**1st workshop on applications of high energy Circular Electron-Positron Collider (CEPC) synchrotron radiation source**

**第一届CEPC同步辐射光源应用研讨会**

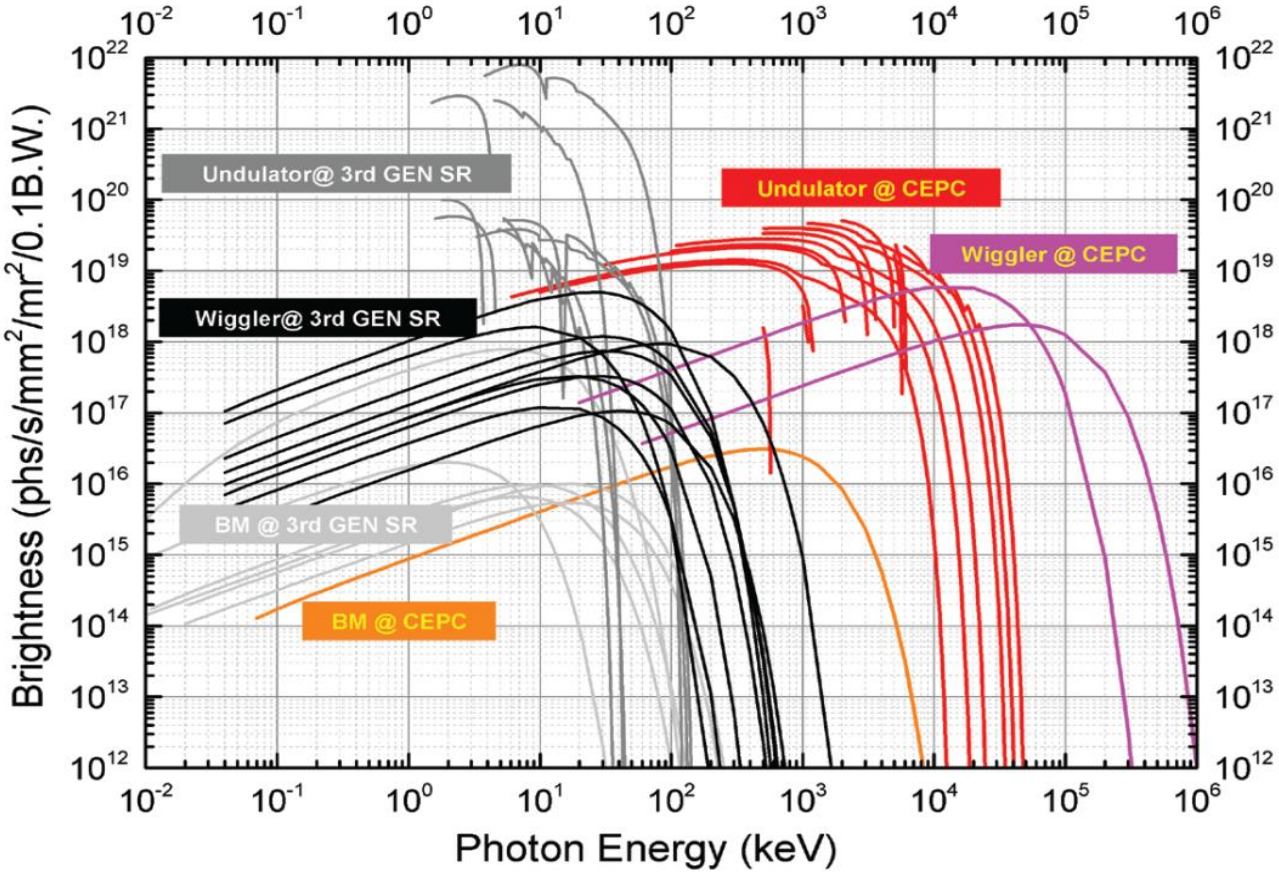
**（6-8 Dec, 2017, IHEP, Beijing）**

# 总结讨论

黄永盛

实验物理中心，高能所

2017.12.08




未来高能粒子对撞机上弯铁、扭摆器、振荡器和低K值的波荡器的亮度(CEPC-CDR)

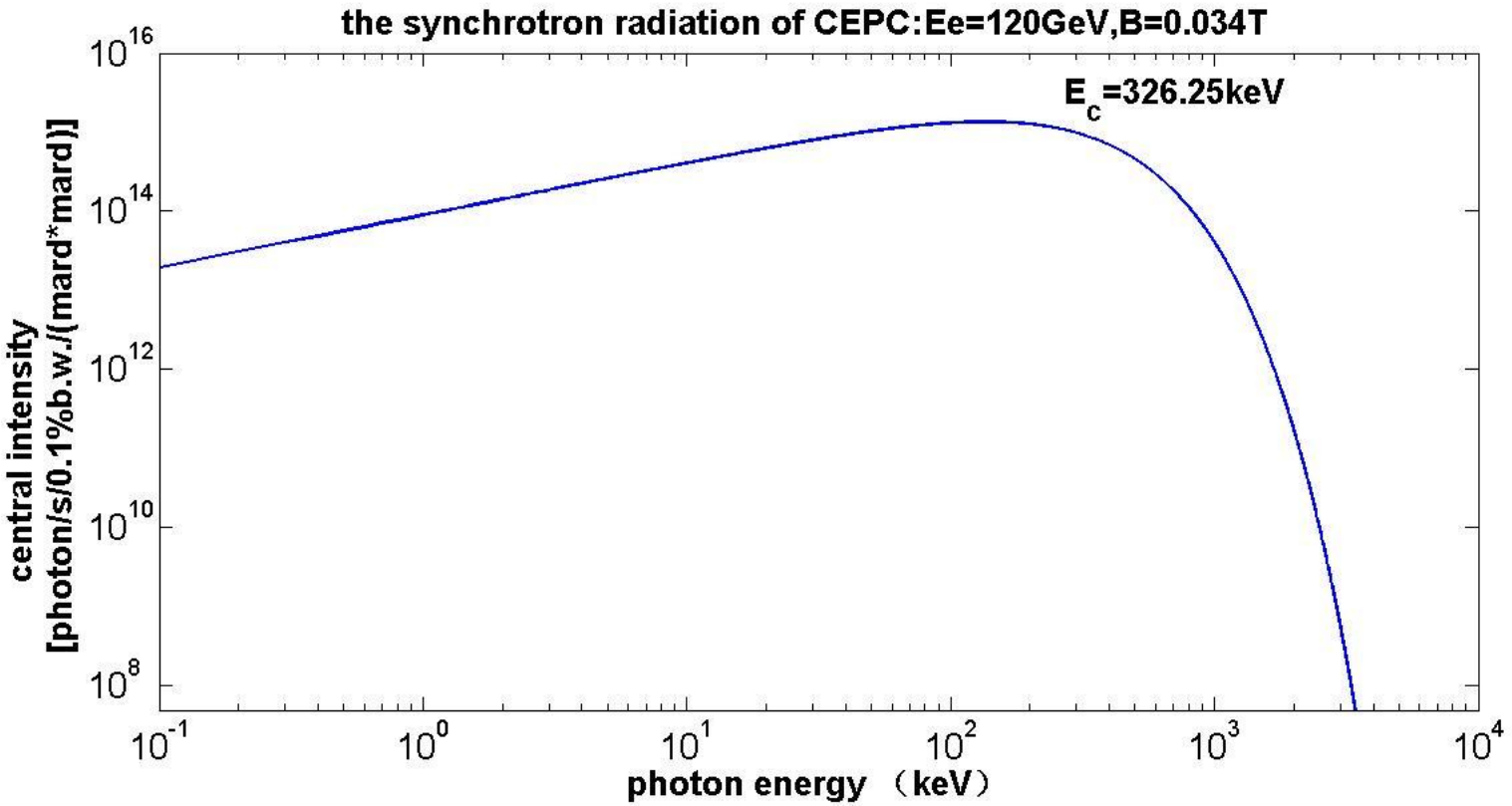
扭摆器的特征γ能量为17.2MeV，高通量辐射能量可达到300MeV。波荡器产生的γ光能量在高通量情况下也能达到20MeV。并且，在大于100keV能区，未来高能粒子对撞机同步辐射源的亮度和通量都高于第三代同步辐射光源的辐射。

# Central intensity of Synchrotron radiation,[photon/s/mrad2/0.1%b.w.]

$$\left.\frac{d^2F_{bm}}{\mathrm{d}\theta d\psi}\right|_{\psi=0} = 1.327\times10^{13}E^2[GeV]I(A)H_2(y)$$

$F_{bm}$ , flux; I, the curent of the ring, $\mathrm{H_2(y)} = \mathrm{y^2K_{\frac{2}{3}}^2(y/2)}$, K, the second Bessel function;

$\mathrm{y} = \epsilon/\epsilon_c$, $\epsilon$,the photon energy, $\epsilon_c = 0.665E^2[GeV]B[T]$.



# CEPC-SR： Applications

光核作用是一种有阈能的反应，(γ,n)和(γ,p)反应的阈能就是靶

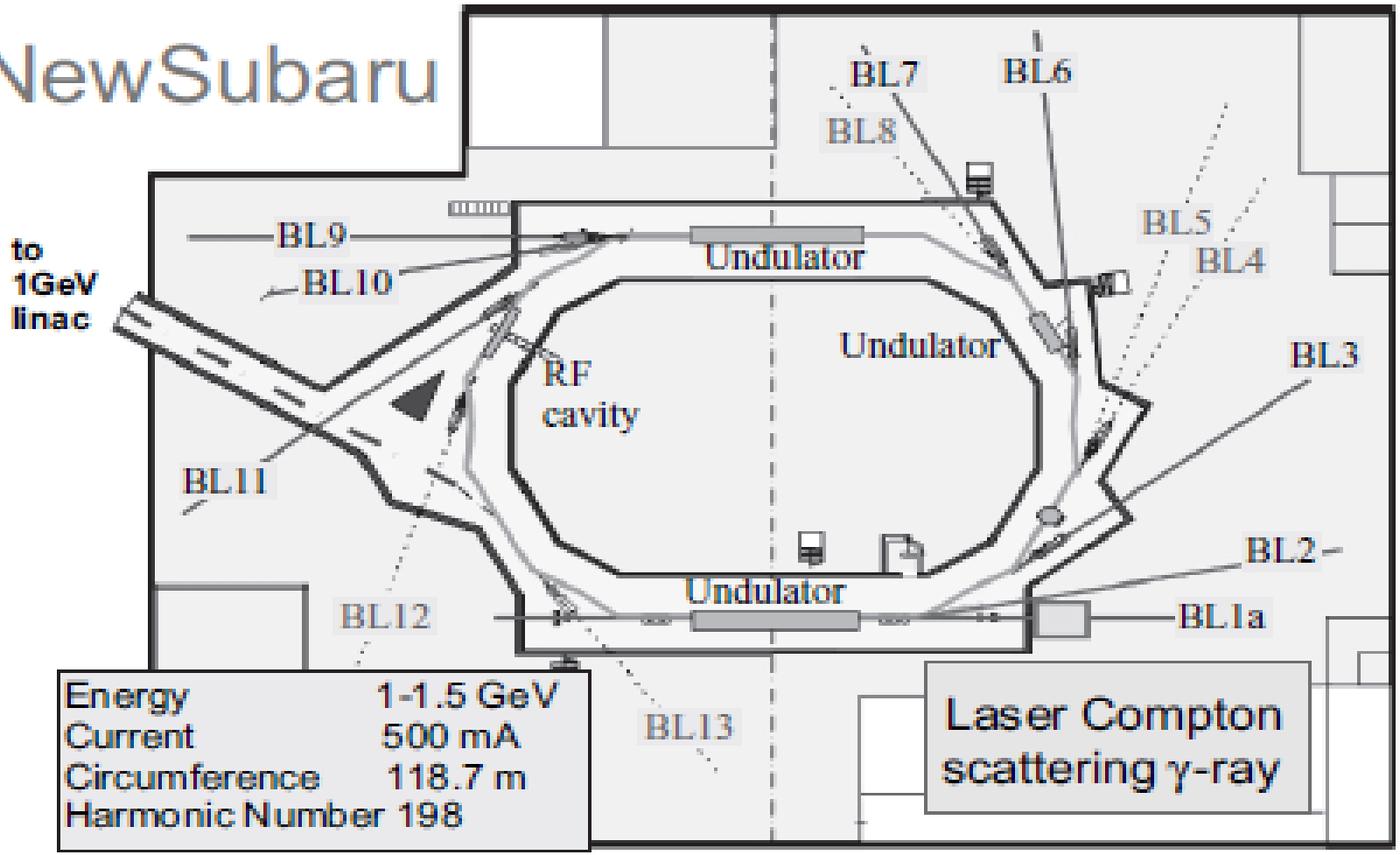
核中的最后一个中子和质子的结合能，通过(γ,n)反应阈值的测

量可以精确地获得最后一个中子的结合能的数据。

# 光核反应的重要性2

- 研究辐射俘获反应的重要手段
  - (p,γ)、(α,γ)、(n,γ)反应，产生能量，合成元素
- 研究方法的原理
  - 在伽玛光源上测量(γ, x)反应
  - 基于细致平衡原理，辐射俘获反应(x, γ)布居产物基态的截面$\sigma_A$可通过测量光致裂解反应(γ, x)的截面$\sigma_B$导出
  - 研究产物核能级密度（NLD），统计模型中的基本参数
- 研究方法的优势
  - 天体物理能区某些反应的σ(γ,x)与σ(x,γ)之比可高达两个量级
  - γ-射线在介质中的平均吸收长度容许采用厚靶
  - $^{16}O(\gamma,\alpha)^{12}C$比$^{12}C(\alpha,\gamma)^{16}O$的反应产额高~6个数量级

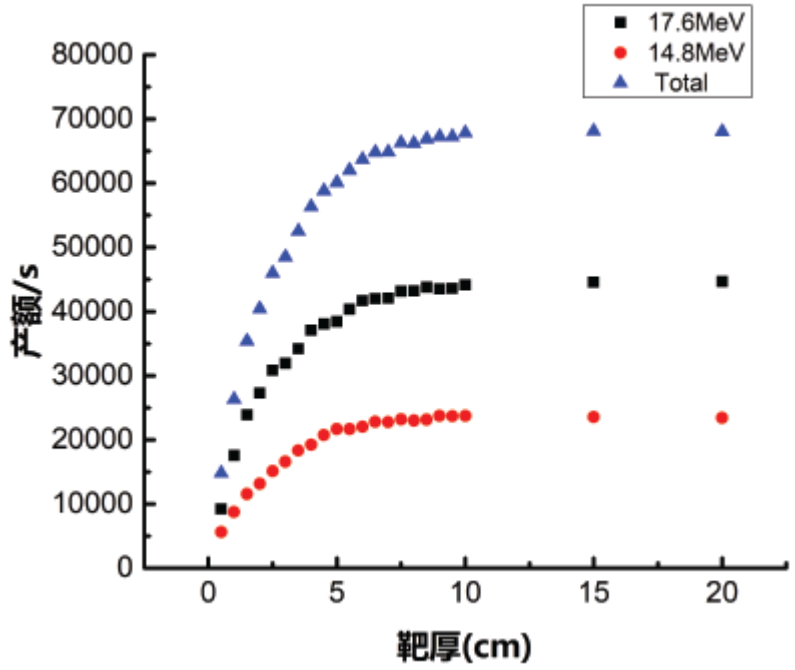
# 4. 高强度的γ射线束在嬗变研究中的重要作用



- 国际上已有少量研究（相对于大量的中子嬗变研究）
- 大多利用采用强激光打高Z靶产生的韧致辐射伽马源进行，效率较低
- 只看到日本有一个实验采用电子束与激光碰撞的逆康普顿散射伽马源进行

→ 得到的结论是对几十公斤的核废料，利用伽马进行嬗变是可行的！

# 共振核反应γ源嬗变能力的探讨，付光永




| 光源类别 | 准单色 | 能量可调 | γ产额 | 反应数 |
|---|---|---|---|---|
| 轫致辐射 | 否 | 是 | - | $10^6/shot$ |
| **激光康普顿** | 是 | 是 | $10^7 \sim 10^9/s$ | $10^8 \sim 10^{11}/h$ |
| $^7Li(p,\gamma)^8Be$ | 是 | 否 | $1.2 \times 10^9/s$ | $10^9 \sim 10^{11}/h$ |

共振核反应γ源和目前建好的LCS装置的嬗变能力相当。

# On the CEPC-γ source

VOLUME 30, NUMBER 8 PHYSICAL REVIEW LETTERS 19 FEBRUARY 1973

## Experimental Verification of the Kramers-Kronig Relation at High Energy

H. Alvensleben, U. Becker, P. J. Biggs, W. Busza, M. Chen, R. T. Edwards, P. M. Mantsch, Thomas P. McCorriston, T. Nash, M. Rohde, H. F. W. Sadrozinski, H. Schubel, Samuel C. C. Ting, and Sau Lan Wu

*Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany, and Department of Physics and Laboratory for Nuclear Science, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139*

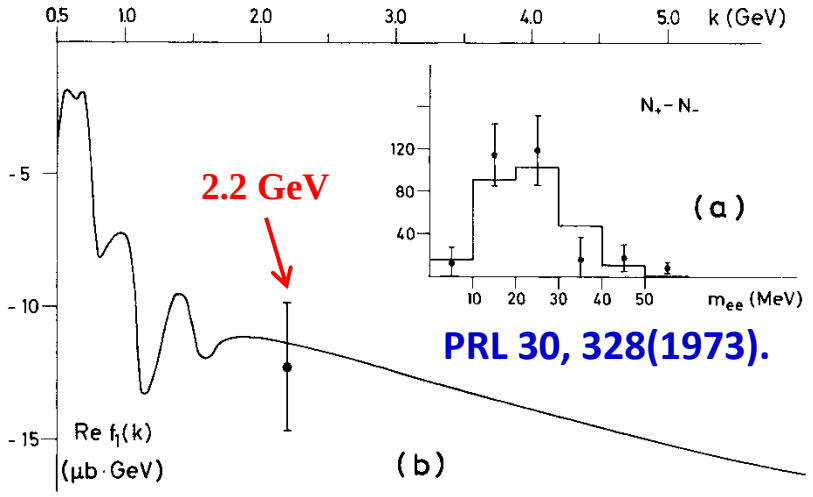
(Received 15 December 1972)

The real part of the forward amplitude for Compton scattering on protons was measured through the interference between the Compton and Bethe-Heithler amplitudes by detecting the zero-degree electron pairs asymmetrically. The measurement was made at an average photon energy of $\langle k \rangle = 2.2$ GeV, and an average momentum transfer to the recoil proton $\langle t \rangle = -0.027$ (GeV/$c$)$^2$. The result confirms the prediction of the Kramers-Kronig relation.

$$\gamma + p \rightarrow p + \gamma(\text{virtual}) \rightarrow e^+ + e^-,$$

**$\gamma$+ N → ?**

**100 MeV γ, λ ≈ 12.4 fm**




PRL 30, 328(1973).

# 恒星演化过程中的毒药及圣杯

---基于伽玛光装置的一点思考，何建军

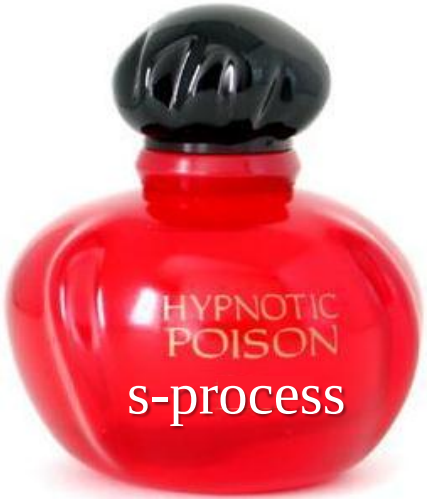
## 慢中子俘获*s*过程中的毒药

第1瓶

$^{17}O(n, \gamma)^{18}O$


第2瓶

$^{13}C(n, \gamma)^{14}C$



# $^{12}C(\alpha,\gamma)^{16}O$圣杯反应

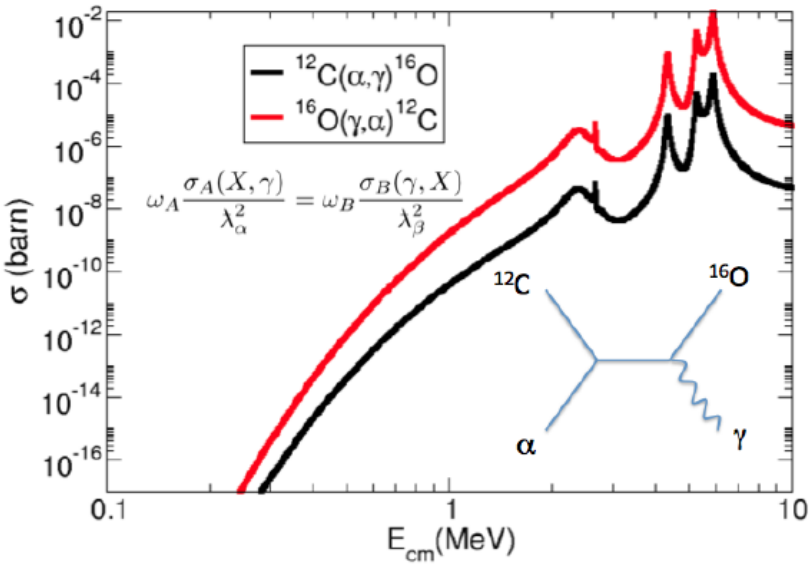
圣杯(Hoyle grail)

$^{12}C(\alpha,\gamma)^{16}O$反应在所有$M > 0.55\ M_{\odot}$恒星的演化中都起着关键作用，其反应截面对上至铁的中等质量核素的合成和大质量恒星后期的演化进程有决定性的影响，被誉为核天体物理的“圣杯”。

# 光核反应$^{16}O(\gamma, \alpha)^{12}C$测量

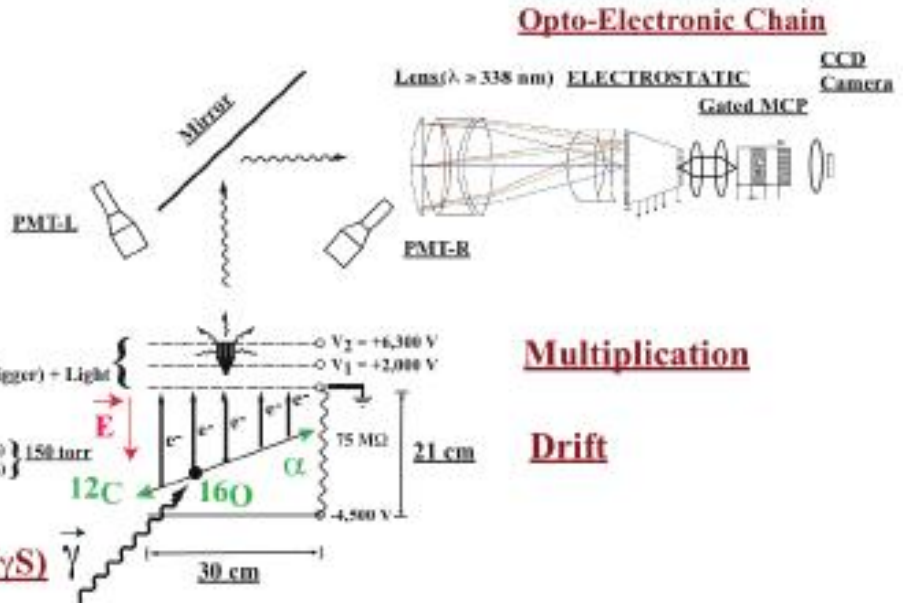
## 德国斯图加特大学：$^{12}C(\alpha,\gamma)^{16}O$

束流：400 μA ($2.5\times10^{15}$ pps),
靶厚：$2\times10^{18}$ atom/cm$^3$
时间：150h




## 光核反应：$^{16}O(\gamma, \alpha)^{12}C$

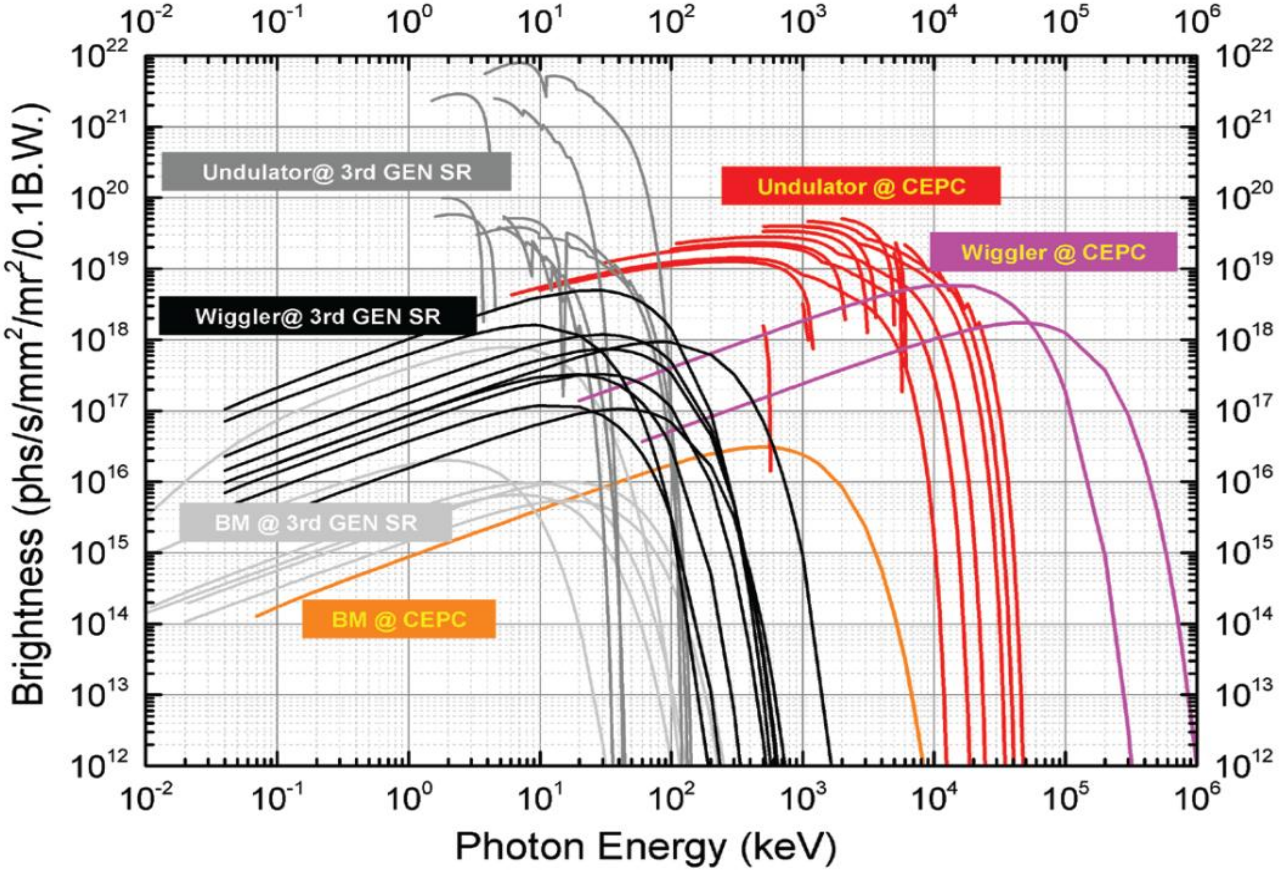
靶厚：×1000倍
反应截面：×100倍
α/γ探测效率比： ×20倍
时间：150h
束流：≥ $10^9$ 个光子/秒



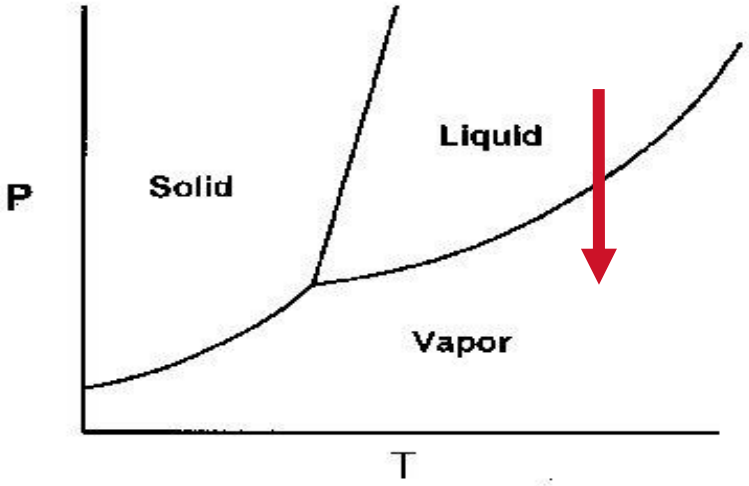

**时间投影室TPC技术**

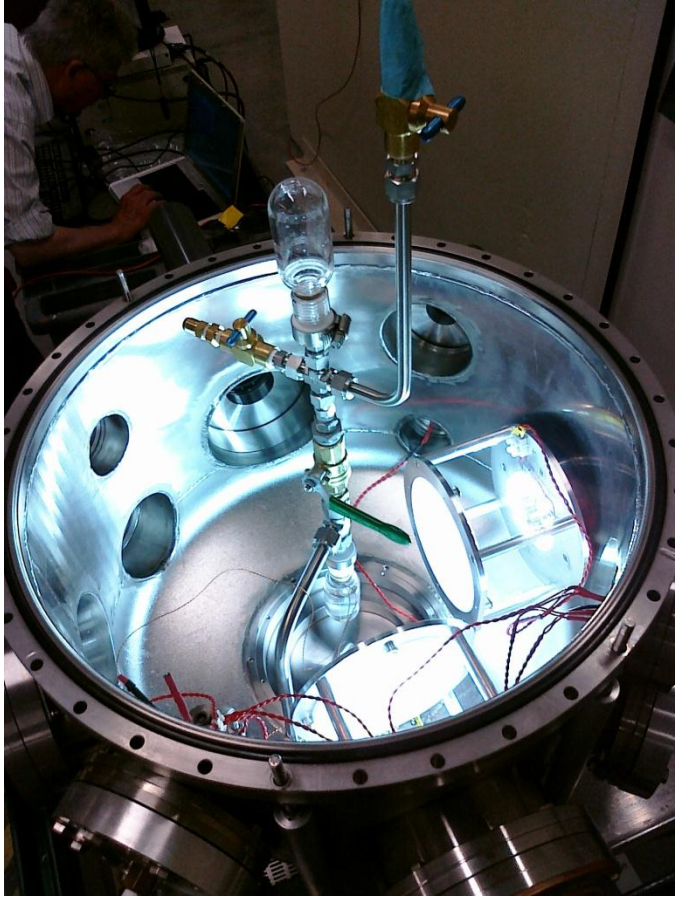
# 圣杯和毒药：必需要加wiggler场

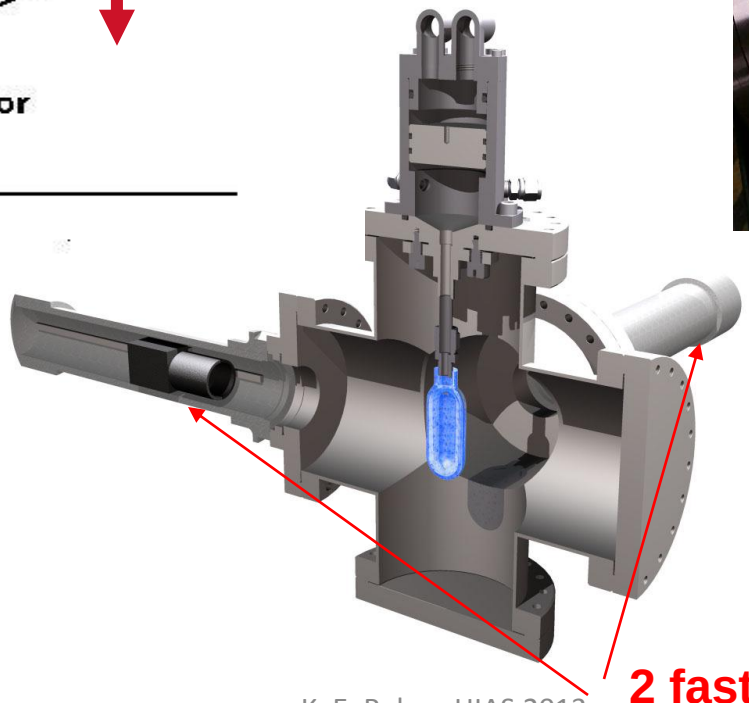
- 可将Wiggler场的最高亮度调整到8.3MeV，为圣杯而歌！



# Proof of Principle of a superheated bubble chamber for the $^{19}F(\gamma,\alpha)^{15}N$ reaction






**P~ 1-6 atm**
**T~20-50 C**

In a classical picture the excess neutrons form a skin around the proton/neutron core with *N Z. An oscillation of the skin vs the core would lead* to an electric dipole excitation mode.

Because this mode bears resemblance to ***a "mini" giant dipole resonance***

***it is often called pygmy dipole resonance (PDR).***

perform very sensitive Ca(γ , γ` ) experiments up to an excitation energy of 10.5 MeV

ents on $^{40}$Ca and $^{48}$Ca

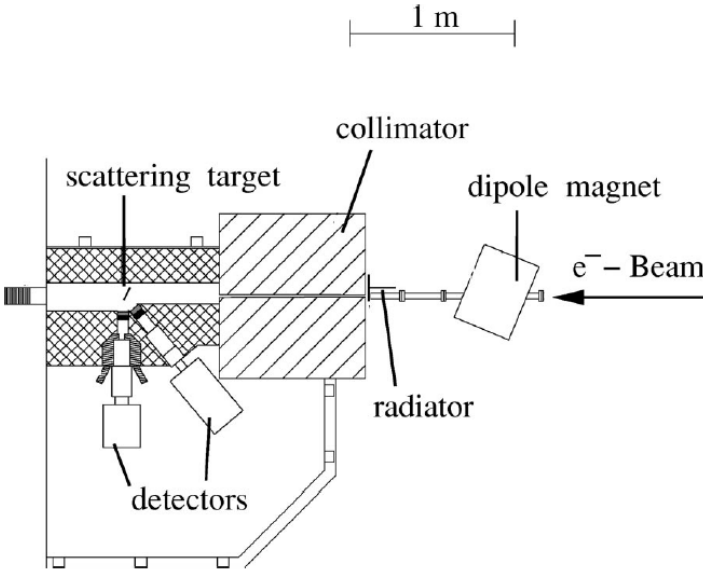



FIG. 1. The NRF setup at the S-DALINAC at Darmstadt versity of Technology. The monoenergetic electron beam witl ergies up to 10 MeV and currents of typically 35 $\mu$A is stopp a Cu radiator. The resulting $\gamma$ radiation with a continuous en distribution is collimated by a 95.5 cm long Cu collimator strikes the scattering target. The decays of the excited nuclei t ground state or other excited levels are detected by two HPG tectors located at angles of 90° and 130° relative to the inco photon beam.

VOLUME 85, NUMBER 2 PHYSICAL REVIEW LETTERS 10 JULY 2000

## Measurement of the Dipole and Electric Quadrupole Strength Distributions up to 10 MeV in the Doubly Magic Nuclei $^{40}$Ca and $^{48}$Ca

T. Hartmann, J. Enders, P. Mohr, K. Vogt, S. Volz, and A. Zilges

*Institut für Kernphysik, Technische Universität Darmstadt, Schlossgartenstrasse 9, D-64289 Darmstadt, Germany*

(Received 23 February 2000)

The doubly magic nuclei $^{40}$Ca and $^{48}$Ca have been studied in high resolution photon scattering experiments. We have derived absolute dipole and quadrupole excitation strengths up to 10 MeV. Evidence was found for a two-phonon quadrupole-octupole state in $^{48}$Ca. At higher energies in contrast to $^{40}$Ca, a concentration of dipole strength is observed in $^{48}$Ca which is discussed in terms of a pygmy resonance originating from the large neutron excess.

# Suggestions for reactions to be studied experimentally

**Photodisintegration reaction measurement: a probe of p-process for nuclear astrophysics, Liuchun He, Bao-Hua Sun, Li-Hua Zhu, Jian-Wei Zhao, Meng Wang, Kang Wang**

**天体物理中建议的可供研究的光核反应！**

TABLE III. Suggestions for reactions to be studied experimentally. Shown are sensitive reactions involving stable or long-lived ($T_{1/2} \geqslant 10^6$ a) targets. Unstable targets are marked by an asterisk, naturally occuring unstable nuclides with superscript $n$. Note that $\alpha$ capture on the unstable targets shown here always has a negative $Q$ value.

| | Target nuclei |
|---|---|
| Priority 1: | |
| $(p,\gamma)$ | $^{80}$Se, $^{79}$Br, $^{84}$Kr, $^{89}$Y, $^{93}$Nb, $^{97}$Tc*, $^{110}$Cd, $^{118}$Sn, $^{128}$Xe, $^{134}$Ba, $^{138}$Ce |
| $(\alpha,\gamma)$ | $^{76}$Se, $^{92}$Mo, $^{94}$Mo, $^{96}$Ru, $^{98}$Ru, $^{102}$Pd, $^{108}$Cd, $^{116}$Sn, $^{124}$Xe, $^{130}$Ba, $^{141}$Pr, $^{148}$Sm$^n$, $^{152}$ Gd$^n$, $^{150}$Gd$^n$, $^{154}$ Dy$^n$, $^{168}$Yb, $^{174}$Hf$^n$ |
| Priority 2: | |
| $(p,\gamma)$ | $^{96}$Mo, $^{106}$Pd, $^{150}$Gd*, $^{156}$Dy, $^{158}$Dy, $^{162}$Er |
| $(\alpha,\gamma)$ | $^{72}$Ge, $^{90}$Zr, $^{118}$Sn, $^{120}$Te, $^{122}$Te, $^{126}$Xe, $^{132}$Ba, $^{139}$La, $^{136}$Ce, $^{140}$Ce, $^{142}$Nd, $^{144}$Nd$^n$, $^{146}$ Sm*, $^{151}$Eu, $^{156}$Dy, $^{158}$Dy, $^{164}$Er, $^{170}$Yb, $^{180}$W, $^{184}$Os, $^{186}$Os$^n$, $^{196}$Hg |

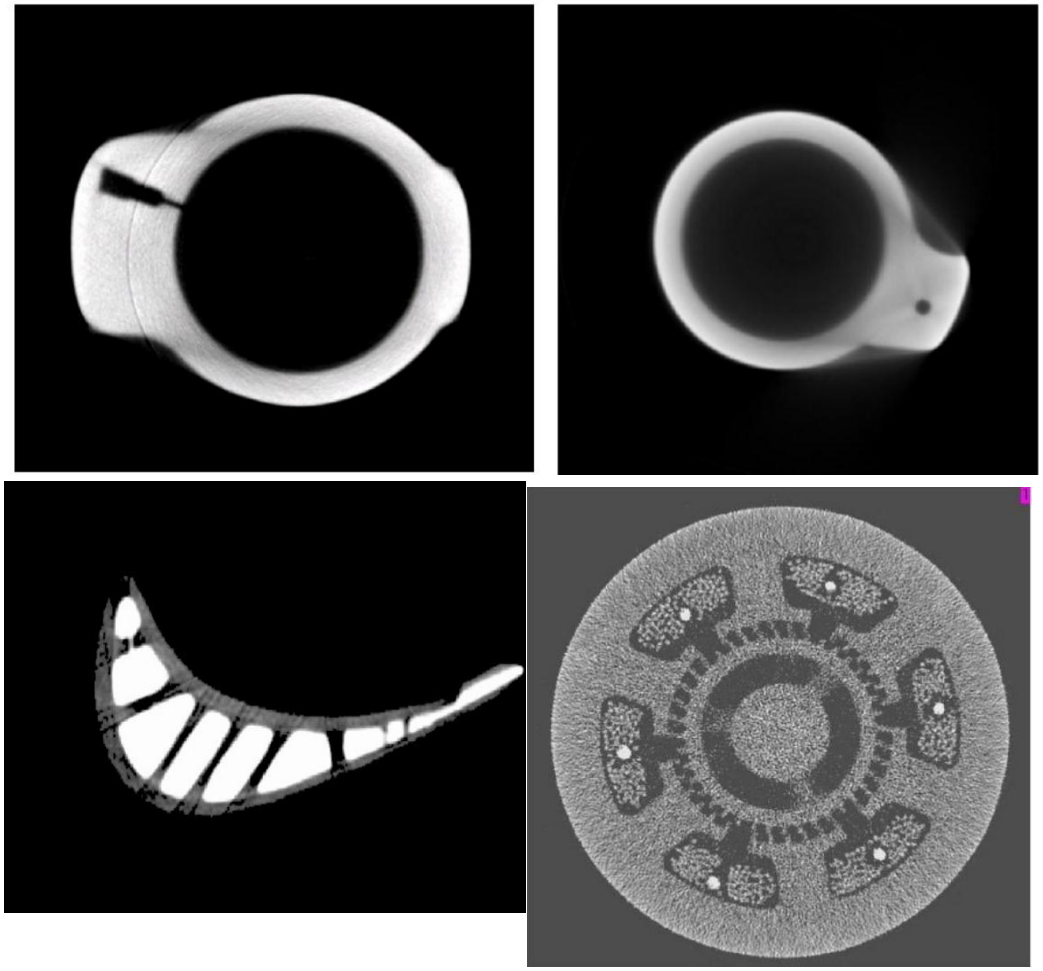
Thomas Rauscher, PRC, 73, 015804 (2006)

# CEPC-SR： Applications-QED related

- **Chou： gg Collider**
- **罗文： QED cascade saturation**
- **余同普： Copious electron-positron pairs generation with PW laser pulses**
- **余金清： The generation of high collimated γ-ray source for the application of photon-photon collider**
- **谢柏松、弯峰：超强激光与等离子体相互作用中非线性Compton散射与韧致辐射**

# CEPC-SR：Applications—工业、材料应用

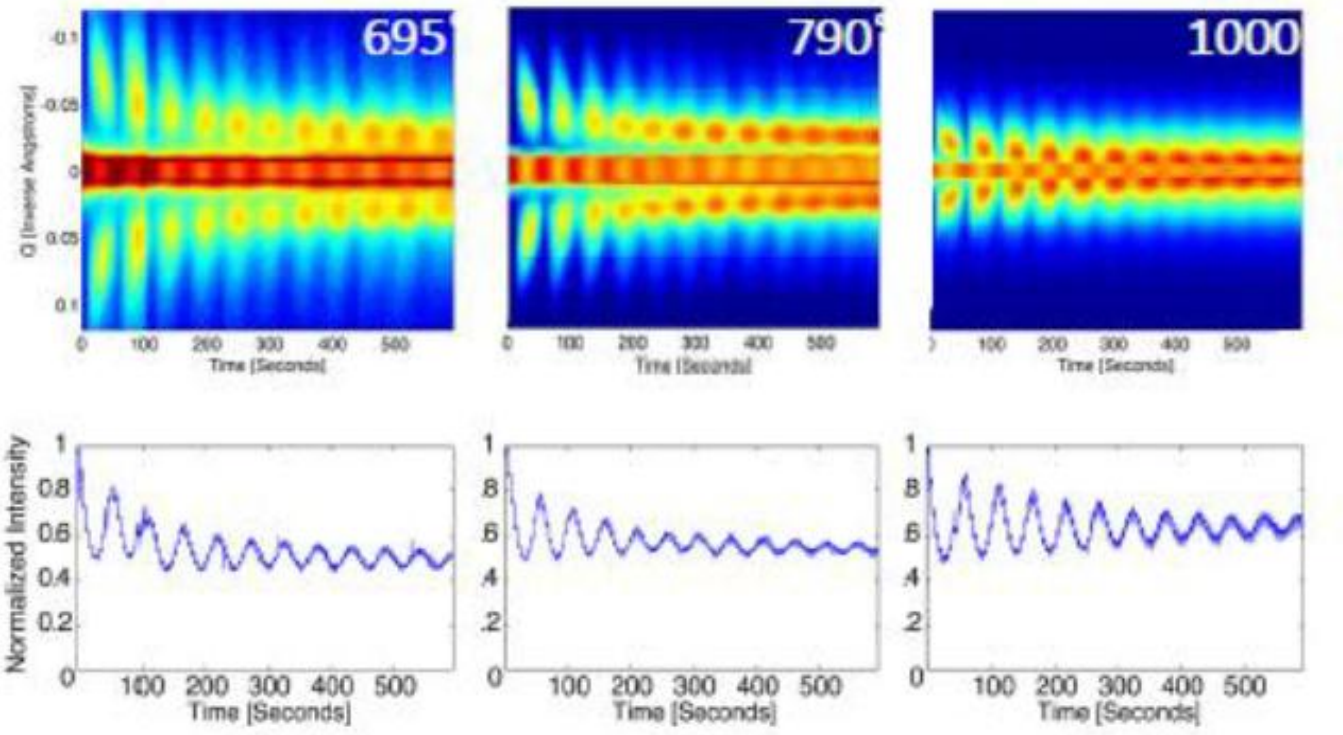
- 1、航空、航天等工业中精密工件内部结构的测量及其缺陷的检测；
- 2、兵器工业中对弹药填充密度的检测和武器关键部件的质量检查；
- 3、汽车工业中的对关键零部件的无损检测
- 4、钢铁工业中产品的在线监控和质量检测；
- 5、地质、考古中对样品的评估；



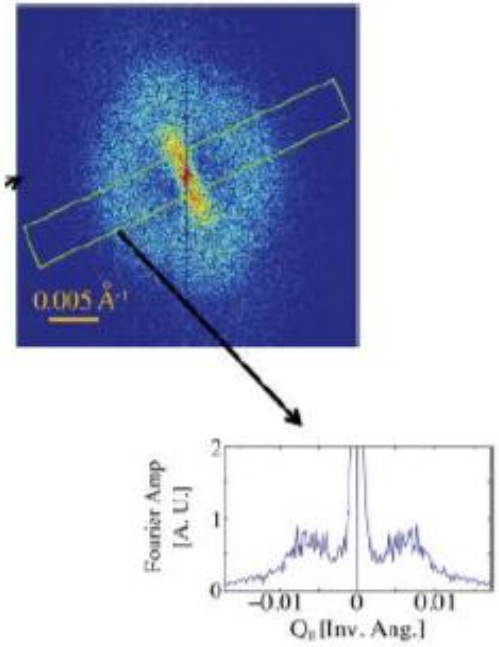
# Science Case 1: Time-resolved XRS probes the growth behaviors of nucleus

**Applications of Synchrotron Radiation X-ray Scattering on Interfacial Structure and Physics，王焕华**

Islands structure on growing $SrTiO_3$ by PLD

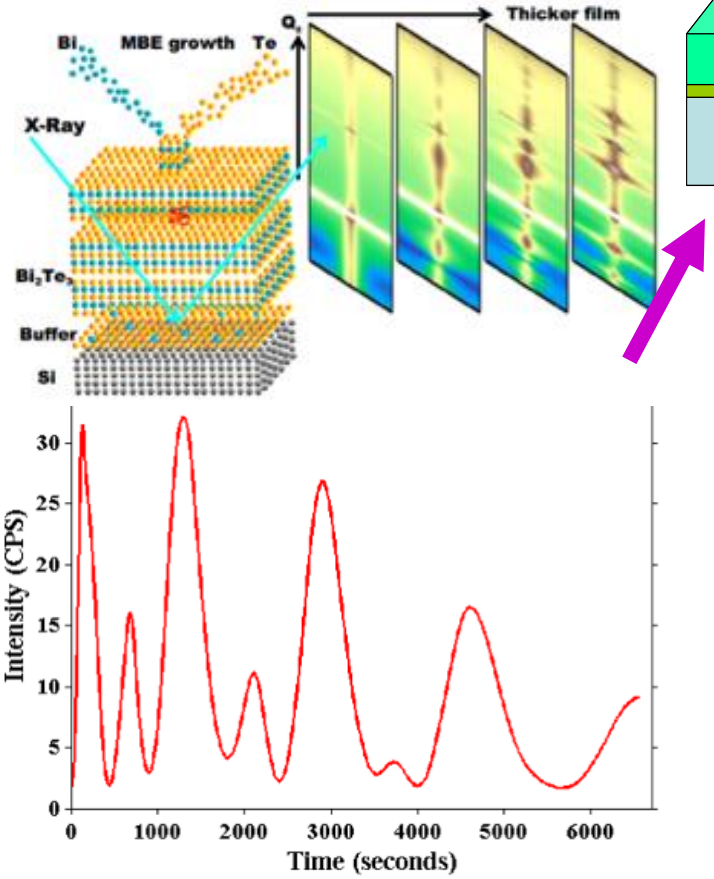



**DXRS intensity ring reveals the islands' separation**

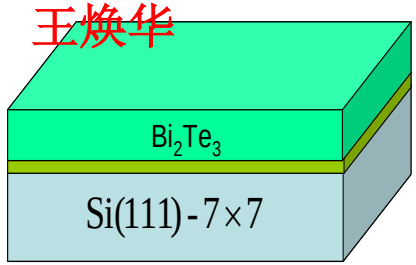


# Science Case 2: Thin film growth and interfacce structure by in-situ (Resonant) SXRS

**Applications of Synchrotron Radiation X-ray Scattering on Interfacial Structure and Physics，王焕华**




Time-resolved XRS intensity oscillations at (0 0 ½)

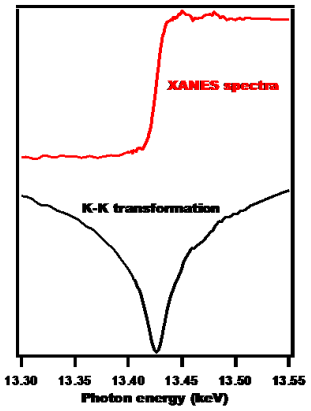


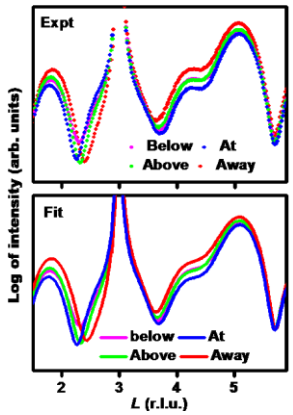

→ Composition？ Thickness?

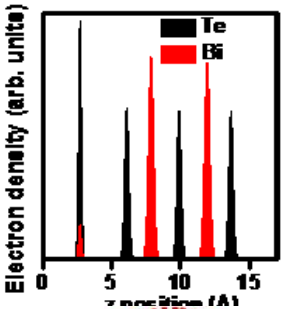
→ Out-of-plane relaxation?

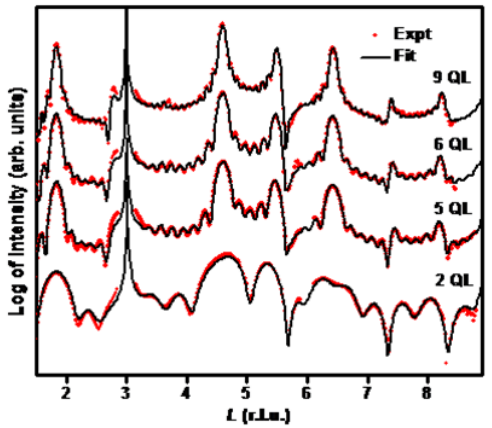
→ In-plane structure？

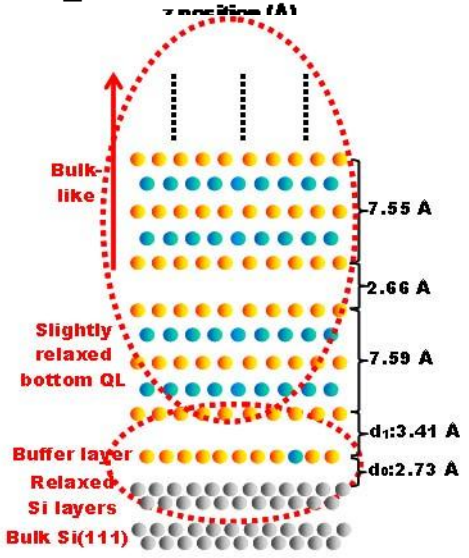
**Resonant XRS: Bi *L*3 edge; EXRR; Structure**



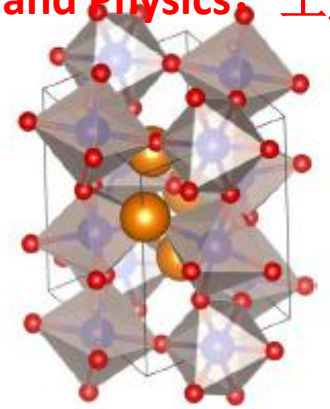



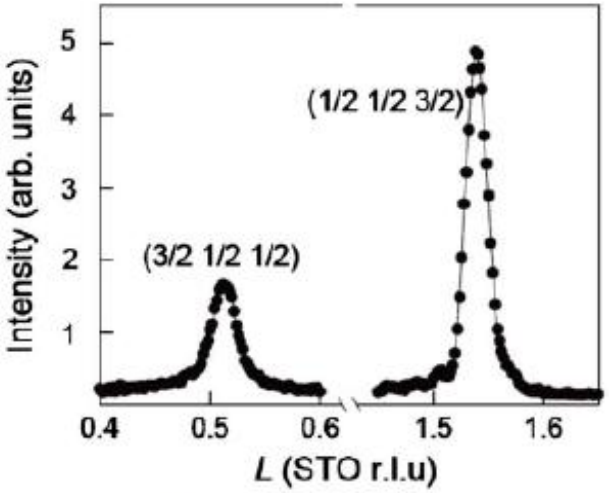



# Science Case 3: Oxygen Octahedral Rotation (OOR) detected by XRD

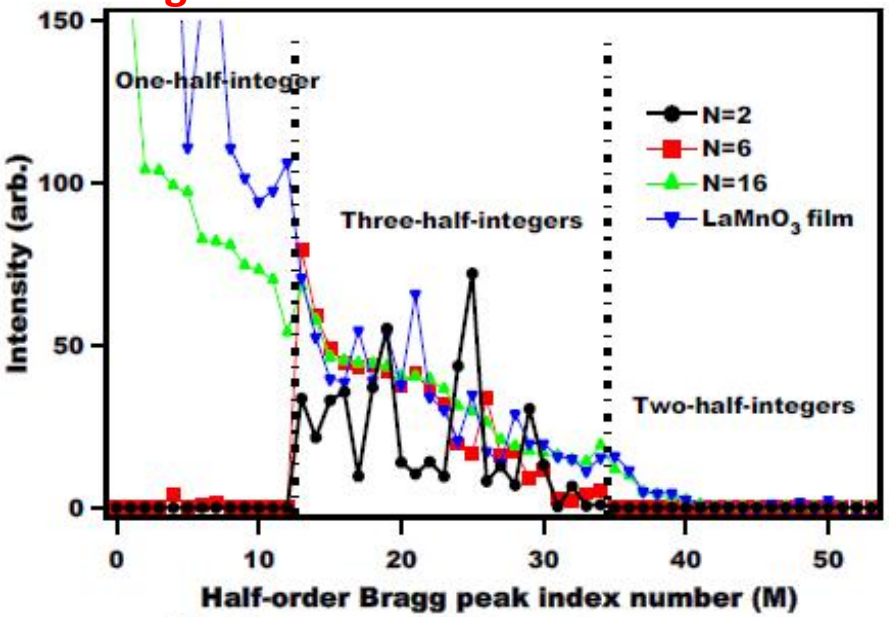
**Applications of Synchrotron Radiation X-ray Scattering on Interfacial Structure and Physics**，王焕华

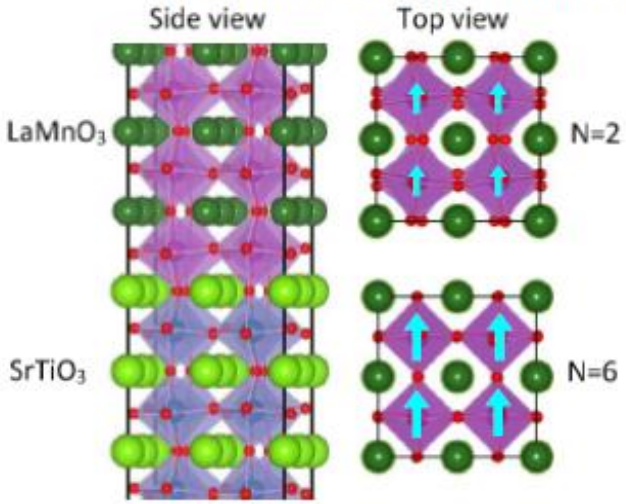
**Doubled lattice periods resulting from OOR lead to half integer Bragg peaks**





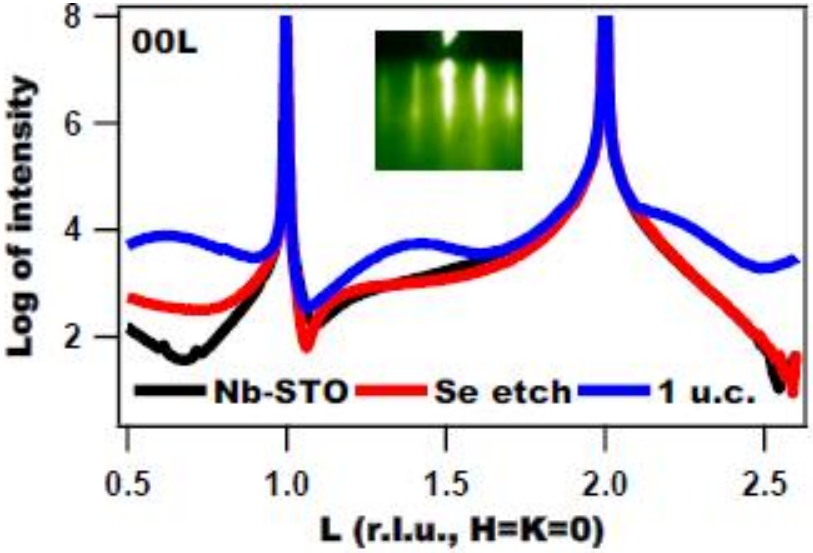

$$F_{hkl} = f_{O^{2-}} \sum_{n=1}^{24} \exp[2\pi i(hu_n + kv_n + lw_n)]$$

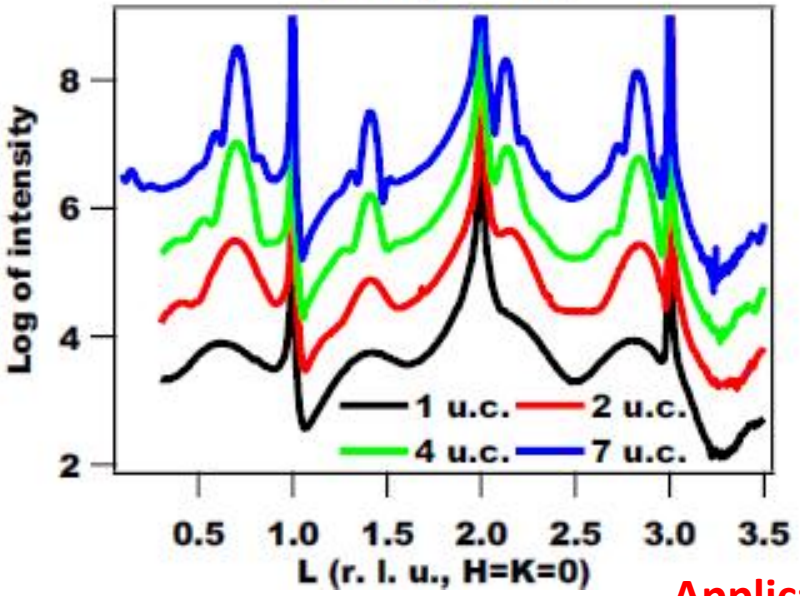


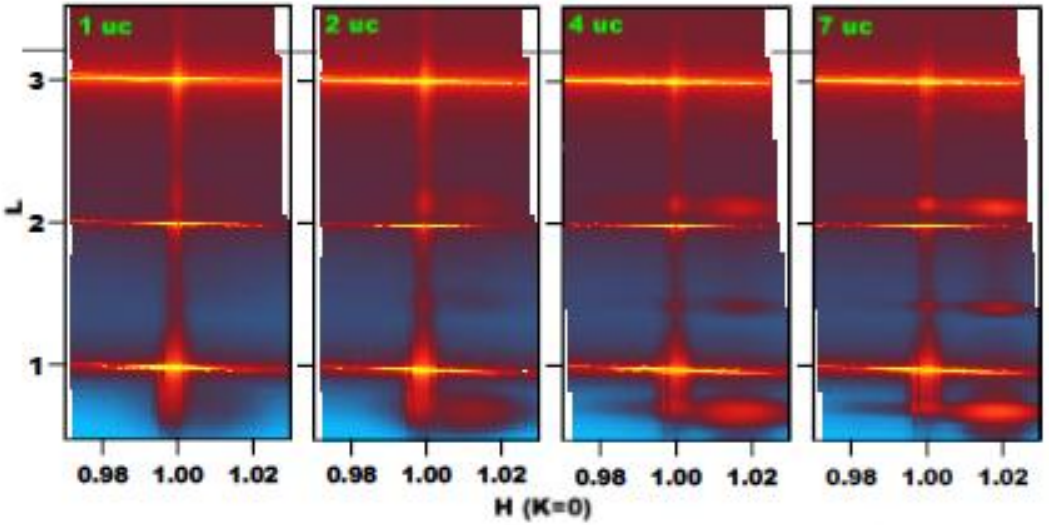

S. May et al., (2012)
X. F. Zhai, Y. Liu, S. Dong, et al. (2014)

# Science Case 4: Interfacial Structure and Multi-interactions coupling at $FeSe/SrTiO_3$ interface

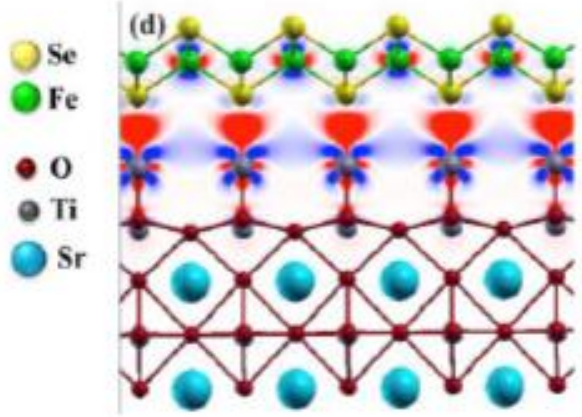



1st→2nd ML: Sudden in-plane structure change




**Key:** **in-situ interfacial structure information**




Q. K. Xue et al., (2012); C. Ahn et al., (2016); Y. Liu, H. Zhou (unpublished)

# $^{12}C(\alpha,\gamma)^{16}O$圣杯反应

圣杯(Hoyle grail)

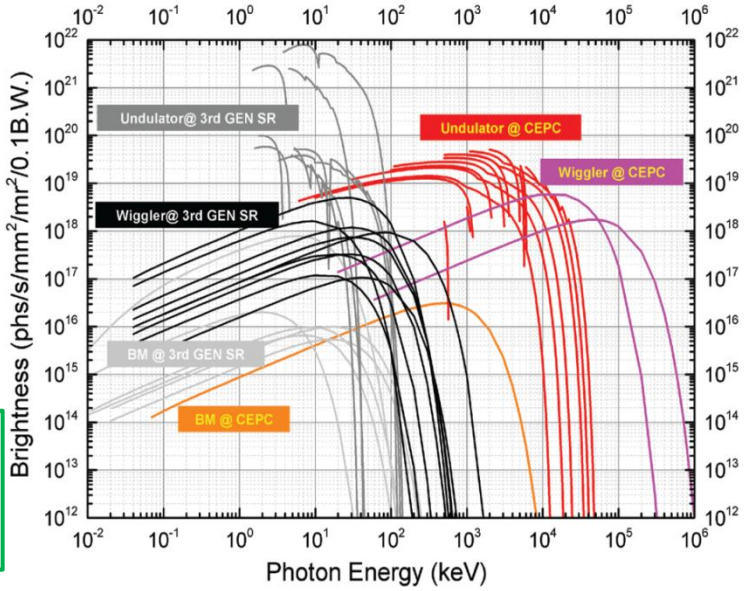
光核反应阈值

伽马辅助嬗变

巨共振、核共振荧光

$\gamma$+ N → ?

100 MeV γ, λ ≈ 12.4 fm




工业、重材料探伤考古等

第1瓶

$^{17}O(n,\gamma)^{18}O$


s-process


s-process

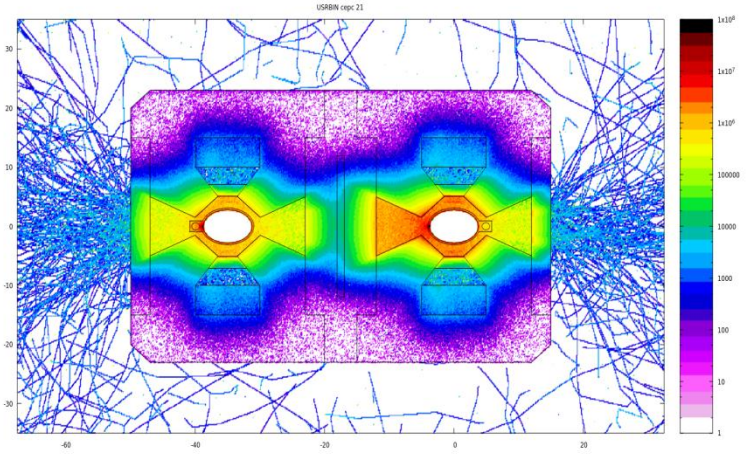
第2瓶

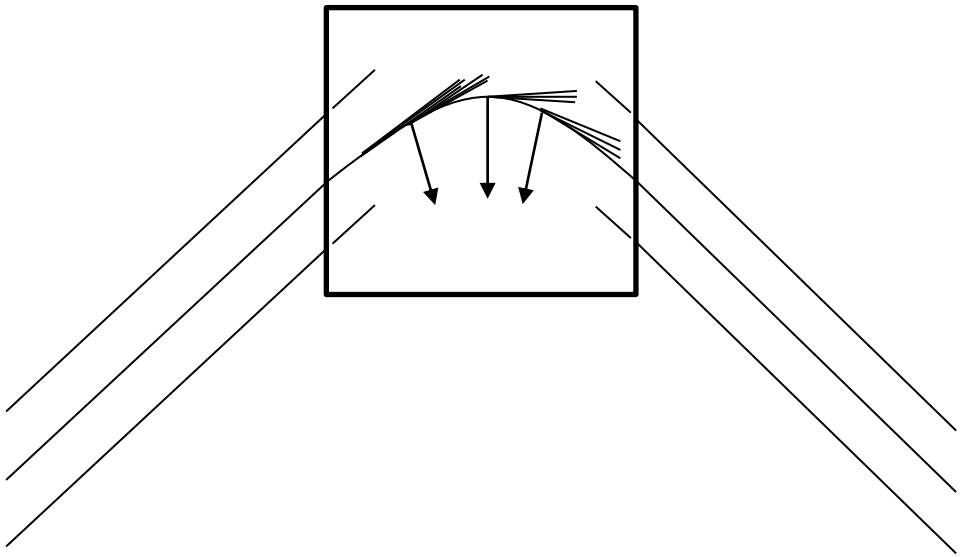
$^{13}C(n,\gamma)^{14}C$

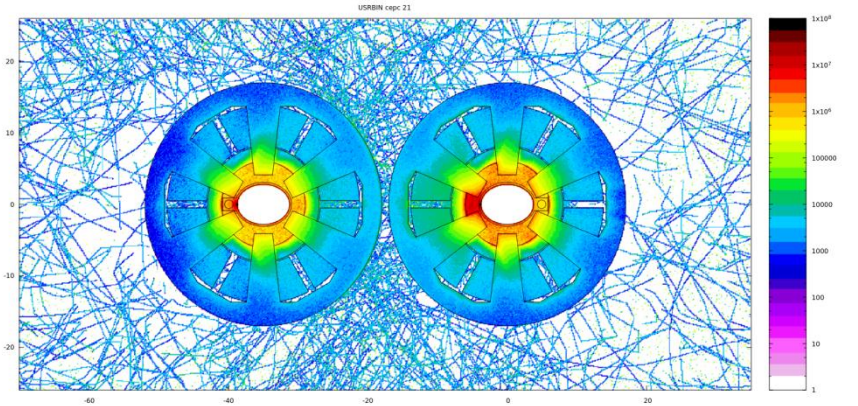
***a "mini" giant dipole resonance it is often called pygmy dipole resonance (PDR).***

# CEPC-SR：Applications—辐射屏蔽与防护，辐射光的引出

- 1、CEPC设计要求：器件老化与温度控制，辐照损伤等等
- 2、合理引出，二级铁末端？

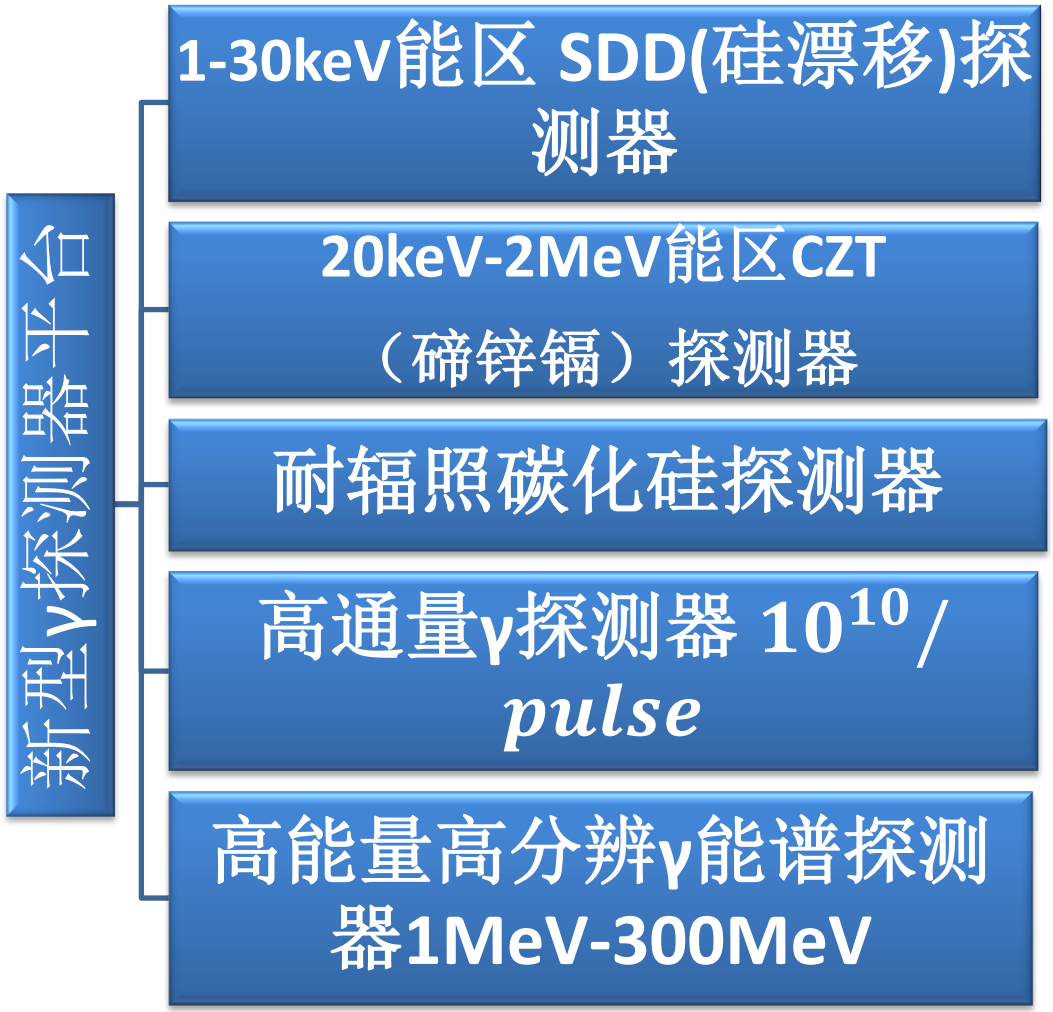




# CEPC-SR： Applications-Detection

## 1keV-300MeV宽能区覆盖

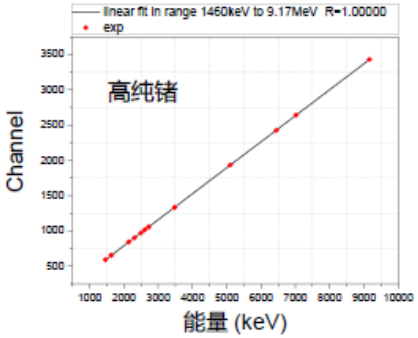


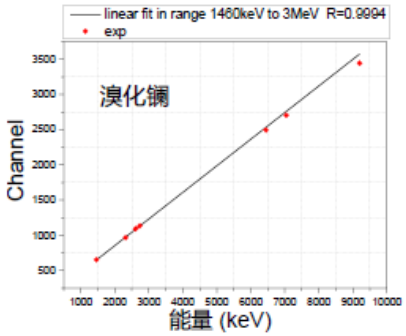

- 1-30keV，能量分辨率135eV@5.9keV,8路探测单元$10mm^2$ SDD探测器
- 20keV-2MeV，25路，5mm*5mm*2mm， CZT（碲锌镉）探测器
- 1Mrad辐照环境下：耐辐照SiC（碳化硅）探测器
- 高纯锗阵列+CsI晶体探测器阵列

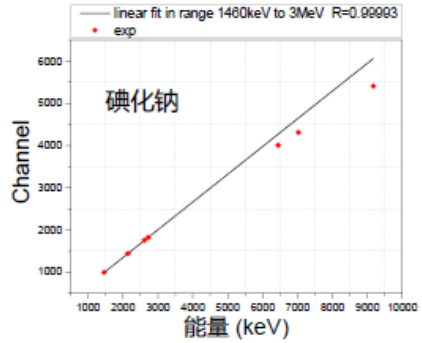
- **脉冲辐射探测器**
  - **闪烁探测器**
    闪烁体: 各种塑闪、BC422Q、LSO、PWO、$CeF_3$、$BaF_2$、$LaBr_3$、YAG）
    光电器件: PMT、MCP-PMT、APD、光电管、CCD相机、条纹相机
  - **康普顿探测器** **发展了5代康普顿探测器**
    真空康普顿探测器（VCD）、介质康普顿探测器（DCD）
  - **电流型半导体探测器**
    Si-PIN、CVD金刚石、CZT、 SiC等
  - **切伦科夫探测器**
    切伦科夫辐射转换体+光电器件
  - **气体电离室**
    气体（$^3He$）+光电器件
  - **核反冲和裂变靶室**
    反冲质子靶室、裂变靶室

# LCS-γ射线探测器的能量及效率刻度研究

党永乐，
北京师范大学&原子能院



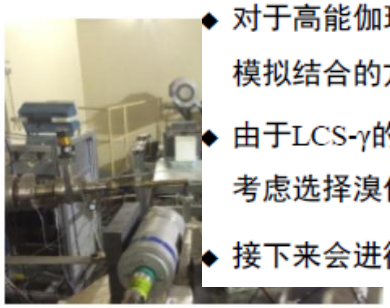




可以看出，在1.5-9MeV的能量范围内高纯锗探测器的能量刻度是非常线性的。溴化镧和碘化钠探测器在3MeV以下能量响应是线性的，在9MeV处溴化镧的非线性达到3.5%，而碘化钠则达到了11%。

- 加速器质子束：E=1.75 MeV， I=8μA，束流能
- 同位素$^{13}C$靶靶厚100μg/cm$^2$
- 探测器：φ55.5mm同轴型高纯锗、3″×3″溴化镧

5″×5″碘化钠探测器

| Detector | L/cm | θ/° | 几何效率 |
|---|---|---|---|
| 高纯锗 | 69 | 28 | 0.040% |
| 溴化镧 | 81 | 38 | 0.055% |
| 碘化钠 | 43.5 | 81 | 0.524% |



- $(p,\gamma)$反应产生的伽玛射线具有确定分立的能量，所以可以根据需要选择合适的反应对探测器进行刻度(20MeV以下)。
- 而溴化镧和碘化钠探测器在3MeV以下的能量响应是线性的，而高纯锗探测器在10MeV左右的能量响应仍具有非常好的线性。
- 对于高能伽玛射线的探测效率刻度，可以采用低能段放射源与高能段GEANT4模拟结合的方法。
- 由于LCS-γ的准单能性，对探测器能量分辨要求并不高，在10MeV以上的测量考虑选择溴化镧探测器。
- 接下来会进行 $^7Li(p,\gamma)\,^8Be$，对14.8MeV、17.6MeV的伽玛射线进行刻度。

$$E'_\gamma = \left(E_0 - \frac{E_0^2}{2Mc^2}\right)\left(1 + \frac{v_0 cos\theta}{c}\right)$$

$$v_0 = \frac{\sqrt{2E_p m}}{M}$$

# LCSγ@IHEP from 2014

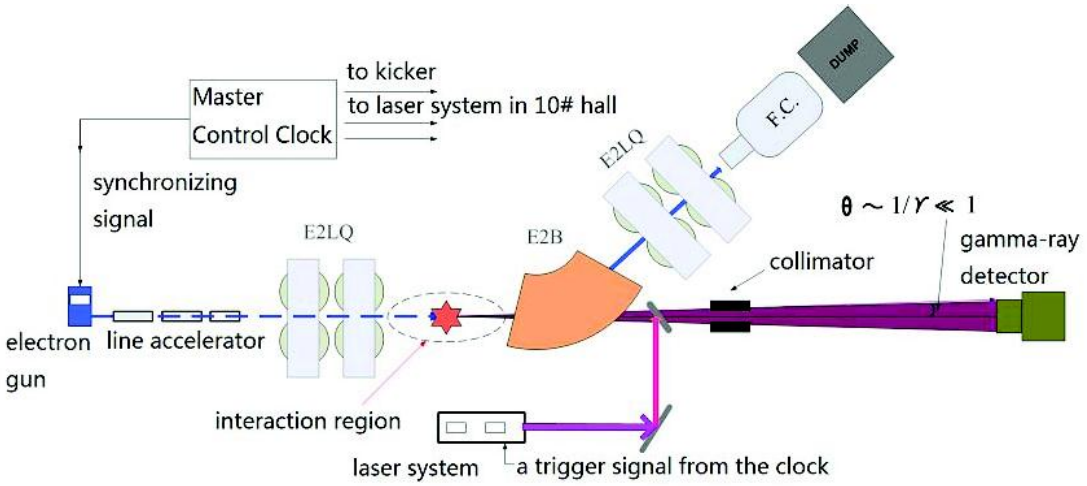
Table 1: Parameters of electron beams and laser pulses.

| electron beamsat E2 line | | the Nd:YAG laser system | |
|---|---|---|---|
| energy(GeV) | 0.2-2.5 | $\lambda$(nm) | 1064 |
| duration(ps) | 10 | duration(ns) | 8-10 |
| charge(nC) | 1-2 | $E_l$(J) | 2 |
| $\sigma_{x,y}$(mm) | 1.2 | $\omega_0$(mm) | 2.4 |
| $\epsilon_{x,y}$(mm·mrad) | 338(370) | | |
| frequency(Hz) | 12.5 | frequency(Hz) | 12.5 |

Table 3: Parameters of two laser systems in the stage II.

| | the Nd:YAG laser system | the $CO_2$ laser system |
|---|---|---|
| energy(J) | 0.5 | 1 |
| duration(ps) | 5-12 | 180 |
| $\lambda(\mu m)$ | 1.0 | 10.8 |
| frequency(Hz) | 12.5 | 12.5 |

$\gamma$产额: $10^8/pulse$ $10^9/pulse$




- 2018年可得到111MeVγ，$\frac{10^5}{pulse}$

# gg Collider

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- **Japan**
  **T. Takahashi, K. Yokoya, K. Homma**
- **Italy**
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- **France**
  **Amplitude Technology**
- **USA**
  **Chris Barty, Bob Byer, Almantas Galvanauskas, Russell Wilcox , Mayda Velasco**
- **Russia**
  **V. Telnov**

- You are welcome!

非常感谢各位专家领导的支持和关注！