

**ANPhA meeting
Nov. 24-25, Sendai, Japan**

Progress of nuclear physics in China

**Weiping Liu
China Insititute of Atomic Energy**

2016-11-24

Thanks Yanlin Ye, PKU

Nuclear physics conference in China



- The 15th nuclear physics conference in China , Oct. 2013, Shanghai
- The 16th nuclear physics conference in China, Oct. 2016, Chengdu

Roadmap and facility

2013 China reasarch facility long range plan

- **Aiming at basic interaction between basic buliding blaock, search for new physcis beyond standard model, enhance research for nuclear and nuclear astrophsyics**
- **Particle physics. High energy cosimic ray array, start neutrino and other non accelarator facility and future accelarartor R&D**
- **Nuclear physics. Advanced heavy ion facilty, to reach to top class in nuclear physics research; start R&D of intense RI beam facility**

Long range plan: Xiangshan forum

“核物理与等离子体物理发展战略研究”第一次会议



2014年9月19-20日



2014年8月28-29日

核物理发展战略研究

核物理发展战略研究编写组

2015年7月31日

8章, ~320页, ~40万字

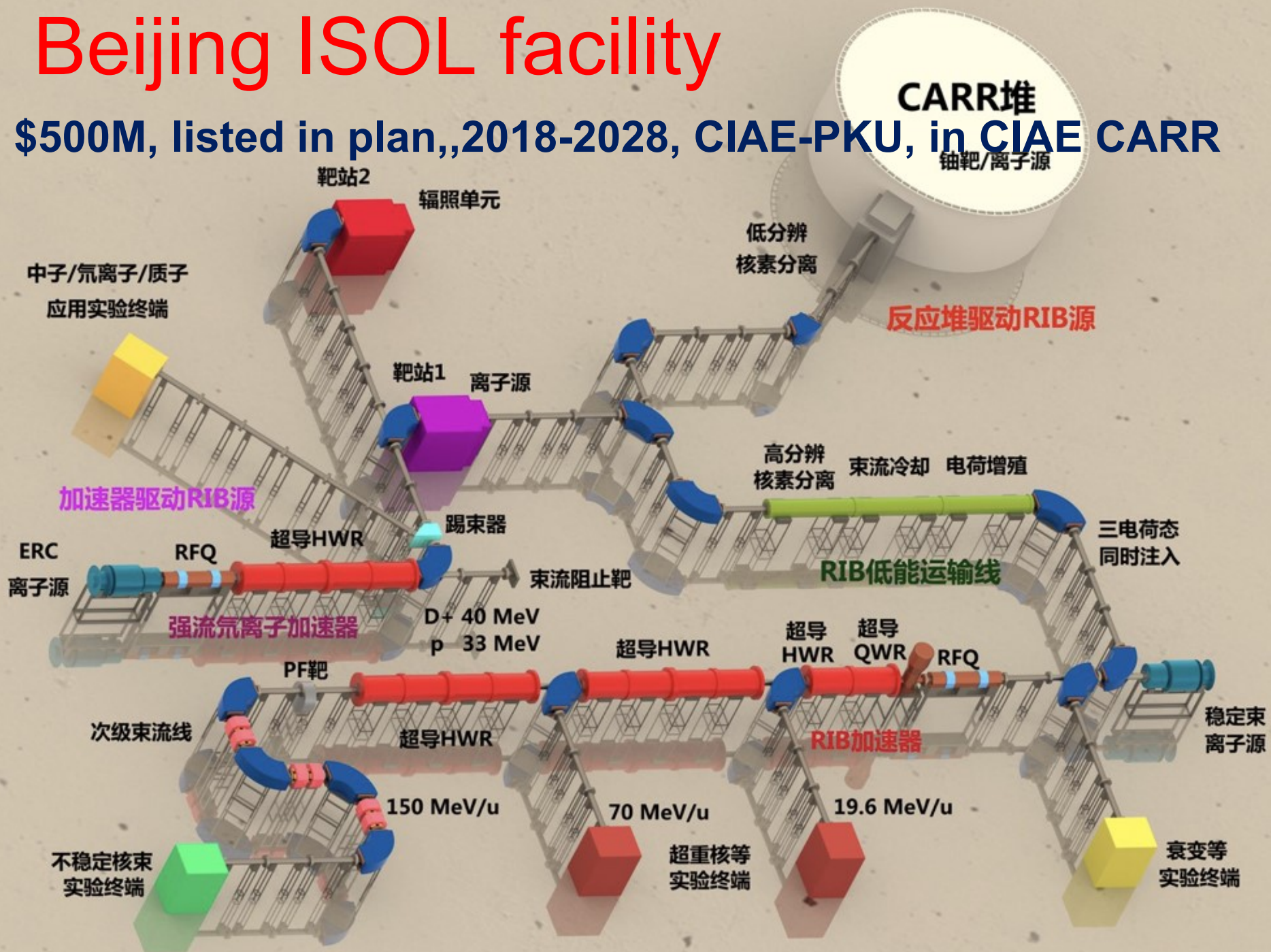
香山科学会议

第502次学术讨论会

我国核物理和核科学装置发展研讨

Beijing ISOL facility

\$500M, listed in plan, 2018-2028, CIAE-PKU, in CIAE CARR



Progress of large facilities

2015–2020

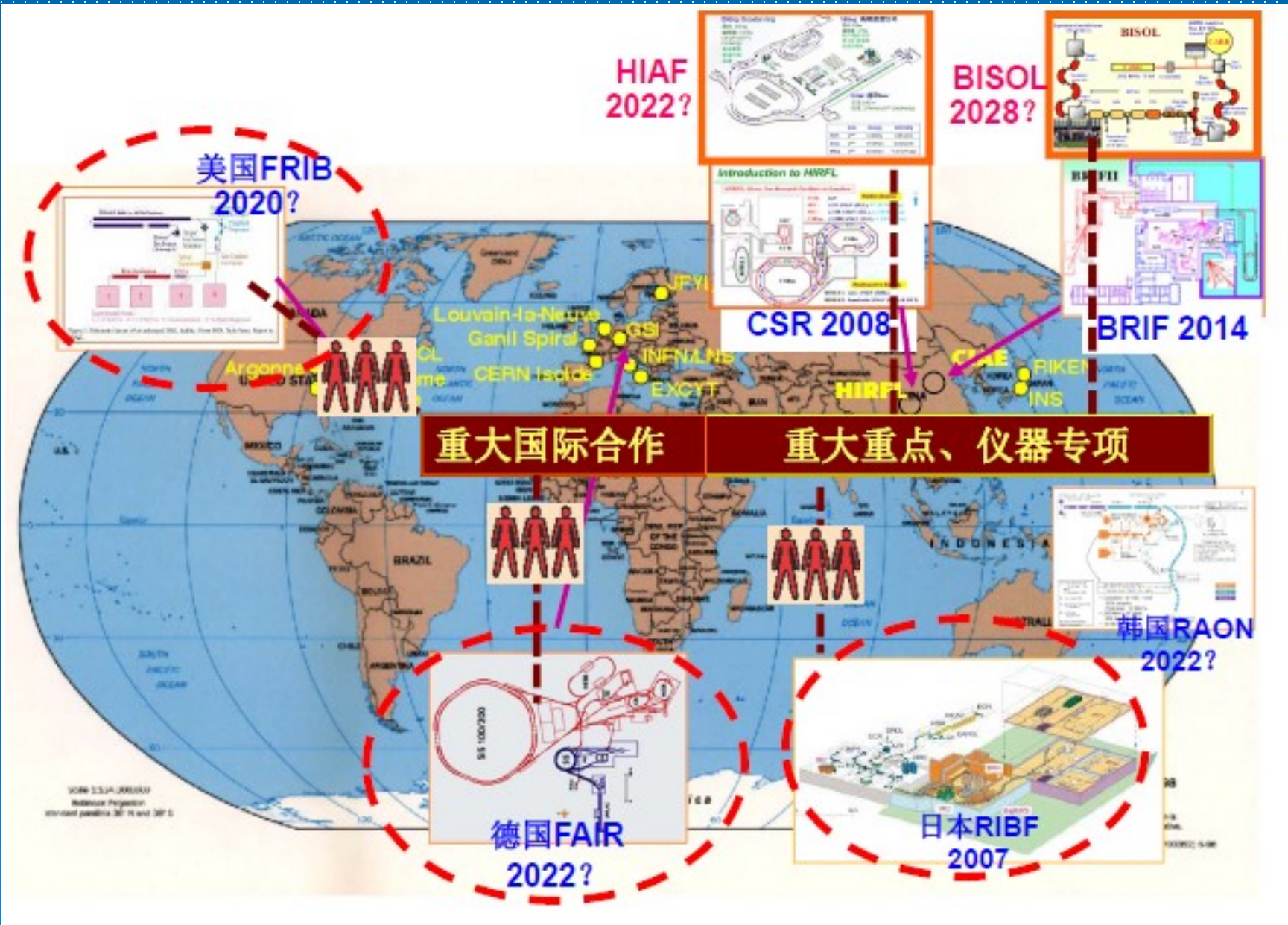
- ◆ ADS facility (CIADS)
- ◆ Heavy ion reserch (HIAF)
- * Laser gamma source in Shanghai (SLEGS)

2025–2030, according to feasibility

- ◆ Beijing online neutron rich beam (Beijing ISOL)

- * Deep underground nuclear science lab

World view



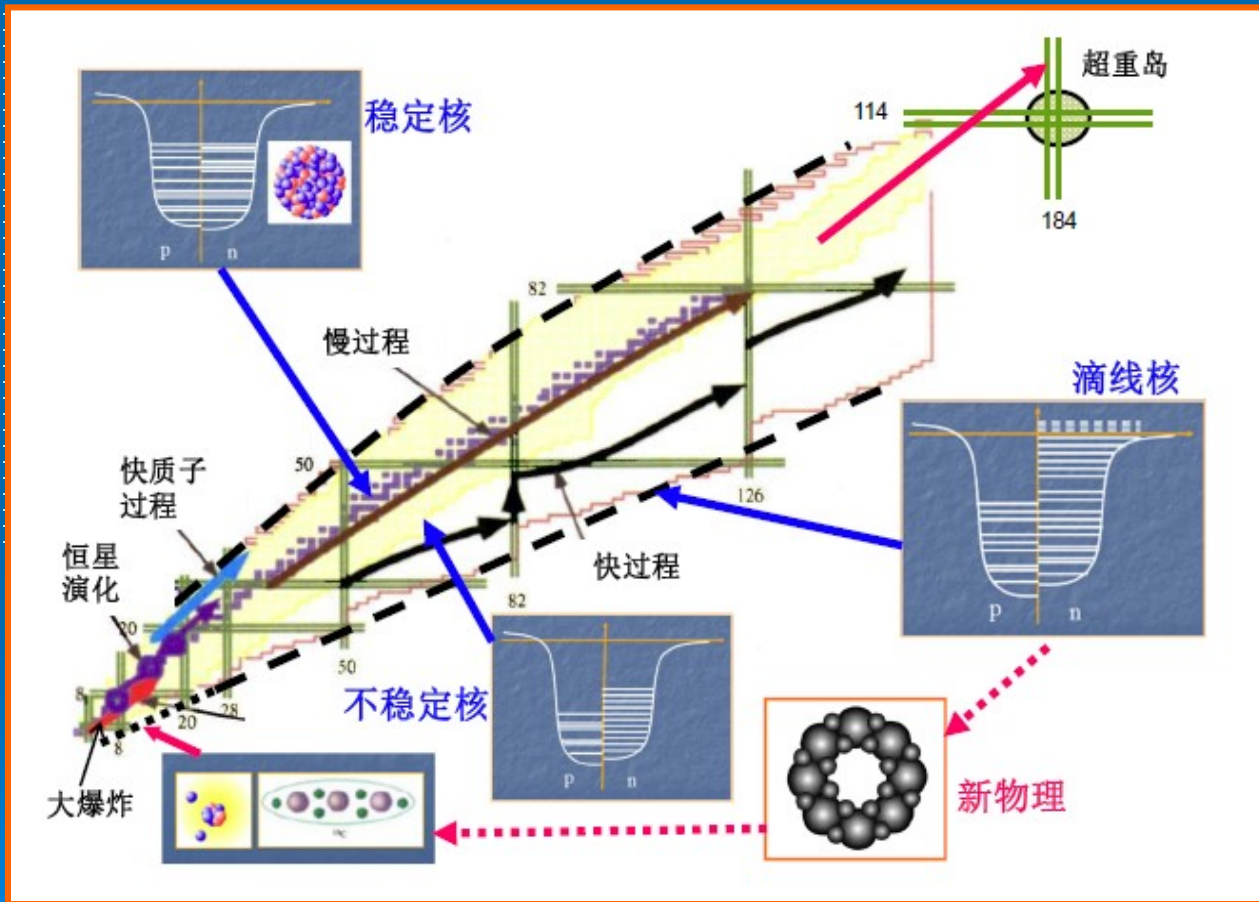
RIBF example

实验路线	思想起源	RIPS成果	BigRIPS成果	新物理
总截面测量	日/美,	N-F, 22C	?	晕,新幻数
动量谱学	美	18-19C	?	壳演化,SP
在束 γ 谱学	日	32Mg	32Ne, 34-38Mg 54Ca 128Pd...	新幻数、 壳演化
E1共振CX	美/日	19C,11Li	31Ne, 37Mg...	晕,
非弹、 破碎+重建	俄/德/美/	11Li, 6-8He, 5-7H	28O,8He, 34Ca...	2n-4n, 集团

RIPS: 2000年前后, 3PRL+几篇PLB; 2003-2013, 4PRL+几篇PLB;
BigRIPS: 2009起, 1篇Nature + 15篇以上PRL + 若干PLB

其他: 核质量、核矩; 核衰变; 弹散,非弹; 转移;
 融合+破碎+裂变; 天体核反应,

Scientific frontier



- **Rip line**
(open system)
- **Super heavy**
(challenge limit)
- **Nuclear synthesis beyond iron**
(big uncertainty)

Thrium based molten reactor

Founded by CAS

2011-2030年

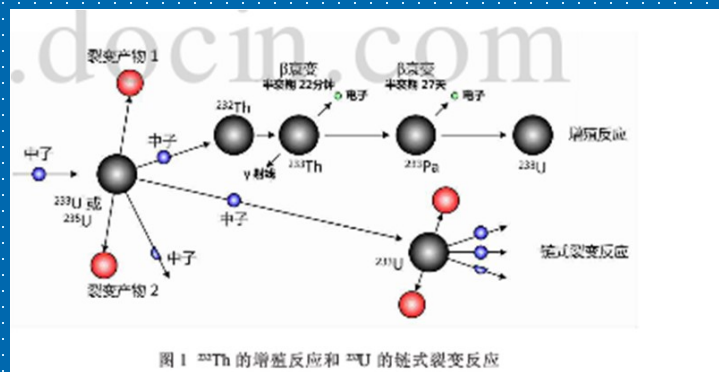
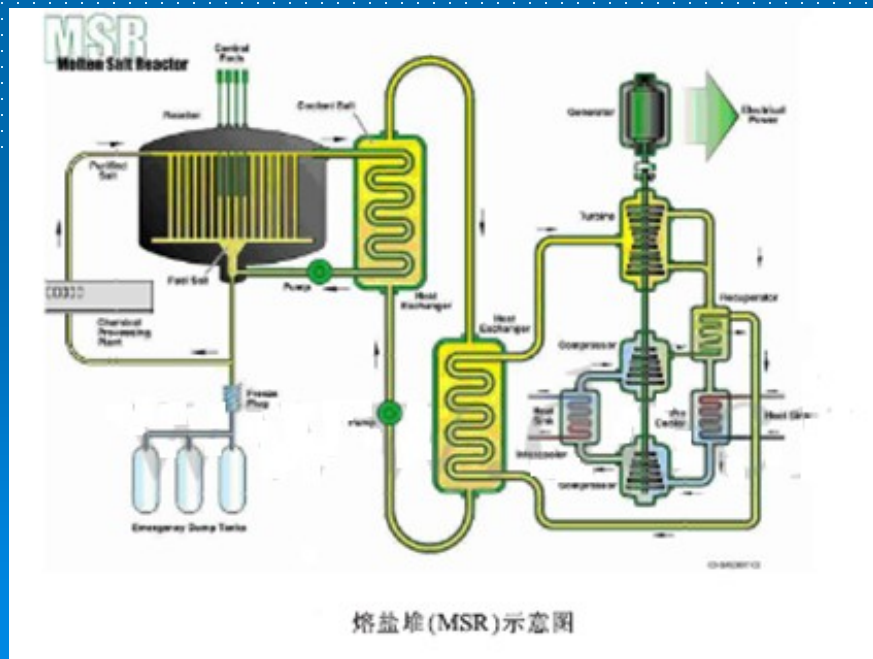
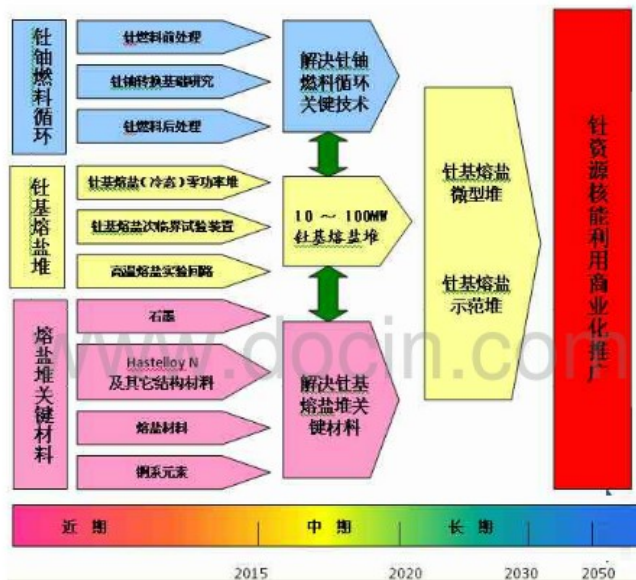


图1 ^{233}Th 的增殖反应和 ^{233}U 的链式裂变反应



基于钍铀体系的核能研究发展设想

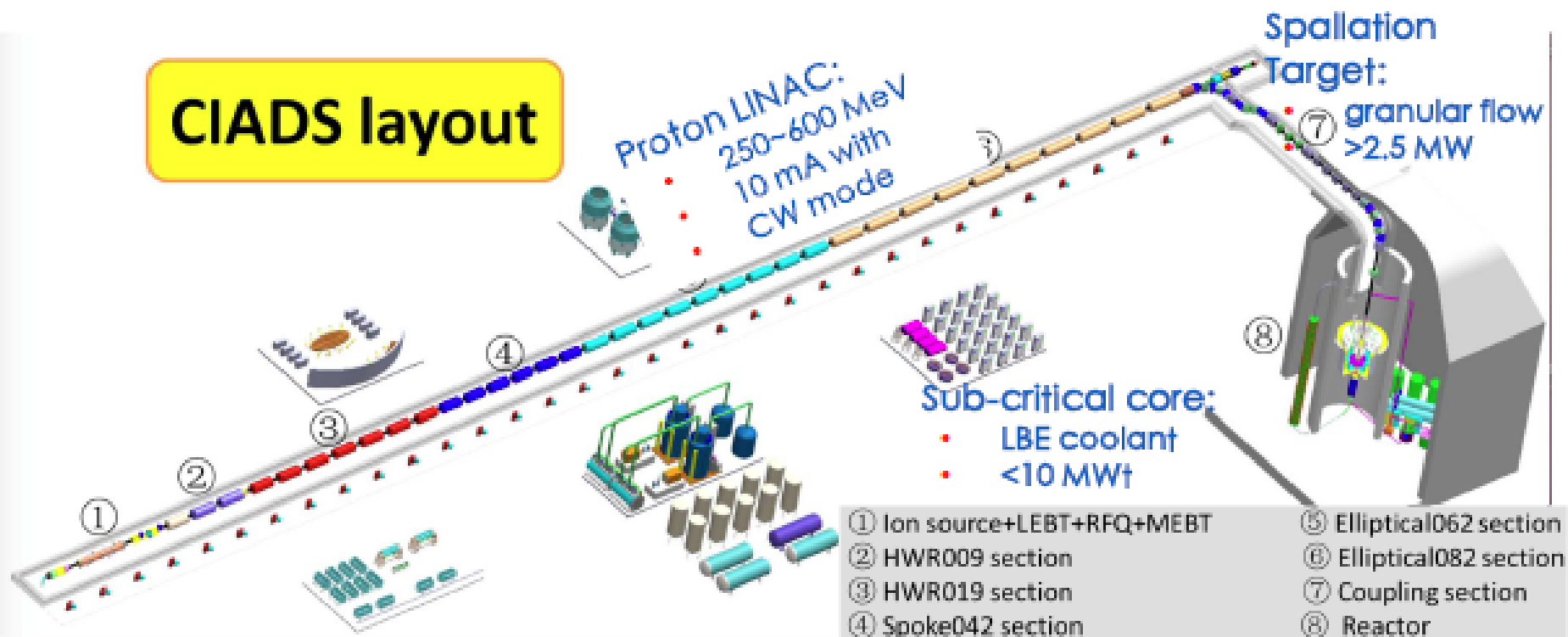


CIADS Project (2016-2023)

China Initiative Accelerator Driven System (CIADS)

- 2015年12月建议书获国家发改委批准
- 经费: ~ (18+12)亿元 (中央财政+地方政府)
- 建设地点: 广东省惠州市
- 建设及合作单位: 广州分院、近物所、高能所、合肥物质院、401、中广核等

CIADS layout



Research high lights

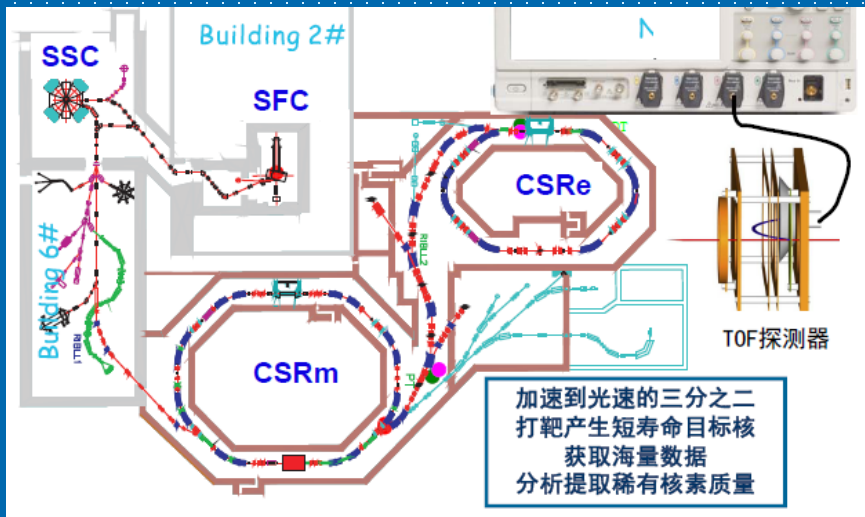


Major basic reaserch program from MOST

Start	Program
2013	Dayabay neutrino physics
	New physics of unstable nuclei
2014	High energy and density matter
2015	Highly compressed hadron physics
2016	Nuclear process in cosmols

- And 4 innovation groups from NSFC

Mass in Lanzhou storage ring



核结构:

- ^{53}Ni : 同位旋多重态质量公式 (IMME)
PRL 109, 102501 (2012)
- ^{51}Co : 同位旋非守恒力
Phys. Lett. B 735,327 (2014)
- ^{52}Co : ^{52}Ni 衰变的理解及传统研究方法质疑
PRL (2016) accepted
- ^{53}Sc : 中子 N=32 新幻数
CPC V39, 104001 (2015)

... ..

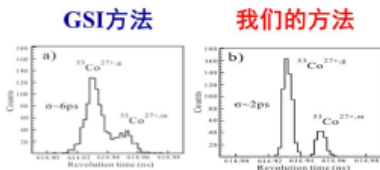
核天体物理:

- ^{65}As : 关于rp-程中的等待点 ^{64}Ge ,
PRL 106, 112501 (2011)
- ^{45}Cr : 关于rp-过程中的 Ca-Sc 循环
Astrophys. J. Lett. 766, L8 (2013)
- ^{82}Zr : 关于 vp-过程的反应路径
in progress

不断发展和创新实验技术和方法, 处于国际领先水平

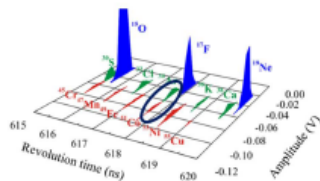
数据処理新方法

提高精度: $\delta m/m: 10^{-5} \rightarrow 10^{-7}$
(IMS方法首次达到 10^{-7} 测量精度)



离子鉴别新方法

回旋周期+信号幅度
(首次实现A/Z相同离子的分辨)



发展新测量技术

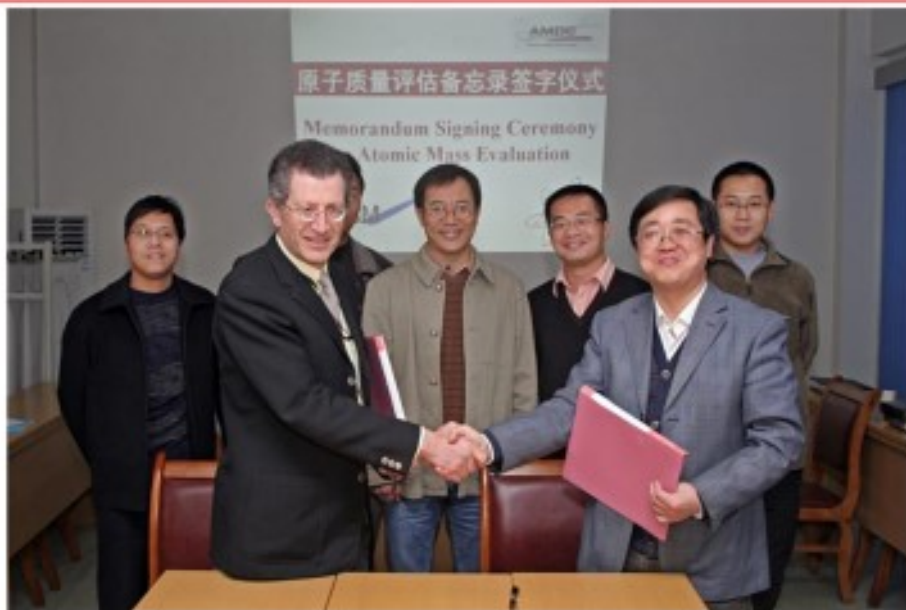
实现最高时间分辨; 发展新型质量谱仪
(更短寿命, 更高精度)



International mass evaluation

- 国际原子（核）质量评估中心于2013年移交近代物理研究所管理
- 最新一期AME核质量数据已于2012年在Chinese Physics C上发表
- 提高了我国杂志在国际上的影响力

<http://amdc.impcas.ac.cn>



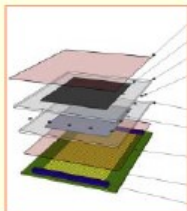
857页，12437个实验数据
2438个原子的基态质量

AME (Atomic Mass Evaluation)中心是被IUPAP认可的收录、评估和发布原子（核）质量数据的国际权威组织，在IUPAP协调下，AME工作以**中国**和**法国**科学家为主，**美国**和**德国**等国科学家参与

Research highlights from PKU



NIMA606(09)645



NIMA663(12)22



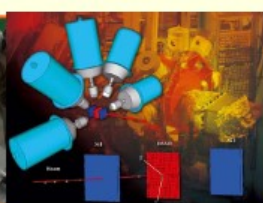
NIMA686(12)38



NIMA728(2013)47



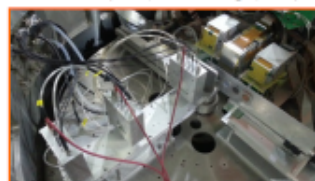
IEEE-NS61(14)596



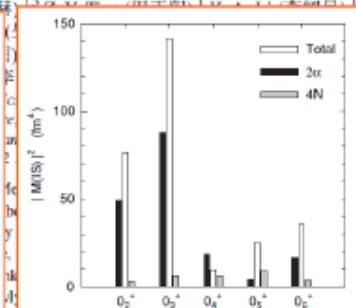
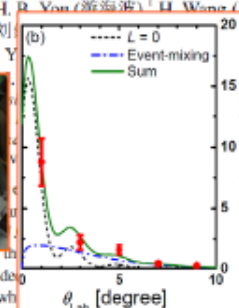
NIMA747(14)52

Observation of Enhanced Monopole Strength and Clustering in ^{12}Be

Z. H. Yang (杨再宏),¹ Y. L. Ye (叶沿林),^{1,4*} Z. H. Li (李志敏),¹ J. L. Lou (楼建玲),¹ J. S. Wang (王建松),² D. X. Jiang (江栋兴),¹ Y. C. Ge (葛榆成),¹ Q. T. Li (李奇特),¹ H. Hua (华辉),¹ X. Q. Li (李湘庆),¹ F. R. Xu (许甫荣),¹ J. C. Pei (裴俊琛),¹ R. Qiao (乔锐),¹ H. P. Yao (姚海波),¹ H. Wang (王赫),^{1,3} Y. L. Sun (孙叶磊),¹ H. N. Liu (刘文超),^{1,3} B. Yang (杨彪),¹ Y. C. Wen (文超),^{1,3}



time. These findings support investigations over the past decade around zero degrees, which signal the cluster formation in a nucleus.



PHYSICAL REVIEW C 91, 024304 (2015)

Helium-helium clustering states in ^{12}Be



SCIENCE CHINA

Physics, Mechanics September 2014 Vol. 57 No. 9: 1613–1617



Spectroscopy of ^{74}Ge : From soft to rigid triaxiality

J.J. Sun^a, Z. Shi^b, X.Q. Li^{a,*}, H. Hua^{a,*}, C. Xu^a, Q.B. Chen^a, S.Q. Zhang^a, C.Y. Song^b, J. Meng^a, X.G. Wu^c, S.P. Hu^c, H.Q. Zhang^c, W.Y. Liang^a, F.R. Xu^a, Z.H. Li^a, G.S. Li^c, C.Y. He^c, Y. Zheng^c, Y.L. Ye^a, D.X. Jiang^a, Y.Y. Cheng^a, C. He^a, R. Han^a, Z.H. Li^a, C.B. Li^c, H.W. Li^c, J.L. Wang^c, J.J. Liu^c, Y.H. Wu^c, P.W. Luo^c, S.H. Yao^c, B.B. Yu^c, X.P. Cao^c, H.B. Sun^d

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^b School of Physics and Nuclear Energy, Lanzhou University, Lanzhou 730000, China

Spectroscopy of ^{76}Se : Prolate-to-oblate shape transition

C. Xu,¹ X. Q. Li,¹ J. Meng,^{1,2} S. Q. Zhang,^{1,2} H. Hua,^{1,3} S. Y. Wang,² B. Qi,² C. Liu,² Z. G. Xiao,^{3,4} H. J. Li,² L. H. Zhu,⁴ Z. Shi,⁵ Z. H. Li,¹ Y. L. Ye,¹ D. X. Jiang,¹ J. J. Sun,¹ Z. H. Zhang,¹ Y. Shi,¹ P. W. Zhao,¹ Q. B. Chen,¹ W. Y. Liang,¹ R. Han,¹ C. Y. Niu,¹ C. G. Li,¹ C. G. Wang,¹ Z. H. Li,¹ S. M. Wyngaardt,⁶ R. A. Bark,⁷ P. Papka,⁸ T. D. Bucher,⁹ A. Kamblawe,⁹ E. Khalael,⁹ N. Khumalo,^{9,10} E. A. Lawrie,⁷ J. J. Lawrie,⁷ S. M. Mullins,⁷ S. Murray,⁷ M. Wiedeking,⁷ J. F. Sharpey-Schafer,¹¹ S. N. T. Majola,¹⁰ J. Ndayishimiye,^{6,7} D. Negi,⁷ S. P. Noncolela,¹² S. S. Nishangase,⁹ O. Shirinda,⁷ P. Sithole,¹³ M. A. Stankiewicz,^{1,10} J. N. Orec,¹⁴ T. Dinoko,¹⁵ J. Easton,¹⁶ B. M. Nyakó,¹¹ and K. Juhász¹²

Band crossing and shape evolution in ^{73}Ge

J. J. Sun (孙君杰),^{1,2} C. Xu (徐川),^{1,2} X. Q. Li (李湘庆),^{1,2} H. Hua (华辉),^{1,2} S. Q. Zhang (张双全),¹ F. R. Xu (许甫荣),¹ W. Y. Liang (梁宇阳),¹ C. F. Jiao (焦长峰),¹ J. Meng (孟杰),¹ X. G. Wu (吴晓光),¹ S. P. Hu (胡世鹏),¹ H. Q. Zhang (张焕春),¹ Z. H. Li (李志敏),¹ Y. L. Ye (叶沿林),¹ D. X. Jiang (江栋兴),¹ Y. Y. Cheng (程奕奕),¹ C. He (何磊),¹ R. Han (韩磊),¹ C. Y. Niu (牛晨阳),¹ C. G. Li (李晨光),¹ C. G. Wang (程奕奕),¹ Z. H. Li (李宇浩),¹ G. S. Li (李广生),¹ C. Y. He (贺创业),¹ Y. Zheng (郑云),¹ C. B. Li (李振博),¹ H. W. Li (李红伟),¹ J. J. Wang (王金龙),¹ J. J. Liu (刘金健),¹ Y. H. Wu (吴文恒),¹

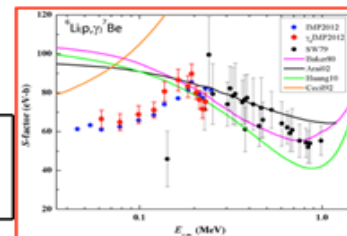
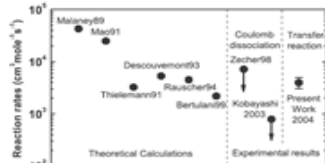
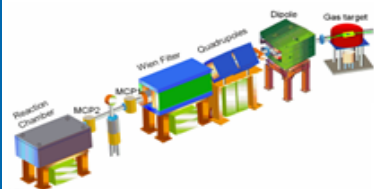
Spectroscopy of ^{155}Yb : Structure evolution in the $N = 85$ isotones

X. Q. Li (李湘庆),¹ C. Xu (徐川),^{1,2} S. Q. Zhang (张双全),¹ H. Hua (华辉),^{1,2} J. Meng (孟杰),¹ R. A. Bark,² Q. B. Chen (陈自博),¹ C. Y. Niu (牛晨阳),¹ R. Han (韩磊),¹ S. M. Wyngaardt,³ S. Y. Wang (王宇华),⁴ S. Wang (王硕),⁴ B. Qi (齐斌),⁵ L. Liu (刘雷),⁴ L. H. Zhu (竺礼华),⁵ Z. Shi (施智),⁶ G. L. Zhang (张高龙),⁶ B. H. Sun (孙保华),⁶ X. Y. Le (乐小云),⁶ C. Y. Song (宋春燕),⁶ Y. L. Ye (叶沿林),¹ D. X. Jiang (江栋兴),¹ F. R. Xu (许甫荣),¹ Z. H. Li (李志敏),¹ J. J. Sun (孙君杰),¹ Y. Shi (石跃),¹ P. W. Zhao (赵鹏),¹ W. Y. Liang (梁宇阳),¹ C. G. Li (李晨光),¹ C. G. Wang (王春光),¹ X. C. Chen (陈鑫),¹ Z. H. Li (李宇浩),¹ D. P. Sun (孙大鹏),¹ C. Liu (刘晨),¹ Z. Q. Li (李志泉),¹ P. Jones,⁷ E. A. Lawrie,⁷ J. J. Lawrie,⁷ M. Wiedeking,⁷ T. D. Dinoko,⁸ B. V. N. Kheswa,⁹ L. Makhathini,⁹ S. N. T. Majola,¹⁰ J. Ndayishimiye,¹¹ S. P. Noncolela,¹² O. Shirinda,¹³ J. Gal,¹⁴ G. Kalinka,¹⁵ J. Molnár,¹⁶ B. M. Nyakó,¹⁷ J. Timár,¹⁸ K. Juhász,¹⁹ and M. Arognjo¹⁰

Elastic scattering and breakup of ^{11}Be on protons at 26.9 A MeV

J. Chen, J. L. Lou,¹ Y. L. Ye, Z. H. Li, Y. C. Ge, Q. T. Li, J. Li, W. Jiang, Y. L. Sun, and H. L. Zhang
School of Physics and State Key Laboratory of Nuclear Physics and Technology, Peking University, Beijing 100871, China
N. Aoi, E. Ideguchi, H. J. Ong, Y. Ayyad, K. Hatanaka, D. T. Tran, T. Yamamoto, M. Tanaka, T. Suzuki, and N. T. Tho
Research Centre for Nuclear Physics, Osaka University, Osaka, Japan

Progress of nuclear astrophysics in CIAE



1993, 我国首个放射性核束实验装置, NPA

2005, $^8\text{Li}(n,\gamma)^9\text{Li}$ 原初核合成反应, PRCR

2011, 基金委创新群体项目支持

2013, $^6\text{Li}(p,\gamma)^7\text{Be}$ 原初反应直接测量, PLB

2015, 基金委重大项目支持锦屏深地核天体JUNA, SC

1993

1996

2005

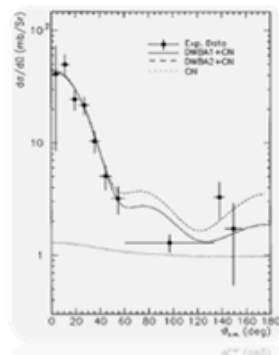
2010

2012

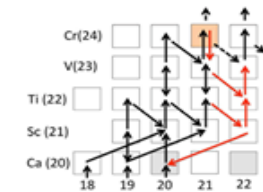
2014

2015

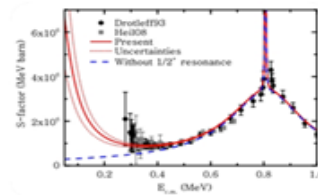
1996, $^7\text{Be}(p,\gamma)^8\text{B}$ 太阳中微子反应, PRL



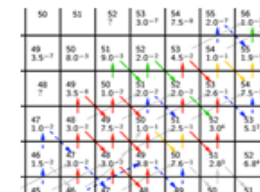
2011, rp 过程质量, PRL, APJL



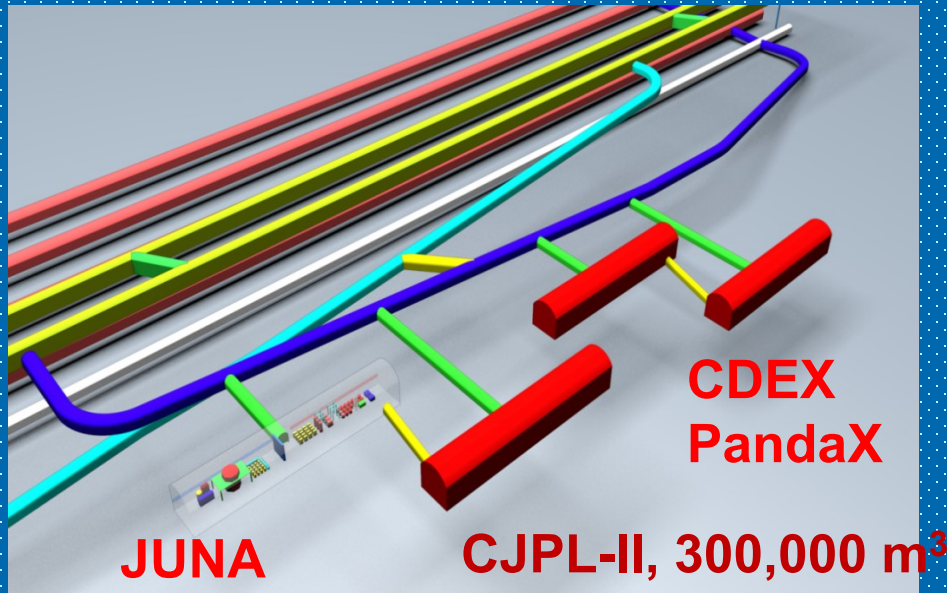
2012, $^{13}\text{C}(\alpha,n)^{16}\text{O}$ 中子源反应, APJ



2014, rp过程衰变测量, PRC

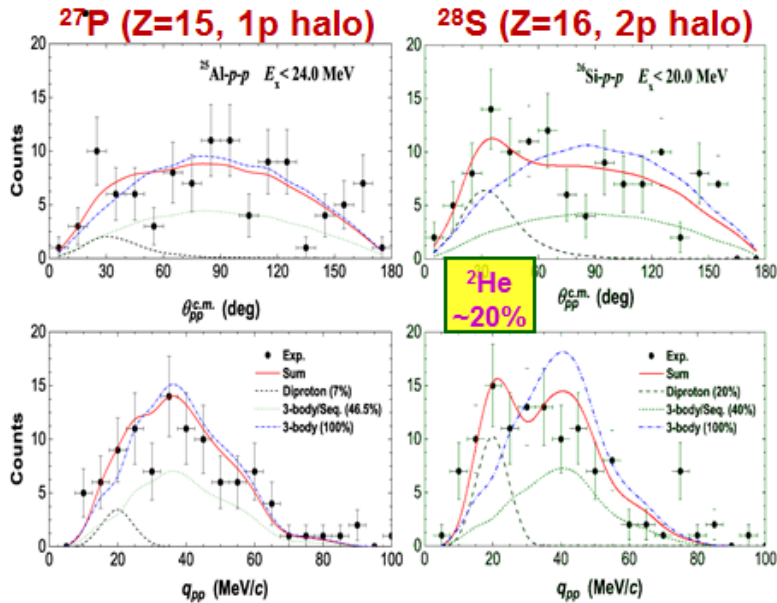


JUNA : Jinping underground nuclear astrophysics



Nuclear reactor in CIAE

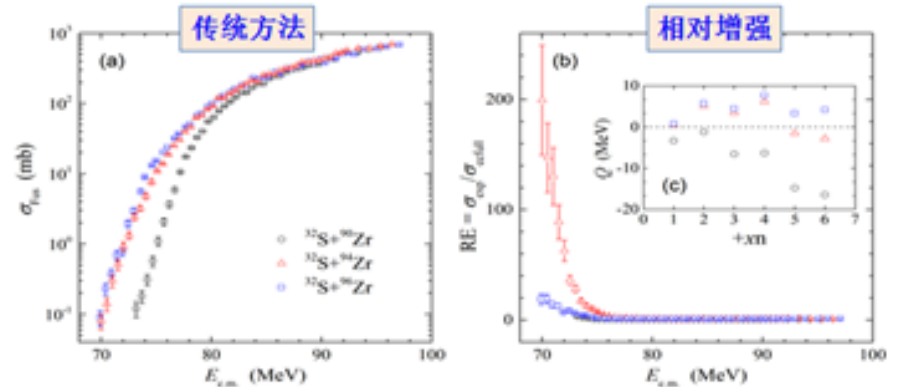
★ Diproton emission is enhanced by $2p$ halo-like states



图：双质子的角关联和动量关联

X.X. Xu, C.J. Lin* et al., Phys. Lett. B 727, 126 (2013).

★ 提出一种新的方法，提供了一个分析熔合增强的标准工具



H.M. Jia, C.J. Lin* et al., Phys. Lett. B 755, 43 (2016).

● Di-proton emission

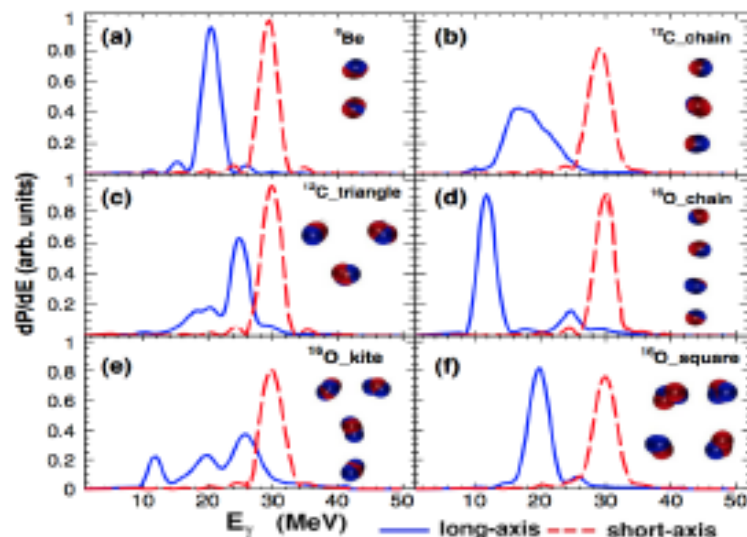
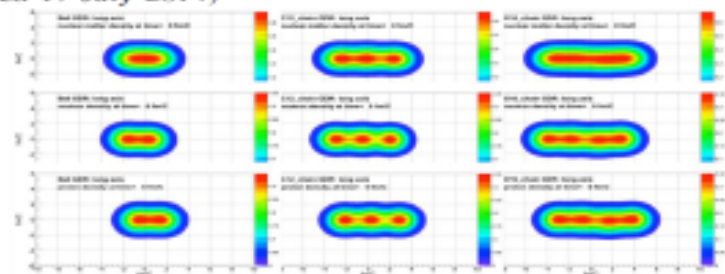
● Transfer coupling

Giant Dipole Resonance as a Fingerprint of α Clustering Configurations in ^{12}C and ^{16}O W. B. He (何万兵),^{1,2} Y. G. Ma (马余刚),^{1,3,*} X. G. Cao (曹喜光),^{1,†} X. Z. Cai (蔡翔舟),¹ and G. Q. Zhang (张国强)¹¹Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China²University of the Chinese Academy of Sciences, Beijing 100080, China³Shanghai Tech University, Shanghai 200031, China

(Received 6 May 2014; published 17 July 2014)

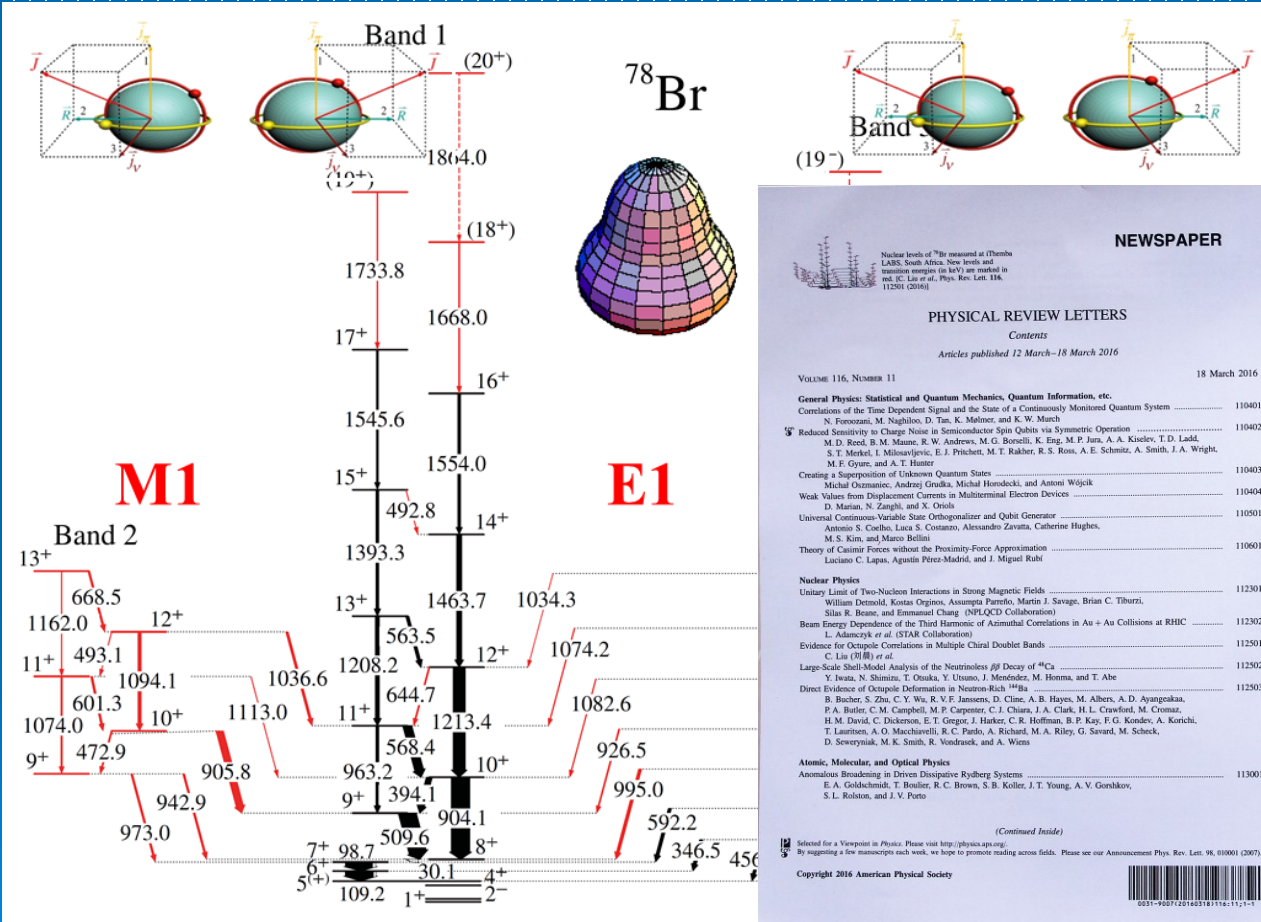
首次提出通过巨共振研究原子核的
 α 集团结构

- ✓ α 集团结构导致GDR谱的分裂，GDR峰的个数及中心能量与集团几何构型有明显对应关系
- ✓ 不同 α 集团构型在短轴方向的巨共振都有30MeV的特征共振峰，此峰可作为鉴别 α 集团是否存在的实验探针
- ✓ 小质量核的GDR谱以子结构在大核中出现有助于更明确的判明 α 集团结构的具体构型



Nuclear structure in Shangdong

► Octupole relevance in double band



NEWSPAPER

PHYSICAL REVIEW LETTERS

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Selected for a Viewpoint in *Physics*. Please visit <http://physics.aps.org>.

By signing a few manuscripts each week, we hope to promote reading across fields. Please see our Announcement Phys. Rev. Lett. 98, 010001 (2007).

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PHYSICAL REVIEW LETTERS

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American Physical Society

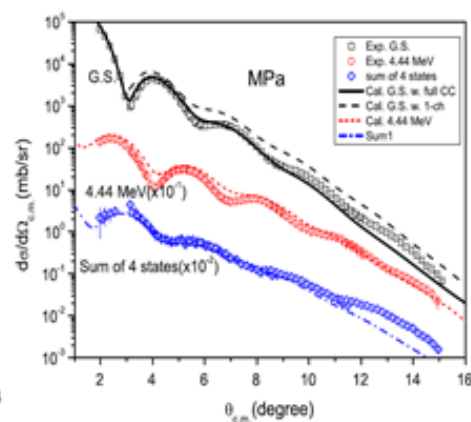
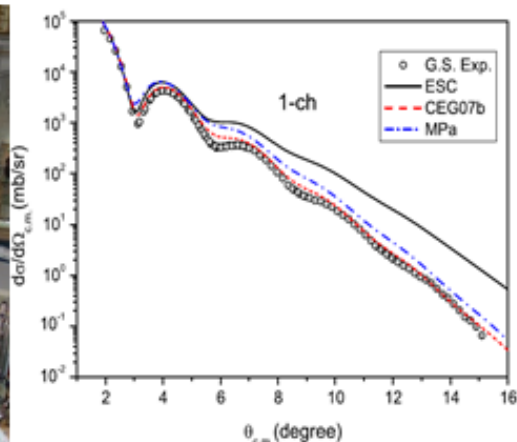
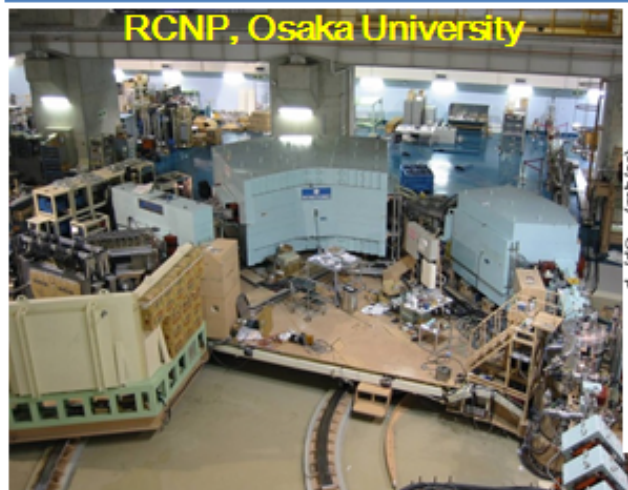
APS
physics

Volume 116, Number 11

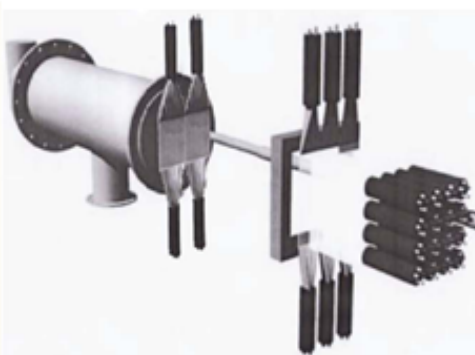
3 body force in Beihang

■ 首次实验上研究原子核三体力相互作用，发现了排斥三体力和耦合道效应扮演重要角色

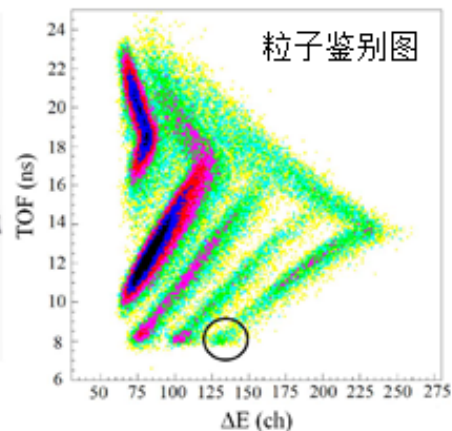
➢ Phys. Lett. B 751 (2015) 1; Nuclear Instrument and Methods A 832 (2016) 243; 已投稿 Physical Review C; 国家自然科学基金面上项目



100A MeV $^{12}\text{C}+^{12}\text{C}$ 弹散和非弹散角分布

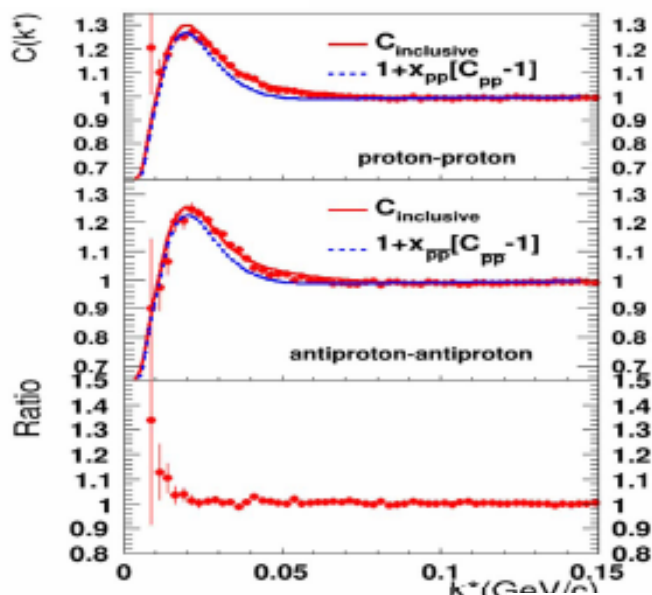


实验装置图

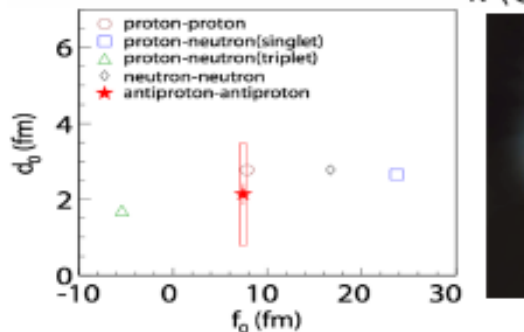


High energy and density matter

中国科学院上海应用物理研究所：首次测量了反物质相互作用
nature 527,345 (2015) 入选“2015年度中国科学十大进展”



首次测量反质子间相互作用参数



2016年度国家自然科学奖二等奖（已通过函评、会议初评、复评等环节）
（预计这是继2007年核物理获得国家自然科学奖以来的再次突破）

2016年度国家自然科学奖初评通过项目

评审组	项目名称	主要完成人	推荐单位（专家）	初评建议等级
物理与天文学组	重离子碰撞中的反物质探测与夸克物质的强子谱学与集体性质研究	马余刚(中国科学院上海应用物理研究所), 陈宏芳(中国科学技术大学), 程建平(清华大学), 陈金辉(中国科学院上海应用物理研究所), 刘峰(华中师范大学)	中国科学院	二等奖

Elliptic Flow Splitting as a Probe of the QCD Phase Structure at Finite Baryon Chemical Potential

Jun Xu,^{1,*} Taesoo Song,² Che Ming Ko,² and Feng Li²

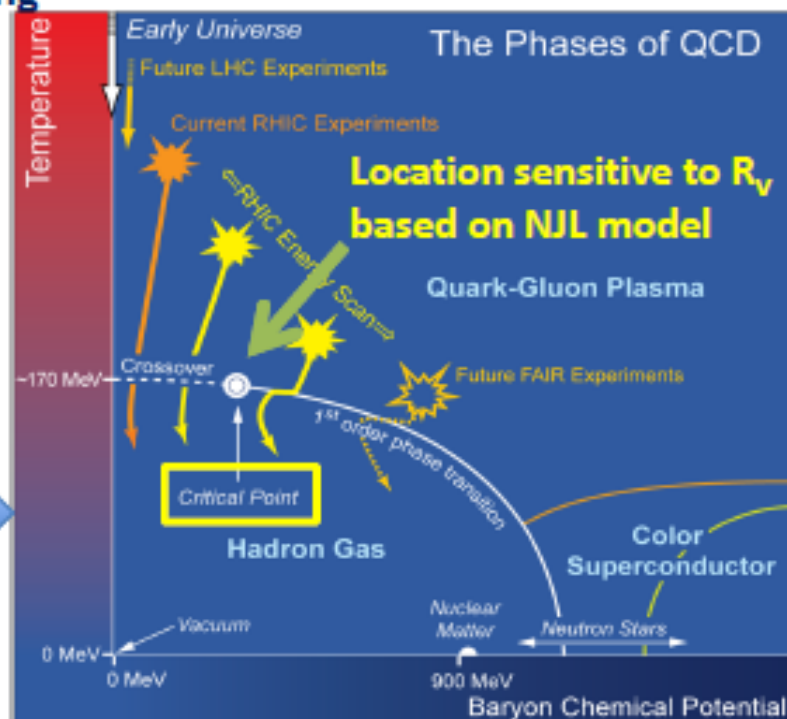
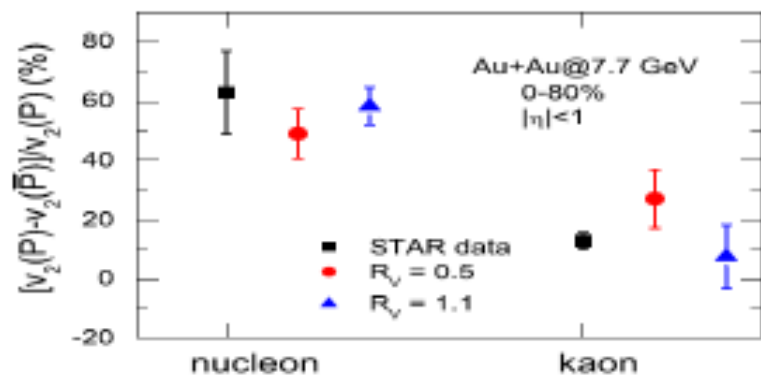
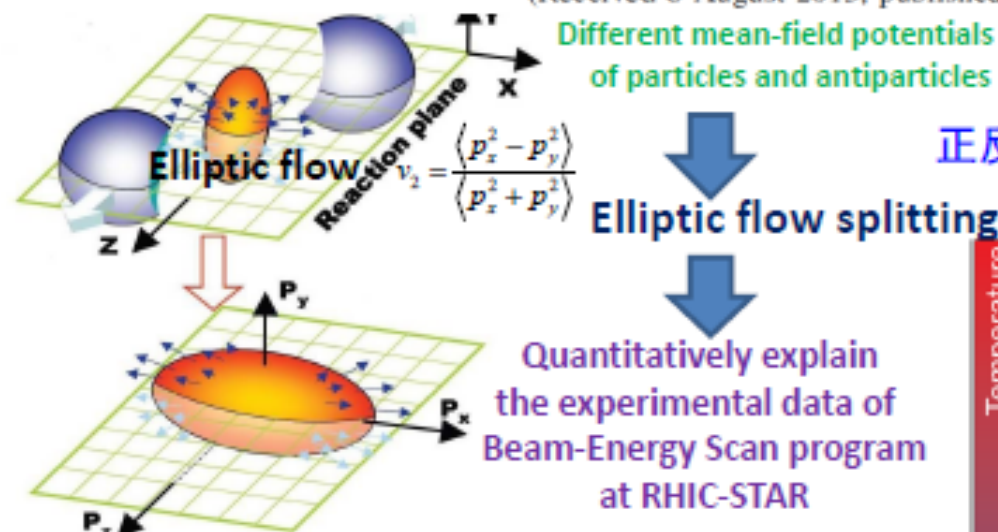
¹Shanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China

²Department of Physics and Astronomy and Cyclotron Institute, Texas A&M University, College Station, Texas 77843, USA

(Received 8 August 2013; published 7 January 2014)

应物所 徐骏 等

正反质子椭圆流的差作为QCD相结构的探针



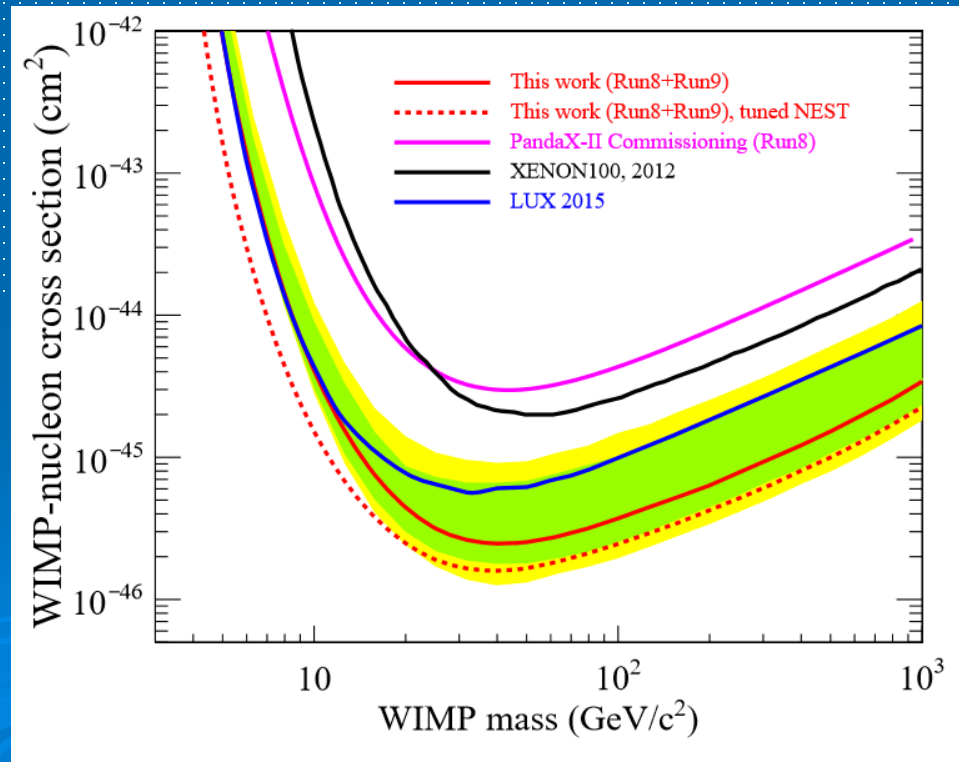
Dark matter in Panda X

SJTU :

33000 kg day, no signal

Most sensitive low limits Phys. Rev.

Lett.Phys.Rev.Lett. 117 (2016) 121303, cover story



Progress on application

Heavy therapy

Medical CT

Material test

眼睑基底细胞癌术后复发



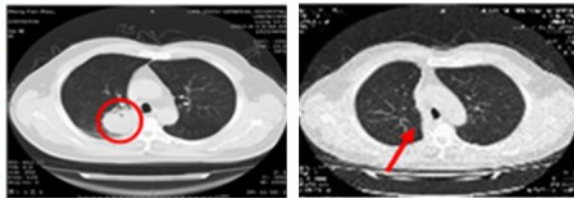
右上臂Merkel细胞癌



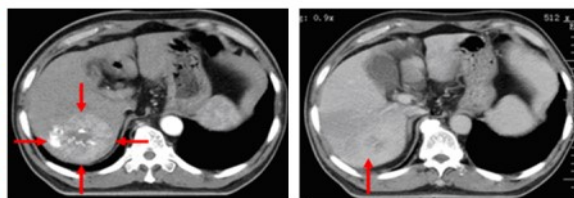
额顶部皮肤鳞癌



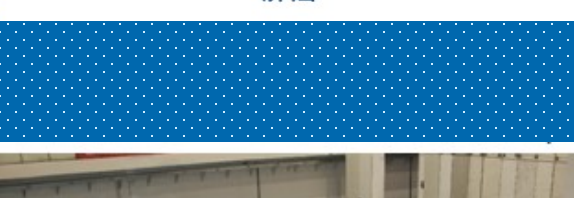
头面部神经纤维瘤



肺腺鳞癌化疗后复发



肝癌



Effectiveness

国家重点新产品 证书

项目名称: 医用重离子加速器

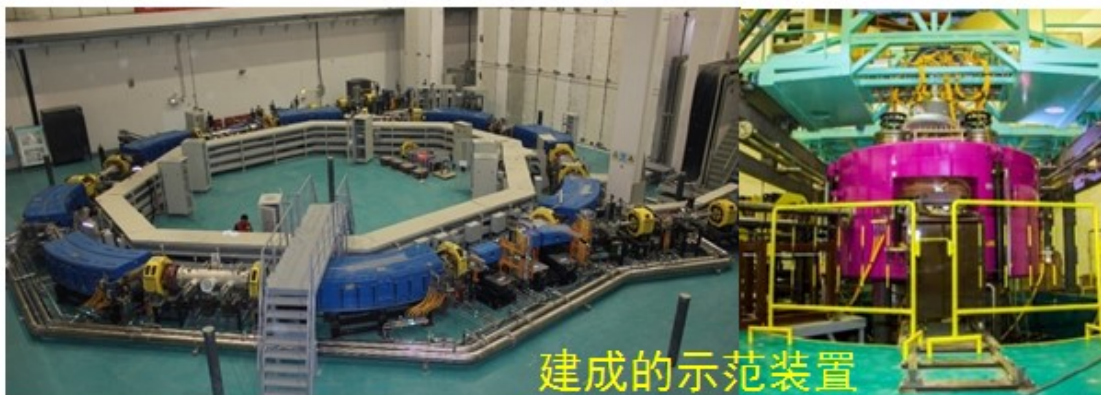
项目编号: 2014GRG10002

承担单位: 兰州科近泰基新技术有限责任公司

发证时间: 二〇一四年十月

有效期: 三年

批准机关: 科学技术部



National acceptance of method

Two demo facilities

Reactor BNCT

First reactor dedicated for cancer therapy



Most compact reactor for cancer therapy

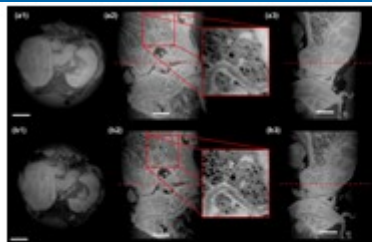
Medical and industrial CT



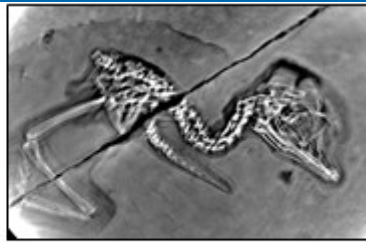
乳腺PET获得国家三类医疗器械注册证



人体全身PET通过注册检验



小鼠关节断层成像



状化石CT成像

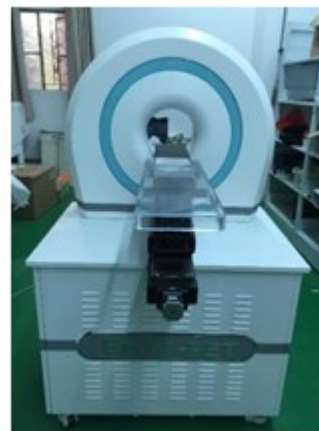


国内首台大尺寸板状微米CT

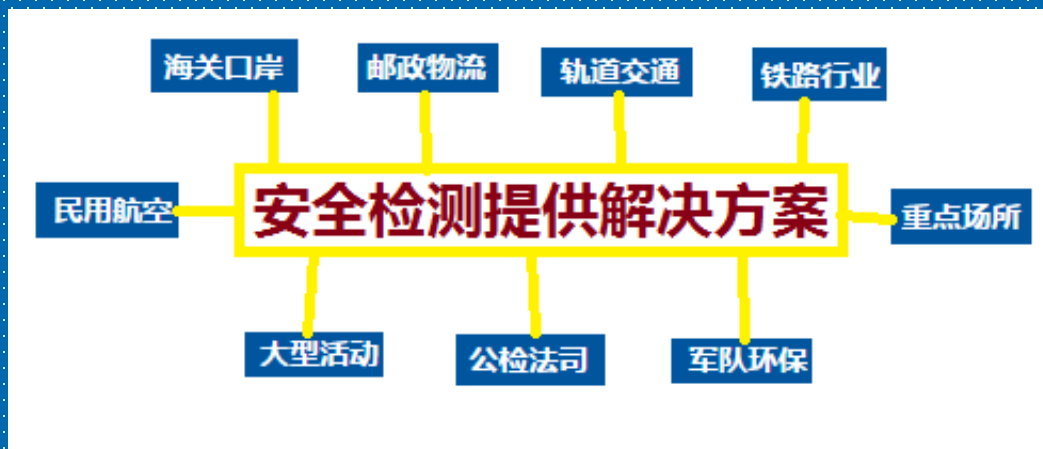


国内首套化石CT

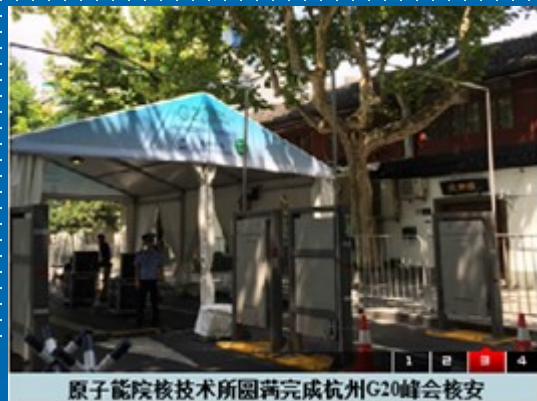
工业CT



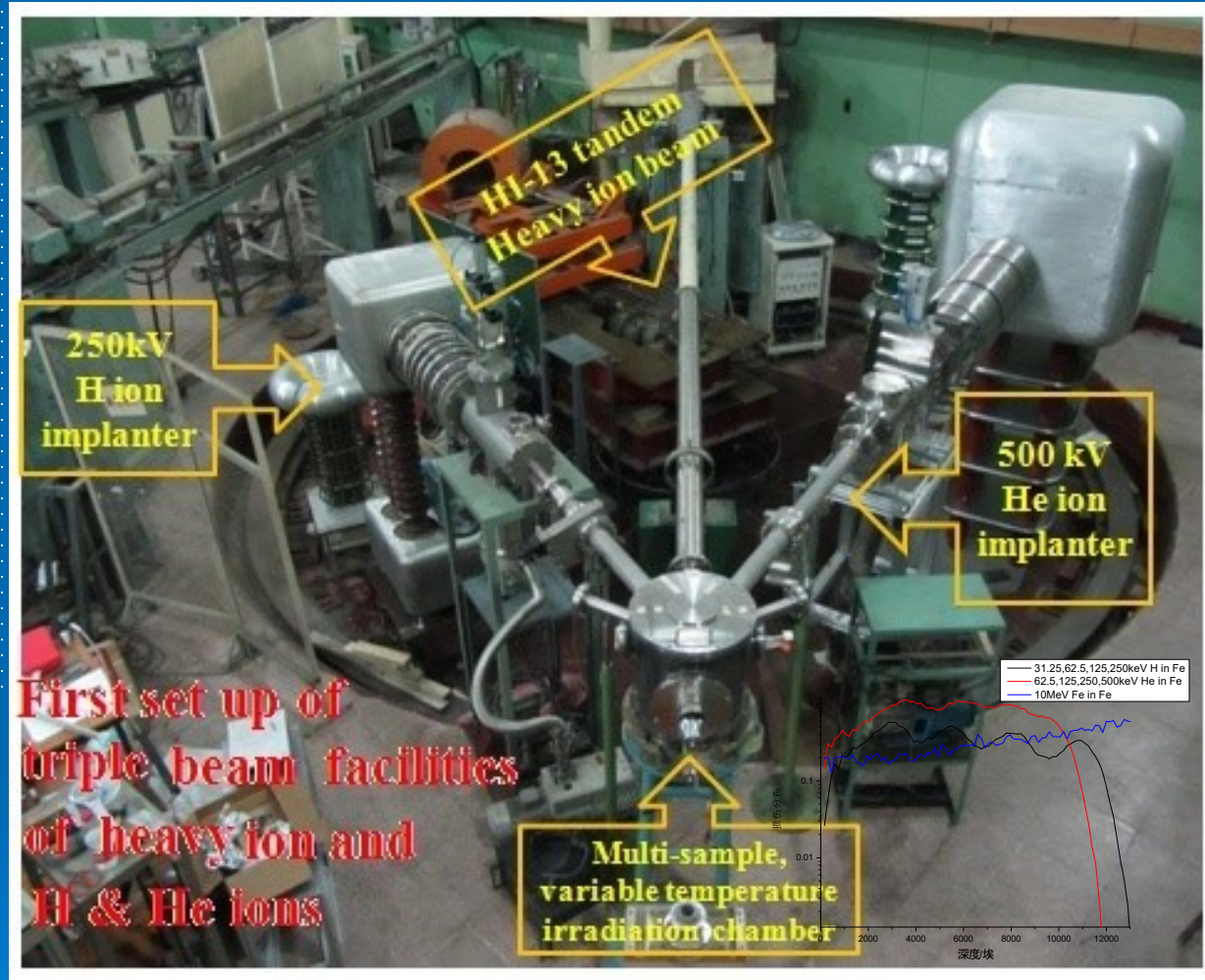
灵长类动物PET



Radiation and explosive material detection



Material test for nuclear reactor



HI, H, He triple beam in CIAE

- ◆ 60er and 70er as PI
- ◆ 70er and 80er as main force
- ◆ 80-90 er as new power

Manpower for future

Example of new team:

Shandong U; Beihang U;

New opportunity:

E. g. : FRIB-CSC research fellow
program

International commmittee

- ◆ IUPAP : Wenlong Zhan, deputy chair
- ◆ IUPAP-C12 : Weiping Liu, deputy chair
- ◆ IUPAP-WG9 : Wenlong Zhan, Weiping Liu,
Yanlin Ye
- ◆ ANPhA : (Yanlin Ye, formal chair) 、
Weiping Liu, deputy chair、 Guoqing Xiao、
Yugang Ma、 Furong Xu

China Japan nuclear conference

- Every 3 year in China and Japan
- The 9th in Japan in 2015

No. series	Place	Date	Number of participants		Number of talks
			Japan	China	
5th	Kyusyu Univ.	2004, Mar. 7-9	74	28	51
6th	Shanghai (SINAP)	2006, May 16-20	30	49	64
7th	Univ. Tsukuba	2009, Nov.16-20	>70	30	72
8th	Beijing (CIAE)	2012, Oct. 15-19	29	41	62
9th	Osaka Univ.	2015, Nov. 3-13	80	31	50
10th	Lanzhou(IMP)	2018			

CNS summer school



Every year with 100+ students
CNS for PhD and postdoc
10+ PhD from China supported

ANPhA activities



**Based on Japan, China, and Korea
Funded in PKU on July 2009**

**With 8 member countries and regions, 1-2
meetings every year**

2011-2014, chaired by Yanlin Ye from PKU

China-U.S. Theory Institute for Physics with Exotic Nuclei, CUSTIPEN



**Funded by DOE with Sino-US collaboration
Based on PKU and TAMU
The 1st meeting in PKU on May 2013**

China-FRIB collaboration



**A Chinese
delegation
of 30+
visited
FRIB on
May 2015**

**Report: The First FRIB-China Workshop on
Physics of Nuclei and Hadrons**

July 2015

China Russia collaboration



第二届（北京，2011年）



第三届（杜布纳，2012年）



第六届（桂林，2015年）



第七届（杜布纳，2016年）

组织了国际核反应动力学(IWND)系列研讨会

The International Workshop on Nuclear Dynamics in Heavy-Ion Reactions (IWND2014)
Aug 15-19, 2014, Lanzhou, China



IWND2014@中科院近代物理所

会议主席：马余刚

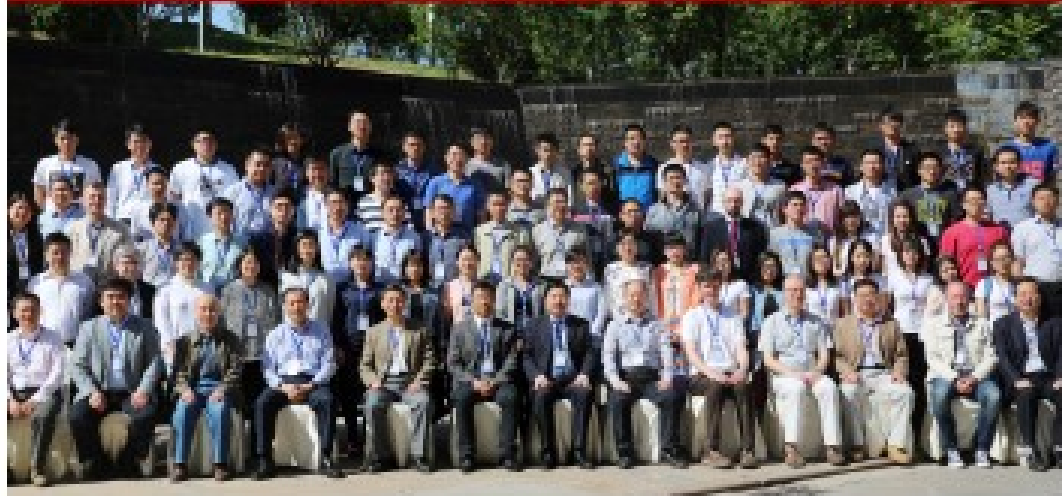
共同主席：

徐珊珊，陈列文，张丰收

学术秘书：

冯兆庆

The 5th International Workshop on Nuclear Dynamics in Heavy-Ion Reactions
第五届国际核反应动力学研讨会 (May. 15-20th, 2016 Xinxiang, China)



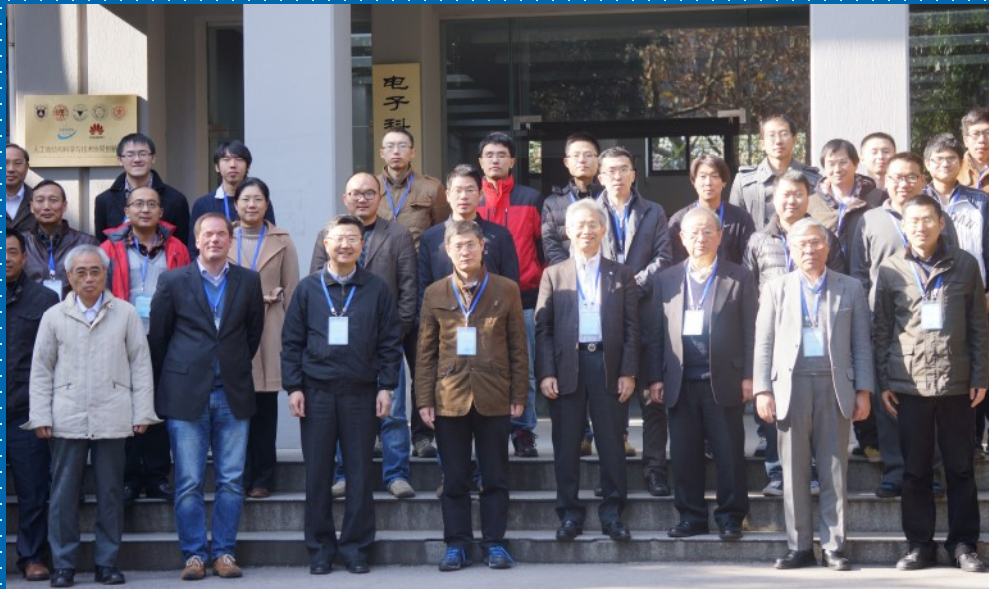
IWND2016@河南师大

会议主席：马余刚

共同主席：陈列文，张丰收

学术秘书：马春旺

Workshop on Nuclear Clustering



第一次 (2014. 12.)
南京大学

第二次 (2015. 9.)
北海道大学
大阪大学

Mini-Workshop on Nuclear Clustering 2016 (MWNC 2016) Beijing, July 2-3, 2016



第三次 (2016. 07.)
北京大学

第四次 (2016. 11.)
横滨大学

International conference in China

- Atomic physics conference
- 13th OMEG conference in Beijing, June, 2015
- ...

The 13th international symposium on Origin of Matter and Evolution of Galaxies (OMEG 2015)
June 24-27, 2015 Beijing, China



Conclusion

- Encouraging long range plan
- Supportive facility funding
- Great man power support
- Wide international collaboration
- Enhanced by ANPhA
- Looking bright future and wish to collaboration even more with ANPhA members!