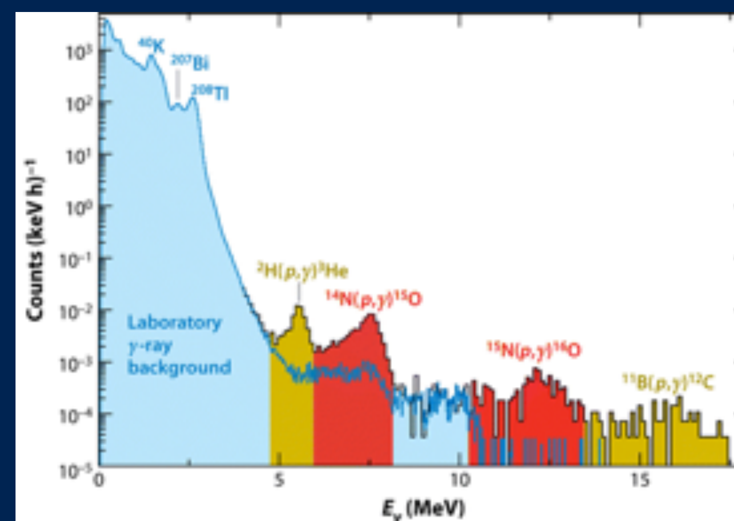




$^3He(^3He,2p)^4He$



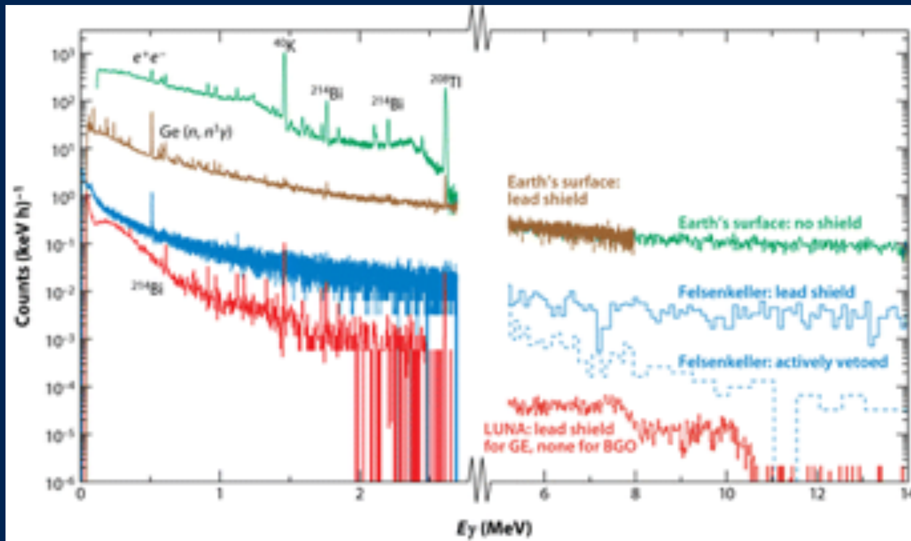
Broggini C, et al. 2010.
Annu. Rev. Nucl. Part. Sci. 60:53–73

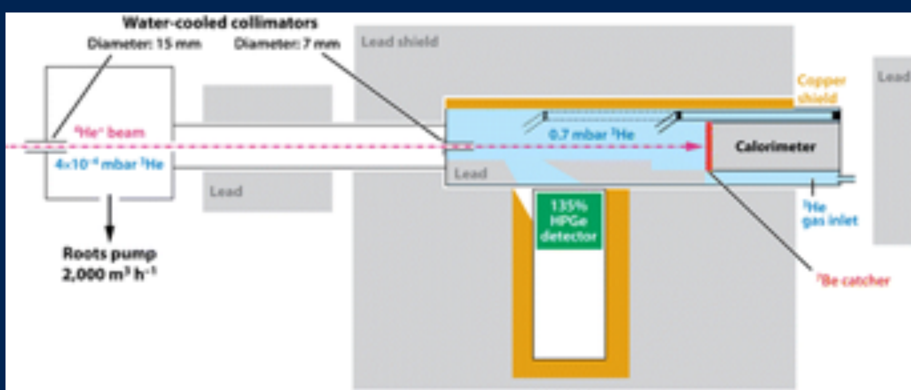


$^{14}N(p,\gamma)^{15}O$

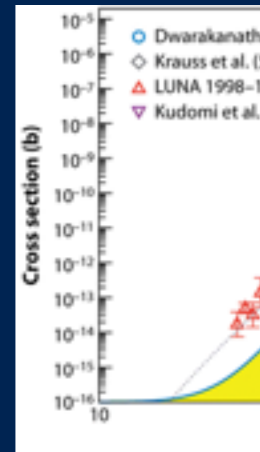
From Paolo Prati

LUNA experiments

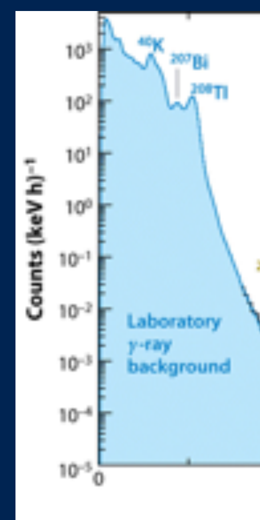




Broggini C, et al. 2010.
Annu. Rev. Nucl. Part. Sci. 60:53–73



^{3}He



$^{3}He(^{3}He,2p)^{4}He$
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

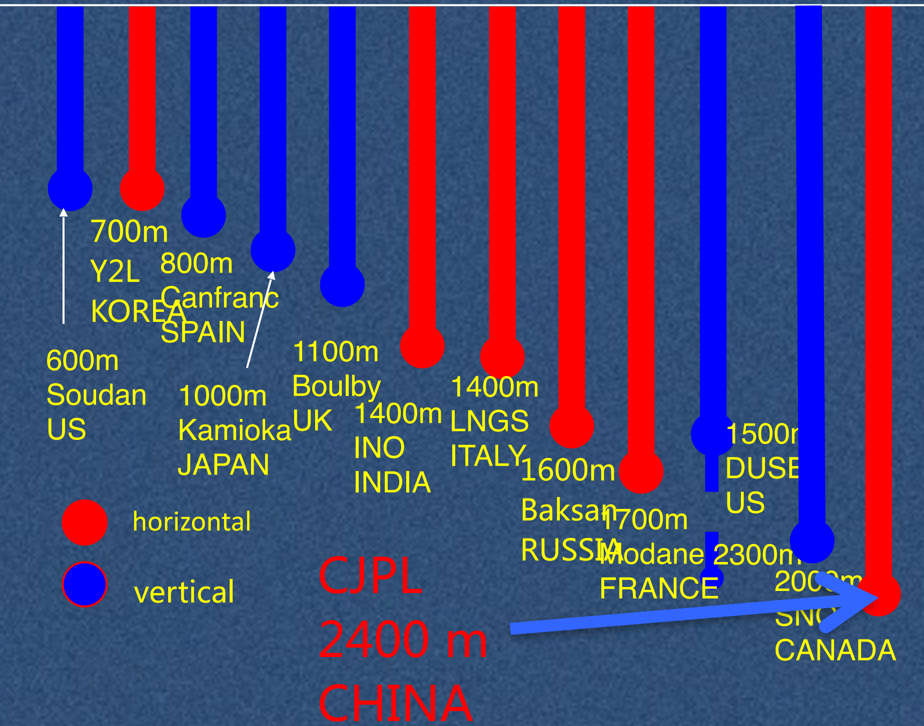
$^{15}N(p,\gamma)^{16}O$
PRC82, 055804(2010)

$^{17}O(p,\gamma)^{18}F$
PRL 109, 202601(2012)

$^{25}Mg(p,\gamma)^{26}Al$
PLB 707(2012) 60

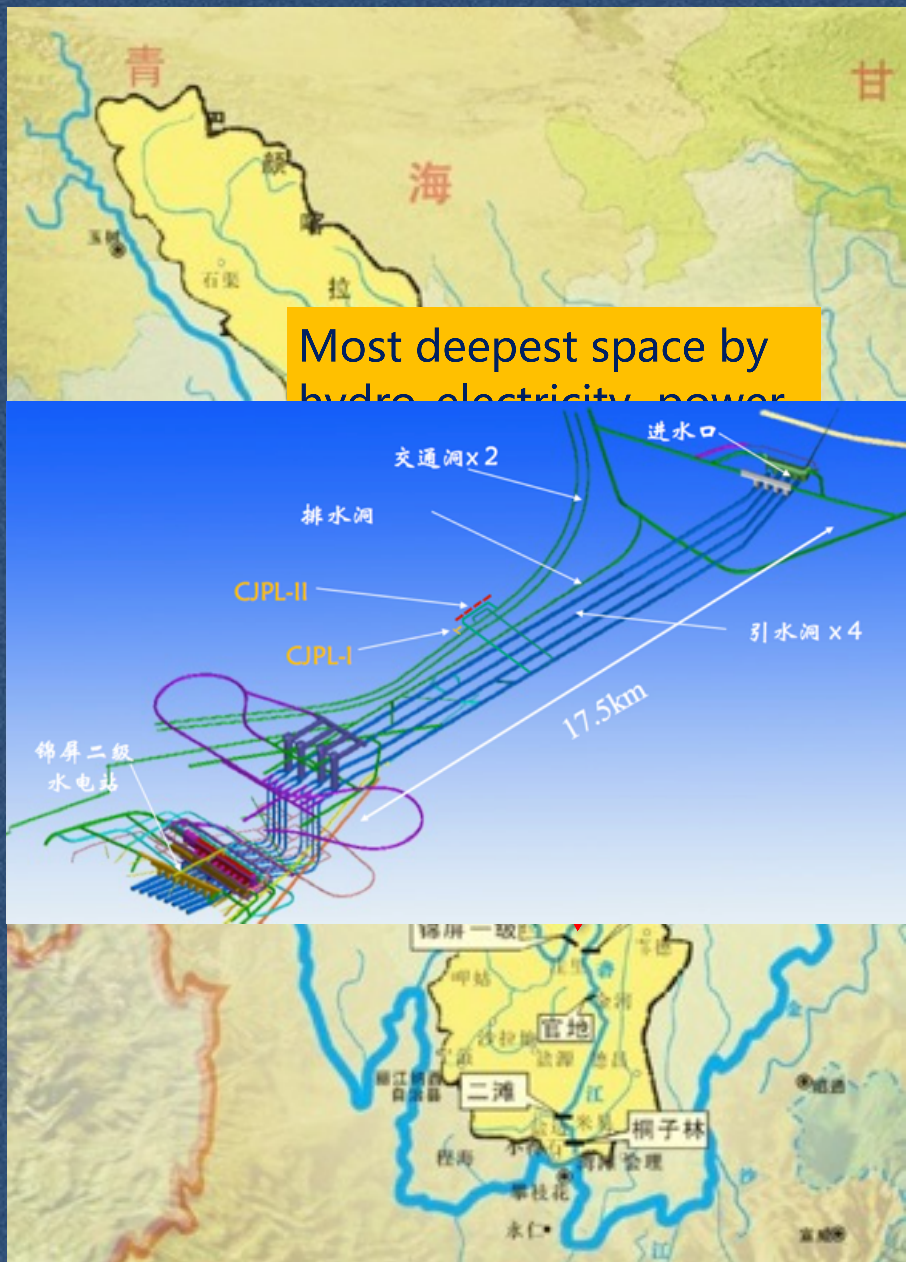
From Qian Yue

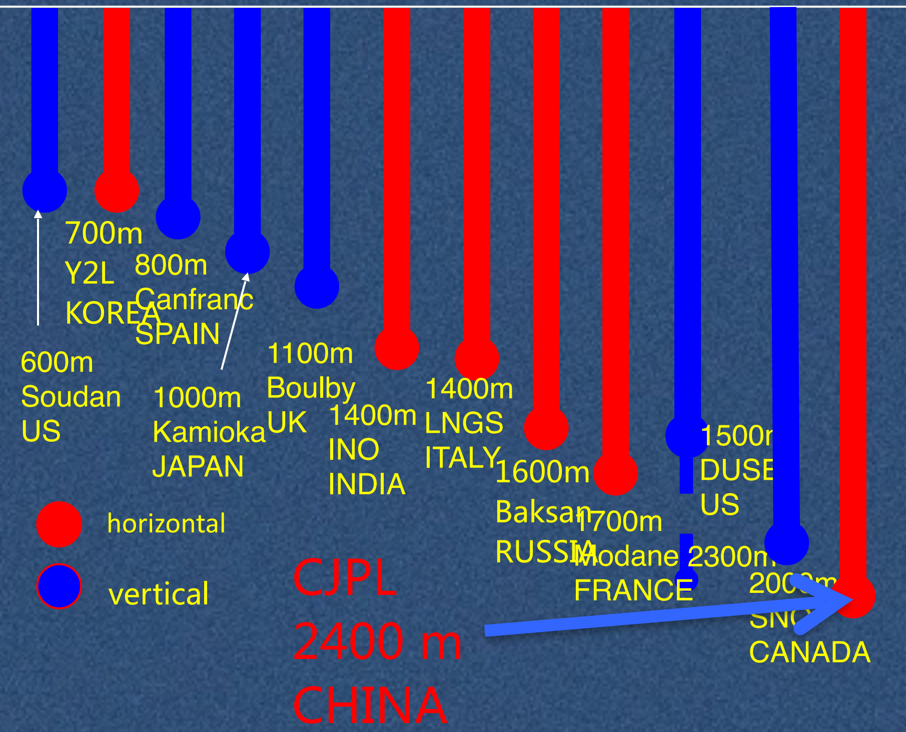
CJPL underground laboratory



From Qian Yue

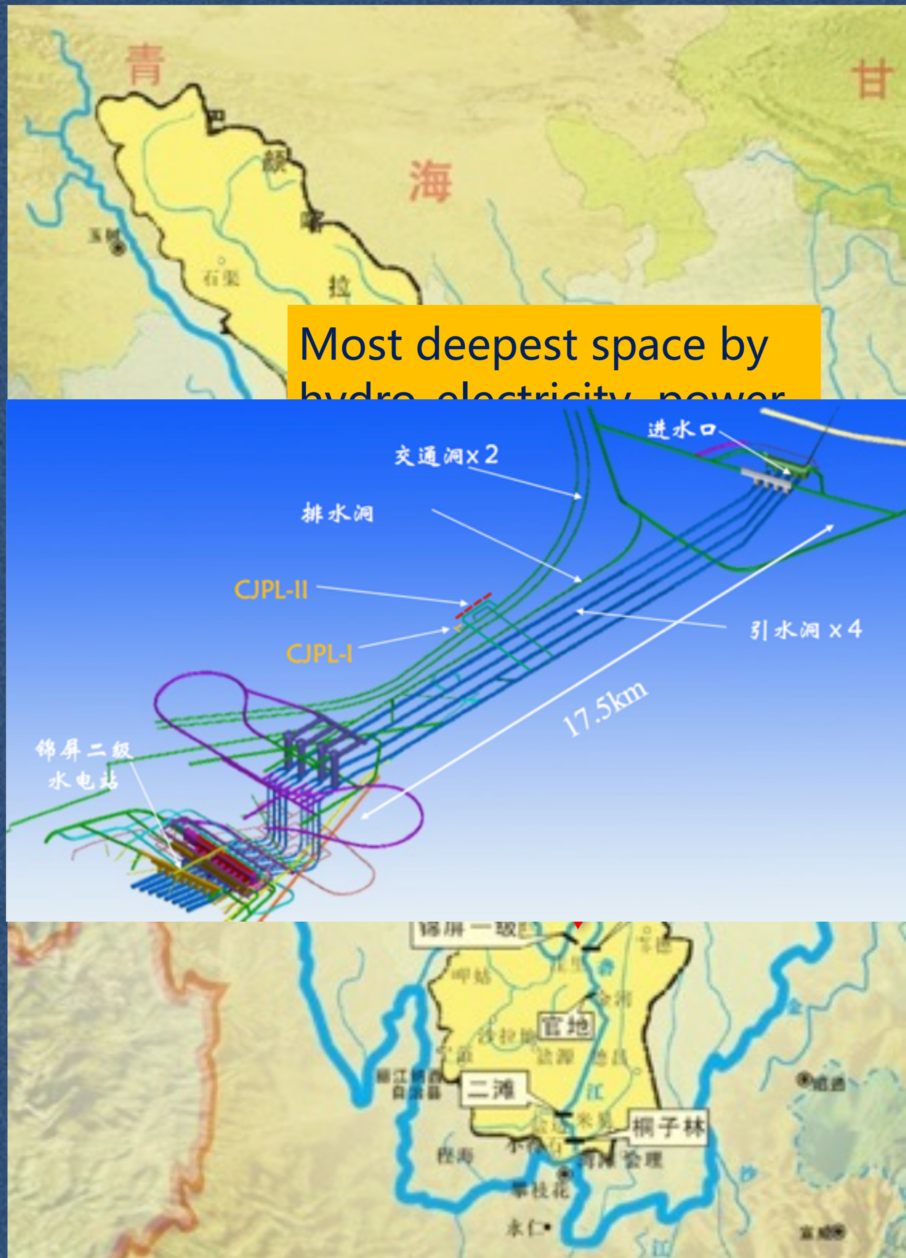
CJPL underground laboratory

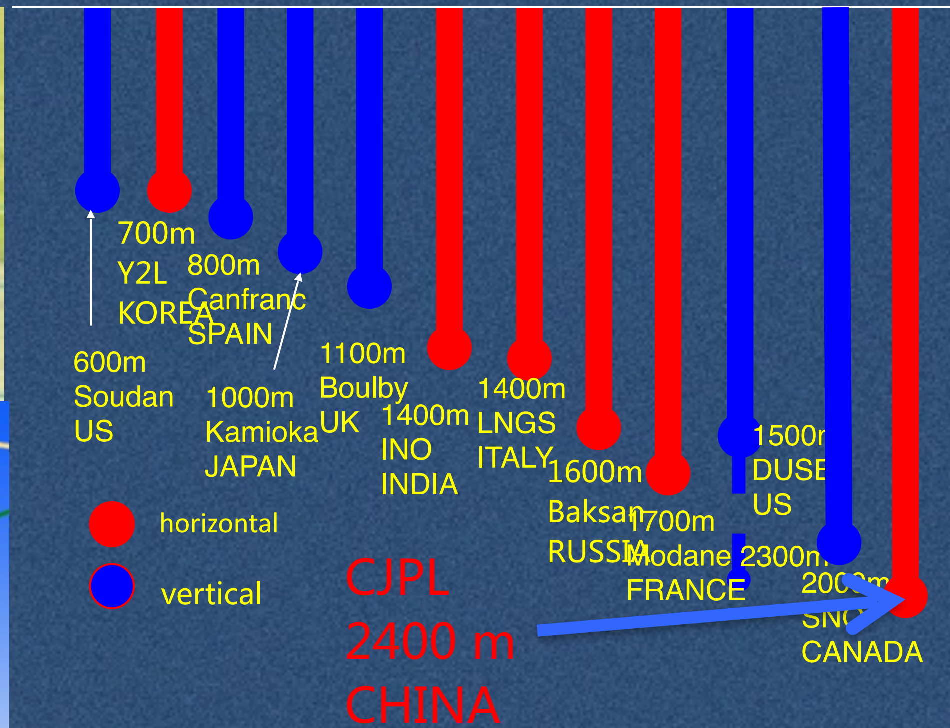


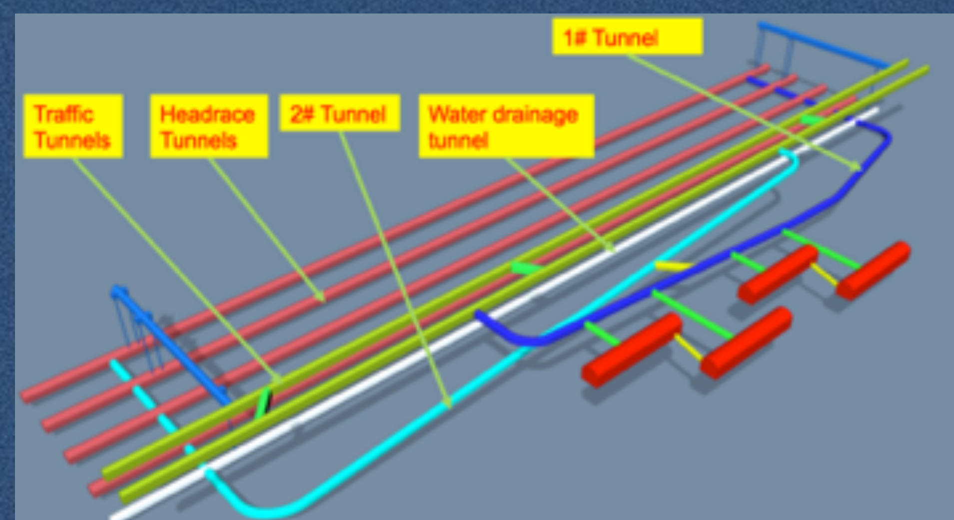


From Qian Yue

CJPL underground laboratory

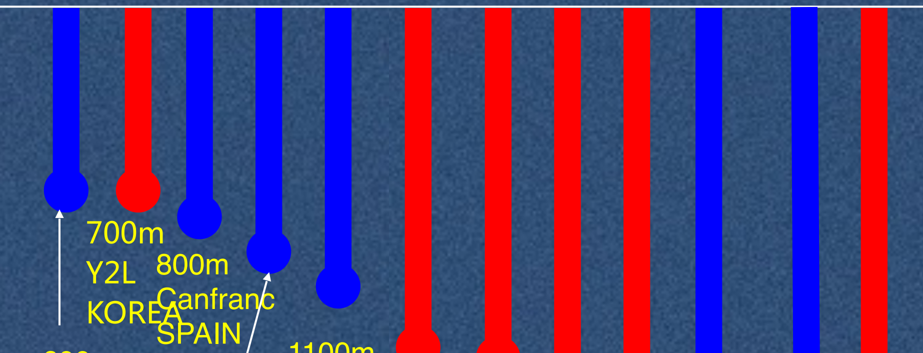




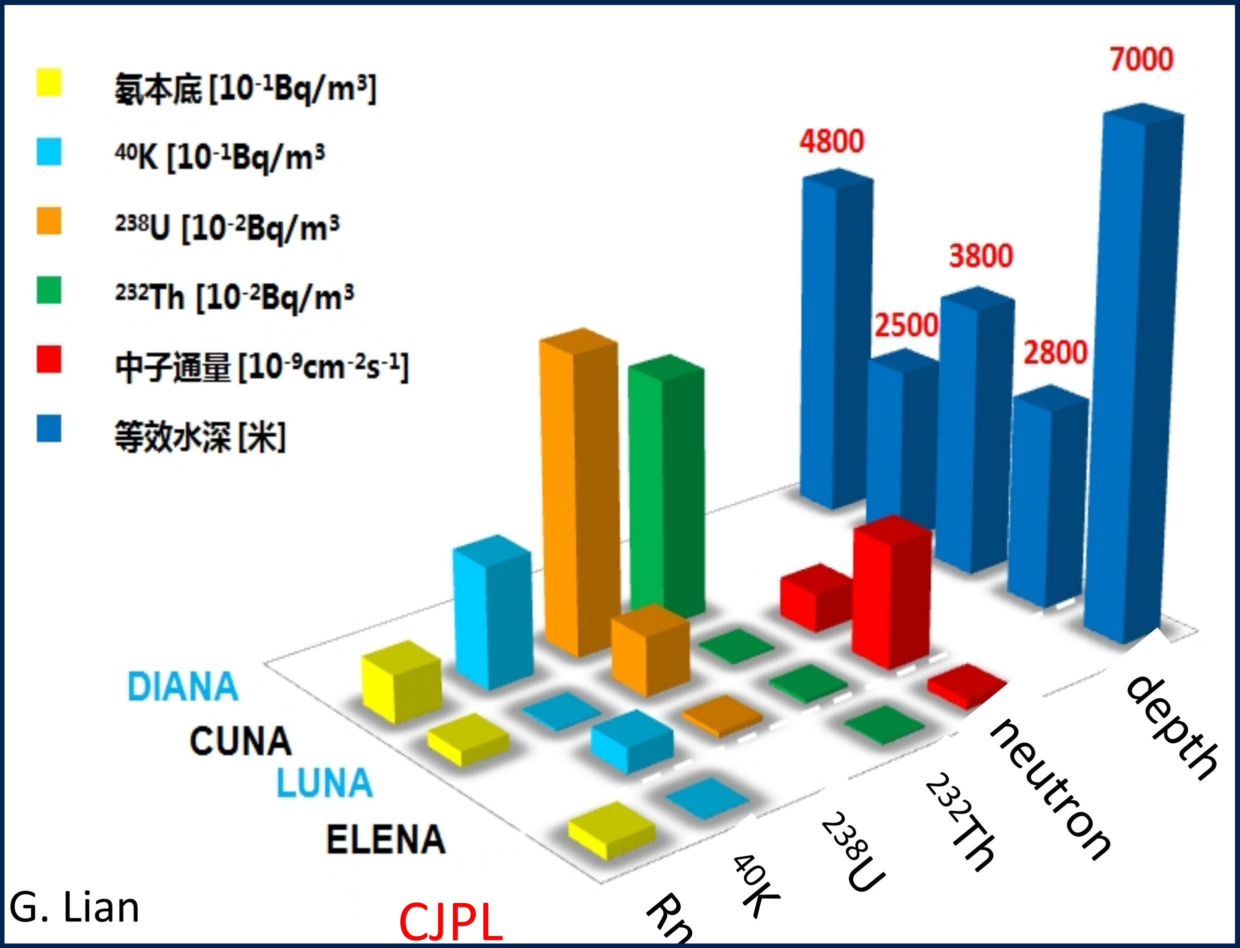


From Qian Yue

CJPL underground laboratory

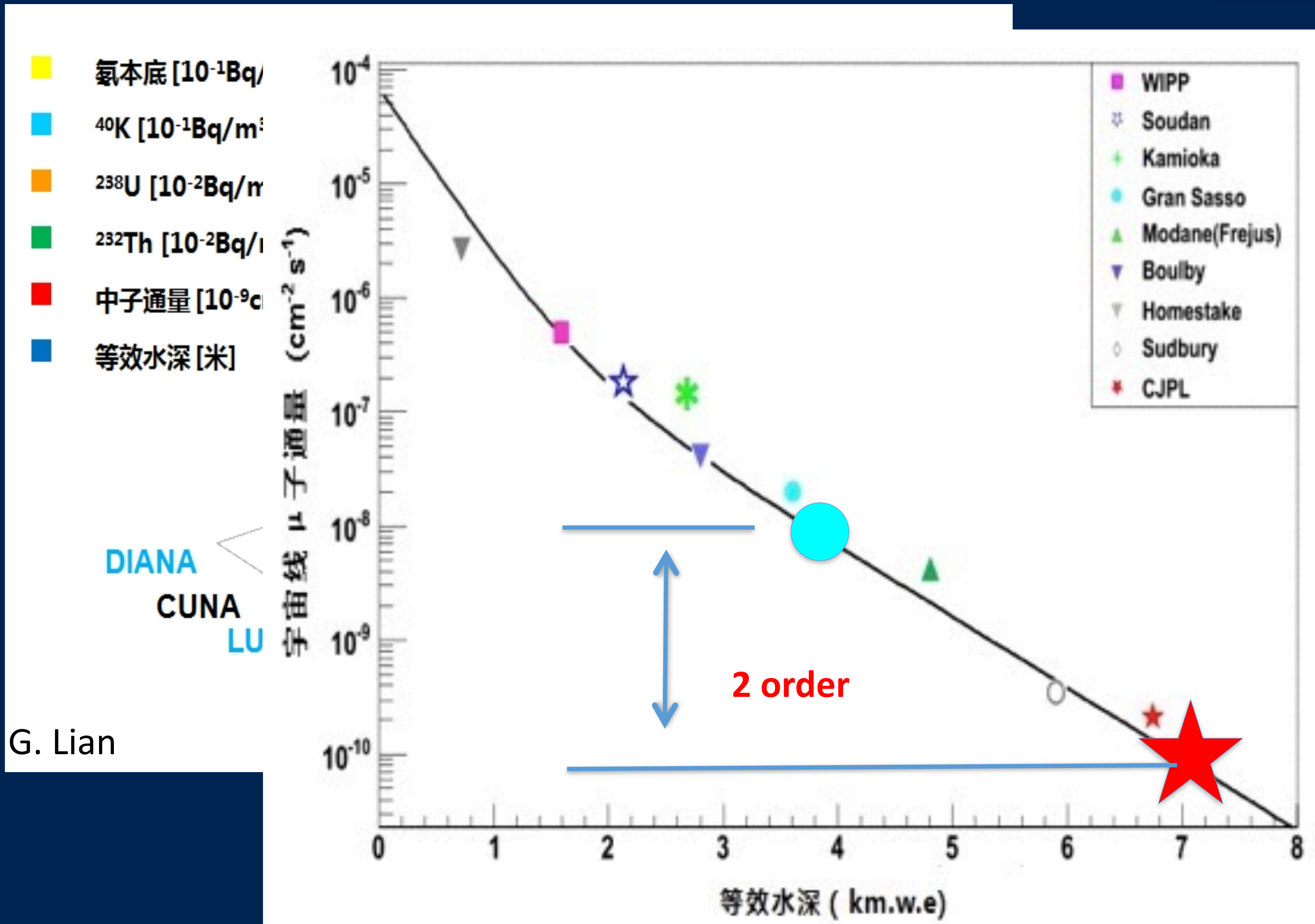


CJPL advantage



From G. Lian

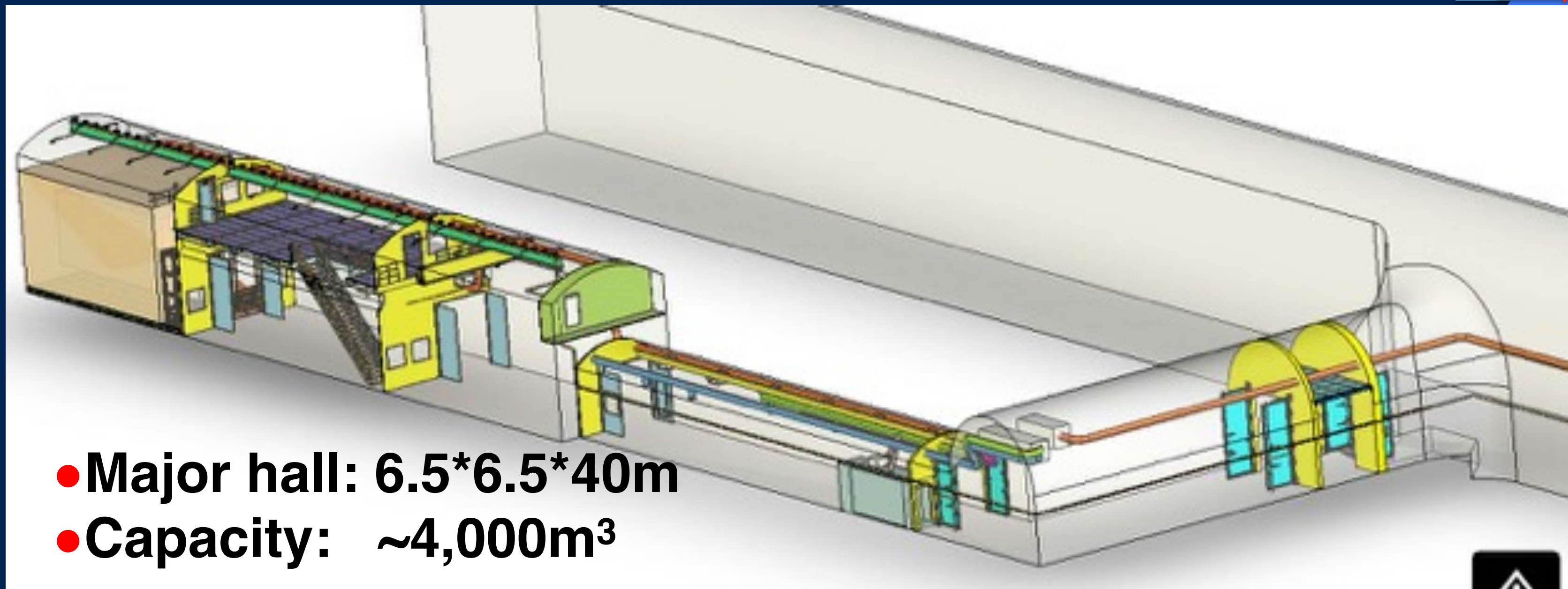
CJPL advantage



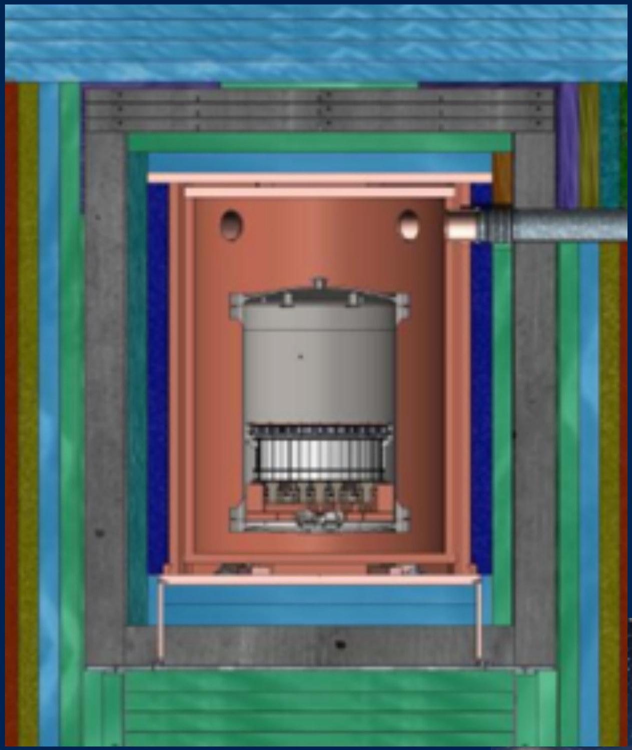
From G. Lian

CJPL-I

JUNA

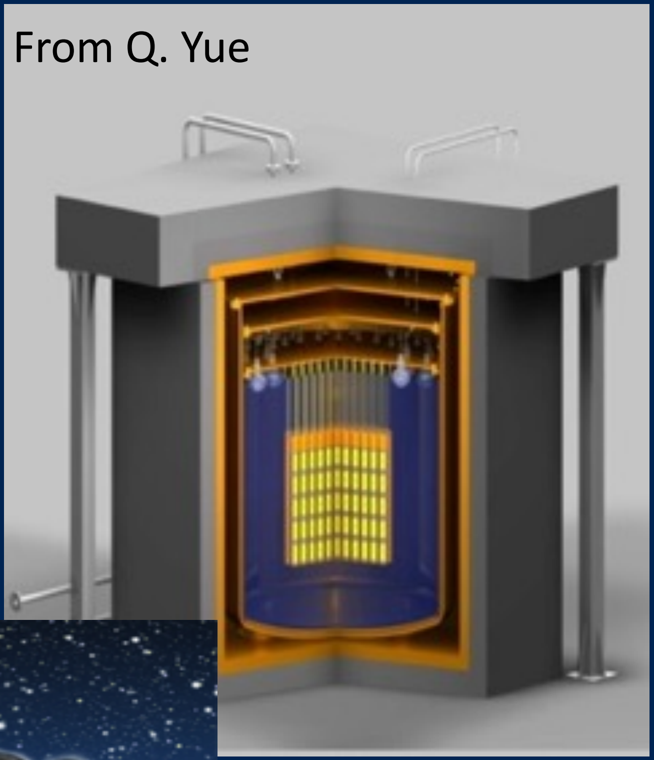


CJPL-II experiments



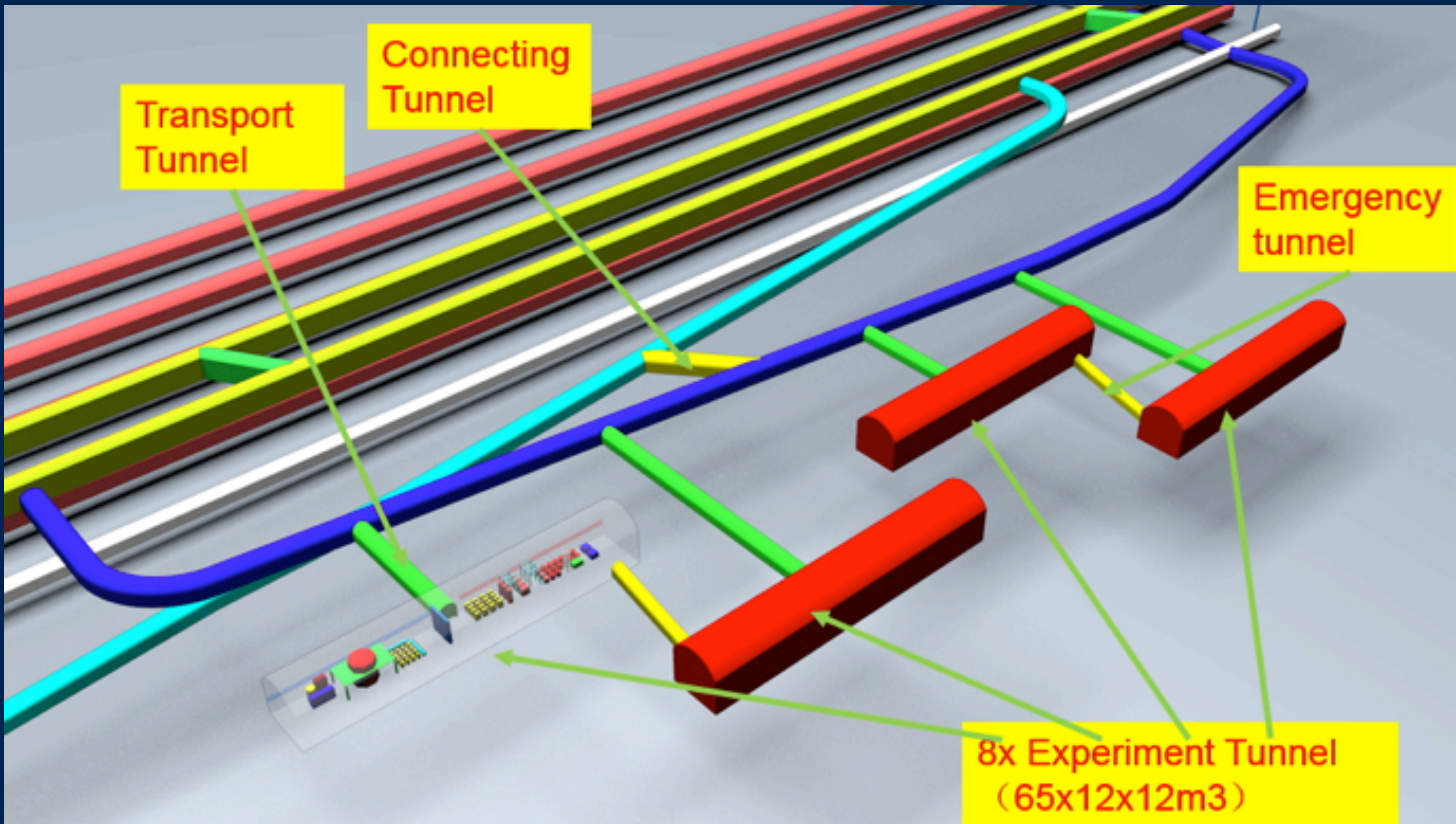
LXe PANDAX

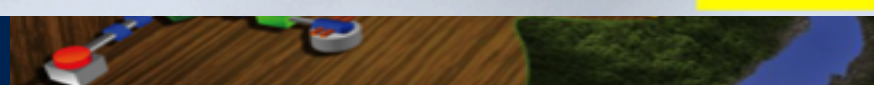
NA
JUNA



HpGe
CDEX

CJPL-II experiments





JUNA organization

JUNA

Group leader

- CIAE
- IMP
- THU
- SJTU
- SCU
- SDU
- SZU
- …

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

中国原子能科学研究院
CHINA INSTITUTE OF ATOMIC ENERGY

中国科学院近代物理研究所
Institute of Modern Physics, Chinese Academy of Sciences

PI

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

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

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

Gang Lian
Accelerator

JUNA

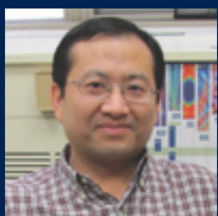
JUNA team

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 international team







Osaka, Isao Tanihata

Monash, Alexander Heger

Notre Dame, Wanpeng Tan

HAS, Maria Lugaro

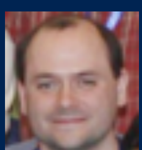
Minisota, Yongzhong Qian

RIKEN, Shigeru Kubono

South Dakota, Dongming Mei

JUNA IAC






M. Wiescher	Chair	UND
T. Motobayashi	Member	RIKEN
H. Wang	Member	TCAS
C. Brune	Member	Ohio
M. Junker	Member	INFN
D. Robertson	Member	UND
F. Strieder	Member	SDSMT
D. Leitner	Member	LBL
Q. Yue	Member	THU




Preparation meeting July 2015 in Beijing, 1st IAC meeting March 1-3, 2016 in CJPL

JUNA-I funding

JUNA

Detectors（NSFC $1.3M）

Electronics, shielding (NSFC $1.0M）

Ion source (CAS $0.8M), accelerator (CNNC $0.5M)

total $4.8+ M

JUNA-I funding

JUNA

Detectors（NSFC $1.3M）

Electronics, shielding (NSFC $1.0M）

Ion source (CAS $0.8M), accelerator (CNNC $0.5M)

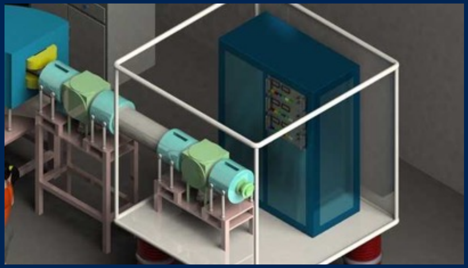
Lab CJPL II（Tsinghua，NSFC $1.2M）

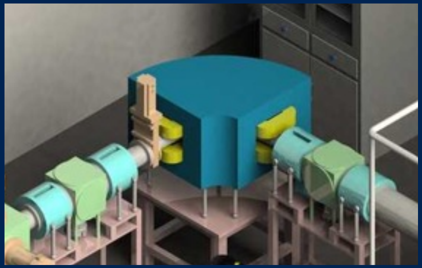
total $4.8+ M

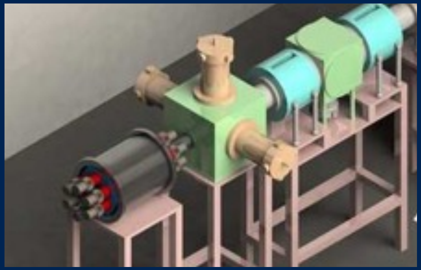
JUNA-I plan

JUNA

CJPL-II cave 4







ECR source **Acceleration** **Magnet** **Detectors**

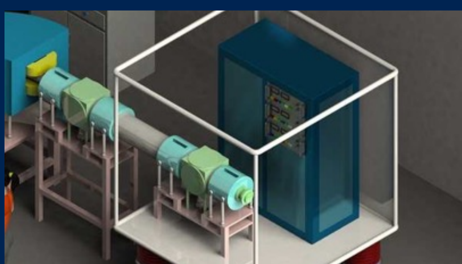
Intensity

Energy

JUNA-I plan

CJPL-II c

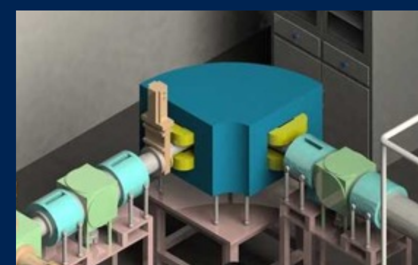
JUNA-I



ECR source

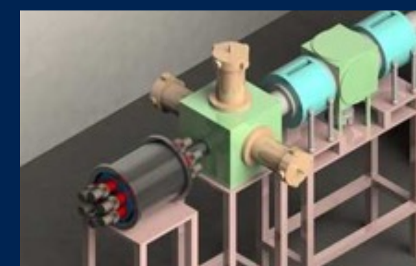
Acceleration

Intensity



Magnet

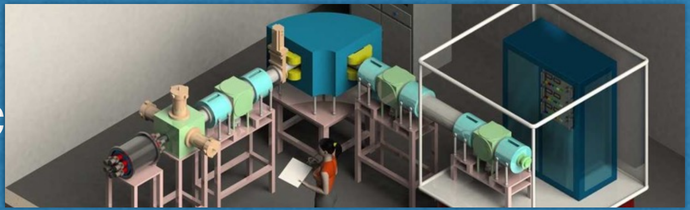
Energy



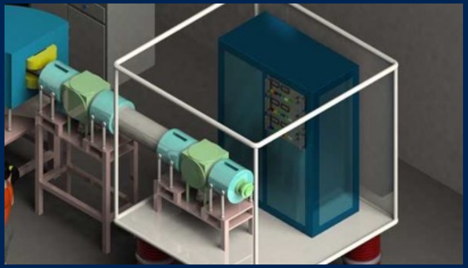
Detectors

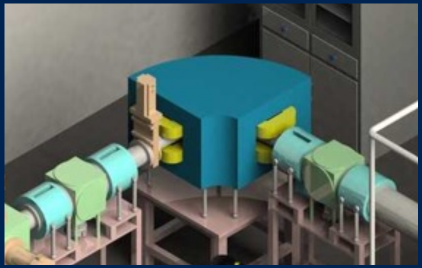
JUNA-I plan

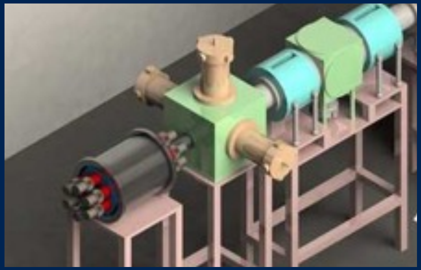
CJPL-II c



JUNA-I







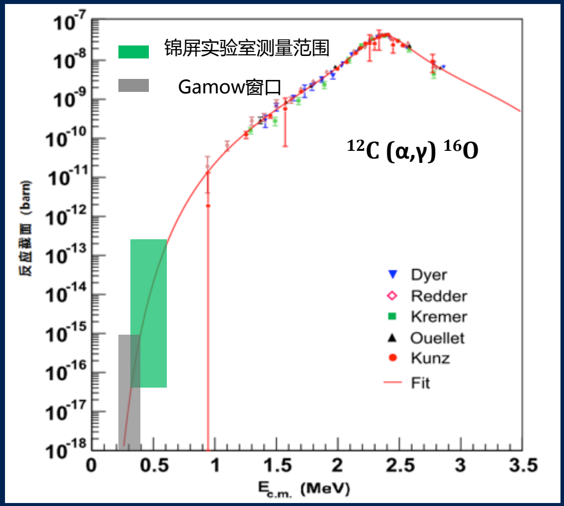
ECR source | Acceleration | Magnet | Detectors

Beam	*Intensity, mA*	*Energy,keV*
H^+	*10*	*70-400*
He^+	*10*	*70-400*
He^{++}	*2-5*	*140-800*

Nuclear astrophysics reactions

JUNA

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



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

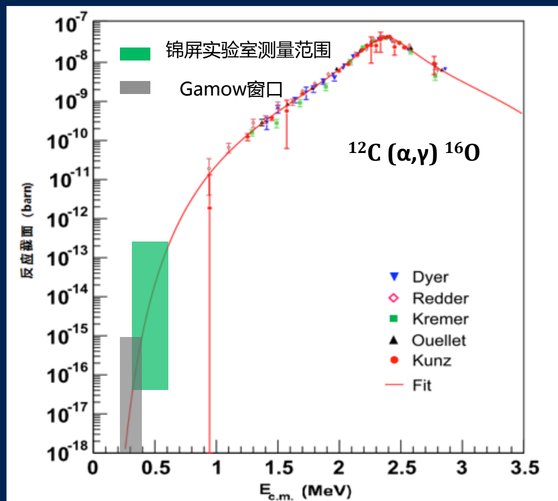
γ astronomy $^{25}Mg(p,\gamma)^{26}Al$

F over-abundant $^{19}F(p,\alpha)^{16}O$

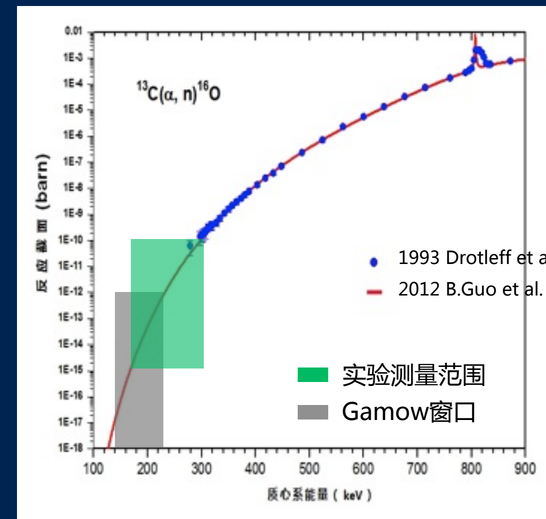
Nuclear astrophysics reactions

JUNA

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



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

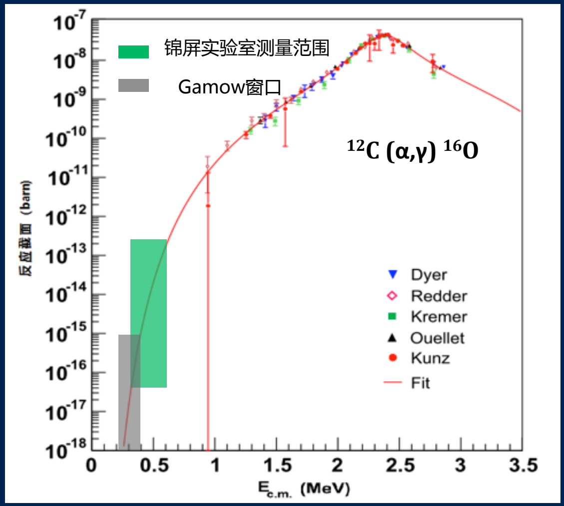


γ astronomy $^{25}Mg(p,\gamma)^{26}Al$

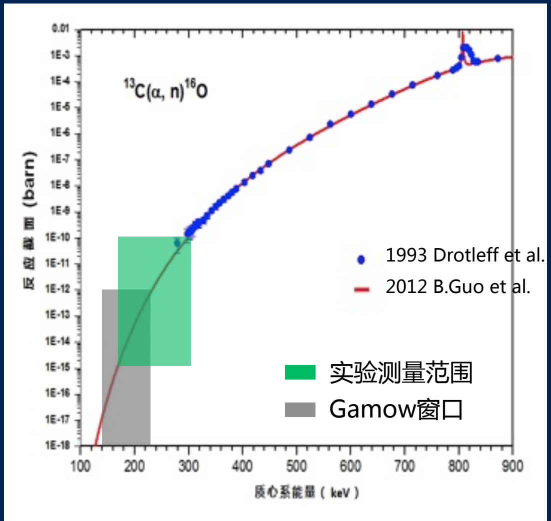
F over-abundant $^{19}F(p,\alpha)^{16}O$

Nuclear astrophysics reactions

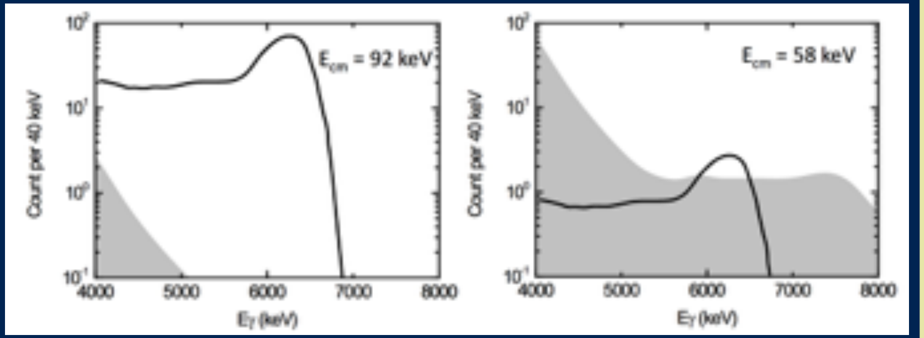
Holly grail $^{12}C(\alpha,\gamma)^{16}O$



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



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

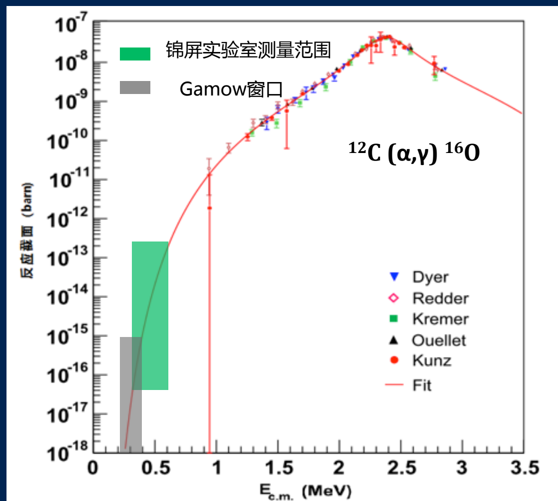


F over-abundant $^{19}F(p,\alpha)^{16}O$

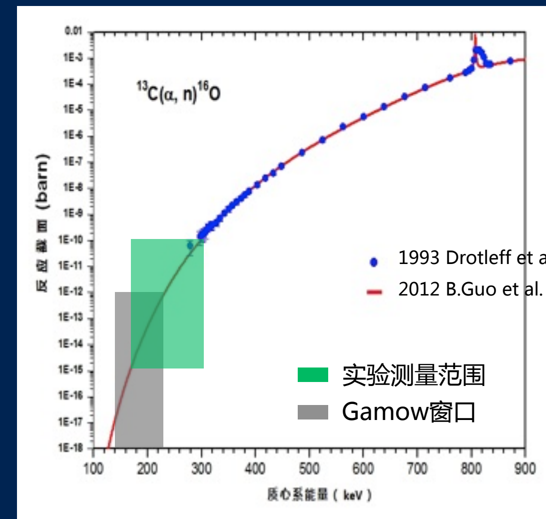
JUNA

Nuclear astrophysics reactions

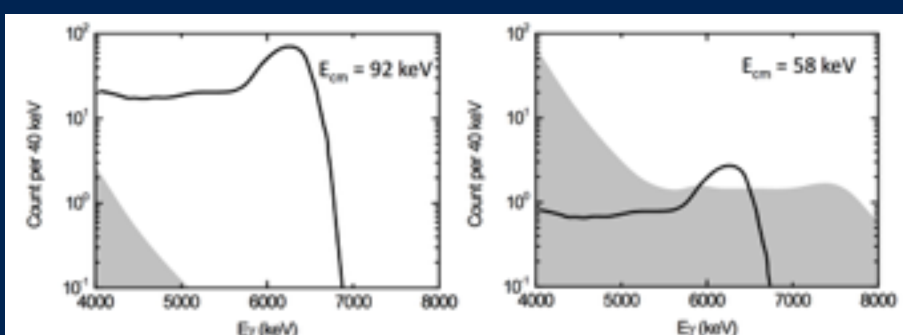
Holly grail $^{12}C(\alpha,\gamma)^{16}O$



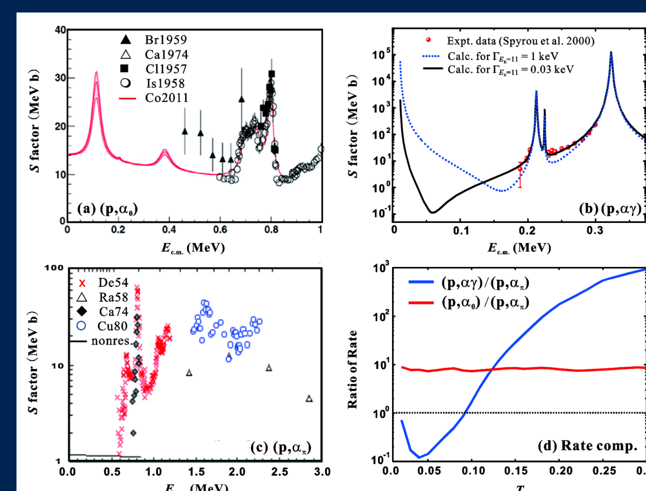
n source $^{13}C(\alpha,n)^{16}O$



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



F over-abundant $^{19}F(p,\alpha)^{16}O$



CJPL-II construction

JUNA

May 2015

CJPL-II construction

May 2015

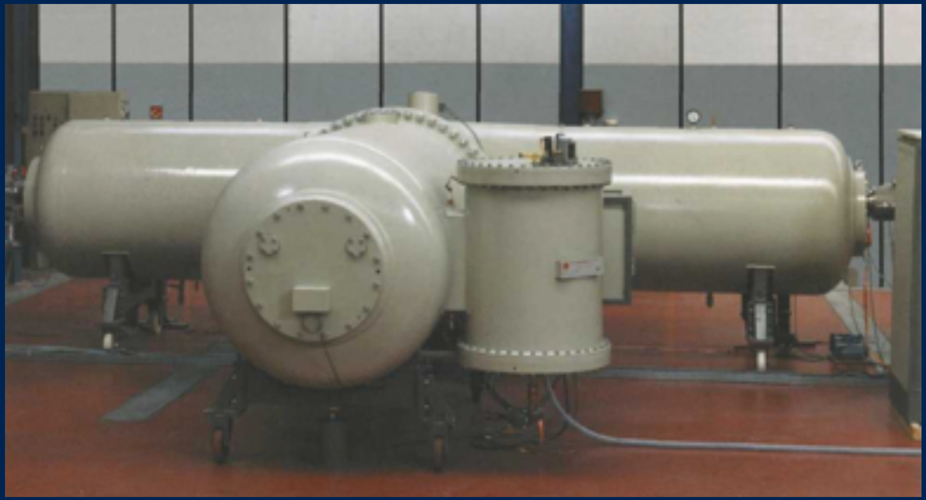
CJPL-II construction

May 2015

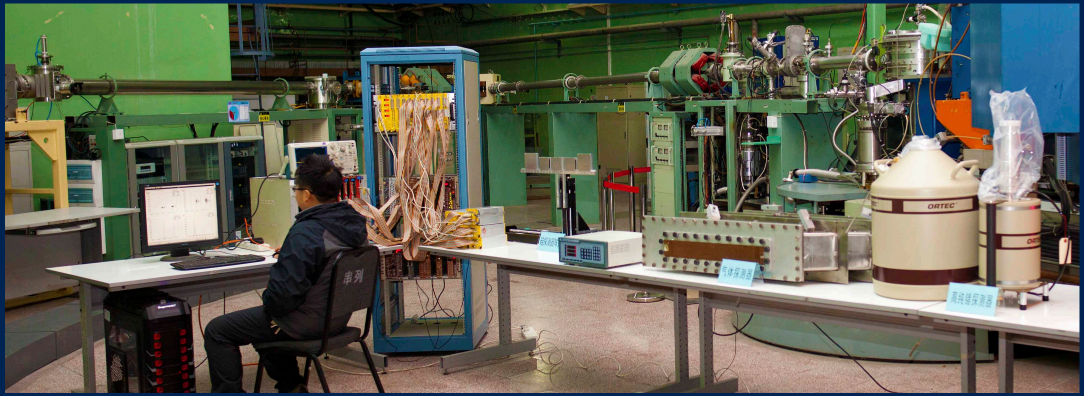
Sept. 2015

Recent progress

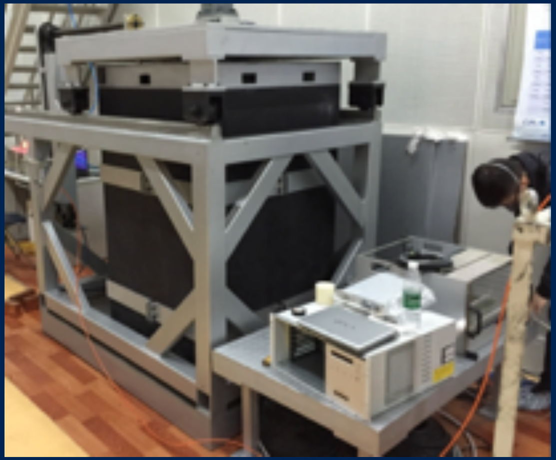
Proton beam with 40 KV and 20 mA



Tandem of implantation target

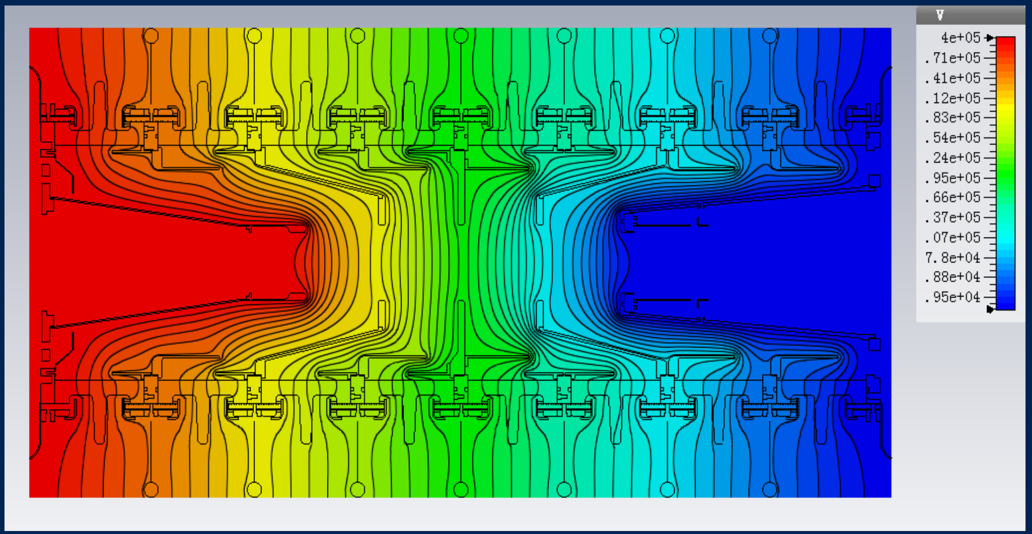


solid and gas detector and electronics

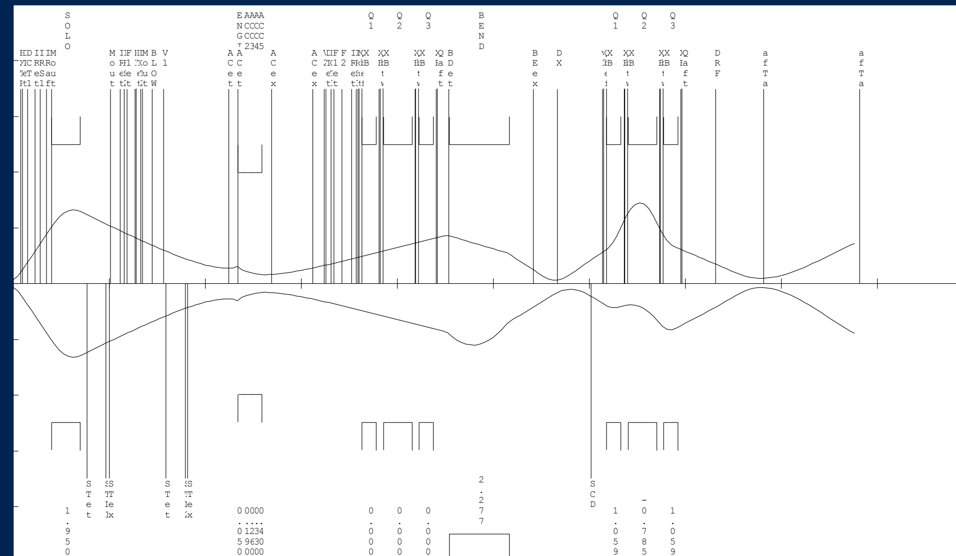


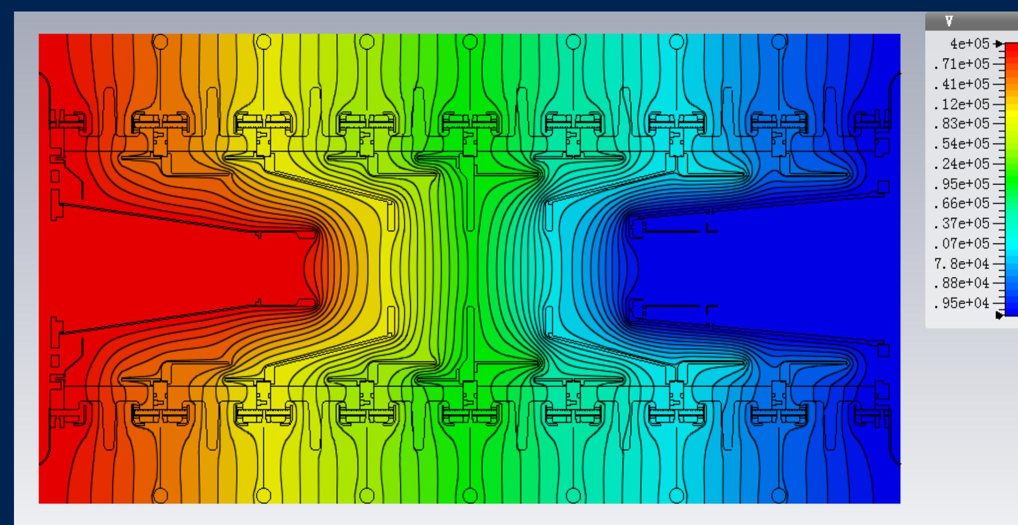
CJPL low background station

Accelerator and ion source design

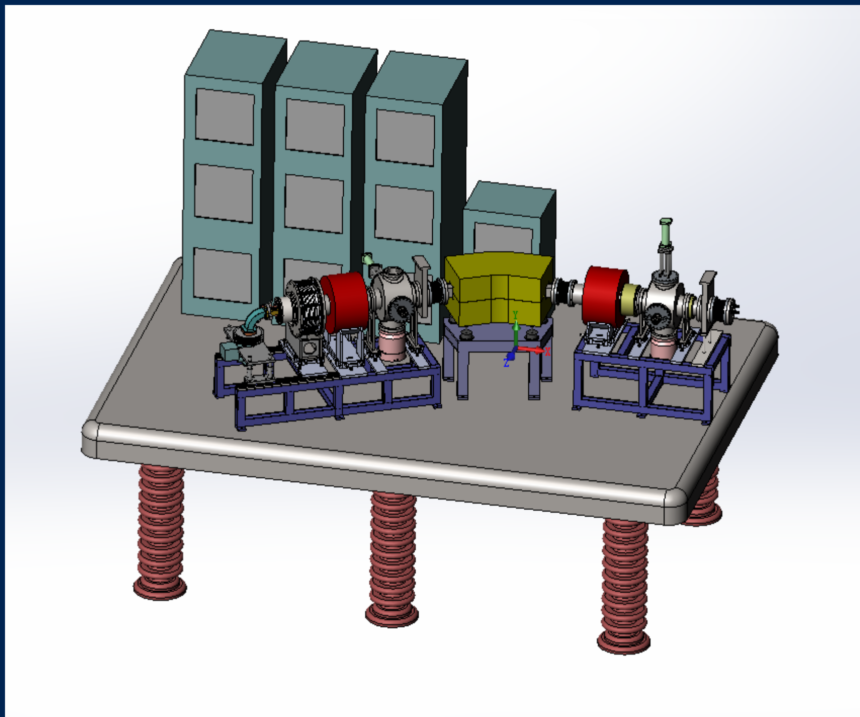


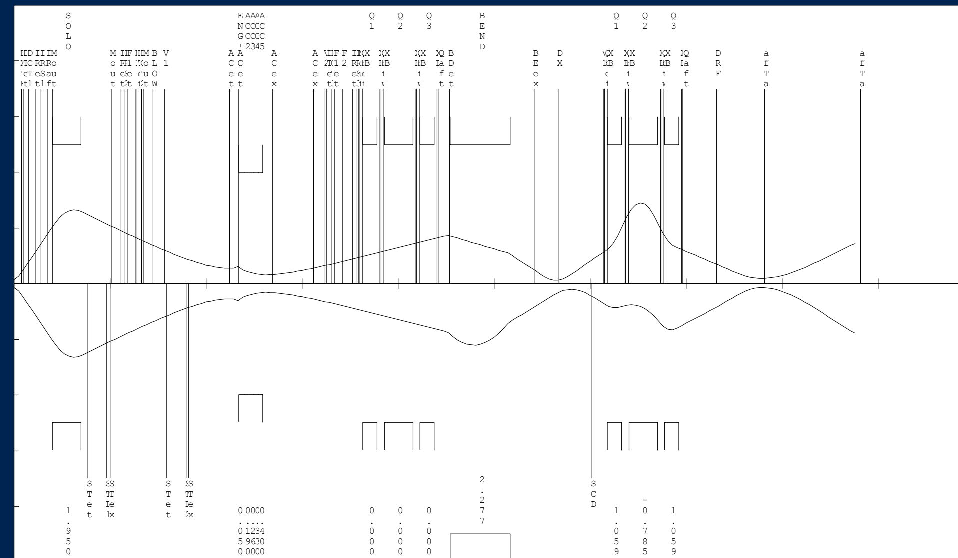
Accelerator and ion source design

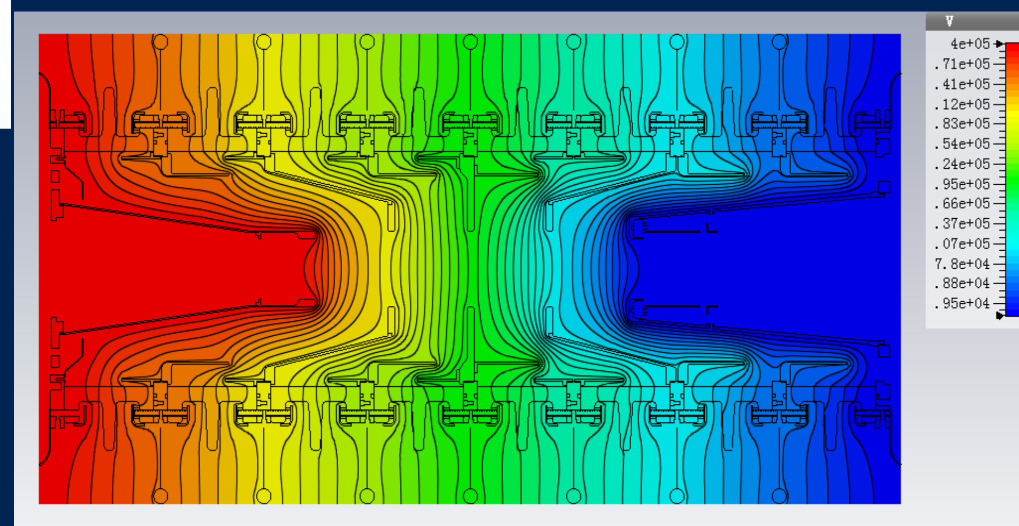




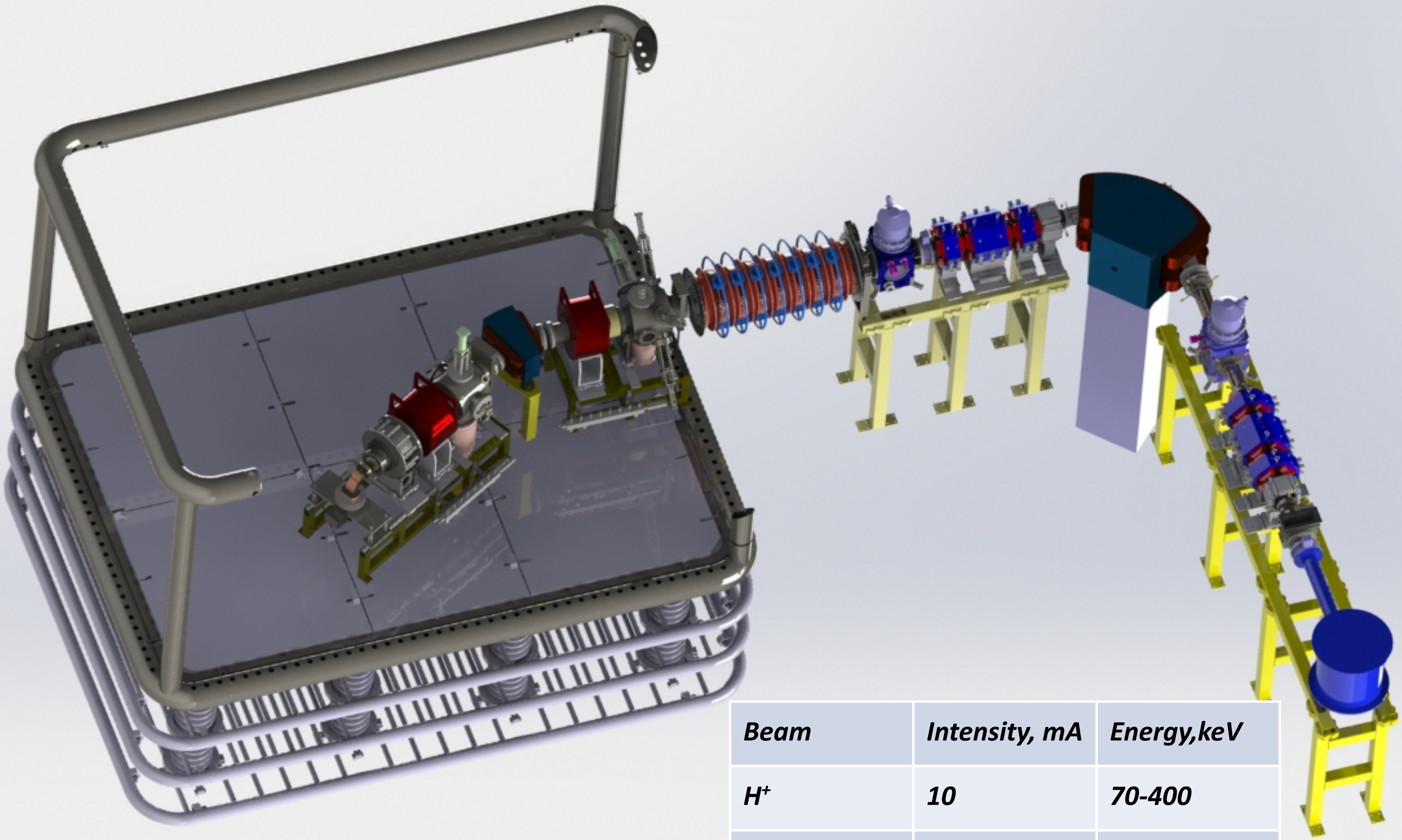
Accelerator and ion source design





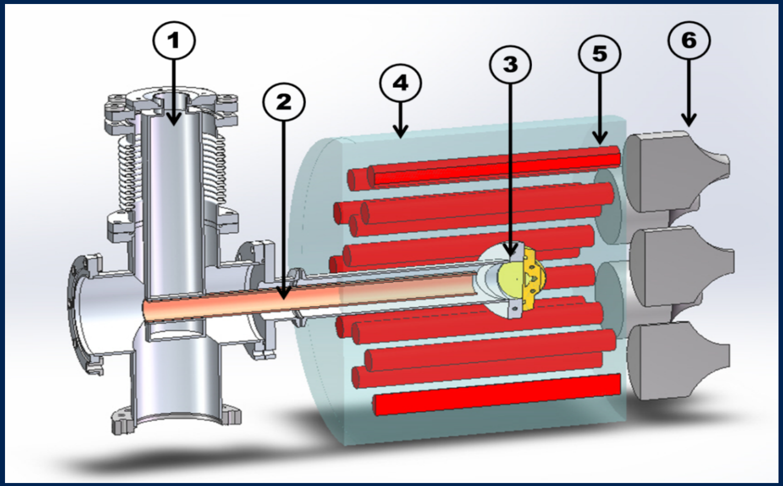


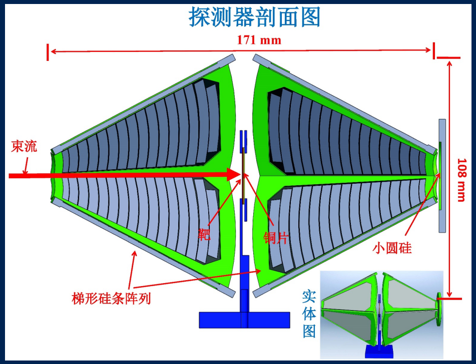
Accelerator and ion source design

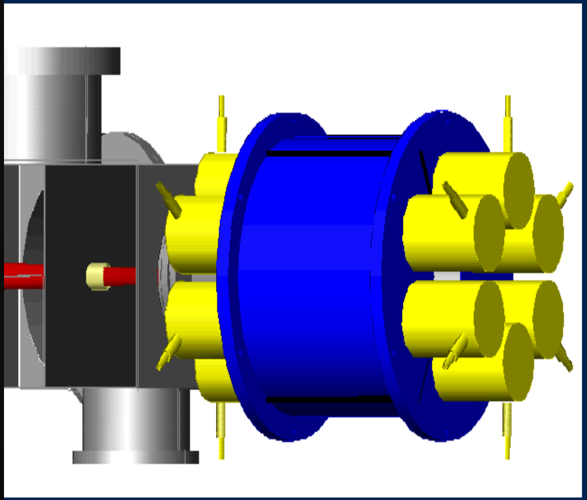


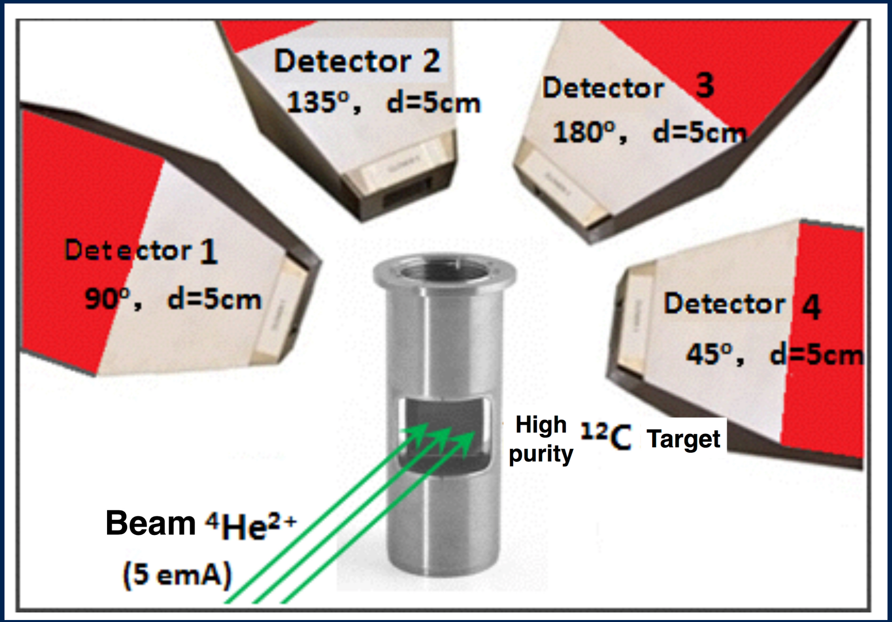
Beam	Intensity, mA	Energy,keV
H^+	10	70-400
He^+	10	70-400
He^{++}	2-5	140-800

Detector design

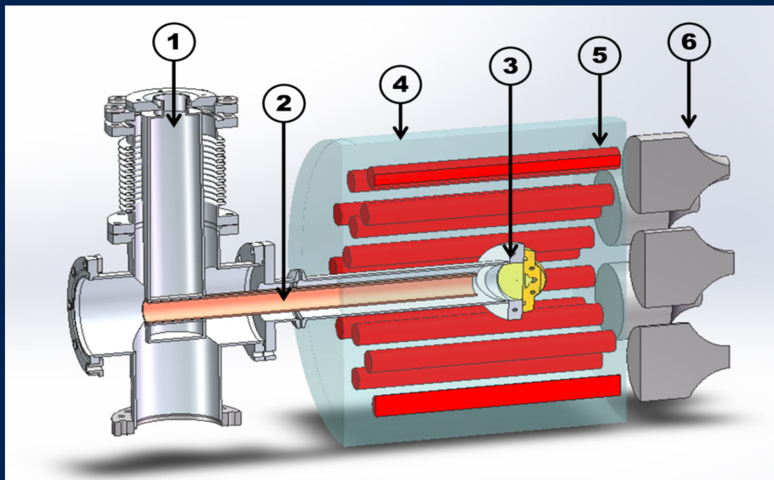


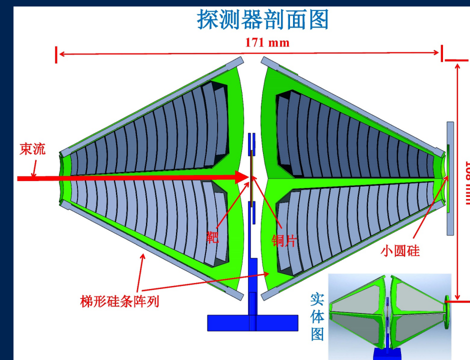


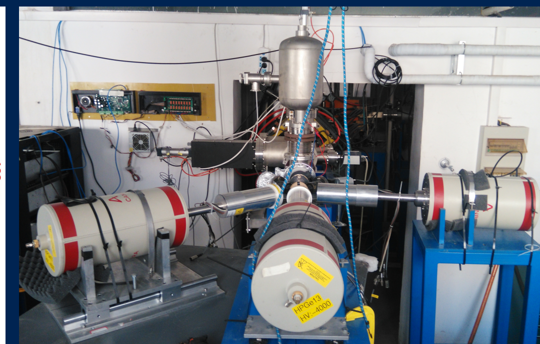


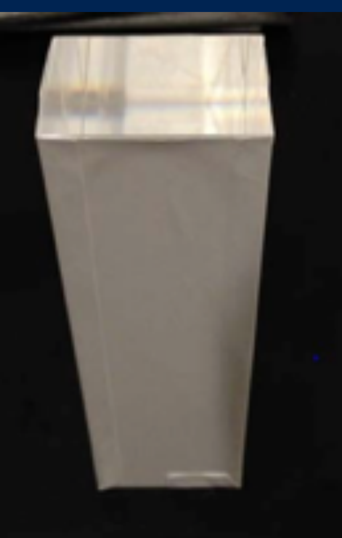


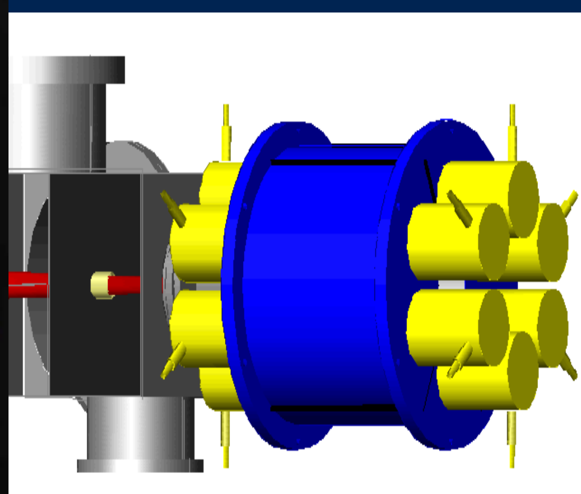
Detector design

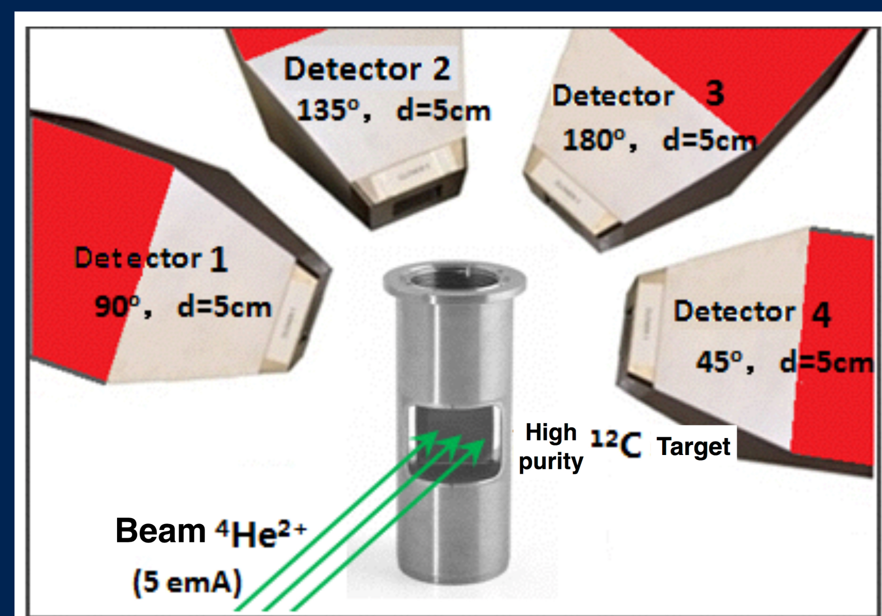




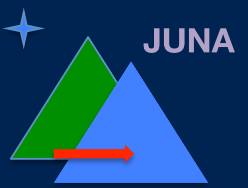


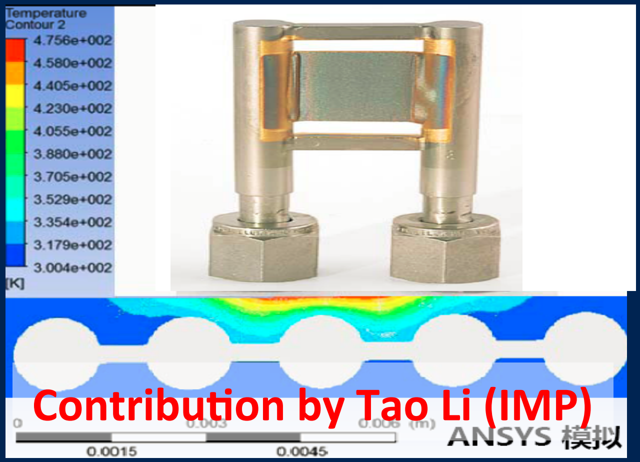


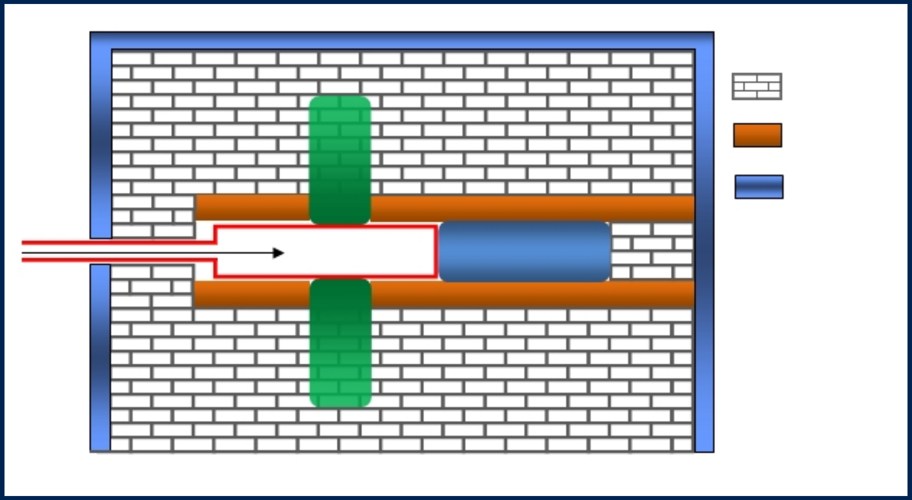


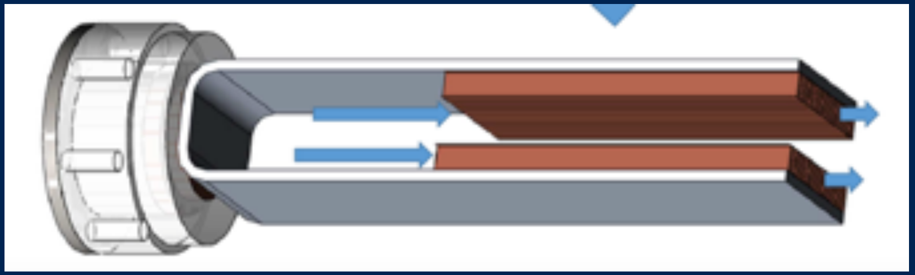


Target and shielding







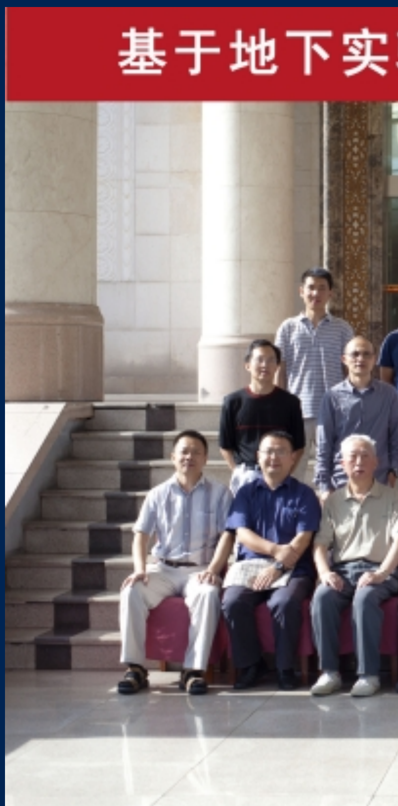


2 year application

Aug. 21, 2013, Xichang

2 year application

Aug. 21, 2013, Xichang



Dec. 24, 2014, CIAE

JUNA in Science

JUNA

PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

By **Dennis Normile**

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese physics," says Nigel Smith, director of the underground SNOLAB in Sudbury, Canada.

Opened in December 2010, CJPL is the deepest facility of its kind, with 2400 meters of rock shielding it from background radiation (see chart). The lab so far has focused on the hunt for dark matter, the universe's postulated missing mass. More space will allow larger and more sensitive dark matter detectors and an expanded research agenda that will include a nuclear astrophysics accelerator to replicate the inner workings of stars. CJPL also hopes to branch out into observing neutrinos and studying exotic particle phenomena.

Deep underground labs elsewhere have a head start in all of these areas. This means the Chinese will have to choose research targets carefully based on "if and where they can do better" than existing experiments, says Alessandro Bettini, director of the Canfranc Underground Laboratory in Spain. Others have confidence in the Chinese quickly coming up to speed. "It's a highly competitive site [with] lots of potential," says John Ellis, a theorist at King's College London who chairs a new international advisory committee that visited the lab last month.

China's ascent in underground physics began serendipitously in August 2008, when Qian Yue, a physicist at Tsinghua University in Beijing, saw a TV report about access tunnels being bored through Jinping Mountain for a massive hydroelectric project. Tsinghua approached the Yalong River Hydropower Development Co. Ltd., which agreed to excavate two experiment halls totaling 4000 cubic meters along one of the tunnels (*Science*, 5 June 2009, p. 1246).

CJPL, run by Tsinghua, now hosts two dark matter experiments. The Particle and Astrophysical Xenon (PandaX) experiment uses a 37-kilogram liquid xenon target to watch for dark matter in the form of postulated weakly interacting massive particles (WIMPs). If WIMPs exist, they should occasionally travel unmolested through the mountain and collide with a xenon nucleus, producing a flash of light. In the other experimental hall, the China Dark Matter Experiment (CDEX) aims to catch the electrical signal produced if a WIMP bumps into a nucleus within a germanium crystal. "There is complementarity" between the two approaches, says Henry Wong, a physicist at Academia Sinica's Institute of Physics in Taipei and member of the CDEX collaboration. Xenon detectors should be better at distinguishing a WIMP signal from flashes sparked by some kinds of background radiation, whereas the more sensitive germanium detectors ought to be able to spot interactions involving lighter WIMPs. Although neither experiment has yet detected a WIMP, they both have helped confirm results from other labs indicating that WIMPs are likely to have very little mass.

For an initial effort, the results are "pretty decent," says Wick Haxton, a theorist at the University of California, Berkeley. To boost its chances of sighting WIMPs and determining their mass, CJPL needs a larger volume of xenon, more germanium crystals, and better shielding. All of that requires more space. "If they significantly enlarge those experiments over the next couple years," Haxton says, "they could end up being very competitive."

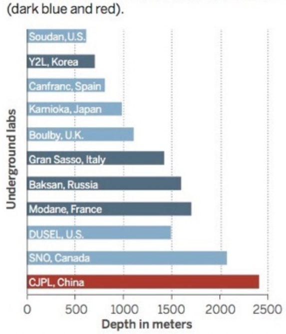
CJPL is about to get the elbow room it needs. Before the hydropower construction work wraps up next year, crews will bore another four 130-meter-long experiment halls. When lined with concrete, each will be 13.2 meters wide with an arched ceiling 13.2 meters high. All told, the enlarged facility will have 120,000 cubic meters of research space, second only to Italy's Gran Sasso National Laboratory, which has 180,000 cubic meters. By piggybacking on the hydropower project, Tsinghua limited the expansion's cost to $50 million. Yue hopes to start experiments in the new halls by the end of 2016.

CDEX aims to boost its sensitivity by increasing its germanium target from 1 to 10 kilograms and by adding more elaborate shielding. The PandaX team is thinking much bigger. "We are interested in building the ultimate dark matter experiment: a 20-ton scale liquid xenon experiment," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University and the University of Maryland, College Park. That would be several times larger than existing liquid xenon experiments. Realizing such a mammoth project, says Ji, who leads PandaX, could require teams worldwide to pool resources.

A new experiment planned for the expanded space is the Jinping Underground laboratory for Nuclear Astrophysics (JUNA). Its pièce de résistance would be a particle accelerator used to replicate the nuclear processes generating energy within stars and the synthesis of heavier elements from hydrogen and helium in the primordial universe. The rock shielding would reduce background noise, making it easier for researchers to detect rare and subtle signals. With a more powerful accelerator and a deeper location than other efforts, says project head Weiping Liu, a physicist at the China Institute of Atomic Energy in Beijing, "JUNA has the potential to take a favorable position among underground nuclear astrophysics labs." ■

Deep, dark labs

In the hunt for dark matter, deeper is better. Labs are built in mines (light blue) and tunnels (dark blue and red).



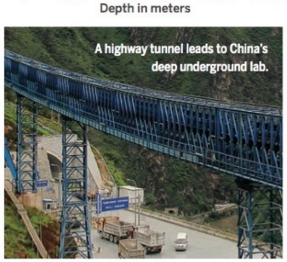

A highway tunnel leads to China's deep underground lab.

PHOTO: CJPL

Published by AAAS

JUNA in Science

JUNA

PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

By **Dennis Normile**

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese physics," says Nigel Smith, director of the underground SNOLAB in Sudbury, Canada.

Opened in December 2010, CJPL is the deepest facility of its kind, with 2400 meters of rock shielding it from background radiation (see chart). The lab so far has focused on the hunt for dark matter, the universe's postulated missing mass. More space will allow larger and more sensitive dark matter detectors and an expanded research agenda that will include a nuclear astrophysics accelerator to replicate the inner workings of stars. CJPL also hopes to branch out into observing neutrinos and studying exotic particle phenomena.

Deep underground labs elsewhere have a head start in all of these areas. This means the Chinese will have to choose research targets carefully based on "if and where they can do better" than existing experiments, says Alessandro Bettini, director of the Canfranc Underground Laboratory in Spain. Others have confidence in the Chinese quickly coming up to speed. "It's a highly competitive site [with] lots of potential," says John Ellis, a theorist at King's College London who chairs a new international advisory committee that visited the lab last month.

China's ascent in underground physics began serendipitously in August 2008, when Qian Yue, a physicist at Tsinghua University in Beijing, saw a TV report about access tunnels being bored through Jinping Mountain for a massive hydroelectric project. Tsinghua approached the Yalong River Hydropower Development Co. Ltd., which agreed to excavate two experiment halls totaling 4000 cubic meters along one of the tunnels (*Science*, 5 June 2009, p. 1246).

CJPL, run by Tsinghua, now hosts two dark matter experiments. The Particle and Astrophysical Xenon (PandaX) experiment uses a 37-kilogram liquid xenon target to watch for dark matter in the form of postulated weakly interacting massive particles (WIMPs). If WIMPs exist, they should occasionally travel unmolested through the mountain and collide with a xenon nucleus, producing a flash of light. In the other experimental hall, the China Dark Matter Experiment (CDEX) aims to catch the electrical signal produced if a WIMP bumps into a nucleus within a germanium crystal. "There is complementarity" between the two approaches, says Henry Wong, a physicist at Academia Sinica's Institute of Physics in Taipei and member of the CDEX collaboration. Xenon detectors should be better at distinguishing a WIMP signal from flashes sparked by some kinds of background radiation, whereas the more sensitive germanium detectors ought to be able to spot interactions involving lighter WIMPs. Although neither experiment has yet detected a WIMP, they both have helped confirm results from other labs indicating that WIMPs are likely to have very little mass.

For an initial effort, the results are "pretty decent," says Wick Haxton, a theorist at the University of California, Berkeley. To boost its chances of sighting WIMPs and determining their mass, CJPL needs a larger volume of xenon, more germanium crystals, and better shielding. All of that requires more space. "If they significantly enlarge those experiments over the next couple years," Haxton says, "they could end up being very competitive."

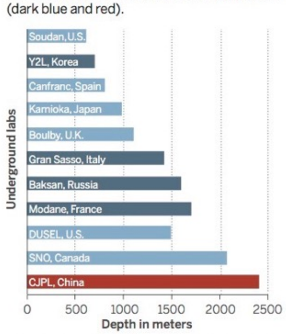
CJPL is about to get the elbow room it needs. Before the hydropower construction work wraps up next year, crews will bore another four 130-meter-long experiment halls. When lined with concrete, each will be 13.2 meters wide with an arched ceiling 13.2 meters high. All told, the enlarged facility will have 120,000 cubic meters of research space, second only to Italy's Gran Sasso National Laboratory, which has 180,000 cubic meters. By piggybacking on the hydropower project, Tsinghua limited the expansion's cost to $50 million. Yue hopes to start experiments in the new halls by the end of 2016.

CDEX aims to boost its sensitivity by increasing its germanium target from 1 to 10 kilograms and by adding more elaborate shielding. The PandaX team is thinking much bigger. "We are interested in building the ultimate dark matter experiment: a 20-ton scale liquid xenon experiment," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University and the University of Maryland, College Park. That would be several times larger than existing liquid xenon experiments. Realizing such a mammoth project, says Ji, who leads PandaX, could require teams worldwide to pool resources.

A new experiment planned for the expanded space is the Jinping Underground laboratory for Nuclear Astrophysics (JUNA). Its pièce de résistance would be a particle accelerator used to replicate the nuclear processes generating energy within stars and the synthesis of heavier elements from hydrogen and helium in the primordial universe. The rock shielding would reduce background noise, making it easier for researchers to detect rare and subtle signals. With a more powerful accelerator and a deeper location than other efforts, says project head Weiping Liu, a physicist at the China Institute of Atomic Energy in Beijing, "JUNA has the potential to take a favorable position among underground nuclear astrophysics labs." ■

Deep, dark labs

In the hunt for dark matter, deeper is better. Labs are built in mines (light blue) and tunnels (dark blue and red).



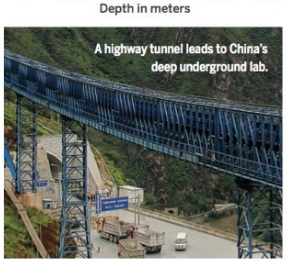

A highway tunnel leads to China's deep underground lab.

PHOTO: CJPL

Published by AAAS

detectors and an expanded research agenda that will include a nuclear astrophysics accelerator to replicate the inner workings of stars. CJPL also hopes to branch out into ob-

JUNA in Science

JUNA

PHYSICS

China supersizes its underground physics lab

Planned expansion could pave way for "ultimate dark matter experiment"

By **Dennis Normile**

The world's deepest physics laboratory is about to become one of its largest. Early next year, workers will start carving four cavernous experiment halls along a tunnel through Jinping Mountain in China's Sichuan province. Once the science at the China Jinping Underground Laboratory (CJPL) is scaled up as well, "it will be a milestone for Chinese physics," says Nigel Smith, director of the underground SNOLAB in Sudbury, Canada.

Opened in December 2010, CJPL is the deepest facility of its kind, with 2400 meters of rock shielding it from background radiation (see chart). The lab so far has focused on the hunt for dark matter, the universe's postulated missing mass. More space will allow larger and more sensitive dark matter detectors and an expanded research agenda that will include a nuclear astrophysics accelerator to replicate the inner workings of stars. CJPL also hopes to branch out into observing neutrinos and studying exotic particle phenomena.

Deep underground labs elsewhere have a head start in all of these areas. This means the Chinese will have to choose research targets carefully based on "if and where they can do better" than existing experiments, says Alessandro Bettini, director of the Canfranc Underground Laboratory in Spain. Others have confidence in the Chinese quickly coming up to speed. "It's a highly competitive site [with] lots of potential," says John Ellis, a theorist at King's College London who chairs a new international advisory committee that visited the lab last month.

China's ascent in underground physics began serendipitously in August 2008, when Qian Yue, a physicist at Tsinghua University in Beijing, saw a TV report about access tunnels being bored through Jinping Mountain for a massive hydroelectric project. Tsinghua approached the Yalong River Hydropower Development Co. Ltd., which agreed to excavate two experiment halls totaling 4000 cubic meters along one of the tunnels (*Science*, 5 June 2009, p. 1246).

CJPL, run by Tsinghua, now hosts two dark matter experiments. The Particle and Astrophysical Xenon (PandaX) experiment uses a 37-kilogram liquid xenon target to watch for dark matter in the form of postulated weakly interacting massive particles (WIMPs). If WIMPs exist, they should occasionally travel unmolested through the mountain and collide with a xenon nucleus, producing a flash of light. In the other experimental hall, the China Dark Matter Experiment (CDEX) aims to catch the electrical signal produced if a WIMP bumps into a nucleus within a germanium crystal. "There is complementarity" between the two approaches, says Henry Wong, a physicist at Academia Sinica's Institute of Physics in Taipei and member of the CDEX collaboration. Xenon detectors should be better at distinguishing a WIMP signal from flashes sparked by some kinds of background radiation, whereas the more sensitive germanium detectors ought to be able to spot interactions involving lighter WIMPs. Although neither experiment has yet detected a WIMP, they both have helped confirm results from other labs indicating that WIMPs are likely to have very little mass.

For an initial effort, the results are "pretty decent," says Wick Haxton, a theorist at the University of California, Berkeley. To boost its chances of sighting WIMPs and determining their mass, CJPL needs a larger volume of xenon, more germanium crystals, and better shielding. All of that requires more space. "If they significantly enlarge those experiments over the next couple years," Haxton says, "they could end up being very competitive."

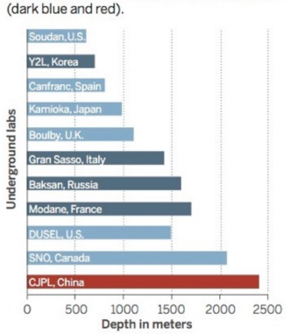
CJPL is about to get the elbow room it needs. Before the hydropower construction work wraps up next year, crews will bore another four 130-meter-long experiment halls. When lined with concrete, each will be 13.2 meters wide with an arched ceiling 13.2 meters high. All told, the enlarged facility will have 120,000 cubic meters of research space, second only to Italy's Gran Sasso National Laboratory, which has 180,000 cubic meters. By piggybacking on the hydropower project, Tsinghua limited the expansion's cost to $50 million. Yue hopes to start experiments in the new halls by the end of 2016.

CDEX aims to boost its sensitivity by increasing its germanium target from 1 to 10 kilograms and by adding more elaborate shielding. The PandaX team is thinking much bigger. "We are interested in building the ultimate dark matter experiment: a 20-ton scale liquid xenon experiment," says Xiangdong Ji, a physicist at Shanghai Jiao Tong University and the University of Maryland, College Park. That would be several times larger than existing liquid xenon experiments. Realizing such a mammoth project, says Ji, who leads PandaX, could require teams worldwide to pool resources.

A new experiment planned for the expanded space is the Jinping Underground laboratory for Nuclear Astrophysics (JUNA). Its pièce de résistance would be a particle accelerator used to replicate the nuclear processes generating energy within stars and the synthesis of heavier elements from hydrogen and helium in the primordial universe. The rock shielding would reduce background noise, making it easier for researchers to detect rare and subtle signals. With a more powerful accelerator and a deeper location than other efforts, says project head Weiping Liu, a physicist at the China Institute of Atomic Energy in Beijing, "JUNA has the potential to take a favorable position among underground nuclear astrophysics labs." ■

Deep, dark labs

In the hunt for dark matter, deeper is better. Labs are built in mines (light blue) and tunnels (dark blue and red).



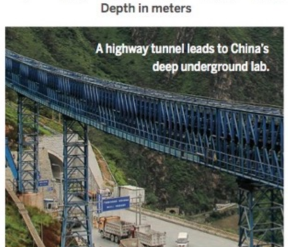

A highway tunnel leads to China's deep underground lab.

PHOTO: CJPL

Published by AAAS

detectors and an expanded research agenda that will include a nuclear astrophysics accelerator to replicate the inner workings of stars. CJPL also hopes to branch out into ob-

A new experiment planned for the expanded space is the Jinping Underground laboratory for Nuclear Astrophysics (JUNA). Its pièce de résistance would be a particle accelerator used to replicate the nuclear processes generating energy within stars and the synthesis of heavier elements from hydrogen and helium in the primordial universe. The rock shielding would reduce background noise, making it easier for researchers to detect rare and subtle signals. With a more powerful accelerator and a deeper location than other efforts, says project head Weiping Liu, a physicist at the China Institute of Atomic Energy in Beijing, "JUNA has the potential to take a favorable position among underground nuclear astrophysics labs." ■

JUNA-I reaction summary

Physics	Reaction	Current	JUNA goal
Massive star	$^{12}C(\alpha,\gamma)^{16}O$	60% 890 keV	test 380 keV
Heavy ion synthesis	$^{13}C(\alpha,n)^{16}O$	60% 279 keV	20% 200 keV
Galaxy ^{26}Al source	$^{25}Mg(p,\gamma)^{26}Al$	20% 92 keV	15 % 58 keV
F aboundace	$^{19}F(p,\alpha)^{16}O$	30 % 180 keV	10% 70 keV
Underground technique	Low background,	10^{-14} b	10^{-17} b

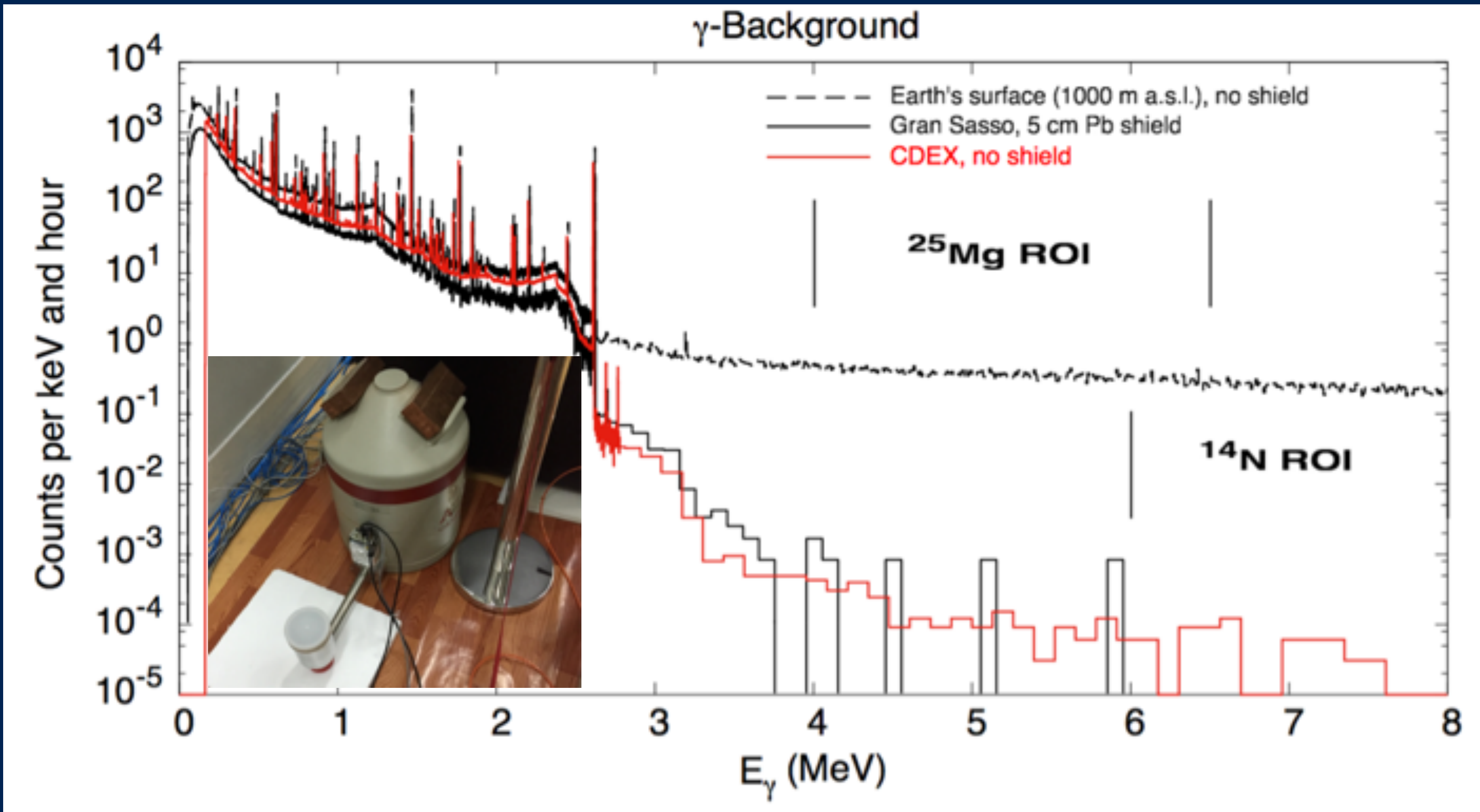
JUNA-I reaction summary

JUNA

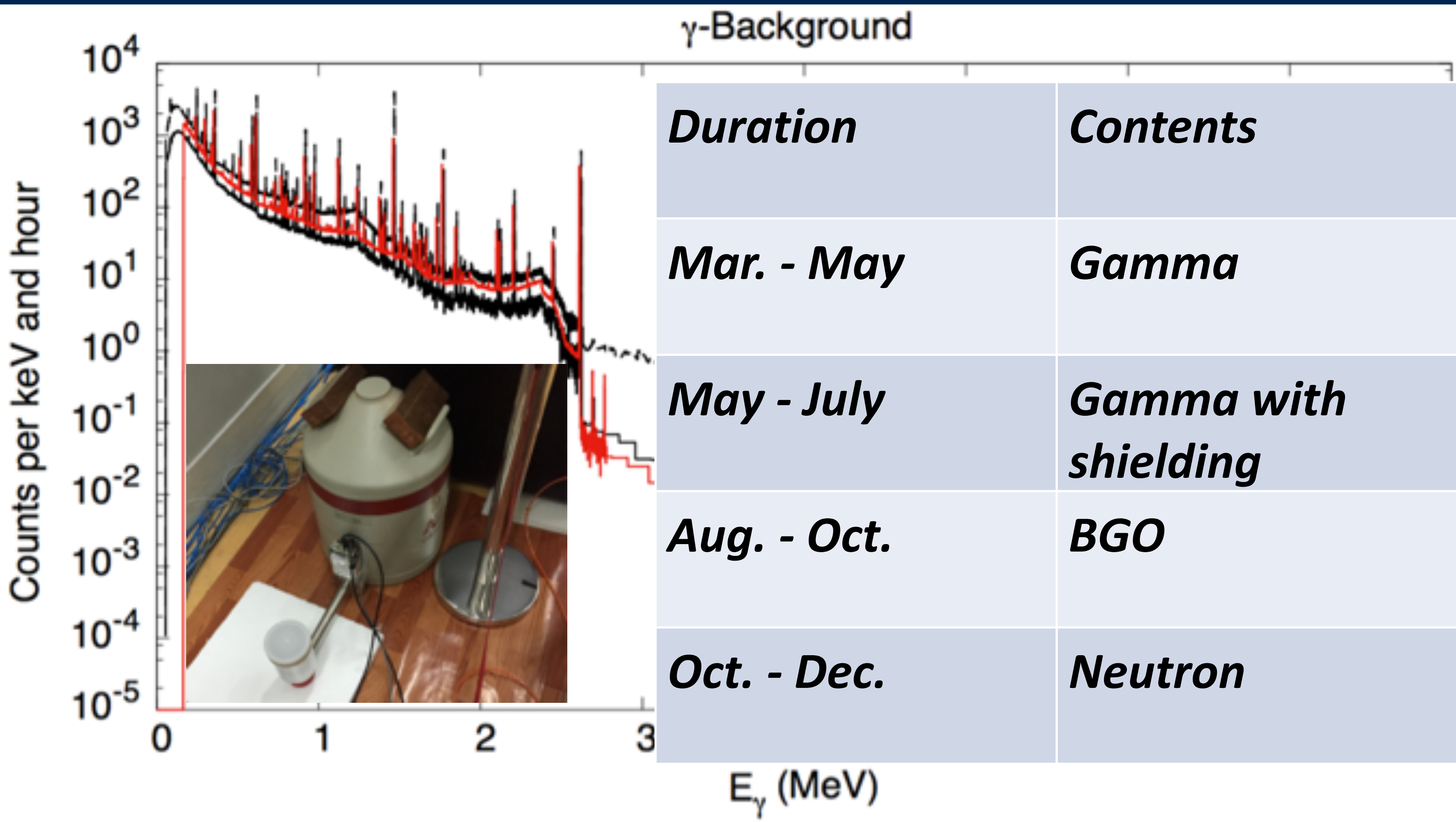
Physics	Reaction	Current	JUNA goal
Massive star	$^{12}C(\alpha,\gamma)^{16}O$	60% 890 keV	test 380 keV
Heavy ion synthesis	$^{13}C(\alpha,n)^{16}O$	60% 279 keV	20% 200 keV
Galaxy ^{26}Al source	$^{25}Mg(p,\gamma)^{26}Al$	20% 92 keV	15 % 58 keV
F aboundace	$^{19}F(p,\alpha)^{16}O$	30 % 180 keV	10% 70 keV
Underground technique	Low background.	10^{-14} b	10^{-17} b

reaction	Beam	Intensity	EC.M.	Cross section	Target thickness	Efficiency	CTS	BGD
$^{12}C(\alpha,\gamma)^{16}O$	He^{2+}	2.5 emA	380 keV	10^{-13} mb	10^{18} atoms/cm^2	75 %	0.2 /day	0.2 /day
$^{13}C(\alpha,n)^{16}O$	He^{1+}	10 emA	200 keV	10^{-12} mb	10^{21} atoms/cm^2	20 %	7 /day	1/day
$^{25}Mg(p,\gamma)^{26}Al$	H^+	10 emA	58 keV	$\omega\gamma=2.1\times10^{-13}$ eV	0.6 μg/cm^2	38 %	1.4 /day	0.2 /day
$^{19}F(p,\alpha)^{16}O$	H^+	0.1 emA	70 keV	10^{-9} mb	4 μg/cm^2	38 %	13 /day	0.2 /day

Background in CJPL



Background in CJPL

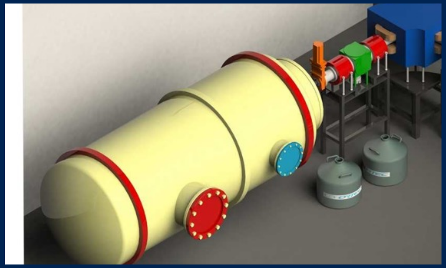


Duration	*Contents*
Mar. - May	*Gamma*
May - July	*Gamma with shielding*
Aug. - Oct.	*BGO*
Oct. - Dec.	*Neutron*

JUNA-II plan

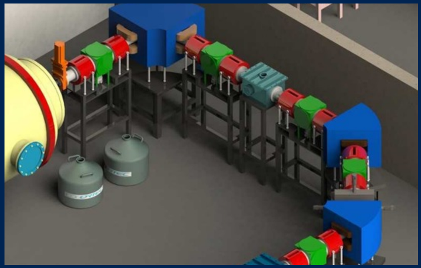
JUNA

CJPL-II cave 4



4MV accelerator

Windowless target

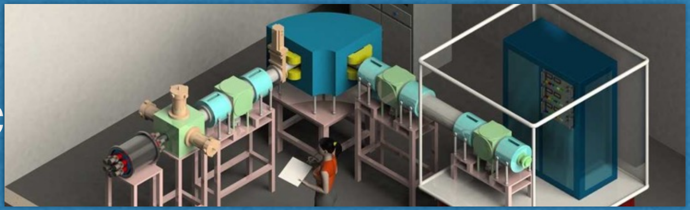


RMS

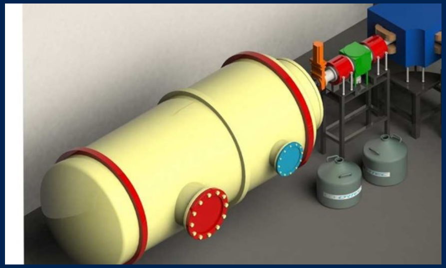
Detectors

JUNA-II plan

CJPL-II c

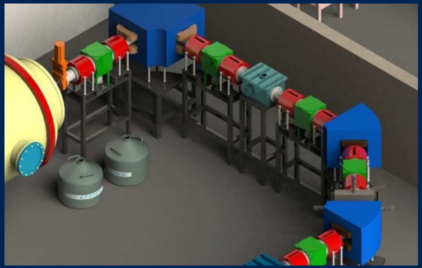


JUNA-I



4MV accelerator

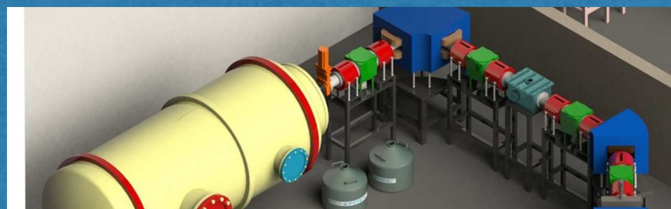
Windowless target



RMS

Detectors

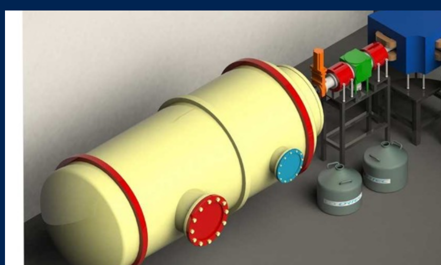
JUNA-II plan



c

JUNA-II

JUNA-I



4MV accelerator

Windowless target

RMS

Detectors

JUNA schedule

JUNA-I

JUNA-I 2015-2019

JUNA schedule

JUNA

Background
2015

JUNA-I

JUNA-I 2015-2019

JUNA schedule

JUNA

Background 2015

Fabrication 2016

JUNA-I

JUNA-I 2015-2019

JUNA schedule

JUNA

Background 2015 | Fabrication 2016 | Installation 2017

JUNA-I 2015-2019

JUNA schedule

JUNA

Background 2015	Fabrication 2016	Installation 2017	Experiment 2018-2019

JUNA-I 2015-2019

JUNA schedule

JUNA

Background 2015 | Fabrication 2016 | Installation 2017 | Experiment 2018-2019

JUNA-I 2015-2019

JUNA-IE 2020-2024

JUNA-II 2018-2023

JUNA-IIE 2023-

JUNA plan

JUNA

H burning

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

$^{2}H(\alpha,\gamma)^{6}Li$

$^{3}He(^{3}He,2p)^{4}He$

$^{7}Be(p,\gamma)^{8}B$

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

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

$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$

$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$

$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

He burning

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

$^{16}O(\alpha,\gamma)^{20}Ne$

$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$

$^{22}Ne(\alpha,\gamma)^{26}Mg$

$^{24}Mg(\alpha,\gamma)^{28}Si$

n source

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

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

$^{25}Mg(\alpha,n)^{28}Si$

$^{26}Mg(\alpha,n)^{29}Si$

C, O burning

$^{12}C+^{12}C$

$^{12}C+^{16}O$

$^{16}O+^{16}O$

γ astronomy

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

JUNA plan

JUNA

H burning

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

$^{2}H(\alpha,\gamma)^{6}Li$

$^{3}He(^{3}He,2p)^{4}He$

$^{7}Be(p,\gamma)^{8}B$

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

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

$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$

$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$

$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

He burning

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

$^{16}O(\alpha,\gamma)^{20}Ne$

$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$

$^{22}Ne(\alpha,\gamma)^{26}Mg$

$^{24}Mg(\alpha,\gamma)^{28}Si$

n source

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

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

$^{25}Mg(\alpha,n)^{28}Si$

$^{26}Mg(\alpha,n)^{29}Si$

C, O burning

$^{12}C+^{12}C$

$^{12}C+^{16}O$

$^{16}O+^{16}O$

γ astronomy

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

JUNA-I

JUNA plan

JUNA

H burning

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

$^{2}H(\alpha,\gamma)^{6}Li$

$^{3}He(^{3}He,2p)^{4}He$

$^{7}Be(p,\gamma)^{8}B$

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

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

$^{15}N(p,\gamma),(p,\alpha)^{16}O,^{12}C$

$^{17}O(p,\gamma),(p,\alpha)^{18}F,^{14}N$

$^{18}O(p,\gamma),(p,\alpha)^{19}F,^{15}N$

$^{19}F(p,\gamma),(p,\alpha)^{20}Ne,^{16}O$

He burning

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

$^{16}O(\alpha,\gamma)^{20}Ne$

$^{20}Ne(\alpha,\gamma)^{24}Mg$

$^{18}O(\alpha,\gamma)^{22}Ne$

$^{22}Ne(\alpha,\gamma)^{26}Mg$

$^{24}Mg(\alpha,\gamma)^{28}Si$

n source

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

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

$^{25}Mg(\alpha,n)^{28}Si$

$^{26}Mg(\alpha,n)^{29}Si$

C, O burning

$^{12}C+^{12}C$

$^{12}C+^{16}O$

$^{16}O+^{16}O$

γ astronomy

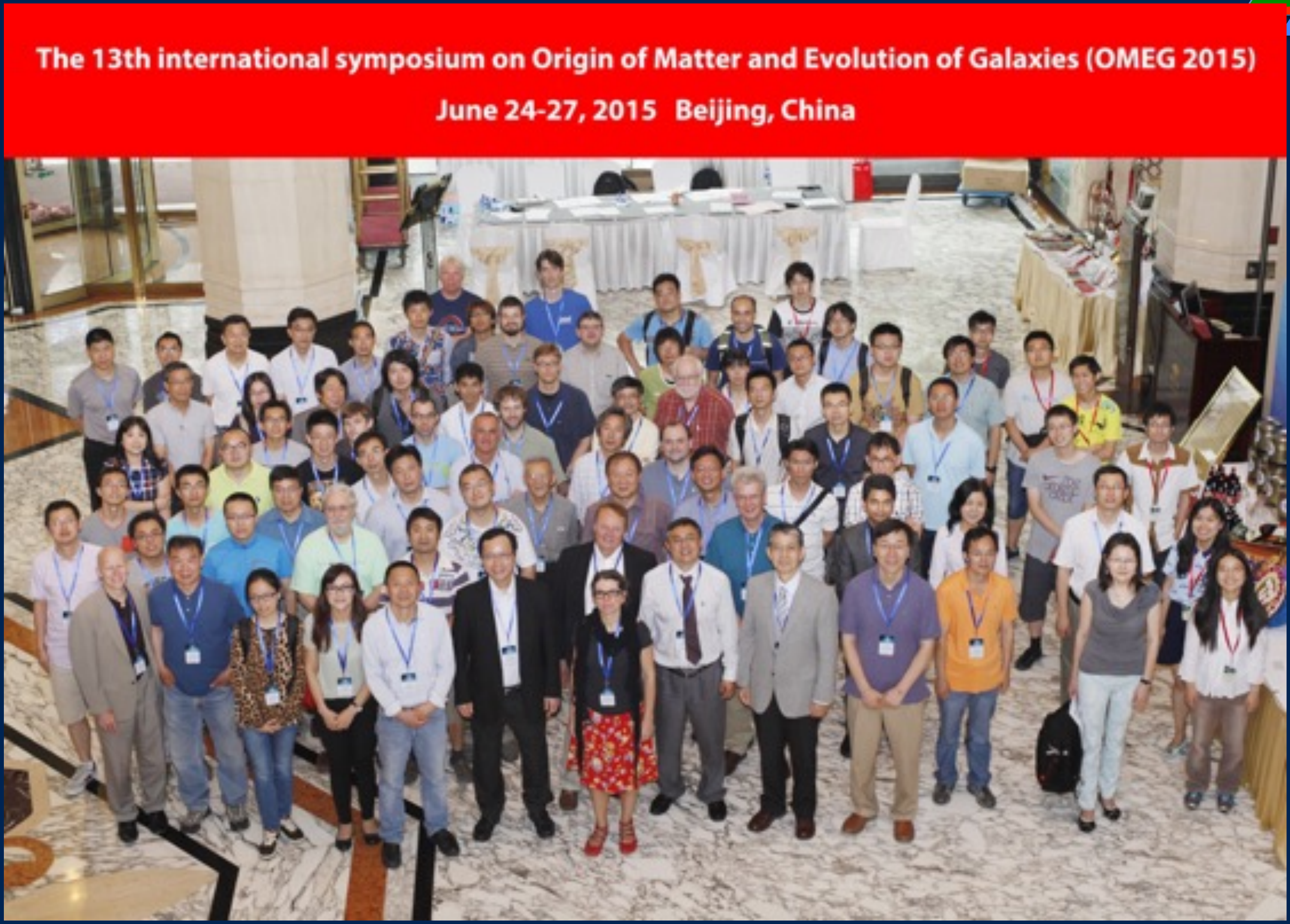
$^{25}Mg(p,\gamma)^{26}Al$:

JUNA-I

JUNA-II

OMEG

JUNA



The 14th will be in Korea in 2017!

Summary

- **Nuclear astrophysics in good progress in China**
- **In-direct approach still productive, decay and mass measurement get new finding**
- **RI facilities in Beijing and China give a contribution in word forces**
- **Underground JUNA will open up new frontier**
- **More collaboration needed to nuclear physics and nuclear astrophysics in Asia, in which ANPhA will take an active role**