

激光电子伽马源（SLEGS）与光核反应实验研究

王宏伟，范功涛，许杭华，刘龙祥，张岳，郝子锐

中国科学院上海高等研究院
上海光源中心/先进成像与工业应用部/激光伽玛组
wanghw@sari.ac.cn

报告内容：

- 1、SLEGS伽马源简介
- 2、SLEGS光中子反应与Back-n的中子俘获反应

1、SLEGS伽马源简介

上海浦东—张江综合性国家科学中心



上海张江先进光源大科学装置集群

<http://www.sari.cas.cn/lari/index.html>



极端光物理线站SEL
100-PW激光装置

上海同步辐射光源 (SSRF)

上海光源已有34条光束线和46个实验站服务用户实验，成为现阶段光子能区覆盖最广、运行线站数量最多的中能第三代同步辐射装置，其总体性能和综合实验能力位居国际先进水平！



上海同步辐射光源 (SSRF)



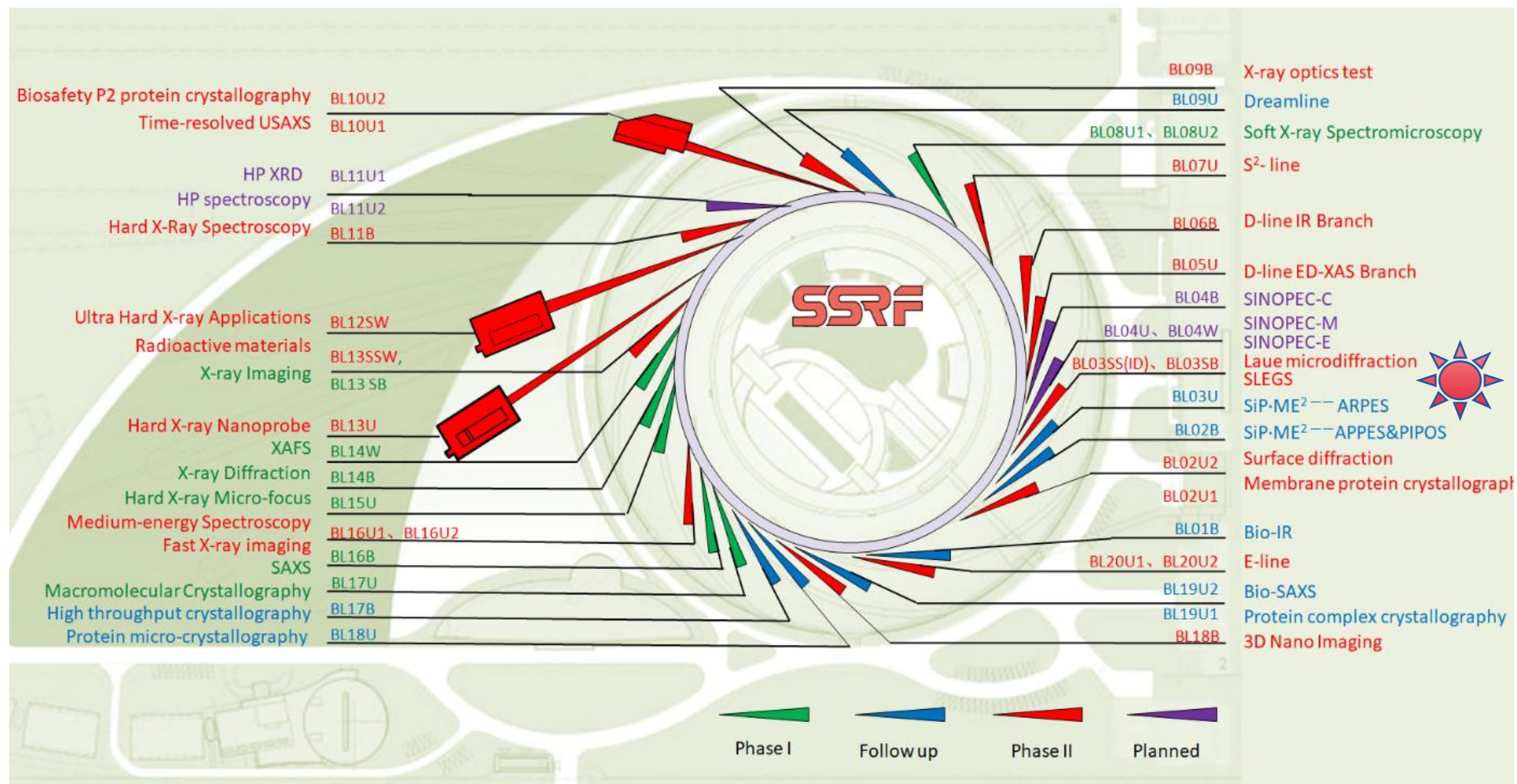
上海软X射线自由电子激光 (Sx FEL)



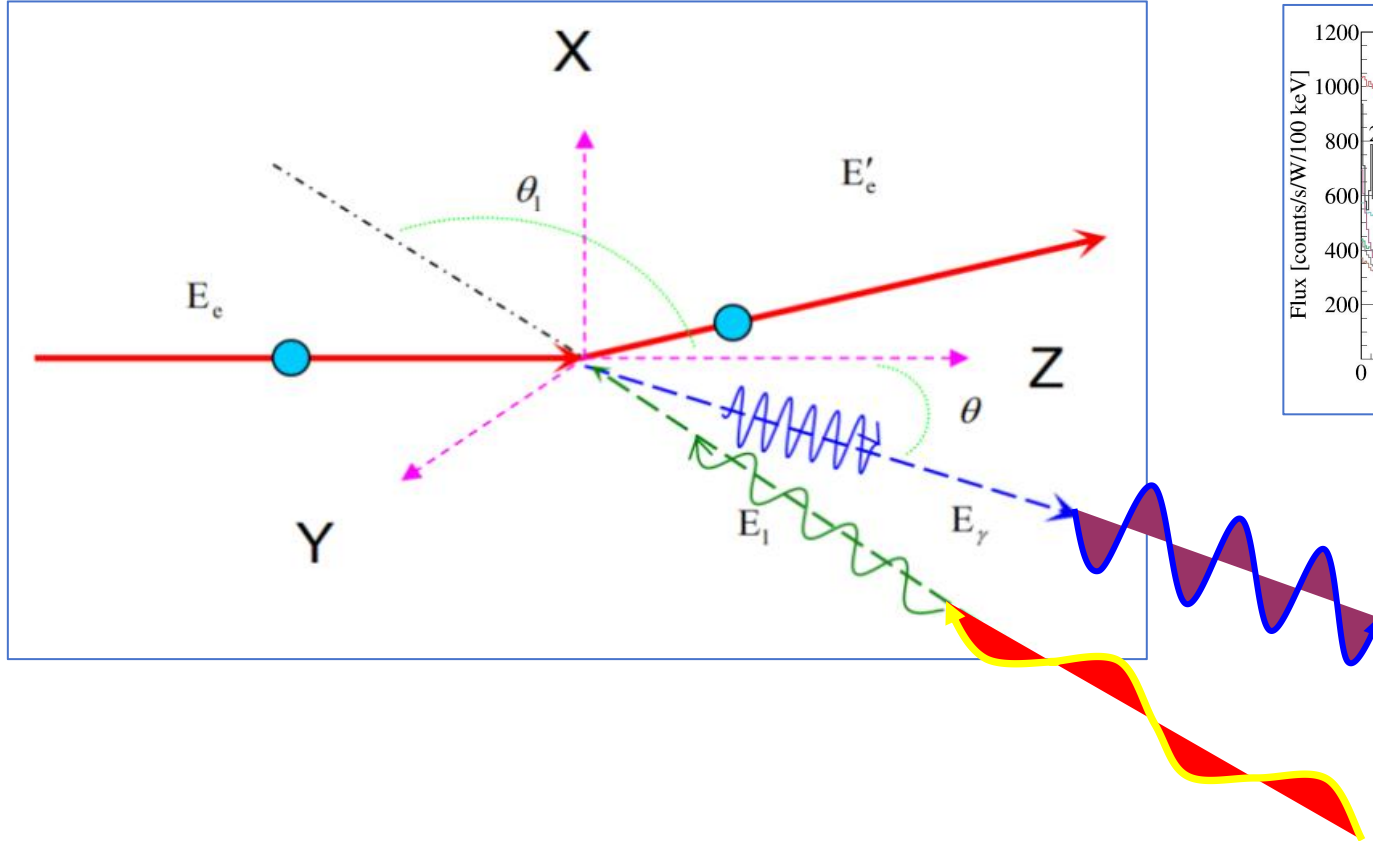
上海硬X射线自由电子激光 (SHINE)

上海同步辐射光源线站布局：上海光源线站工程2016.11-2023.07（二期）

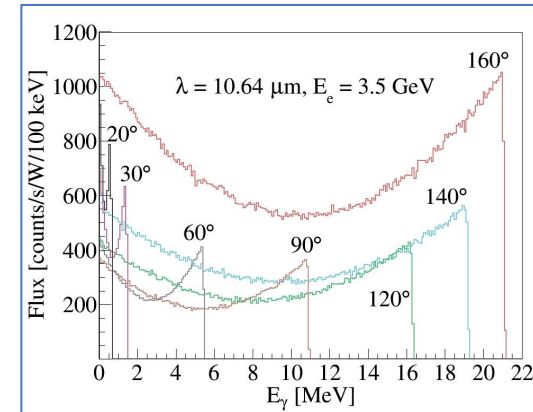
有34条光束线和46个实验站服务用户实验



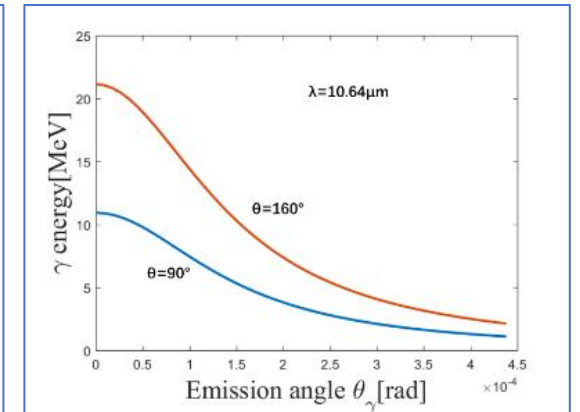
逆康普顿散射原理



伽马能谱分布



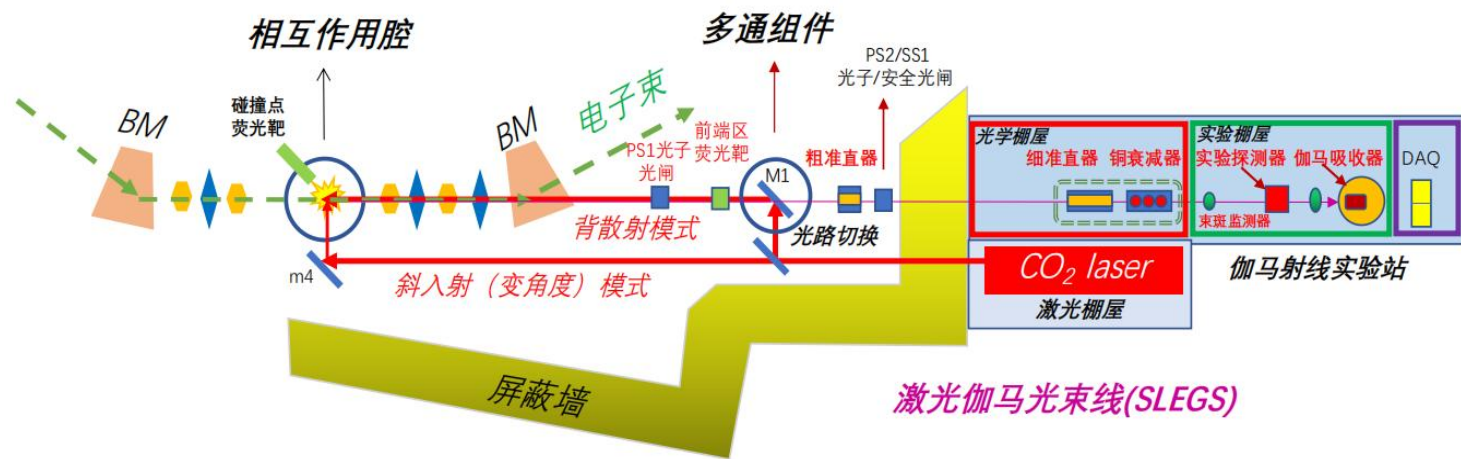
伽马角分布



改变伽马能量 E_γ 的方法:

- 改变电子的能量 E_e ;
- 改变激光的能量 E_l ;
- 改变激光和电子碰撞夹角 θ_l 。
- 选择伽马出射角度 θ 。

$$E_\gamma = \frac{E_l (1 + \beta \cos \theta_L)}{1 - \beta \cos \theta + \frac{E_l \{1 - \cos(\theta_L - \theta)\}}{E_e}}$$



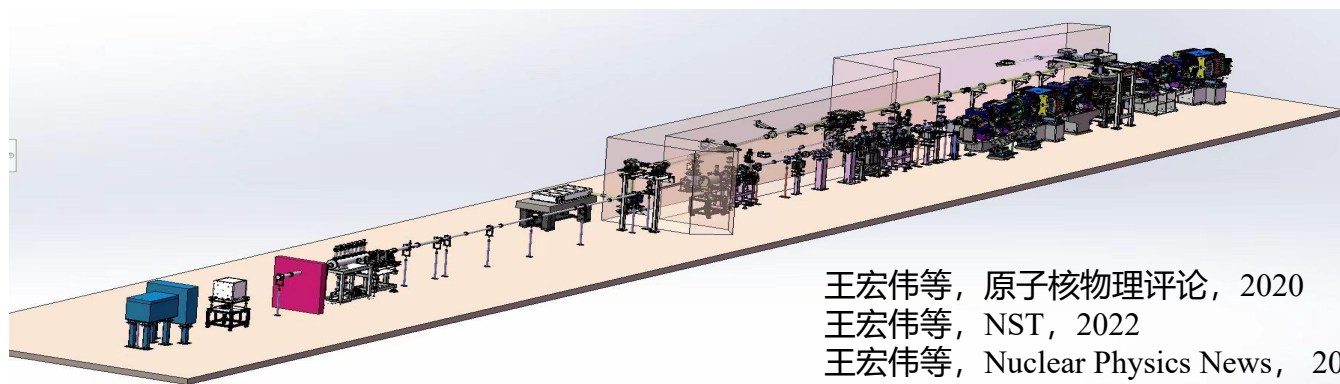
- 能量范围: 0.25(20°) - 10.9(90°) - 21.1(160°), 21.7(180°) MeV
- 能量分辨率: 5% @ 2mm - 15% @ 3mm with Collimator
- 发射度: < 0.5 mrad
- 总积分流强: 2.14x10⁵ @ 20° phs/s
2.45x10⁶ @ 90° phs/s
5.99x10⁶ @ 160° phs/s
1.20x10⁷ @ 180° phs/s

➤ 光核物理基础研究:

- ✓ 核物理: 核结构 巨共振GDR, 矮共振PDR和核共振荧光 NRF
- ✓ 核天体物理: 重元素的起源问题

➤ 光核物理应用研究

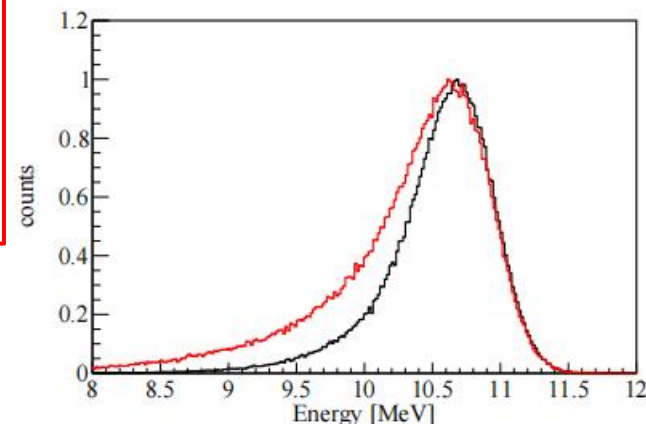
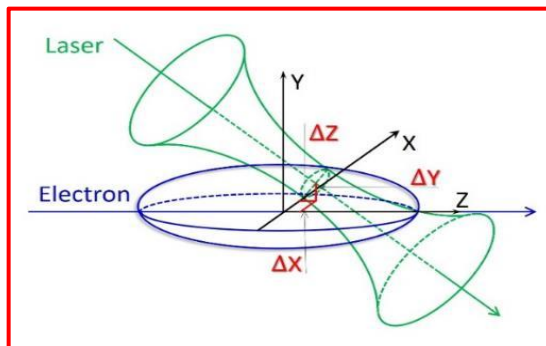
- ✓ 空间 X/γ 探测器定标
- ✓ 核废料嬗变与核能安全,
- ✓ 核医学与医用同位素产生研究
- ✓ 伽马成像



王宏伟等, 原子核物理评论, 2020
 王宏伟等, NST, 2022
 王宏伟等, Nuclear Physics News, 2023
 王宏伟等, 原子核物理评论, 2024

散射光子的能量分布——伽马能谱展宽

伽马束流的重要参数之一：能谱分辨



$$\frac{\sigma_{E'_{ph}}}{E'_{ph}} = \sqrt{\left(\frac{\sigma_{\theta_{max}}}{E_{\theta_{max}}}\right)^2 + \left(\frac{\sigma_{\gamma}}{E_{\gamma}}\right)^2 + \left(\frac{\sigma_L}{E_L}\right)^2 + \left(\frac{\sigma_{\epsilon}}{E_{\epsilon}}\right)^2}$$

影响能谱展宽因素

电子束发射度

$$\frac{\sigma_{\epsilon}}{E_{\epsilon}} = \sqrt{\left(\frac{\sigma_{\epsilon_x}}{E_{\epsilon_x}}\right)^2 + \left(\frac{\sigma_{\epsilon_y}}{E_{\epsilon_y}}\right)^2} = \frac{\sqrt{2}\gamma^2}{1+X} \sqrt{\frac{\epsilon_x^2}{\beta_x^*2} + \frac{\epsilon_y^2}{\beta_y^*2}}$$

出射伽马能量

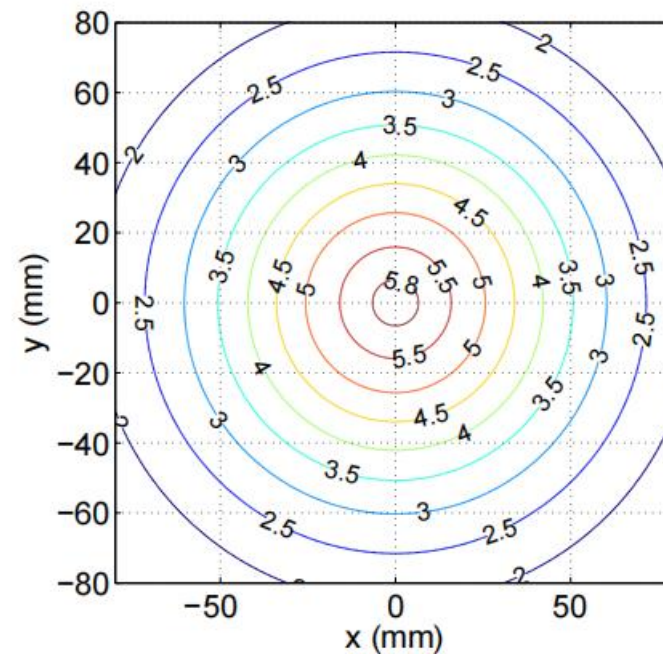
$$\frac{\sigma_{\gamma}}{E_{\gamma}} = \frac{2+X}{1+X+\psi^2} \frac{d\gamma}{\gamma}$$

激光光子能量

$$\frac{\sigma_L}{E_L} = \frac{1+\psi^2}{1+X+\psi^2} \frac{dE_L}{E_L}$$

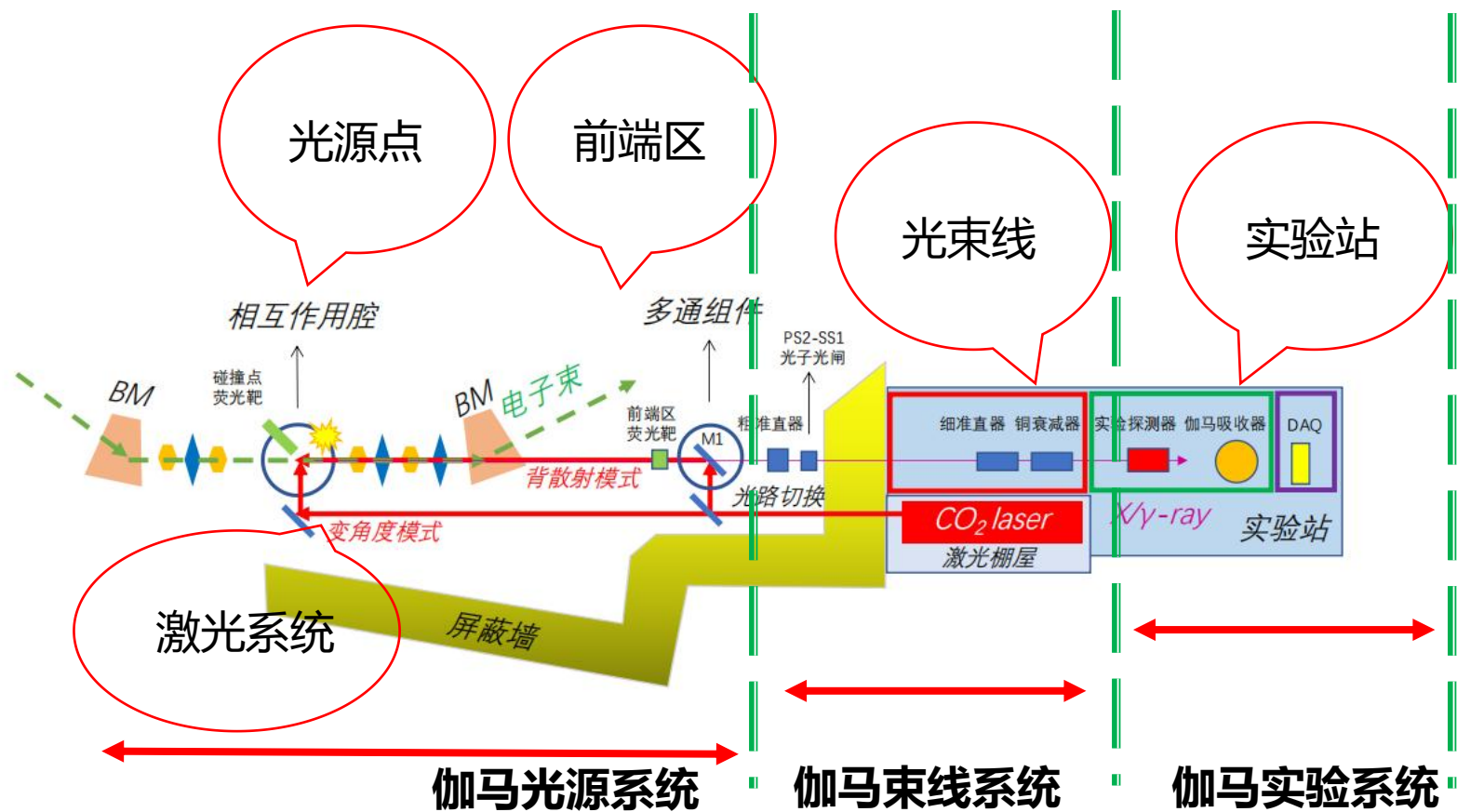
准直器孔径

$$\frac{\sigma_{\theta_{max}}}{E_{\theta_{max}}} = \frac{1}{\sqrt{12}} \frac{\psi^2}{1+X+\psi^2/2}, \quad \psi = \gamma\theta_{max}$$



伽马能量分布

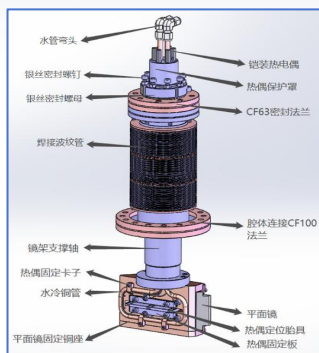
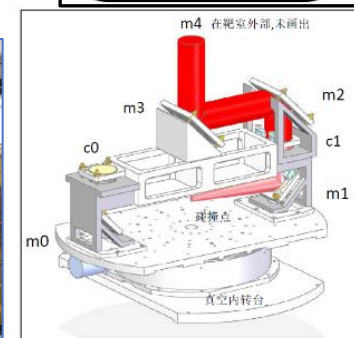
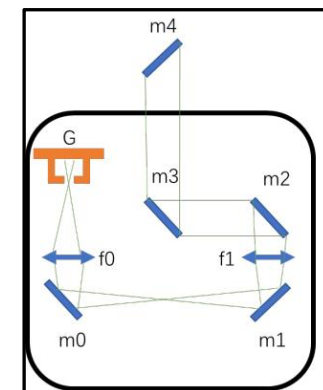
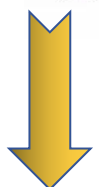
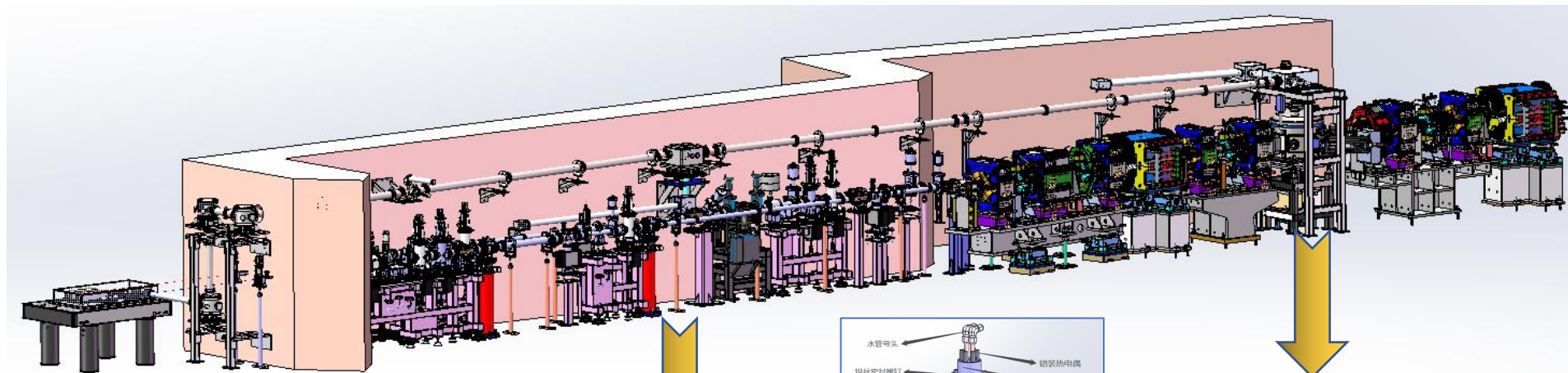
激光伽马束线站的关键部件 - 全部自研



- ①Hongwei WANG, et al., Nuclear Physics Review, 2024, 41(1): 67-74. doi: 10.11804/NuclPhysRev. 41. 2023CNPC38
- ②Yuxuan YANG, et al., Nuclear Physics Review, 2024, 41(1): 433-438. doi: 10.11804/NuclPhysRev. 41. 2023CNPC42
- ③Pan KUANG, et al., Nuclear Physics Review, 2023, 40(1): 58-65. doi:10.11804/NuclPhysRev. 40. 2022040
- ④H. W. Wang, et al., Nucl. Sci. Tech. 33:87 (2022). doi:10.1007/s41365-022-01076-0.
- ⑤Hongwei WANG, et al., Nuclear Physics Review, 2020, 37(1): 53-63. doi: 10.11804/NuclPhysRev. 37. 2019043
- ⑥PAN Qiang-yan, et al., Nuclear Physics Review, 2008, 25(2): 129-134. doi: 10.11804/NuclPhysRev. 25. 02. 129

1、伽马光源系统：

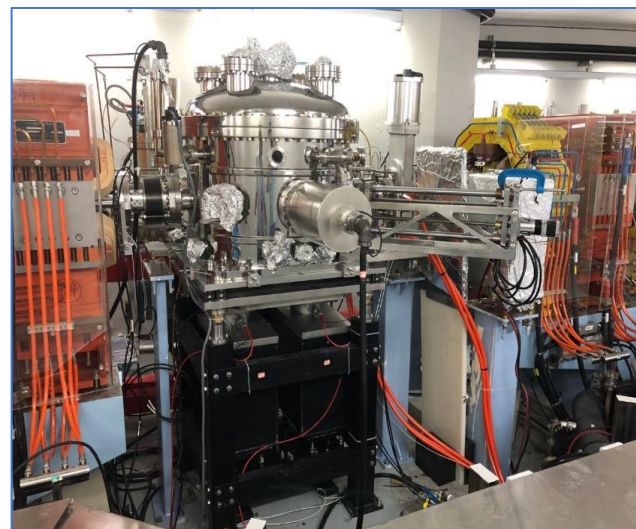
- 相互作用腔部分光路@储存环
- 多通组件部分光路@前端区
- 激光光路@激光棚屋



解决了：
1、激光传输，
2、激光功率检测，激光扩束、扫描/聚焦，激光偏振等



解决了：
1、背散射碰撞
2、韧致辐射及同步辐射出射
3、激光入射角度偏转



解决了：
1、变角度碰撞
2、超高真空
3、激光功率吸收

激光光路@激光棚屋

多通组件部分光路@前端区

相互作用腔部分光路@储存环

2、伽马束线系统：

□前端区/粗准直器

□光学棚屋/细准直器、衰减器

~18m

~32m

~45m

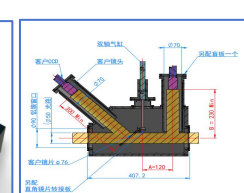
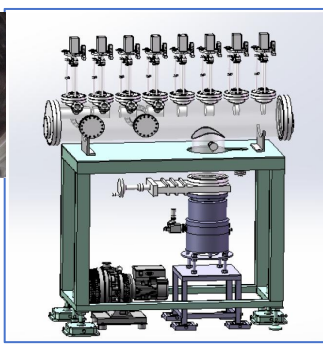
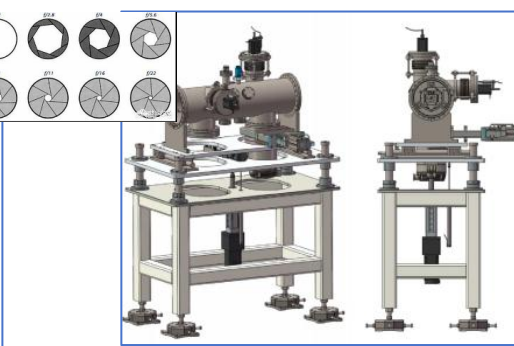
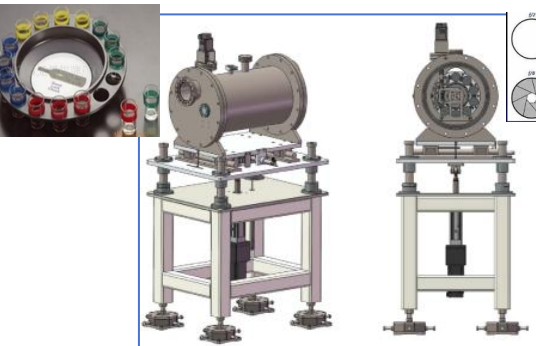
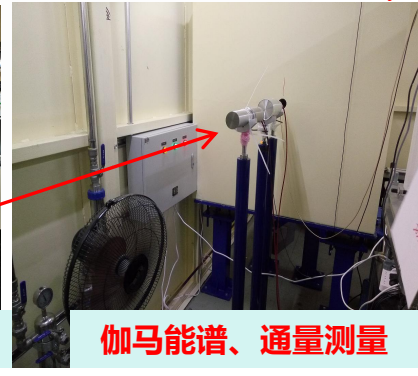
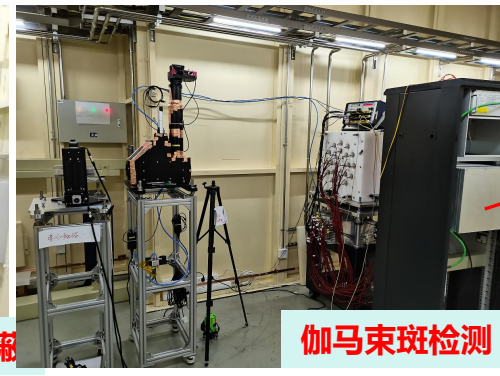
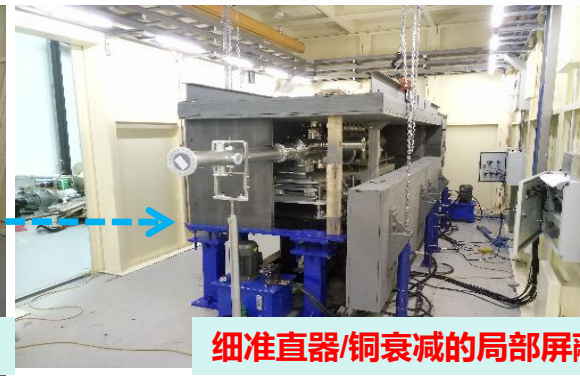
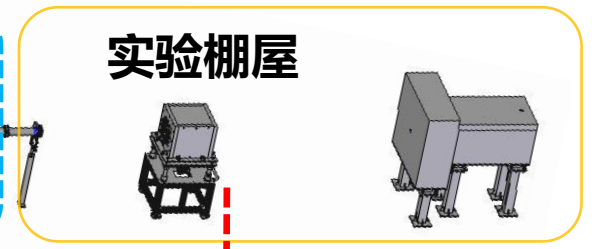
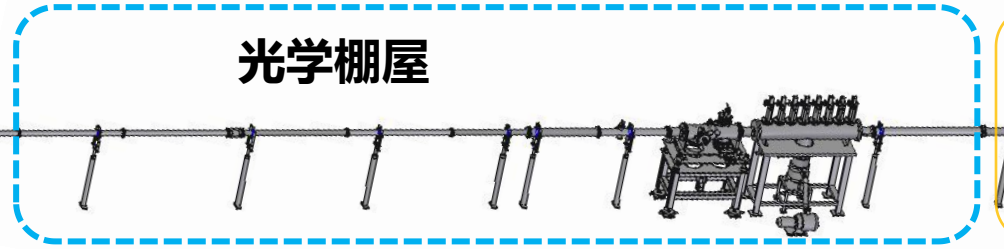
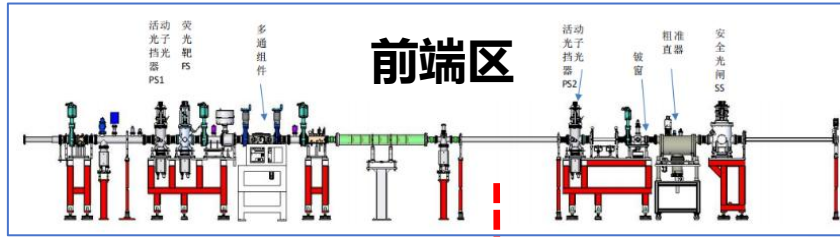


表 3.2.2.6-1 伽马束探测系统主要技术参数

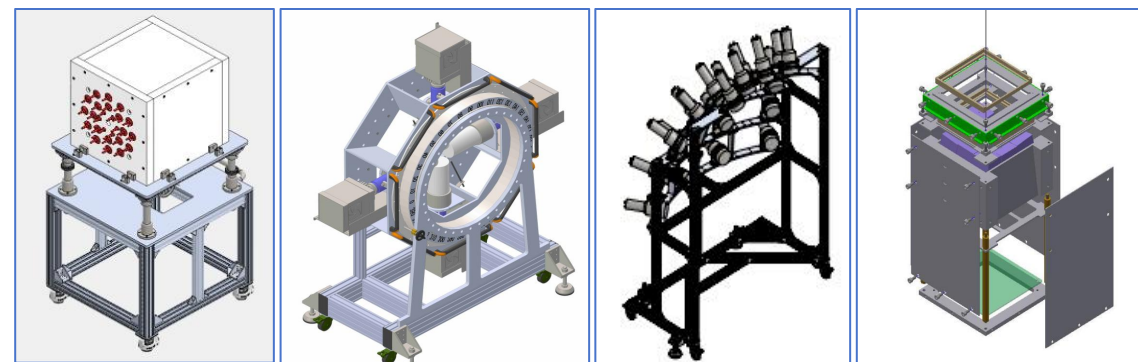
类型	探测器尺寸	分辨率	能量效率
LaBr ₃	326x106x65	3.2%	>80% @ 204keV, >60% @ 1098keV
BGO	106x65x206x65	4%	>80% @ 10.204keV
NbKTl	106x65x206x65	6%	>80% @ 10.204keV



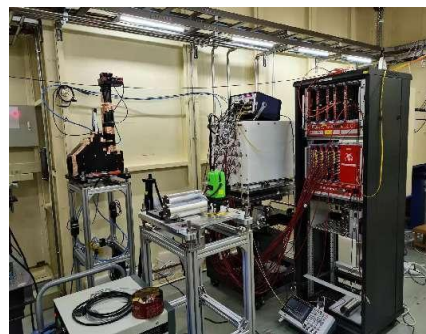
BGO $\phi 76 \times 200 \text{mm}$
LaBr₃ $\phi 76.2 \times 101.6 \text{mm}$

3、伽马实验系统：实验站设备 $\gamma/n/\alpha$ 谱仪，探测器电子学/数据获取

- ① (γ, γ) 反应： NRF - 核共振荧光实验谱仪 (HPGe 2台+ CLOVER 2台 + LaBr₃ 8件)
- ② (γ, n) 反应： FED - 平坦效率中子谱仪 (³He正比计数器 26组)
- ③ $(\gamma, n\gamma)$ 反应： TOF - 中子飞行时间谱仪+NRF (塑闪+液闪中子探测器, 20件EJ301)
- ④ $(\gamma, p/\alpha)$ 反应： LCP - 轻带电粒子探测谱仪 (GIC+Si strip+ CsI 望远镜探测器 4-6组)
- ⑤ $(\gamma, \text{Fission})$ 反应： 目前暂未考虑
- ⑥ 独立的探测器电子学与数据获取 (> 20台 Digitizer, >120ch)



核共振荧光谱仪-NRF



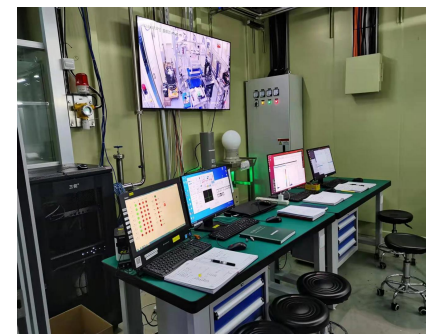
4 π 平坦效率谱仪-FED



飞行时间谱仪-TOF

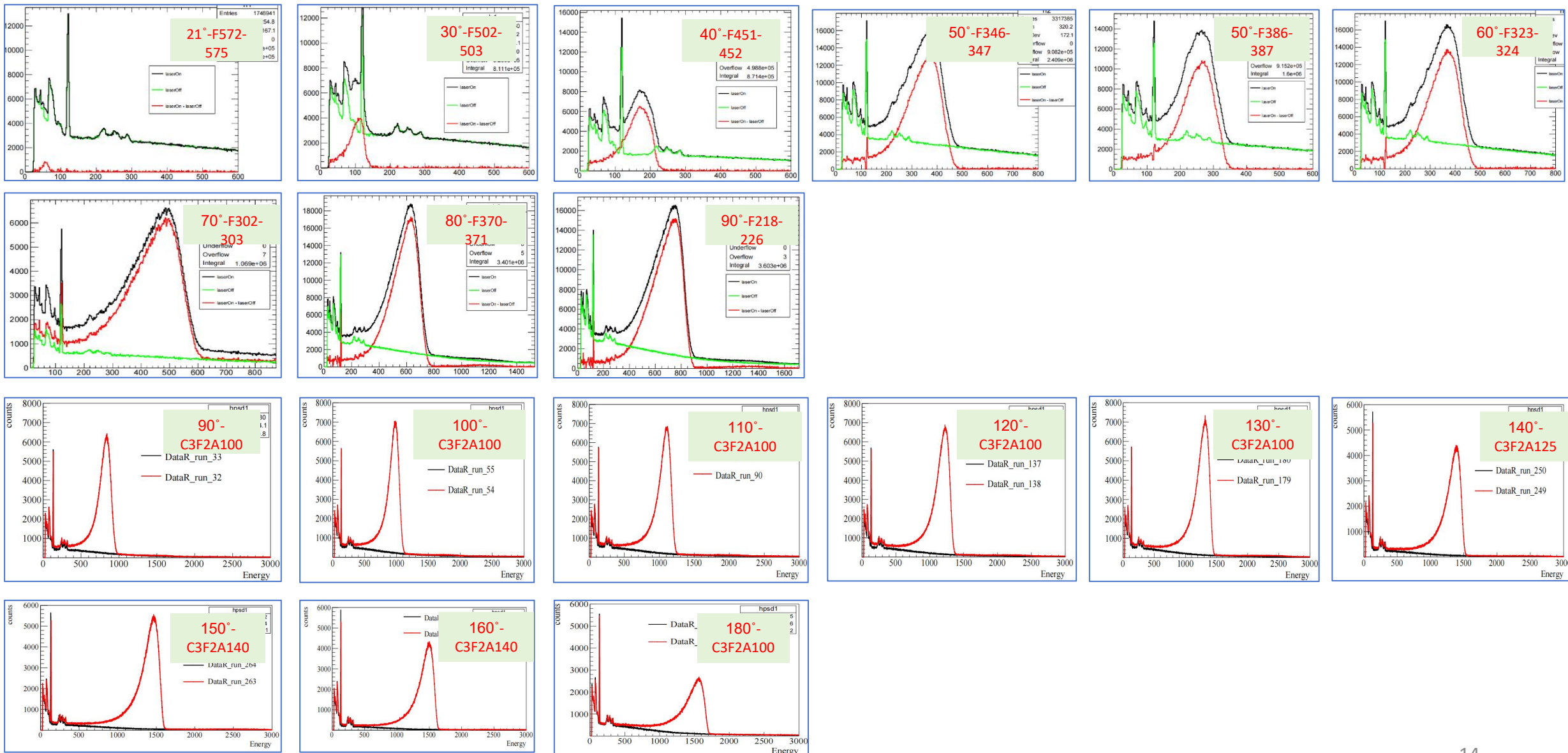


轻带电粒子谱仪-LCP

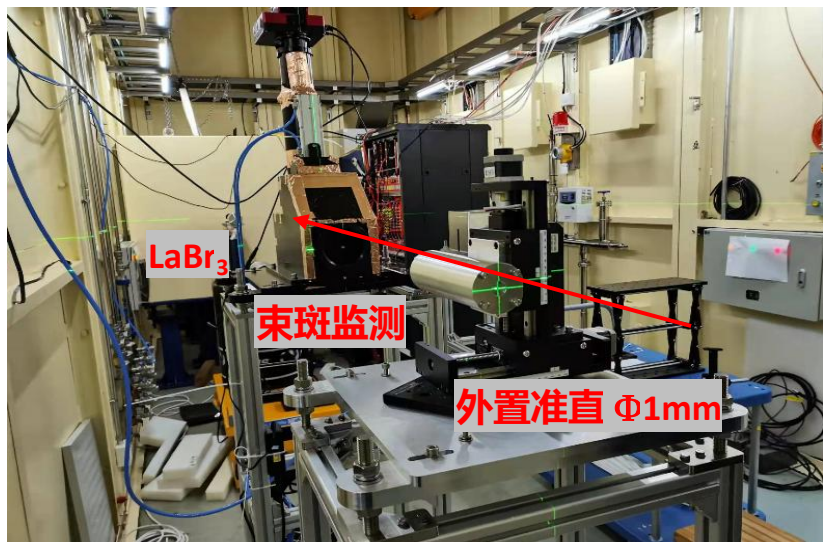
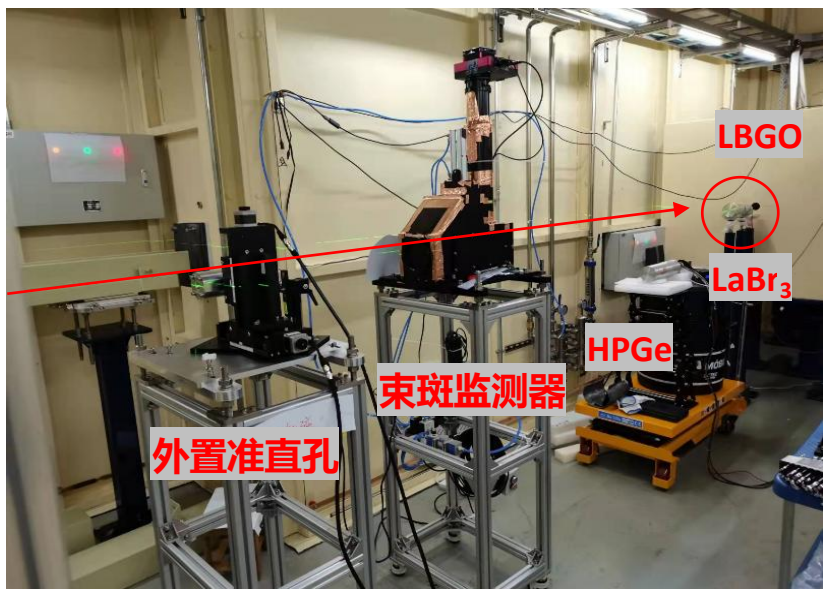


束线控制与数据获取-DAQ

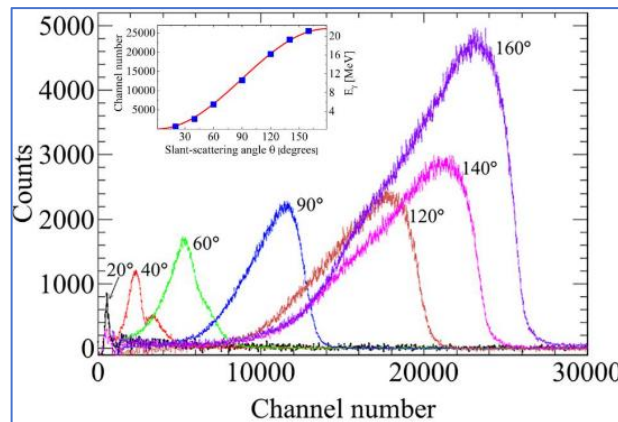
20-160, 180角度激光伽马谱测量结果



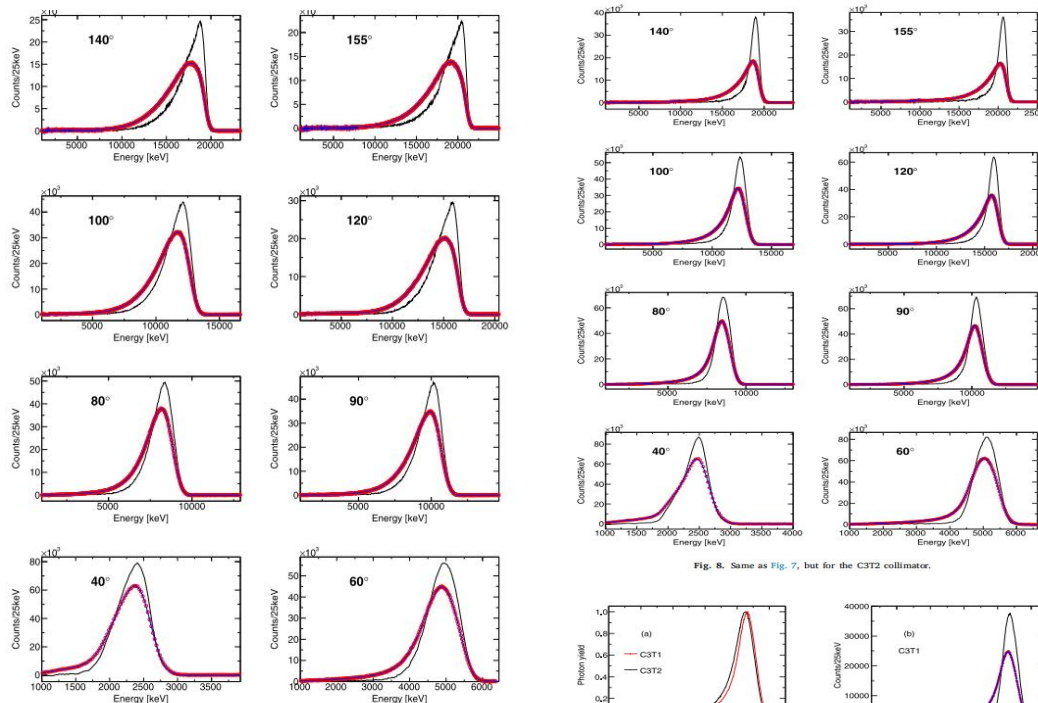
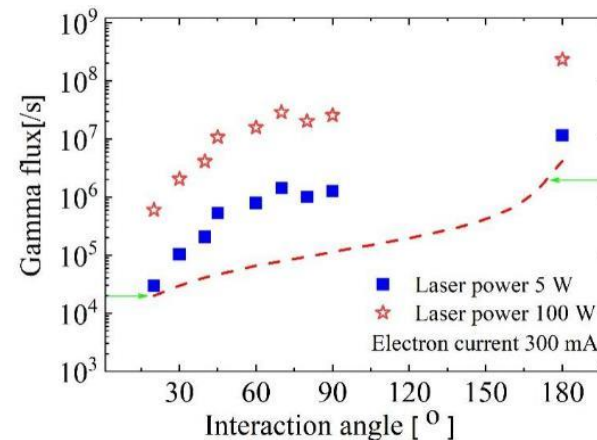
3.1 伽马束能谱测量和解谱:



斜入射伽马能谱



伽马能量可以覆盖
0.25 MeV ~ 21.7 MeV



5~15% @ 2mm
单色性的准单能伽马源

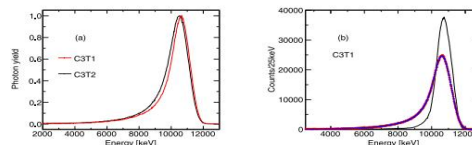
Experimental total-energy responses of the 76 mm × 200 mm BGO detector to LCSS γ -ray beams

L. X. Li et al.,
Energy profile of laser Compton slant-scattering γ -ray beams determined by direct unfolding of total-energy responses of a BGO detector, NIMA 1063 (2024) 169314, Doi.org/10.1016/j.nima.2024.169314

responses of the 76 mm × 200 mm BGO detector to LCSS γ -ray beams generated with the C3 collimator

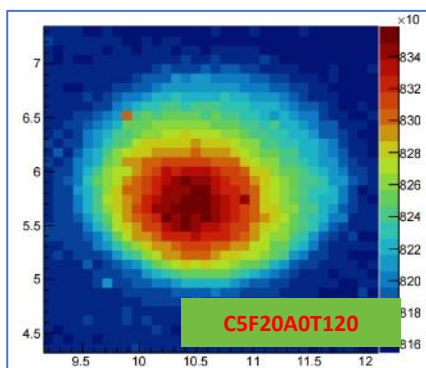
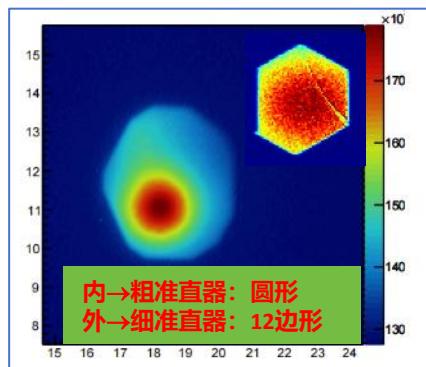
C3 Collimator

Fig. 8. Same as Fig. 7, but for the C3T2 collimator.

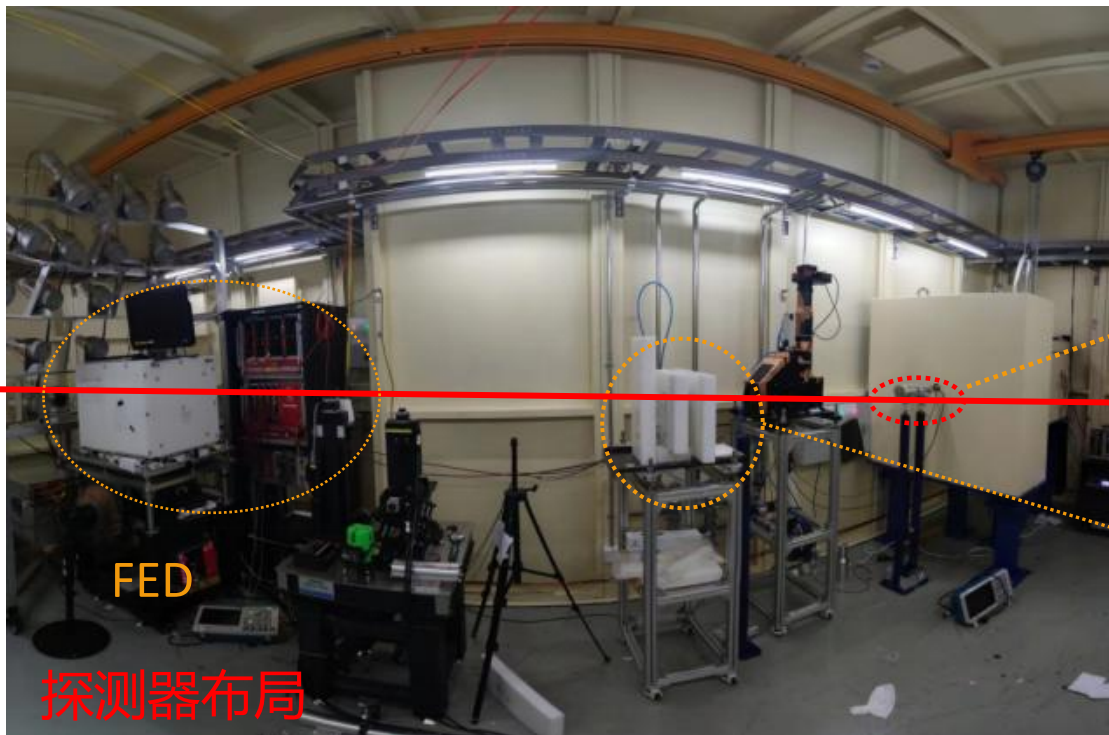


C3T1/C3T2 Collimator

3.2 伽马束斑及束流监测:



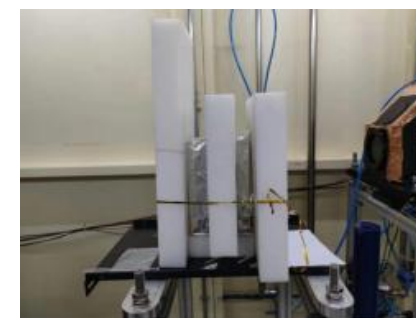
γ -ray



探测器布局



LaBr₃探测器



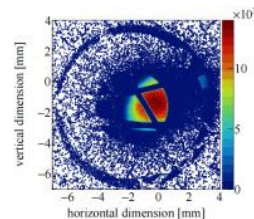
铜衰减



金靶

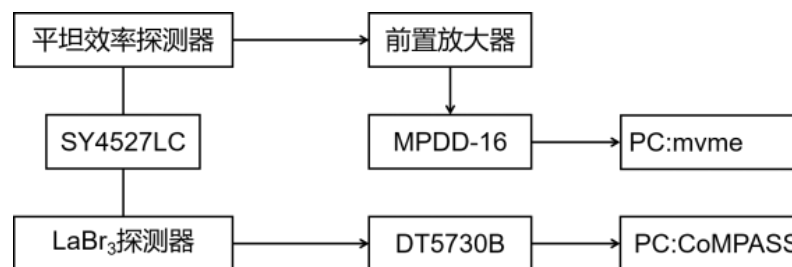
钽靶

定位靶



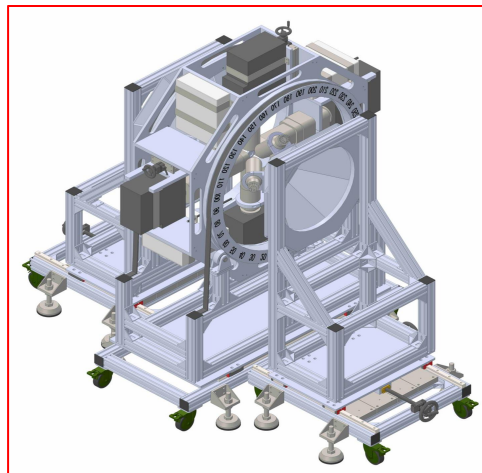
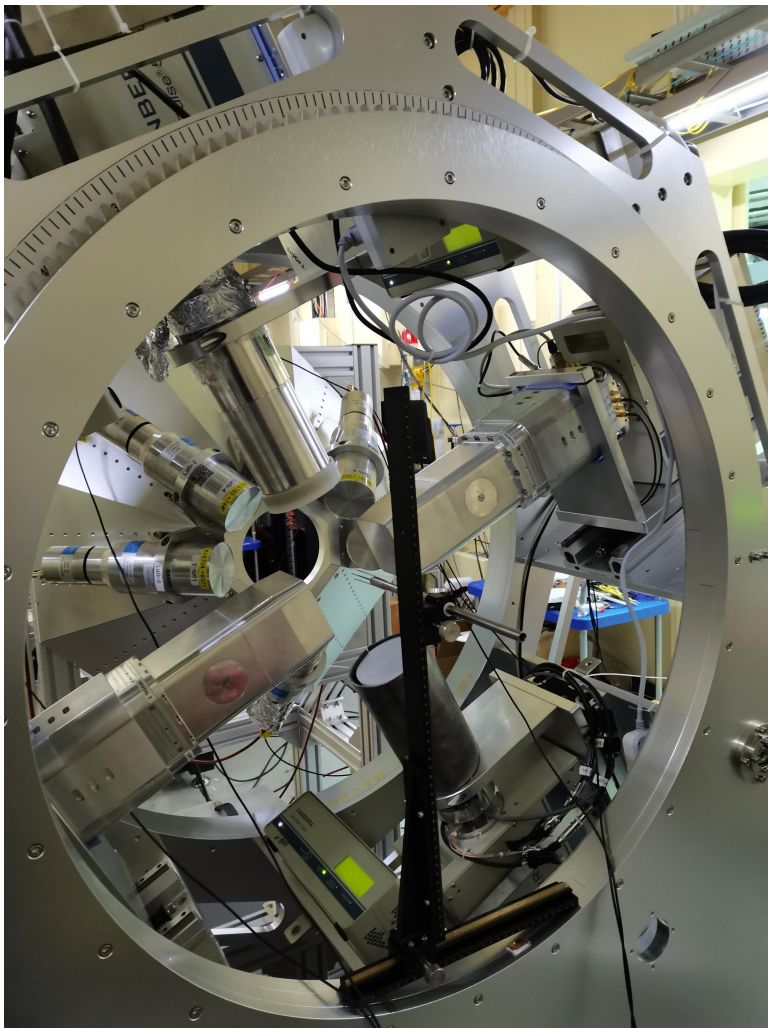
定位靶成像

金靶 $\Phi 10.5 \times 1\text{mm} \times 4$ / 钽靶 $\Phi 10 \times 4\text{mm}$



20MeV高能量与 10^6 ph/s 高流强同时监测存在困难?

3.3 核共振荧光谱仪-NRF: 大尺寸同轴HPGe+CLOVER探测器+LaBr₃+MVME/CoMPASS



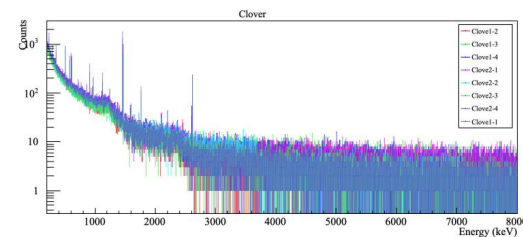
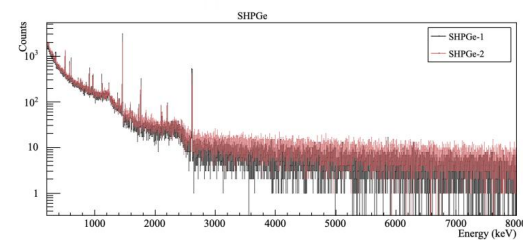
Item	Model	Specifications description	Qty
1	CLOVER	CLOVER CPS 4x50x70	2
2	REPAIR KIT	NKR200 & VOP10	2

设备安装测试

用标准源进行测试，探测器测试结果如下：

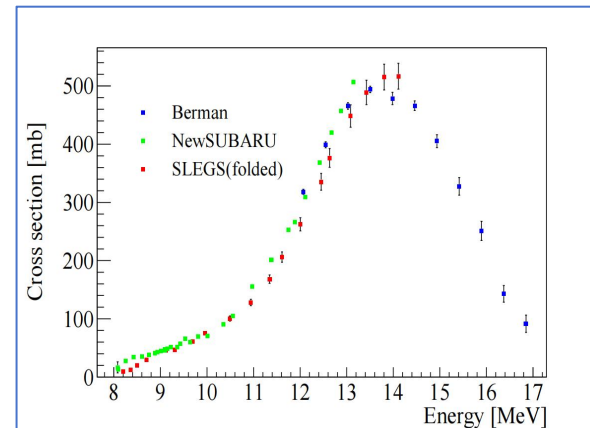
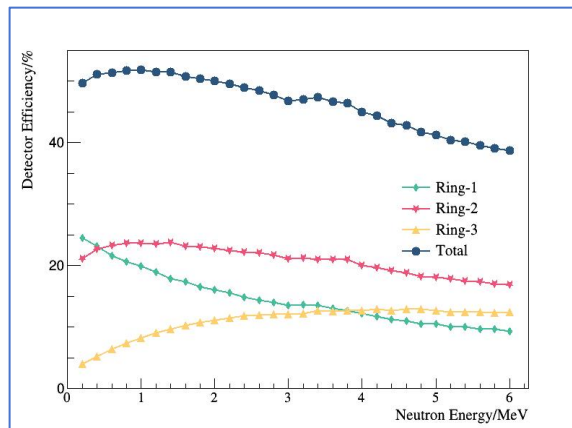
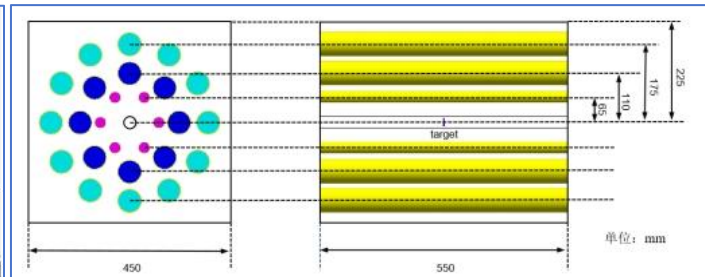
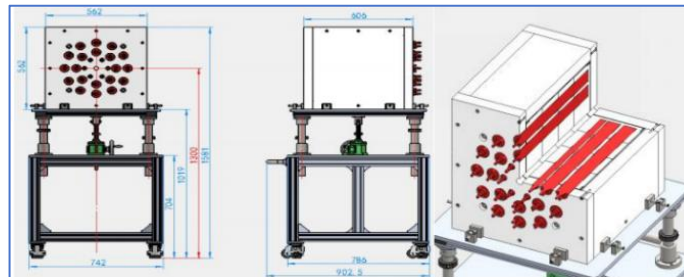
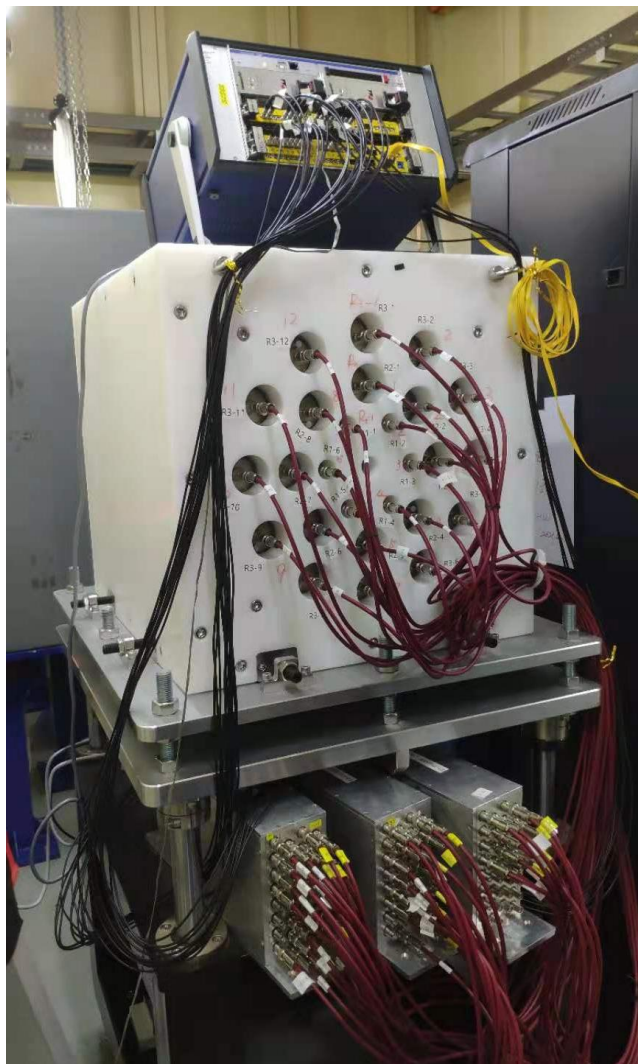
探测器 编号	CLOVER (SN200)				CLOVER (SN201)			
	01	02	03	04	01	02	03	04
分辨率@59.5keV	0.73	0.82	0.81	0.72	0.76	0.81	0.66	0.72
分辨率@122keV	0.82	0.88	0.92	0.85	0.78	0.86	0.86	0.88
分辨率@661keV	1.47	1.32	1.32	1.33	1.31	1.38	1.35	1.39
分辨率@1332keV	1.79	1.77	1.80	1.74	1.82	1.81	1.79	1.86
相对效率	22.6%	22.1%	22.3%	22.7%	23.3%	22.1%	22.4%	23.1%
峰康比	46.5	49.6	49.6	51.5	50.4	50.5	50.2	50.1

探测器	分辨率@5.9keV	分辨率@122keV	分辨率@1332.5keV	相对效率
GX9021/S(SN5541)	0.95keV	0.933keV	1.856keV	105%
GX9021/S(SN5542)	0.898keV	0.963keV	1.963keV	105%



3.4 4π平坦效率谱仪-FED：计数法测量中子

³He正比计数器 + 16路集成前放电子学（自研） + MDPP-16 + CAEN GECO多路高压模块+ MVME DAQ



¹⁹⁷Au(γ, n)¹⁹⁶Au

慢化体：45 mm×45 cm×55 cm 聚乙烯

正比计数器：³He×26 (2 atm)

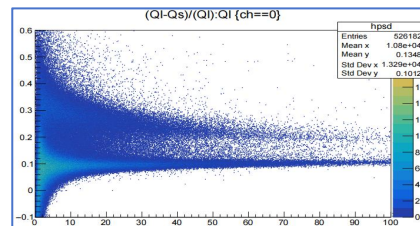
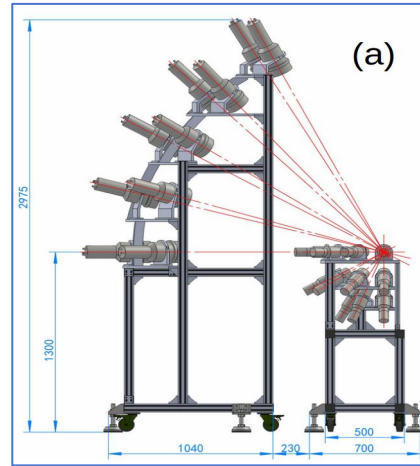
排列状态：3环 (6-8-12) 距离中心 65 mm, 110 mm, 175 mm

探测器效率：**42.32% - 34.83%**

探测器系统误差：**3.37%**

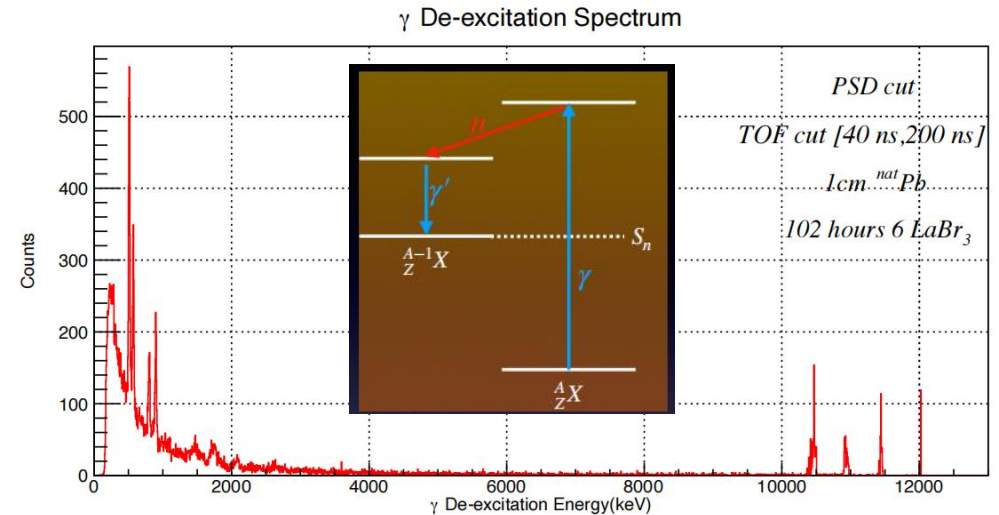
3.5 中子飞行时间谱仪-TOF：飞行时间法测量中子能量+脉冲形状甄别PSD

大尺寸液闪EJ301+LaBr₃探测器+V1730S Digitizer+CoMPASS DAQ

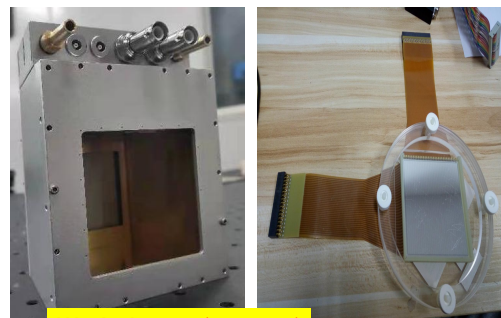
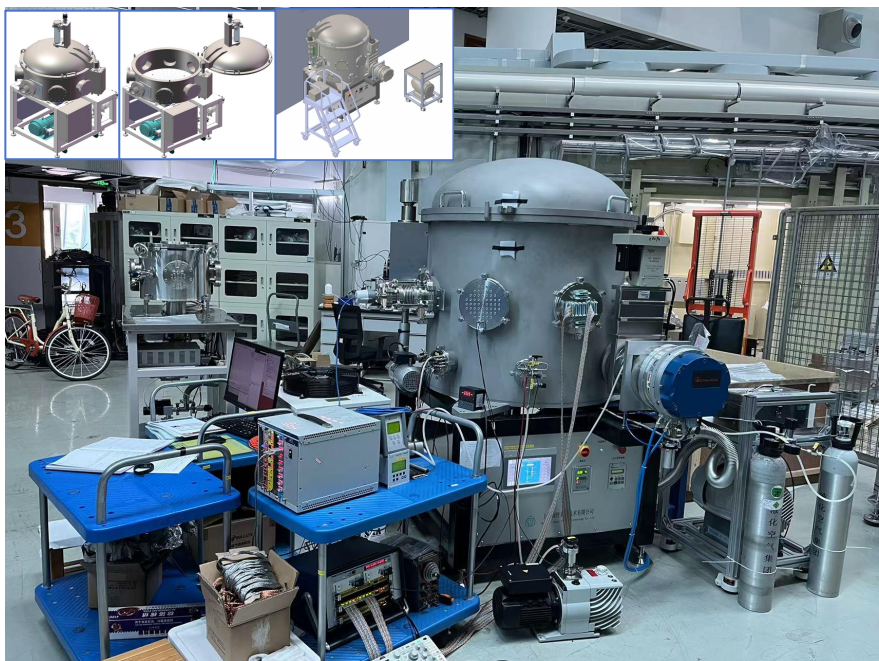


类型	材料	数量	直径/cm	长度/cm	距靶/cm
中子测量	EJ301	20	12.7	5.4	150
	EJ276	4	7.6	7.6	150
伽马测量	LaBr ₃	8	7.6	102	30
	CsI	5	5.0	20.0	30
	BGO	4	5.0	15.0	30

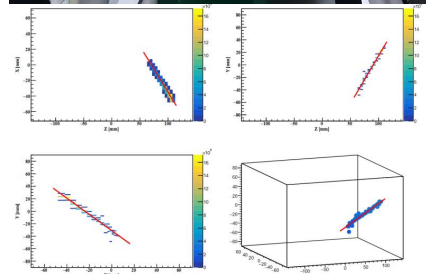
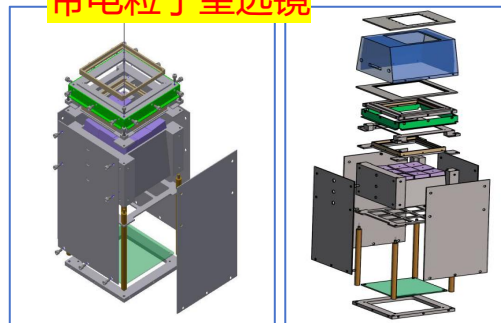
2024年3月, natPb靶测试实验



3.6 轻带电粒子谱仪-LCP：光核反应中只有轻粒子发射，能量低，截面低



带电粒子望远镜



复旦大学AT-TPC

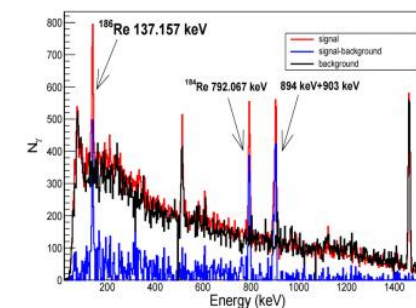
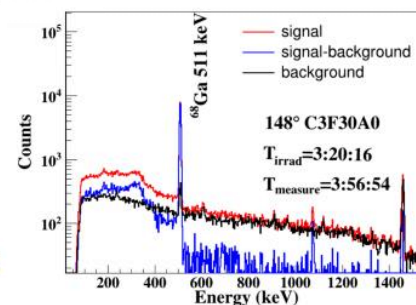
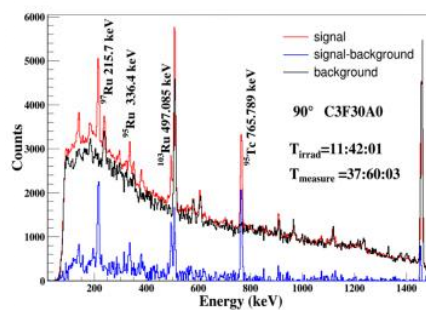
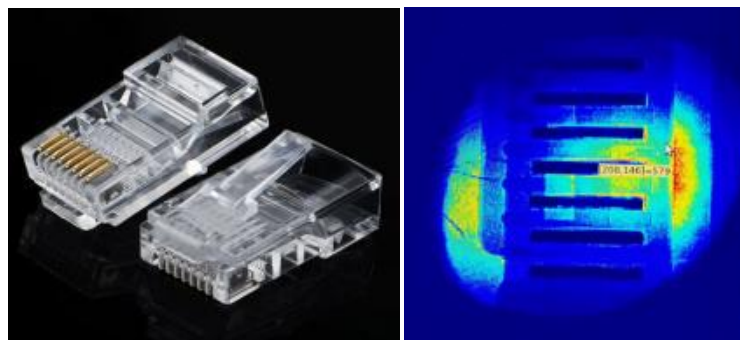
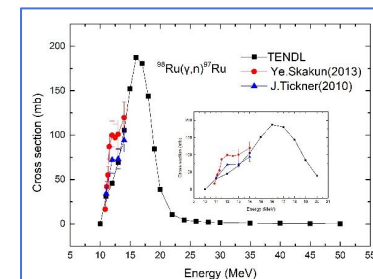
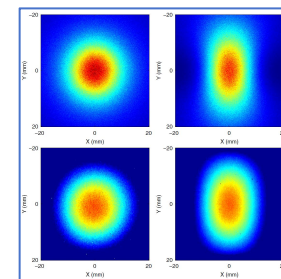
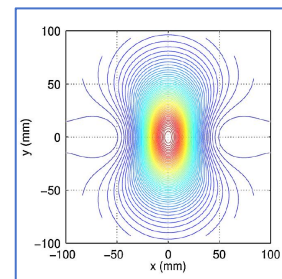
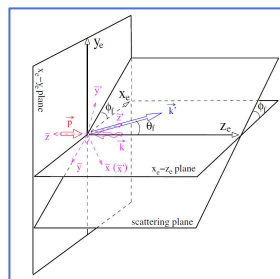
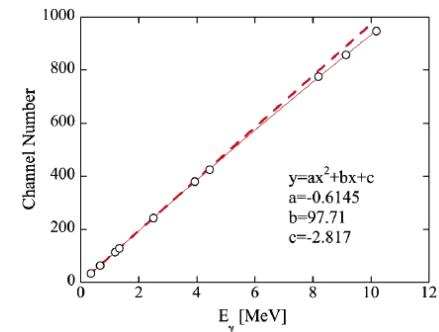
一、上海光源望远镜探测器

- ① 真空室 + 带电粒子望远镜 组合
- ② 带电粒子望远镜：屏栅电离室 + 硅条探测器 + CsI晶体闪烁体
- ③ Mesytec PreAMP + MDPP32 Digitizer + MVME DAQ

二、复旦大学AT-TPC探测器

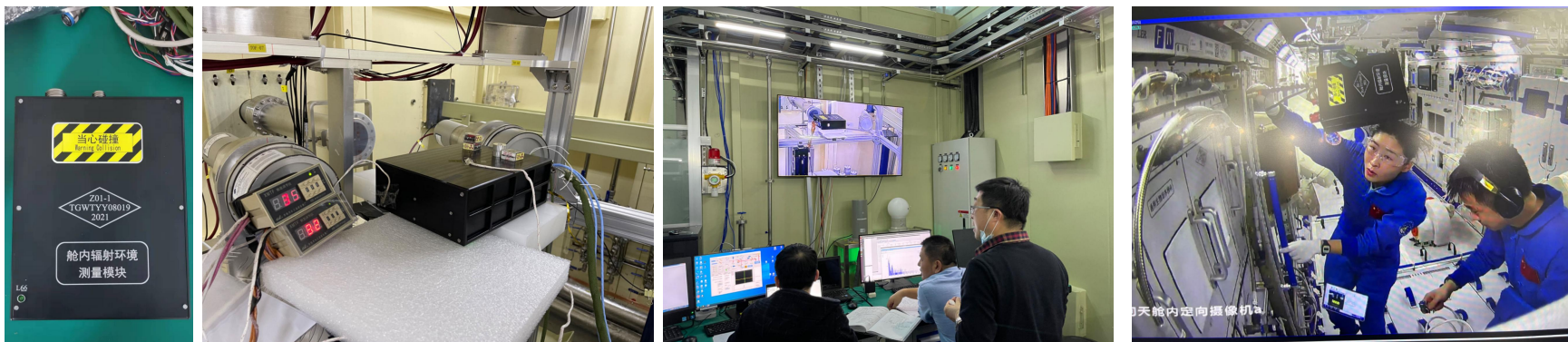
SLEGS伽马源开展的其他应用基础研究:

- 伽马标定实验
- 伽马成像实验
- 伽马活化实验
- 伽马辐照实验
- 伽马极化实验
- 正电子产生及湮灭实验



3.7 伽马探测器标定:

苏州大学文万信团队——舱内辐射模块地面标定实验-2022



中国科学院近代物理研究所及 RIBILL 研究室、中国原子能科学研究院物理所、中国科学院上海高等研究院及 SLEGS 研究室等单位与团队克服疫情影响和实验时机极其紧缺的困难,为舱内辐射模块地面定标实验的顺利完成提供了实验条件保障和全面的技术支撑。中国科学院空间科学与应用总体部同时向上述单位及团队表示衷心的感谢!

特此祝贺!

中国科学院空间科学与应用总体部
2022年7月29日

中国科技大学封长青团队——面向行星表面元素测量的小型化伽马谱仪刻度-2023

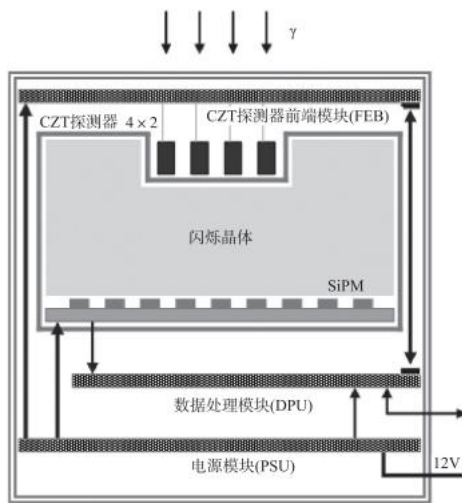


图4 谱仪原理样机结构

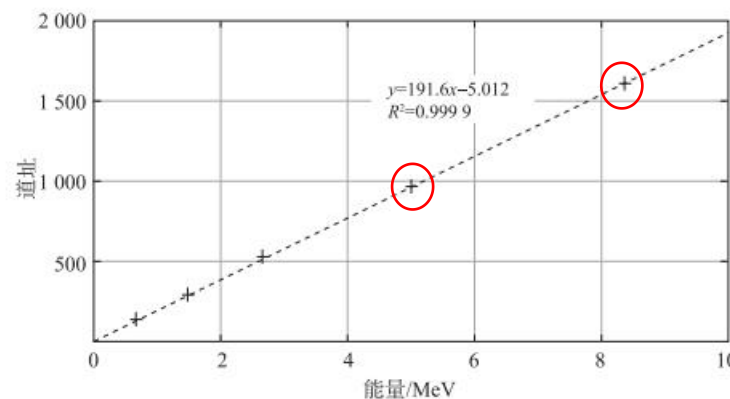


图13 BGO 探测器对伽马射线的响应曲线

第44卷 第1期
2024年1月

核电子学与探测技术
Nuclear Electronics & Detection Technology

Vol.44 No.1
Jan. 2024

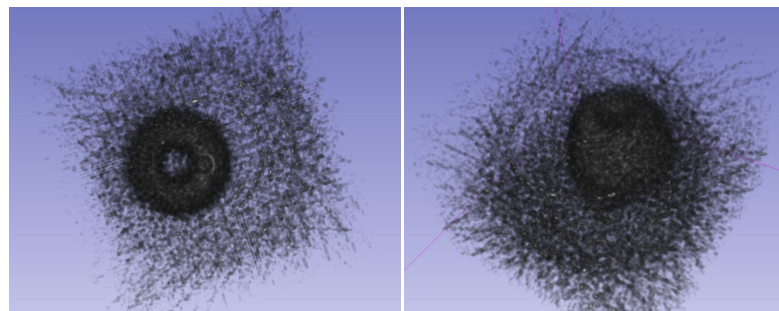
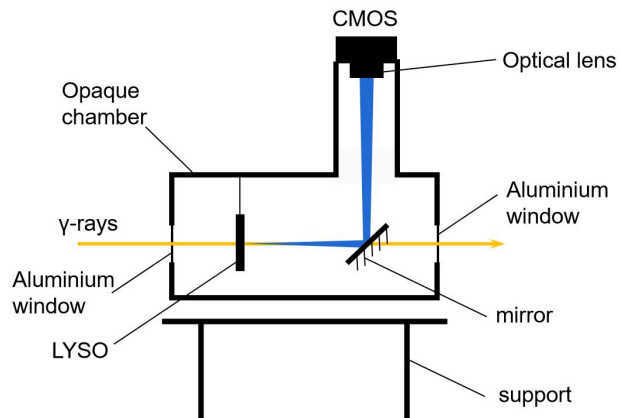
面向行星表面元素测量的
小型化伽马谱仪原理样机设计

黄磊^{1,2},王扶超^{1,2},封常青^{1,2,3*},王宇^{1,2},王婷^{1,2},刘树彬^{1,2}

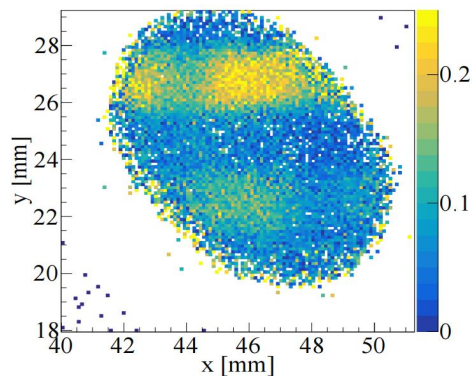
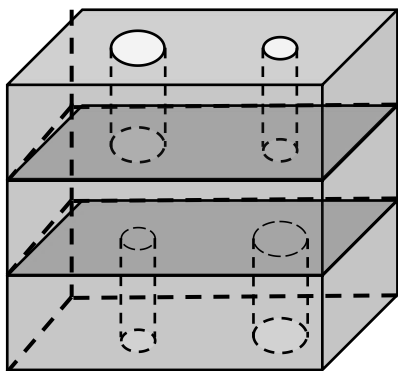
(1.中国科学技术大学核探测与核电子学国家重点实验室,合肥 230026;
2.中国科学技术大学近代物理系,合肥 230026;
3.深空探测实验室,合肥 230022)

3.8 伽马源成像研究:

实验方法学研究-伽马成像 许杭华, 郝子锐



伽马3D成像测试



Gamma imaging system at SLEGS beamline.

Z.R. Hao^a, H.H. Xu^{a,*}, G.T. Fan^{a,b,c}, L.X. Liu^a, H.W. Wang^{a,b,c}, W.X. Wen^d, C.Y. Zu^d, Y.X. Yang^{b,e}, K.J. Chen^{b,f}, S. Jin^{b,c}, Q.K. Sun^{b,c} and Z.W. Wang^{b,c}

^aShanghai Advanced Research Institute, Chinese Academy of Sciences, Shanghai 201210, China

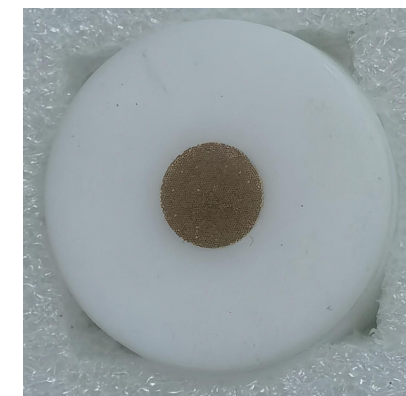
^bShanghai Institute of Applied Physics, Chinese Academy of Sciences, Shanghai 201800, China

^cUniversity of Chinese Academy of Science, Beijing 100080, China

^dSoochow University, Suzhou 215006, China

^eSchool of Physics and Microelectronics, Zhengzhou University, Zhengzhou 450052, China

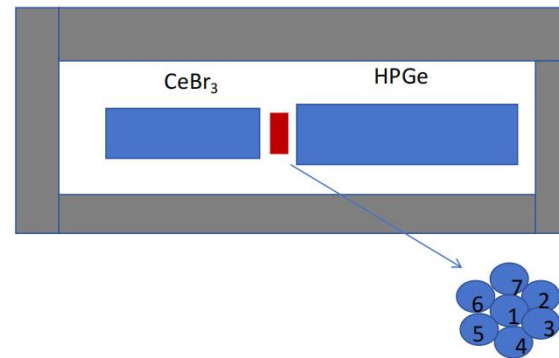
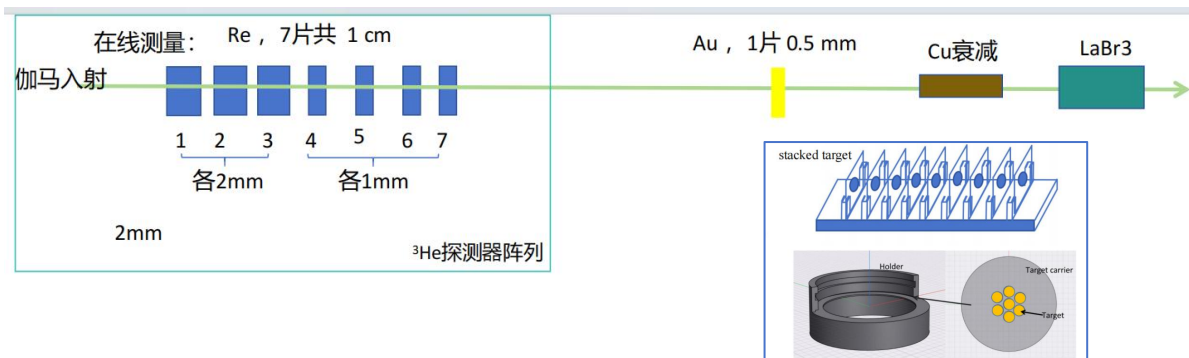
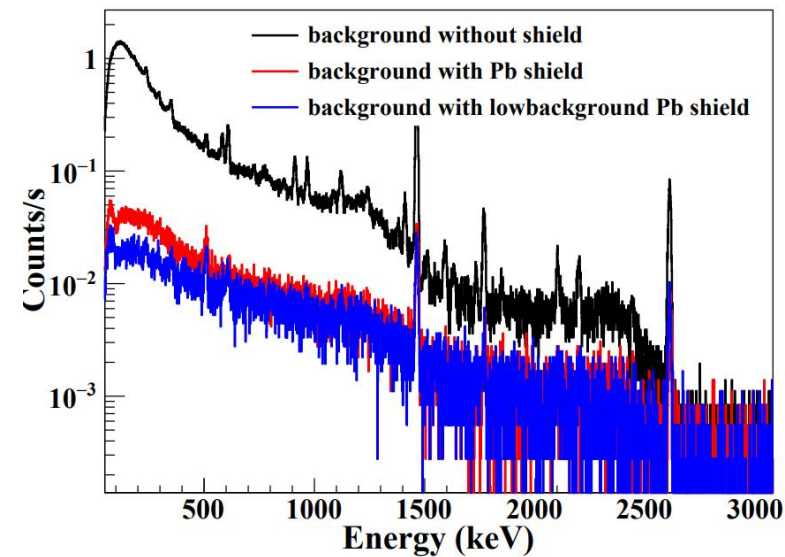
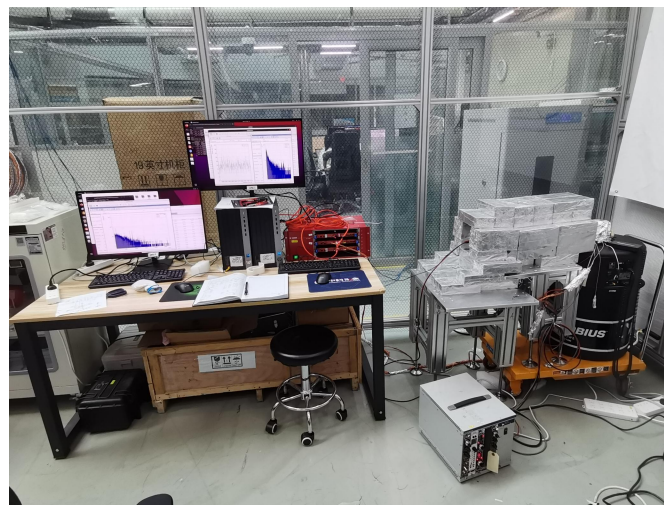
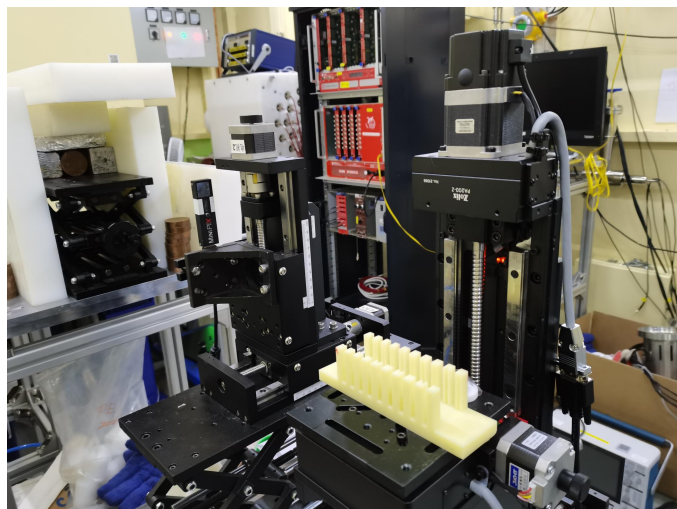
^fSchool of Physical Science and Technology, ShanghaiTech University, Shanghai 201210, China



3.9 伽马活化分析:

伽马在束活化与HPGe低本底系统
开展天然材料的光核反应实验、医用同位素产生截面, 科技考古等研究

杨宇萱, 张岳, 王宏伟

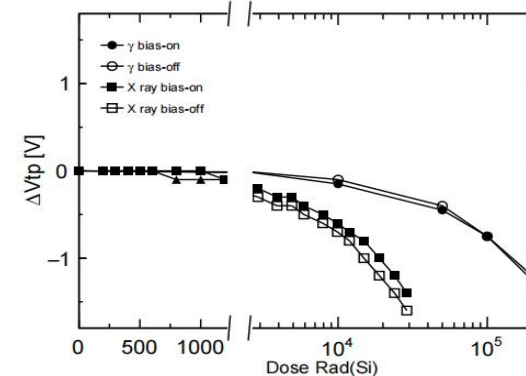
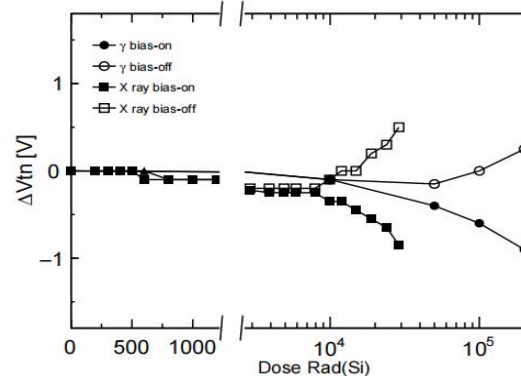
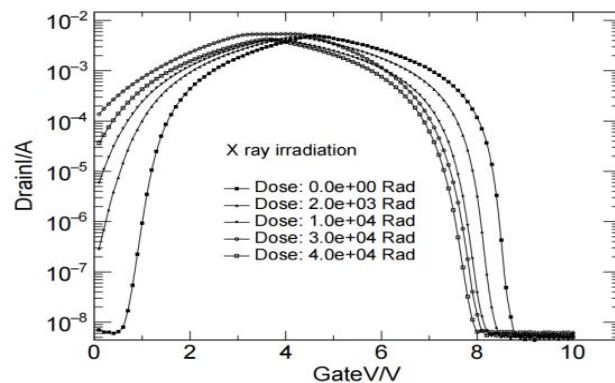
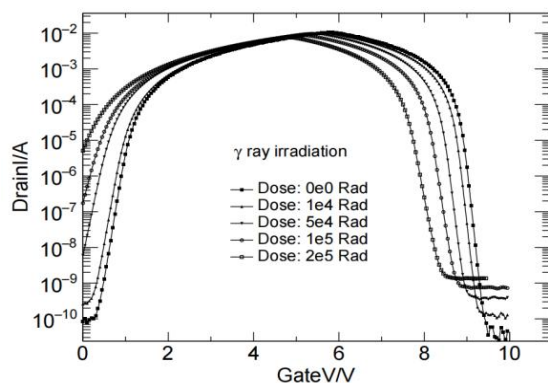
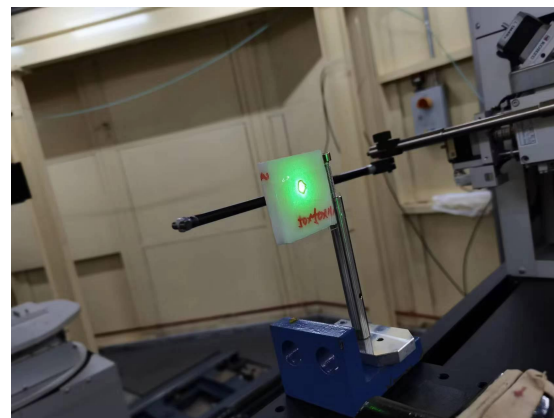
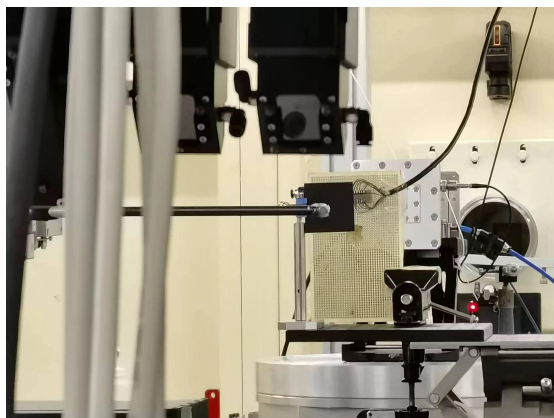


3.10 X/ γ 辐照效应分析:

伽马辐照平台已经搭建完成, 采购了半导体测试仪4200等设备,

刘龙祥, 范功涛, 吾勤之

在SLEGS束线站、超硬线站及新疆理化所 ^{60}Co 伽马源进行了芯片/聚乙烯样品、硼纤维等材料的辐照效应测试实验;



3.11 伽马极化与伽马涡旋:

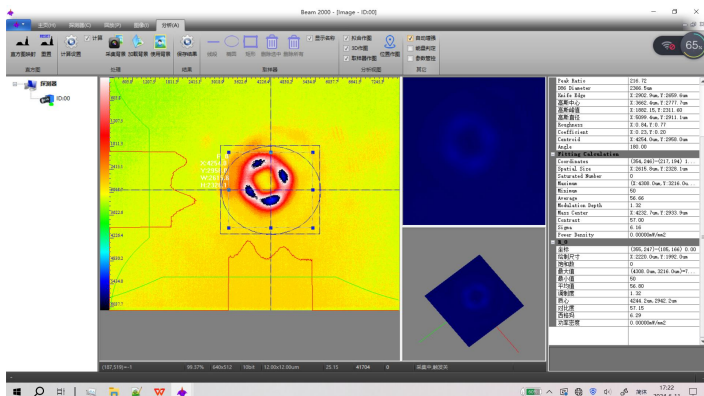
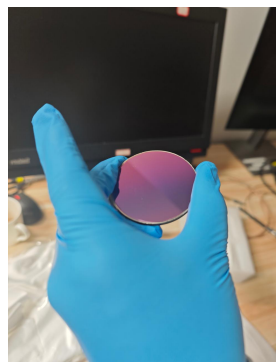
采用入射激光极化方式, 背散射伽马极化率在90-95%以上。

变角度模式下的伽马极化率不清楚? 理论无法计算。

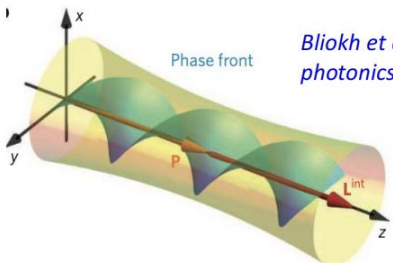
采购了相位板, 测试了CO₂激光涡旋的产生, 伽马涡旋束准备测试

许杭华, 范功涛

栗建兴, 牛一斐报告



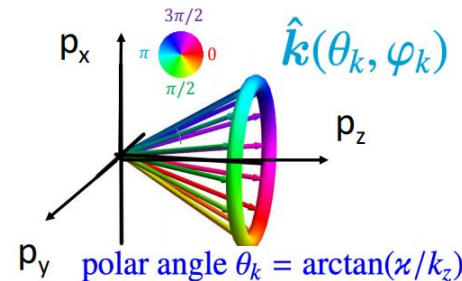
Coordinate space



Bliokh et al., Nature photonics 9, 796(2015)

✓ Vortex wavefunction:

Momentum space



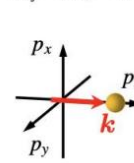
polar angle $\theta_k = \arctan(p_x/p_z)$

✓ Superposition of plane waves

Manipulation of giant resonances via vortex photon

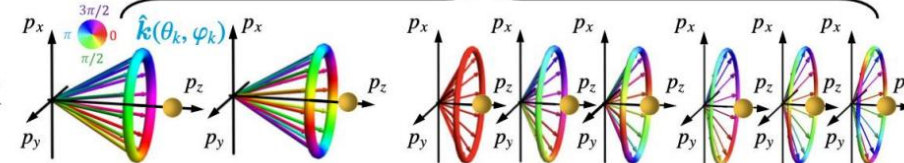
Plane wave γ photons:

$$M_f - M_i = \Lambda$$

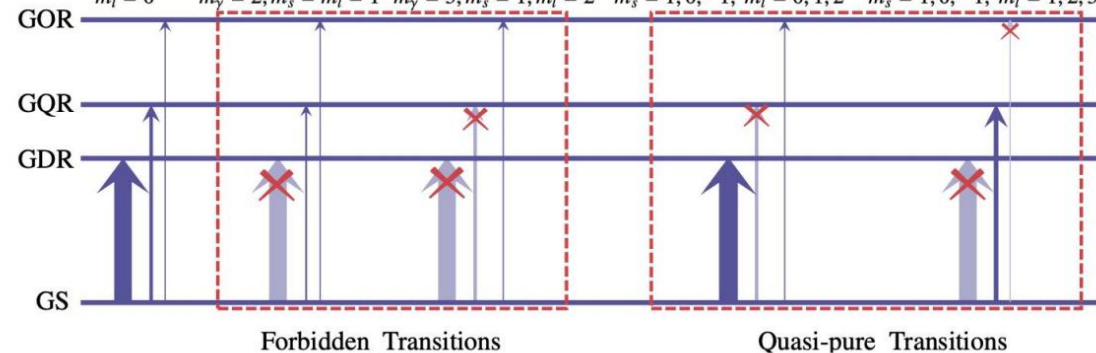


$$m_\gamma = m_s = 1, m_l = 0$$

Vortex γ photons: $M_f - M_i = m_\gamma$



small θ_k (as an example) $m_\gamma = 2, m_s = m_l \approx 1$ $m_\gamma = 3, m_s \approx 1, m_l \approx 2$
 $m_\gamma = 1$, specific large θ_k $m_s = 1, 0, -1, m_l = 0, 1, 2$ $m_\gamma = 2$, specific large θ_k $m_s = 1, 0, -1, m_l = 1, 2, 3$

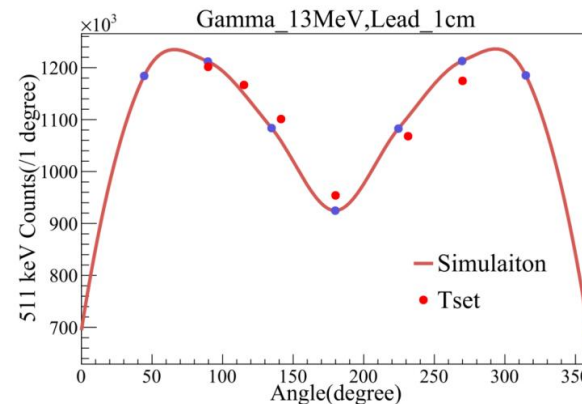
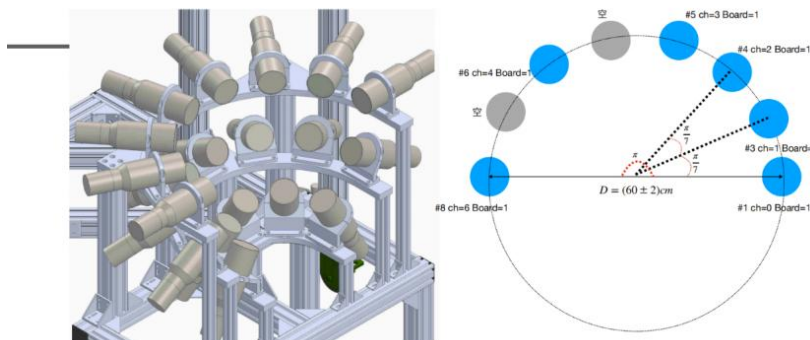
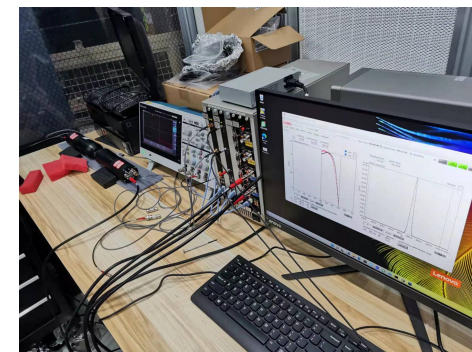
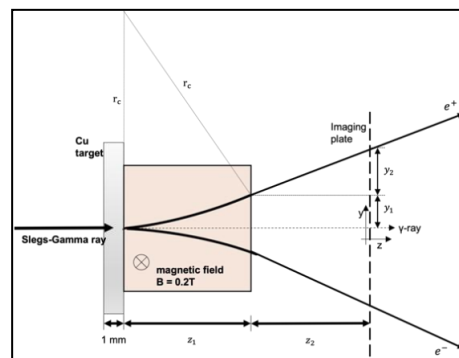
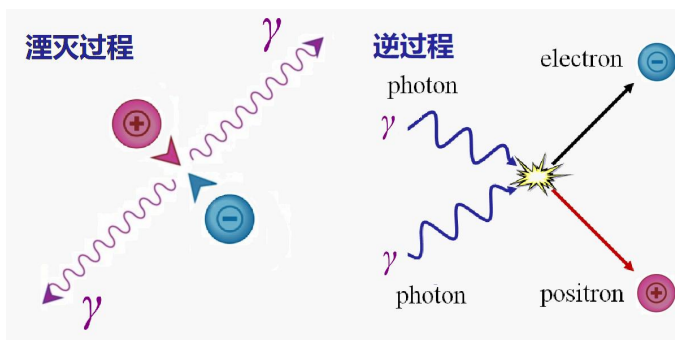
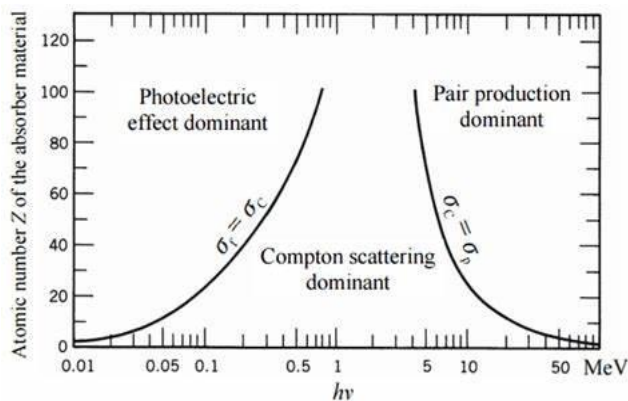


Z. W. Lu, L. Guo, Z. Z. Li, M. Ababekri, F. Q. Chen, C. B. Fu, C. Lv, R. R. Xu, X. J. Kong, Y. F. Niu, and J. X. Li, PRL 131, 202502 (2023)

3.12 伽马源正电子产生与湮灭:

实验方法学研究-正电子产生 金晟

- 基于GEANT4的模拟计算, 分析伽马射线产生正电子的能谱, 产额和角分布; 结合SLEGS束线装置, 模拟计算正电子的能谱, 产额和角分布;
- 基于GEANT4模拟分析正电子谱仪特征参数;



SLEGS伽马源特点：唯一的连续变角度斜入射碰撞运行模式 (LCSS)

➤ 能量扫描精度、发射度、流强稳定性等参数及能量调节方式优于美国HIGS，SLEGS将具有很强的国际竞争力。

束线参数	美国HIGS		日本LEPS-I/II		中国SLEGS		欧盟ELI-NP	
	低能段	高能段	低能段	高能段	斜入射	背散射	背散射	背散射
伽马能量[MeV]	1-20	21-60	1055-2400	1500-2900	0.4-21.1	21.7	0.2-3.5	3.5-19.5
电子能量[GeV]	0.4-0.7	0.7-1	8.0	8.0	3.5	3.5	0.36	0.72
入射激光波长[nm]	450-1064	190-450	355	266	10640	10640		
总流强[ph/s]	10^{8-9}	10^8	$(1-3) \times 10^6$	$(1-3) \times 10^5$	10^{6-7}	$> 10^7$	$> 10^{11}$	
能量分辨[%]	0.8-10		< 15		5-15%		0.5%	
能量扫描精度[keV]	40				14			
发射角[mrad]($\theta=1/\gamma$)	1.27-0.73				0.15			
样品处流强[ph/s]	$0.7 \times 10^4 - 0.4 \times 10^6$ (距离光源点60 m)				$1.2 \times 10^4 - 1.2 \times 10^6$ (距离光源点38 m)		$> 4 \times 10^8$	
流强稳定性[%]	>20				<5			
能量调节方式/速度	储存环电子/min		激光波长/hour		激光入射角/s		直线加速器/min	
运行时间	1996-至今		1999(I)-2013(II)-至今		2021-至今		预计2025年建成	

运行和在建的低能LCS伽马源：

➤ **LCS伽马源面向应用研究。**

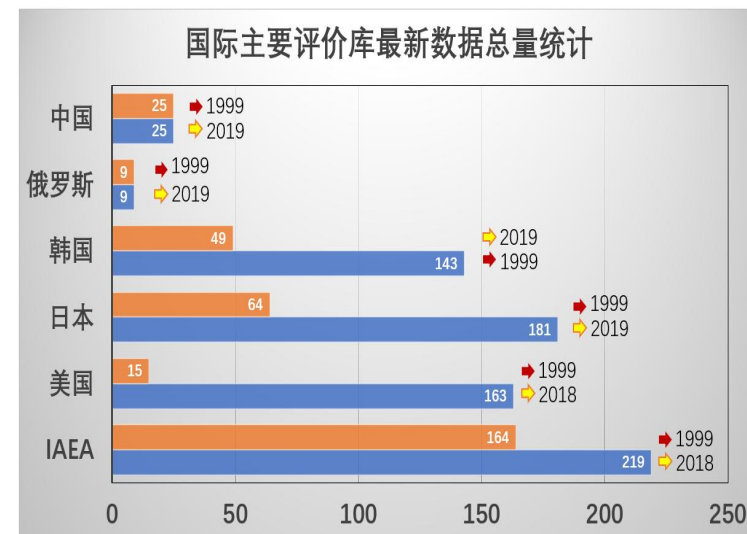
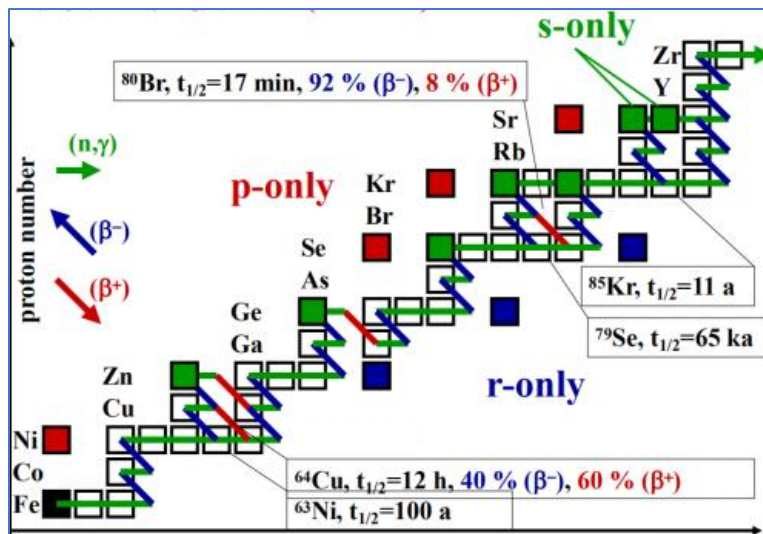
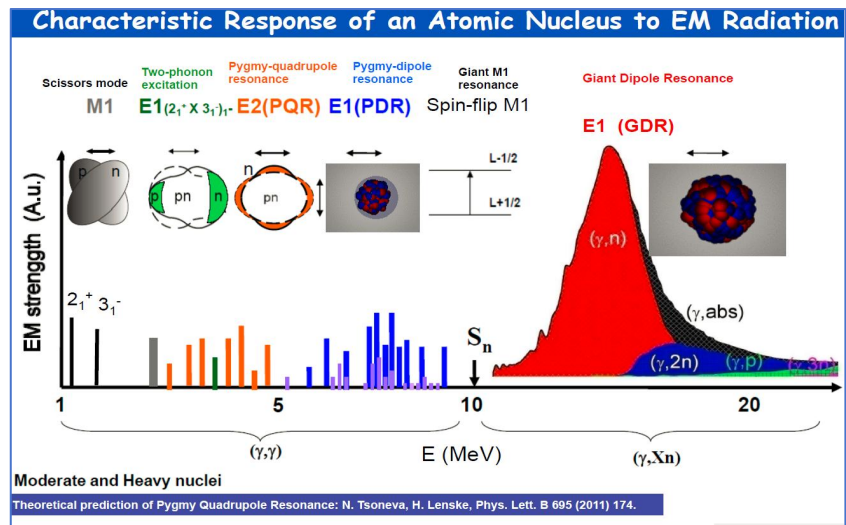
束线参数	日本UVSOR-III@BL01		清华VIGAS		西安XGLS
伽马能量[MeV]	背散射 1.1-5.4	90度碰撞 6.6	低能段 0.2-2.4	高能段 2.4-4.8	背散射 0.1-3.5
电子能量[MeV]	750@90MHz		50-350@10Hz		120@10Hz
入射激光波长[nm]	1940-10600		400	800	800
总流强[ph/s]	~10 ⁷		> 4x10 ⁸	> 1x10 ⁸	> 10 ⁸
能量分辨[%]	2.4-20.3		< 1.5		< 3 (中心抖动< 1%)
脉冲宽度[ps]	电子630, 激光1kHz, 1ps		电子< 2, 激光< 10		< 10
重复频率[Hz]	5.63MHz		10		5
样品处流强 [ph/s]	4 × 10 ⁵ @ 2mm (距离光源点6.5-7.4m)		> 4x10 ⁶	> 4x10 ⁶	5 × 10 ⁶ @3%,13.5um,3MeV
能量调节方式/速度	储存环电子/min		X波段直线加速器/min		S波段直线加速器/min
运行时间	2005-至今		预计2024年底		

2、SLEGS光中子反应与Back-n的中子俘获反应

光核反应:

光核反应研究原子核性质，揭示核力相互作用，发现集体运动新现象、探索宇宙重元素起源。光核反应数据在反应堆安全、医学检测、航空航天、国防安全等方面需求广泛。

- ❑ 光核反应实验研究不足，IAEA光核数据库219个，20年新增不到60个：误差大，精度低。
- ❑ 光核反应应用仅美国建有辐照及医学同位素产生平台，欧洲筹划在建辐照，正电子源平台。
- ❑ 中国一直没有合适伽马源装置，光核反应的实验研究空白！光核实验技术和人才缺乏。



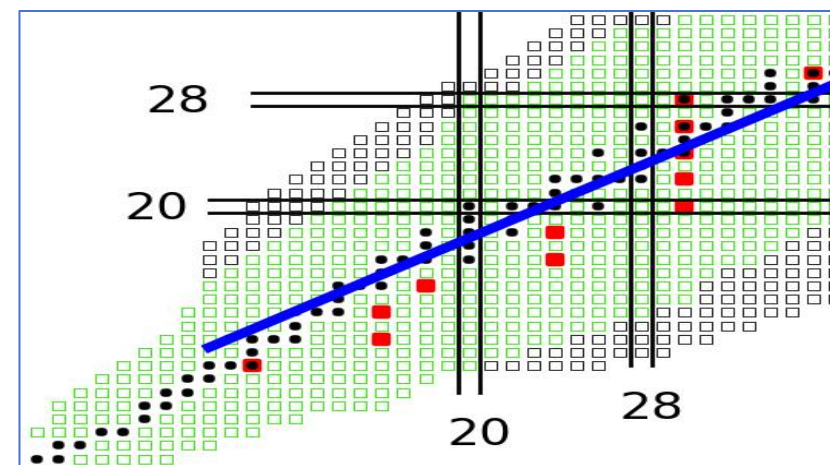
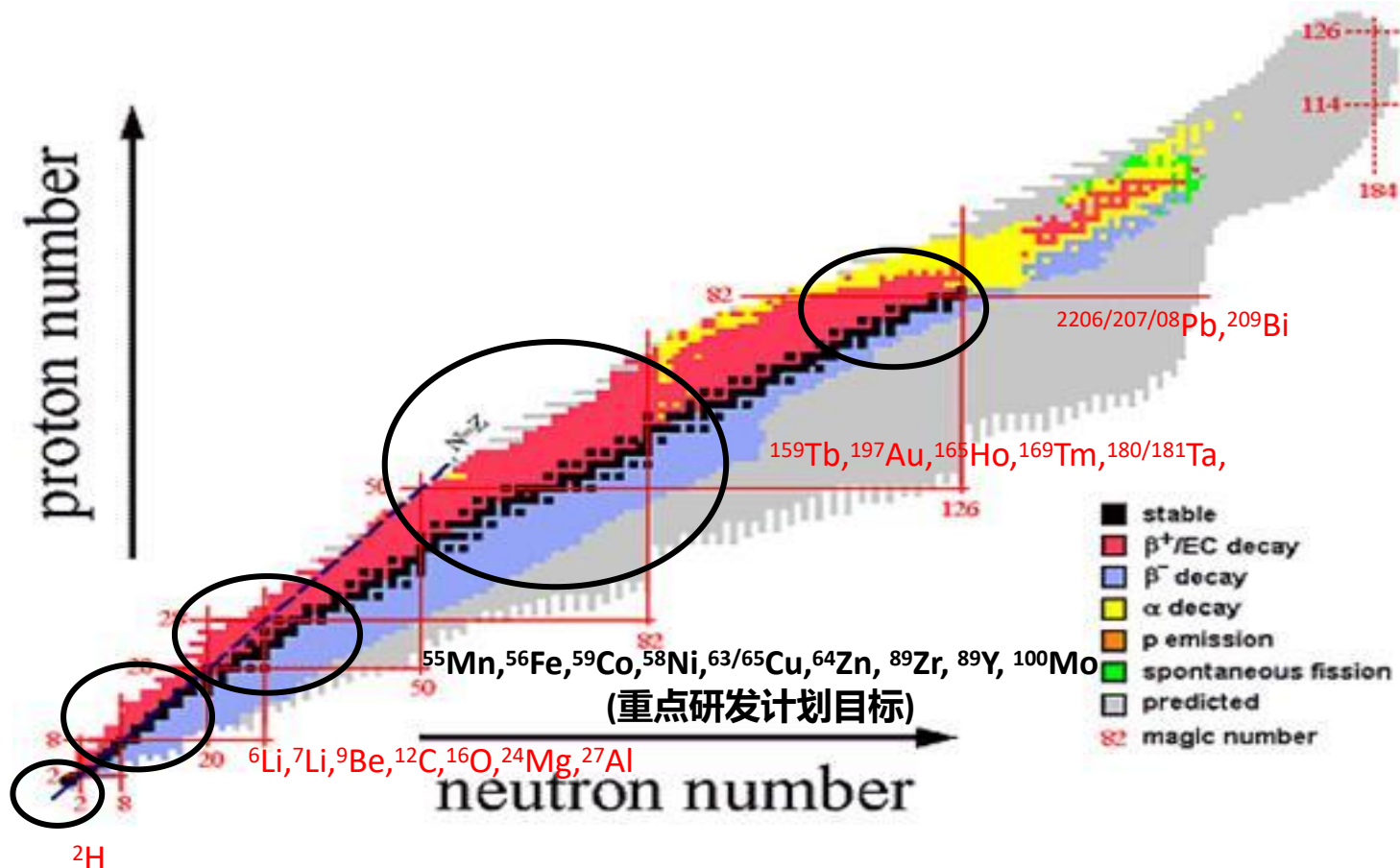
原子核集体运动研究：巨偶极共振 (GDR) + 矮共振 (PDR)

核天体物理：p-核及p-过程研究

原子核奇异结构：团簇构型

SLEGS的预期研究目标

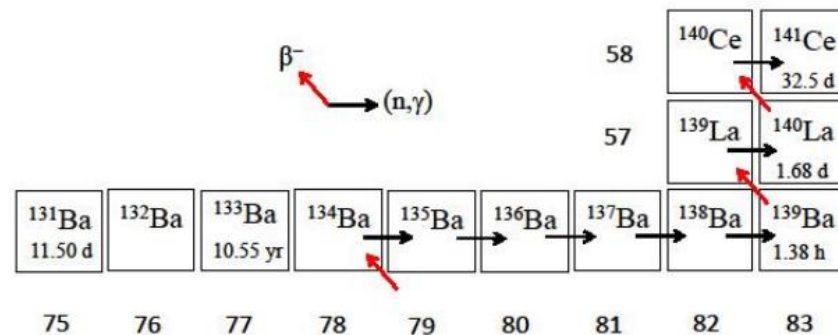
1. 可制靶的稳定核光核反应截面测量，特别是光中子，光致带电粒子截面，从 $^2\text{H} \sim ^{208}\text{Pb}/^{209}\text{Bi}$;
2. 核天体s-process, r-process, p-process过程相关的光核反应截面;
3. 核能级结构研究, NRF过程, PDR过程;



- N=30同中子素链，整条链上都有中子矮偶极共振或质子矮偶极共振，其中 ^{60}Zn ($Z=30, N=30$)是个质子、中子矮偶极共振的分界点，它本身的跃迁密度显示有质子、中子矮偶极共振共存的现象。(兰大牛一斐老师建议)

伽马强度函数衔接中子俘获截面与光中子截面

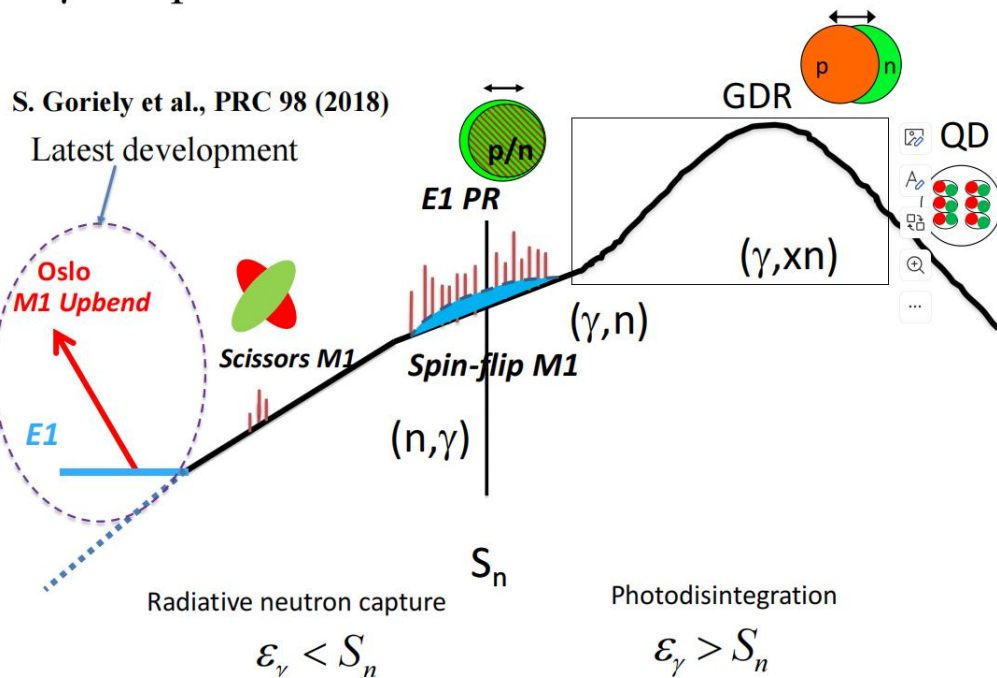
γ SF upward or downward?



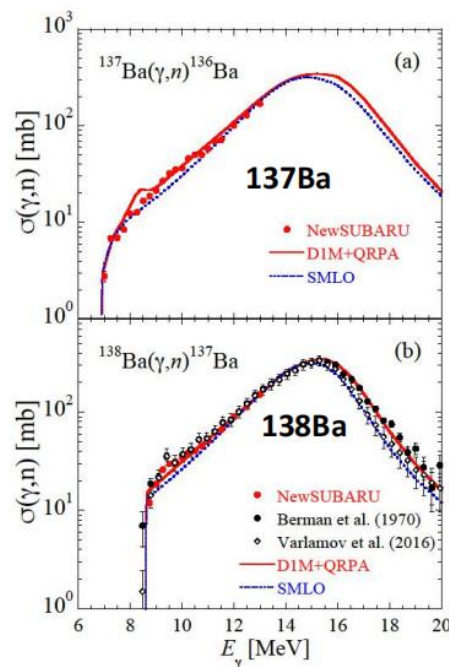
^{130}Ba : 0.11%, ^{132}Ba : 0.10%, ^{134}Ba : 2.42%, ^{135}Ba : 6.59%, ^{136}Ba : 7.85%, ^{137}Ba : 11.2%, ^{138}Ba : 71.7%

S. Goriely et al., PRC 98 (2018)

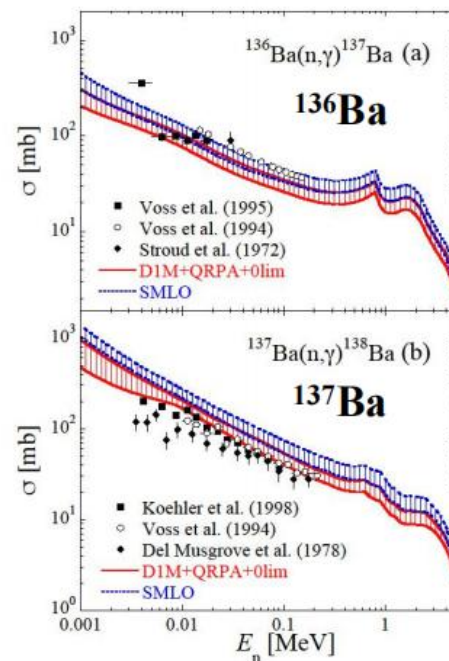
Latest development



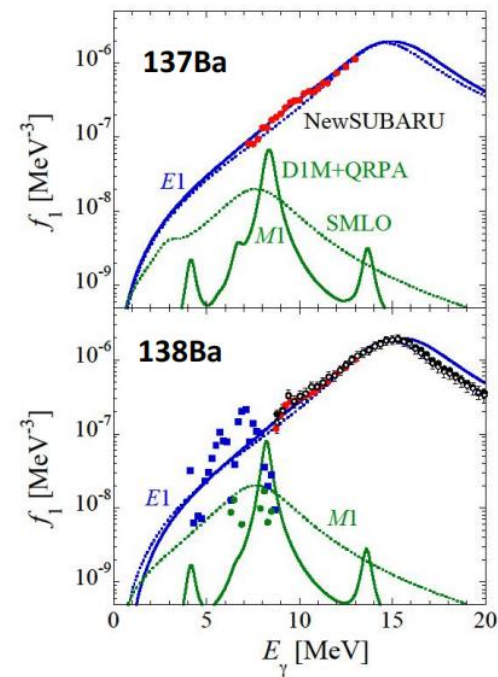
(γ, n) cross sections



(n, γ) cross sections



Upward γ SF



Brink-Axel Hypothesis

D.M. Brink, Ph.D thesis, Oxford University, 1955.

P. Axel, Phys. Rev. 126, 671 (1962)

S. Goriely, S. Hilaire, S. Péru, and K. Sieja, PRC 98, 014327 (2018)

S. Goriely, PRC 98 (2018)

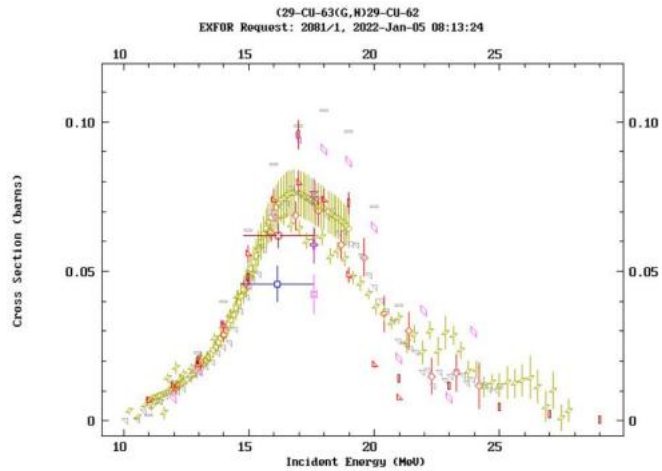
S. Goriely and V. Plujko, PRC 99 (2010)

H. Utsunomiya, PR C 99 (2018)

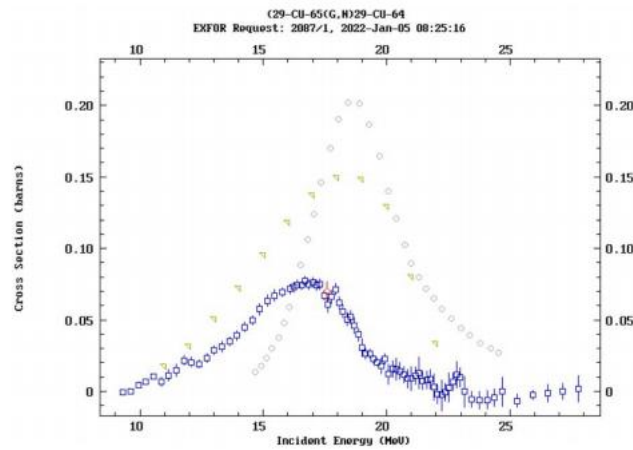
H. Utsunomiya, PR C 100, 034605 (2019)

SLEGS 伽马强度函数研究：近期目标核

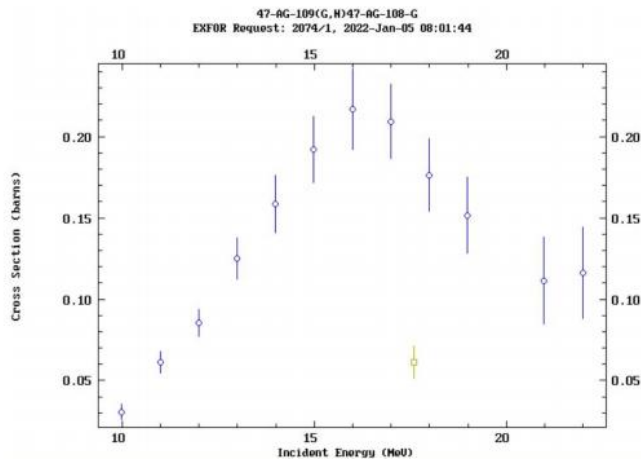
^{63}Cu : 69.1 %



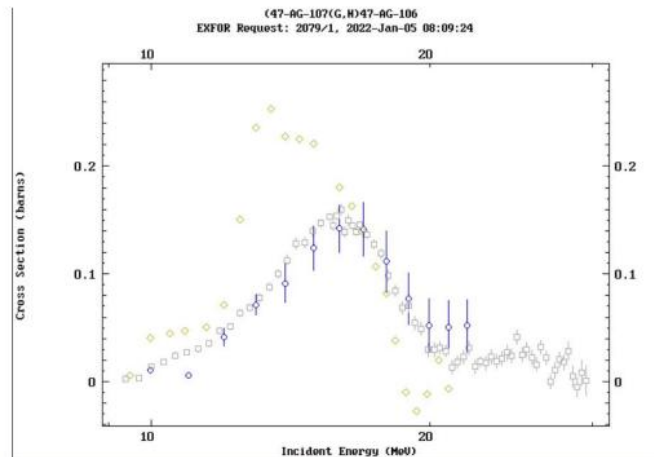
^{65}Cu : 30.9 %



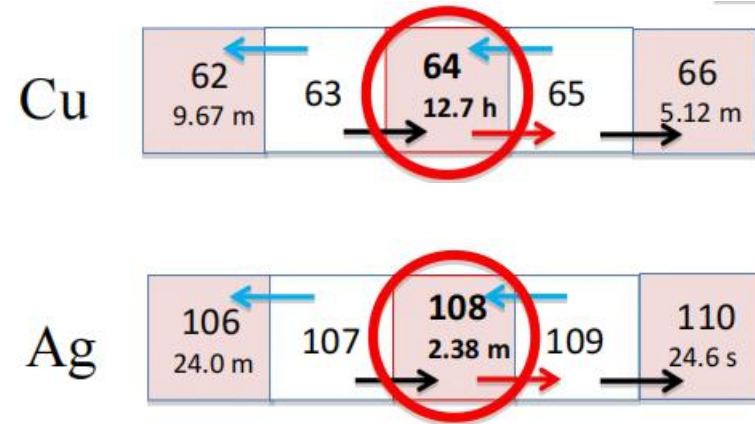
^{109}Ag : 48.2 %



^{107}Ag : 51.8 %



- ← (γ, n) : We measure.
- (n, γ) : Existing
- (γ, n) : We predict with γ SF method



PANDORA project:—Photo-Absorption of Nuclei and Decay Observation for Reactions in Astrophysics

PANDORA Project: Organization Since 2019

Nuclear Experiments

RCNP

Osaka Univ.

A. Tamii, N. Kobayashi, T. Sudo, Z. Yang, T. Furuno, M. Murata, A. Inoue, H. Mori

ELI-NP

ELI-NP

D. Balabanski, P.-A. Söderström, L. Capponi, T. Petruse, D. Nichita, Y. Xu

iThemba LABS

iThemba LABS, Witswatersland Univ., Stellenbosh Univ.

L. Pellegri, R. Neveling, F.D. Smit, J.A.C. Bekker, S. Binda, H. Jivan, T. Khumal, M. Wiedeking, P. Adsley, L.M. Donaldson, E. Sideras-Haddado, K.L. Malatji, S. Jongile, A. Netshiya

TU-Darmstadt

P. von Neumann-Cosel, N. Pietralla, J. Isaak

Nuclear Theory

AMD

M. Kimura, Y. Taniguchi, H. Motoki **Antisymmetrized Molecular Dynamics**

NRFT

E. Litvinova, P. Ring, H. Wibowo **Nuclear Relativistic Field Theory**

TALYS

S. Goriely, E. Khan

UHECR Theory

Propagation

D. Allard, B. Baret, I. Deloncle, J. Kiener, E. Parizot, V. Tatischeff

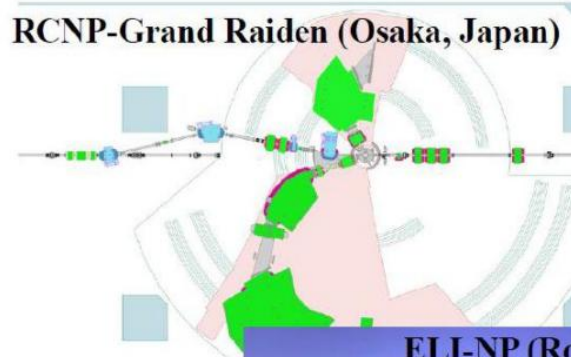
Production

S. Nagataki, J. Oliver, H. Haoning E. Kido

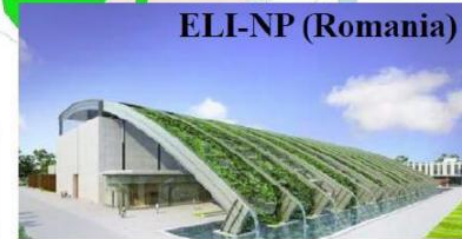
PANDORA Project Photo-Absorption of Nuclei and Decay Observation for Reactions in Astrophysics

Joint project among three experimental facilities with nuclear theories and astrophysical simulations

RCNP-Grand Raiden (Osaka, Japan)

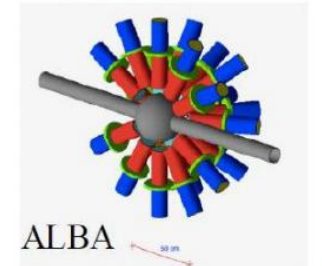


ELI-NP (Romania)



complementary experimental techniques

iThemba LABS South Africa



SLEGS



未来新一代康普顿散射伽马源的关键技术研究：

- ① 基于科技部国家重点研发计划的SLEGS流强提升关键技术：激光功率提升，指向稳定性等
- ② 基于软X射线自由电子激光（SXFEL）装置的直线加速器型激光康普顿散射（LCS）伽马源：谐振腔技术，超快激光定时与定位技术等；
- ③ 未来基于硬X射线自由电子激光装置（SHINE）的超高能激光康普顿散射（LCS）伽马源：X射线偏转技术，超高能量伽马射线测量与监控技术，电子标记技术等；
- ④ 未来小型、应用型激光康普顿散射（LCS）伽马源关键技术：用于医学同位素产生，正电子束湮灭等应用研究

- **SLEGS 科学顾问:** 沈文庆, 马余刚
- **SLEGS 建设与运行团队:** 王宏伟, 范功涛, 许杭华, 刘龙祥, 张岳, 郝子锐

SLEGS系列研讨会: 每年举办, SLEGS-2024计划12月举办
上海光源用户会:

2022年科技部重点研发项目:

准单能伽马源的光核反应与关键技术研究 (2022YFA1602400)

项目负责人: 王宏伟

复旦大学: 邓先概, 周波

北京师范大学: 何建军, 张立勇

原子能科学院: 续瑞瑞, 贺创业

北京航空航天大学: 孙保华, Kajino

上海应用物理研究所: 胡继峰, 黄勃松

上海高等研究院: 曹喜光, 范功涛, 许杭华, 刘龙祥

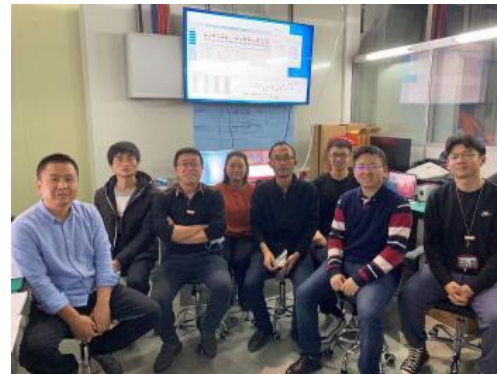
2023年科技部重点研发项目:

项目: 基于高能强流电子束的核物理实验相关探测技术研究 (2023YFA1606900)

项目负责人: 符长波

课题1: 逆康普顿高能伽马束产生关键技术 (2023YFA1606901)

上海高等研究院: 范功涛 (课题负责人), 许杭华, 汪金国



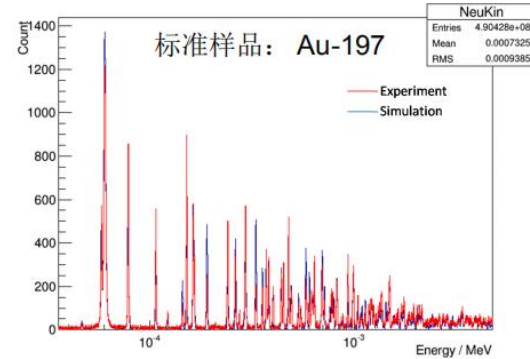
SLEGS组在Back-n上的中子俘获截面研究

上海高等研究院SLEGS组为CSNS Back-n束线站首批用户之一，2019年开始就开展了宽能区中子俘获截面实验研究，主要有胡新荣和李鑫祥博士完成的主要工作。2021年以后胡新荣博士在成都理工大学、李鑫祥博士在南华大学继续开展中子俘获截面实验研究，SLEGS组继续参与和支持他们的研究工作，一直关注Back-n的进展。

两台装置的互补性很强，用户基本一致，期待在**带电粒子实验测量**，**TPC探测器**，**活化及无损检测**方面开展深入合作。

SLEGS组在Back-n束线站开展中子俘获截面实验研究情况（截至2024年8月）

时间	目标靶材料	靶直径 (mm)	厚度 (mm)	束流功率 (kW)	结果发表
2019.01	^{197}Au	50	1	~34	Nucl. Sci. Tech. (2021)
	natSe	50	2		Chin. Phys. B (2022)
	^{89}Y	50	1		Analyzing by CDUT
2019.05	^{197}Au	30	1	~50	核技术 (2020)
	natEr	50	1		Phys. Rev. C (2021, 2022)
	natSm	50	1		preparing
2020.01	^{63}Cu	30	0.1	~80	Analyzing
	^{65}Cu	30	0.1		
2021.04	^{107}Ag	30	0.1	~100	Chin. Phys. B (2022)
	^{109}Ag	30	0.1		
2022.07	natAg	30	0.1	~150	Analyzing
2022.11	natYb	30	0.1	~150	
2023.10	^{65}Cu	30	0.1	~150	
	^{209}Bi	40	1		



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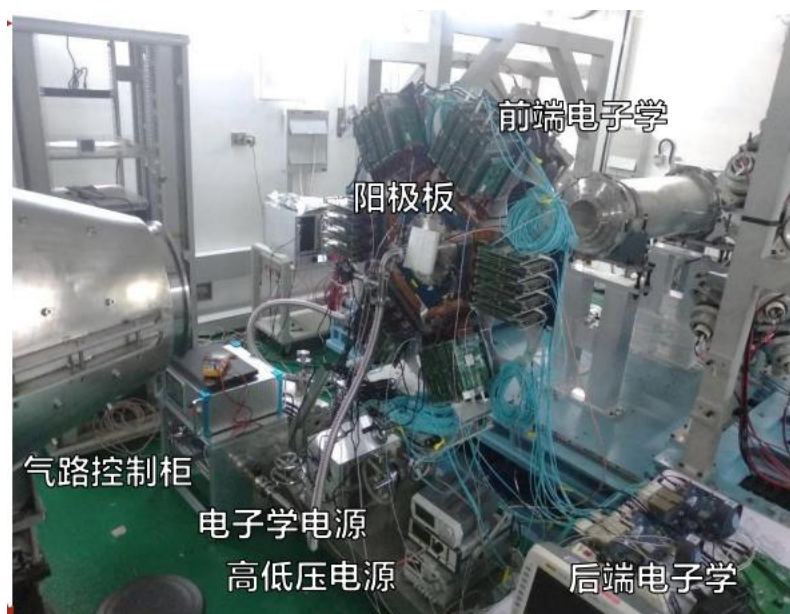


来自于李鑫祥博士统计

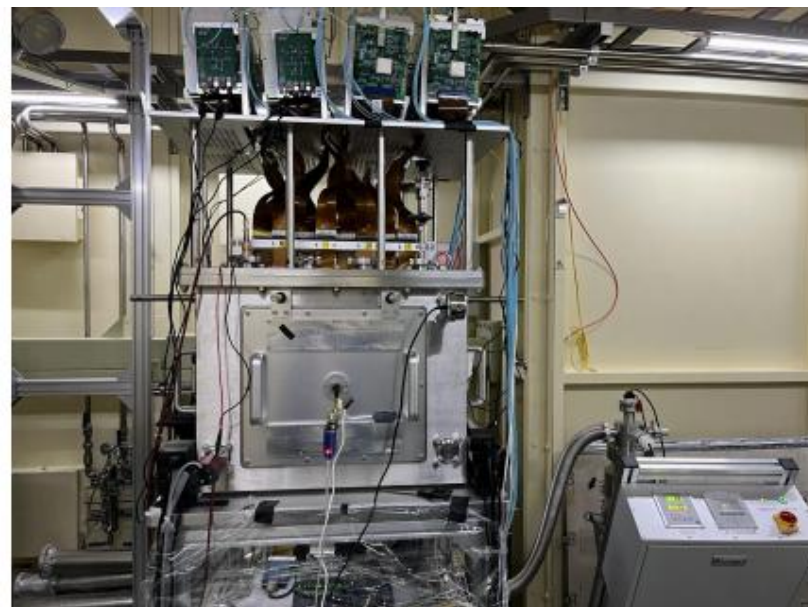
Back-n与SLEGS具有相似的实验探测器设备

- ① 中子与伽马都不带电，在实验测量探测器与实验方法学上具有一定的可借鉴与参考性；
- ② 中子俘获反应(n,γ)与光中子反应(γ,n)互为正逆反应，可以通过细致平衡原理推导得到；
- ③ 带电离子测量设备，如望远镜探测器，AT-TPC等探测器；
- ④ 中子活化与伽马活化；
- ⑤ 中子嬗变与伽马嬗变；

多用途时间投影室MTPC—樊瑞睿，易晗报告



多用途活性靶时间投影室—邓先概，吴黄恺报告



谢谢，祝Back-n装置研究成果丰硕，祝用户会议圆满成功！



欢迎申请伽马束流机时， <https://lssf.cas.cn>

SLEGS 近期相关文章参考

- ① H. H. Xu, et al., Interaction Chamber Design for an Energy Continuously Tunable Sub-MeV Laser-Compton Gamma-Ray Source, **IEEE Transactions on Nuclear Science** 63 (2) (2016) 906–912. doi:10.1109/TNS.2015.2496256.
- ② H. H. Xu, et al., A new consecutive energy calibration method for X/γ detectors based on energy continuously tunable laser Compton scattering light source, **Nuclear Science and Techniques** 28 (9) (2017) 121. doi:10.1007/s41365-017-0272-1.
- ③ Z.R. Hao, et al., Design and simulation of 4π flat-efficiency 3He neutron detector array, **NUCLEAR TECHNIQUES**, Vol.43, No.11, November 2020, DOI: 10.11889/j.0253-3219.2020.hjs.43.110501
- ④ H. W. Wang, et al., Development and prospect of Shanghai laser compton scattering gamma source, **Nucl. Phys. Rev.** 37 (2020) 53–63. doi:10.11804/NuclPhysRev.37.2019043
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- ⑥ H. W. Wang, et al., Commissioning of laser electron gamma beamline SLEGS at SSRF, **Nucl. Sci. Tech.** 33:87 (2022). doi:10.1007/s41365-022-34201076-0.
- ⑦ Z. R. Hao, et al., A new annular collimator system of SLEGS beamline at Shanghai Light Source, **Nucl. Instrum. Methods Phys. Res. B** 519(2022) 9–14. doi:10.1016/j.nimb.2022.02.010.
- ⑧ H. H. Xu, et al., Interaction chamber for laser Compton slant-scattering in SLEGS beamline at Shanghai Light Source, **Nucl. Instrum. Methods Phys. Res. A** 1033 (2022) 166742. doi:10.1016/j.nima.2022.166742.
- ⑨ H. Utsunomiya, et al., p-process chaser detector in n-γ coincidences, **Nuclear Inst. and Methods in Physics Research**, A 1034 (2022) 166819, doi.org/10.1016/j.nima.2022.166819
- ⑩ K. J. Chen et al., Simulation and test of the SLEGS TOF spectrometer at SSRF, **Nuclear Science and Techniques** (2023) 34:47, https://doi.org/10.1007/s41365-023-01194-3
- ⑪ K. Pan et al., Nuclear Resonance Fluorescence Spectrometer Design and Detector Performance Analysis of Shanghai Laser Electron Gamma Source(SLEGS), **Nuclear Physics Review**, 2023, 40(1):58-65. doi:10.11804/NuclPhysRev.40.2022040
- ⑫ L. X. Liu, et al., Energy profile of laser Compton slant-scattering γ-ray beams determined by direct unfolding of total-energy responses of a BGO detector, **Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment** 1063 (2024) 169314. doi:10.1016/j.nima.2024.169314.
- ⑬ Z. R. Hao, et al., Quasi-monochromatic gamma beam modulation at slegs, **Radiation Measurements** 174 (2024) 107127. doi:10.1016/j.radmeas.2024.107127.
- ⑭ Y.X. Yang, et al., Simulation study on the production of medical radioisotopes ^{186g}Re by photonuclear reaction, **Radiation Physics and Chemistry** 218 (2024) 111599, doi.org/10.1016/j.radphyschem.2024.111599