中国科学院上海高等研究院

The 12th Workshop on Hadron Physics and Opportunities Worldwide

Status of Electron/Photon Beam Facility at SHINE for Hadron Physics

Hanghua Xu, on behalf of the SLEGS Team

SSRF Science Center

2024年8月5-9日，大连

Outline

1. GeV electron beam at SHINE

2. Proposal of GeV gamma beam at SHINE

3. Working basis and progress

4. Summary

1. GeV electron beam at SHINE

Shanghai HIgh repetitioN rate XFEL and Extreme light facility

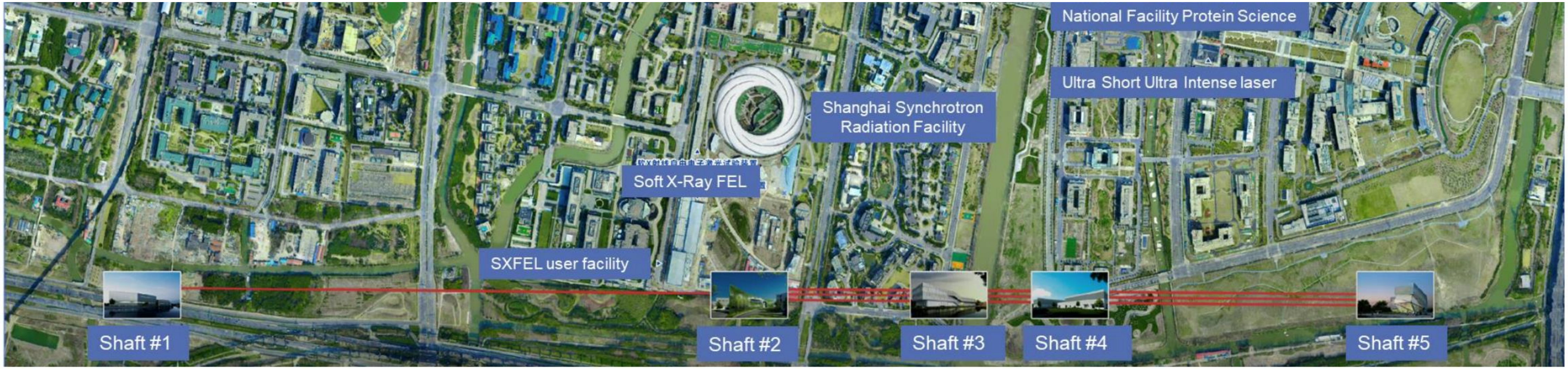
SHINE

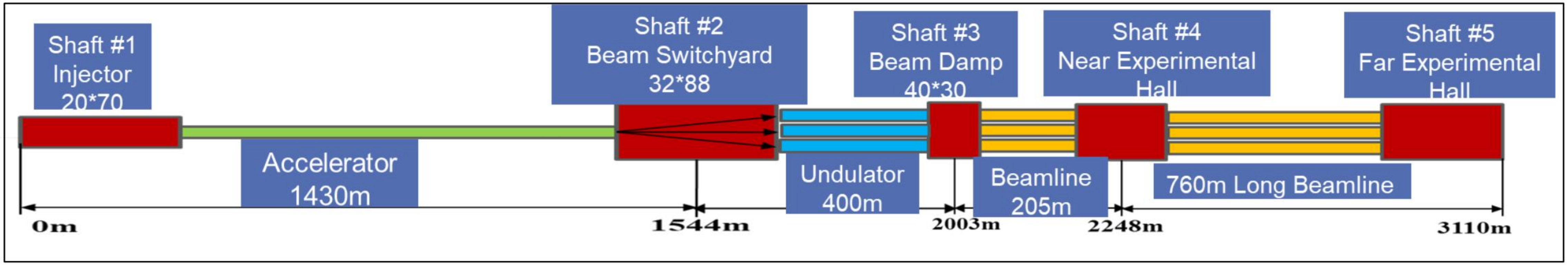
- **A Major National Science and Technology Infrastructure**

- **An 8GeV CW SRF Linac based hard X-ray free electron laser facility**
- **Co-funded by central and local governments with a ratio of ~20:80**
- **ShanghaiTech, SARI and SIOM are the main designers and constructors**

The groundbreaking was made on April 27, 2018.

1. GeV electron beam at SHINE



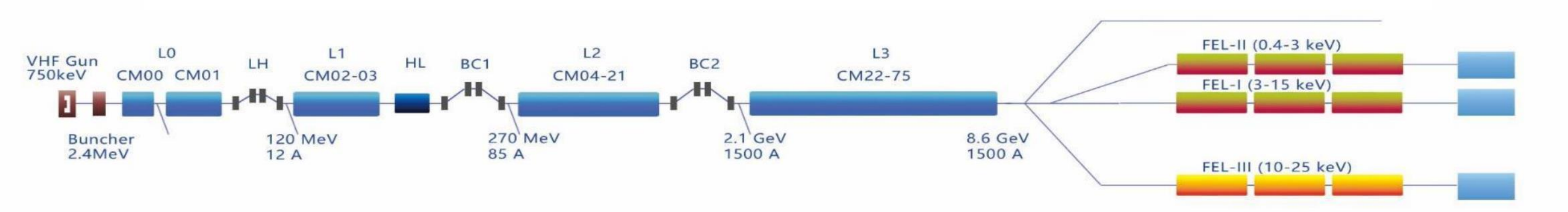


An **8 GeV** SCRF linac, 3 undulator lines to deliver photons from **0.4-25 keV**, up to **1 MHz** pulse train with pulse duration of 1-100fs

- 3 X-ray beamlines and 10 End-stations
- 100 PW super-intense laser facility
- Total length 3110 m; 29.0 m underground

1. GeV electron beam at SHINE

SHINE Accelerator and FEL Lines



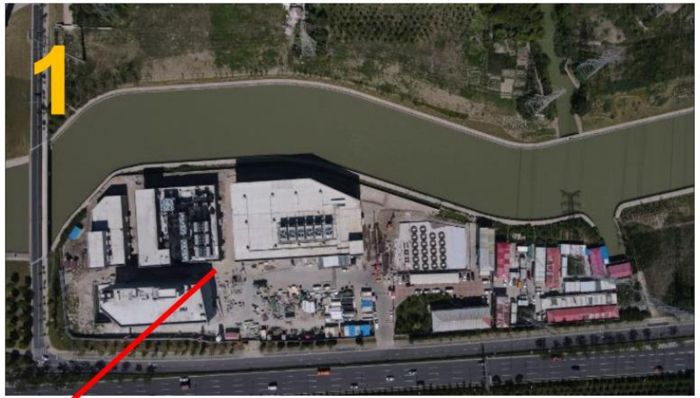
	Nominal	Range
Beam energy/GeV	8.0	4-8.6
Bunch charge/pC	100	10-300
Max rep-rate/MHz	1	up to 1
Beam power/MW	0.8	0 - 2.4
Photon energy/keV	0.4-25	0.4-25
Pulse length/fs	20-50	5-200
Peak brightness	5×10^{32}	1×10^{31}-1×10^{33}
Average brightness	5×10^{25}	1×10^{23}-1×10^{26}
Total facility length/km	3.1	3.1
Tunnel diameter/m	5.9	5.9
2K Cryogenic power/kW	12	12
RF Power/MW	2.28	3.6

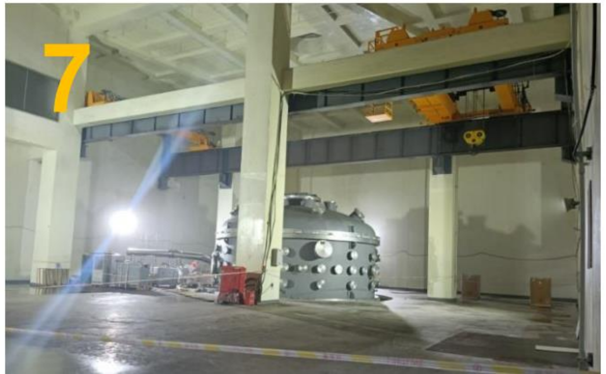
FEL Line	Nominal	Objective
FEL-I		
Photon energy/keV	3-15	3-15
Photon number per pulse @12.4keV	$>10^{10}$	$>10^{11}$
Max pulse repetition rate/MHz	0.66	1
FEL-II		
Photon energy/keV	0.4-3	0.4-3
Photon number per pulse @1.24keV	$>10^{12}$	$>10^{13}$
Max pulse repetition rate/MHz	0.66	1
FEL-III		
Photon energy/keV	10-25	10-25
Photon number per pulse @15keV	$>10^{9}$	$>10^{10}$
Max pulse repetition rate/MHz	0.66	1

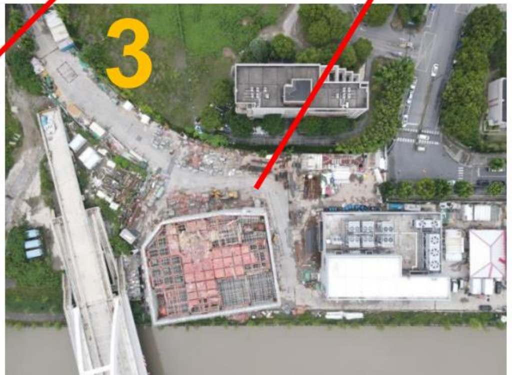
1. GeV electron beam at SHINE

Civil Construction

1. Shaft #1,   2. Shaft #2
3. Shaft #3,   4. Shaft #4
5. Shaft #5,   6. Linac Tunnel
7. Target Chamber in #5-B5

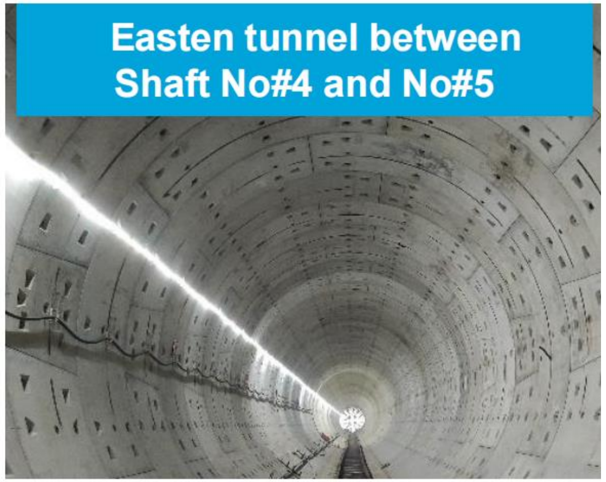




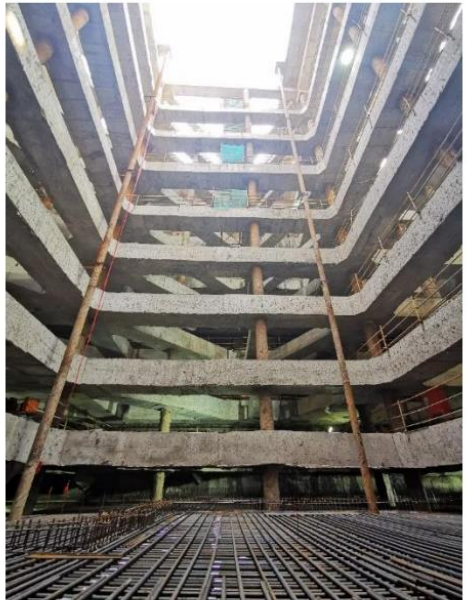


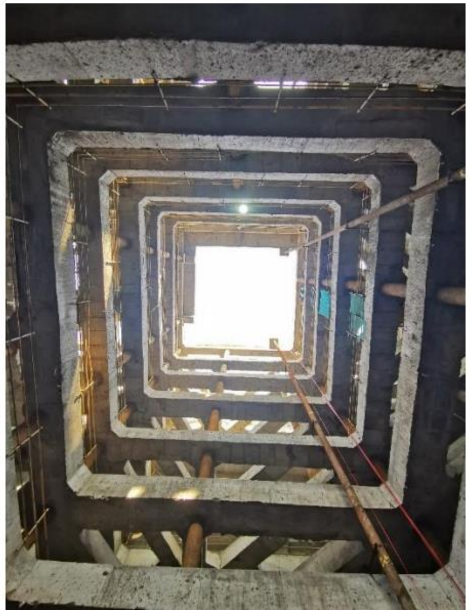
1. GeV electron beam at SHINE

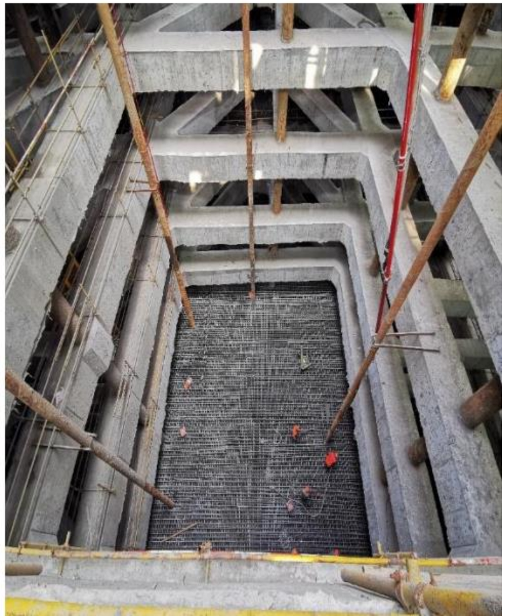
- Till March 2023, ten tunnels between shaft No#1to No#5 have been all constructed.



- Non-circular structure of shafts
  - 5 shafts have been constructed
  - Shafts No.#1 to #3 adopted opposite braces and diagonal braces
  - Shaft No. #4 & #5 adopted opposite braces and side braces, 9 or 10 supporting beams are used along the depth of the foundation pits.





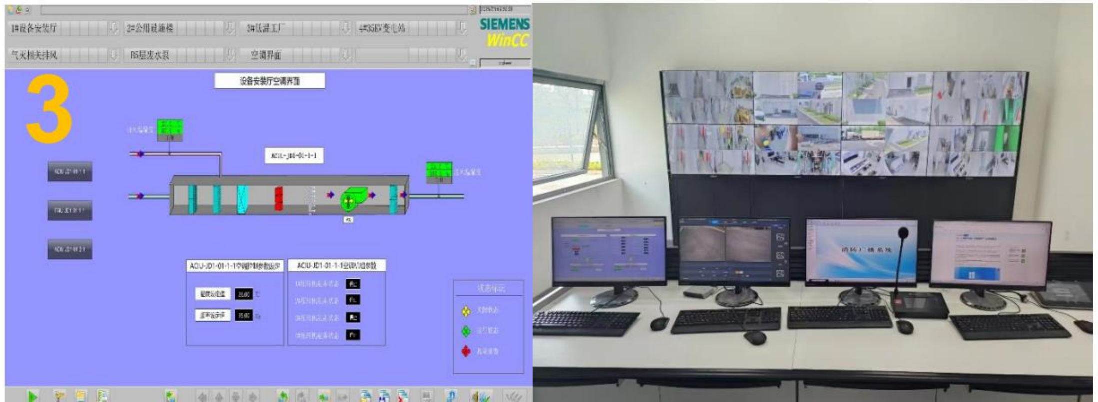


SHINE

1. GeV electron beam at SHINE

Utilities

1. High-voltage Electric System
2. Cooling Water System
3. Control & Low-voltage Electric
4. Fire Protection System



1. GeV electron beam at SHINE

Brief summary

- SHINE, a high rep-rate hard X-ray FEL facility, is being developed in Shanghai, consisting of an 8 GeV CW SCRF linac, a 100PW laser system, 3 phase-I undulator lines and 10 end-stations;
- R&Ds and protypes of key technologies and components are ongoing and still challenging;
- Mass production of key components started and is in progress;
- This hard X-ray FEL project, started construction in April 2018, achieved good progress, aiming to achieve the first XFEL lasing in 2025.

Outline

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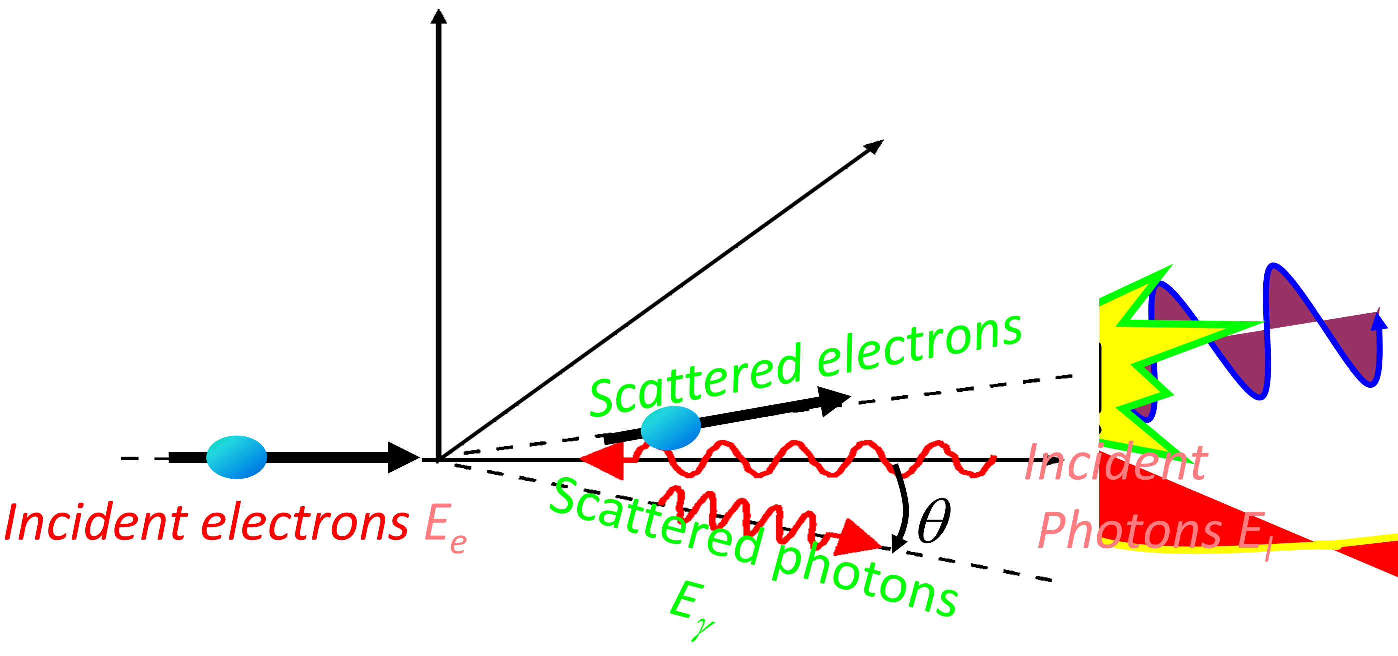
2. Proposal of GeV gamma beam at SHINE

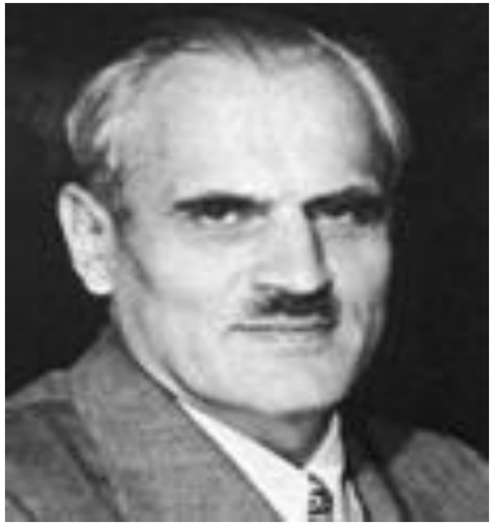
3. Working basis and progress

4. Summary

2. Proposal of GeV gamma beam at SHINE

Laser-Compton scattering



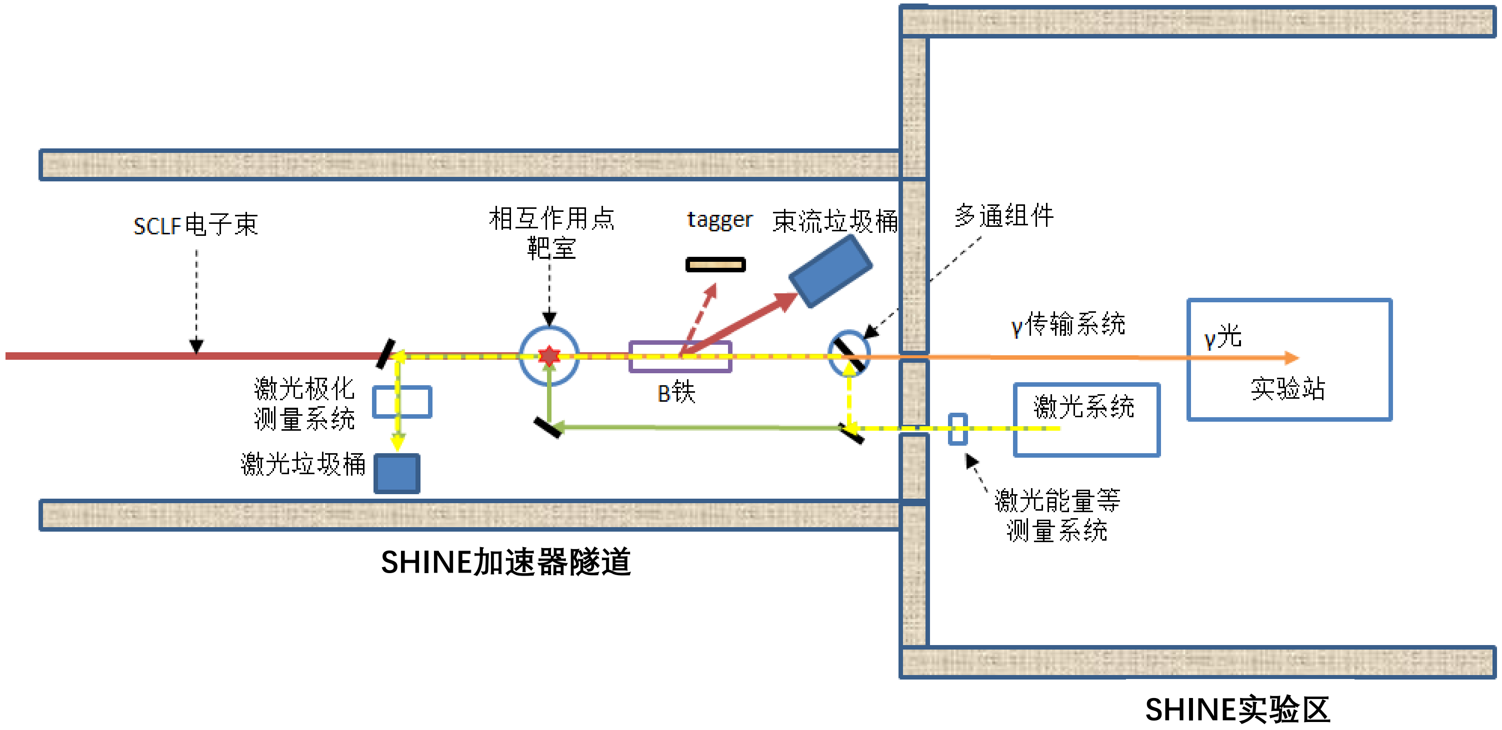


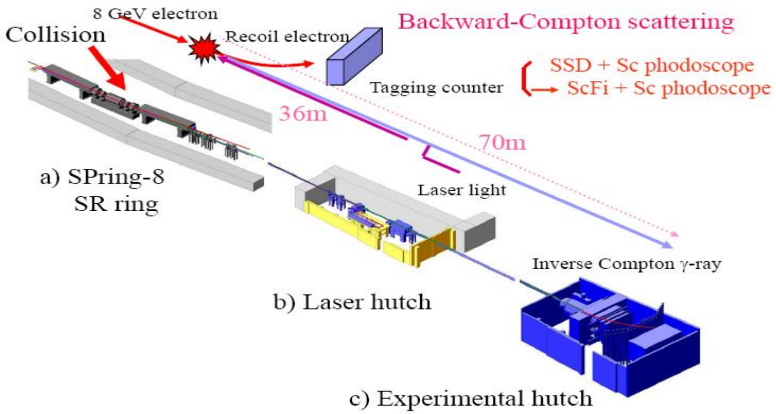
A. H. Compton
(1892-1962)

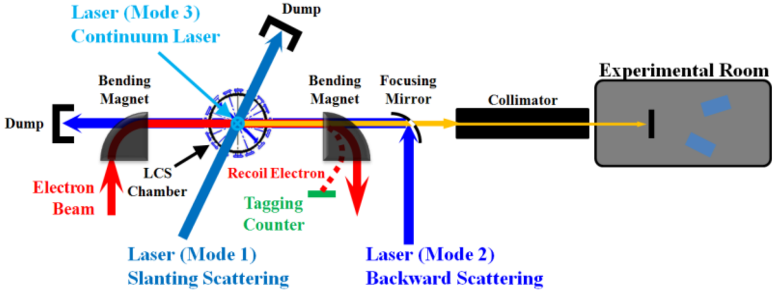
$$E_\gamma = \frac{E_l\left(1-\beta\cos\theta_L\right)}{1-\beta\cos\theta+\dfrac{E_l\left\{1-\cos\left(\theta_L-\theta\right)\right\}}{E_e}}$$

2. Proposal of GeV gamma beam at SHINE

Model I: External laser + Electron



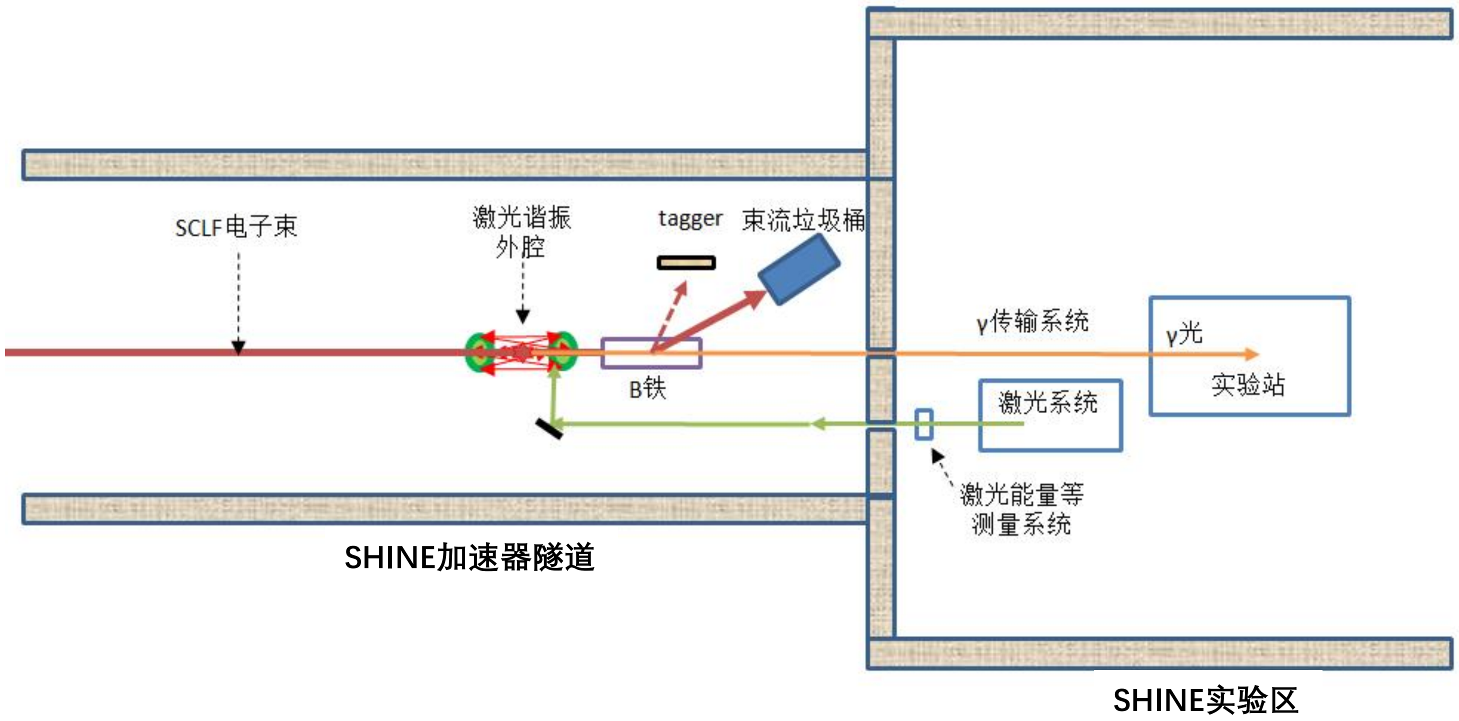


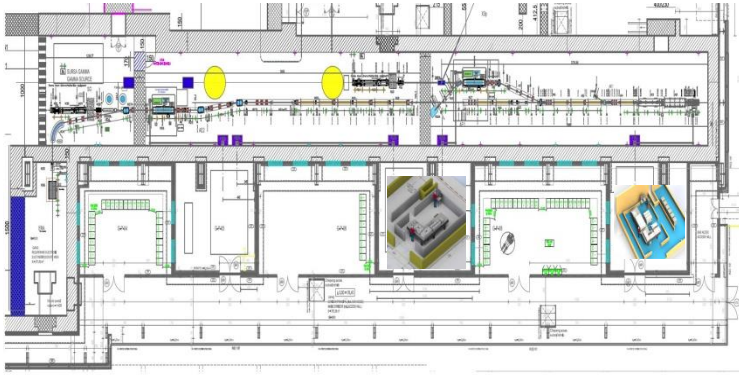


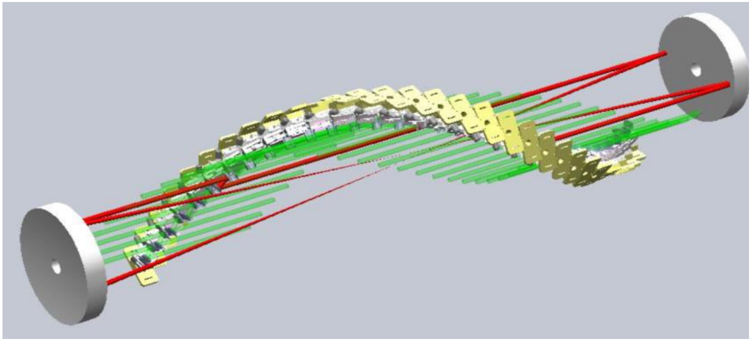
Laser wavelength um/nm	Type	Power /W	Duration fs/ps	Frequency /Hz	Single Pulse /J	Gamma Energy /MeV	Gamma flus photons/s/W
10.64um	CW	1				112.7	7.59×10^{6}
1.64um	CW	1				999.8	9.49×10^{5}
355nm	CW	1				2397.8	2.75×10^{5}
266nm	CW	1				2908.0	1.79×10^{5}

2. Proposal of GeV gamma beam at SHINE

Model II: High power pulsed laser + Electron



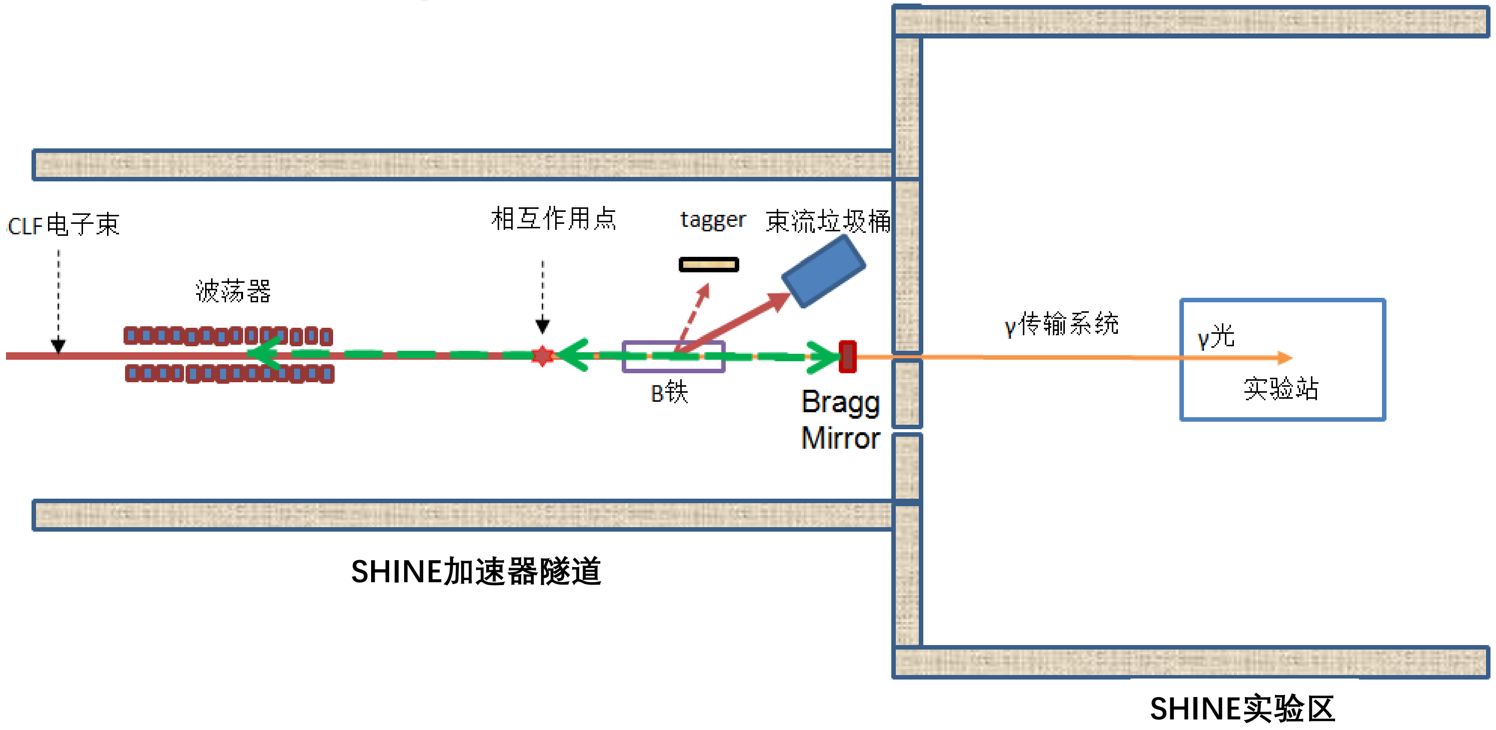


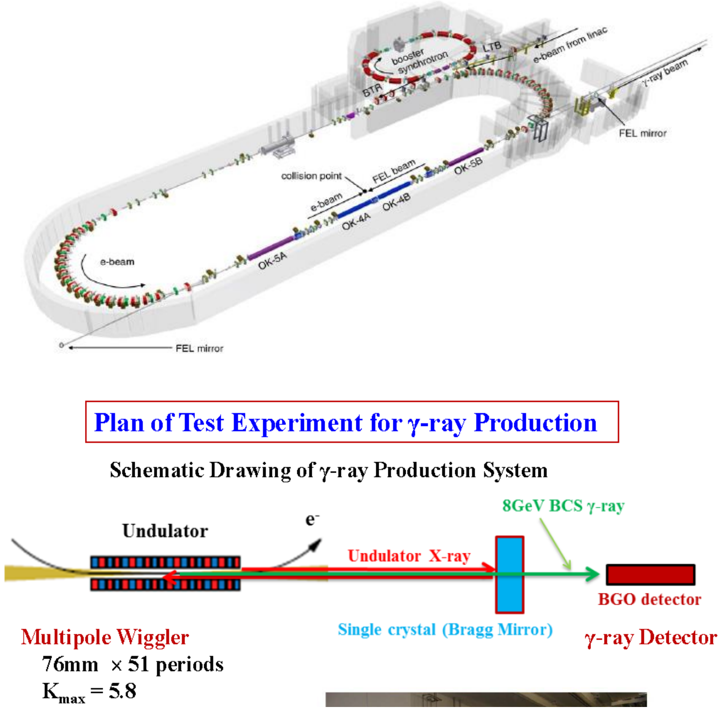


Laser wavelength um/nm	Type	Power /W	Duration /fs	Frequency /Hz	Single Pulse /J	Gamma Energy /MeV	Gamma flus photons/s
800nm	Puls		50	10	5	1277.4	1.04×10^{10}

2. Proposal of GeV gamma beam at SHINE

Model III: X-ray from SHINE + Electron

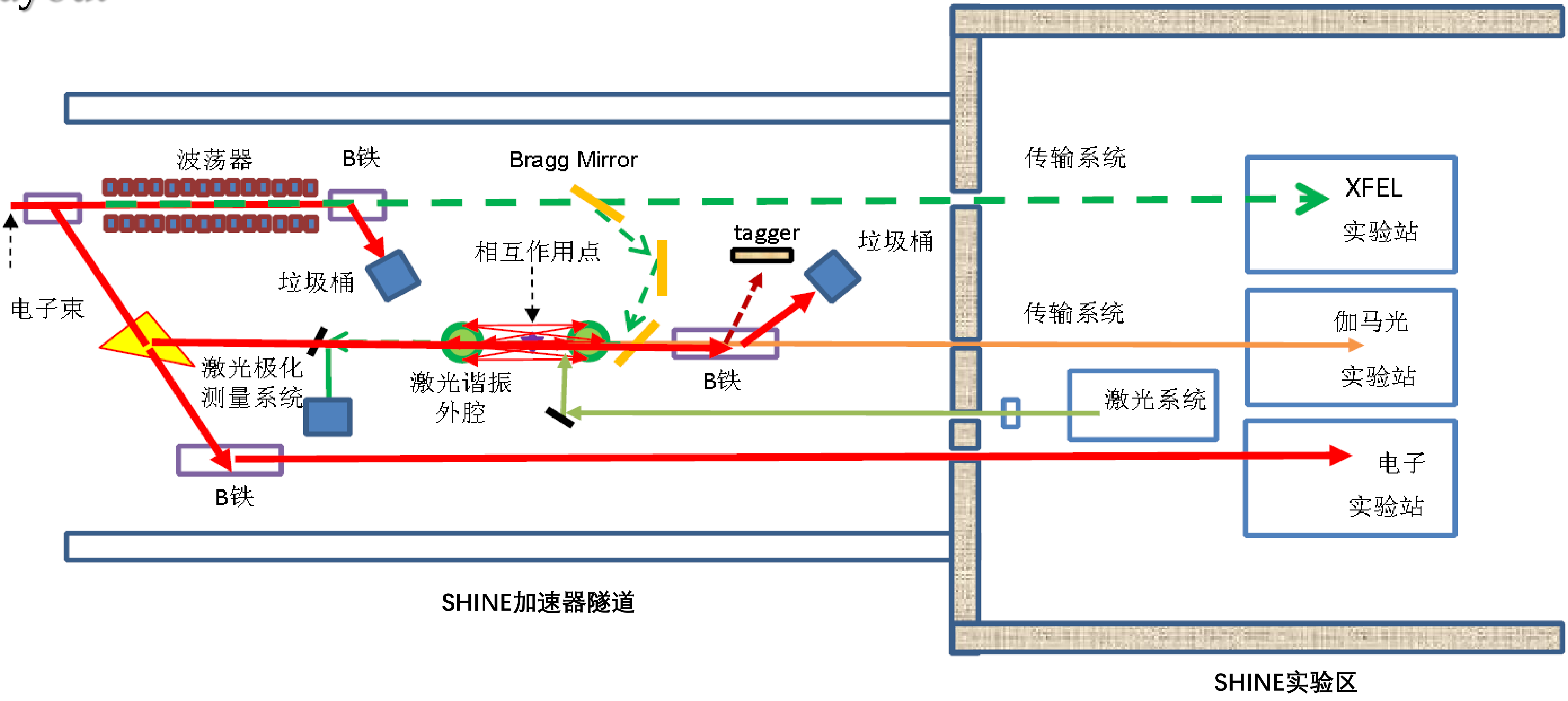




Laser wavelength um/nm	Type	Power /W	Duration /fs	Frequency /Hz	Photons /Pulse	Gamma Energy /MeV	Gamma flus photons/s
0.1keV@FEL	Puls		30	10^6	10^{13}	7398.6	1.04×10^8
1.0keV@FEL	Puls		30	10^6	10^{13}	7937.8	1.97×10^7

2. Proposal of GeV gamma beam at SHINE

Layout



2. Proposal of GeV gamma beam at SHINE

Laser wavelength um/nm	Type	Power /W	Duration fs/ps	Frequency /Hz	Single Pulse /J	Photons /Pulse	Gamma Energy /MeV	Gamma flus photons/s
10.64um	CW	1					112.7	7.59×10^{6}
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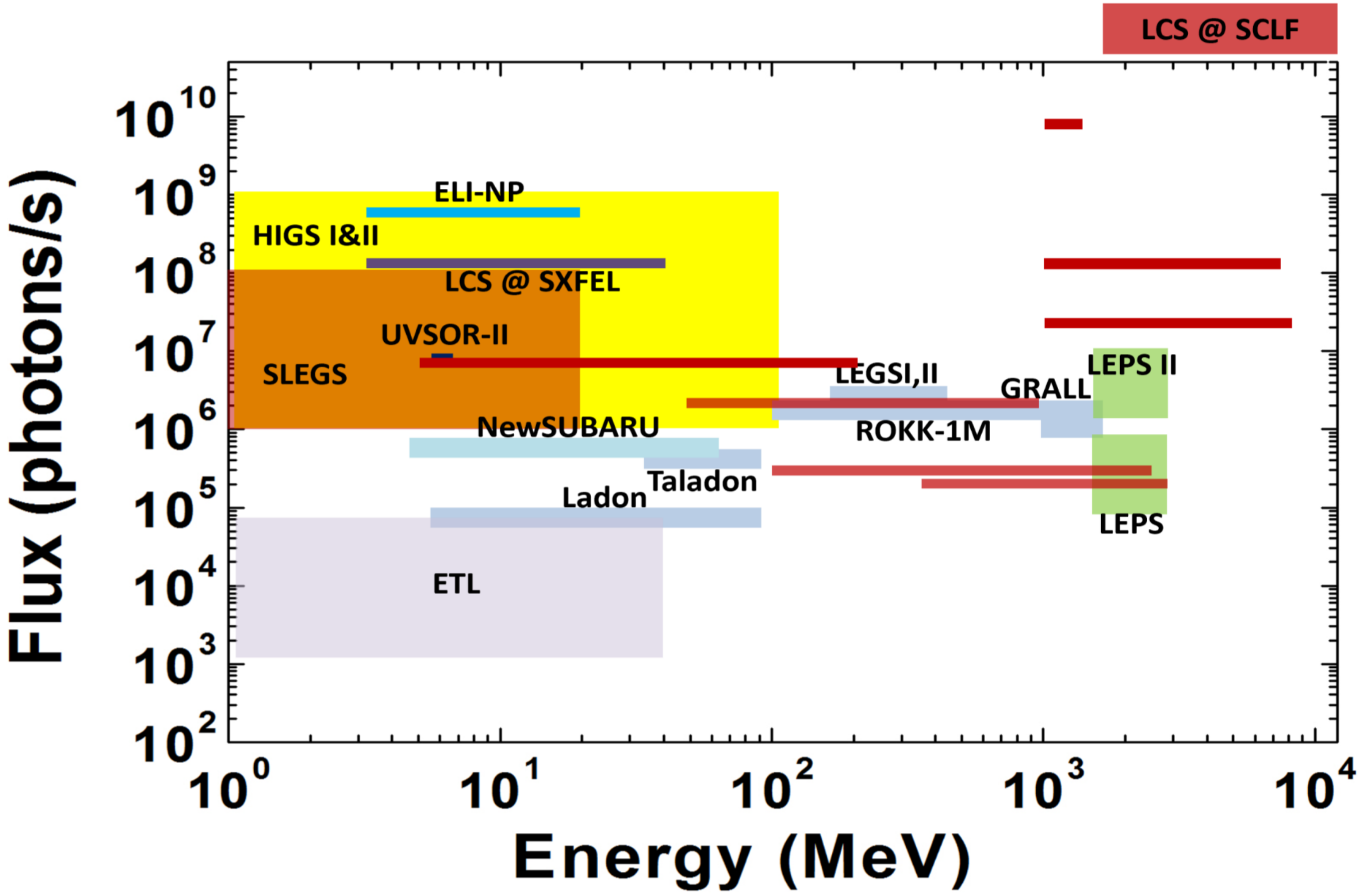
2. Proposal of GeV gamma beam at SHINE



Outline

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2. Proposal of GeV gamma beam at SHINE

3. Working basis and progress

4. Summary

3. Working basis and progress

- **National Key Research and Development Program（国家重点研发计划）：** Research on Detection Techniques Related to Nuclear Physics Experiments Based on High Energy High Current Electron Beams

符长波
项目负责人
课题二负责人
复旦大学,教授

- 上海“东方英才领军人才” “东方学者”特聘教授；中科院粒子协同创新中心“青年优秀人才” “青年拔尖人才”奖。
- 主持**国家自然科学基金重点项目**、面上项目多项；参与多项。
- 近五年发表SCI文章 20 余篇[多篇第一/通讯发表在 **Phys. Rev. Lett.，Nat. Comm]；H-因子33；被引>7000余次**
- 主要研究领域：光核物理；暗物质探测。

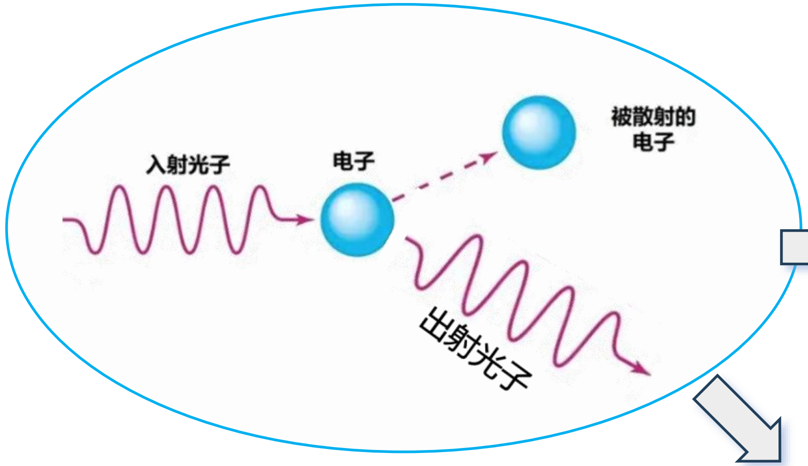
范功涛：课题一负责人，中科院上海高研院, 研究员； 强逆康普顿束SLEGS核心骨干

赵宇翔：课题三负责人，中科院近物所，研究员;**青年千人**；核子夸克胶子结构

李数：课题四负责人，上海交通大学, 李政道学者；**青年千人**；暗物质探测

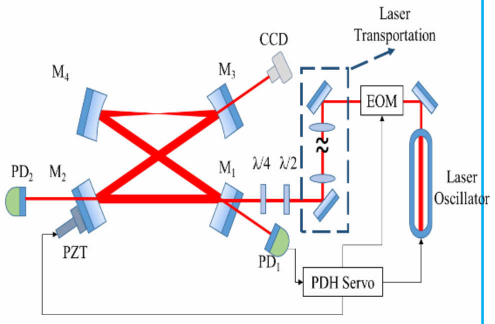
3. Working basis and progress

Topic 1: Inverse Compton Gamma Light Source



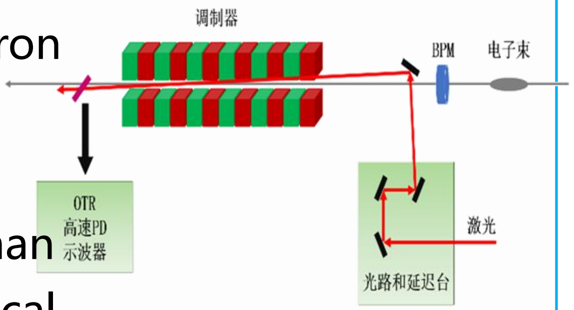
❖ Optical enhancement cavity technology

Offline construction of laser resonant cavity, achieving a more than **10 times** increase in effective laser power at the interaction point:



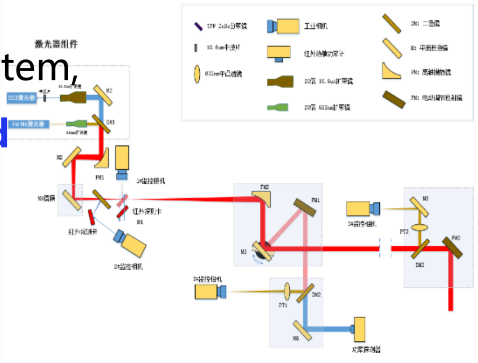
❖ Time synchronization technology

Realize laser electron beam time synchronization accuracy of less than **100ps** (=3cm optical motion)



❖ Spatial coincidence technology

Based on SLEGS laser system, achieve **10 μ m laser and electronic position coincidence** technology through upgrading and transformation.

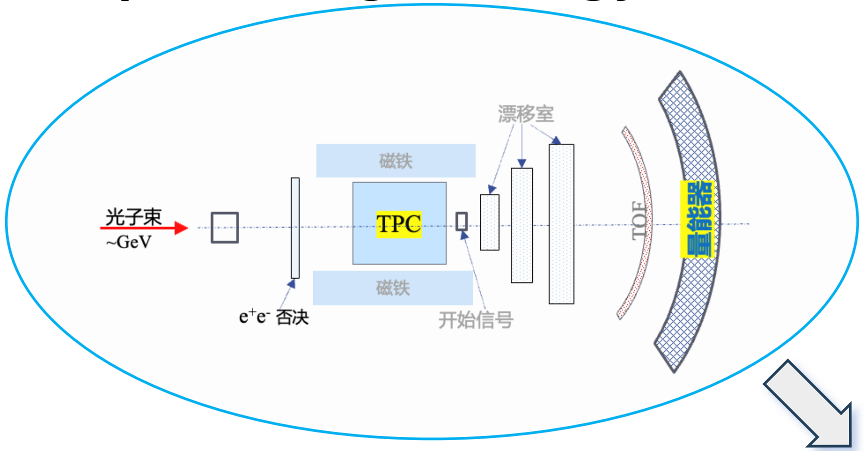


Main features

- **Characteristics of Gamma Beam**
  - Wide energy range
  - High flow strength
  - High polarization
- **Multiple LCS cutting-edge technologies**
  - GeV LCS ps time synchronization technology
  - LCS specific laser external OEC technology

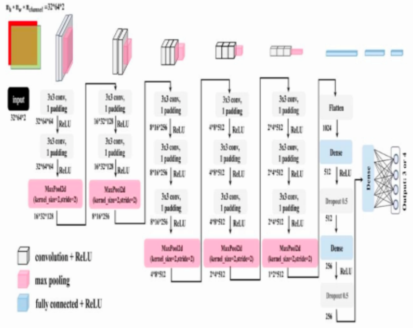
3. Working basis and progress

Topic 2: High Energy Gamma Ray Nuclear Physics Platform



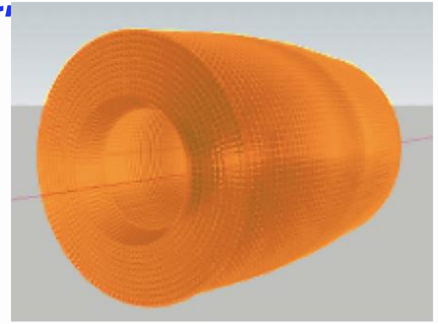
❖ Software for gamma photonuclear physics

a software framework for the simulation and analysis of high-energy gamma photonuclear physics data



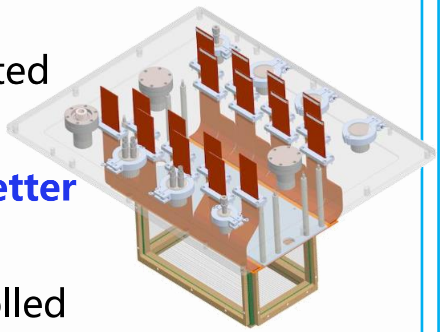
❖ electromagnetic calorimeter

Irradiation-resistant, high-count-rate, **principle prototype resolution: energy 2.5% @1GeV; position 5mm**



❖ Time Projection Chamber (TPC) technology

High event rate response;
TPC-specific highly integrated electronics;
TPC **position resolution better than 2mm**;
an autonomous and controlled distributed acquisition system;

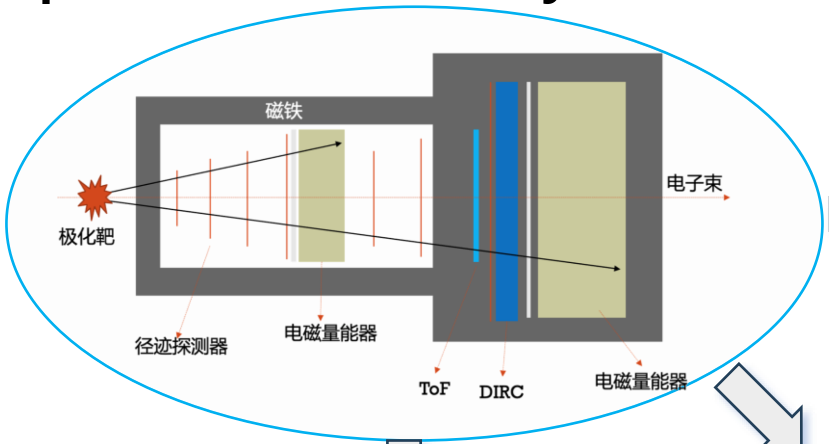


Main features

- **High count rate**
- **Pure CsI crystal**
- **Expected 80kHz [Currently typical 6kHz**
- **Irradiation resistant**
- **for higher beam intensities**
- **100krad (10 years)**
- **Highly integrated electronics**
- **Anticipated 256 channels [currently typical 64 channels]**

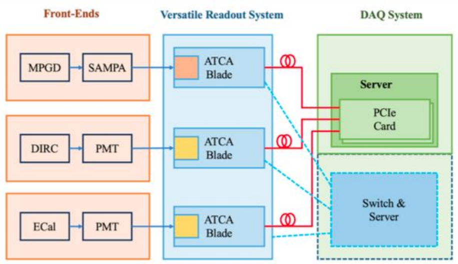
3. Working basis and progress

Topic III. Hadron Physics Detection Technology for e beam



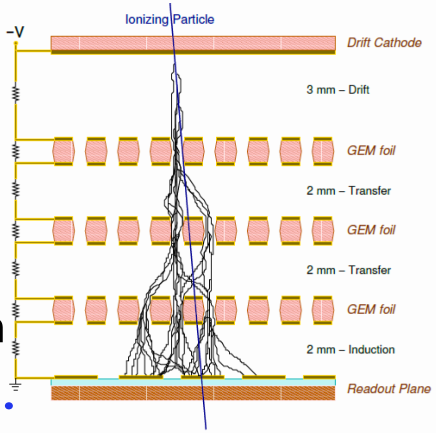
❖ Data acquisition system

Utilizing the SAMPA chip, a single chip with 32 channels of charge amplification, shaping, digitizing, and data packing; ATCA architecture readout system



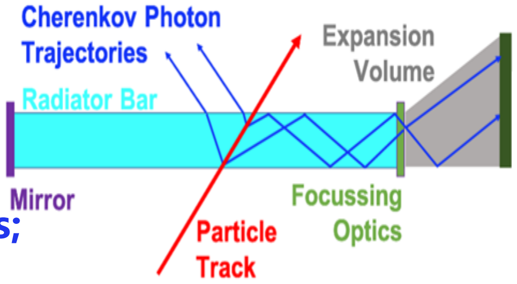
❖ Microstructure Gas Trail Detector

Large area detector (0.6m * 1.2m); expected position resolution **better than 100um.**



❖ DIRC Cherenkov detector

Reconstruction of the Cherenkov radiation angle using a high-purity quartz radiator and sensor; **time resolution 90 ps; angular resolution 1mrad**



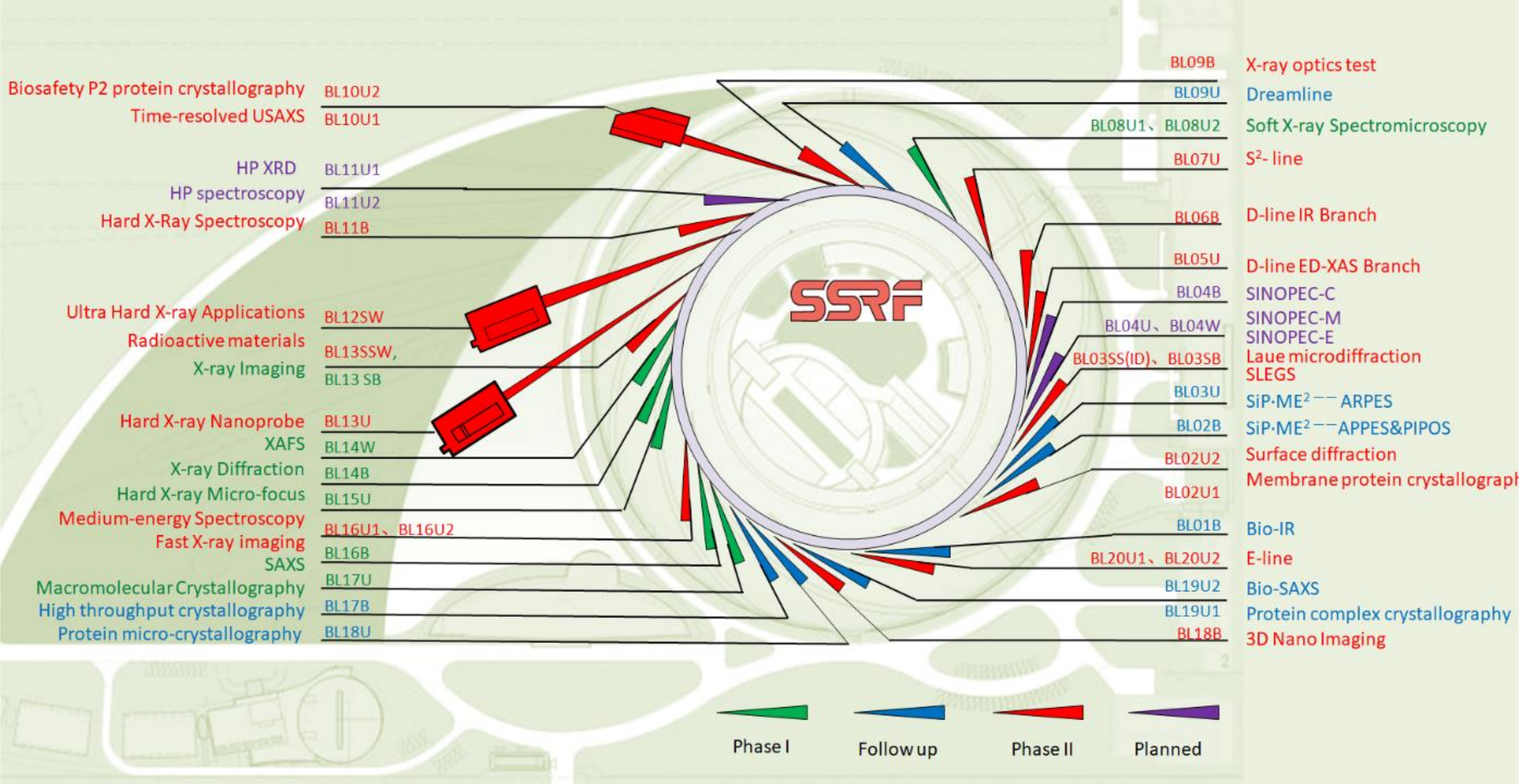
Main features

- **Wide momentum range PID**
- **Not yet available in China**
- **Momentum range 1.5-7 GeV**
- **Simultaneous position + time measurement**
- **Large area 0.6*1.2m**
- **Relatively simple structure is maintained at the same time**

3. Working basis and progress

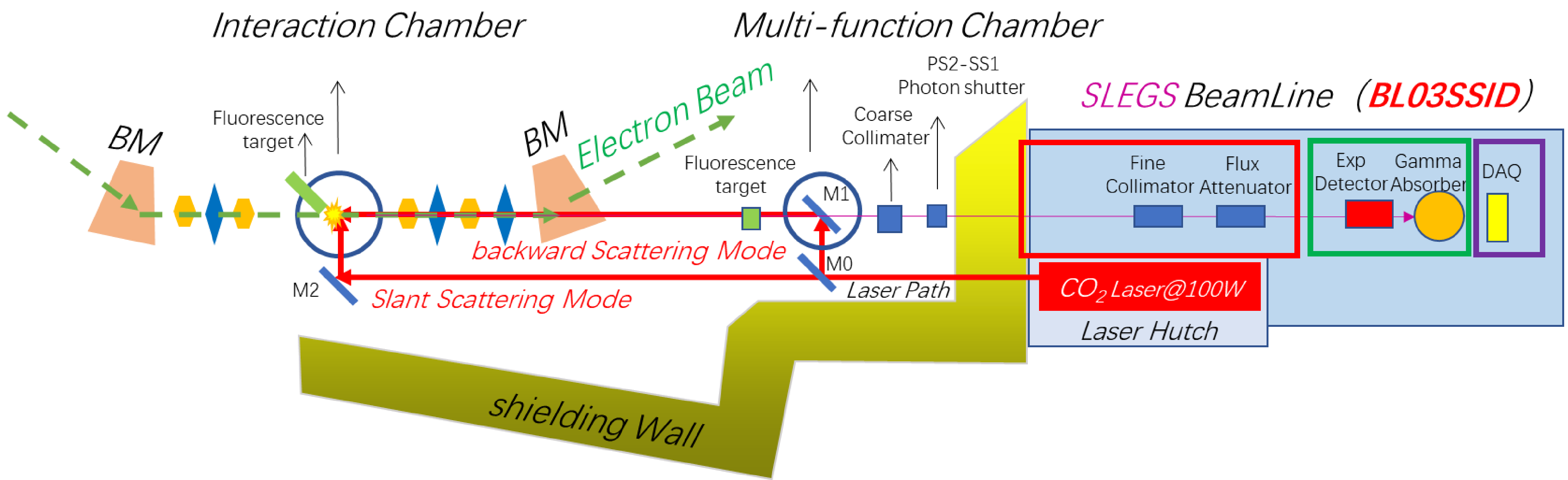
Energy	3.5 GeV
Beam Sizeσ_x	276.9 um
Beam Sizeσ_y	12.24 um
Pulse RMS	3 mm
Current	**300 mA**
Q_e	1.44 nC
Emittance$\varepsilon_x/\varepsilon_y$	2.59 / 2.59E-2 nmrad
Divergenceη_x/η_y	0.207 / 0 m
β_x/β_y	14.86 / 5.78 m
Energy spread	0.944E-3
Pulse Number	500

3. Working basis and progress



3. Working basis and progress

Layout



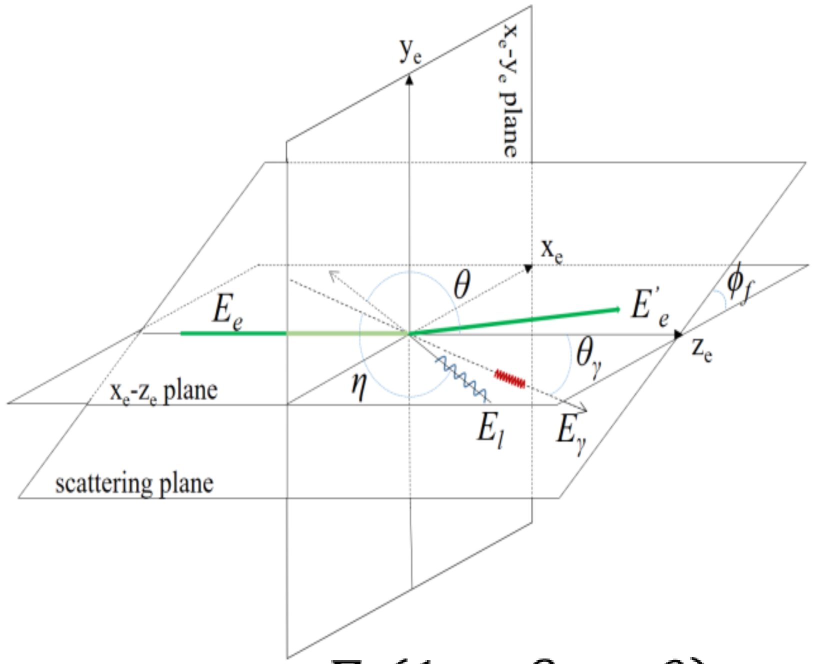
(1) Gamma source: electron, laser, LCS chamber(slanting mode), mirror chamber(back scattering).

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

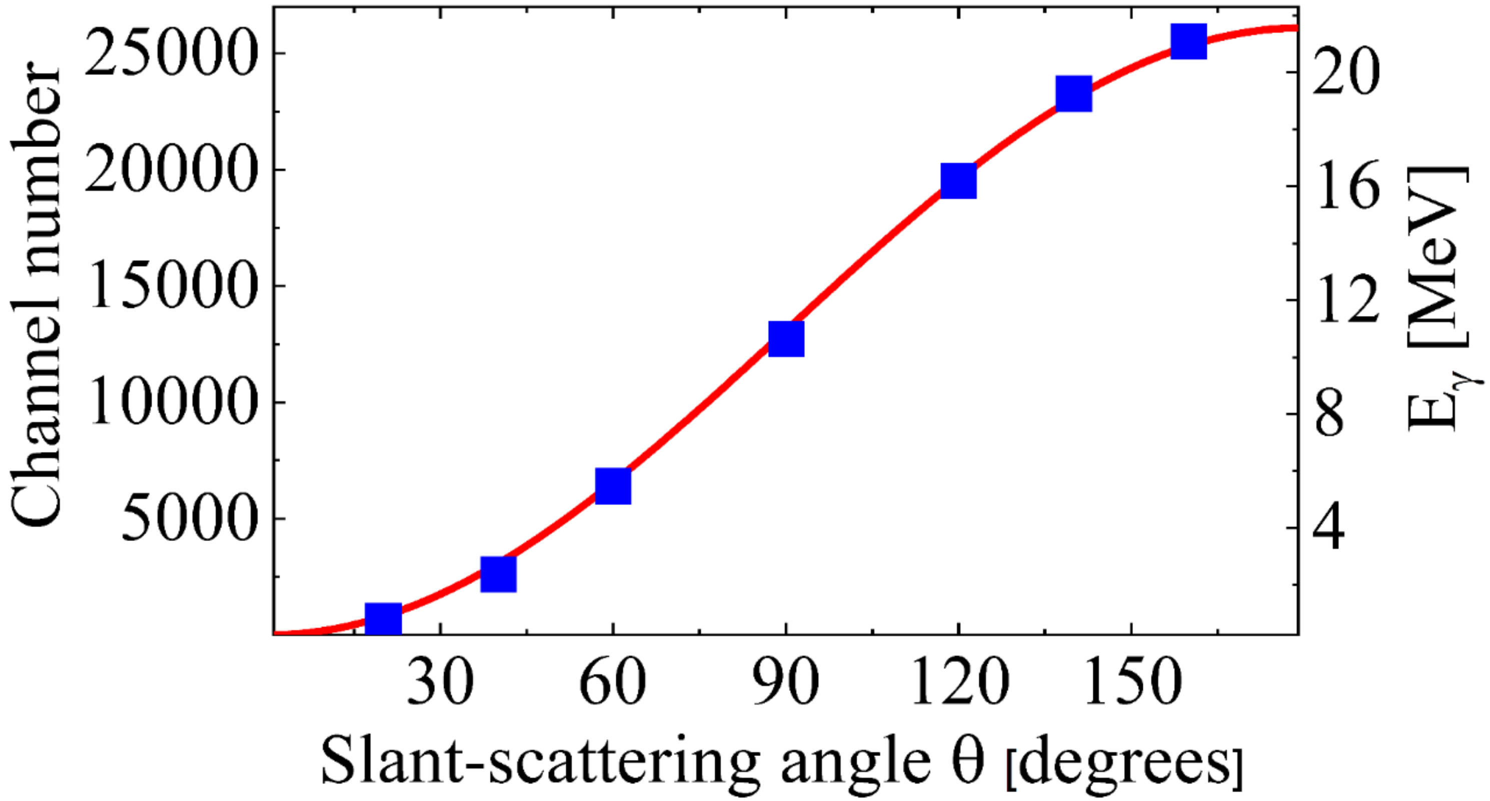
(3) End station: (γ,n) Neutron detector, (γ,p/α) Charged particle detector, (γ,γ) Gamma detector

3. Working basis and progress

Gamma properties – energy & scattering angle



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



3. Working basis and progress

Gamma properties – spots

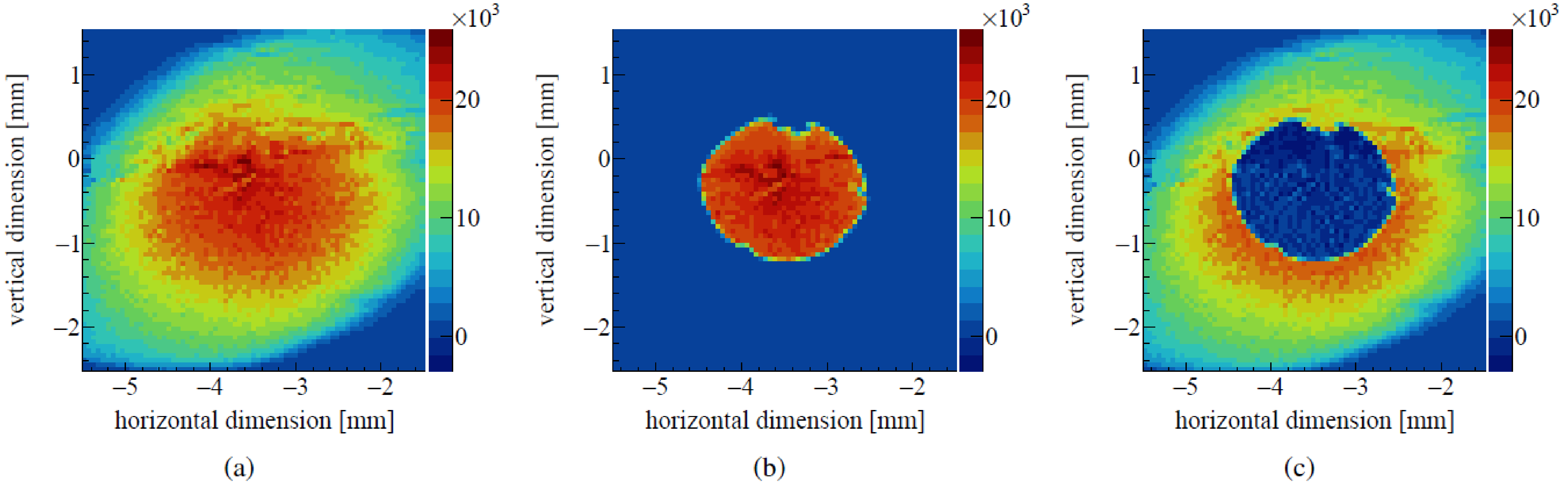
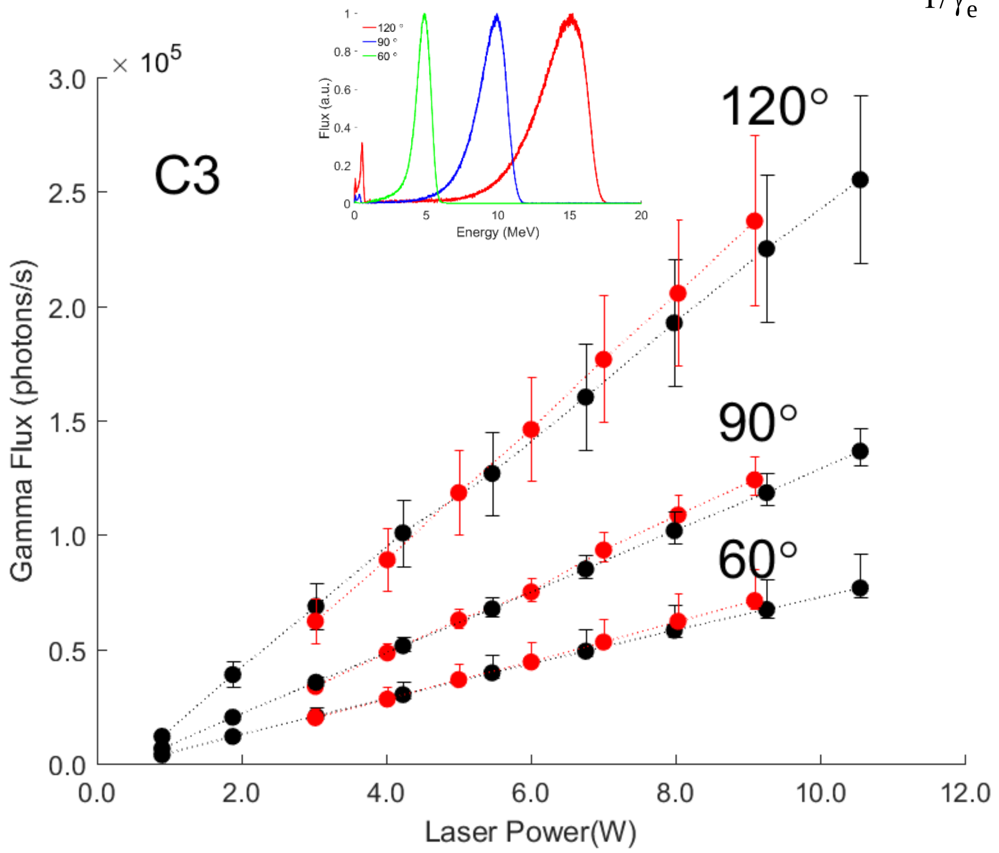
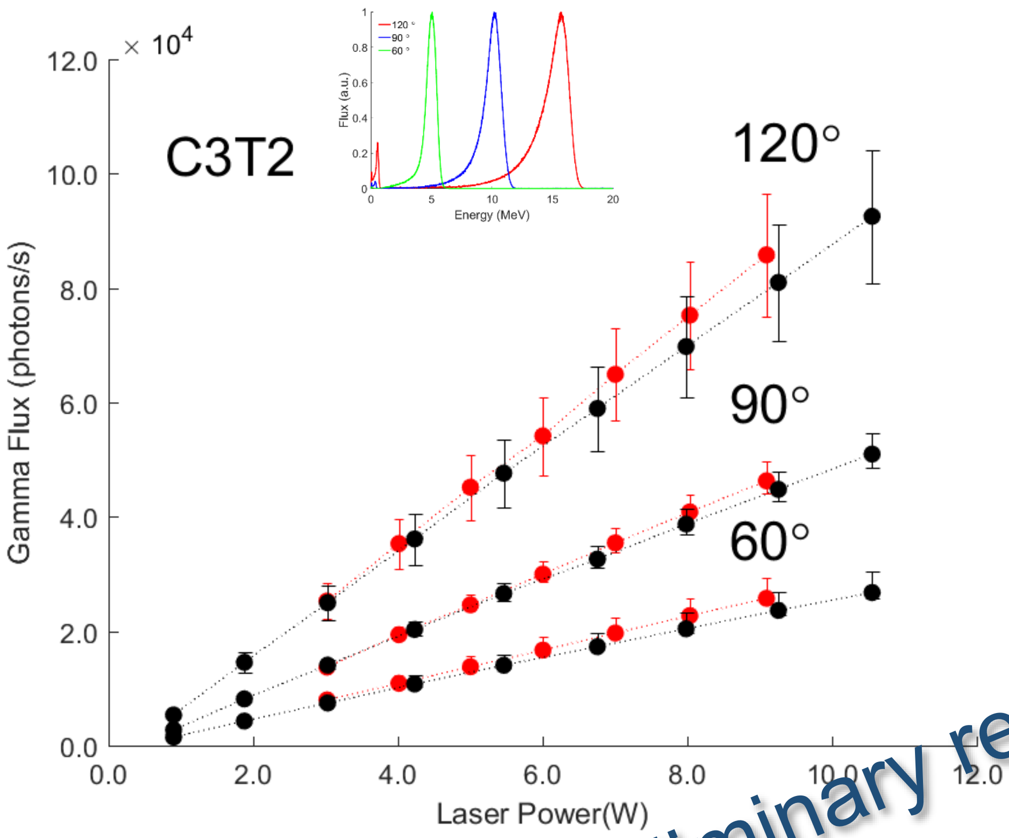


Figure 4: False color image of beam spot. (a) Beam spot with 3 mm coarse collimator. (b) Beam spot with 3 mm coarse collimator and 2 mm external collimator. (c) The substraction image of image (a) by image (b), showing the filtered beam by the external is the center part of the beam.

3. Working basis and progress

Gamma properties – flux

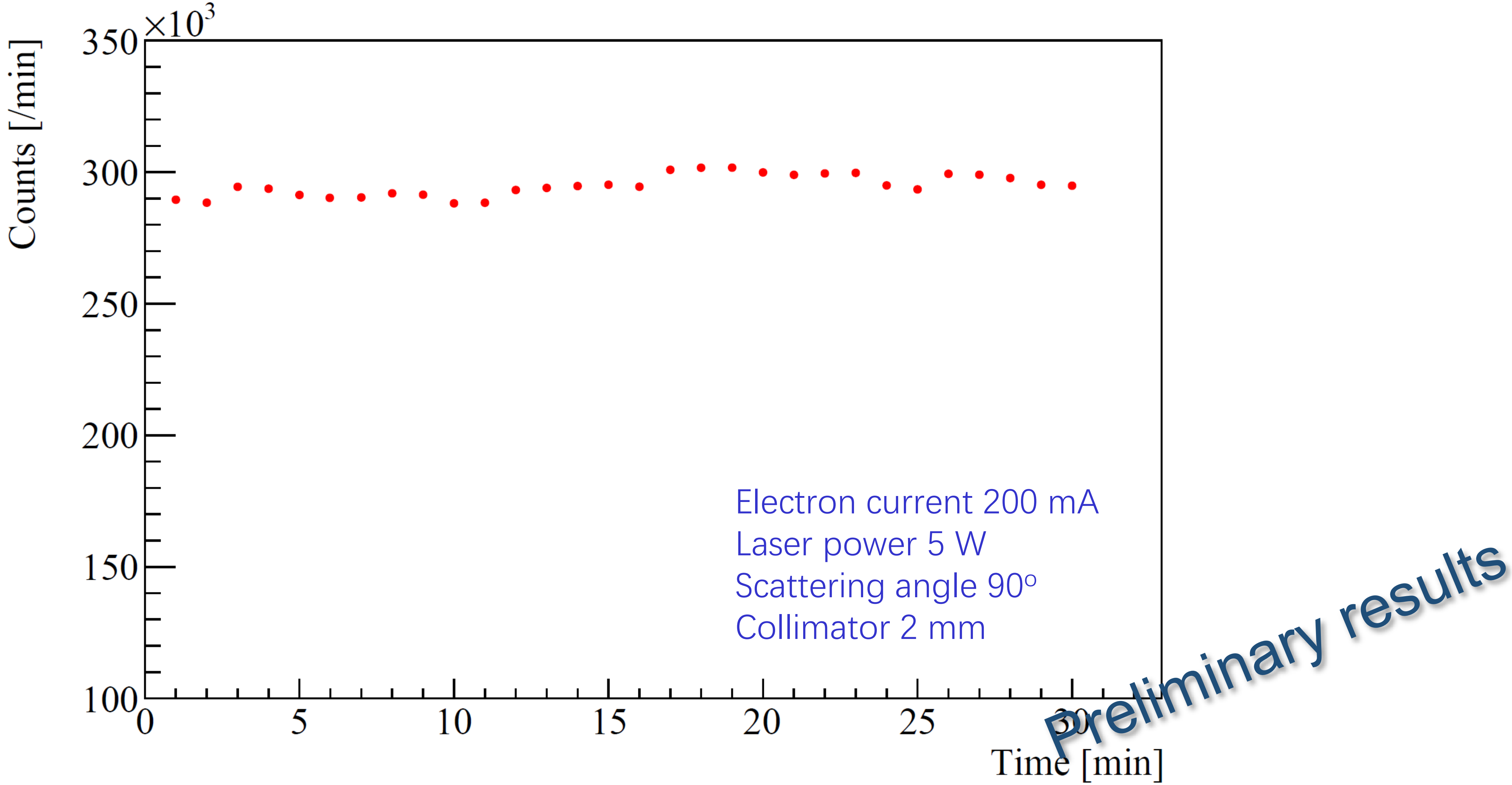




Preliminary results

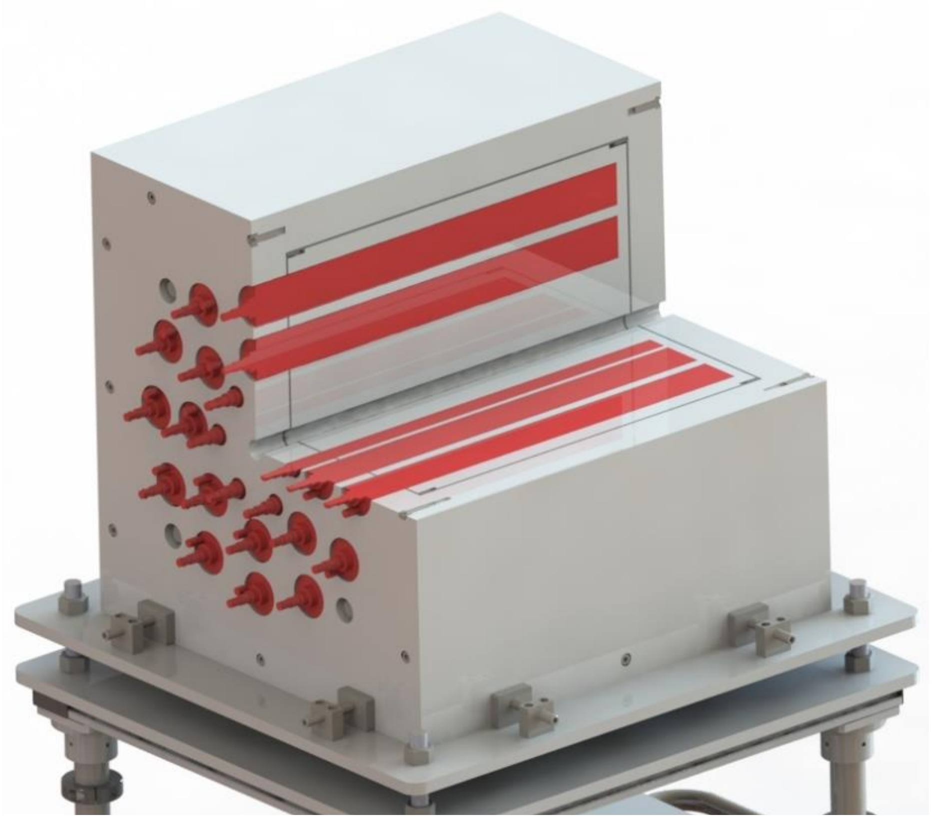
3. Working basis and progress

Gamma properties – flux stability



3. Working basis and progress

Status - End station:3He 4π 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

3. Working basis and progress

Status - End station:3He 4π neutron detector

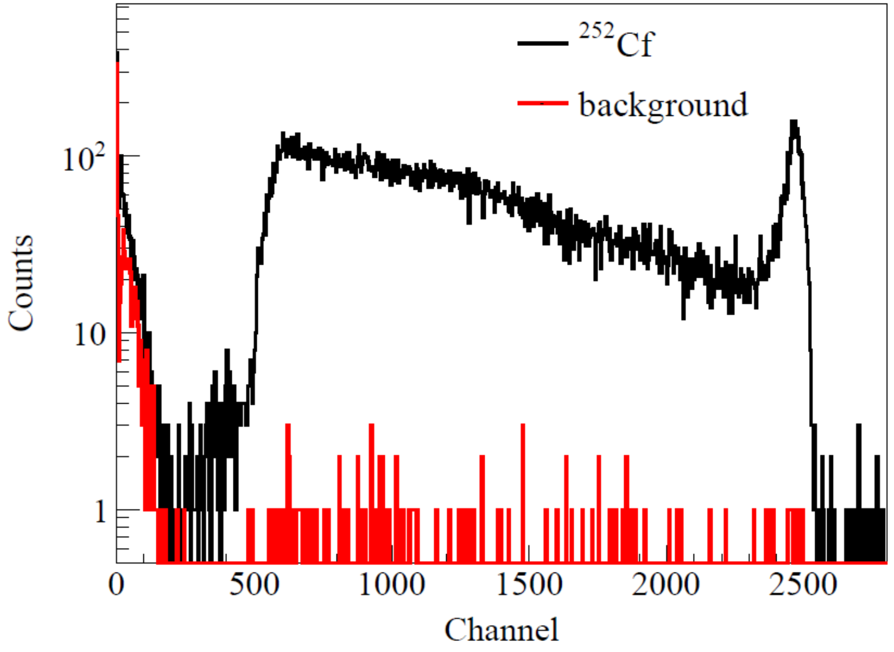
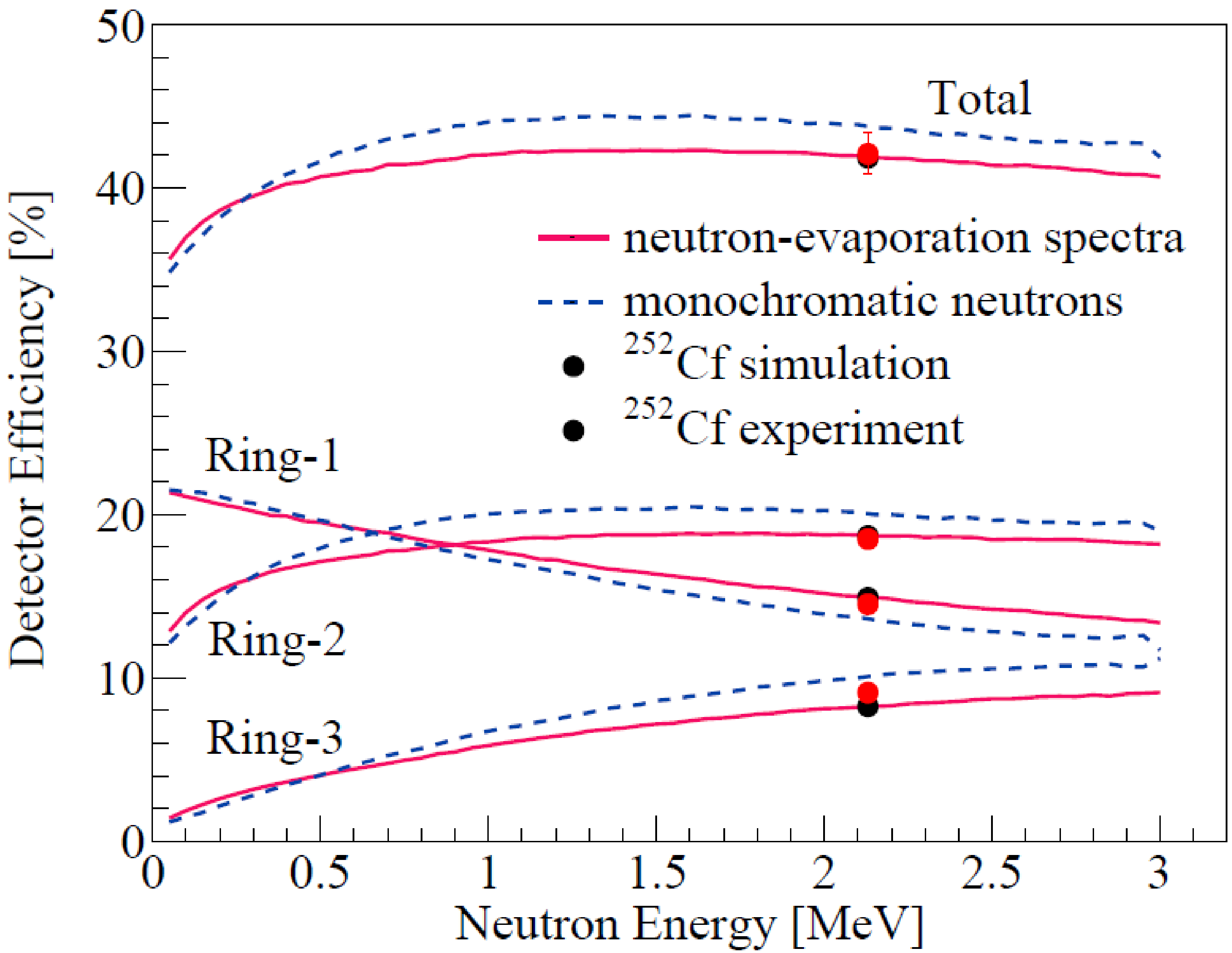


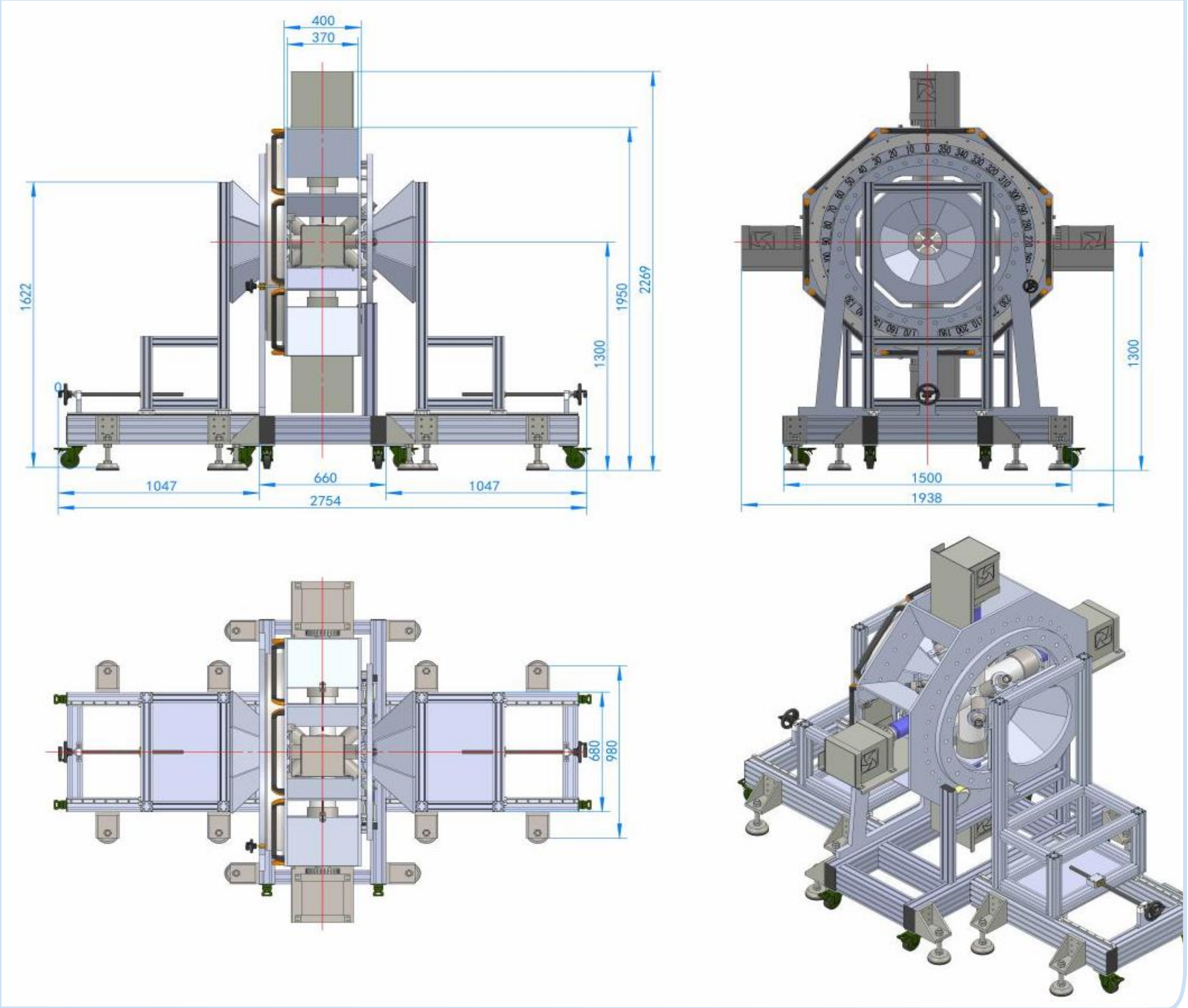
Table 1
Adjustment of the setting parameters and the resultant detector efficiencies.

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%



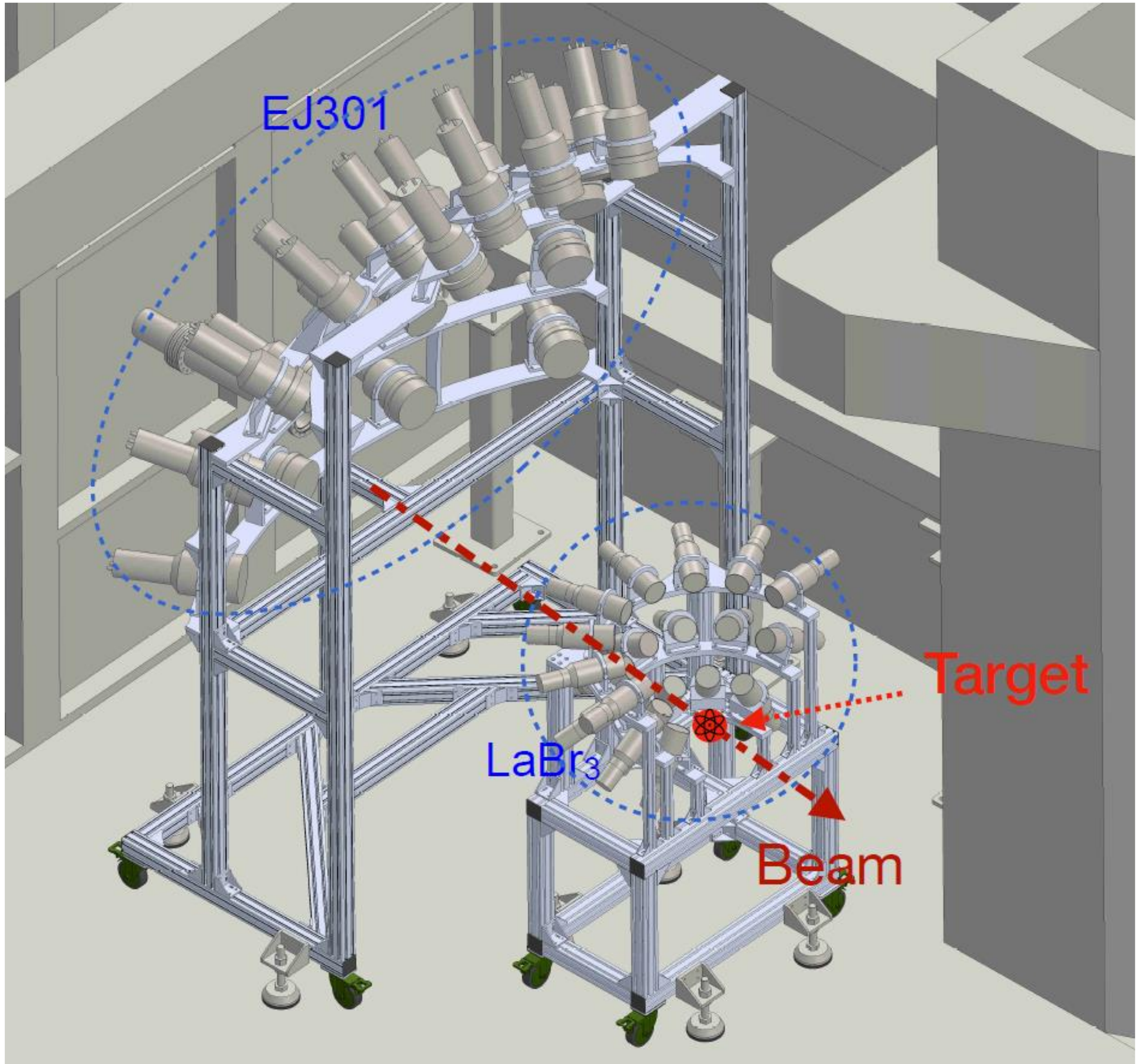
3. Working basis and progress

Status - End station: HPGe and LaBr3



3. Working basis and progress

Status - End station: TOF



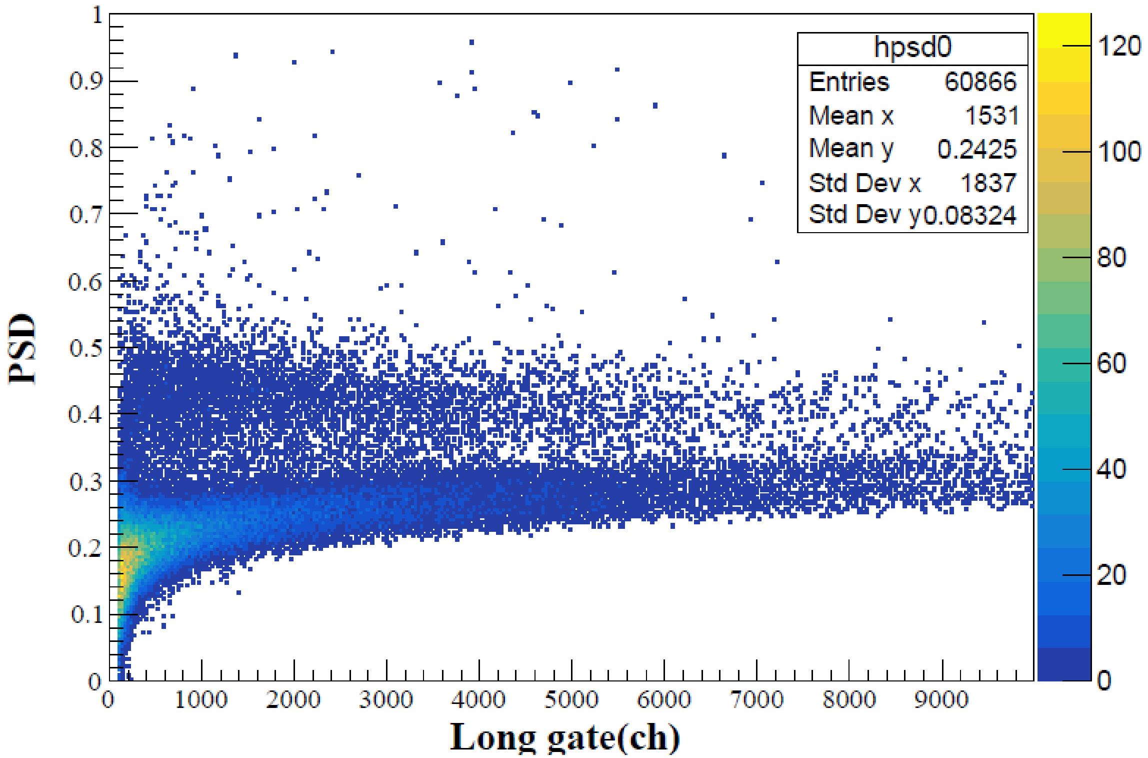


TABLE 1. The related parameters of the SLEGS TOF spectrometer.

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

Nuclear Science and Techniques, accepted (2023)

Summary

- SHINE, a high rep-rate hard X-ray FEL facility, is being developed in Shanghai, consisting of **an 8 GeV CW SCRF linac** 10 end-stations. It started construction in April 2018, achieved good progress, aiming to achieve the first XFEL lasing in 2025.
- GeV gamma-ray from inverse Compton scattering at SHINE. It will produce gamma-rays in the energy range of **0.11–8.0 GeV** with a flux of **10^5–10^{10}photons/s** based on the inverse Compton scattering of different type lasers.
- The High energy electron beam with high repetition rate and the GeV gamma-rays are possible probes for the study of hadron physics. Several preliminary research preparation work are being conducted.

Summary

SLEGS team

上海高等研究院：
SLEGS组：沈文庆，王宏伟，范功涛，许杭华，刘龙祥，张岳，曹喜光，国强，卢飞

SHINE & SXFEL：刘波，邓海啸，张猛，汪金国，王兴涛

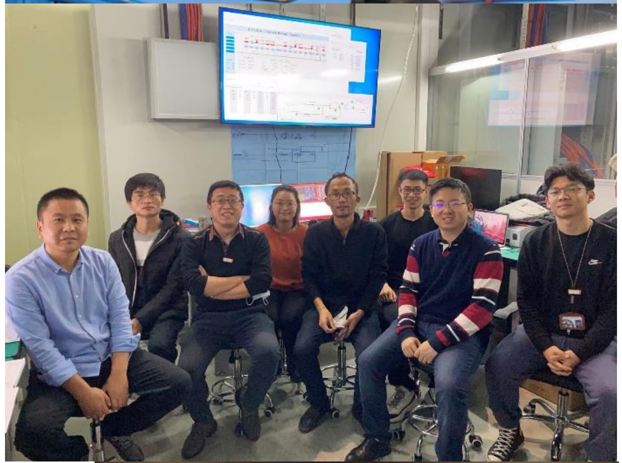
复旦大学：邓先概
北京师范大学：何建军
原子能科学院：续瑞瑞
北京航空航天大学：孙保华
应用物理研究所：黄勃松

重点研发项目

FuSiA
复旦大学：马余刚，方德清，陈金辉，马国亮，张松，符长波，寿齐烨
中科院上海应用物理研究所：蔡翔舟，陈金根，郭威

PHOENIX Collaboration
Konan U: H. Utsunomiy
NewSUBARU: S. Miyamoto
ELI-NP:D. Filipesu, I. Gheorghe
U of Oslo: S. Siem, T.Remstrom
Moscow State U: V. arlamov
ULB: S. Goriey

SLEGS咨询委员会
张焕乔，叶沿林，季向东，任中洲，李小源，张玉虎，葛志刚，吾勤之，郭冰，唐晓东，何建军，肖志刚，孙保华，牛一斐，石金水，符长波，蔡翔舟，王建松



Back up

VHF Gun and Injector Development

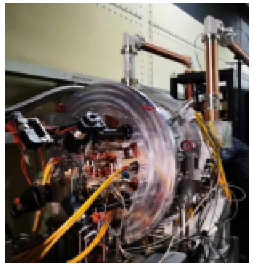
- Three VHF guns have been constructed by an accelerator group of Tsinghua University for testing the manufacturing techniques, high power CW operations and electron beam commissioning.

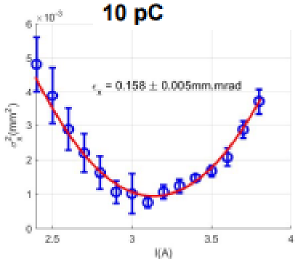
Gun RF performance

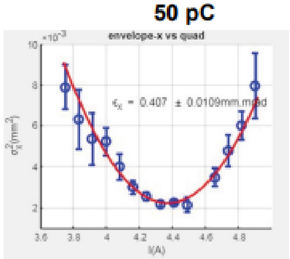
RF parameters	In design	Achieved
Operation mode	CW	CW
Cathode gradient	30 MV/m	~28 MV/m
Input power	90.4 kW	~80 kW
Voltage	868 keV	~800 keV

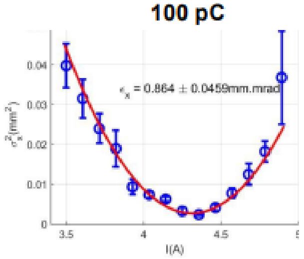
30 MeV injector was built for beam measurement

Bunch charge	Projected emittance (95%) $(um \cdot rad)$	Slice emittance (95%) $(um \cdot rad)$	Bunch length (mm rms)
10 pC	0.16	0.15	0.49
50 pC	0.41	0.38	1.15
100 pC	0.85	0.72	1.44



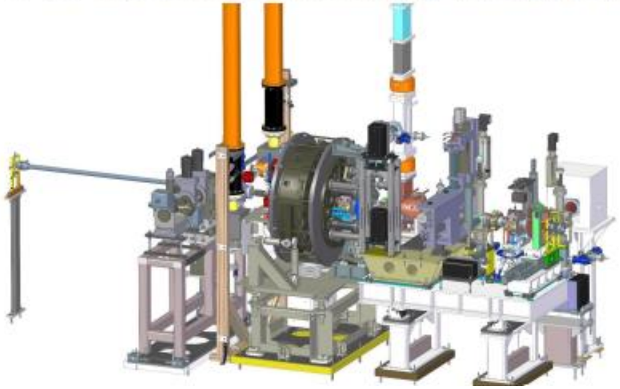


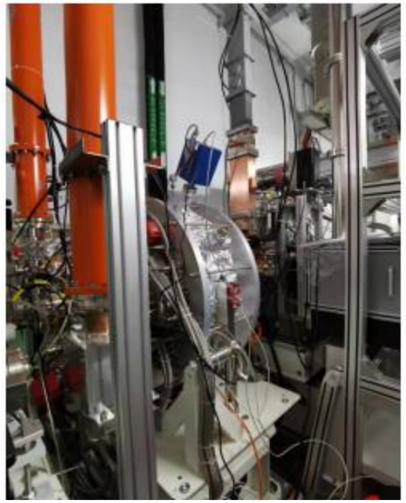




VHF Gun and Injector Development

- The SHINE VHF-gun and its beamline has been installed.
- RF and beam commissioning will start soon.

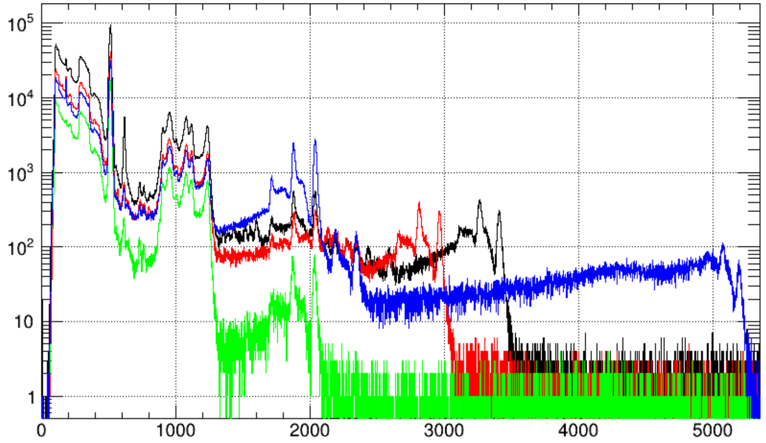




SLEGSγ-ray properties

❑ spectra

calibration-(p,γ)experiment



多角度高能沿能量