Shanghai Laser Electron Gamma Source (SLEGS) and its Photonuclear Reaction Research

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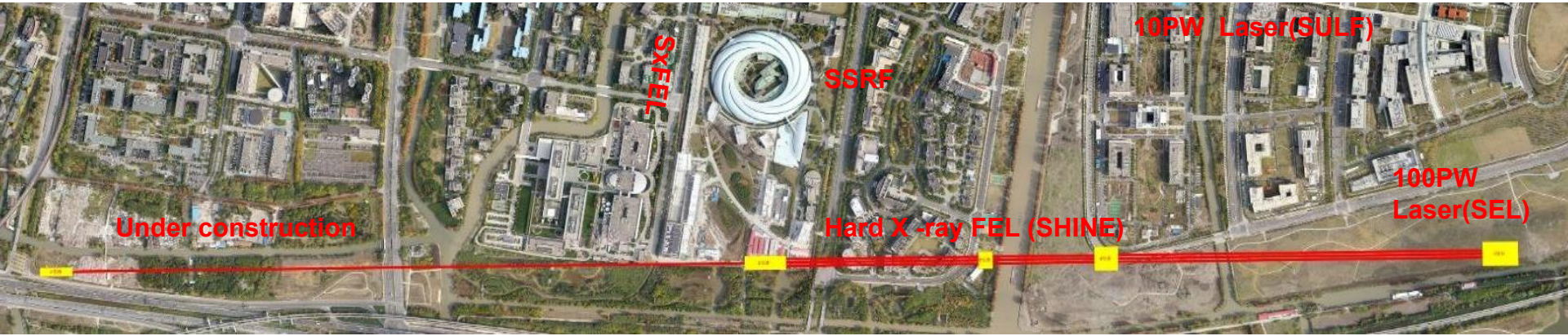
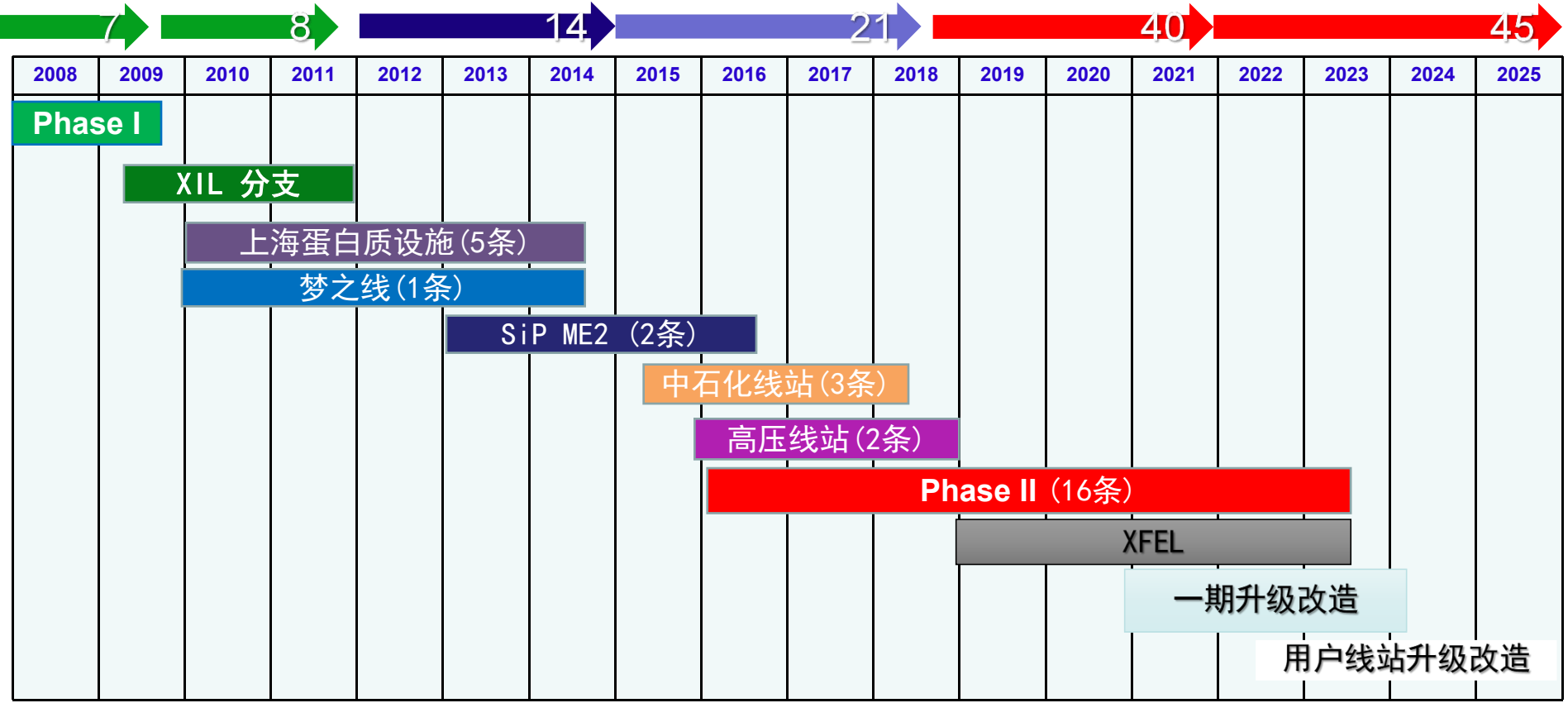
Outline

1. A brief introduction to SSRF

Energy	3.5 GeV
Beam Sizeσ_x	276.9 um
Beam Sizeσ_y	12.24 um
Pulse RMS	3 mm
Current	**300 mA**
Q_e	1.44 nC
Emittance$\varepsilon_x/\varepsilon_y$	2.59 / 2.59E-2 nmrad
Divergenceη_x/η_y	0.207 / 0 m
β_x/β_y	14.86 / 5.78 m
Energy spread	0.944E-3
Pulse Number	500

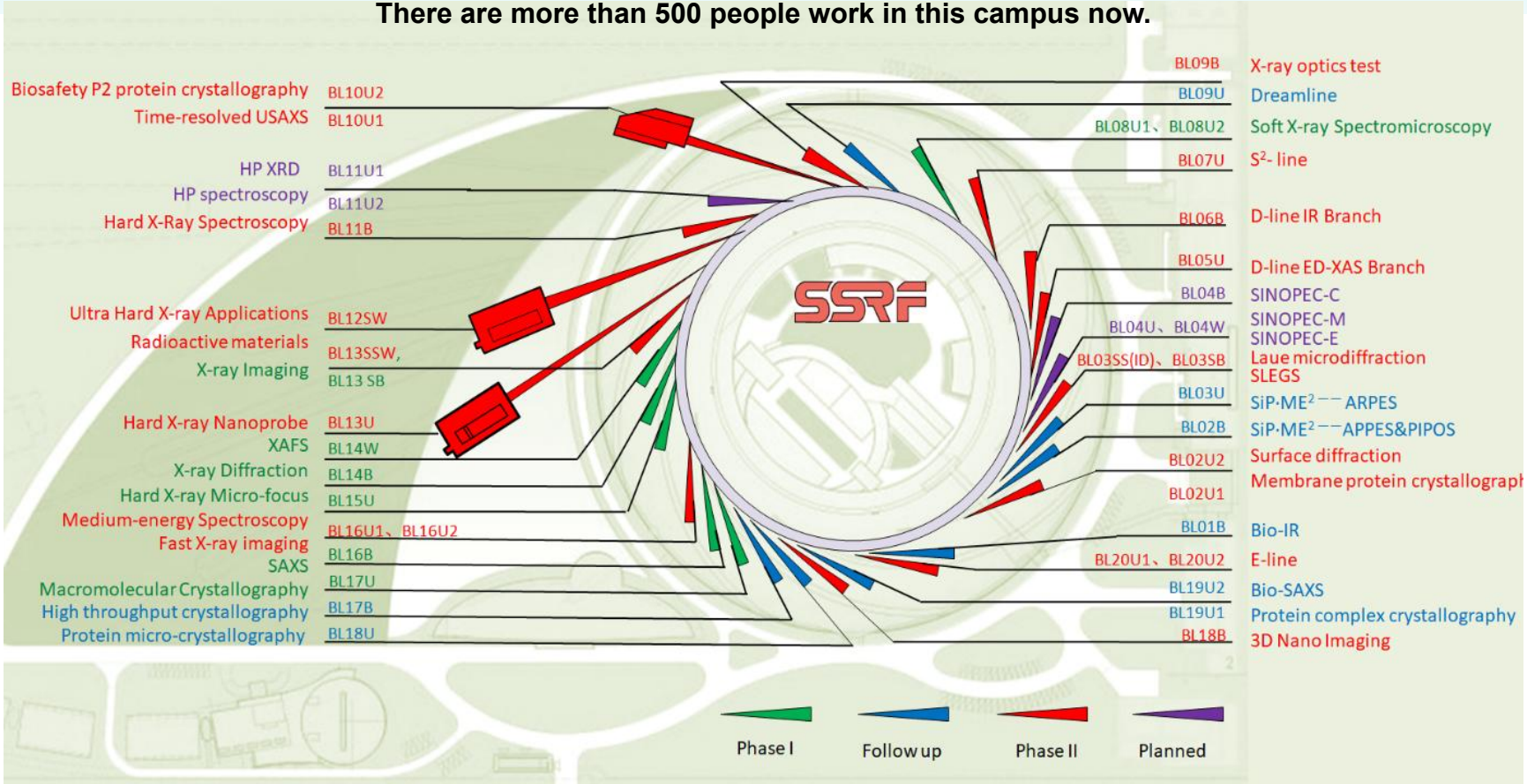


1. A brief introduction to SSRF



1. A brief introduction to SSRF

The funding for the phase I is about 1 billion Chinese yuan, and for phase II is about 1.7 billion Chinese yuan.
There are more than 500 people work in this campus now.



2. Shanghai Laser Electron Gamma Source

Design Properties

Design properties

- Energy range: 0.4-20 MeV
- Energy resolution : ~5% @ 2mm Collilator
- Divergence angle: 0.5mrad(milli-radian)
- Total Flux: 10^6 - 10^7 phs/s@180°/300mA/100W CO_2

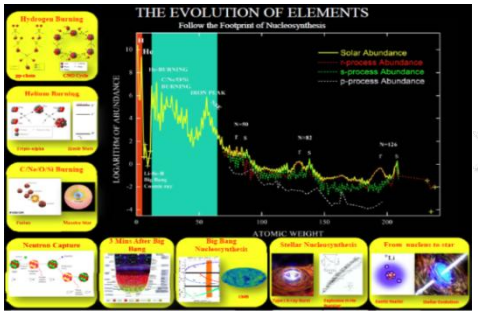
Final properties

- Energy range: 0.25-21.7 MeV (0.66-21.7MeV Compton Edge)
- Energy resolution : ~5% @ 2mm - 15%@5mm (Coarse Collilator)
- Divergence angle: < 0.45mrad(milli-radian)
- Total Flux: 2.1x10^6(20°) - 2.5x10^6(90°) - 1.0x10^7 phs/s(160°)
- & 1.2 x10^7 phs/s(180°) /300mA/100W CO_2
- ☞ Beam spot: 2mm - 25mm

2. Shanghai Laser Electron Gamma Source

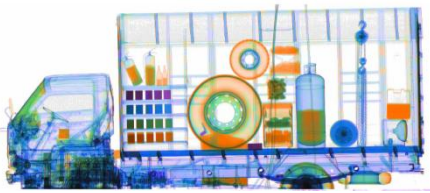
Scientific goals

- Photo-nuclear physics:
  - ✓ Nuclear Astrophysics： nuclear reactions which have a critical impact on stellar evolution and nucleosynthesis of elements
  - ✓ Nuclear structure GDR and NRF, etc.
- Research on the anti-γ radiation properties of aerospace device and calibration for the X/γ detector equipped on aerospace device
- Nuclear waste transmutation research and nuclear safety,
- Gamma-ray imaging techniques (in particular: isotope imaging technology), etc.

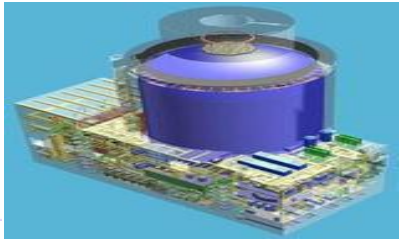


Space (radiation hardened)

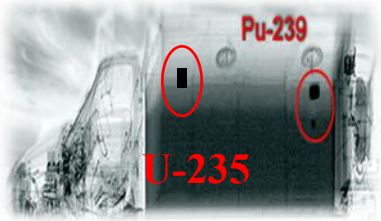
Nuclear technology and data



Gamma image



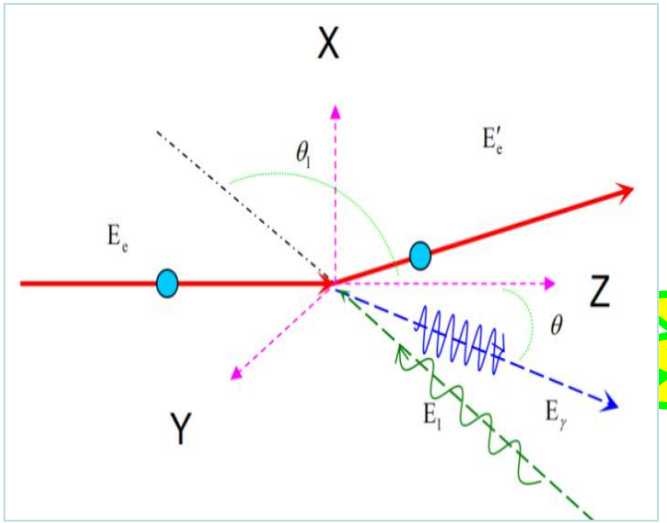
Nuclear reactor

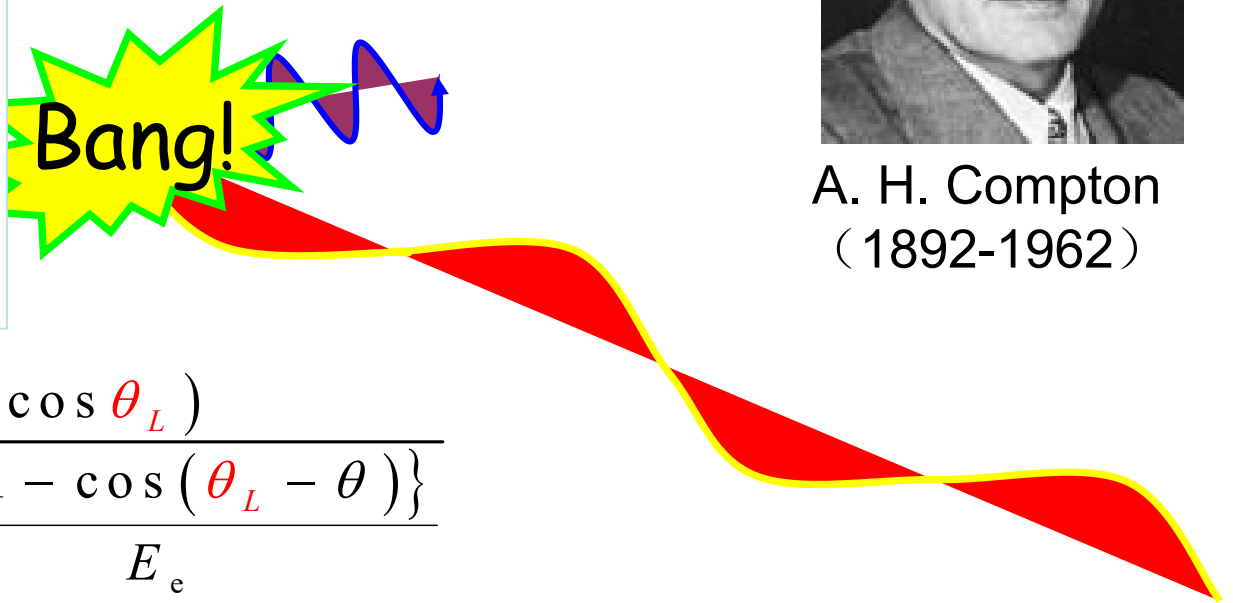


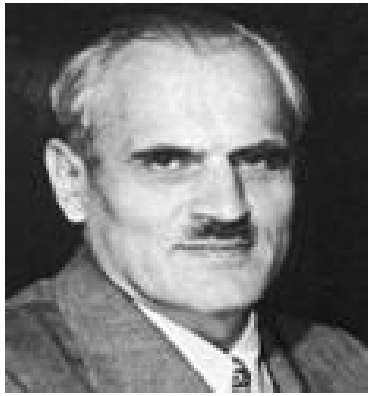
Isotope Detection

2. Shanghai Laser Electron Gamma Source

Construction Status





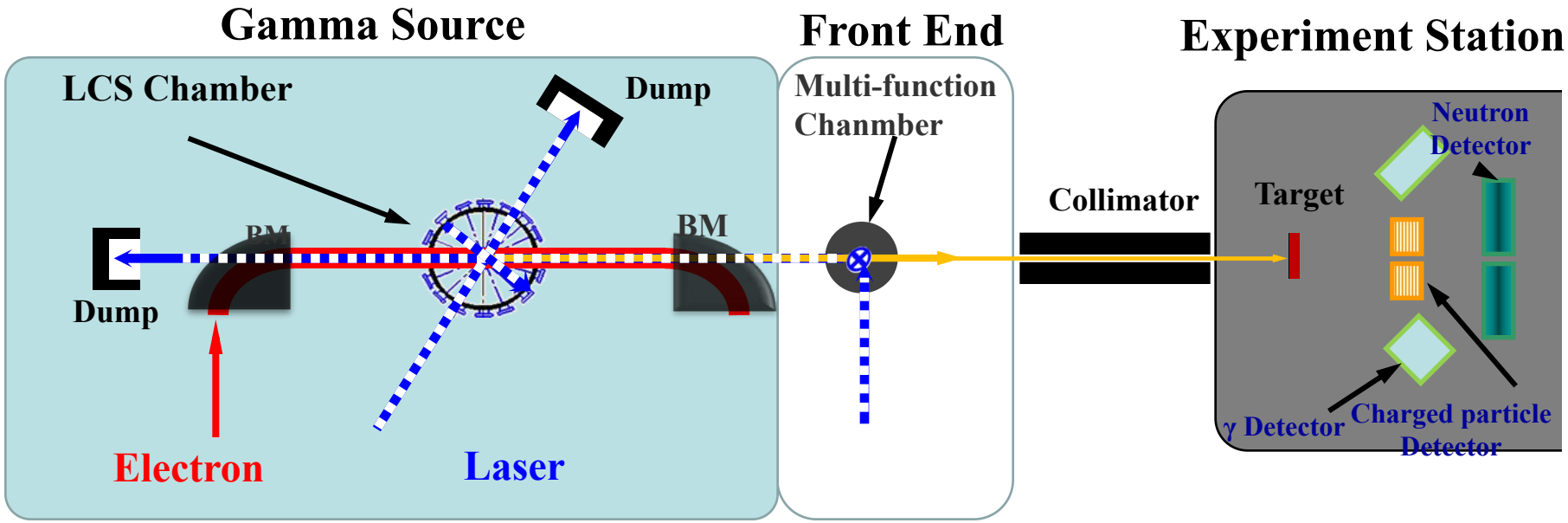


A. H. Compton
（1892-1962）

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

2. Shanghai Laser Electron Gamma Source

Status - Operating mode



LCS Mode 1
Slanting Scattering

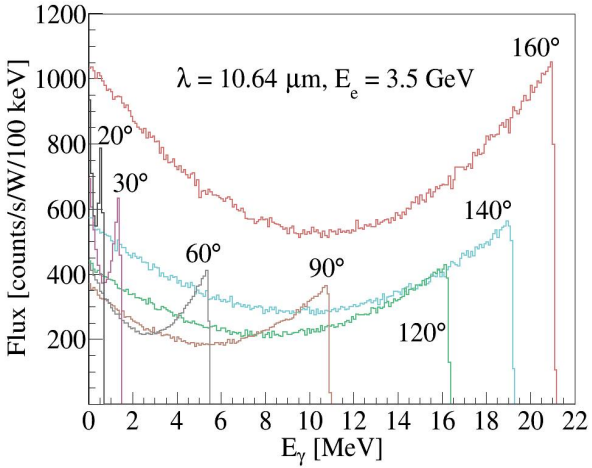
LCS Mode 2
Backward Scattering

Alternative mode
Slanting Scattering

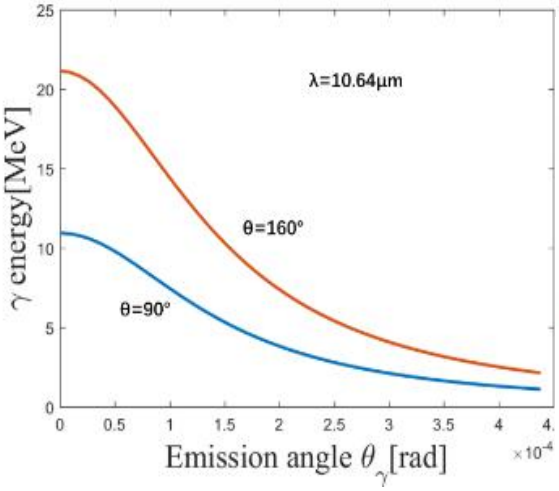
Reset

2. Shanghai Laser Electron Gamma Source

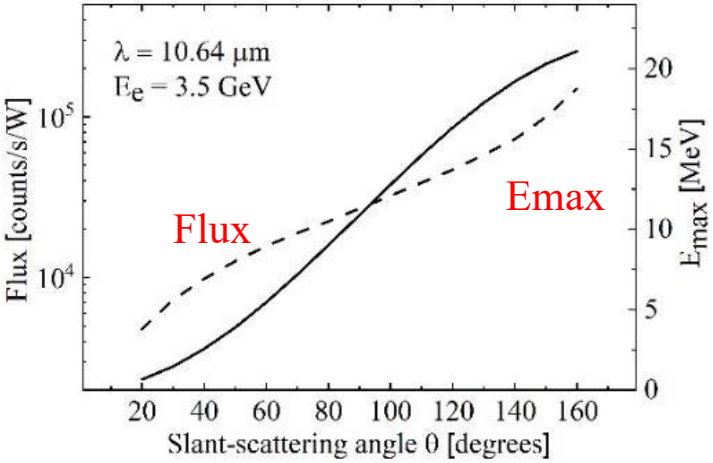
Energy



Angle



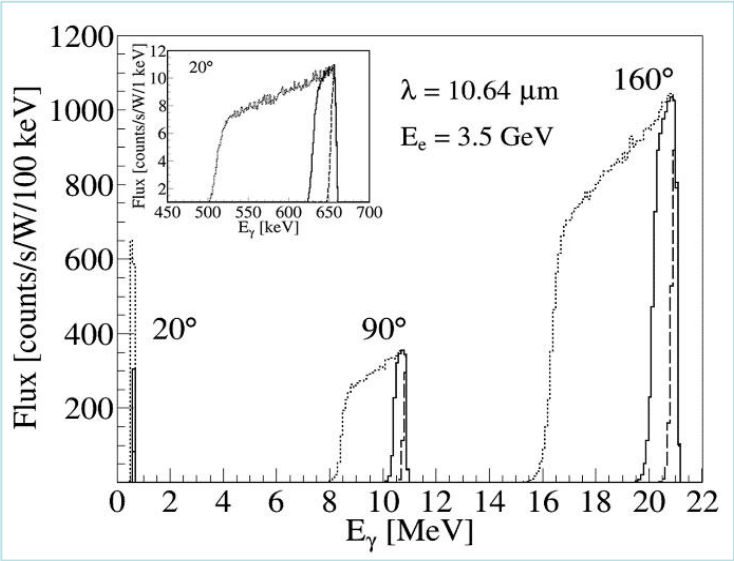
Flux & Emax

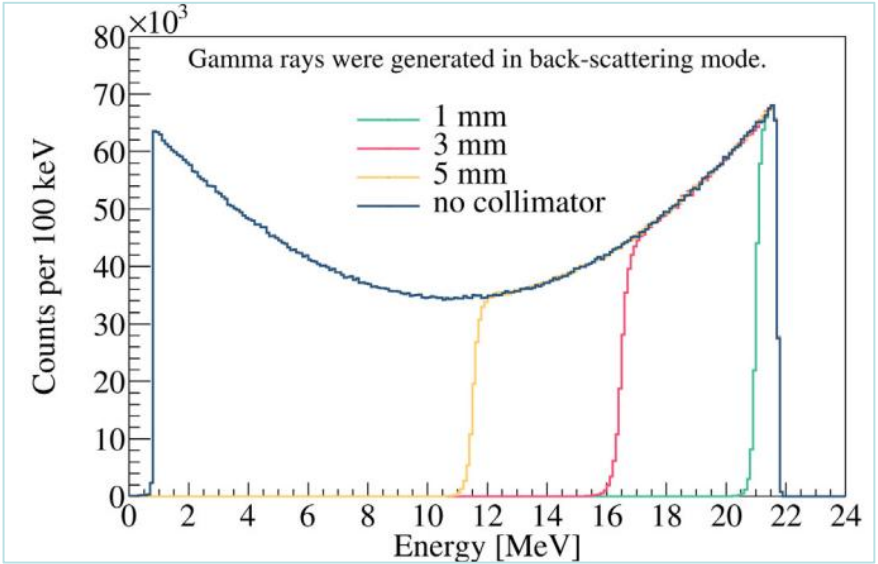


- The energy distribution is saddle shaped, with different angles corresponding to different maximum energies.
- The angle distribution is axially shaped, and near the axis, the higher energy.
- The flux and maximum energy increase with increasing angle.

2. Shanghai Laser Electron Gamma Source

Collimator selection(G4 Simulation)

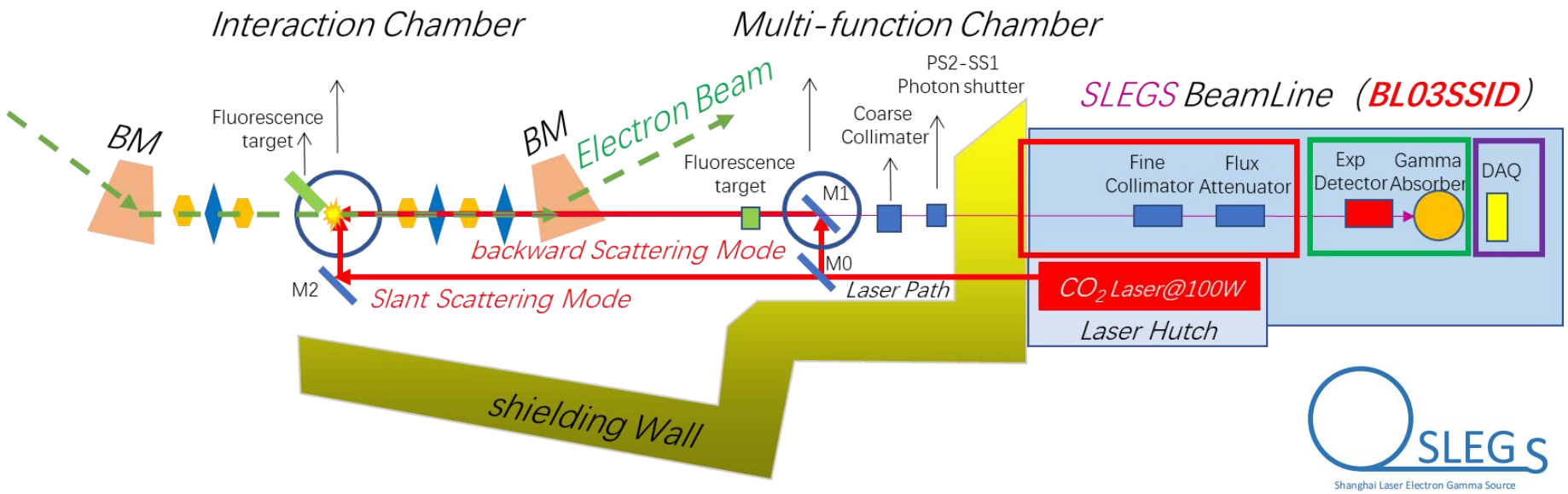




The relationship between the bandwidth and flux for representative apertures of 1, 3, and 5 mm as well as for no collimation. As the aperture decreases, the beam bandwidth (energy spread) of the gamma-ray beam drastically changes, reaching 3.29%(FWHM) at the 1 mm aperture.

2. Shanghai Laser Electron Gamma Source

Status - Layout



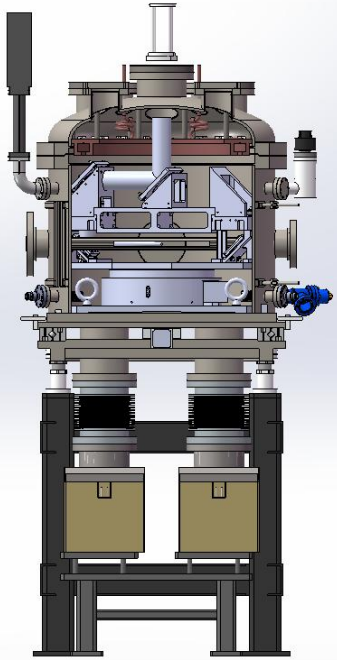
(1) Gamma source: electron, laser, LCS chamber(slanting mode), multi-function chamber(back scattering).

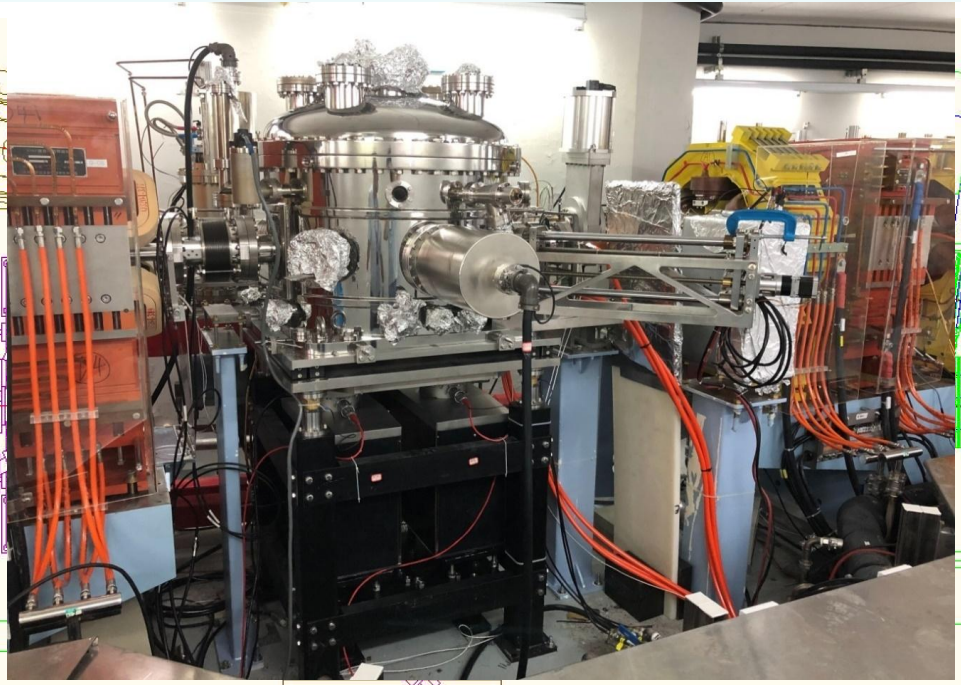
(2) Beamline: Collimators, attenuator, energy/position/ flux monitor and absorber.

(3) EXP station: (γ,n) Neutron detector, (γ,p/α) Charged particle detector, (γ,γ) Gamma detector

2. Shanghai Laser Electron Gamma Source

Status - Gamma source





Consists of Rotating optical system, Vacuum system, Shielding finger, and Fluorescent target.

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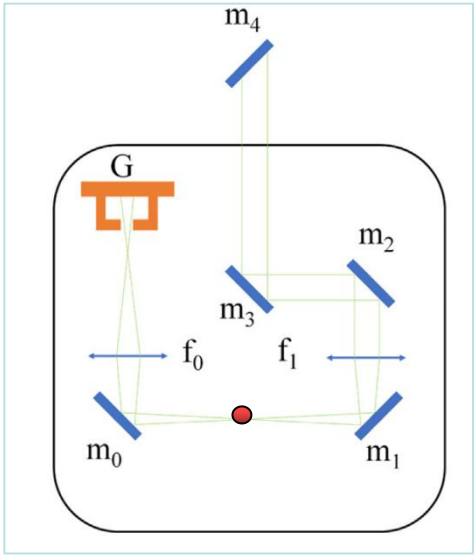
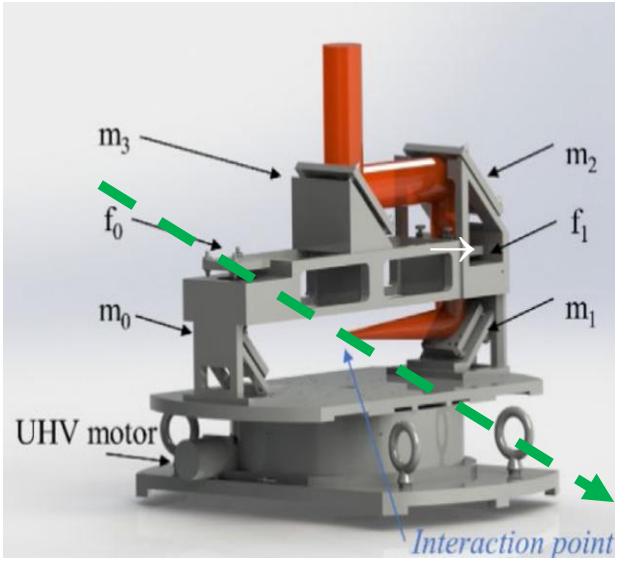
2. Shanghai Laser Electron Gamma Source

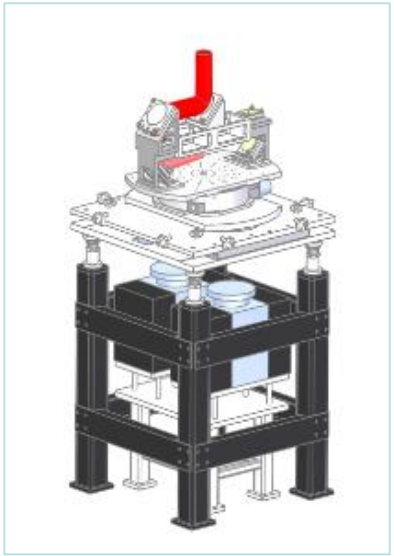
Status - Gamma source

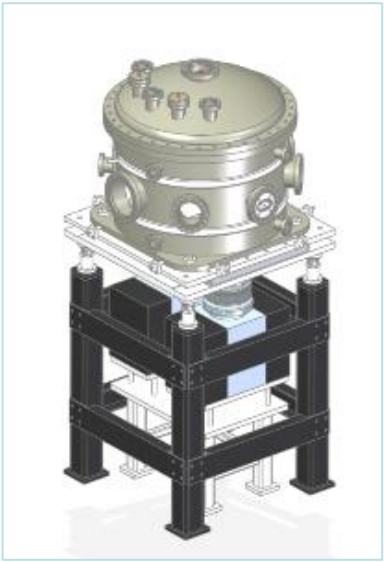
angular range of 20–160°

Φ716 mm x 760 mm height.







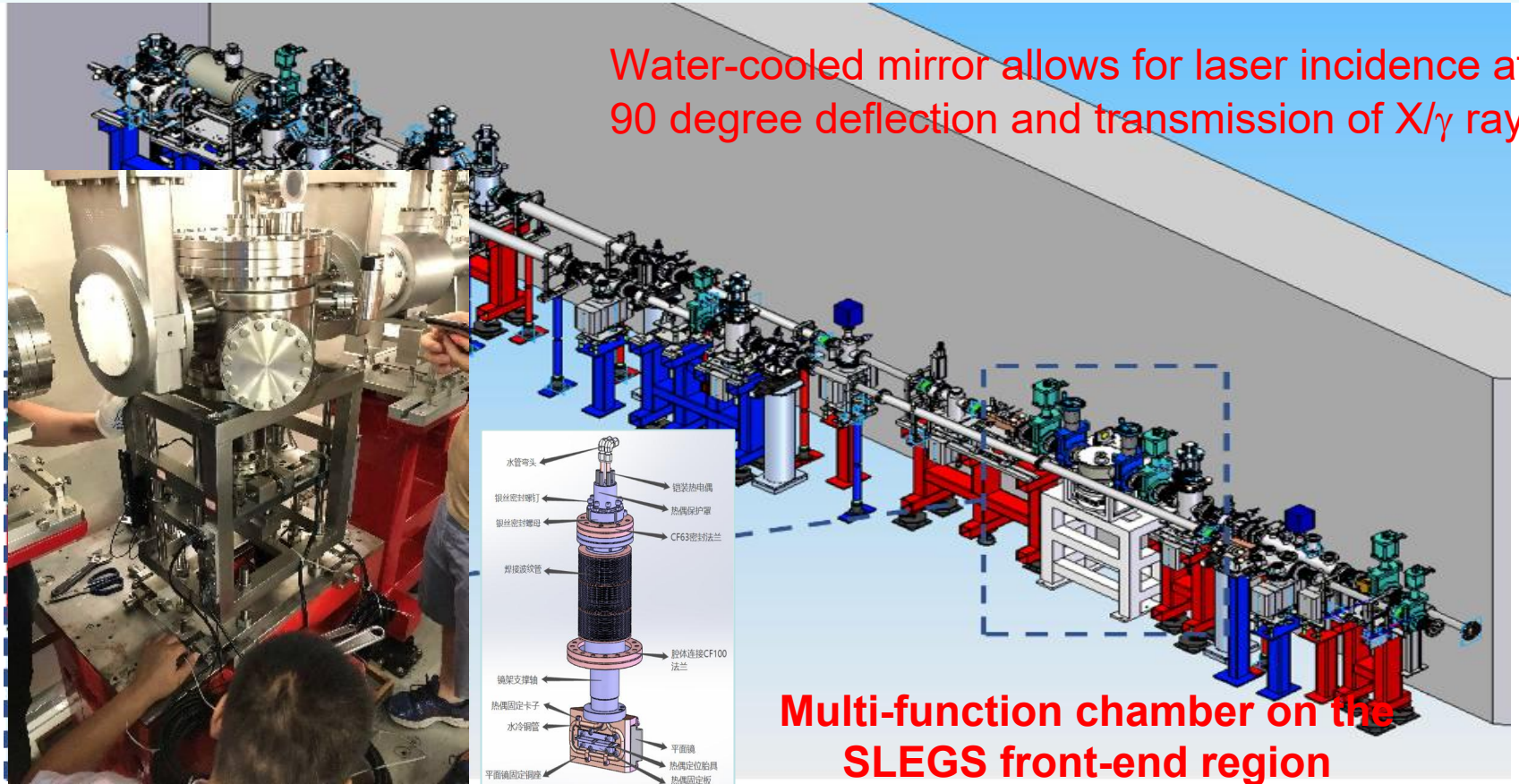


Configuration of optical elements and rotating optical system, Interaction Chamber

A laser vertically injected → along the rotation axis m4 into the interaction chamber, guided through m3, m2, f1, and m1, and horizontally led to the interaction region with the electron beam

2. Shanghai Laser Electron Gamma Source

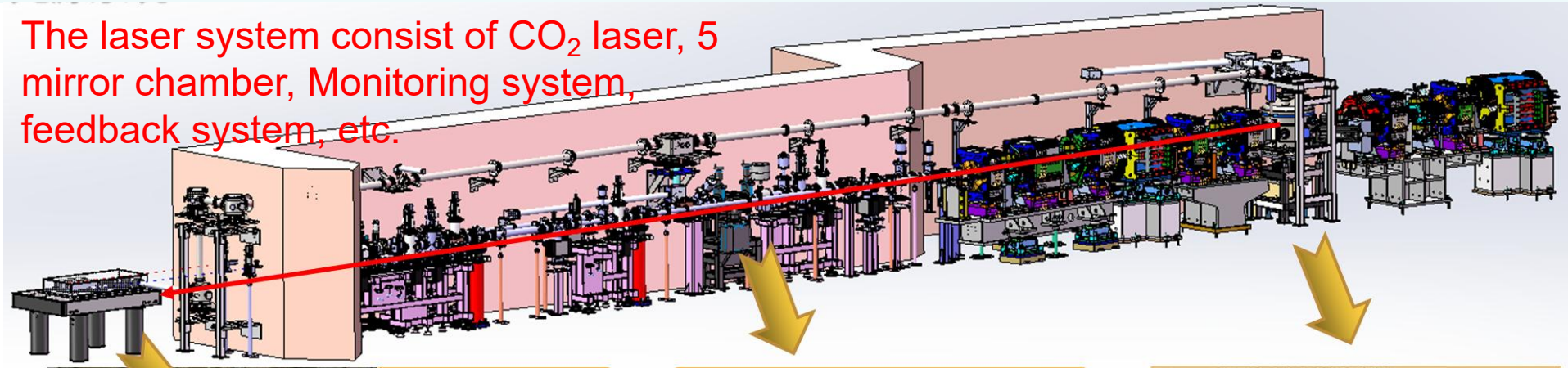
Status - Gamma source

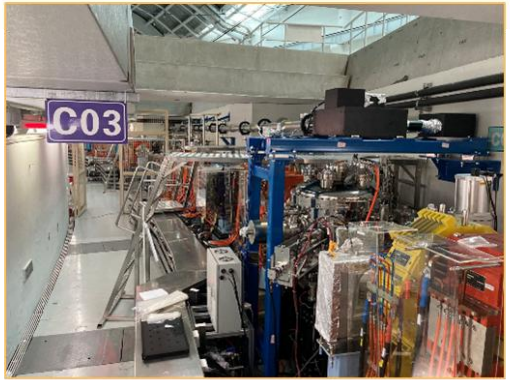


2. Shanghai Laser Electron Gamma Source

Status - Gamma source

The laser system consist of CO_2 laser, 5 mirror chamber, Monitoring system, feedback system, etc.





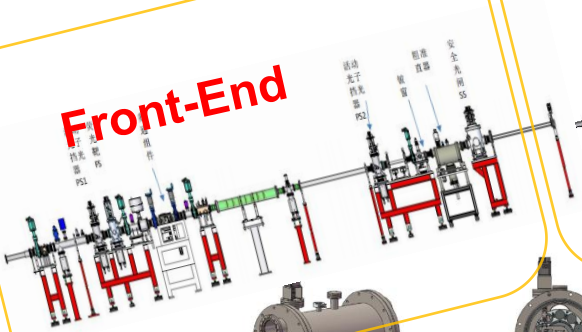
Proceeding of IPAC2021

2. Shanghai Laser Electron Gamma Source

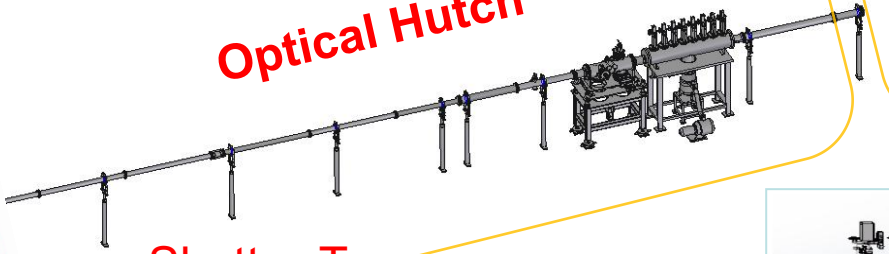
Status - Beam line

Outsaid shielding wall, and the main equipments are Coasre/Fine Collimators, attenuator etc

Front-End

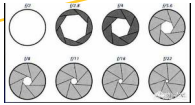


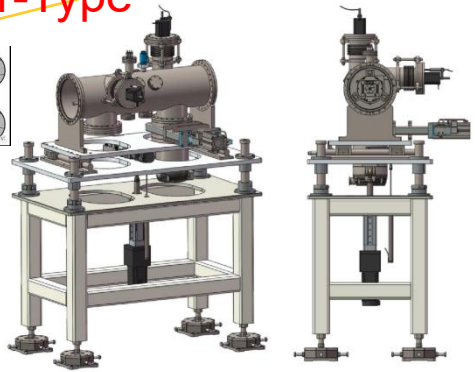
Optical Hutch

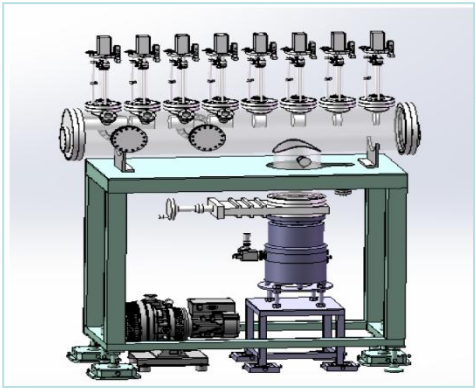


EXP Hutch

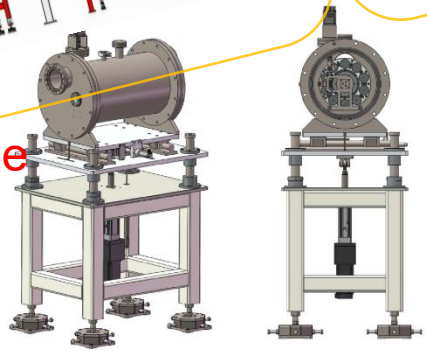
Shutter-Type







Runer-Type



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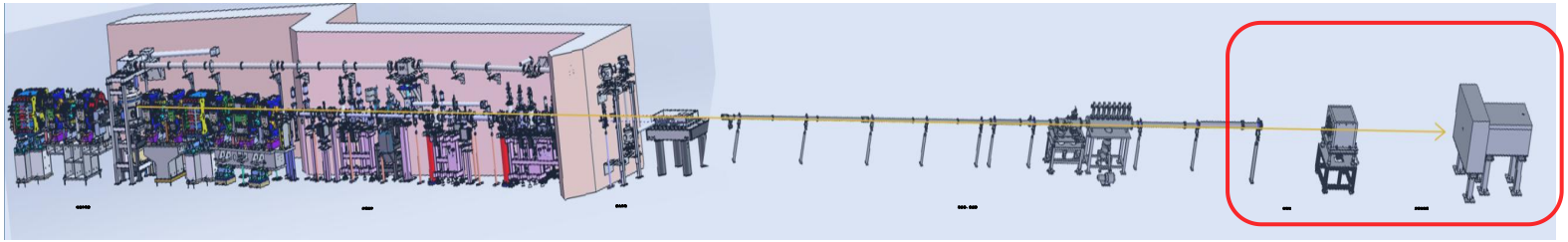
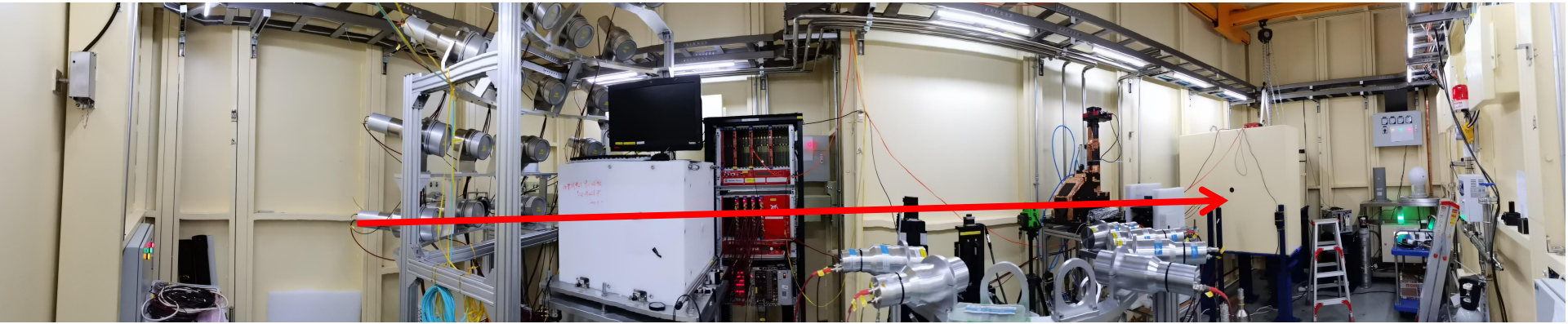
2. Shanghai Laser Electron Gamma Source

Status - EXP station

Behind the optical hutch



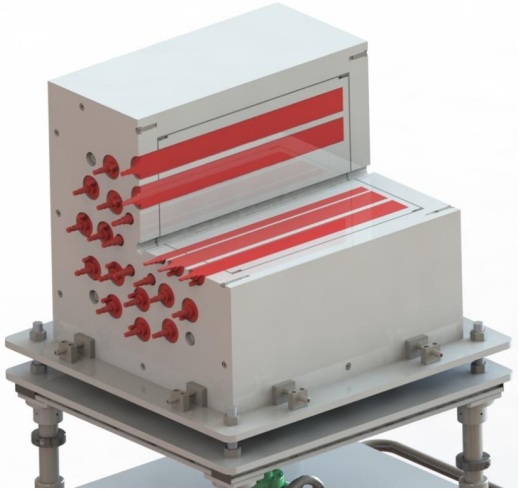
Space Limited By SSRF Building



(γ,n) Neutron detector， (γ,p/α)Charged particle detector，(γ,γ)Gamma detector

2. Shanghai Laser Electron Gamma Source

Status - EXP station: ^{3}He 4π FED neutron detector



Detail parameters of the ^{3}He propotional Counter.

Name	^{3}He	Distance to center [mm]	Diameter [mm]	Effect length [mm]	Gas presure [atm]
Ring-1	6	65	25.4	500	2
Ring-2	8	110	50.8	500	2
Ring-3	12	175	50.8	500	2

2. Shanghai Laser Electron Gamma Source

Status - EXP station: ^{3}He 4π neutron detector

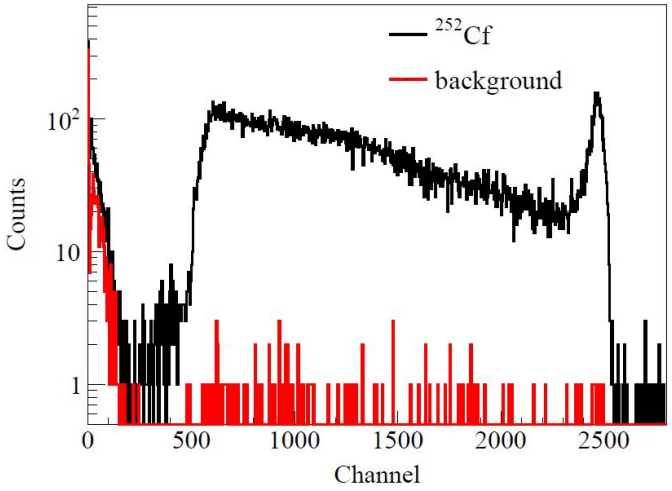
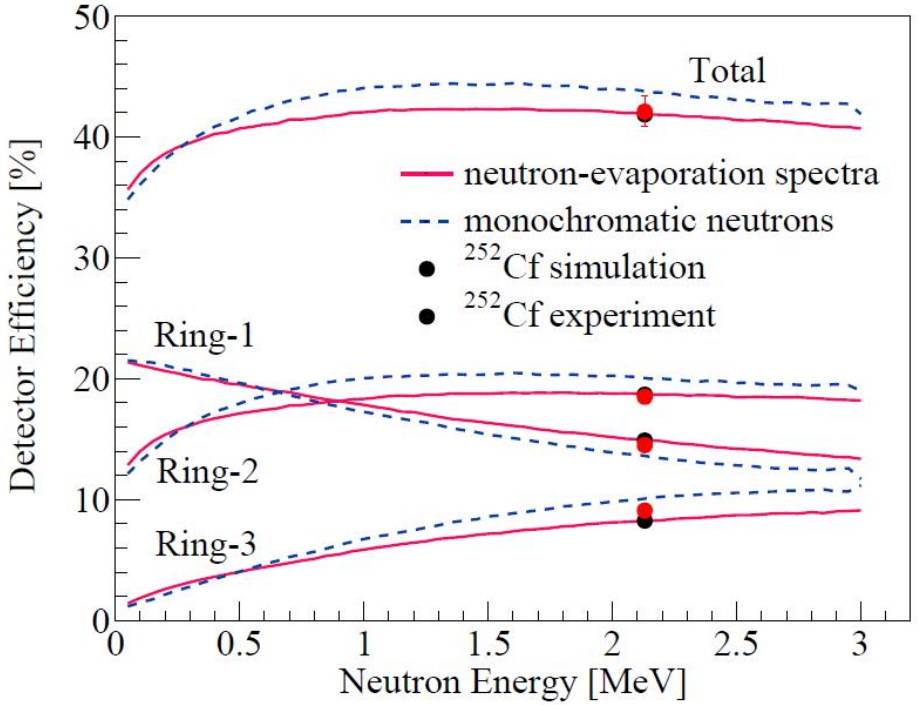


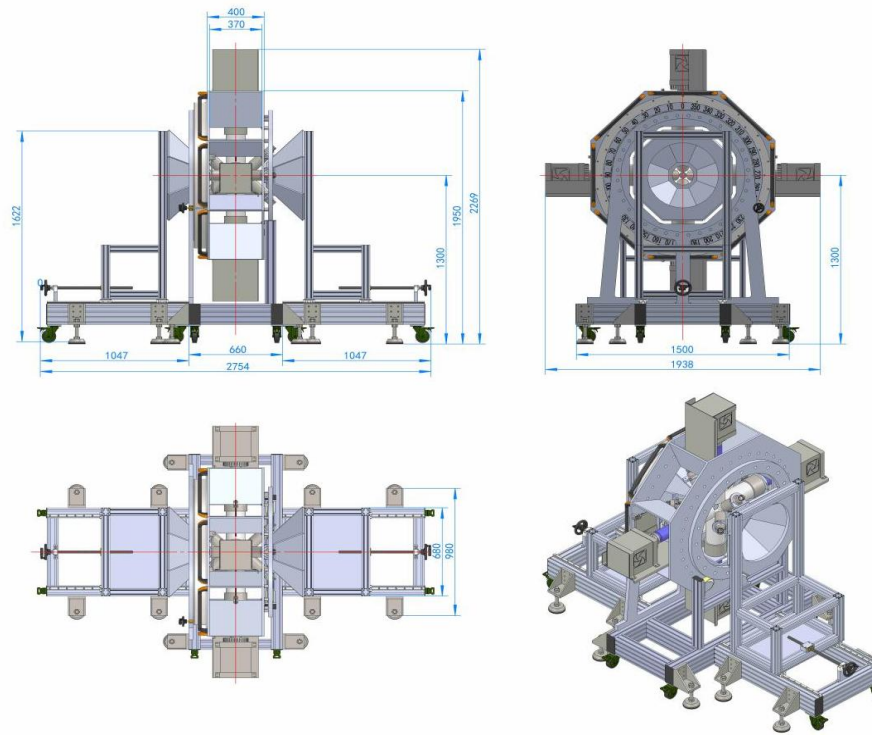
Table 1
Adjustment of the setting parameters and the resultant detector efficiencies.

Settings	Offset	Efficiency
Threshold	+10	42.16%
Pz	+1 μs	42.13%
Pz	-1 μs	42.11%
Shaping time	- 11 μs	42.11%
Gain	× 2	41.94%



2. Shanghai Laser Electron Gamma Source

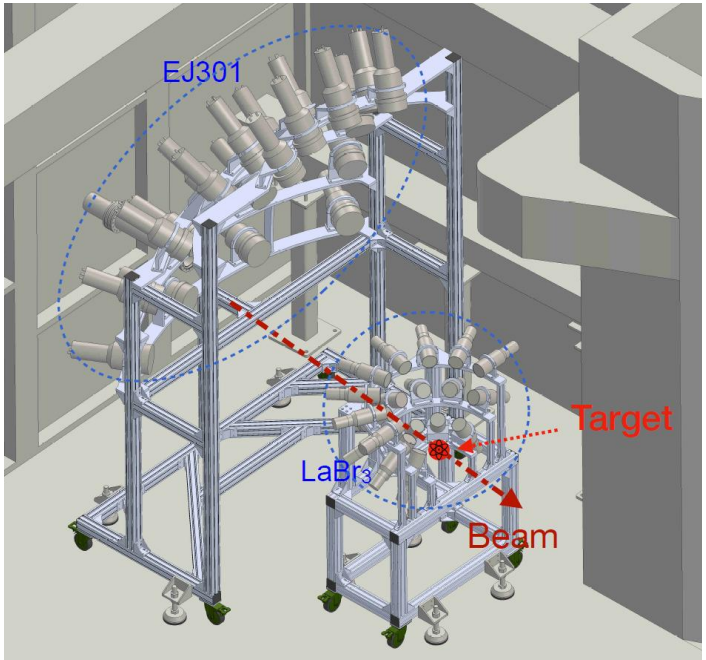
Status - EXP station: HPGe and $LaBr_3$



Consisted of 4 High-purity Germanium detectors and 8 Bromine:Lanthanum detectors.

2. Shanghai Laser Electron Gamma Source

Status - EXP station: TOF



Consisted of 20 EJ301 neutron detectors and 8 Bromine:Lanthanum detectors

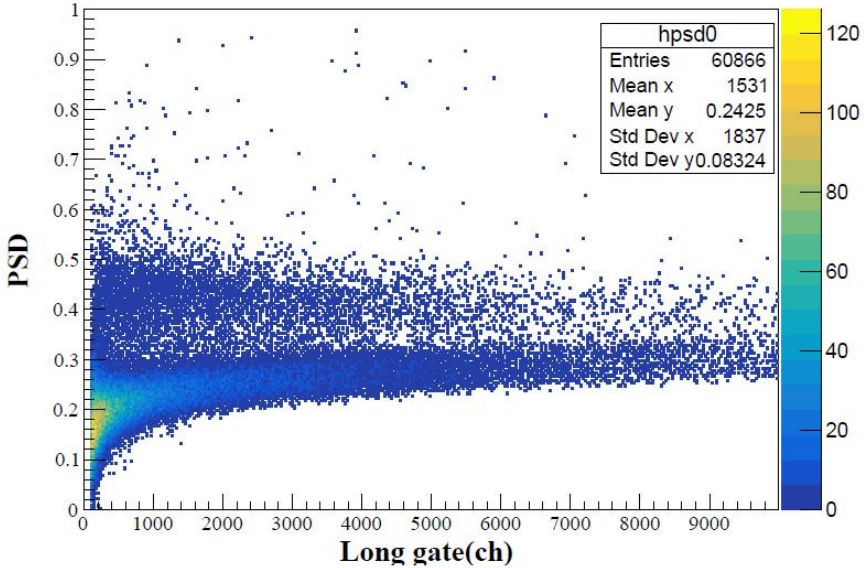


TABLE 1. The related parameters of the SLEGS TOF spectrometer.

Detector	Number	Material	Density	Distance	Diameter	Thickness
$LaBr_3$	8-20	$LaBr_3$	$5.10\,g/cm^3$	30 cm	3 inches	4 inches
EJ301	20	xylene	$0.86\,g/cm^3$	150 cm	5 inches	2 inches

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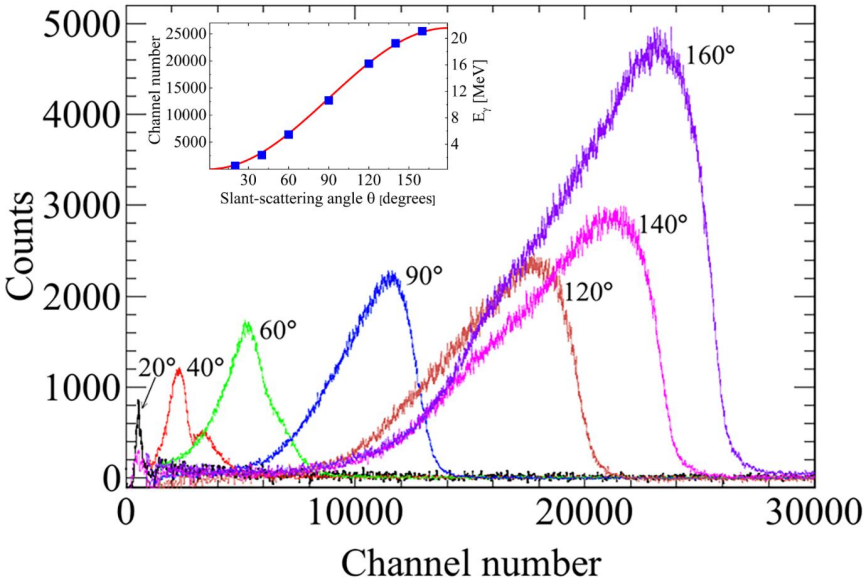
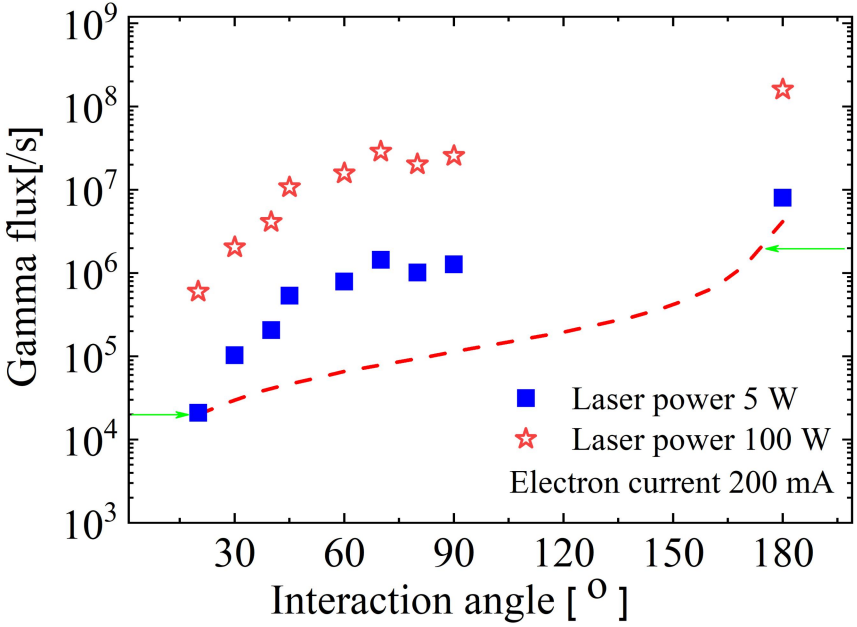
2. Shanghai Laser Electron Gamma Source

Gamma properties – Gamma spectrum

Coarse Collimatore Φ3mm



Last year, 2022,Commissioning

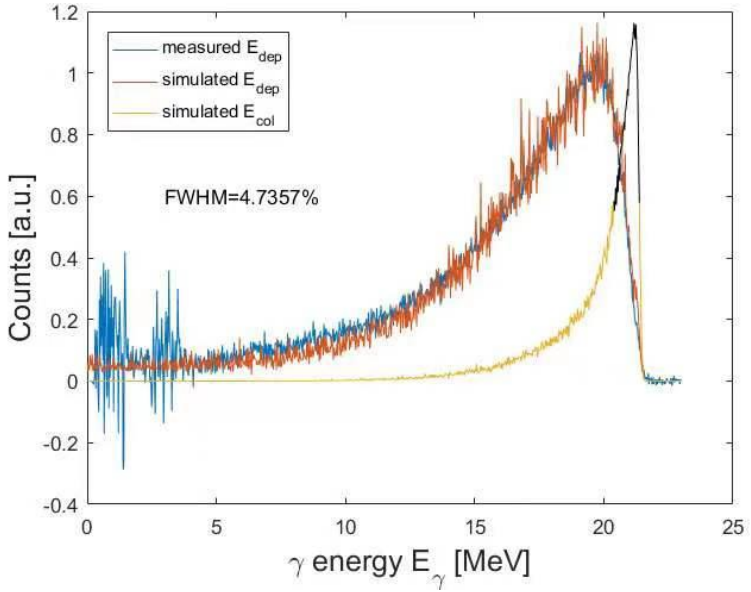


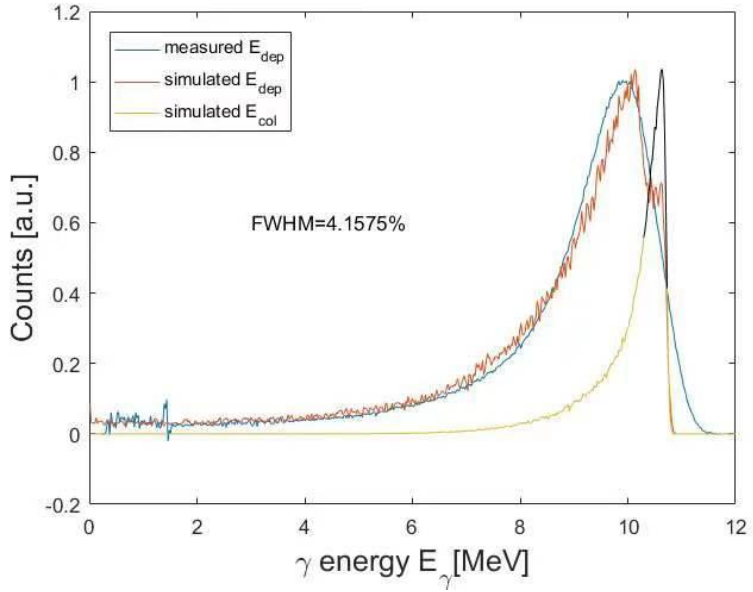
Typical SLEGS γ spectra and flux at different sacattering angles recorded with the LaBr and BGO detector

2. Shanghai Laser Electron Gamma Source

Gamma properties – spectrum

Coarse Collimatore Φ3mm and Fine Collimator Φ1 mm/Φ2 mm



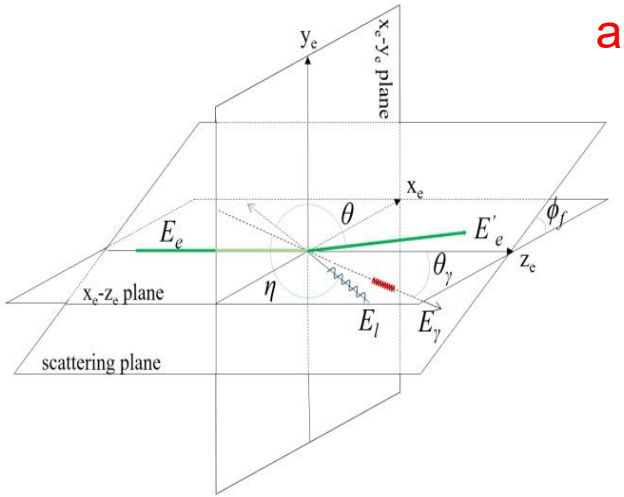


The $LaBr_3$ experimental response functions are well reproduced by the GEANT4 simulations. Energy spreads of 5% in the full width at half maximum (FWHM) were obtained respectively.

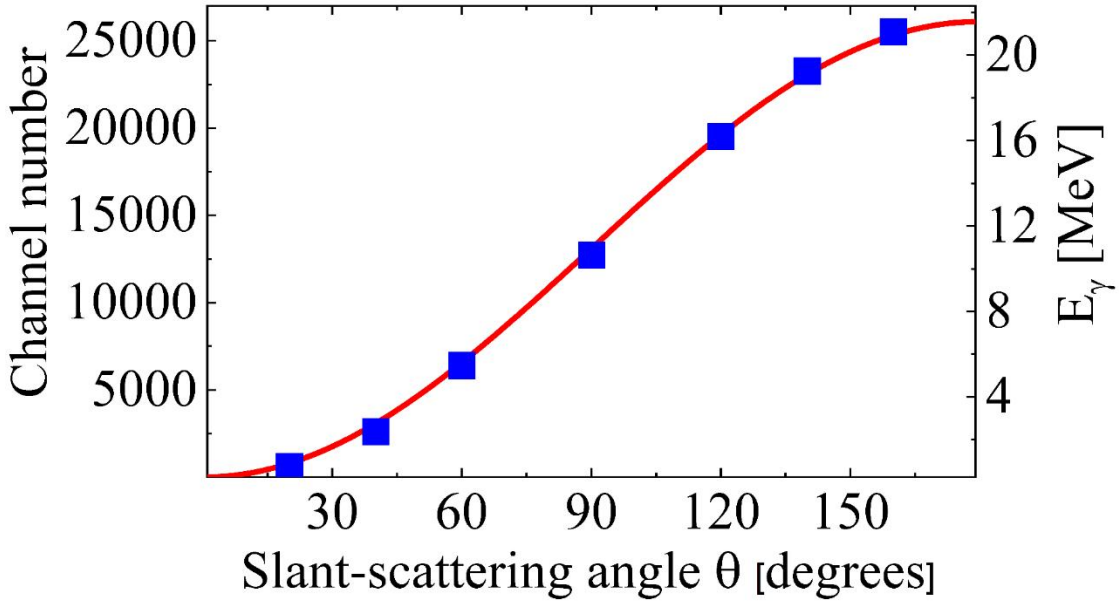
2. Shanghai Laser Electron Gamma Source

Gamma properties – energy & scattering angle

Angles from 20 to 160, energy tunable in slant-scattering, a best-fit curve.



$$E_\gamma = \frac{E_l(1-\beta cos\theta)}{\left(1-\beta cos\theta_\gamma\right)+\frac{E_l}{E_e}\left(1+cos\eta\right)}$$



Total flux from 4.8 × 10^5 to 1.5 × 10^7 photons/s @ 100 W CO_2 laser

2. Shanghai Laser Electron Gamma Source

Gamma properties – spots

The 3 mm coarse collimator aperature and the 2 mm fine collimator aperture

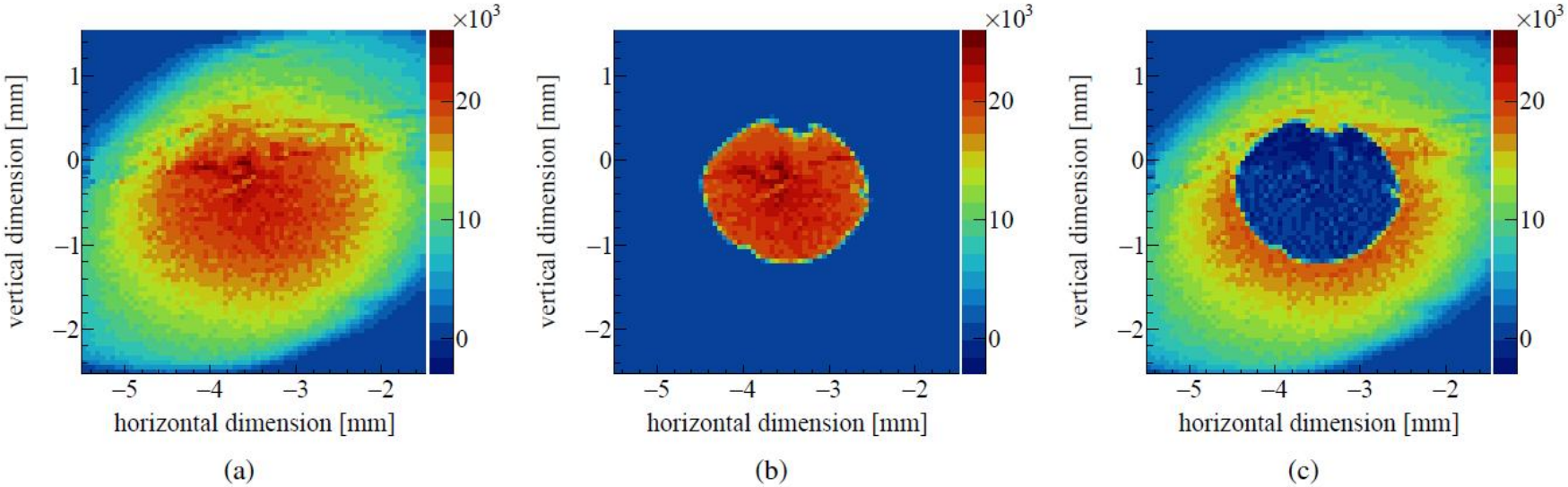
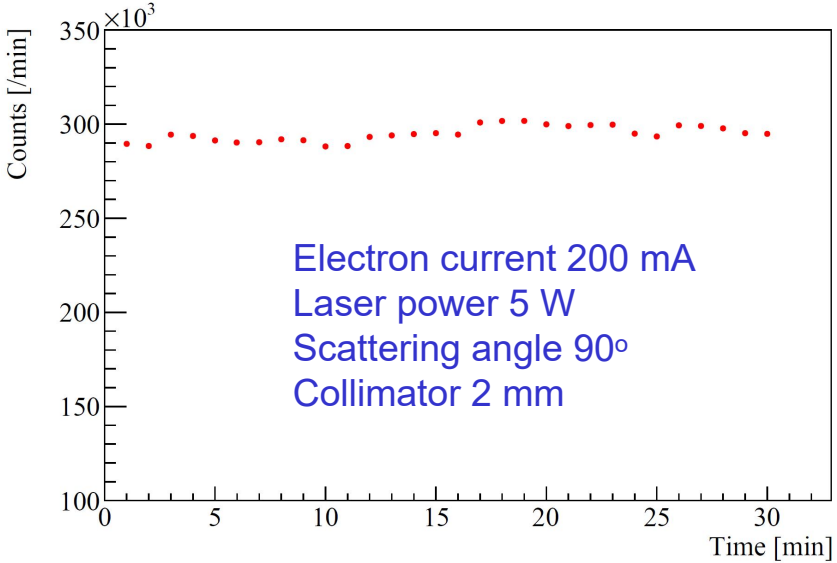


Figure 4: False color image of beam spot. (a) Beam spot with 3 mm coarse collimator. (b) Beam spot with 3 mm coarse collimator and 2 mm external collimator. (c) The substraction image of image (a) by image (b), showing the filtered beam by the external is the center part of the beam.

is sufficient in filtering the center of the beam.

2. Shanghai Laser Electron Gamma Source

Gamma properties – flux stability



- The Gamma Flux time fluctuation measured over 30 min time interval.
- Gamma-rays were generated at the slant-scattering angle 90° and the CO_2 laser power 5W in the top-up operation of the electron storage ring at 200 mA.
- The time fluctuation was less than 5 %.

3. Shanghai Laser Electron Gamma Source

Photoneutron Reaction(PR) Measurement

a new choice in addition to neutron beam, proton beam, electron beam and heavy ion beam.

① （γ，γ′） **reaction： NRF -** （HPGe 2 sets+ CLOVER 2set + $LaBr_3$ 8 Sets）

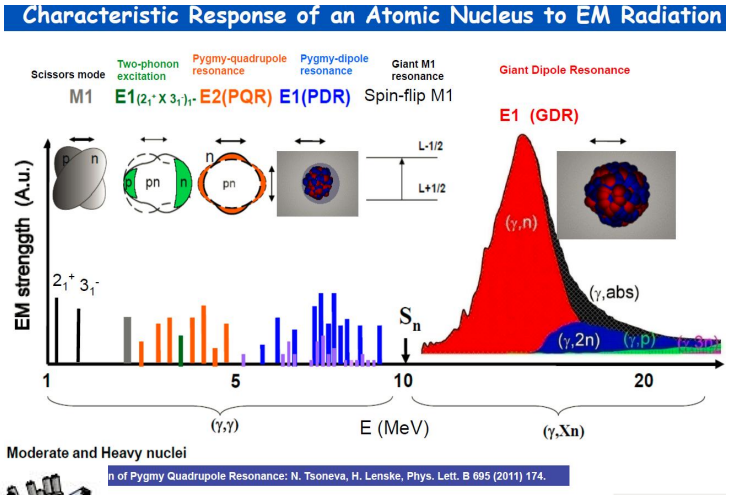
② （γ，n） **reaction： FED -** （^{3}He propotional tube, 26 sets from LND Company）

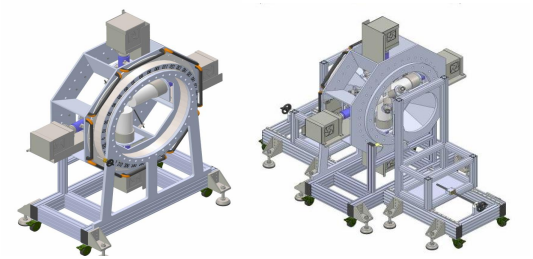
③ （γ，nγ） **reaction： TOF + NRF**（Liquudi Scintillator，20 EJ301）

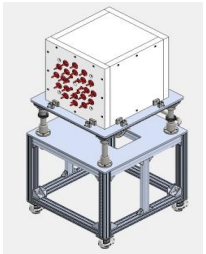
④ （γ，p/α）**reaction： LCP -** （GIC+Si strip+ CsI Telescope 6 sets）

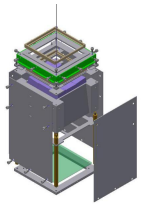
⑤ （γ，Fission）reaction： not include in SLEGS

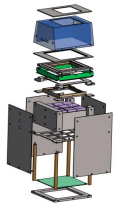
⑥ **Independent detector electronics and data acquisition（Electronics & DAQ，> 20台 Digitizer, >120ch）**







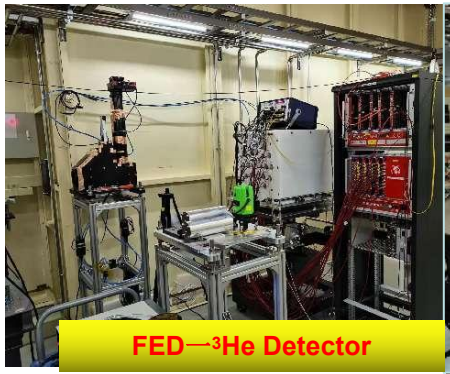




NRF- nuclear resonance fluorescent, FED-Flat efficiency detector, TOF-Time of Flight, LCP- light charge particle

3. Shanghai Laser Electron Gamma Source

Photoneutron Reaction(PR) Measurement


FED—^{3}He Detector


LCP—Telescope Detector


NRF—HPGe Detector


TOF-Liquid Scintilltor

PAA-photon activation analysis


DAQ room- Digitizer

Photos of the experimental detector of SLEGS，
A large number of CAEN and MESYTEC electronic modules are being used.

3. Shanghai Laser Electron Gamma Source

Photoneutron Reaction(PR) Measurement

SLEGS: One of the two MeV quasi-monoenergetic gamma source user devices currently operating internationally, It is one of the best tools to carry out photonuclear reaction research, and now is the best time to carry out photonuclear reaction research in China.

参数	HIGS		SLEGS		优势
伽马能量[MeV]	低能段	高能段	斜入射	背散射	
	1-20	21-60	0.4-21.1	21.7	
电子能量[GeV]	0.4-0.7	0.7-1	3.5	3.5	
入射激光波长[nm]	450-1064	190-450	10640	10640	
流强[ph/s]	10^{8-9}	10^{8}	10^{6-8}	10^{8}	
能量分辨[%]	0.8-10		2-5		
能量扫描精度[keV]	40		14		
发射角[mrad](θ=1/γ)	1.27-0.73		0.15		
样品处流强密度 [ph/s/mm²]	0.7×10^{4}-0.4×10^{6} （距离光源点60 m）		1.2×10^{4}-1.2×10^{6} （距离光源点38 m）		
流强稳定性[%]	>20		<5		
能量调节方式/速度	储存环电子/min		激光入射角/s		

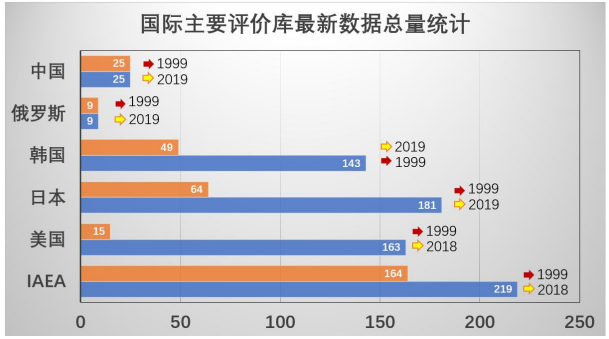
In the 0.25 to 21.7 MeV energy range and in nuclear physics/nuclear astrophysics, SLEGS has the best energy scanning accuracy, flux density and efficient energy regulation ability.

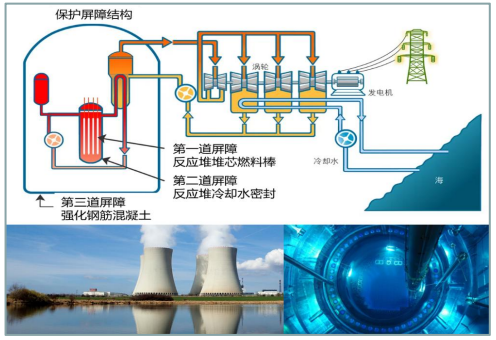
3. Shanghai Laser Electron Gamma Source

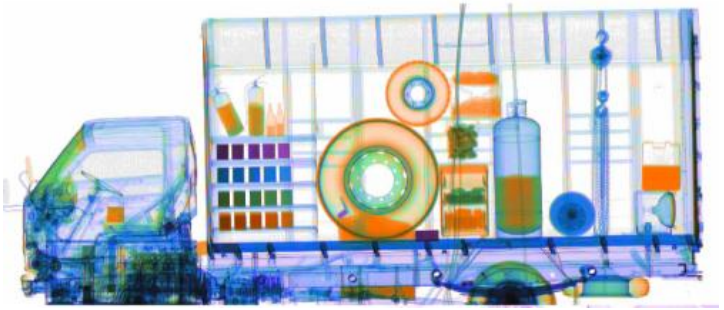
Photoneutron Reaction(PR) Measurement

Photoneneneba nuclear reaction studies the properties of atomic nuclei, reveals the interaction of nuclear forces, discovers new phenomena of collective movement, and explores the origin of heavy elements in the universe. Potonuclear reaction data is widely needed in reactor safety, medical detection, aerospace, national security and other aspects.

- The experimental research on photonuclear reaction is insufficient. There are 219 photonuclear data in IAEA database, and less than 60 new ones have been added in last 20 years: large error and low precision.
- There has been no suitable gamma source before SLEGS in China, and the experimental research on photonuclear reaction is blank! There is a shortage of photonuclear experimental technology and talents.

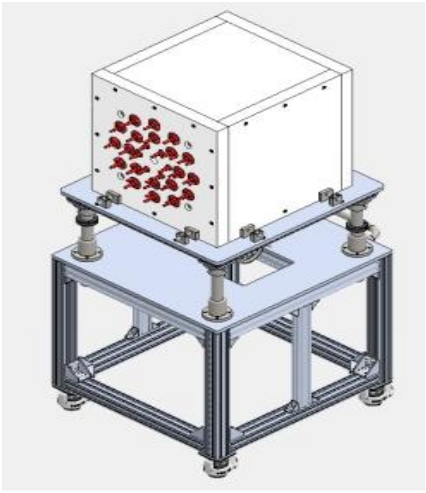


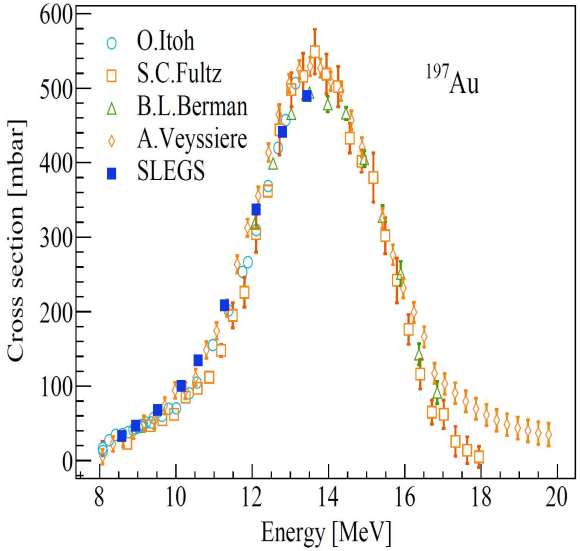


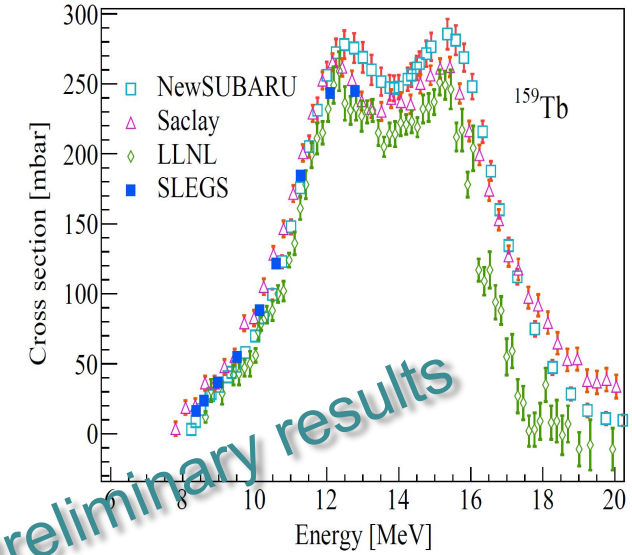


3. Shanghai Laser Electron Gamma Source

Photoneutron Reaction(PR) Measurement





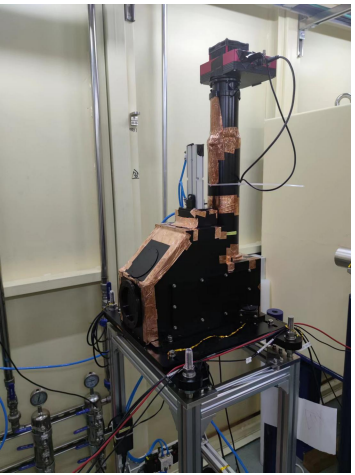


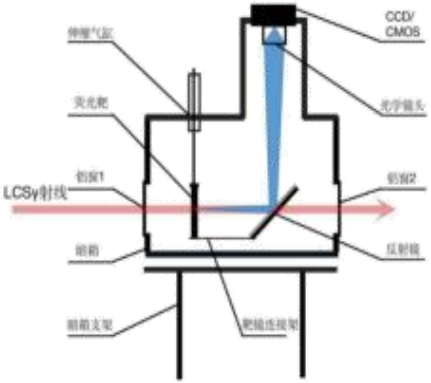
Test experiments： the newly cross section meets or exceeds the previous data！

SLEGS will offer a new opportunity for photoneutron cross section measurement and Database research！

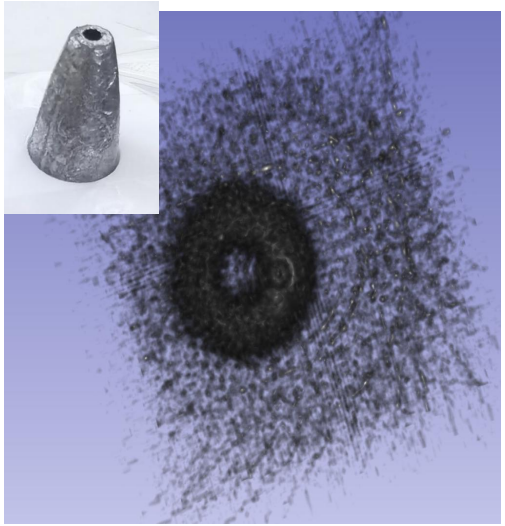
3. Shanghai Laser Electron Gamma Source

Test experiment – gamma CT





(a) Schematic configuration



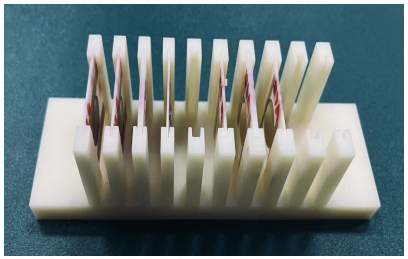
the Gamma Camera system： gamma CT

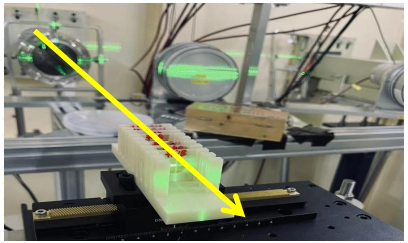
3-D image of a lead sample

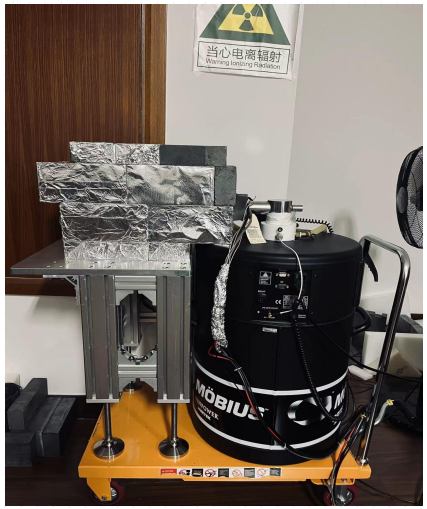
The system can achieve a spatial resolution of 0.8 mm.

3. Shanghai Laser Electron Gamma Source

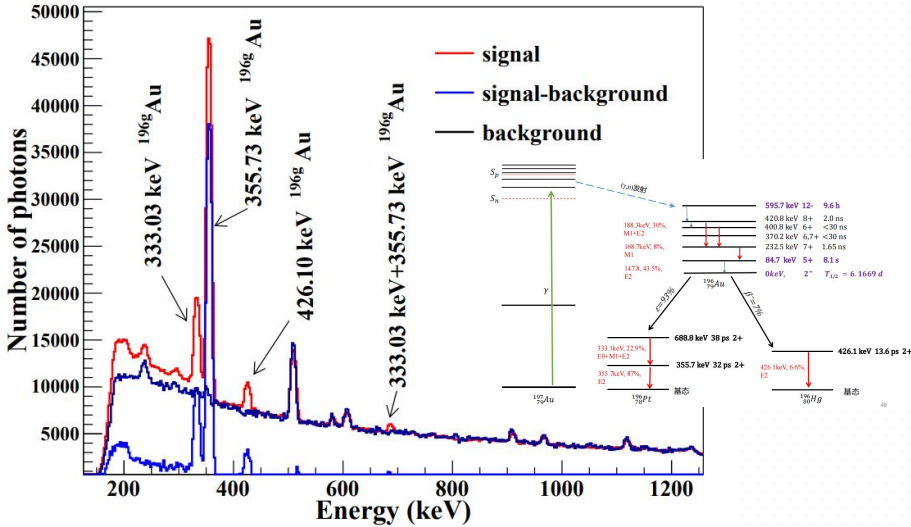
Test experiment – Photon Activation Analysis(PAA)







$^{197}Au+\gamma \rightarrow {}^{196g}Au(\beta-)+n$



The Gamma Activation： Target support and Low backgroud HPGe Detector.

The photon activation analysis applications: gamma beam intensity, low abundance short lifetime photon cross-section, medical isotope production, cultural relic composition identification, and nuclear astrophysical research.

3. Shanghai Laser Electron Gamma Source

- Innovation and contribution LCS technology:

  - The first LCS beamline with Slant Scattering and Back Scattering operating modes.
  - The first Slant Scattering mode with large angle system adjustment, from 20-160 Degree.
  - The best energy scanning accuracy, beam density and current stability.
  - The accelerator and laser technology expanded the application fields.
  - Precise exp measurement of key parameters -energy dissipation of SSRF electron.
  - Real-time monitoring of parameters-vacuum and electron orbit of SSRF .
  - Accurate exp parameters measurement- size and focal spot of strongly focused laser beams.
  - Provide reference for stability control technology of ultra long distance laser transmission.

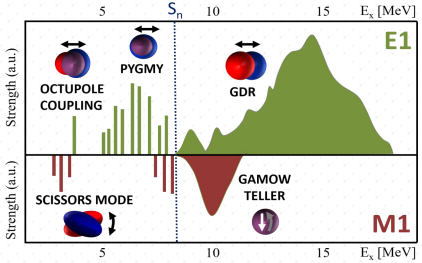
3. Shanghai Laser Electron Gamma Source

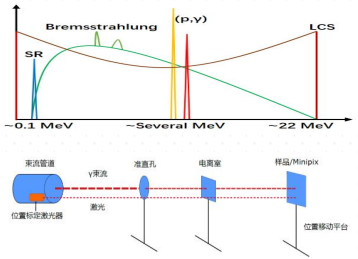
Future Plan:

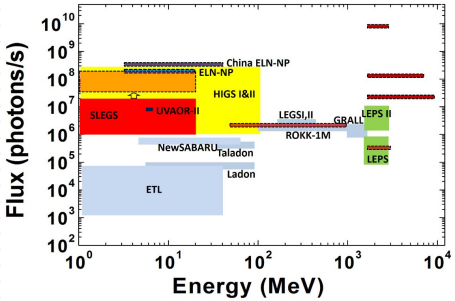
1. SLEGS beam line carries out Photo-Neutron cross section (GDR energy region) measurement, Nuclear resonance fluorescence(NRF) measurement, etc., provides direct measurement results for photonuclear data.

2. Construction of application platforms for gamma irradiation effects, gamma detector calibration, gamma positron generation, gamma activation, gamma transmutation, and other aspects in SLEGS beamline. Research on technology applications based on gamma sources.

3. Technology research on the future new generation of laser Compton scattering gamma source, design a new laser electron gamma source on the soft X-ray free electron laser (SxFEL) and hard X-ray free electron laser (SHINE) devices.







3. Shanghai Laser Electron Gamma Source

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3. **NUCL SCI TECH 33:87 (2022)**
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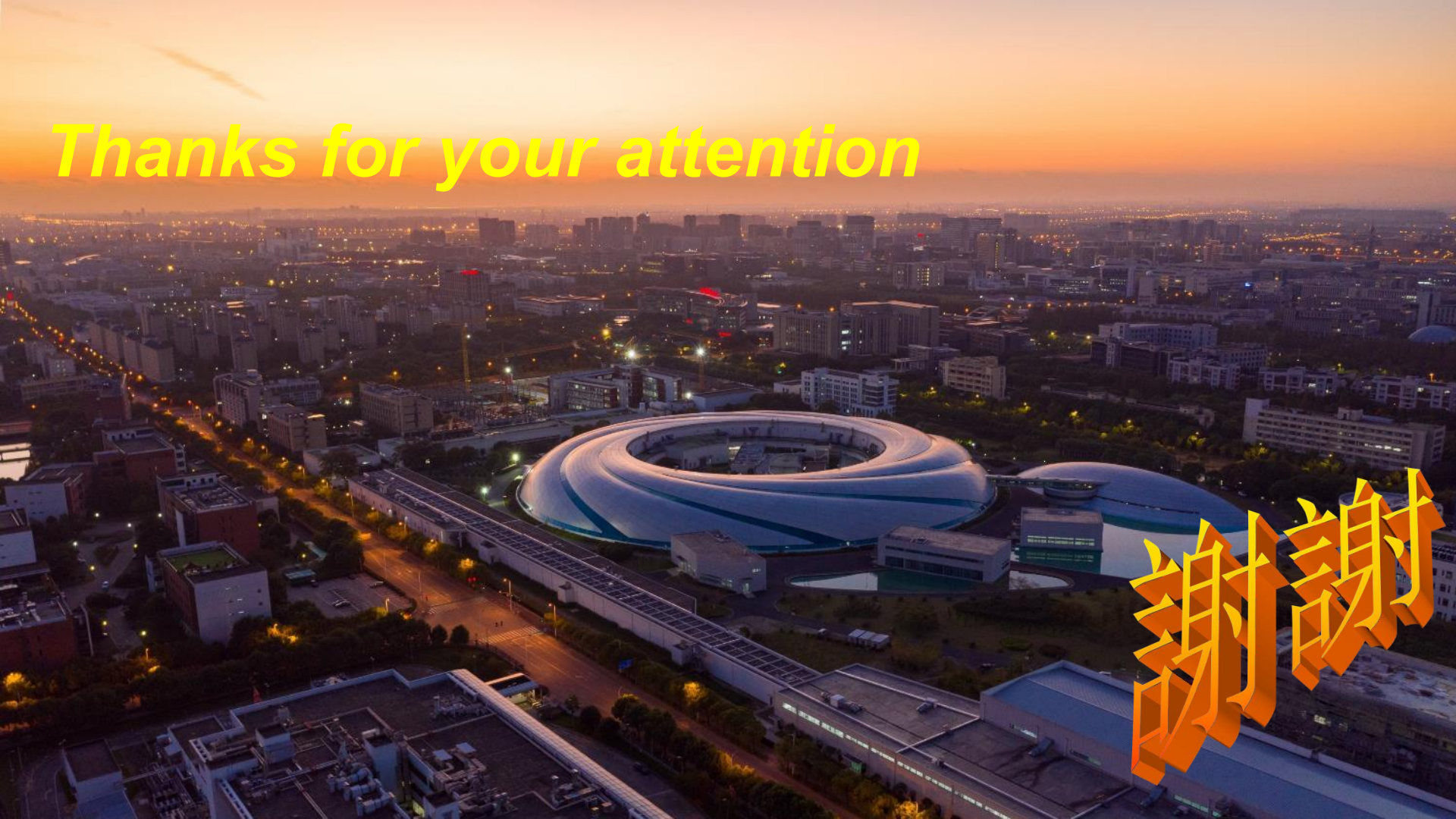
5. **Nuclear Inst. and Methods in Physics Research, A** 1033, 166742 (2022)
6. **Nuclear Inst. and Methods in Physics Research, B** 519, 9-14 (2022)
7. **Chinese. Phys. B** 31, 038204 (2022)
8. .....

4. Summary

- We have developed SLEGS at Shanghai Light Source. Gamma-ray beams are produced in the slant-scattering and back-scattering in the energy range of 0.25 – 21.1 & 21.7 MeV with an angular divergence of 0.5 mrad.
- By an appropriate setting of the double collimator system, quasi-monochromatic gamma-ray beams with a flux of 10^5 – 10^7 photons/s and energy resolution of better than 5% in FWHM are produced.
- **Now SLEGS ready for open.**


Thanks for your attention
謝謝