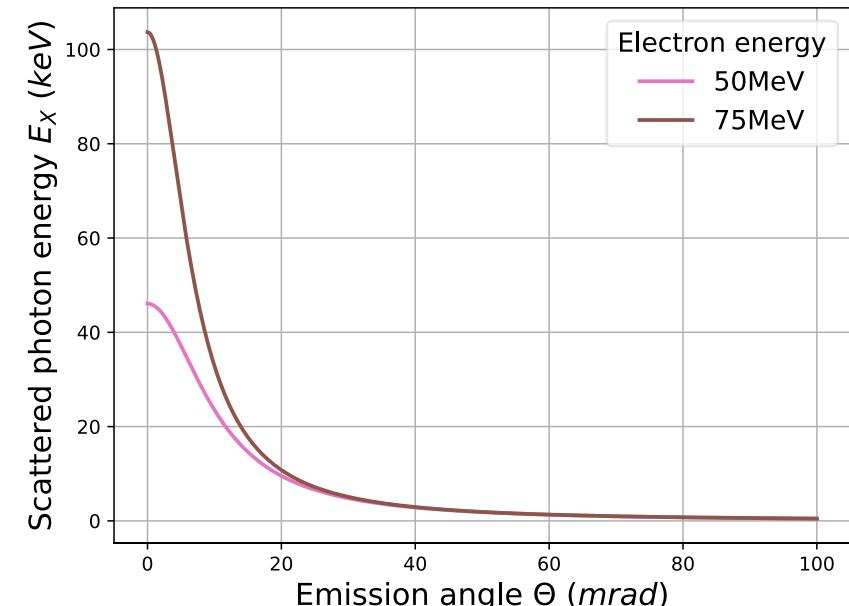
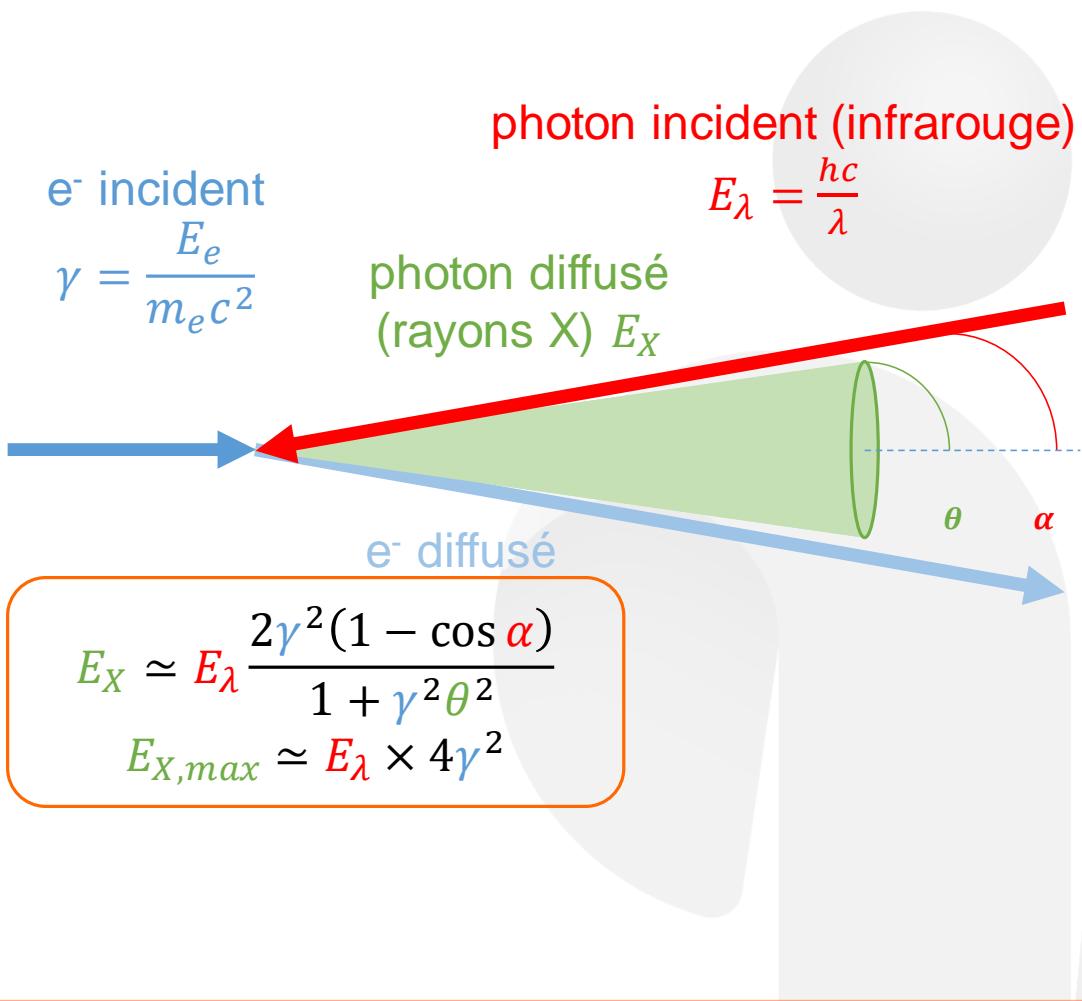


Design d'une cavité optique Fabry-Perot pour le stockage plusieurs centaines de kW et l'interaction avec des faisceaux de particules : application à l'ERL PERLE

Alice RENAUD
CNRS/IN2P3/IJLab

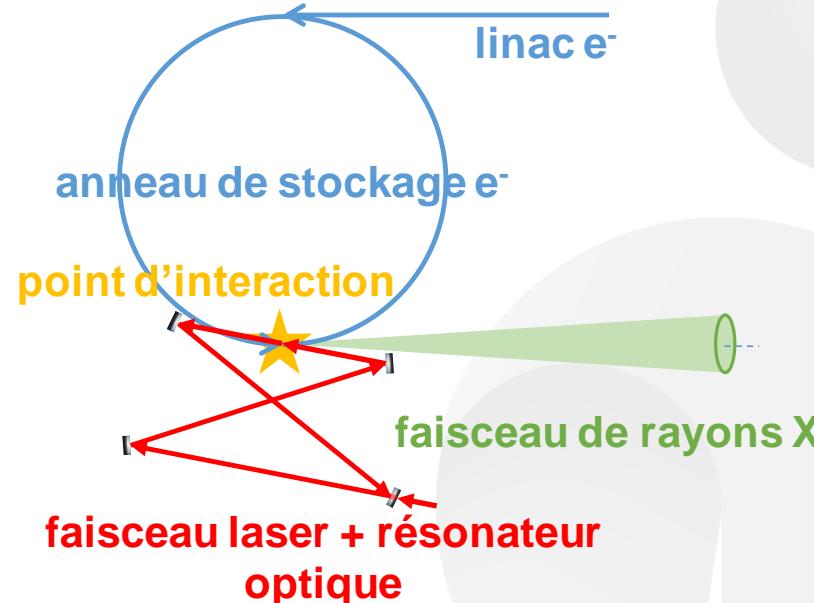
Journées “Accélérateurs” de la Société Française de Physique



$$\lambda = 1030\text{nm} \rightarrow E_\lambda = 1.2\text{eV}$$



Sources Compton compactes



- Section efficace de l'interaction Compton inverse très faible ($\simeq 0.6\text{ barn}$)
- Maximisation du flux de rayons X
- Paramètres du faisceau d' e^- fixés
- **Très forte puissance laser moyenne nécessaire : $\geq 100\text{kW}$**

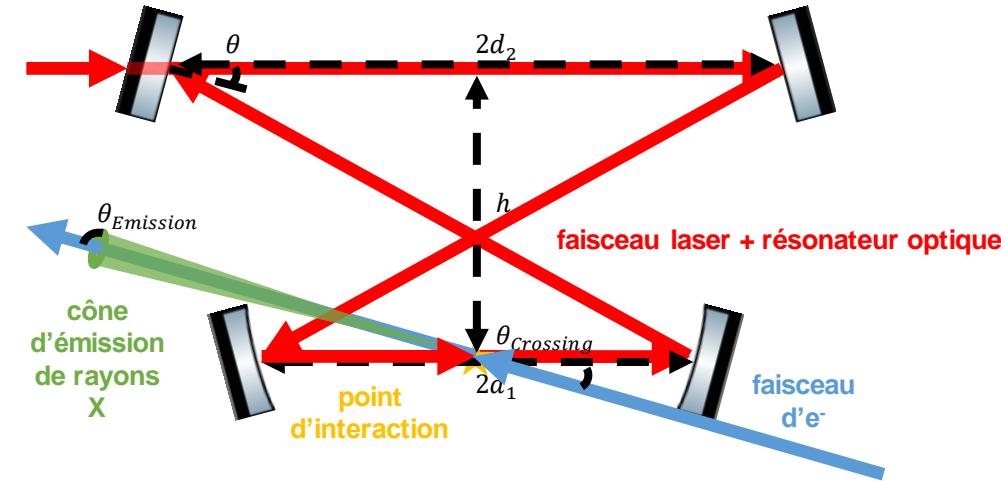
ThomX @ IJCLab

- Énergie des rayons X : 45-90 keV
- Flux de rayons X : $10^{11}\text{-}10^{13} \text{ ph.s}^{-1}$



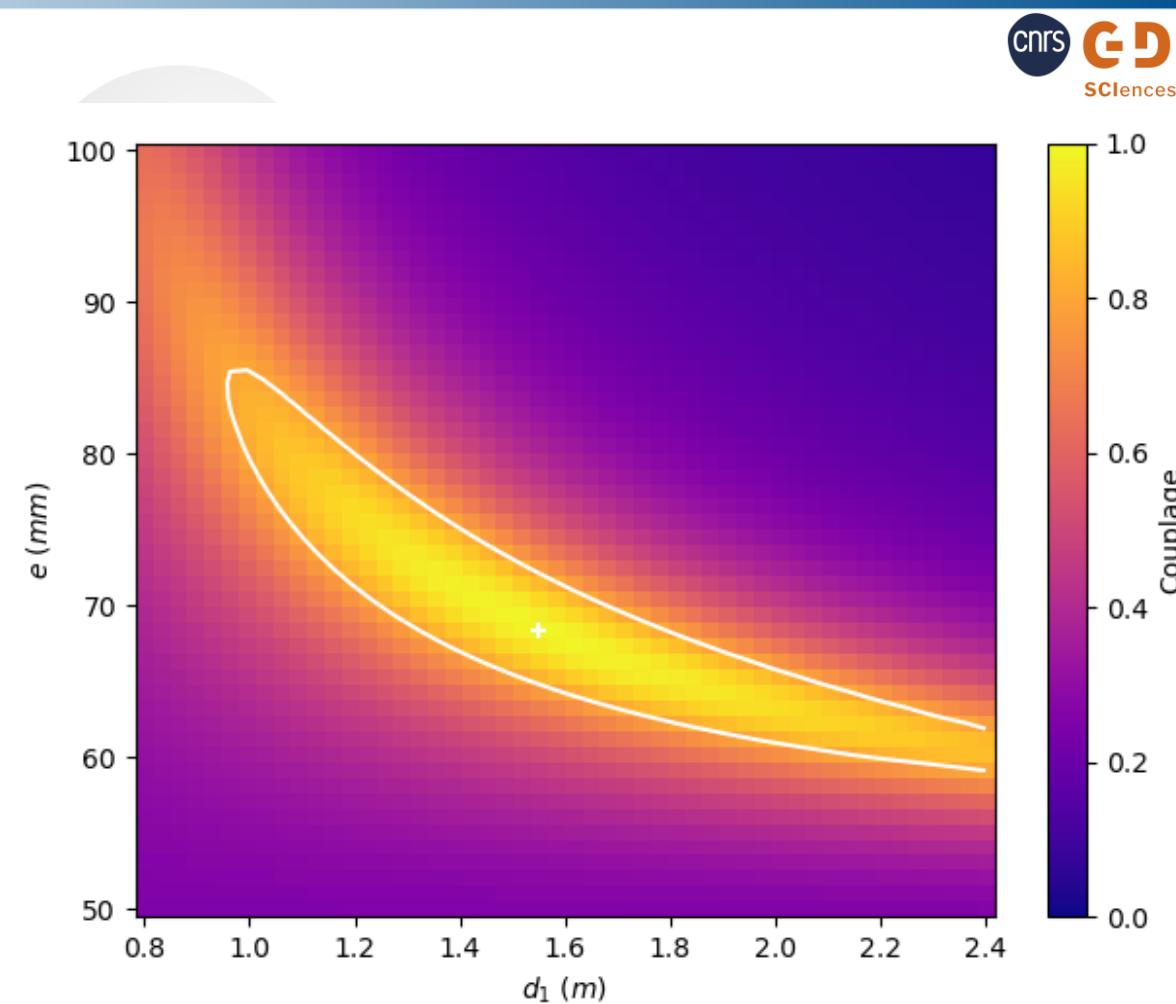
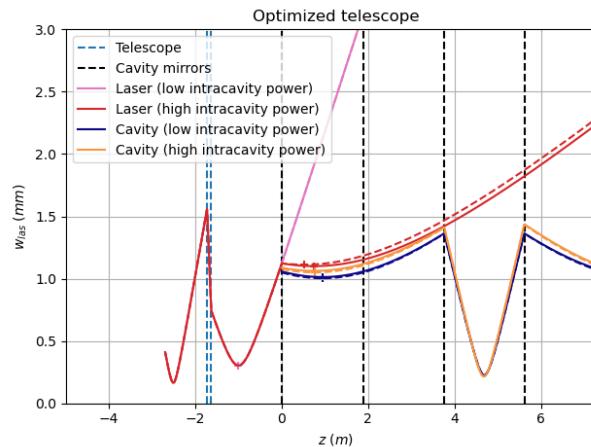
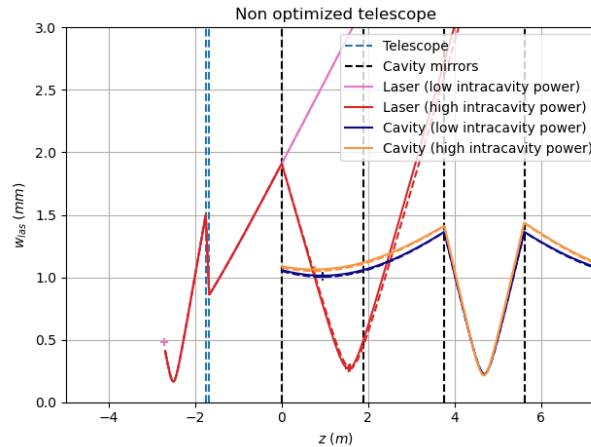
Design d'une cavité à 515nm pour l'ERL PERLE

- Caractéristiques de PERLE :
 - Contraintes d'encombrement
→ Choix de $f_{rep} \rightarrow L_{cav}, d_1, d_2, h, \theta_{Crossing}$



- Maximisation du flux de rayons X :
 - Maximisation du flux de rayons X sans couplage géométrique
 - Maximisation du couplage géométrique
 - Prise en compte des effets thermiques → minimisation de la perte de flux et de couplage dû aux changements dans le mode propre fondamental de la cavité
 - Choix de R
 - Design d'un télescope

- *Design d'un télescope :*



- *Design d'une cavité pour la production de rayons X avec l'ERL PERLE :*
 - Design d'une cavité
 - Design d'un télescope
 - Prise en compte d'effets thermiques présents à haute puissance intracavité

→ Contribution au *Technical Design Report*

→ R&D expérimentale autour des cavités

UCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

R&D on optical resonators : storing several hundreds kW of laser power in high-finesse optical cavities

Alice RENAUX^{a,b}, Ronic CHICHE^a, Kevin DUPRAZ^a, HUANG Wen-Hsi^a, HUANG Yu-Tong^a, LIU Jing^a, LU Xin-Yi^a, Aurélien MARTENSEN^a, Danièle NUTARELLI^a, Viktor SOKSOV^a, TANG Chuan-Xiang^a, YAN Li-Xin^a, YANG Zhao^a, ZHAO Yan^a, Fabian ZOMER^b

^a Université Paris-Saclay, CNRS/IN2P3, UCLab, 91405 Orsay, France
^b Department of Engineering Physics, Tsinghua University, Beijing 100084, China

UCLab's Laser-Electron Interaction group has been developing high-gain, high-average power (several hundreds kW) optical cavities operated in pulsed regime. The main application of this technology is the production of highly monochromatic X-ray beams through inverse Compton scattering^[1]. The storing of such optical powers remains challenging, namely regarding the seeder laser's phase noise, the mirrors' coatings and the management of thermal effects, but new records were recently set in both pulsed^[2,3] and CW regimes, which could enable new applications.

cnrs **CDR SCiPAC**
SCIences of Particle ACcelerators

Compton scattering^[1, 2]

Inverse Compton Sources^[1, 2]

High intracavity power experiment at Tsinghua University (Beijing, China) (CW regime)

Experimental setup

Results

References

- [1] Fawcett, D. Etude et conception d'une cavité Fabry-Pérot de haute fréquence pour la source compacte de rayons X Thés. PhD These 2017. Date de soutenance: 2017-06-20. Directeur(s) principal(s): Zomer, Fabien. Présenté par: Université Paris-Saclay (Comité de soutenance: Zomer, Fabien (Président), Martensen, Aurélien, Renaux, Alice, Soksov, Viktor, Nutarelli, Danièle, Tang, Chuan-Xiang, Yan, Li-Xin, Yang, Zhao, Zhao, Yan, Zomer, Fabien).
- [2] K. J. L., H. Chen, R. Duguet, A. Martens, D. Nutarelli, W. Stoen, F. Zomer, X. Li, J. X. Wang, B. H. Huang, C. X. Tang, C. G. Zhou, Y. Li, Y. Yang, Y. Zhao, Y. Yan, L. X. Yan, Y. Yang, Z. Zhao, Y. Zhao, Y. Yan, F. Zomer, and F. Zomer, "A 4-mirror bow-tie cavity for high-power inverse Compton scattering," *Nature*, vol. 495, pp. 44–47, November 2013.
- [3] K. J. L., H. Chen, R. Duguet, A. Martens, D. Nutarelli, W. Stoen, F. Zomer, X. Li, J. X. Wang, B. H. Huang, C. X. Tang, C. G. Zhou, Y. Li, Y. Yang, Y. Zhao, Y. Yan, L. X. Yan, Y. Yang, Z. Zhao, Y. Zhao, Y. Yan, F. Zomer, and F. Zomer, "A 4-mirror bow-tie cavity for high-power inverse Compton scattering," *Nature*, vol. 495, pp. 44–47, November 2013.

Optical resonators : optical enhancement cavities (pulsed regime)^[1]

Laser-cavity coupling^[1, 3, 4]

Temporal coupling (pulsed regime)

- Combs lines spacing matching: $f_{\text{FSR}} = f_{\text{FSR}}$
- Combs positions matching : carrier envelope phase (CEP)

Spatial coupling

- Make the cavity mode's and the laser's waist positions and sizes match by means of a 2-lens telescope.

Some challenges^[1, 3, 4]

- Seeder laser phase noise : frequency jitter $\Delta \omega$ (\sim a few kHz), 3pm
- CW laser optical frequency = 300THz → very low phase noise
- Mirrors surface : high reflectivity, low absorption and scattering
- Thermal effects with a high intracavity power → changes in the mirrors' radii of curvature → changes in the cavity's transverse mode(s) and in the cavity's resonance frequencies → coupling losses
- Maximum stored power in pulsed regime (UCLab) : **7100W** for a **47.5PW** input in a 2-mirror cavity^[2] and **530kW** for a **75PW** input in a 4-mirror bow-tie cavity^[3] (stable for ≥ 10 minutes with a relative standard deviation ≤ 0.6% in both cases) in 2024.
- Maximum stored power in CW regime (Tsinghua University) : **700kW** for a **BSW** input in April 2025 (stable for 2 minutes with a relative standard deviation ≤ 0.6%) and **> 800kW** for a **= 100W** input (stable for 1 minute) in a 4-mirror bow-tie cavity in July 2025.
- Current detector technologies : waveplates, waveplates, wave detectors (LIGO, VIRGO), high-harmonic generation, X-ray production^[2].
- Potential future applications : steady-state microbunching of electrons for the production of high-power and high-repetition rate EUV beams for EUV lithography, photoneutralization of negative hydrogen and deuterium ion beams for nuclear fusion experiments.

Merci pour votre attention

Des questions ?