Progress of nuclear astrophysics in China and JUNA project

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INPC, 2016

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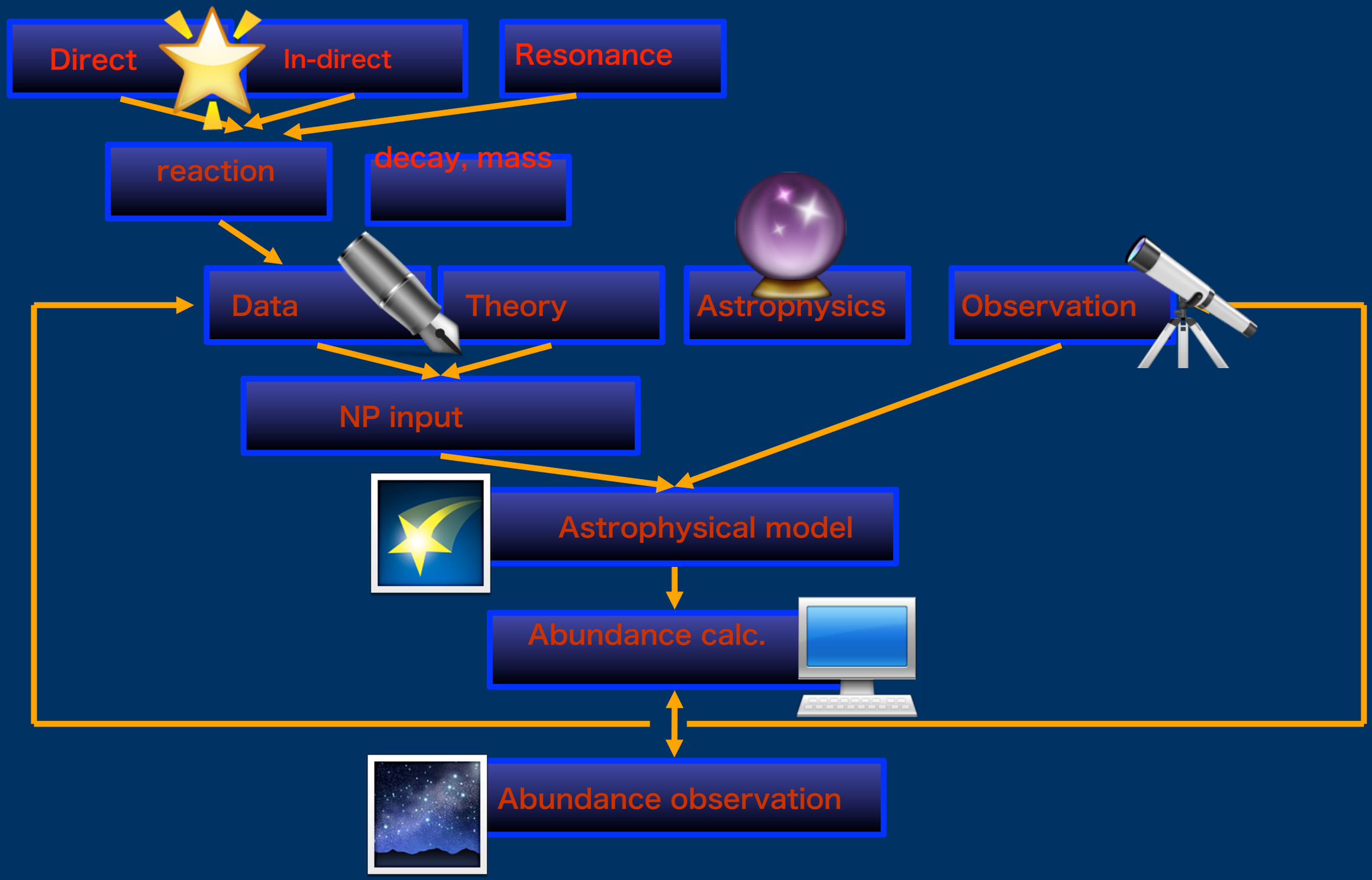
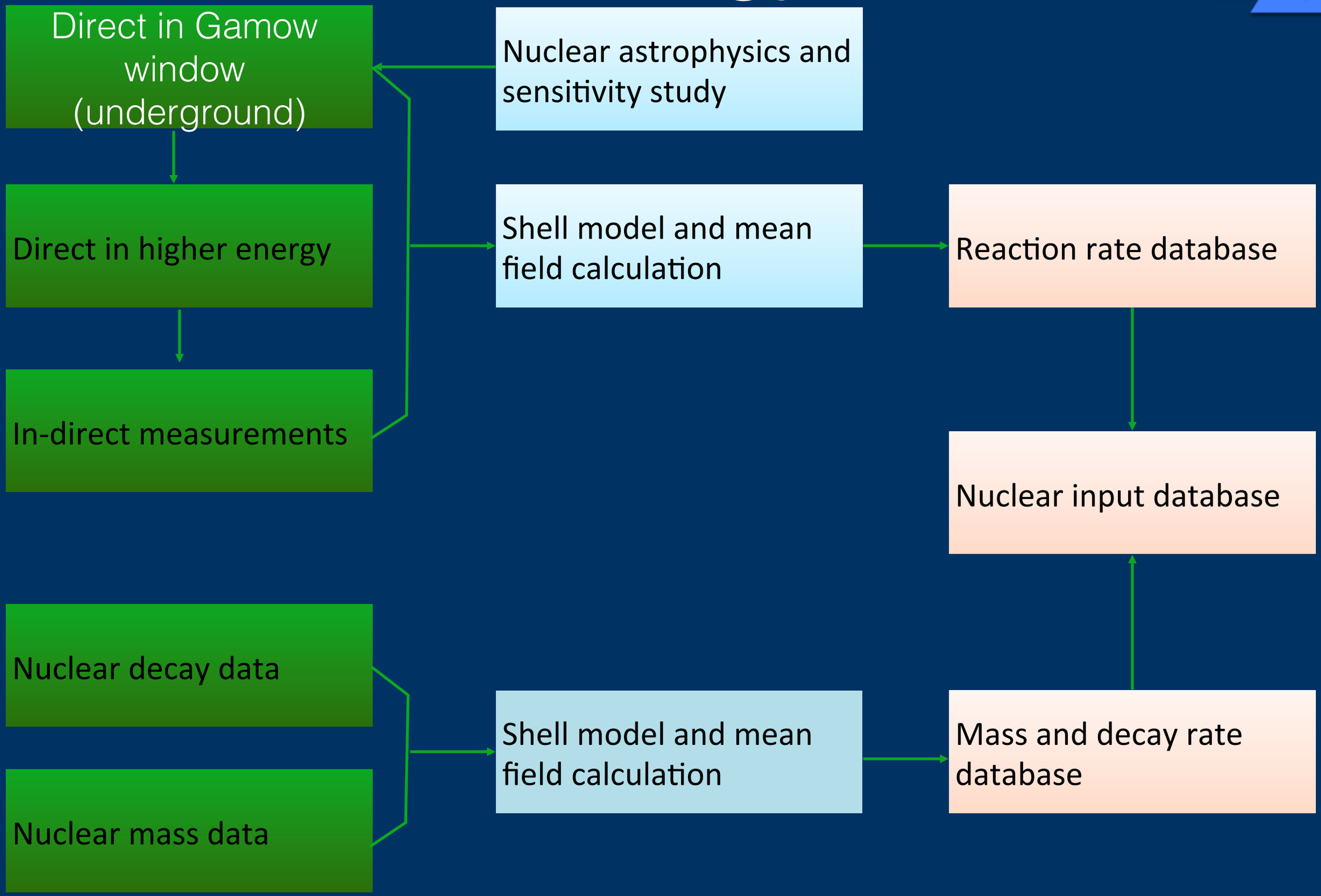
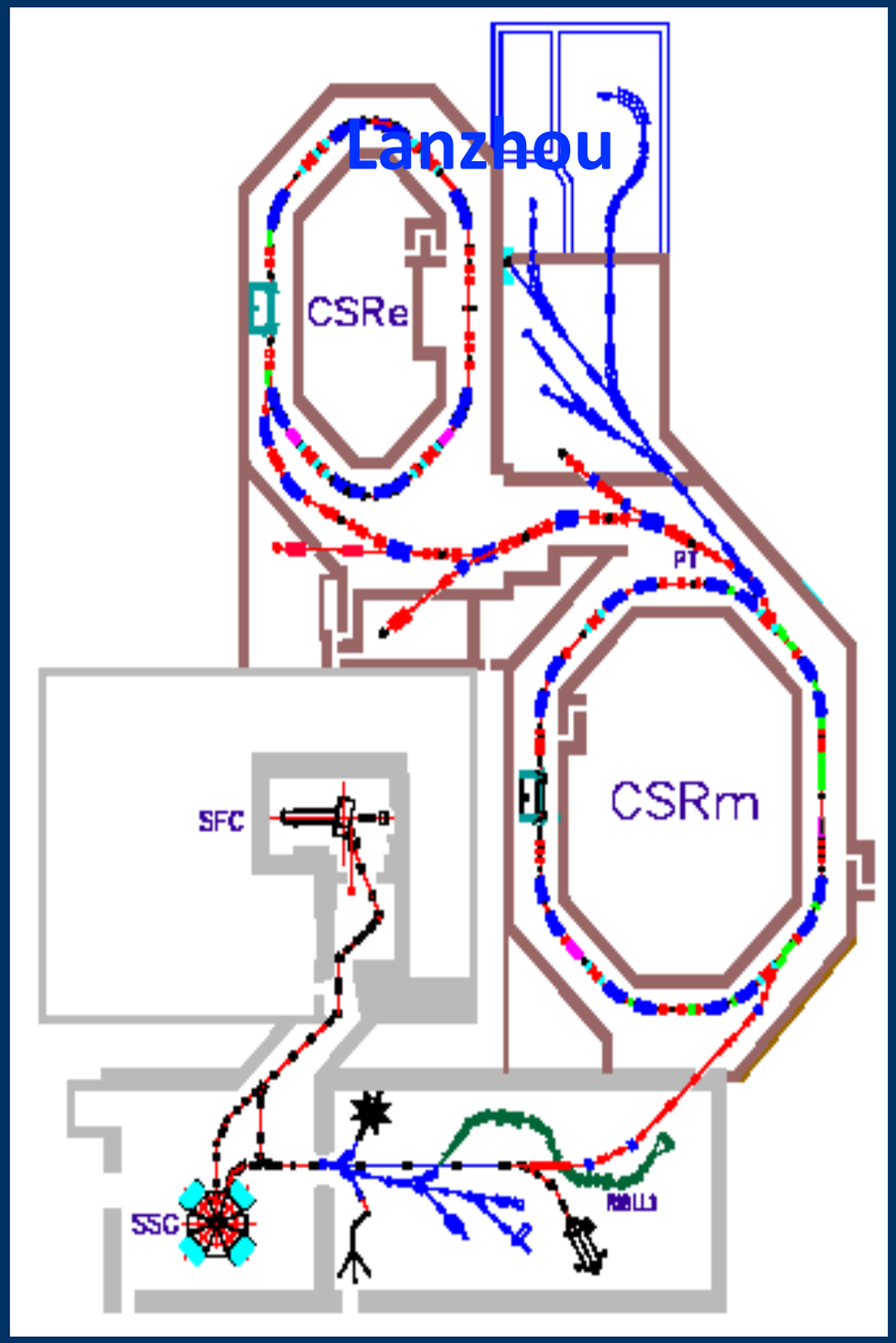
Nuclear Astrophysics roadmap

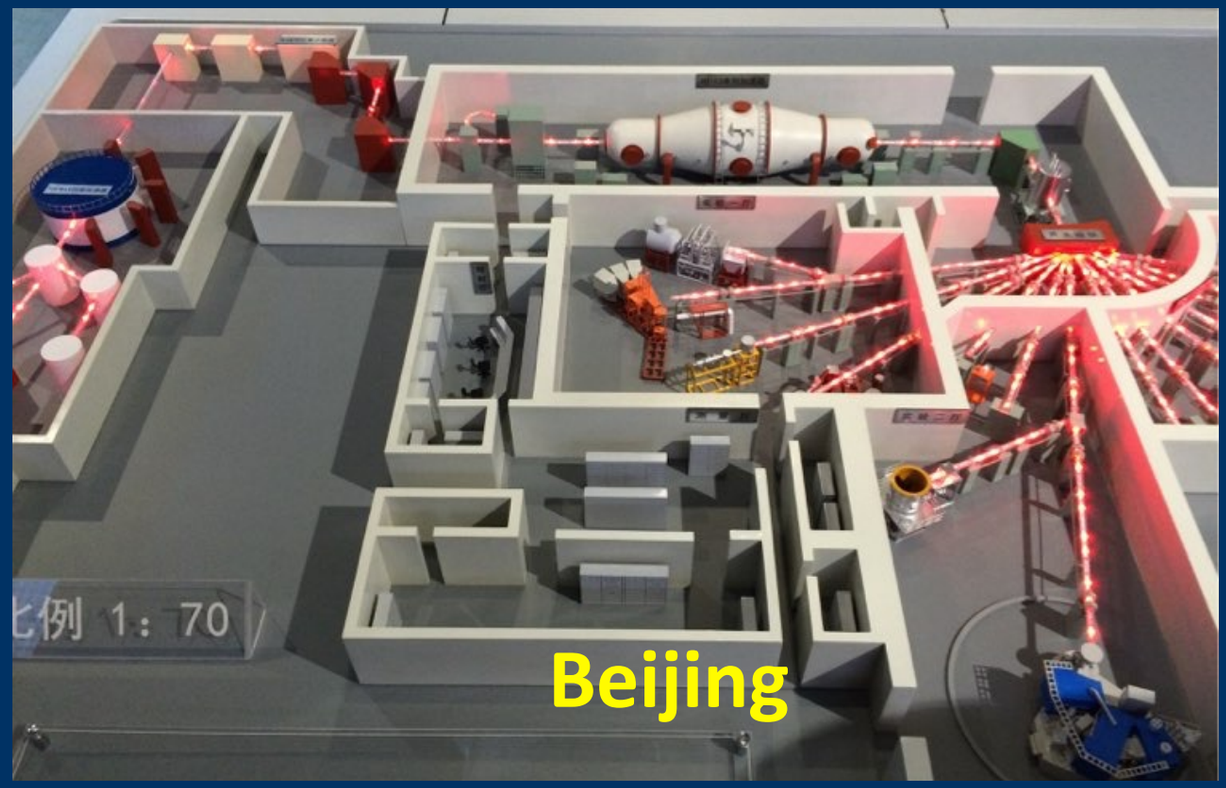


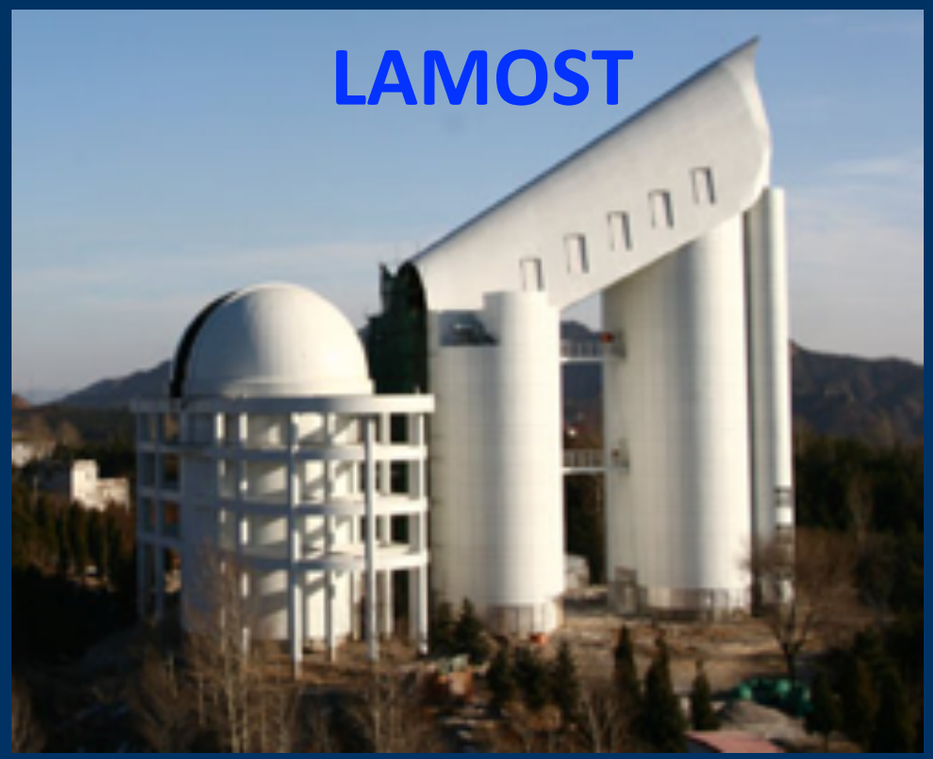
Methodology



Big platforms in China







Milestones of NA in China

1993, first RI beam line in China

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

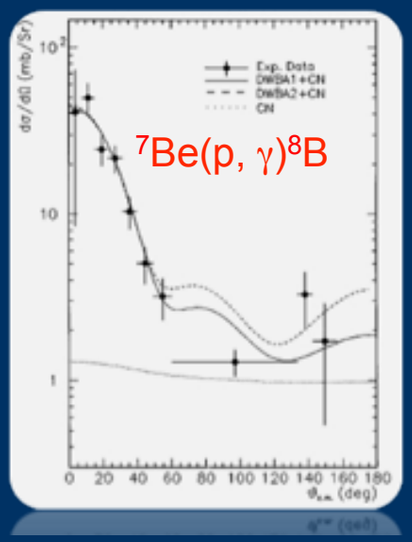
2011, NSFC group fund for Nucl. Astrophys.

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

2015, NSFC major fund for JUNA

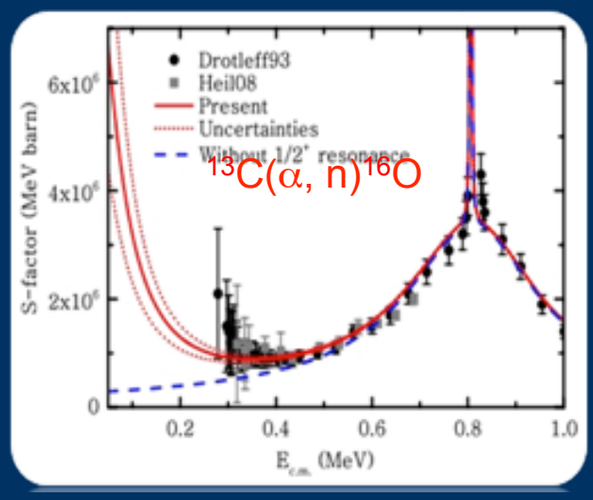
1993 → 1996 → 2005 → 2010 → 2012 → 2014 → 2015

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

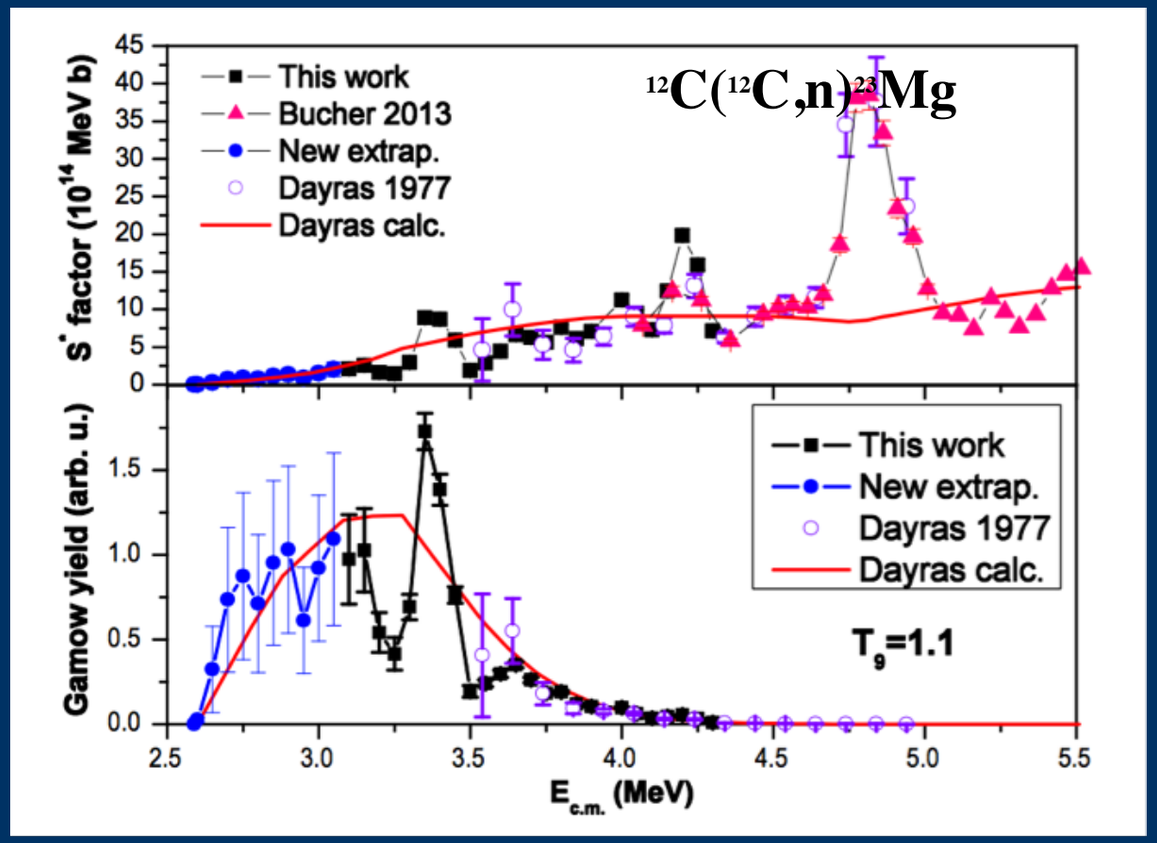


2011, rp mass PRL, APJ

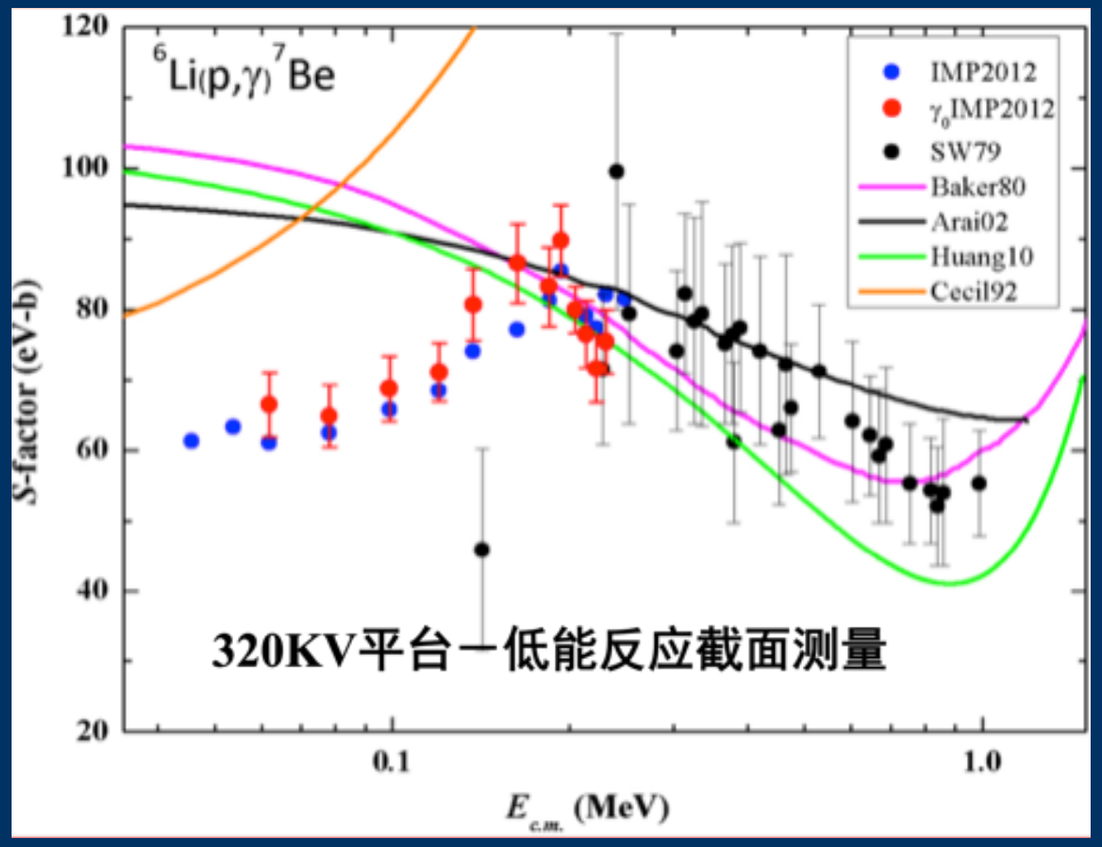
2012, $^{13}C(\alpha, n)^{16}O$ in-direct in APJ



Direct measurement

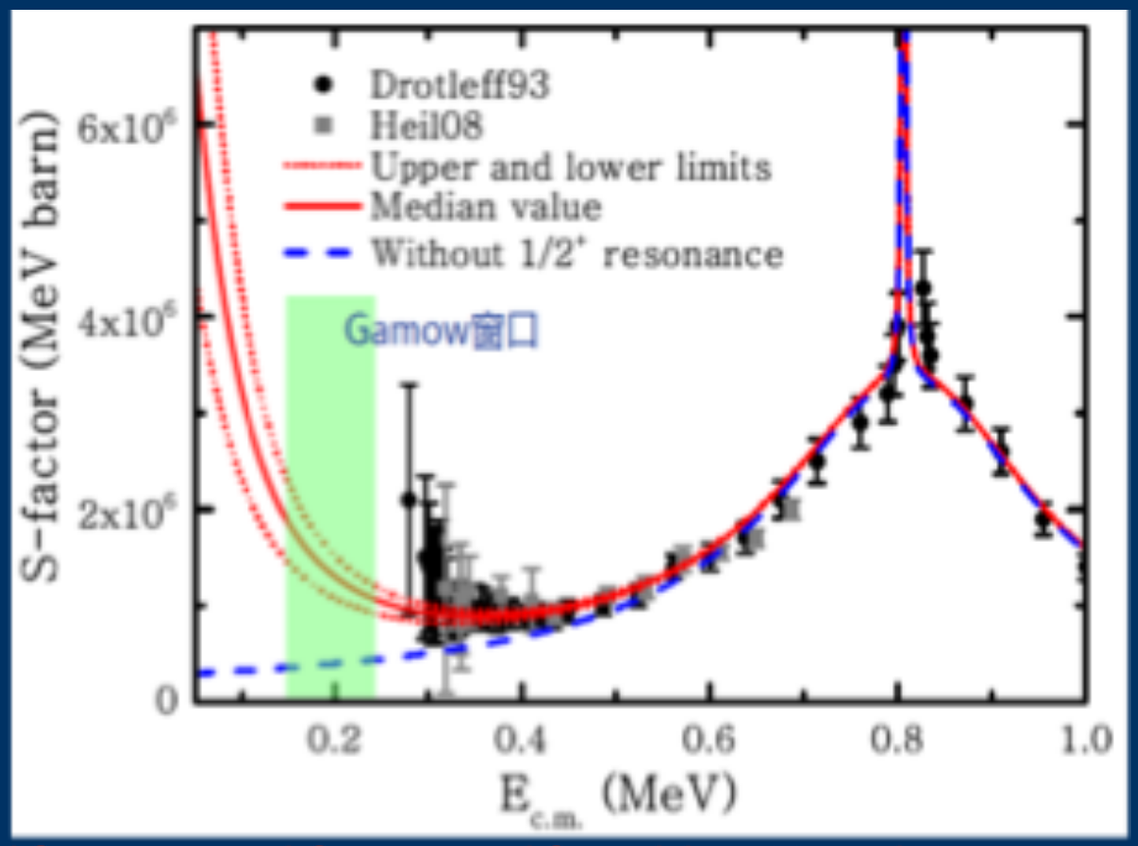


B. Bucher, X. D. Tang* et al., PRL 114(2015)251102

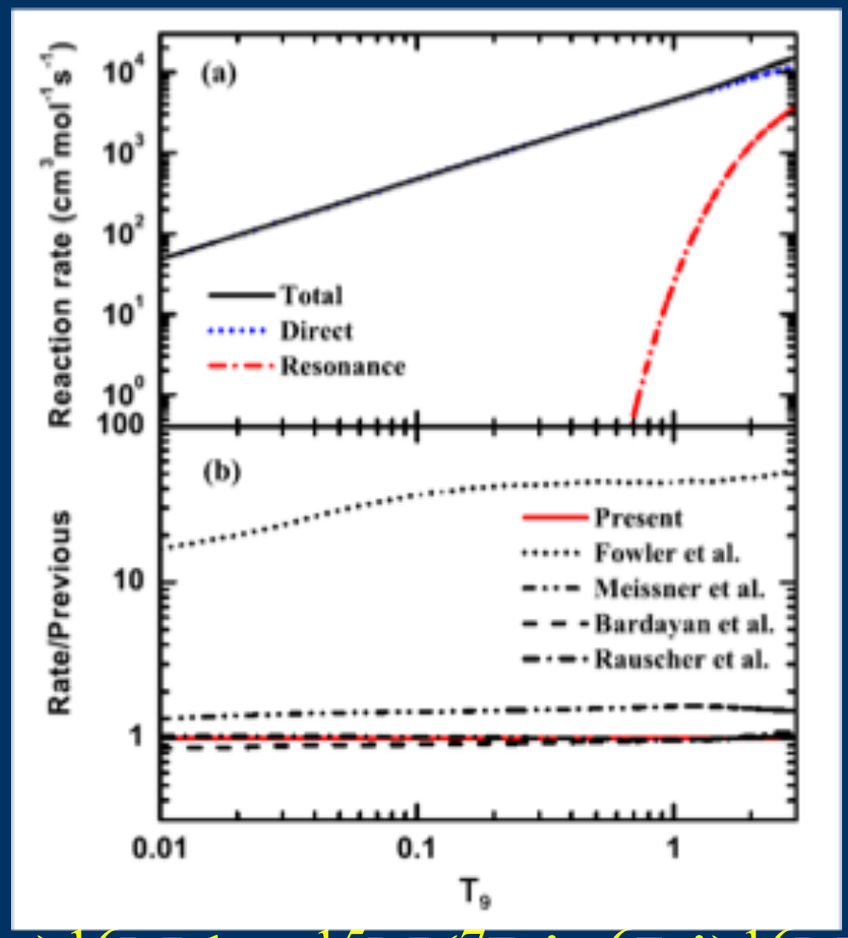


J.J. He, et al., PL B 725 (2013) 287

Indirect measurement



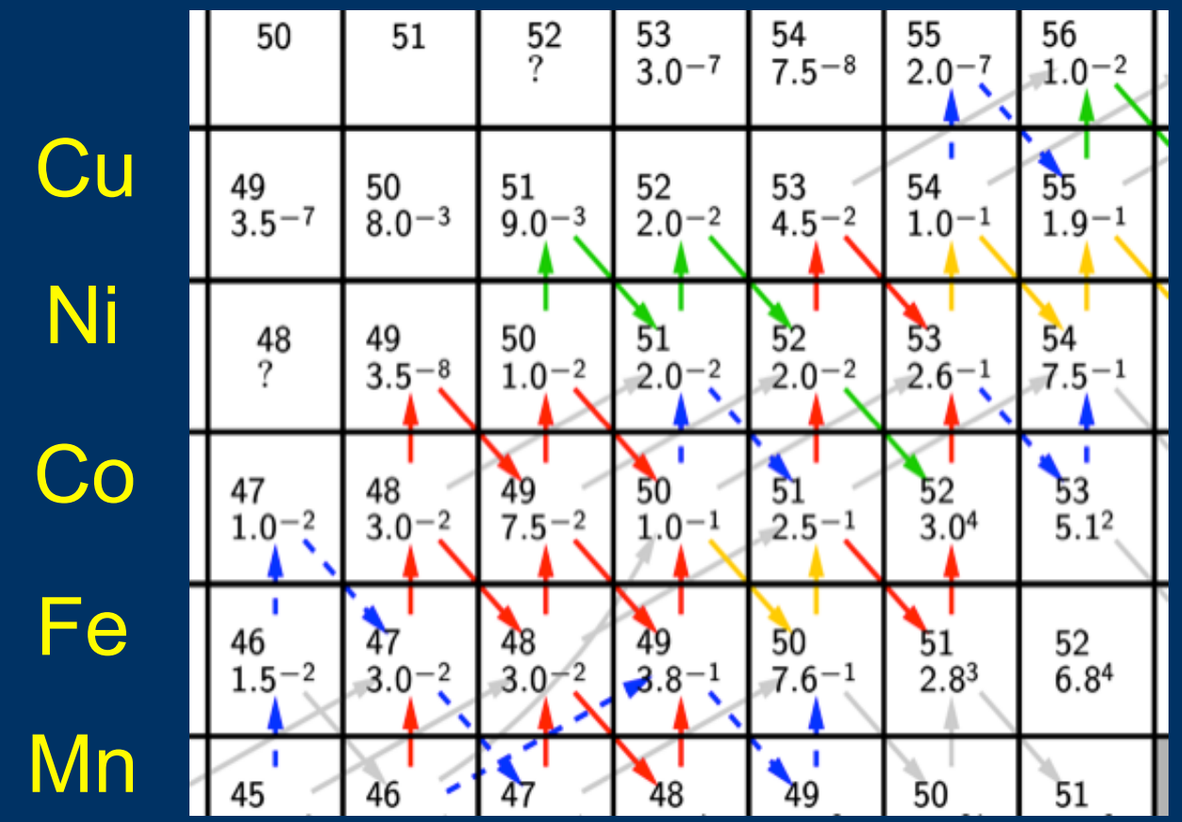
$^{13}C(\alpha,n)^{16}O$ by $^{13}C(^{11}B,^{7}Li)^{17}O$
B. Guo , Z. H. Li et al. , APJ, 756 (2012) 193

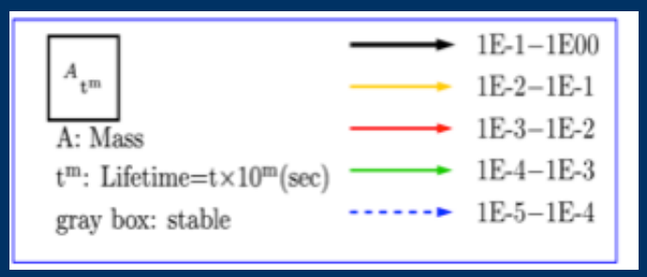


$^{15}N(n,\gamma)^{16}N$ by $^{15}N(^{7}Li, ^{6}Li)^{16}N$
B. Guo, Z. H. Li et al., PRC 89 (2014) 012801(R)

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

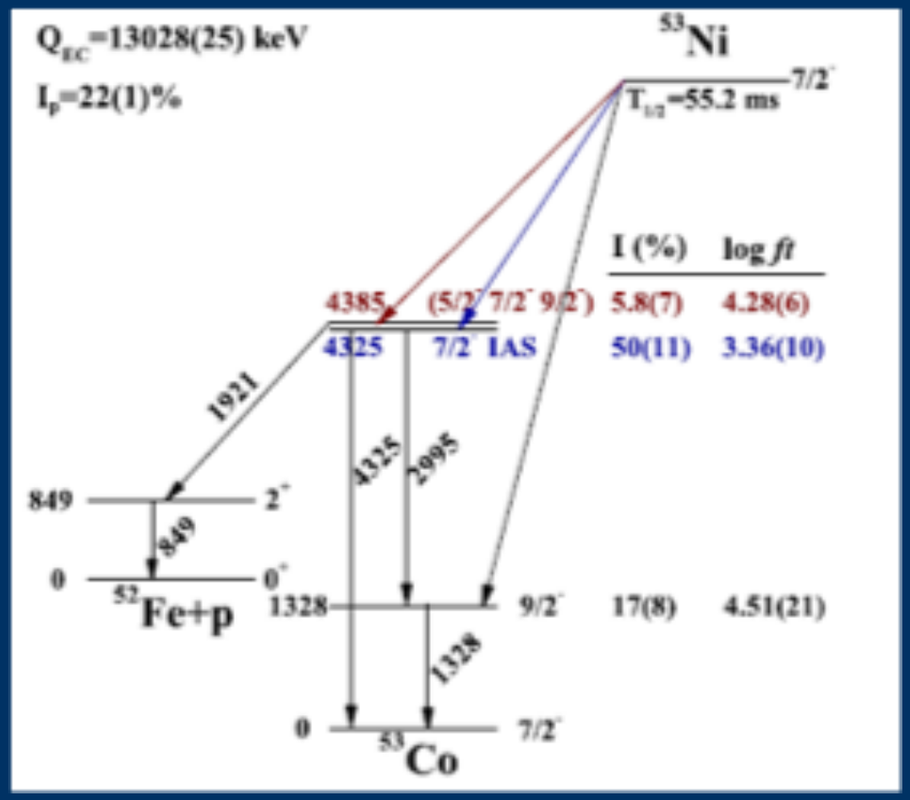


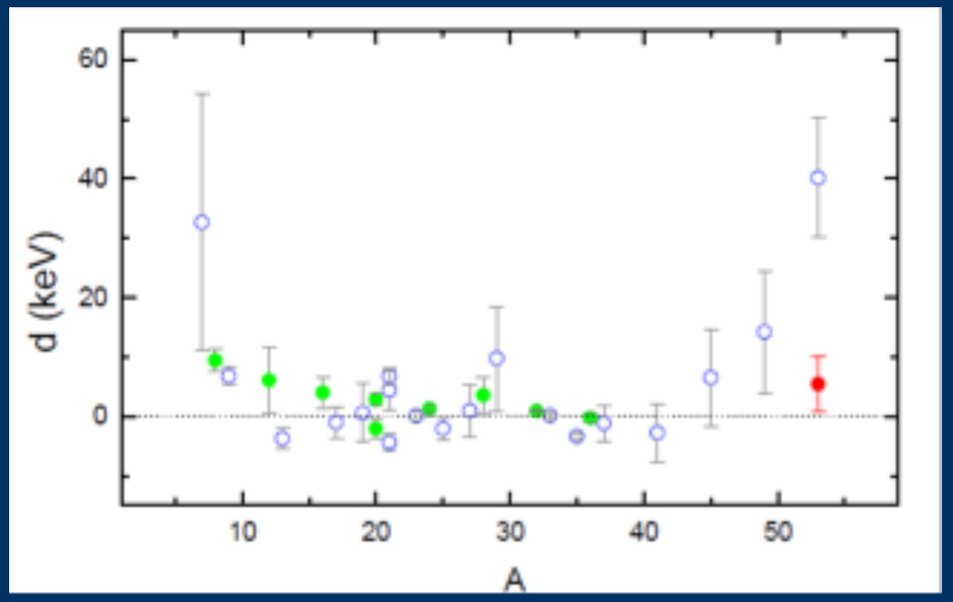


J. su et al., CIAE, Phys. Rev. C 87 ,024312 (2013)

Testing IMME

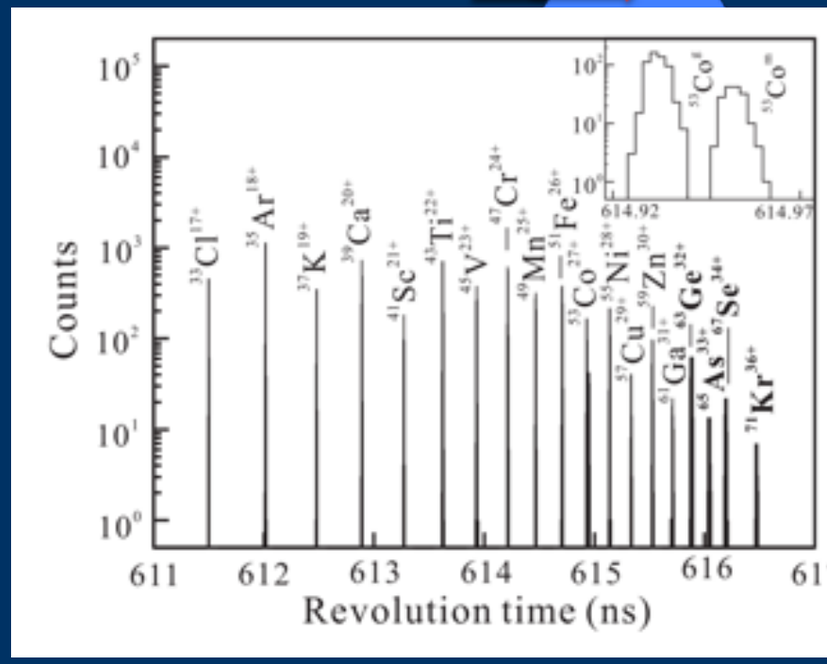
$$M(T, T_z) = a + bT_z + cT_z^2 + \mathbf{dT_z^3}$$

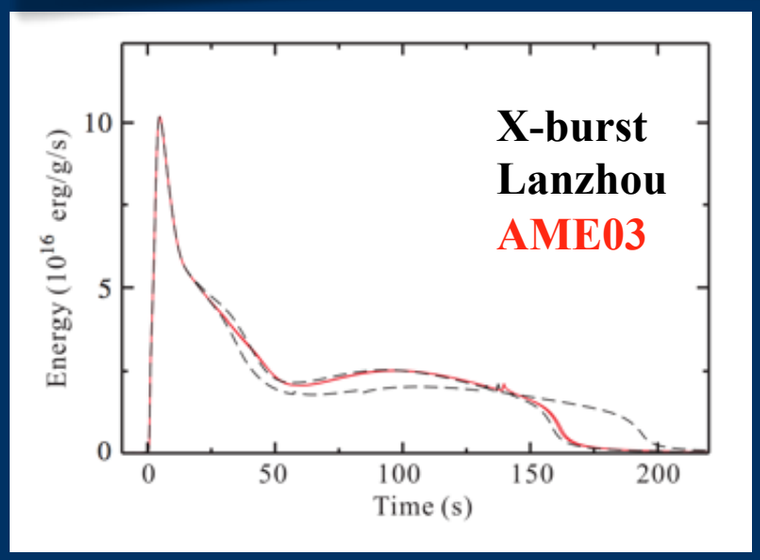


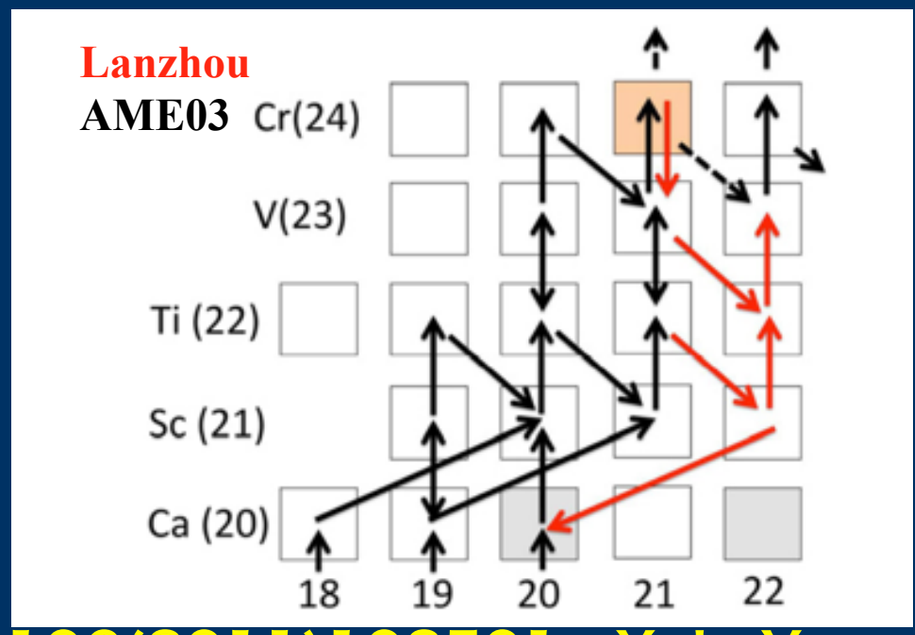


J. Su, W. P. Liu et al., PLB756(2016)323

Mass in CSR Lanzhou



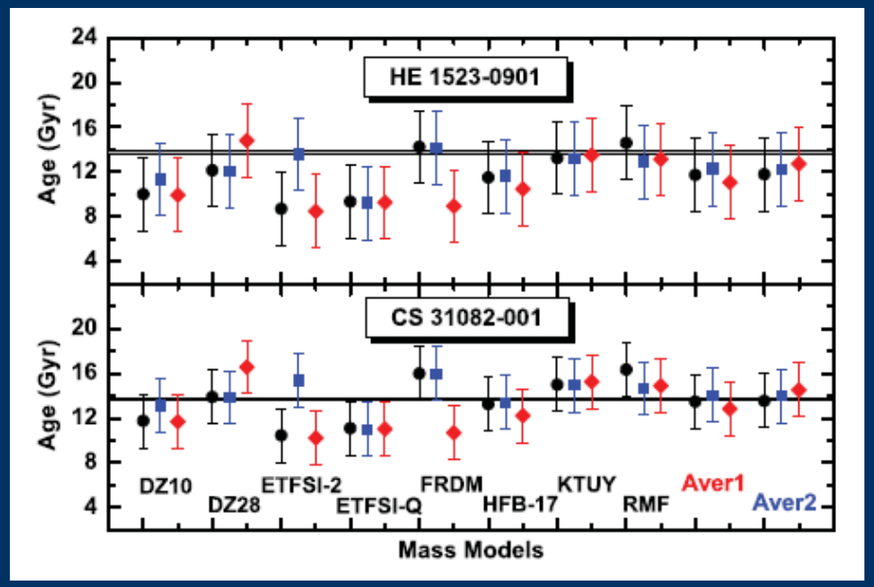




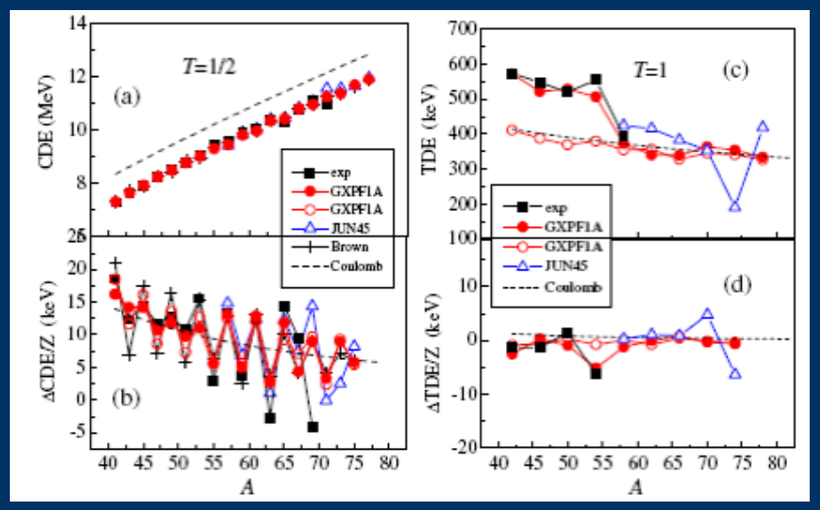
X. L. Tu et al., PRL106(2011)102501; X. L. Yan et al., ApJL 766(2013)8, IMP

More from M. Wang in this meeting

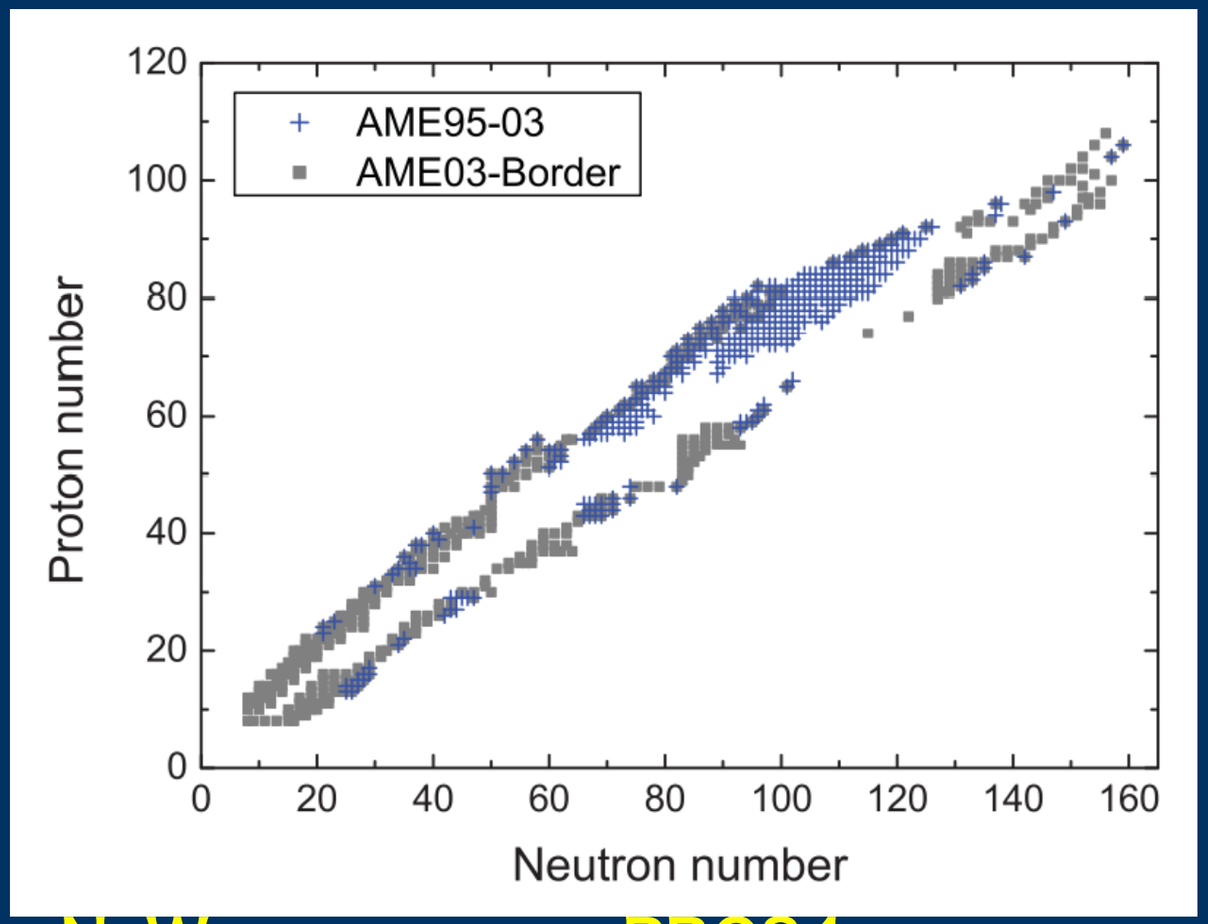
Theory



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

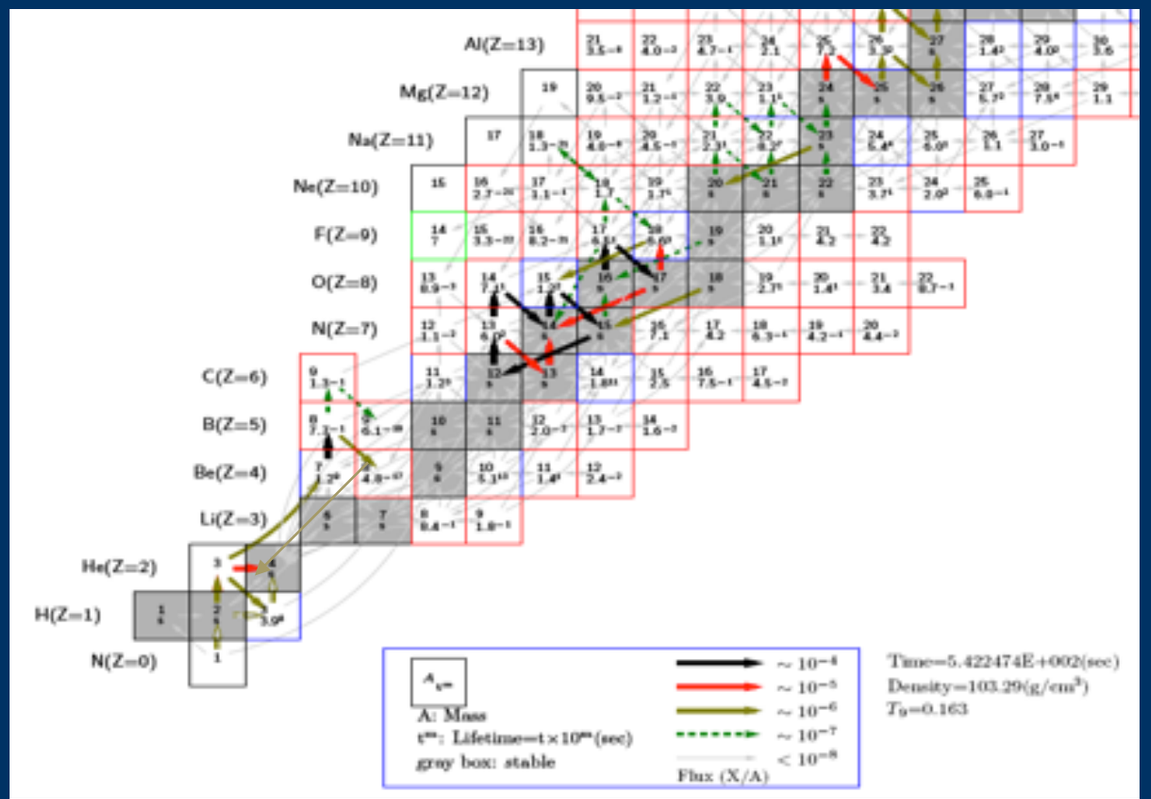


K. Kaneko, Y. Sun, et al., PRL 110, 172505 (2013)

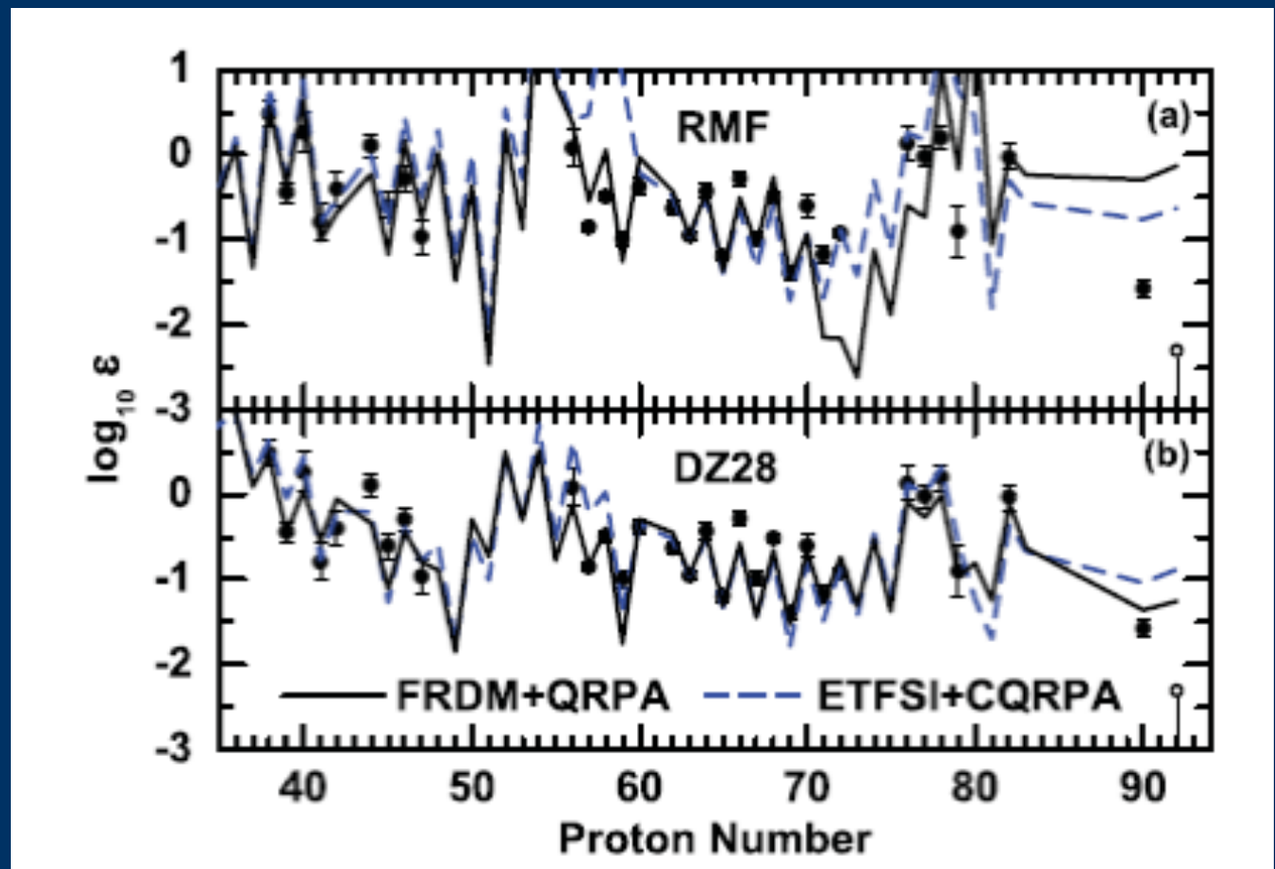


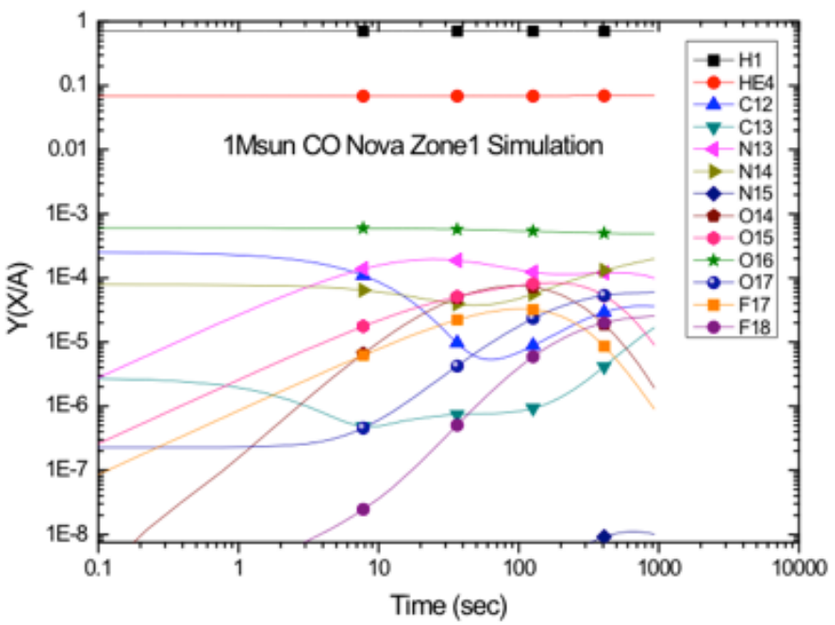
N. Wang, mass, PRC84, 051303R(2011)

Network calc



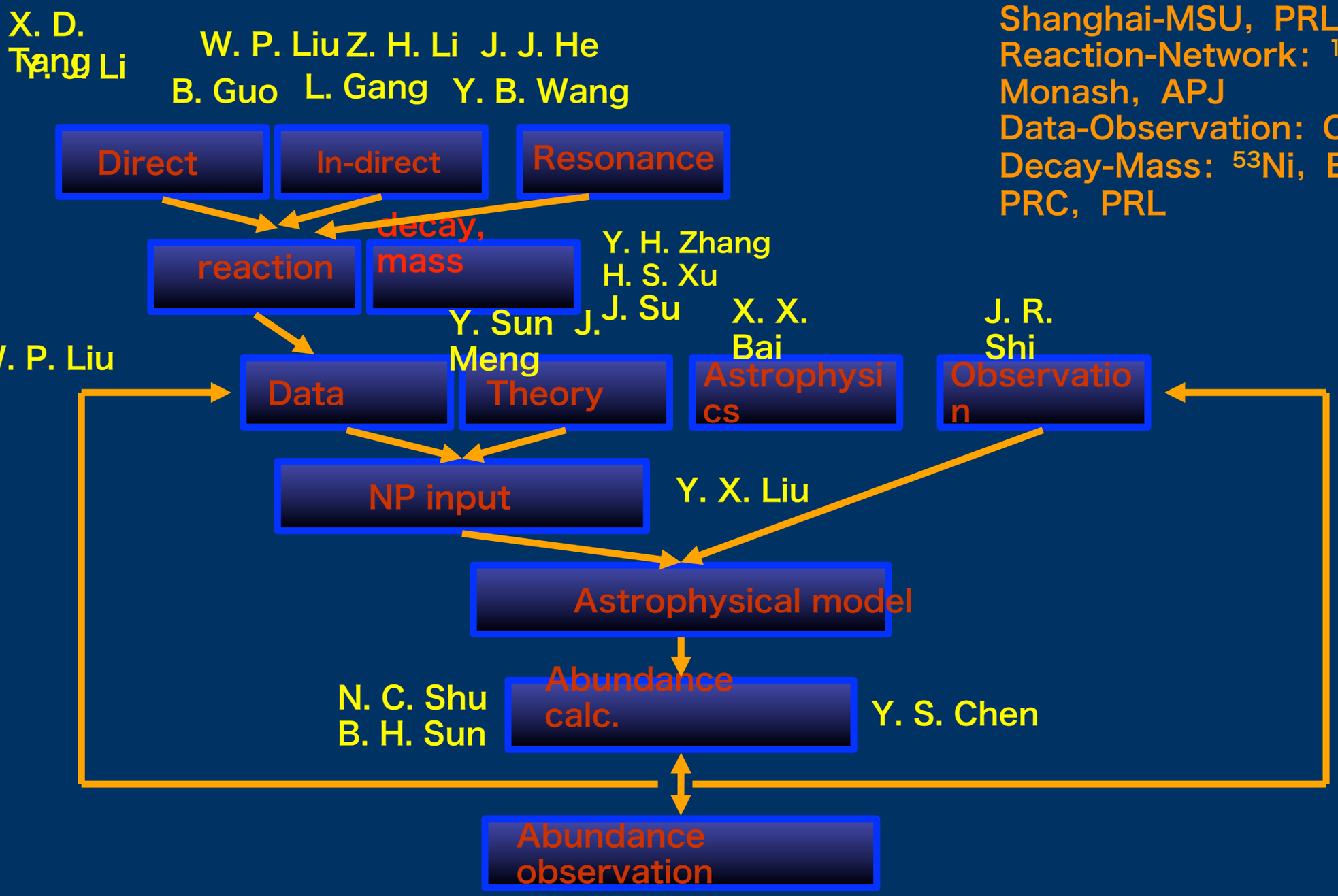
N. C. Shu, Y. S. Chen et al.,
NPA 758 (2005) 419c





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

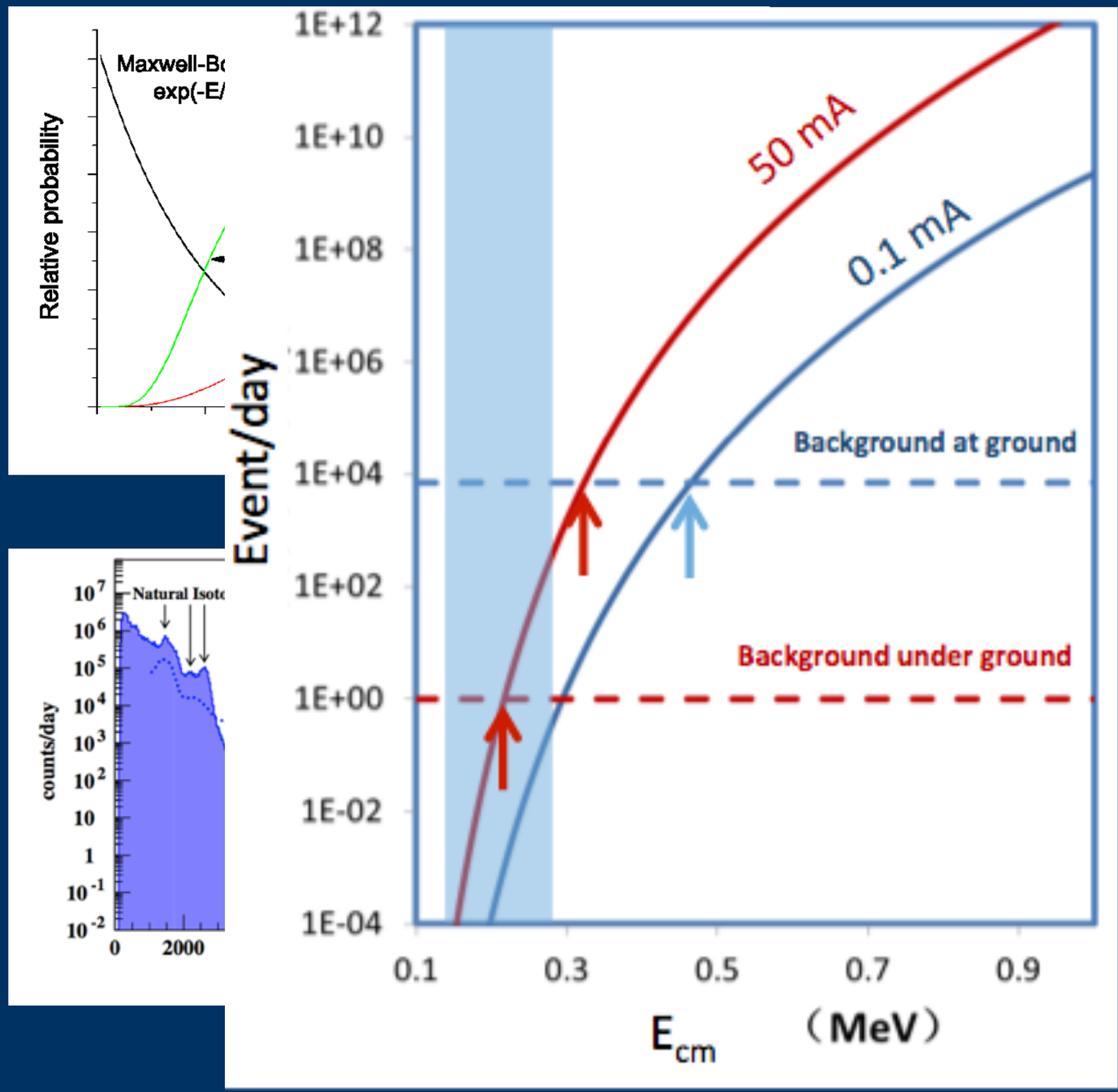
Full coverage of NA



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

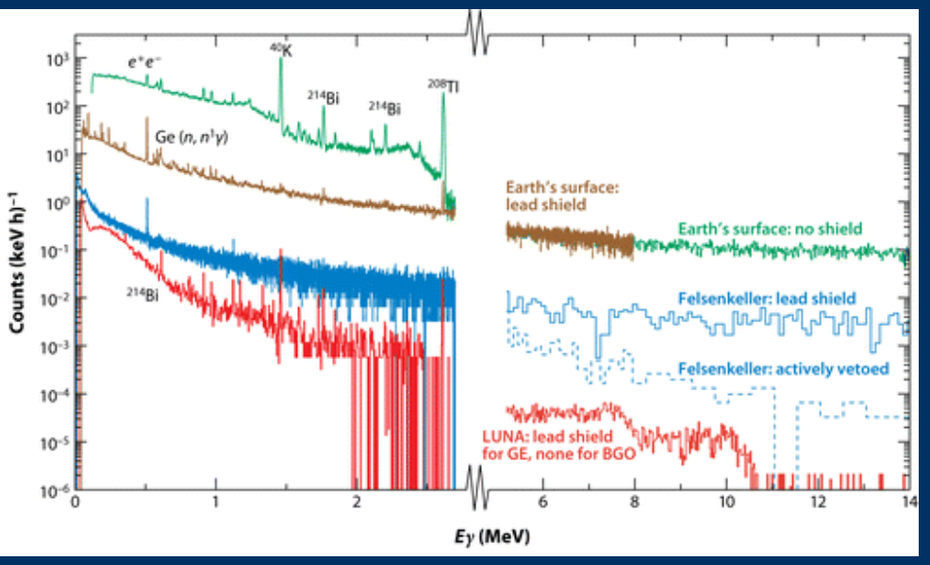
Underground nuclear astrophysics

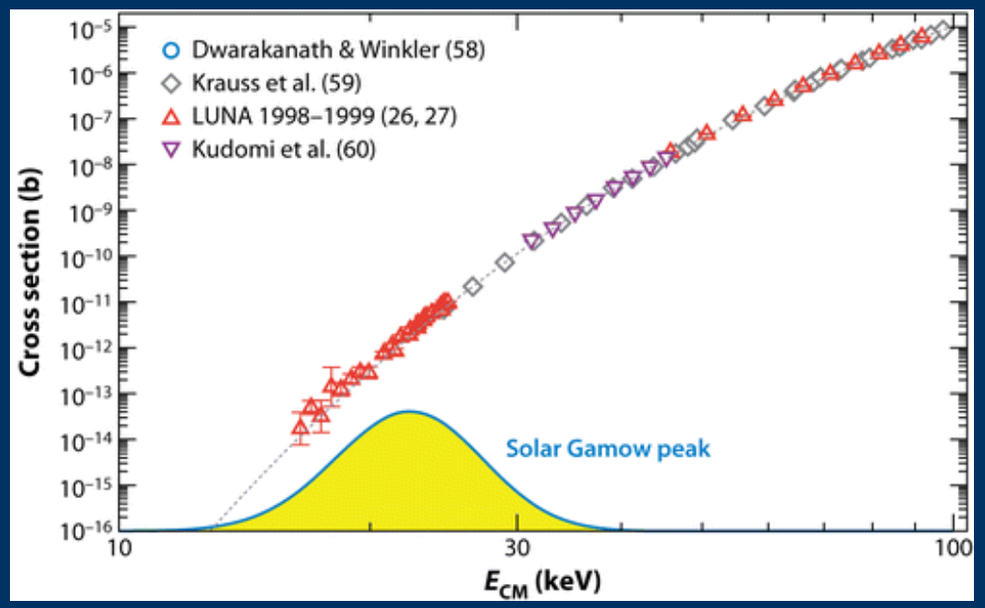
- Direct is the way to get rid of model dependence
- Direct in Gamow window have to go underground
- Underground is list in top priority
- Many world lab planned, with LUNA operational



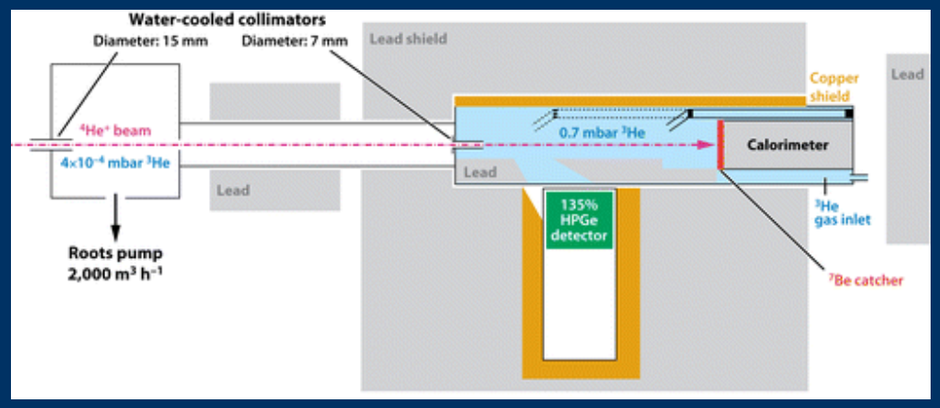
From X. D. Tang

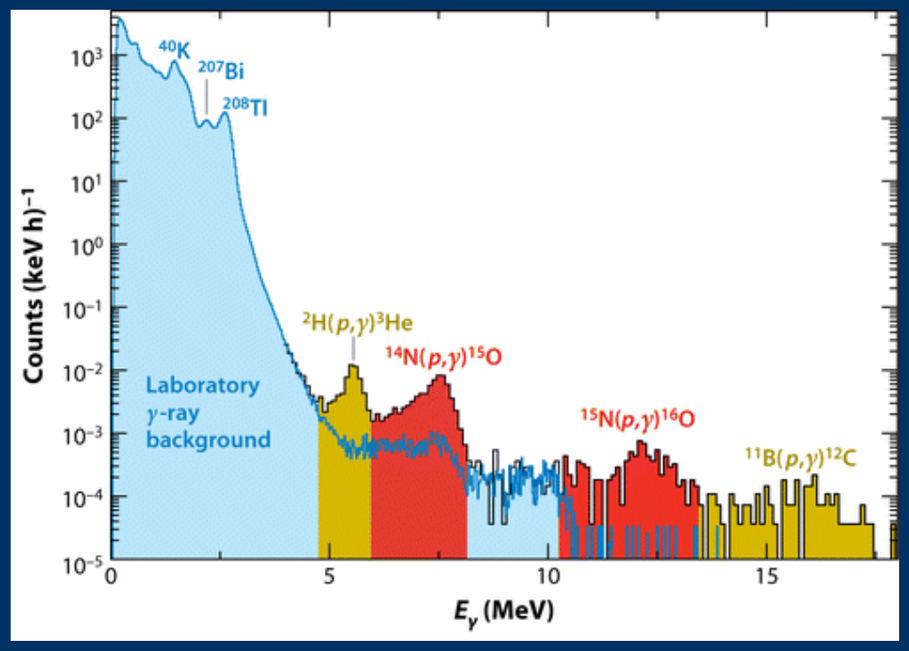
LUNA experiments





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





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

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

Paolo Prati

$^3He(^3He,2p)^4He$
PRL82(1999)5205

$^2H(^3He,p)^4He$
PLB482(2000)43

$^2H(p,\gamma)^3He$
NPA 706(2002)203

$^3He(\alpha,\gamma)^7Be$
PRL 97(2006)122502

$^{14}N(p,\gamma)^{15}O$
PLB 591(2004)61

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

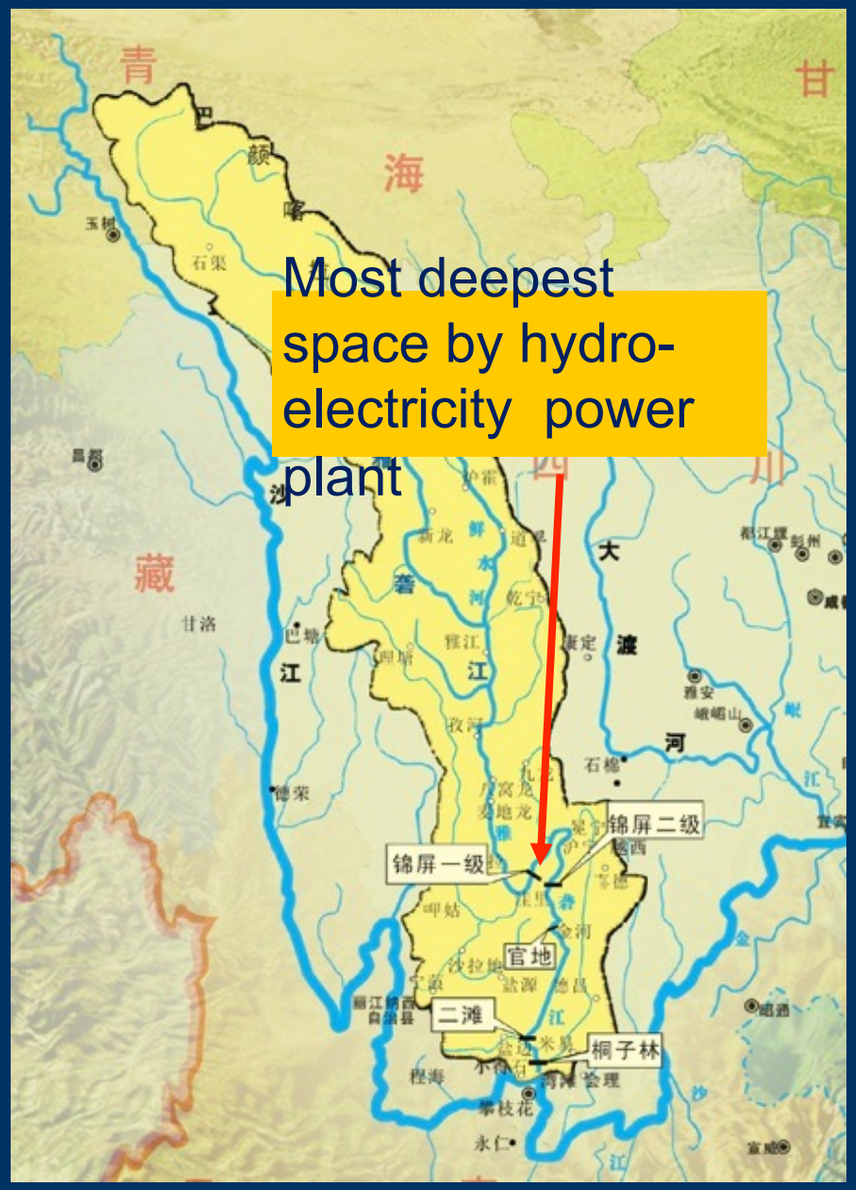
$^{17}O(p,\gamma)^{18}F$
PRL 109, 202601(2012

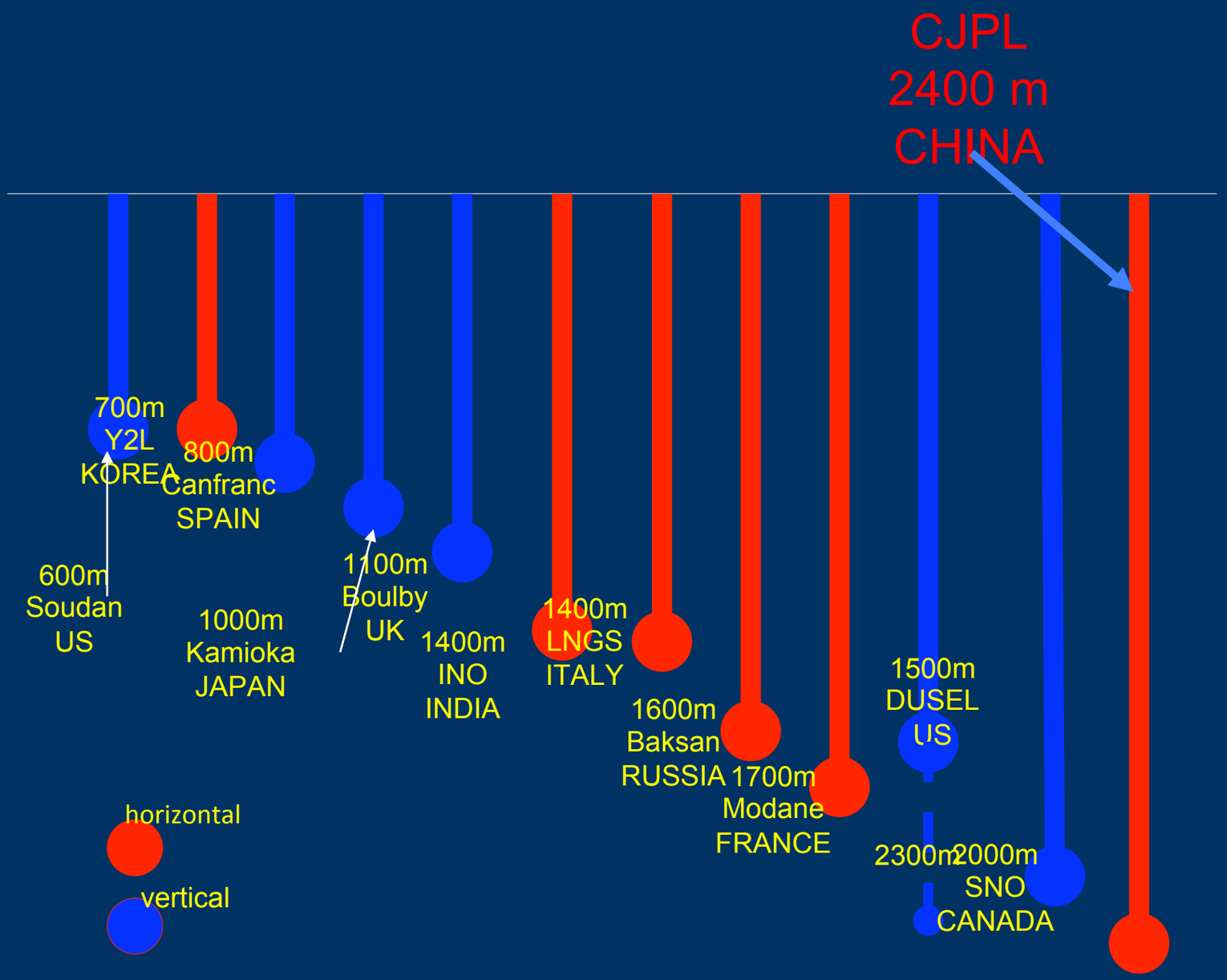
$^{25}Mg(p,\gamma)^{26}Al$
PLB 707(2012) 60

Physics focused

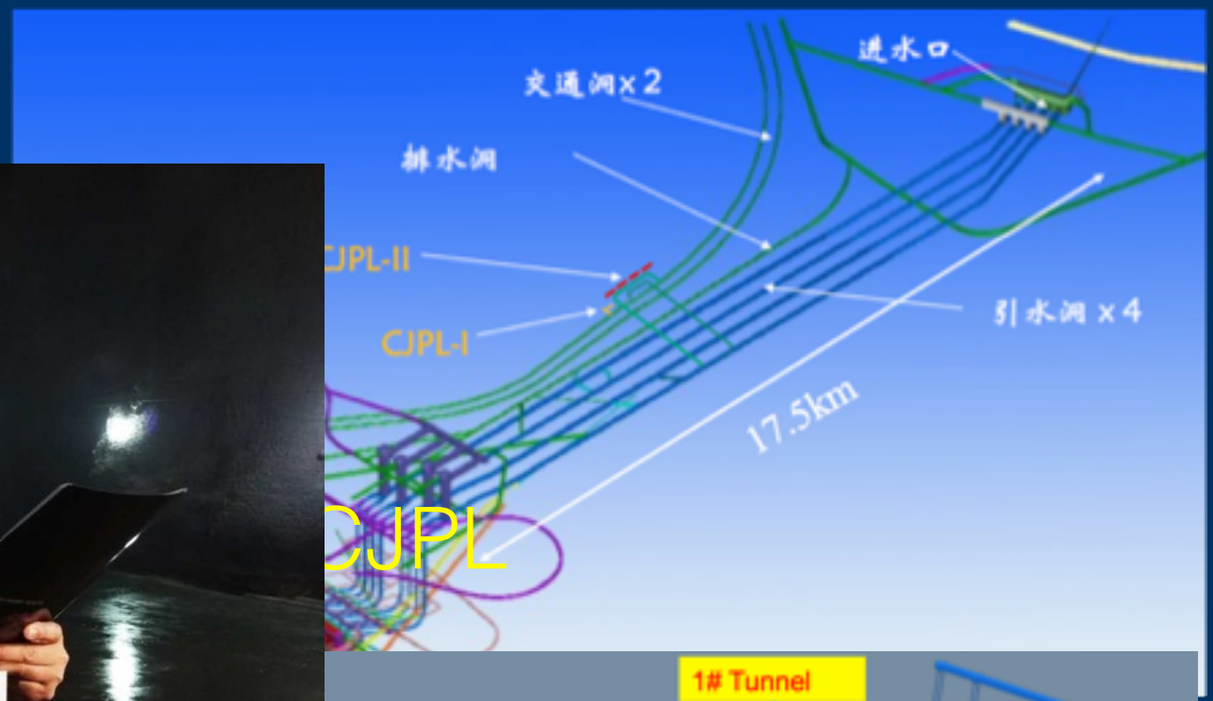
Physics	Reaction	Current	Desired
Massive star	**$^{12}C(\alpha,\gamma)^{16}O$**	**60% 890 keV**	**20% 220-380 keV**
s-process neutron source	**$^{13}C(\alpha,n)^{16}O$**	**60% 279 keV**	**10% 140-230 keV**
Galaxy ^{26}Al source	**$^{25}Mg(p,\gamma)^{26}Al$**	**20% 92 keV**	**5% 50-300 keV**
F aboundace	**$^{19}F(p,\alpha)^{16}O$**	**80 % 189 keV**	**5 % 50-250 keV**

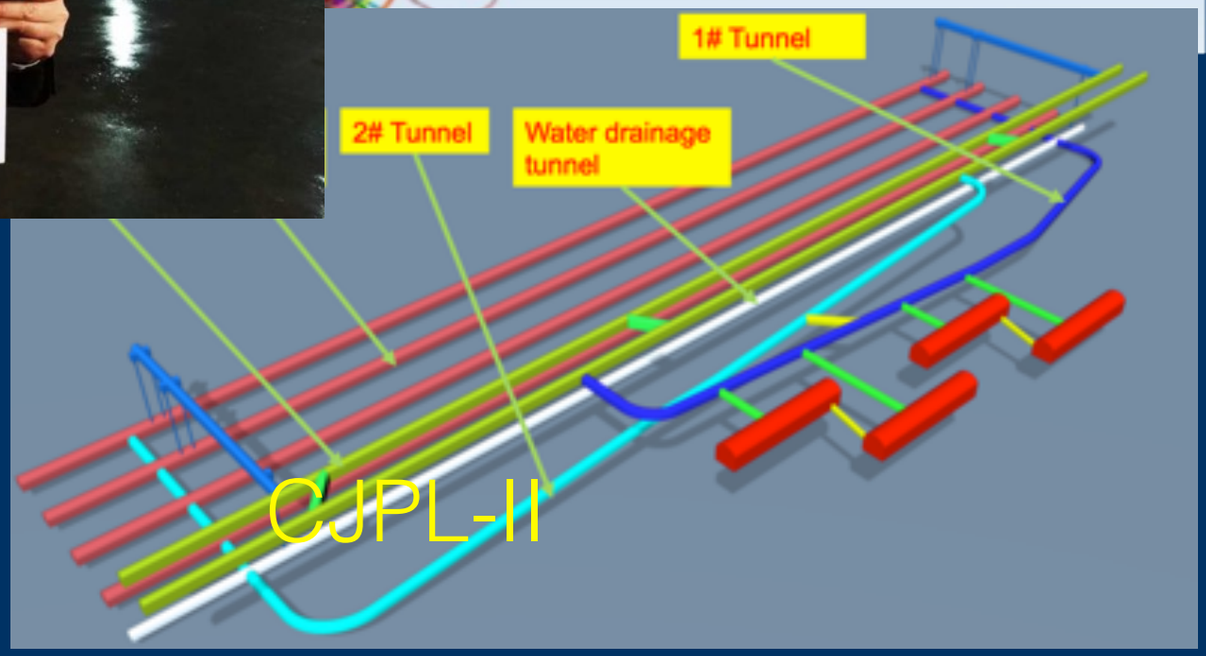
CJPL underground laboratory





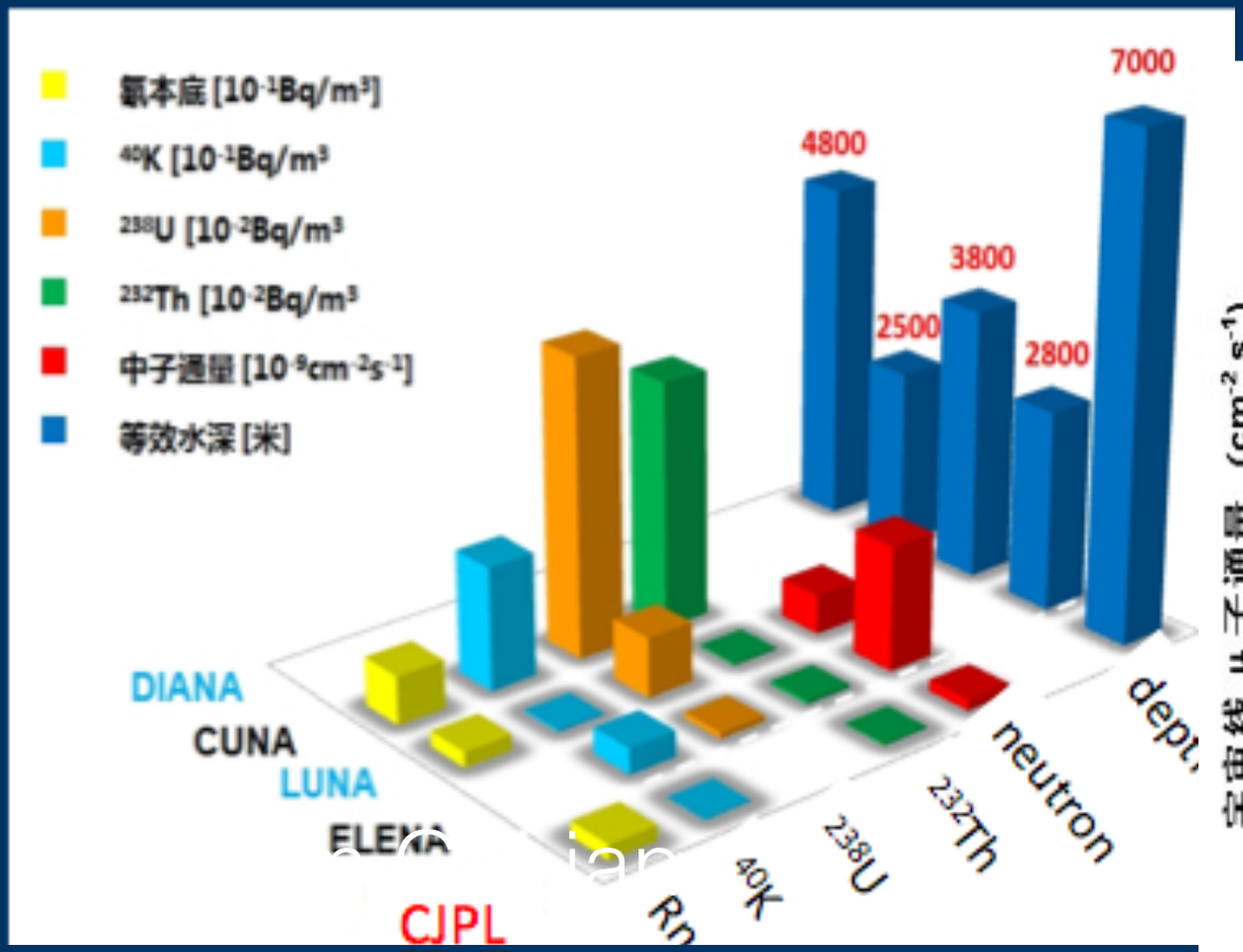
CJPL and CJPL-II

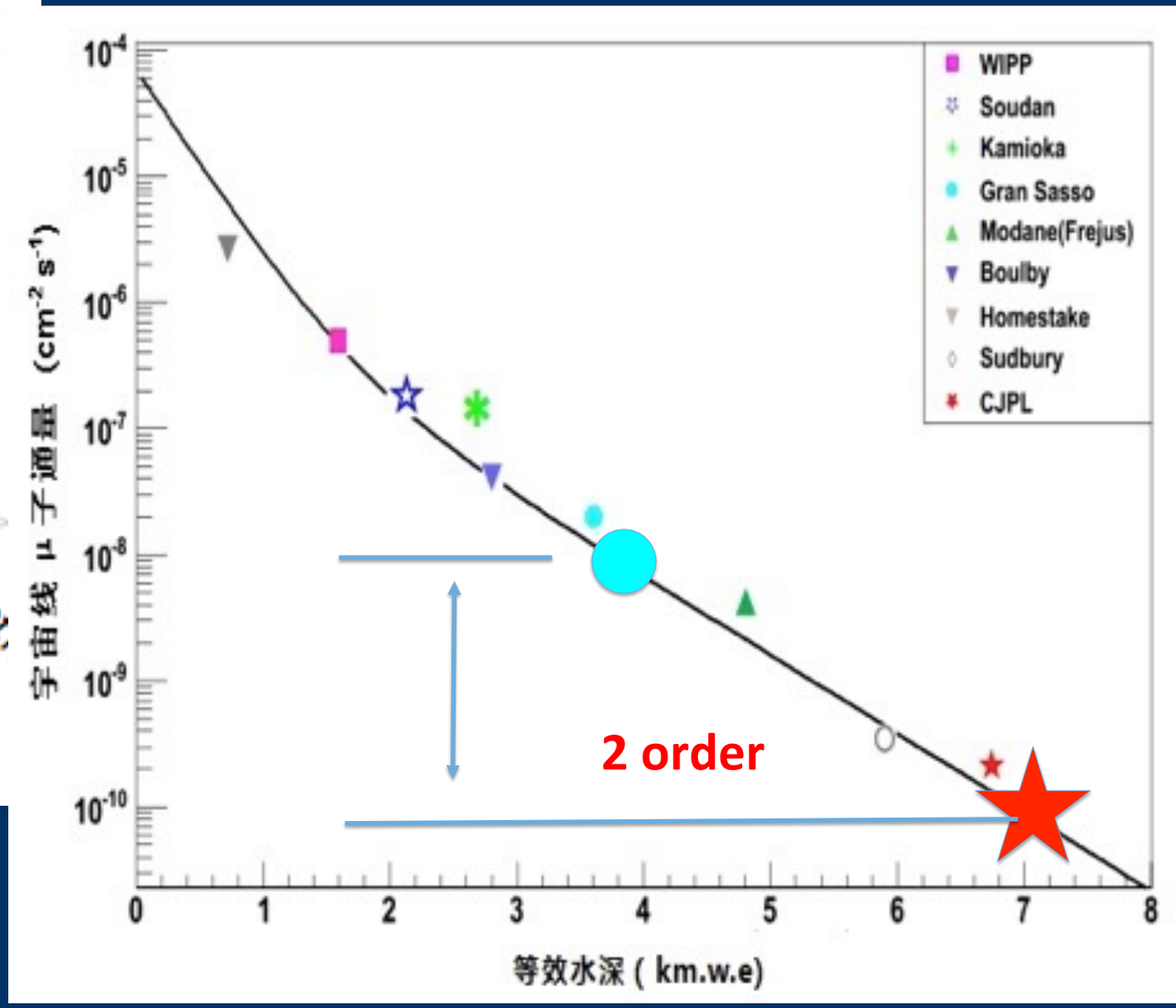




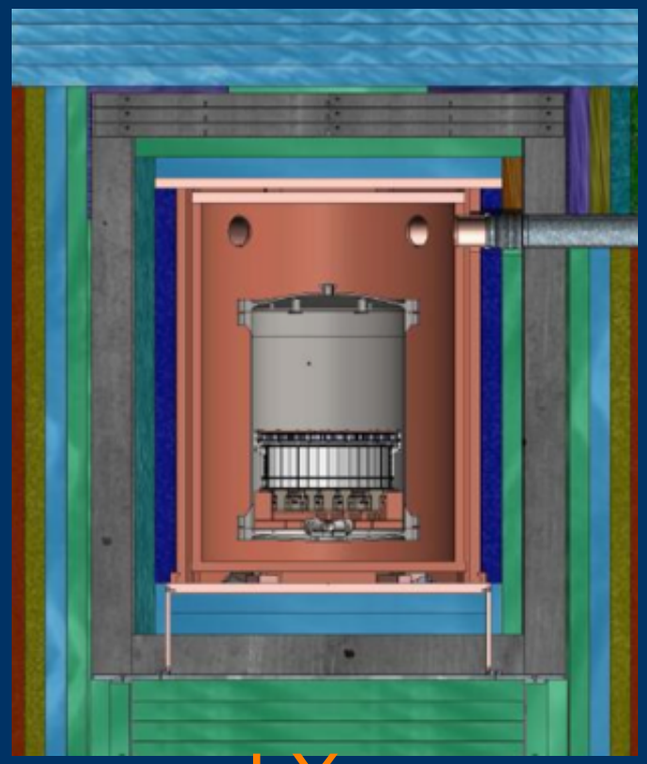
2014

CJPL advantage



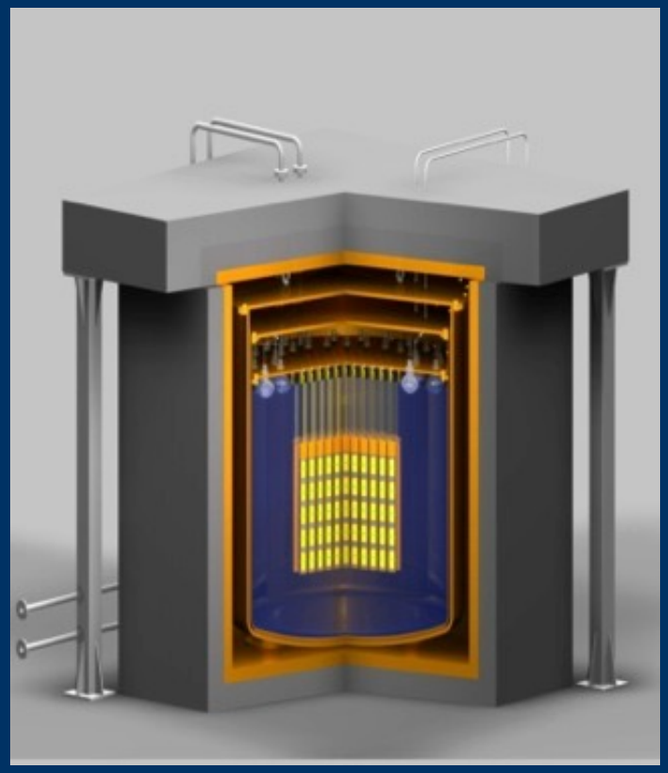


CJPL-II experiments



LXe
PANDAX
30T

Nuclear
Astrophysics
JUNA
400 kV



HpGe
CDEX 1T

JUNA PI introduction

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

Group leader

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]

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[5]Shanghai Jiaotong University, Shanghai, China, [6]Monash University, Melbourne, Victoria, Australia

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[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

Xiaoc
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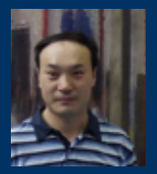
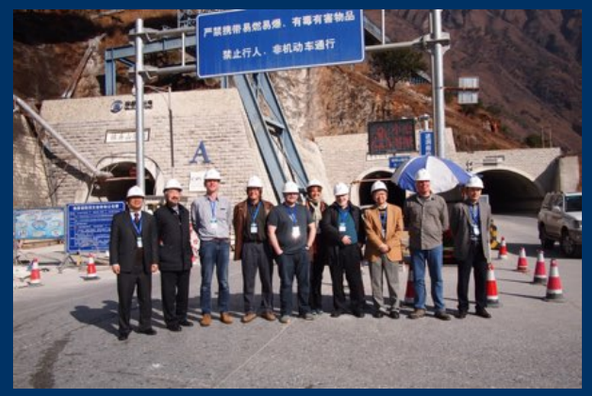


M. Wiescher	UND
T. Motobayashi	RIKEN
H. Wang	TCAS
C. Brune	Ohio
M. Junker	INFN
D. Robertson	UND
F. Strieder	SDSMT
D. Leitner	LBL
Q. Yue	THU



IAC, CJPL entrance

IAC+JUNA, CJPL-II-8

IAC, 305 m high dam

1st meeting July 2015， 1st formal IAC meeting March， 2016

JUNA funding

Detectors（NSFC $1.3M）

Electronics, shielding (NSFC $1.0M）

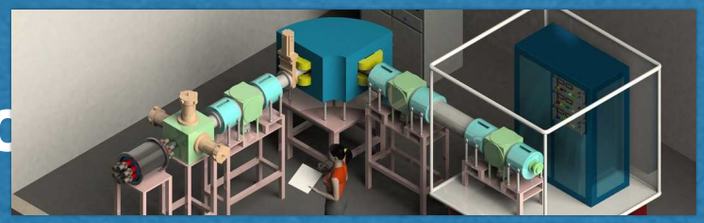
Ion source (CAS $0.8M), accelerator (CNNC $1.0M)

Lab CJPL II（Tsinghua，NSFC $1.2M）

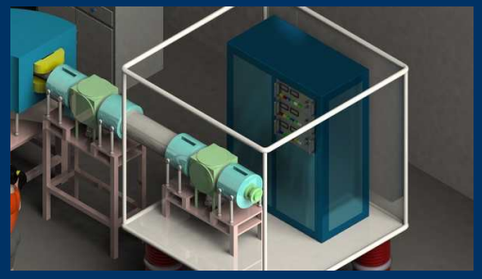
total $4.8+ M

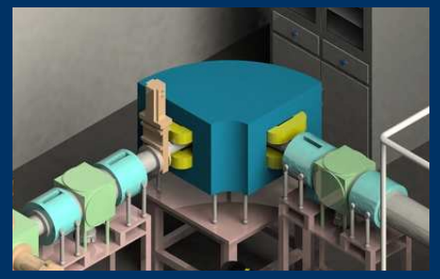
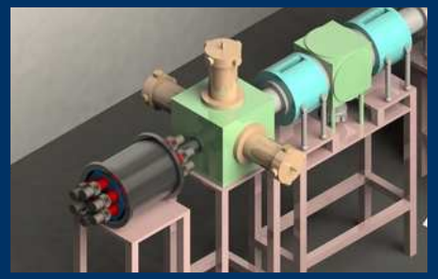
JUNA plan

CJPL-II c



JUNA



ECR source Acceleration Magnet Detectors

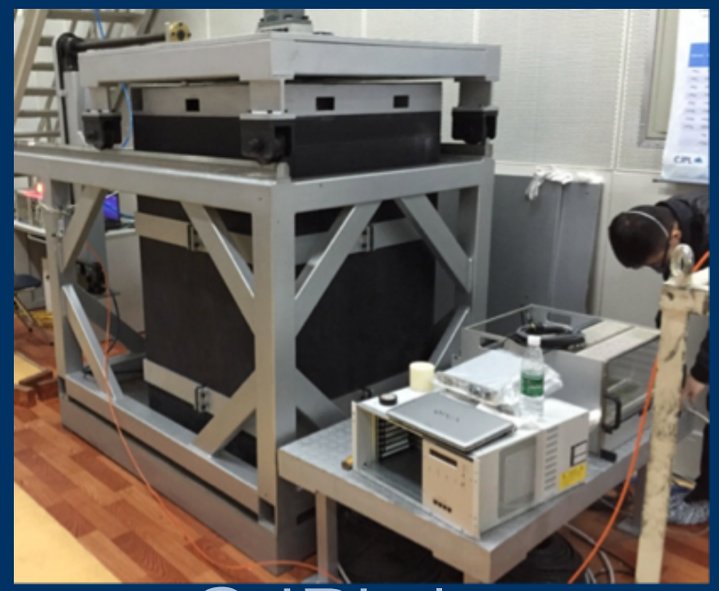
Beam	Intensity, mA	Energy,keV
H^+	10	70-400
He^+	10	70-400
He^{++}	2-5	140-800

Ground facilities

beam with 40 KV and 20 mA

Tandem of implantation target

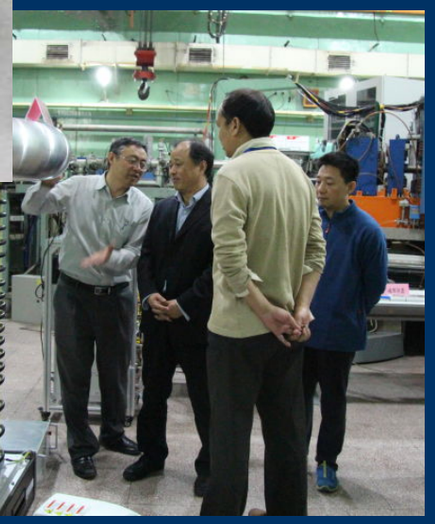
solid and gas detector and electronics



CJPL low background station

Ion source and accelerator

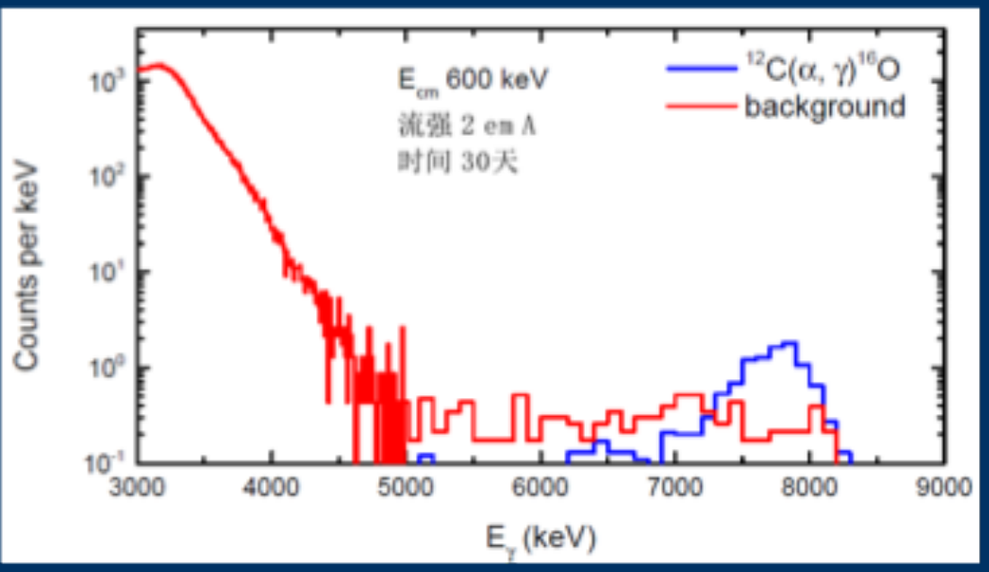
Ion source installed,
1 mA tested;
7/31/16



Accelerator tube
check by NSFC

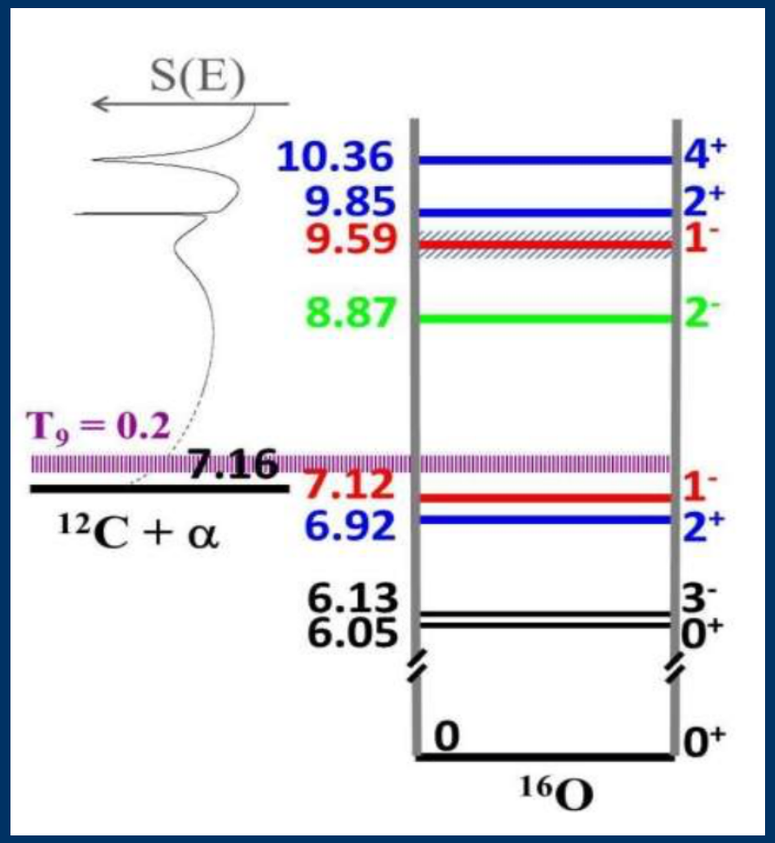
Accelerator tank
established 8/30/16

^{12}C progress



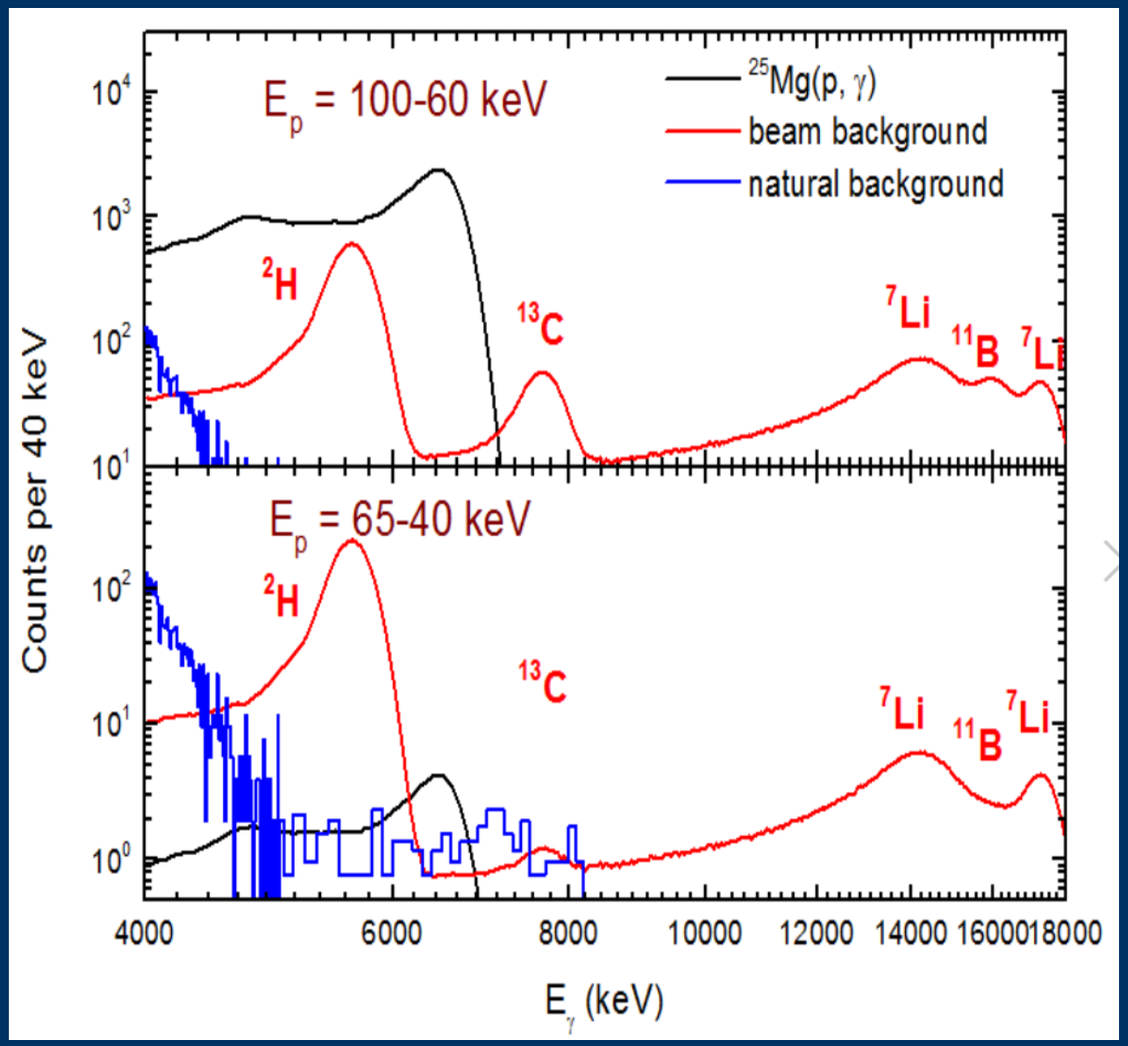
Simulation fro BGO

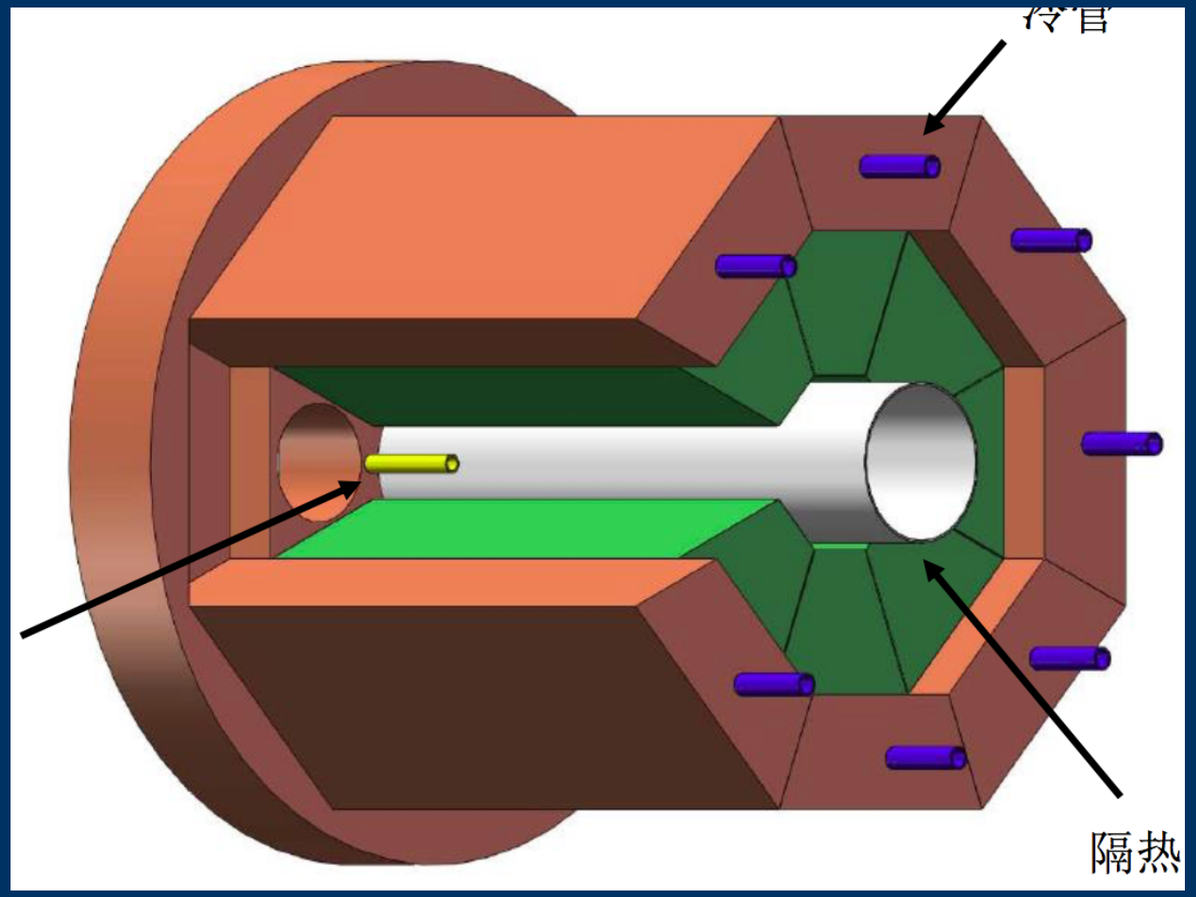
^{12}C implantation target tested 30/8/16



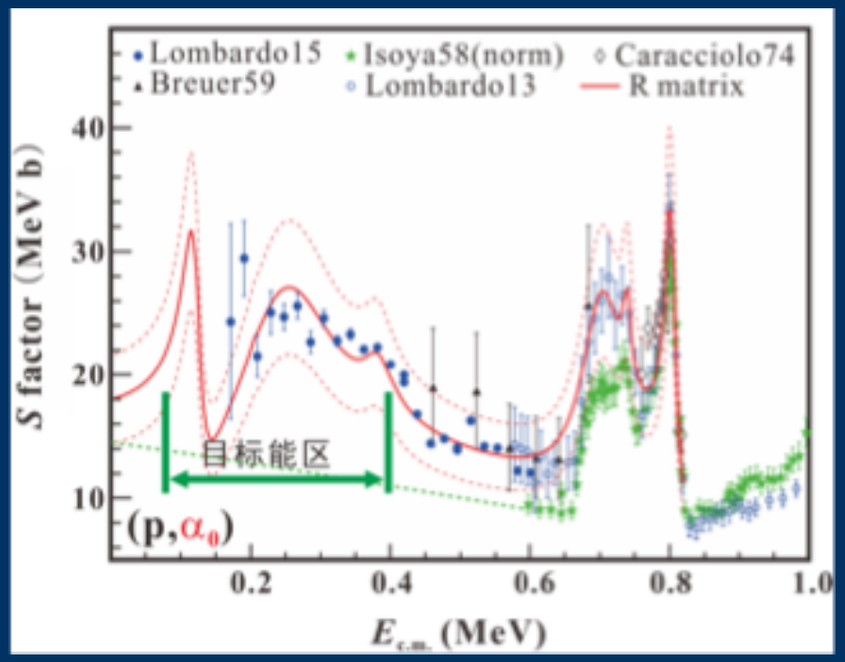
Test exp. SCU 12/16

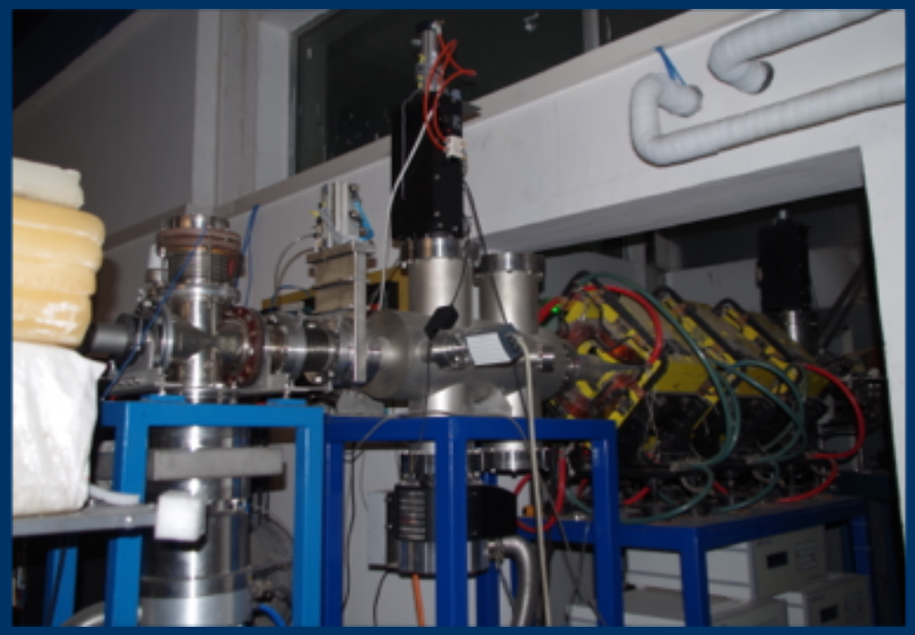
^{25}Mg progress

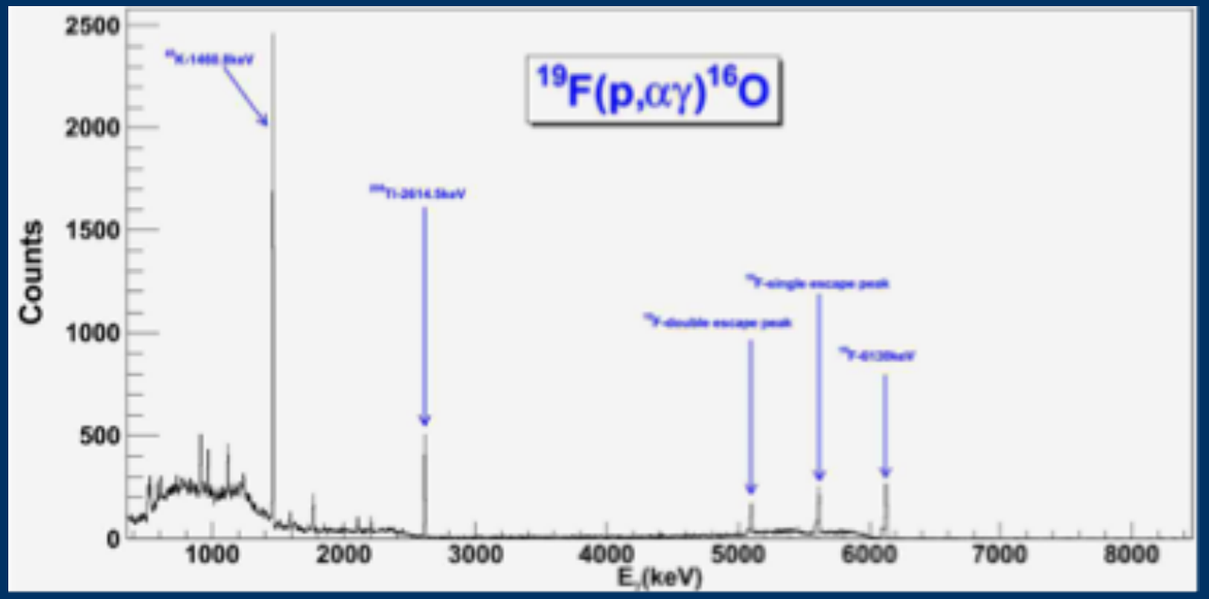




^{19}F progress

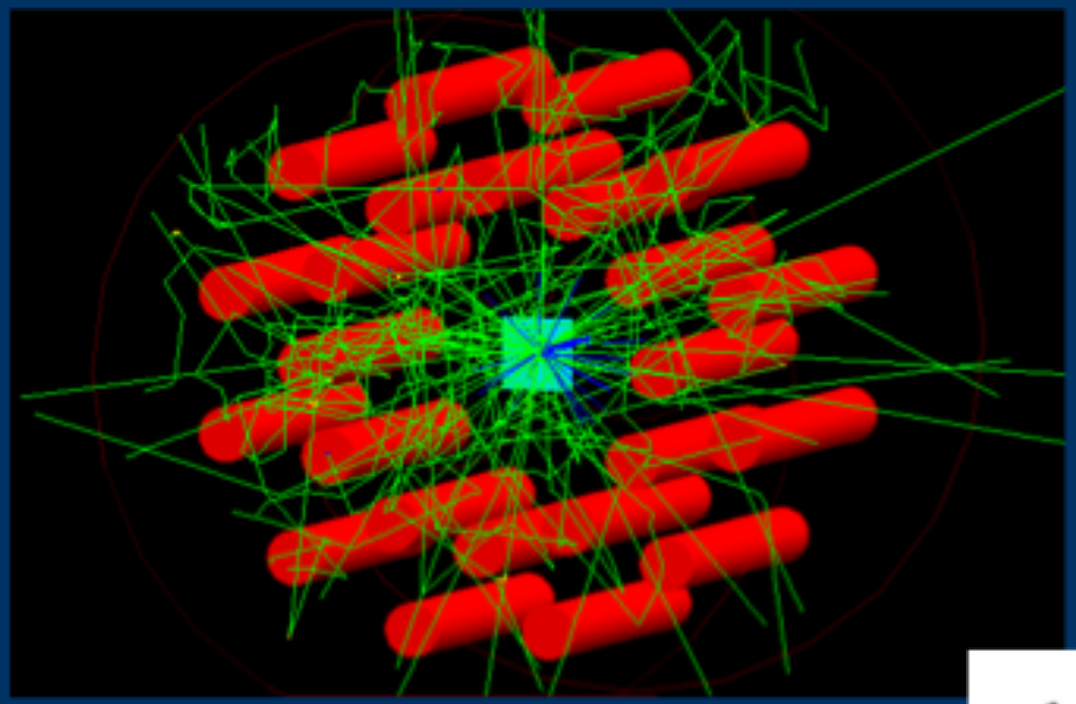




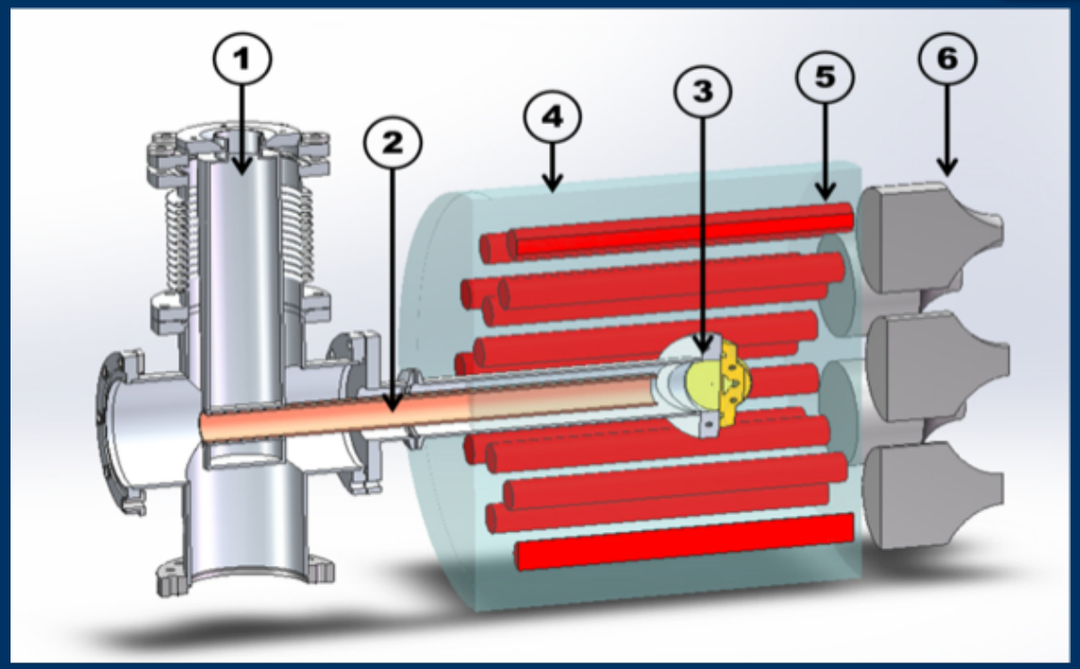


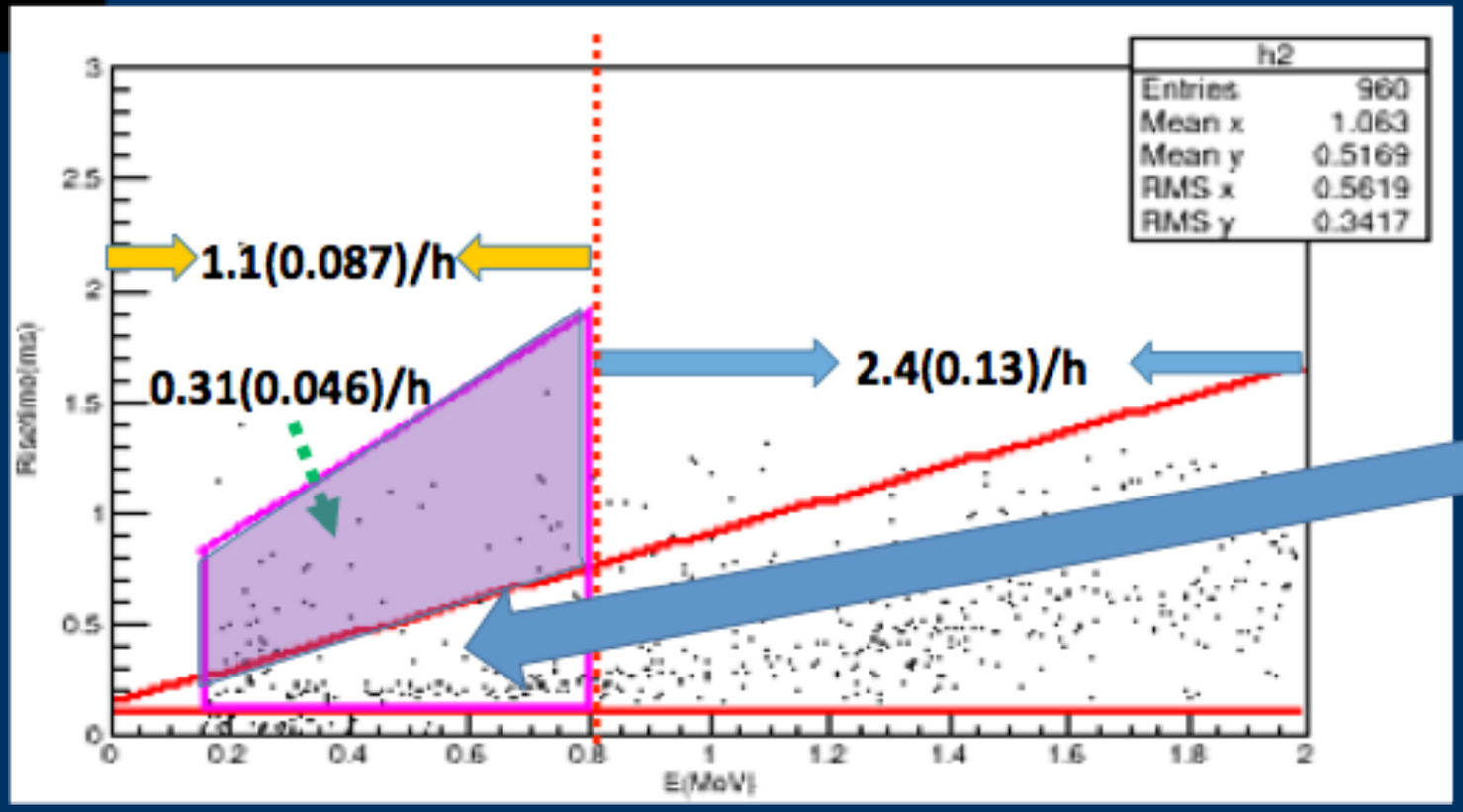
J. J. He

^{13}C progress



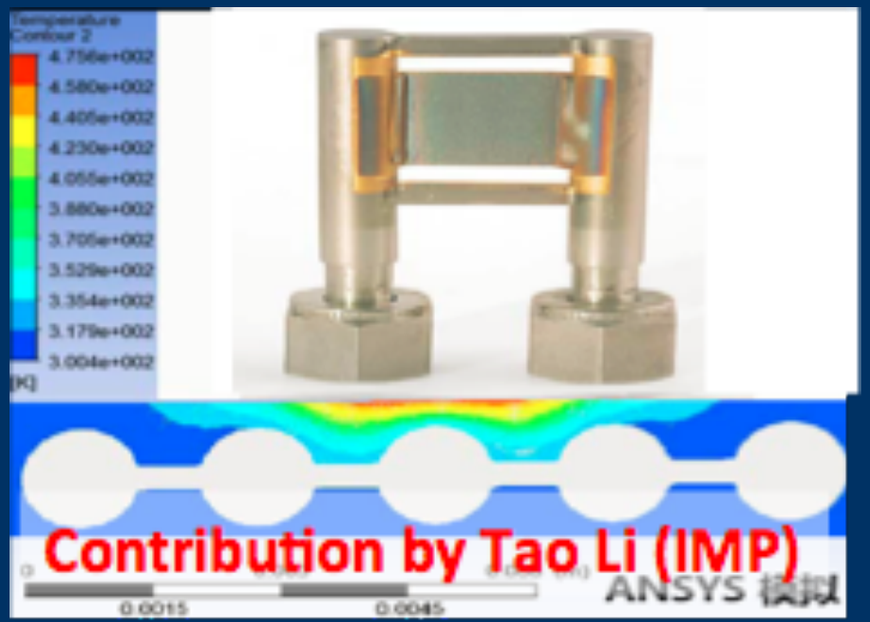
快中子：液闪探测器
慢化中子：24根^{3}He正比管

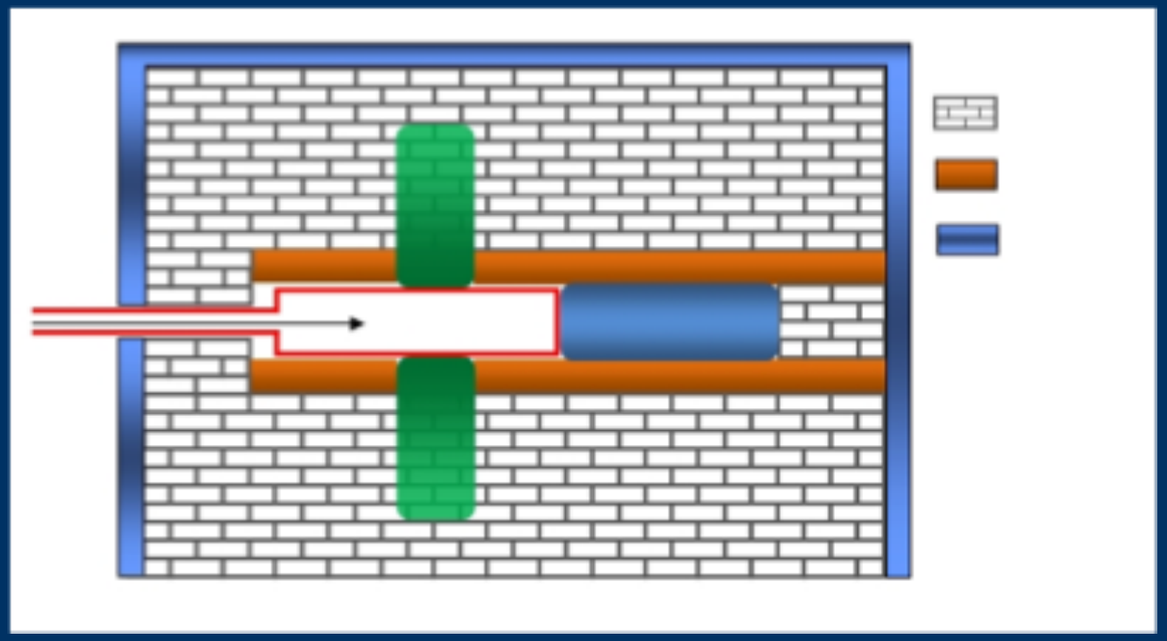


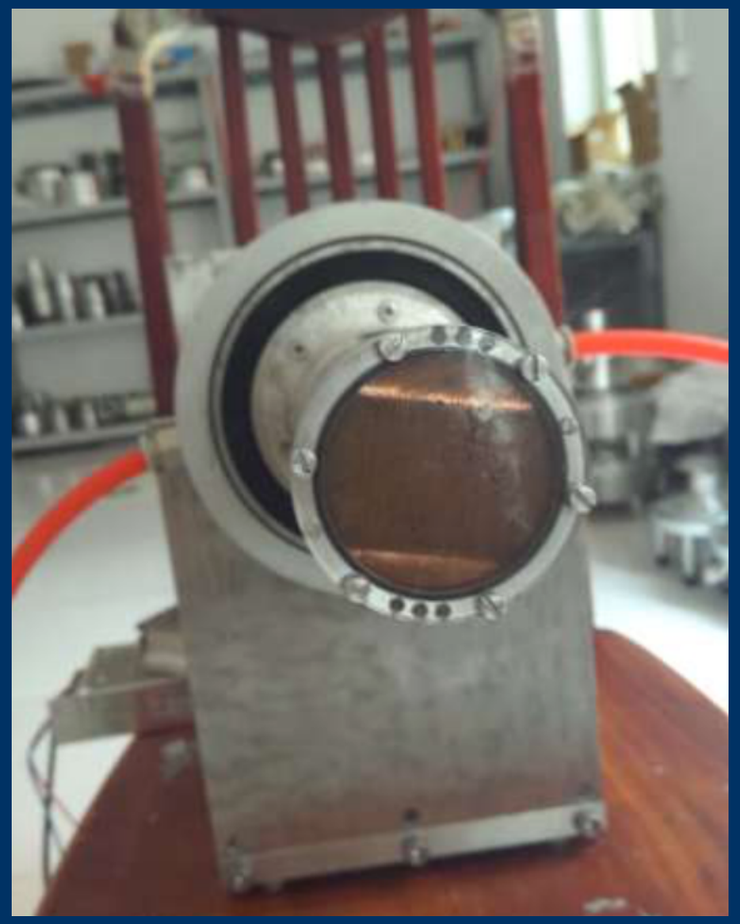


X. D. Tang

Target and shielding

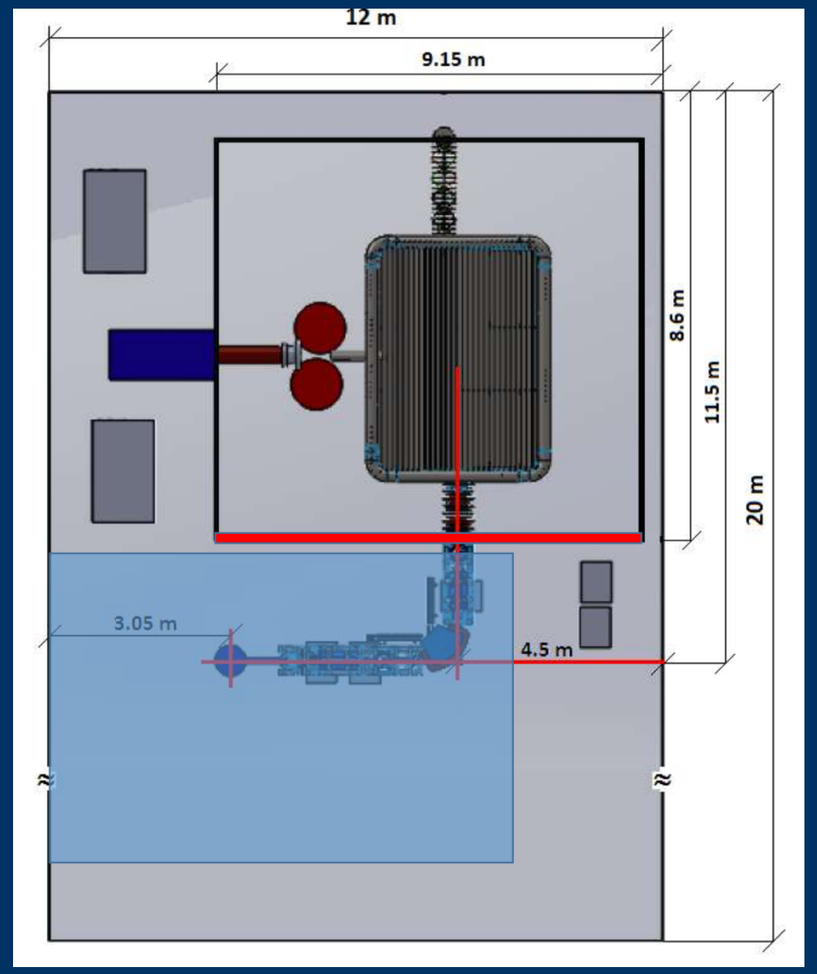






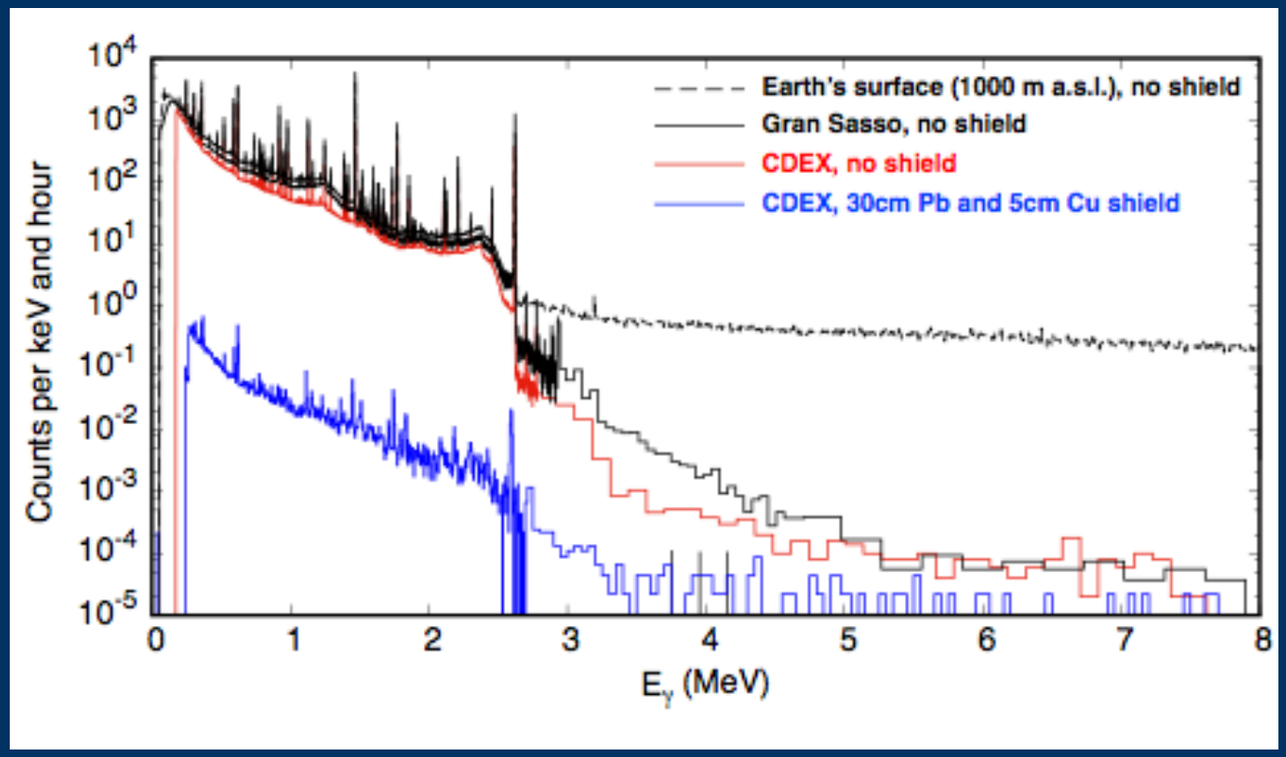
Rotation target tested
30/8/16

Lab construction

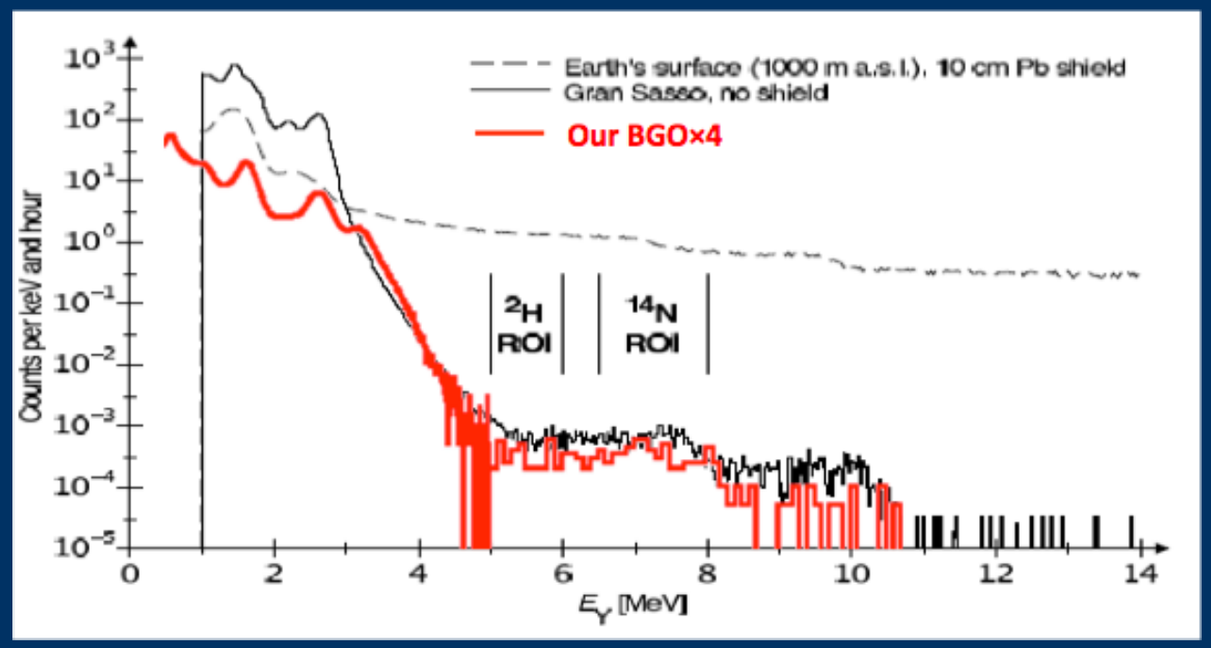


Accelerator floor plan
30/8/16

HPGe and BGO background in CJPL-I



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



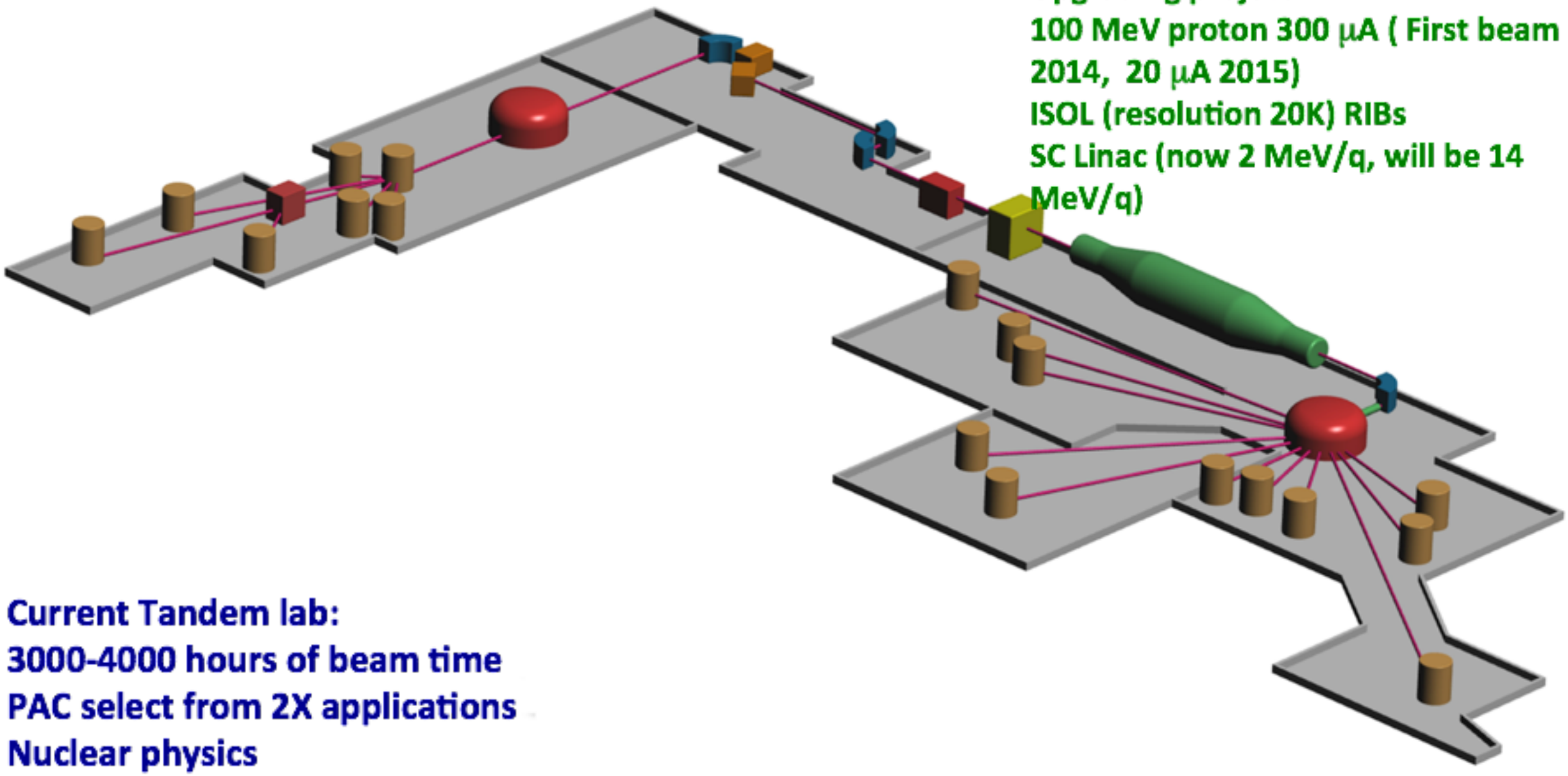
JUNA expectation

reaction	beam	inten. (emA)	Ec.m. (keV)	cross section (mb)	target atoms/cm^2	eff. %	CTS (/day)	BKD (/day)
$^{12}C(\alpha,\gamma)^{16}O$	$^4He^{2+}$	2.5	380	10^{-13}	10^{18}	75	0.7	0.7
$^{13}C(\alpha,n)^{16}O$	$^4He^{1+}$	10	200	10^{-12}	10^{21}	20	7	1
$^{25}Mg(p,\gamma)^{26}Al$	$^1H^{1+}$	10	58	$\omega\gamma$ 2.1×10^{-13} eV	0.6 μg/cm^2	38	1.4	0.7
$^{19}F(p,\alpha)^{16}O$	$^1H^{1+}$	0.1	100	7.2×10^{-9}	4 μg/cm^2	75	27	0.7

reaction	physics	current limit (keV)	precision (%)	ref.	JUNA limit (keV)	Gamow energy (keV)	precision (%)
$^{12}C(\alpha,\gamma)^{16}O$	Massive star	890	60	[17]	380	220-380	test
$^{13}C(\alpha,n)^{16}O$	HI synthesis	279	60	[18]	200	140-230	20
$^{25}Mg(p,\gamma)^{26}Al$	Galaxy ^{26}Al	92	20	[13]	58	50-300	15
$^{19}F(p,\alpha)^{16}O$	F abundance	189	80	[19]	100	50-350	10

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

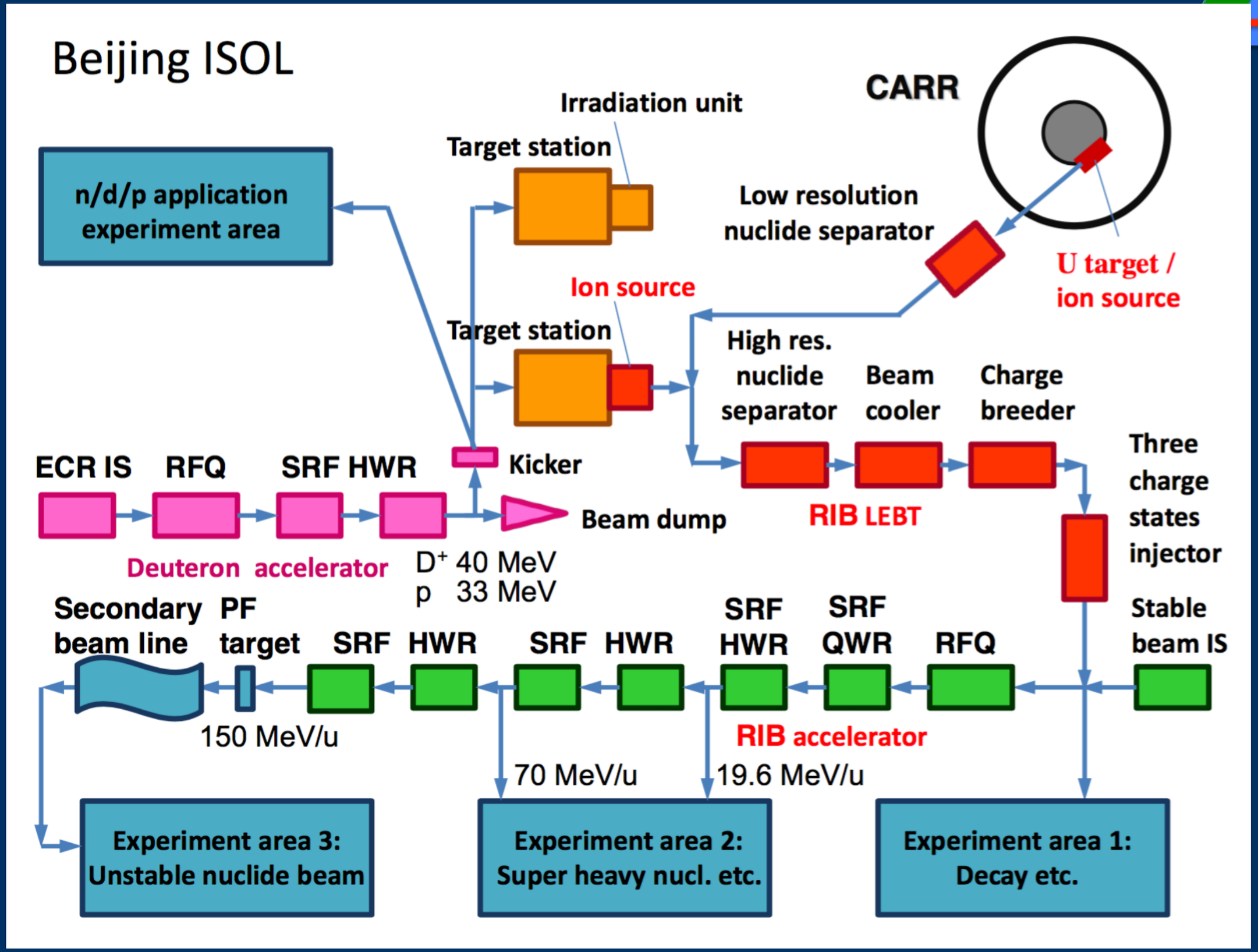
Tandem lab.



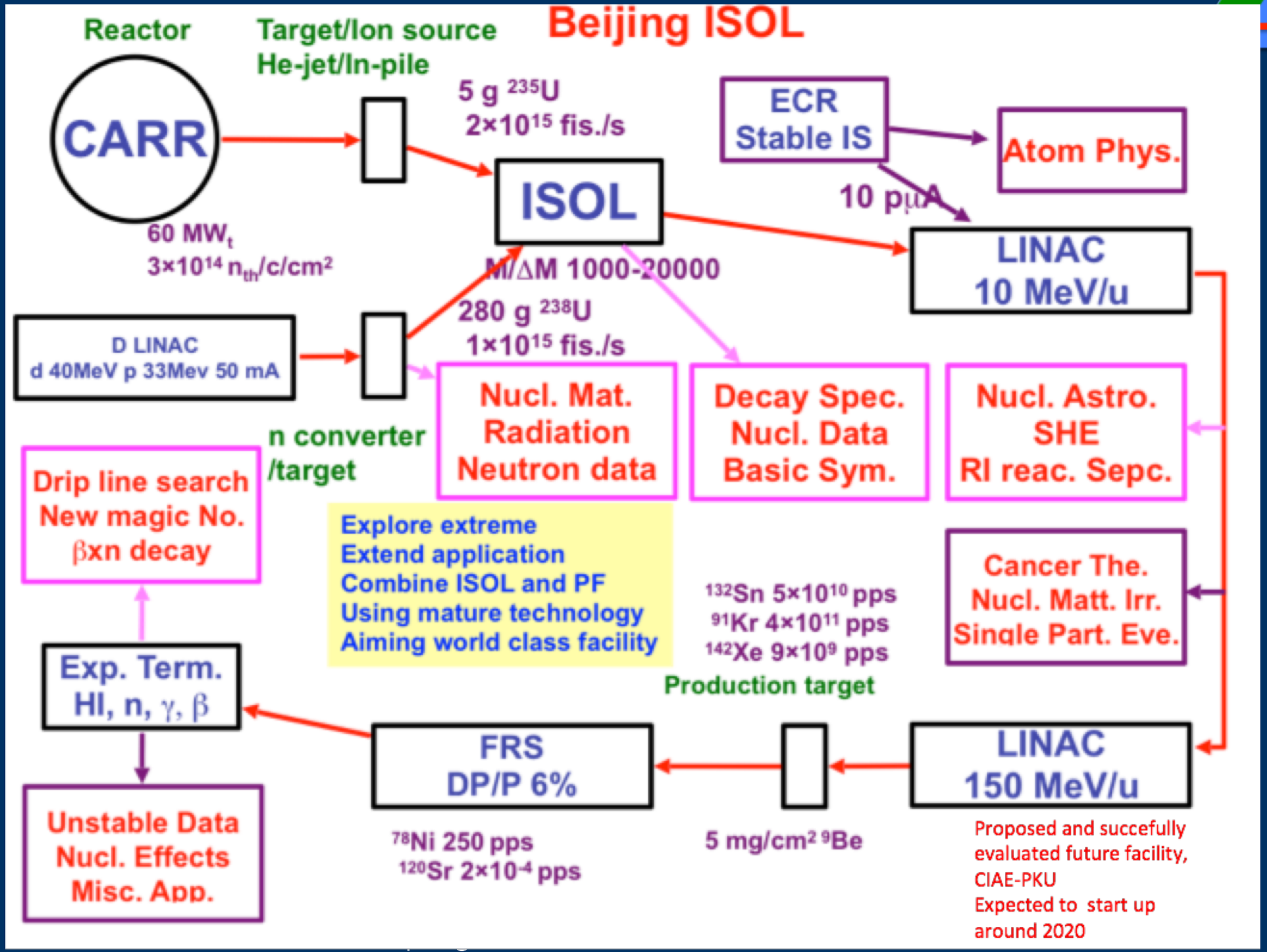
Upgrading project BRIF:
100 MeV proton 300 μA (First beam 2014, 20 μA 2015)
ISOL (resolution 20K) RIBs
SC Linac (now 2 MeV/q, will be 14 MeV/q)

Current Tandem lab:
3000-4000 hours of beam time
PAC select from 2X applications
Nuclear physics
Nuclear application

Beijing ISOL layout



Beijing ISOL physics



Summary

- **Nuclear astrophysics in good progress in China**
- **In-direct approach still productive**
- **Decay and mass measurement get new finding**
- **Live theoretical activities and network calculations**
- **Underground JUNA is in progress, see schedule**
- **JUNA collaboration needed to tackle key experimental and technique challenges**
- **Beijing ISOL will open up new opportunities for nuclear physics**