EOサンプリングを用いたタイミング・ドリフト制御によるHHGシード型EUV-FELの高ヒット率化

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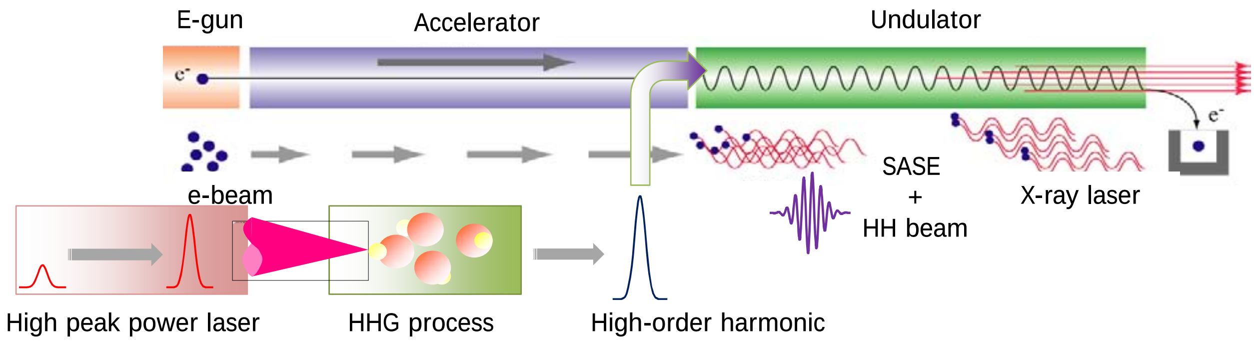
RIKEN XFEL Division

On behalf of all the staffs contributed to
HHG-seeded EUV-FEL (SCSS) and improvements of SACLA

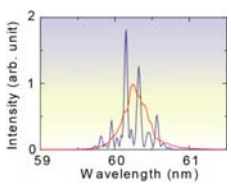
SASE光のシード化の目的

SASE-FEL: (Self Amplified Spontaneous Emission)

Special coherence: *100%*
Temporal coherence: **～1%**

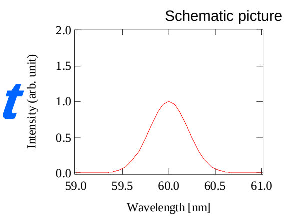


SASE-FEL



Full- Coherent

Seeded FEL

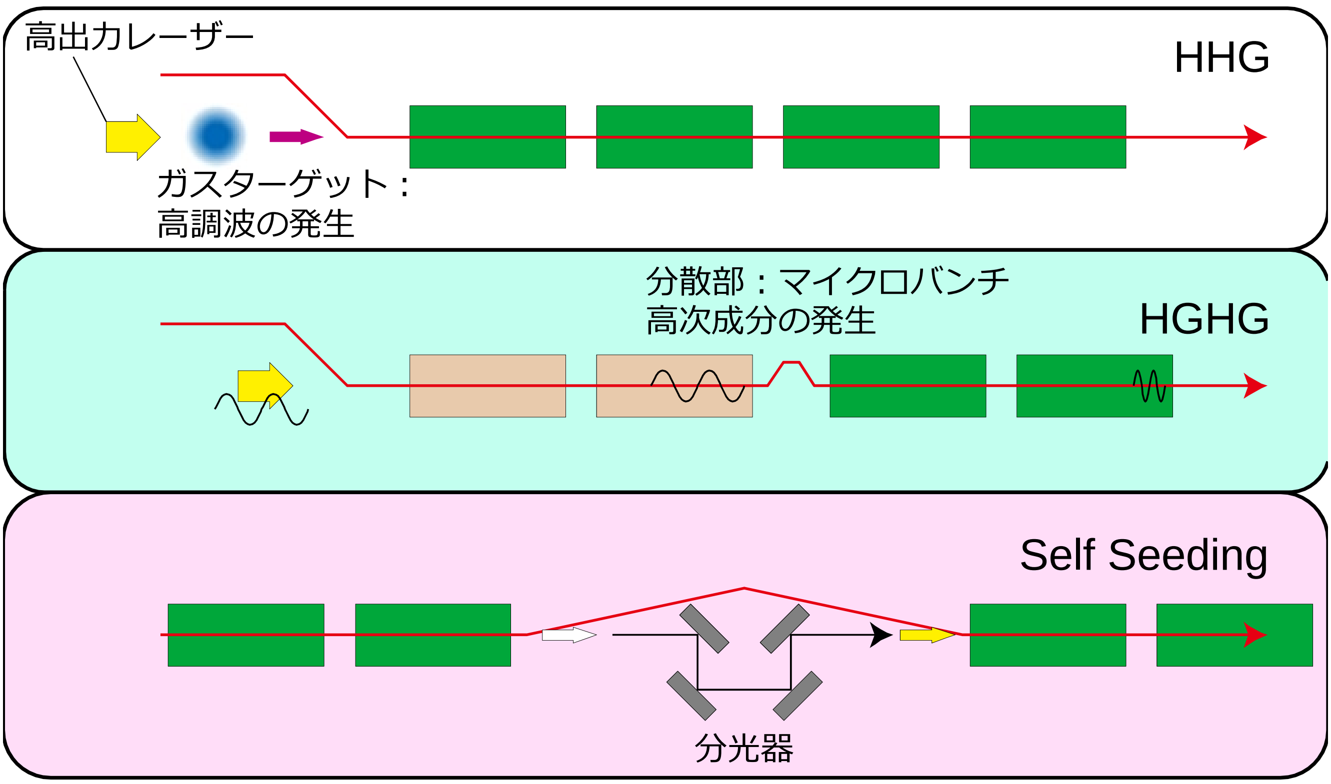


SASE FELからシードFELへ

- **第二世代FEL**
  - 空間だけなく時間方向でもコヒーレントな光源とする。
  - スペクトルの狭帯域化と中心波長の安定性。

    （現在の応用ではもっぱら、この特性を利用する実験が多い）
- **（硬X線）HXR領域のシーディング**
  - Self-seedingという方式が用いられるようになり、現在これを超える方式は提案されていない。
- **（軟X線）SXR領域のシーディング**
  - HHG(光学レーザ）をシード光として用いて、その後の短波長化はHGHGなどを用いることで達成する。

シーディングの短波長化



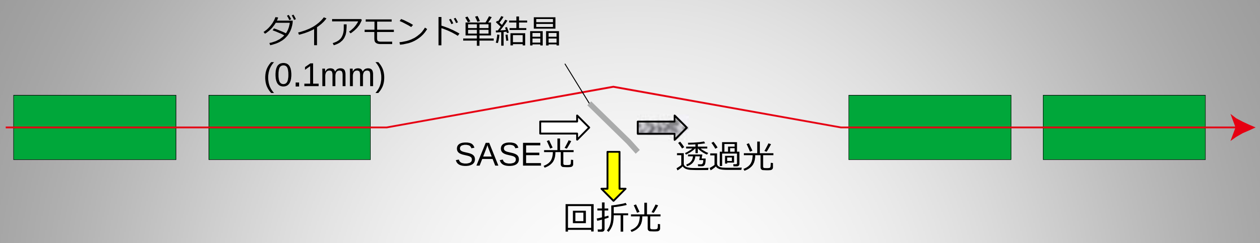
各種シーディング法の比較

- シード光の短波長化
  - HHG：高出力レーザーによる高調波発生
  - HGHG：マイクロバンチ高次成分の利用
  - シード光と電子ビームの同期精度？
  - 数nmが限界？
- セルフシーディング
  - 飽和前のSASE光を分光器にて単色化し、シード光として利用
  - 短波長限界、同期精度の問題なし
  - GeV電子ビームでは長大なスペースが必要

Hard X-ray Self Seeding (HXRSS)

- Hard X-ray Self Seeding
  - SASE型FELの欠点である、不完全な時間コヒ ーレンスを改善するシーディング手法を、硬Ｘ線 領域で実現する試み
  - Self Seedingは元々軟Ｘ線でシーディングを実 現するためにDESYグループによって提案され た手法で、同期の問題を回避できるが、そのま ま硬Ｘ線に適用するのは若干非効率
  - より簡便な方法が同グループから提唱され、これがLCLS、SACLAで採用へ。

セルフシーディングの新手法[1]



- 単結晶の回折効果により、透過光には単色 光成分が含まれる
- この成分は入射光の主成分から時間的に若干遅れている(数μm~数10μm)
  - 適切な遅延を電子ビームに与えることによって シード光として利用できる

[1] G. Geloni, V. Kocharyan, E. Saldin, DESY 10-053

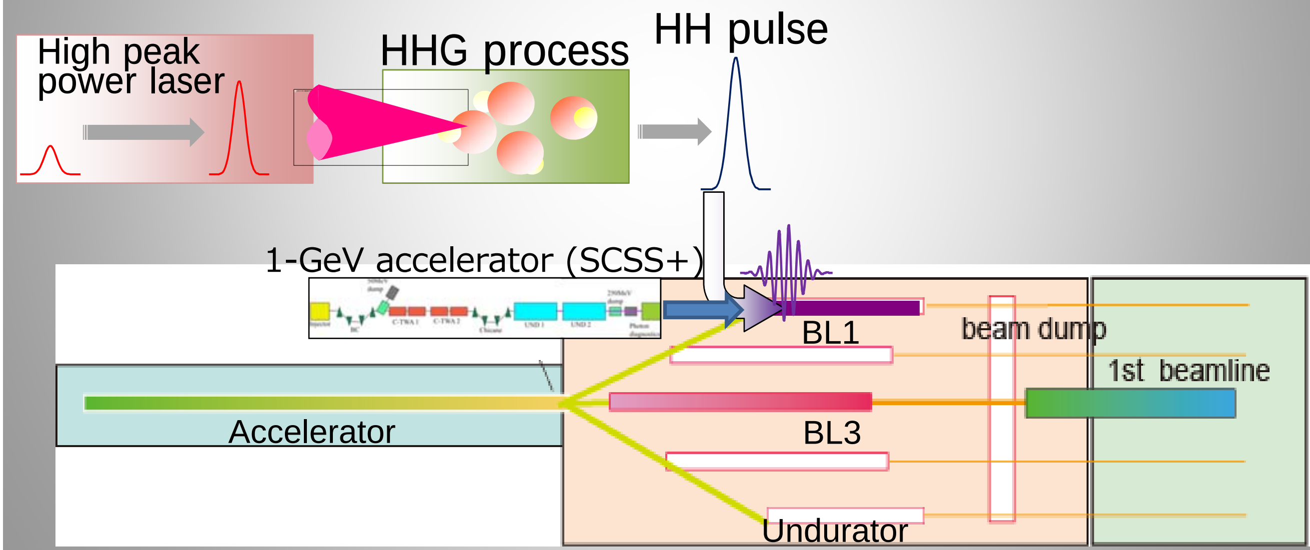
SACLAでのシードFELの目標と戦略（術）

- **目標（Mission）**
  - 常時シード化したFELを発振させ、利用実験に供する。
  - SXRのシード技術を確立する（SCSS増強・移設後にWater Windowまで達成する）。
- **戦略（Strategy）**
  - HHGパルスと電子バンチの３次元的重なりの最適化と保持
    （正確には、６次元位相空間でのフル・マッチングが必要）
- **戦術（Tactics）**
  - HHG(レーザ）、加速器、タイミングシステムの総合的安定化
  - EOタイミング計測によるドリフトの制御による高ヒット率化

SCSS⁺のシード計画(最終目標)

160 nm ⇒ <u>61 nm</u> ⇒ 13 nm
(SCSS)
⇒Water window (2-4 nm)

SACLA

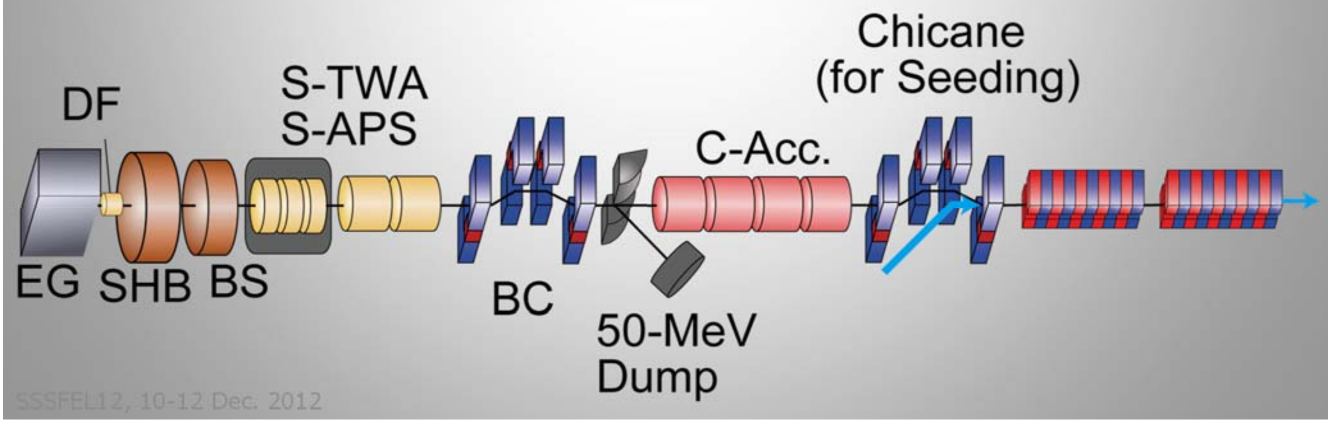


History of Seeding Experiments

Date	Event	Condition	Reference
June 2006	The first SASE amplification with our new machine concept	250 MeV, 49nm	
Dec. 2006	Seeding at **160 nm**	150 MeV, HHG 5th	G. Lambert et al., Nat. Physics 4, 296 (2008)
Sept. 2007	SASE saturation	250 MeV, 50~60nm	T. Shintake et al., Nat. Photonics. 2, 559 (2008)
Oct. 2010	Seeding at **61 nm**	250 MeV, 300 fsec HHG **13th**	T. Togashi, et al., Opt. Exp. 19, 317 (2011)
March 2011	The first test of Arrival time monitor (relative timing btw. e-bunch and HHG with EO sampling)		H. Tomizawa, BIW2012, Newport News, VA (2012)
July 2012	Seeding at **61 nm** **(hit rate: ~30%)**	250 MeV, 600 fsec HHG **13th**	H. Tomizawa, et al., LINAC2012, Tel-Aviv (2012)
July 2012	Experiments with stabilized seeded FEL at **61 nm**		to be submitted

Seeding at SCSS Test Accelerator

- SCSS Test Accelerator
  - Constructed and operated to demonstrate the concept of SACLA (250MeV, 60nm)
  - Just in front of the undulator section, a chicane has been installed to inject a laser beam for seeding experiments



シードEUV-FELの共同開発＆利用実験チーム

HHG
Extreme photonics Research Group, Riken
E. Takahashi, K. Midorikawa

High Power Laser
Japan Atomic Energy Agency
M. Aoyama, K. Yamakawa

SACLA **(青字はEO-Sampling関係者)**
T. Togashi, T. Sato, **K. Ogawa**, **S. Matsubara**, **Y. Okayasu**, T. Watanabe, H. Tomizawa, T. Hara, M. Nagasono, T. Tanaka, H. Tanaka, Y. Otake, M. Yabashi, T. Ishikawa

Ultrafast EO Crystal
RIKEN SENDI
T. Matsukawa,
H. Minamide

Application
Tokyo Univ.
A. Iwasaki, S.　Owada, K. Yamanouchi

Task force in our collaboration for HHG-seeding

Supports for this projects:
•RIKEN/JASRI XFEL project
•SCSS test accelerator operation team (Engineers)
Financial supports :
•RIKEN extreme photonics (Dr. Midorikawa)
•MEXT   X-ray free electron laser utilization research (Prof. Kaoru Yamanouchi, The University of Tokyo), *"Pump and probe experiment of atom, molecule and cluster by XFEL light and advanced laser light"*

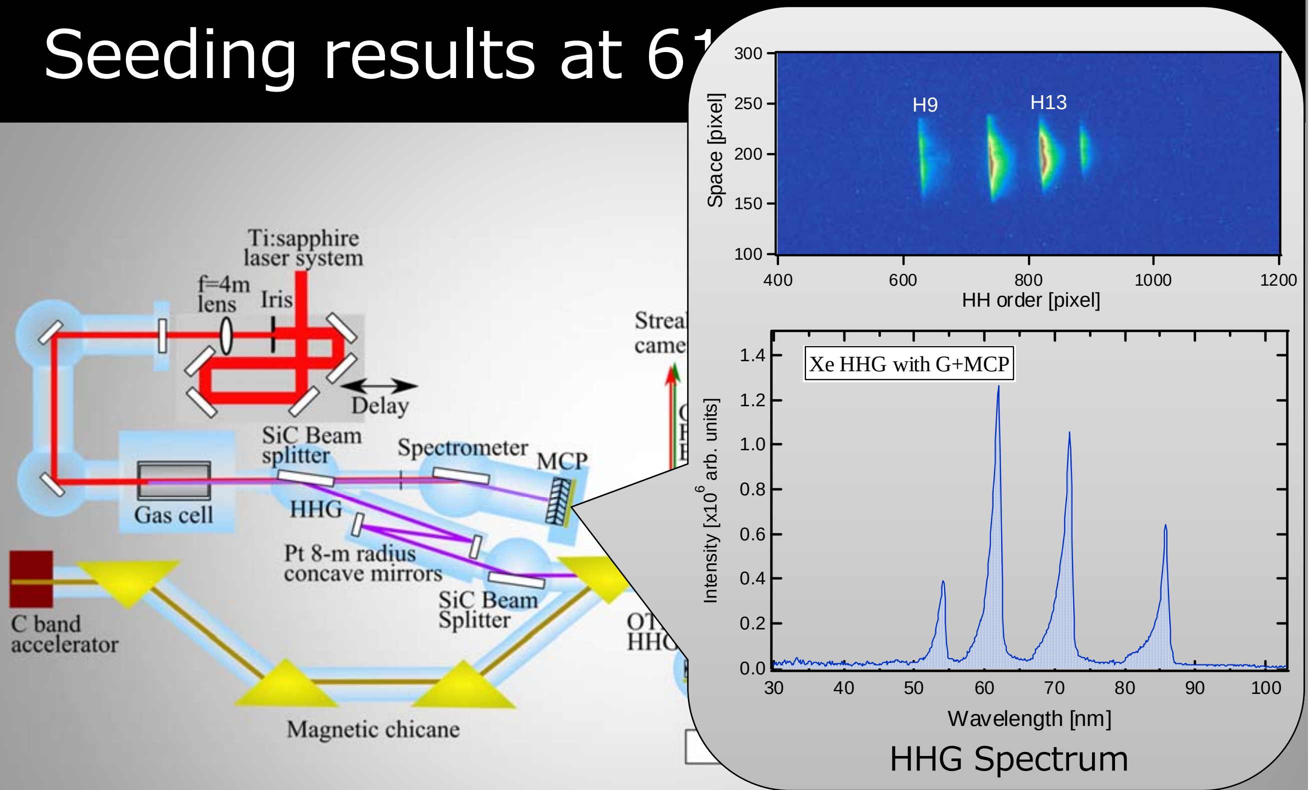
Japan Atomic Energy Agency, Quantum Beam Science Directorate
M. Aoyama, K. Yamakawa,
Synchrotron SOLEIL
Marie E. Couprie

THE UNIVERSITY OF TOKYO

JAEA

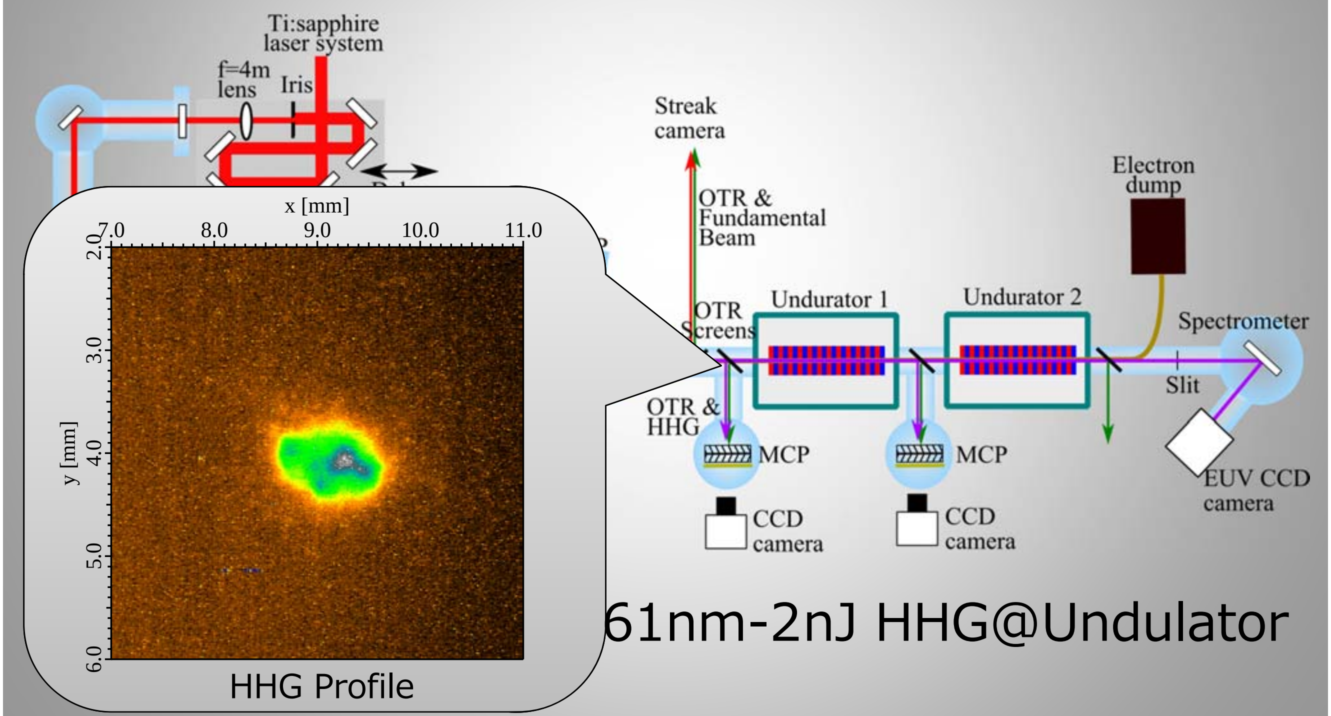
RIKEN

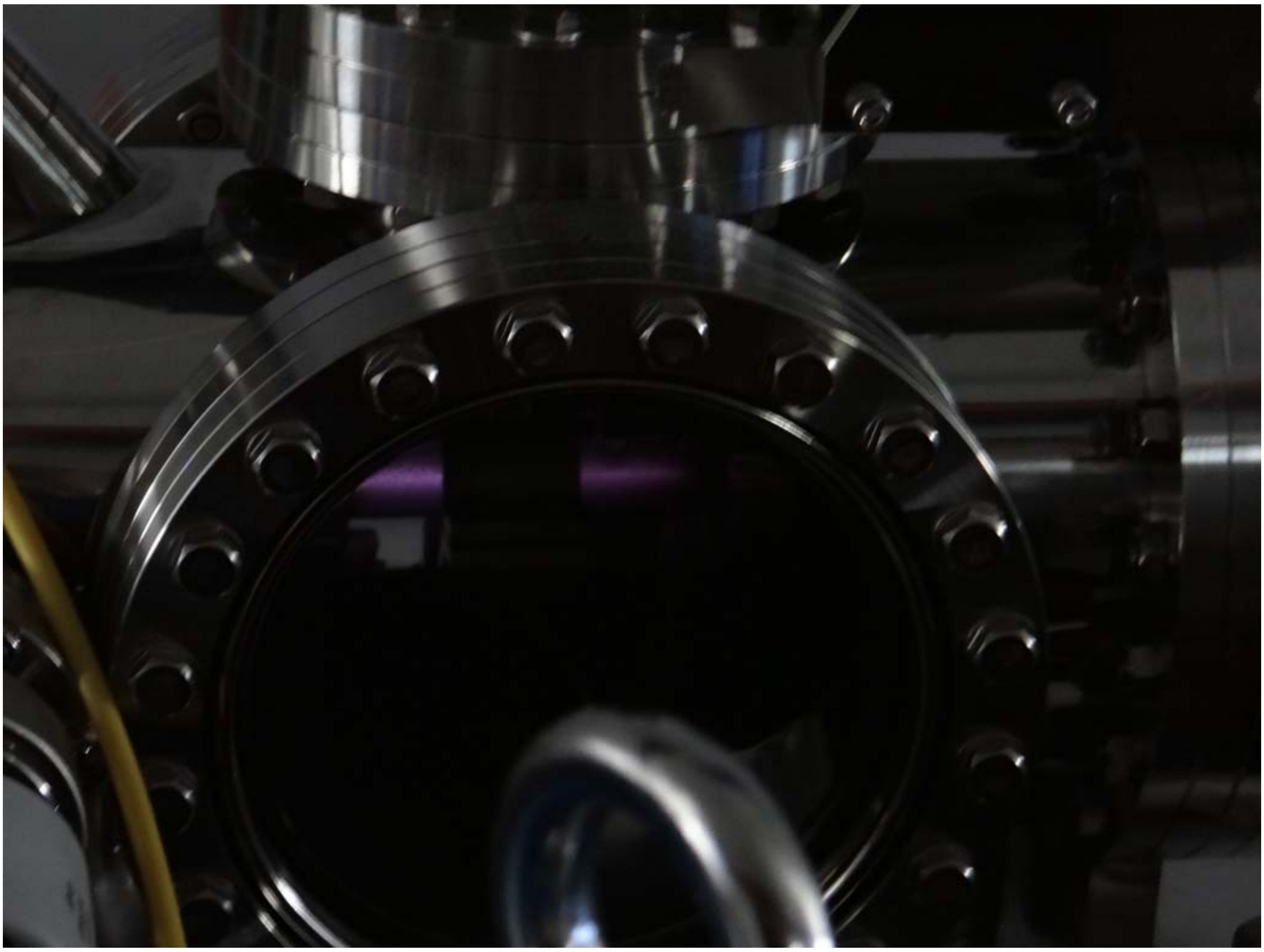
Seeding results at 61



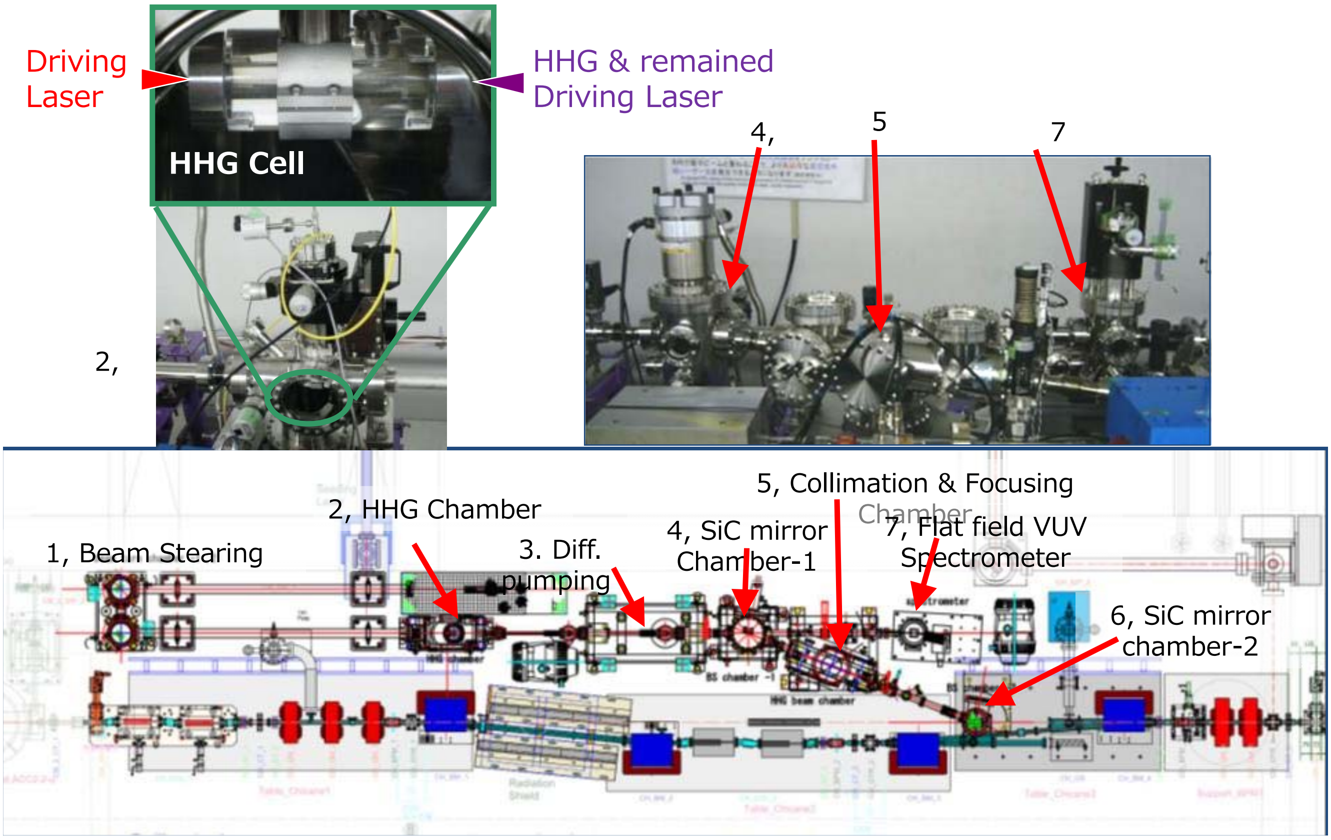
61nm-2nJ HHG@Undulator

Seeding results at 61 nm in 2010 (1)

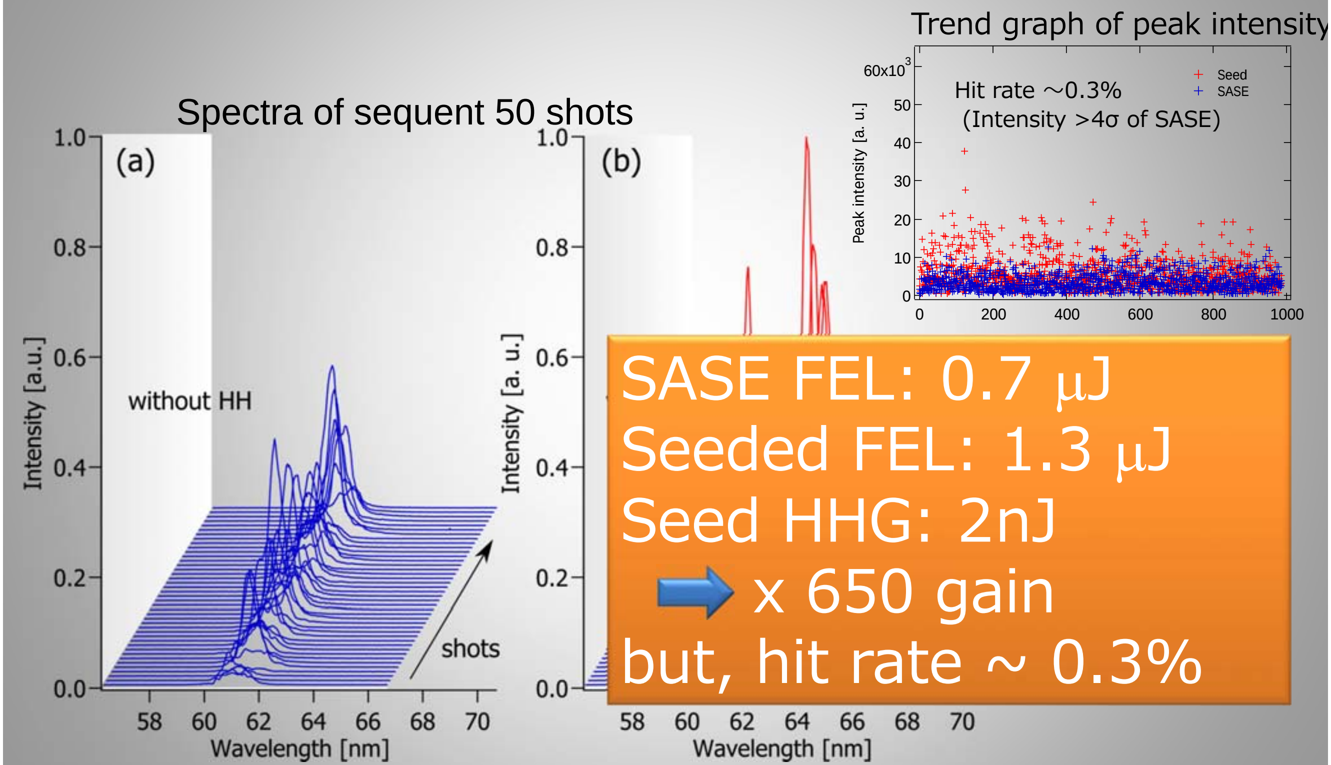




Experimental setup: HHG and injection



Seeding results at 61 nm in 2010 (2)

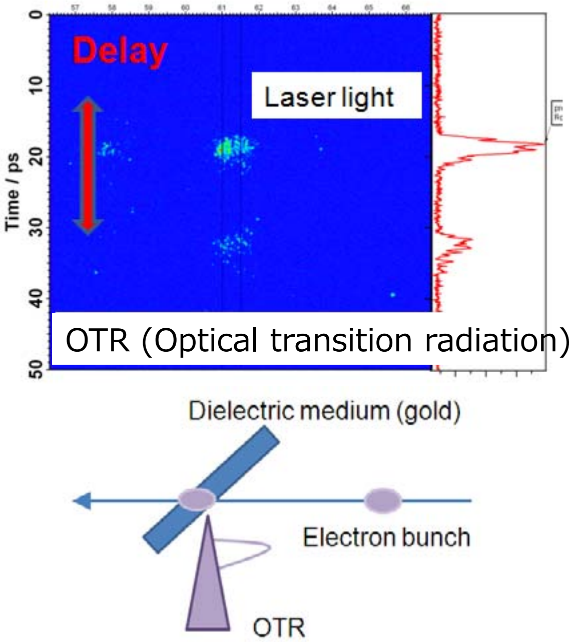


SASE FEL: 0.7 μJ
Seeded FEL: 1.3 μJ
Seed HHG: 2nJ
➡ x 650 gain
but, hit rate ~ 0.3%

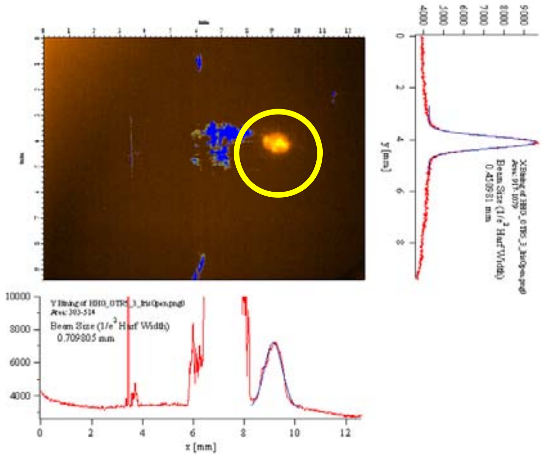
T. Togashi *et. al.*, Optics Express, Vol. **19** Issue 1, pp.317-324 (2011)

Optimization of temporal and spatial overlap between e-bunch and driving HH-laser pulse

Temporal Overlap



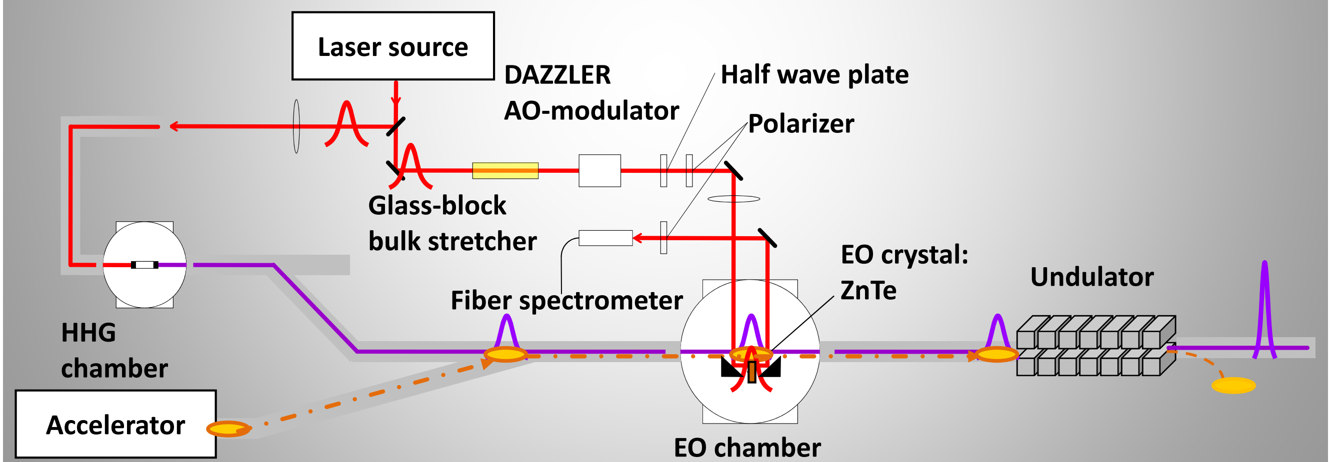
Spatial Overlap



- MCP + Phosphor Screen + CCD
- Before and after 1st undulator

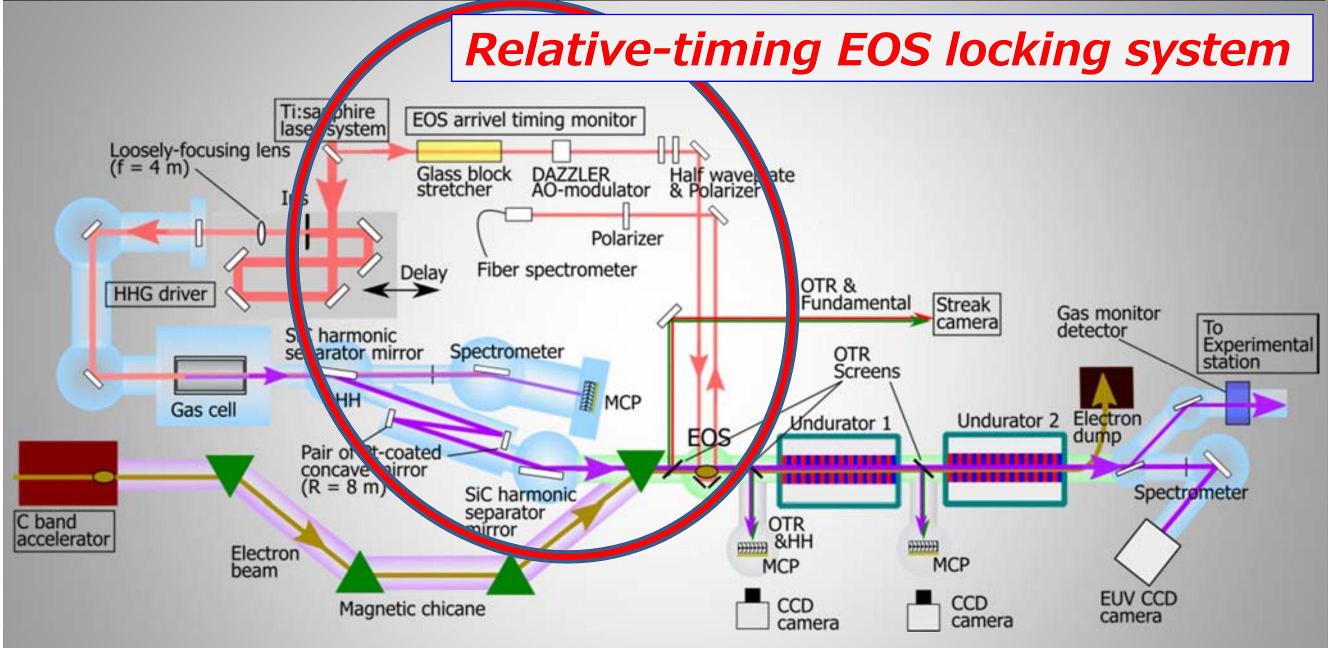
Improvement of Hit Rate (~2012) (1)

- Bunch length stretched (0.3⇨0.6 psec)
- Arrival time monitor by means of EO-sampling implemented



H. Tomizawa, Linac2012, Tel-Aviv

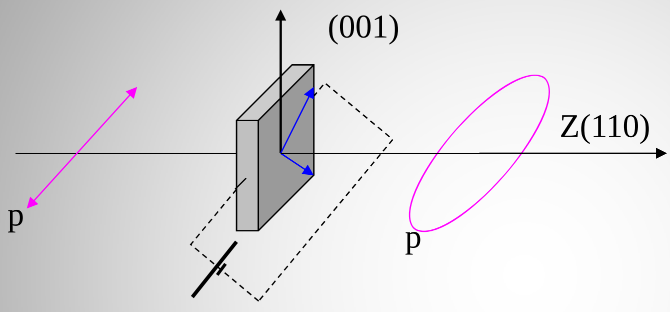
Improvement of Hit Rate (~2012) (2)



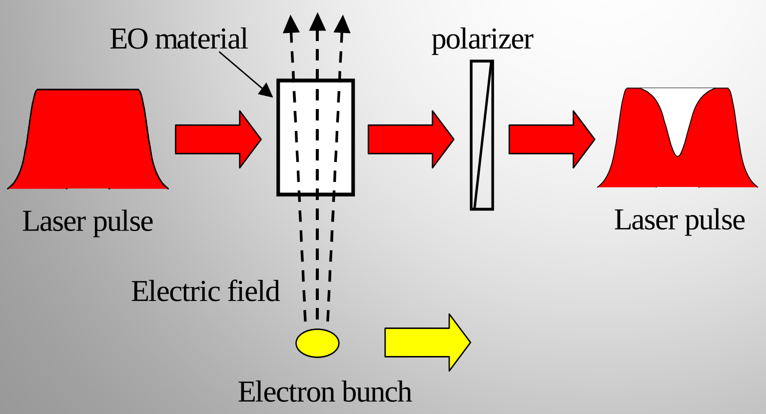
61nm-2nJ HHG@Undulator

Principle of EOS (Electro-optic Sampling)

Pockel's effect (ZnTe)

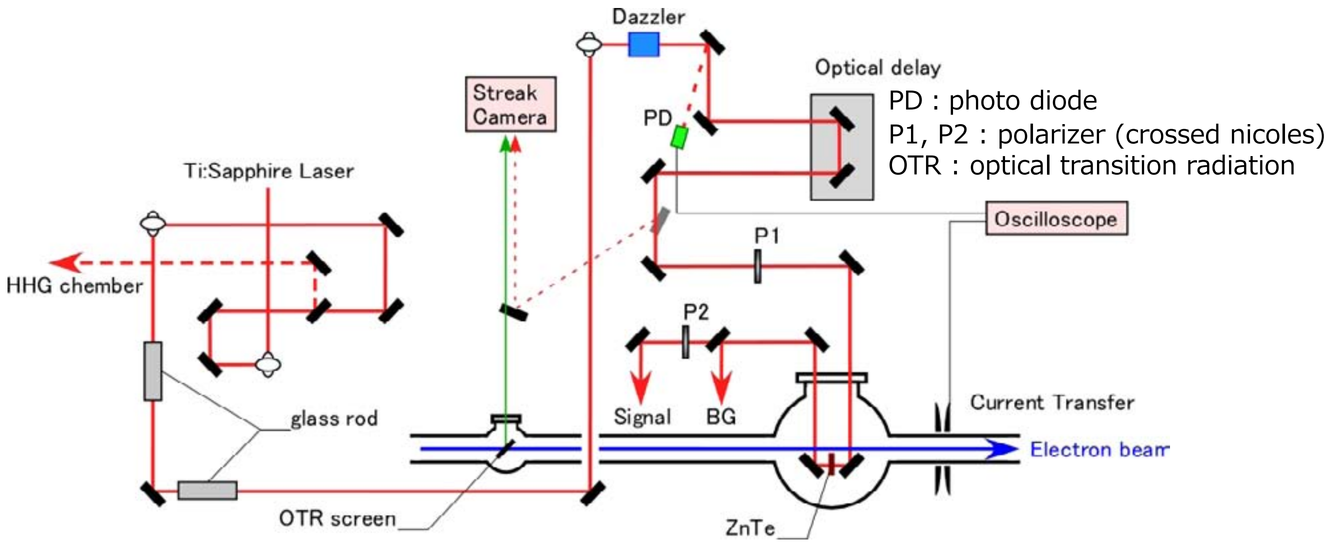


By detecting this phase shift we will know the electrical field



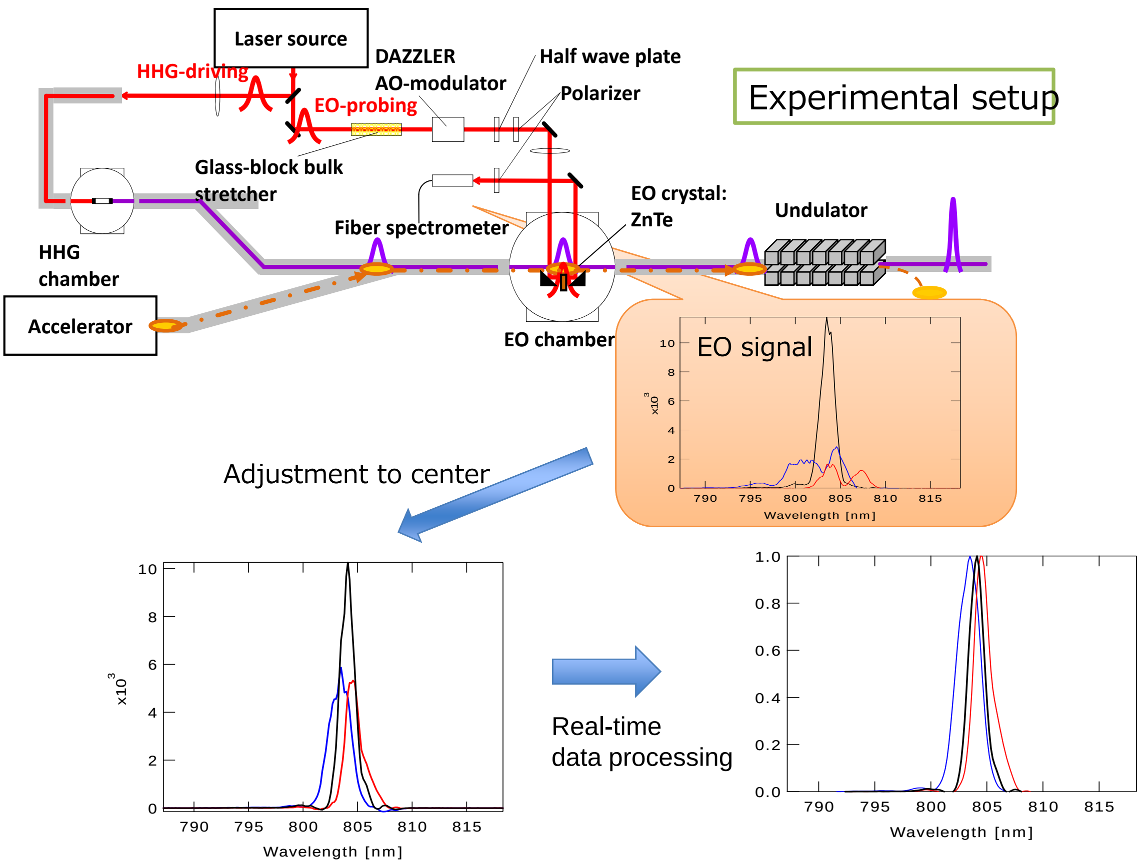
- Spectral decoding
- Temporal decoding
- Spatial decoding

EOサンプリング法によるタイミング制御

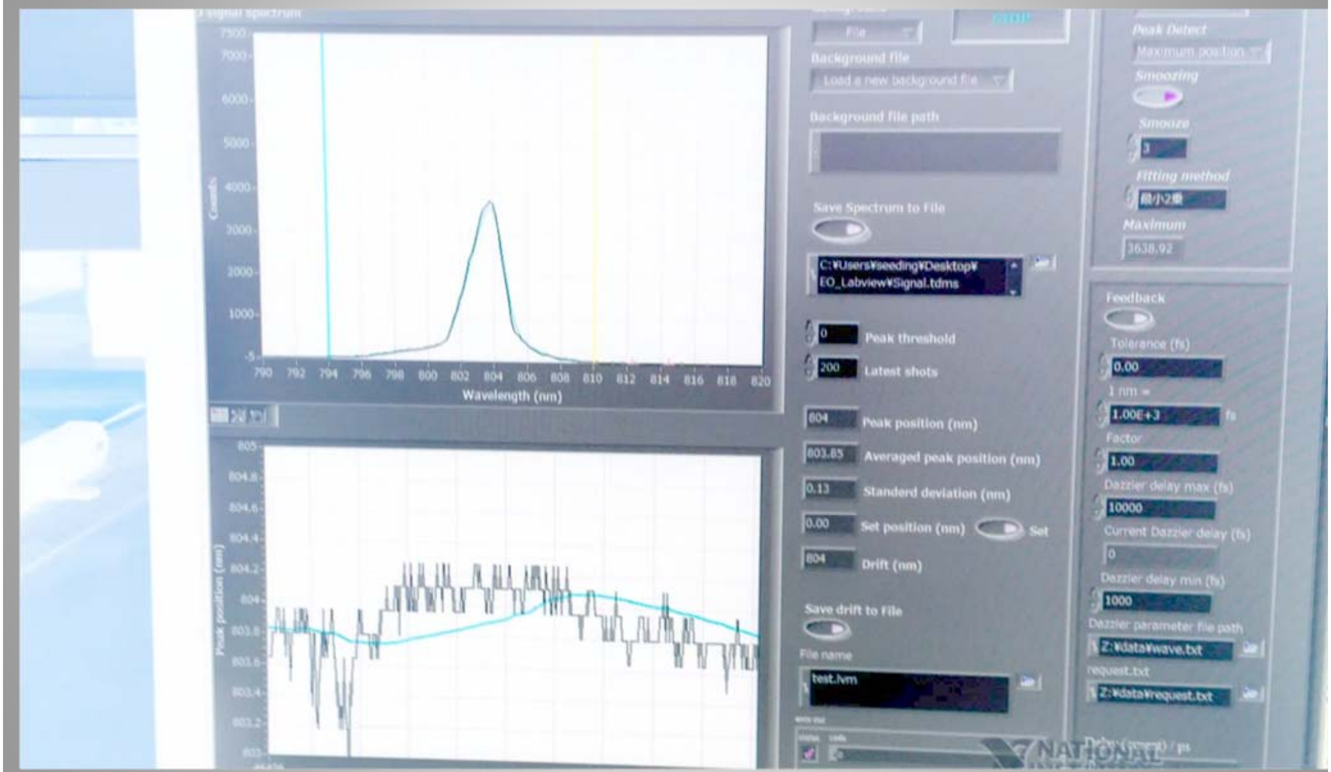


- HHG用同期レーザーの一部をEOサンプリング測定用に使用。
- 高分散ガラスブロック(n= 1.96, L=20 cm)でパルスをチャープ(175 fs → ~14 ps)
- 同期レーザーと電子ビームのタイミングの観測方法
  - ➢ ストリークカメラによる観測。
  - ➢ オシロスコープでPDとCurrent Transferのタイミング差を観測。
- P1, P2の角度をEO信号が最も強くなるように調整。
- 同期レーザーのタイミング
  - ➢ EO信号のピークとArガスモニターを参照してCandoxで調整。

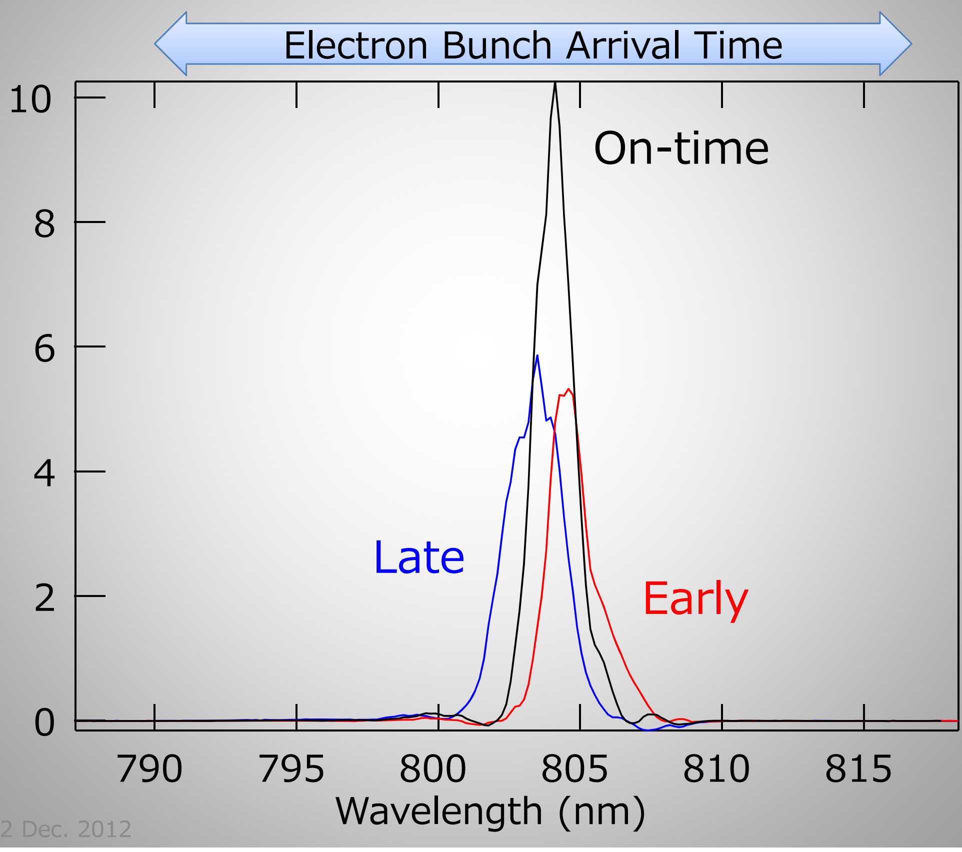
Timing feedback with EO



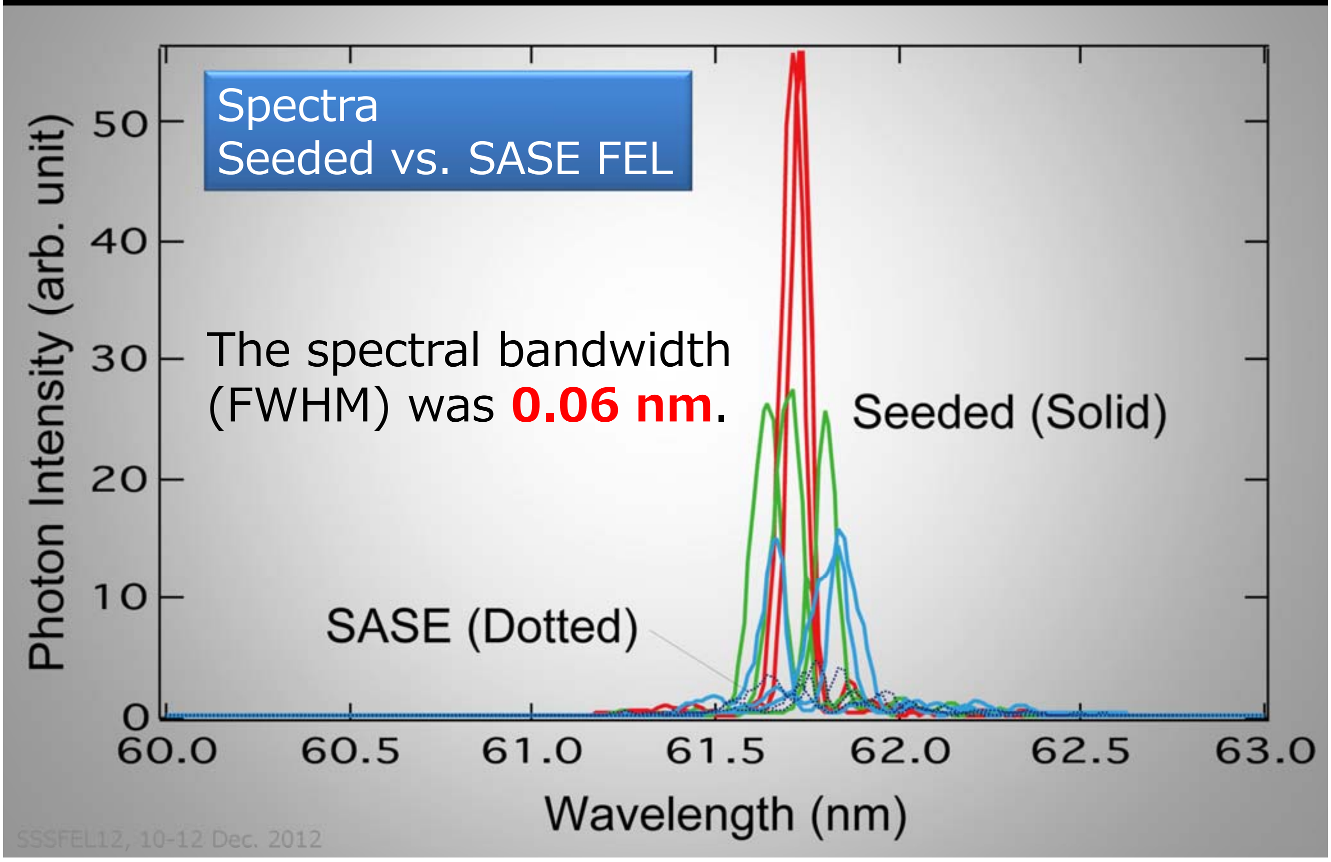
Improvement of Hit Rate (3)



Improvement of Hit Rate (3)



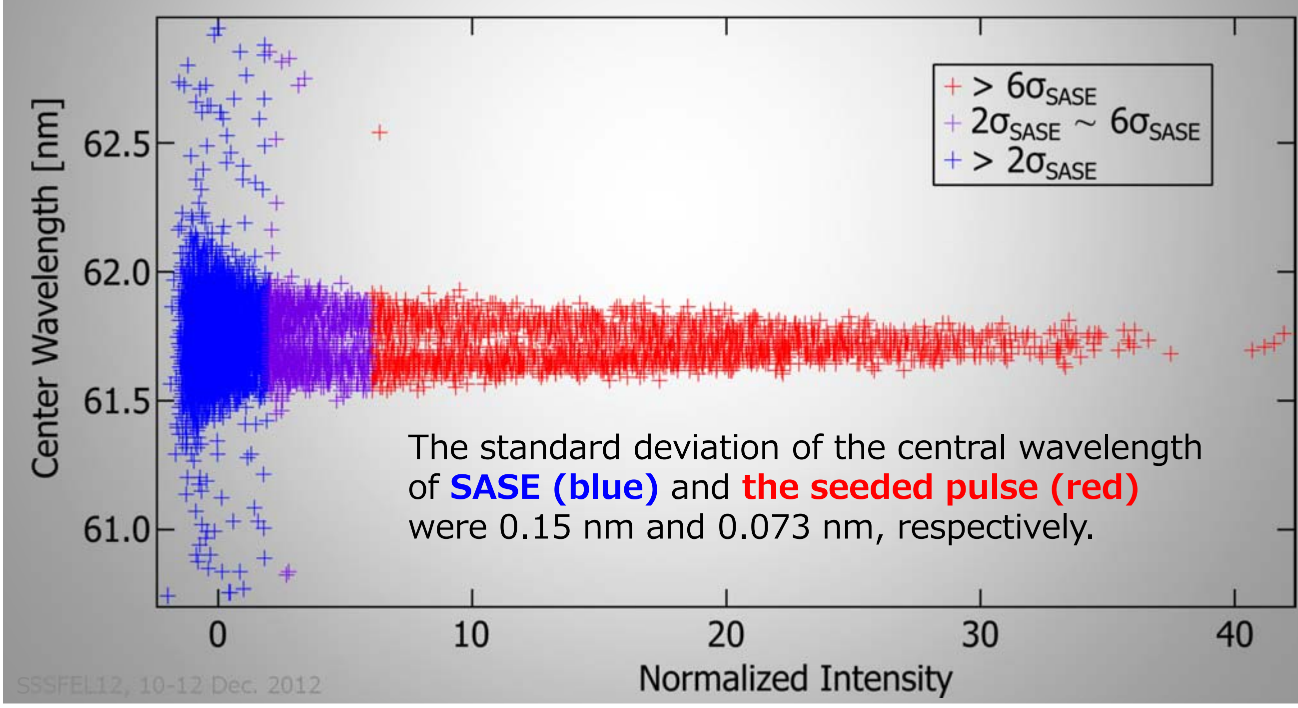
Seeded FEL Performances (1)



Seeded FEL Performances (2)

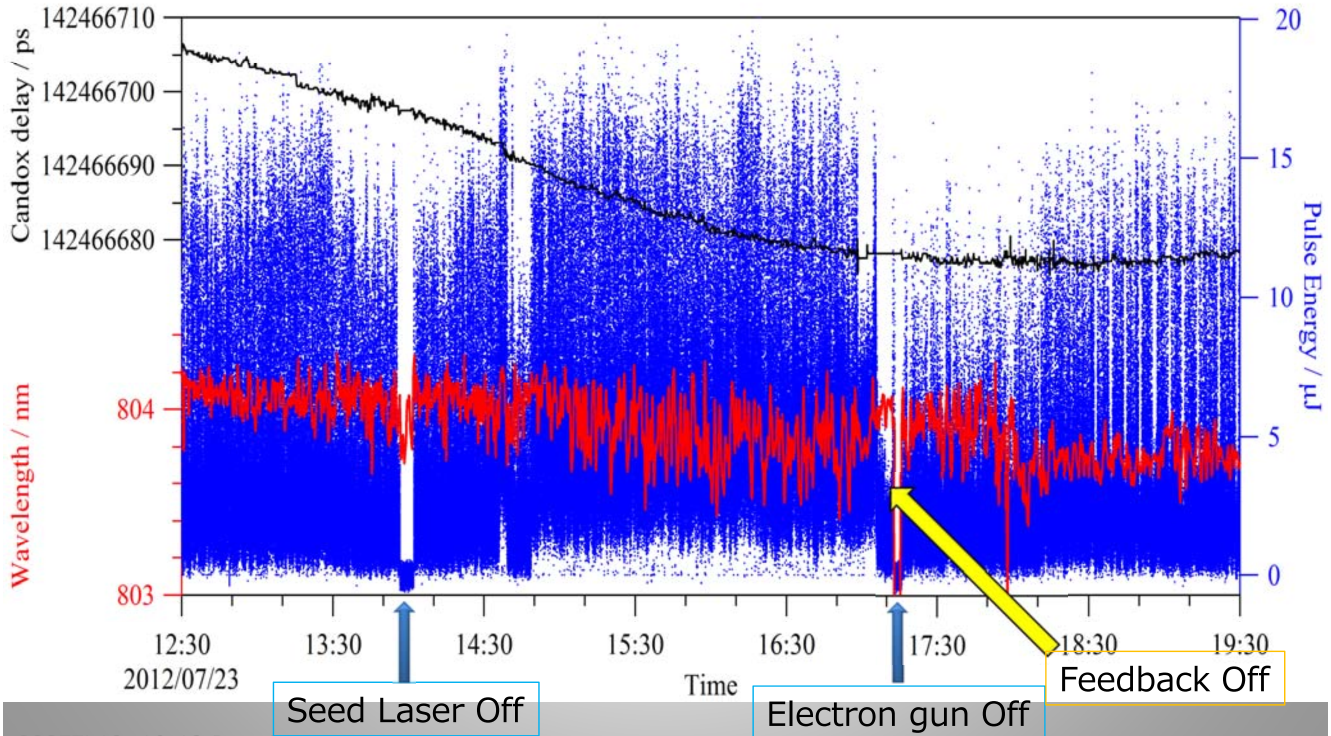
Seeded FEL Performances (3)

The correlation data plot between the normalized intensity and central wavelength for 10000 shot data



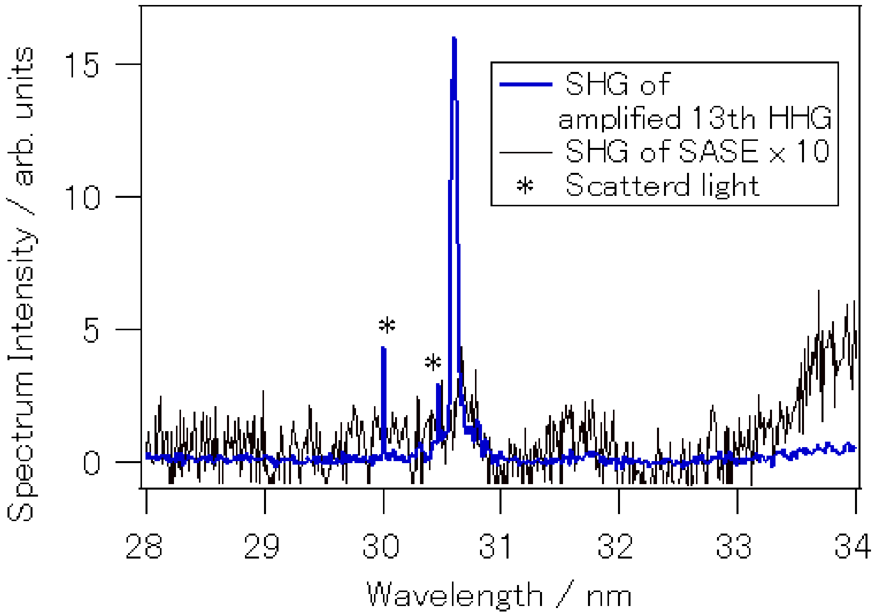
Seeded FEL Performances (4)

Seeded FEL Long Term Stability



The Second harmonic generation of 61.5 nm

SHG of 13th HHG (30.7 nm) (off axis emission)

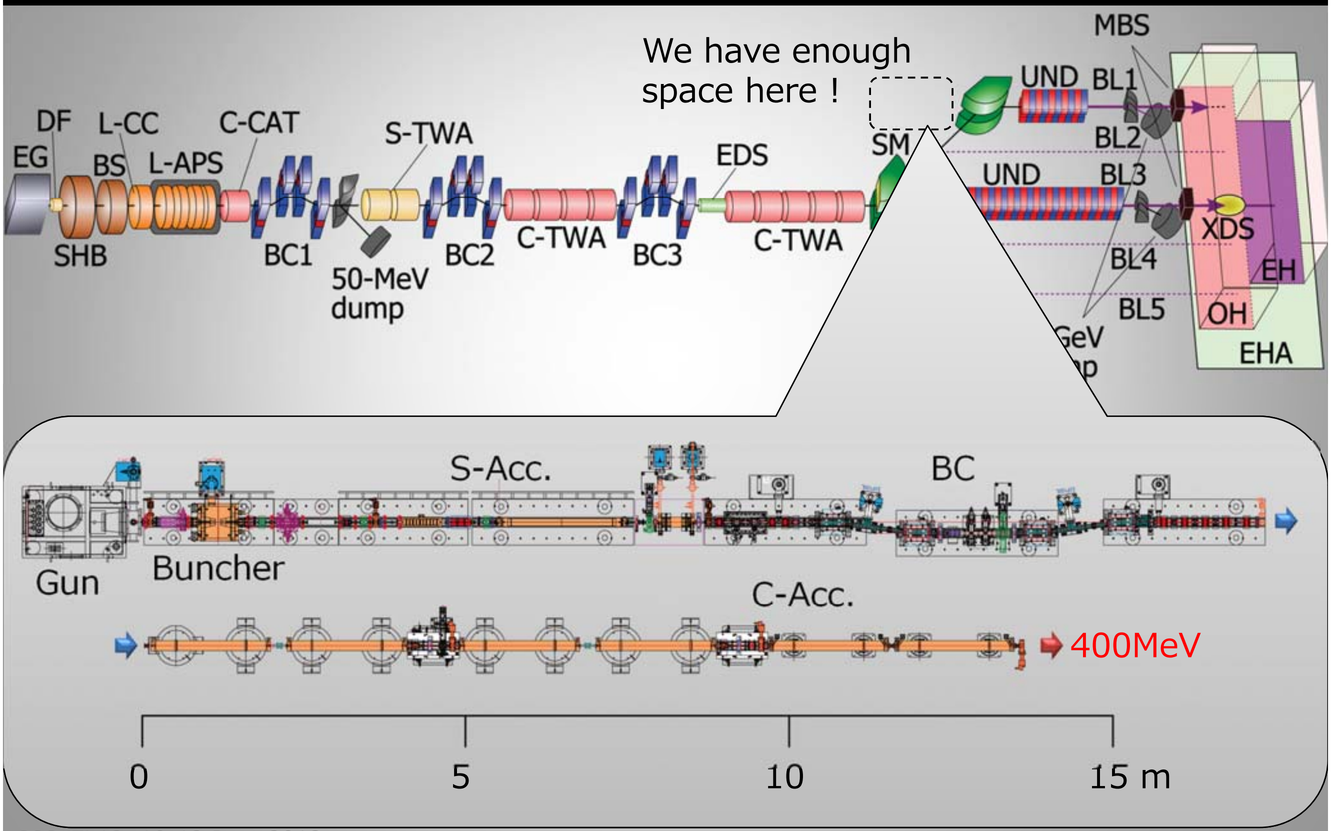


Energy contrast to SASE-FEL > 100

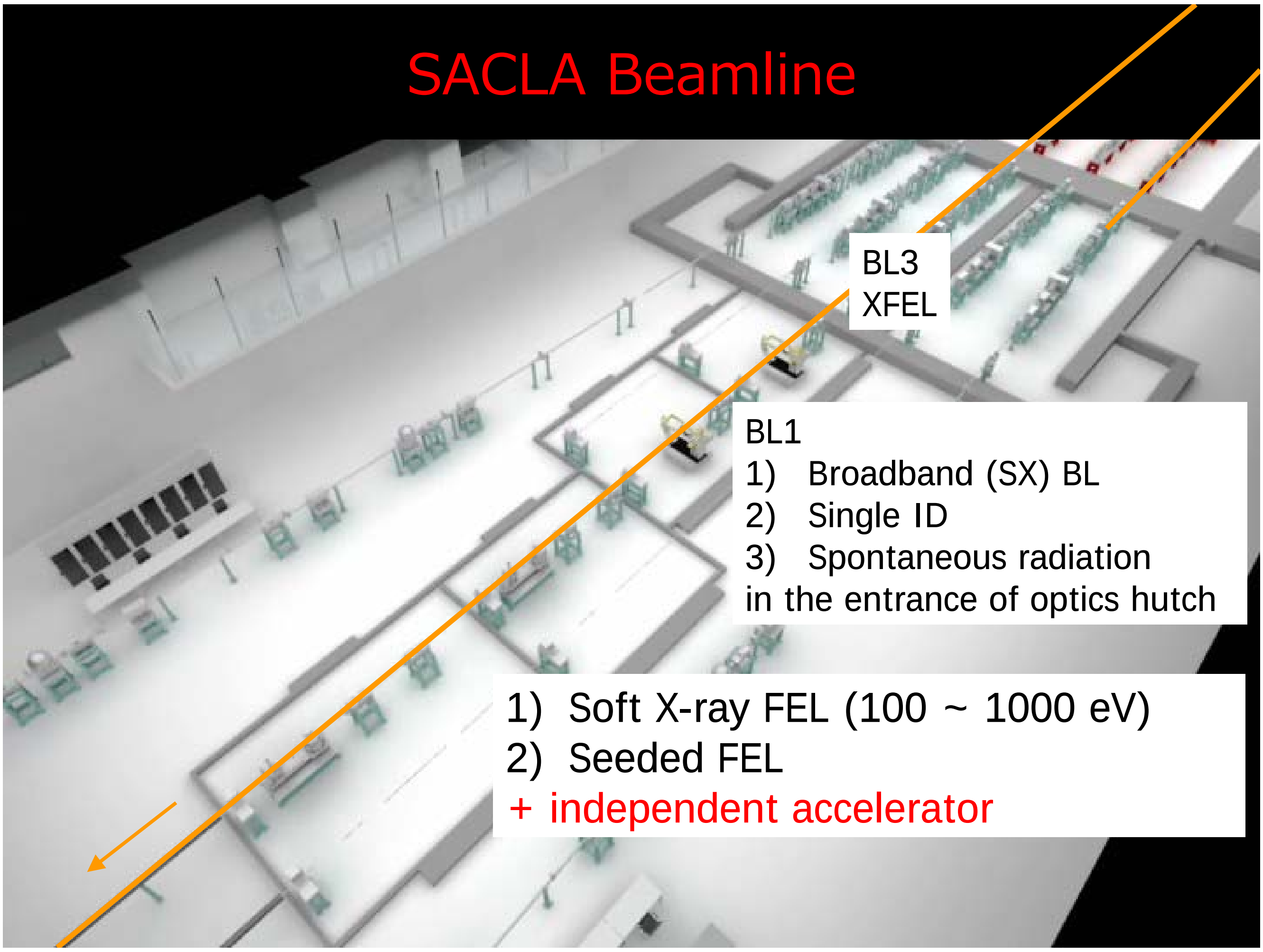
Future Perspective

- SCSS test accelerator is going to be decommissioned in June 2013
- Accelerator components moving to BL1@SACLA (SCSS+)
  - Dedicated beamline to EVU & SXR regions
  - Start with 400 MeV & 30~50 nm, to be extended to 1.4 GeV & **3 nm**
- Seeding method under exploration (self seed, HHG, HGHG,..)

Initial Machine Layout of ***SCSS+***



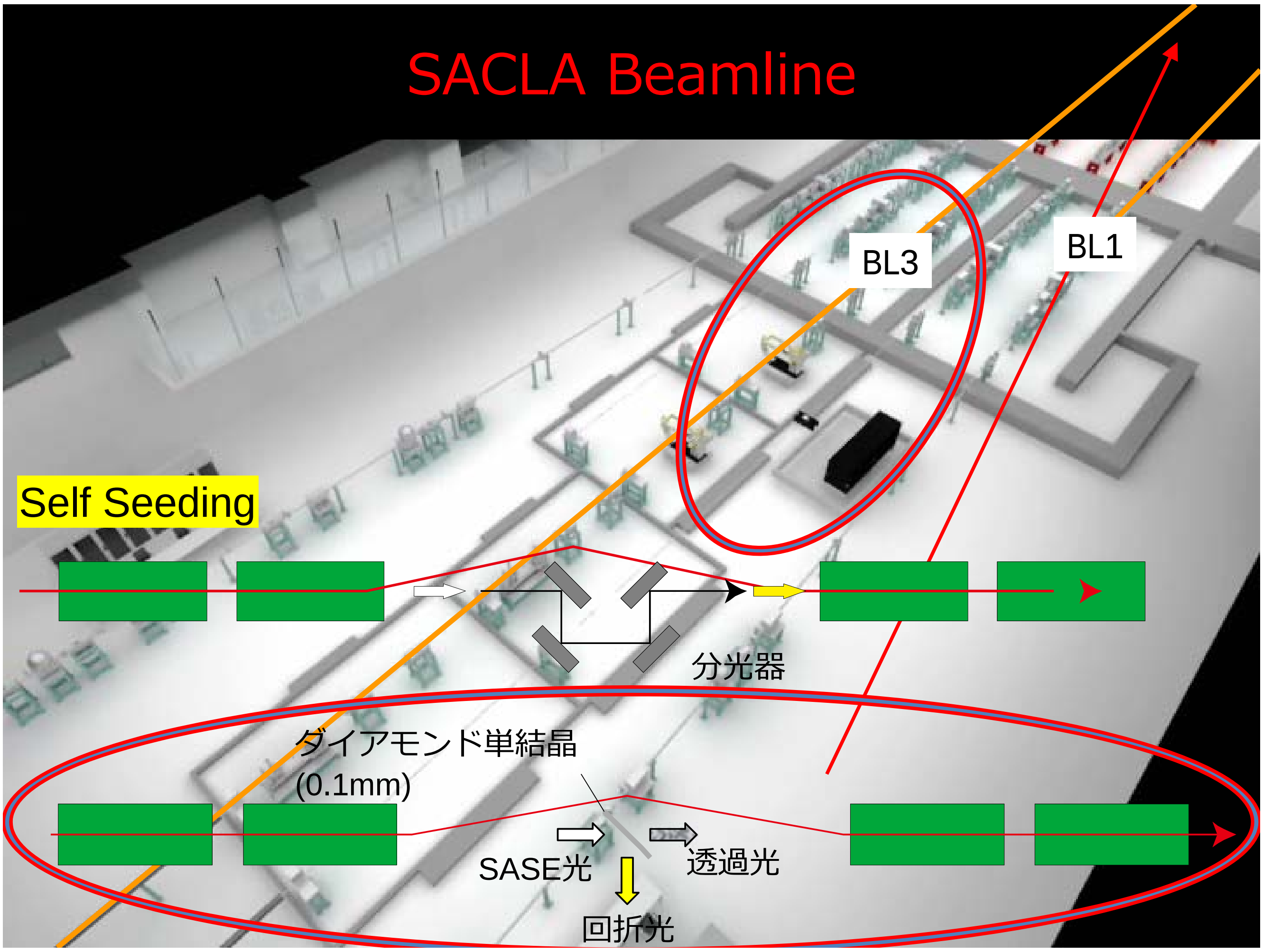
SACLA Beamline



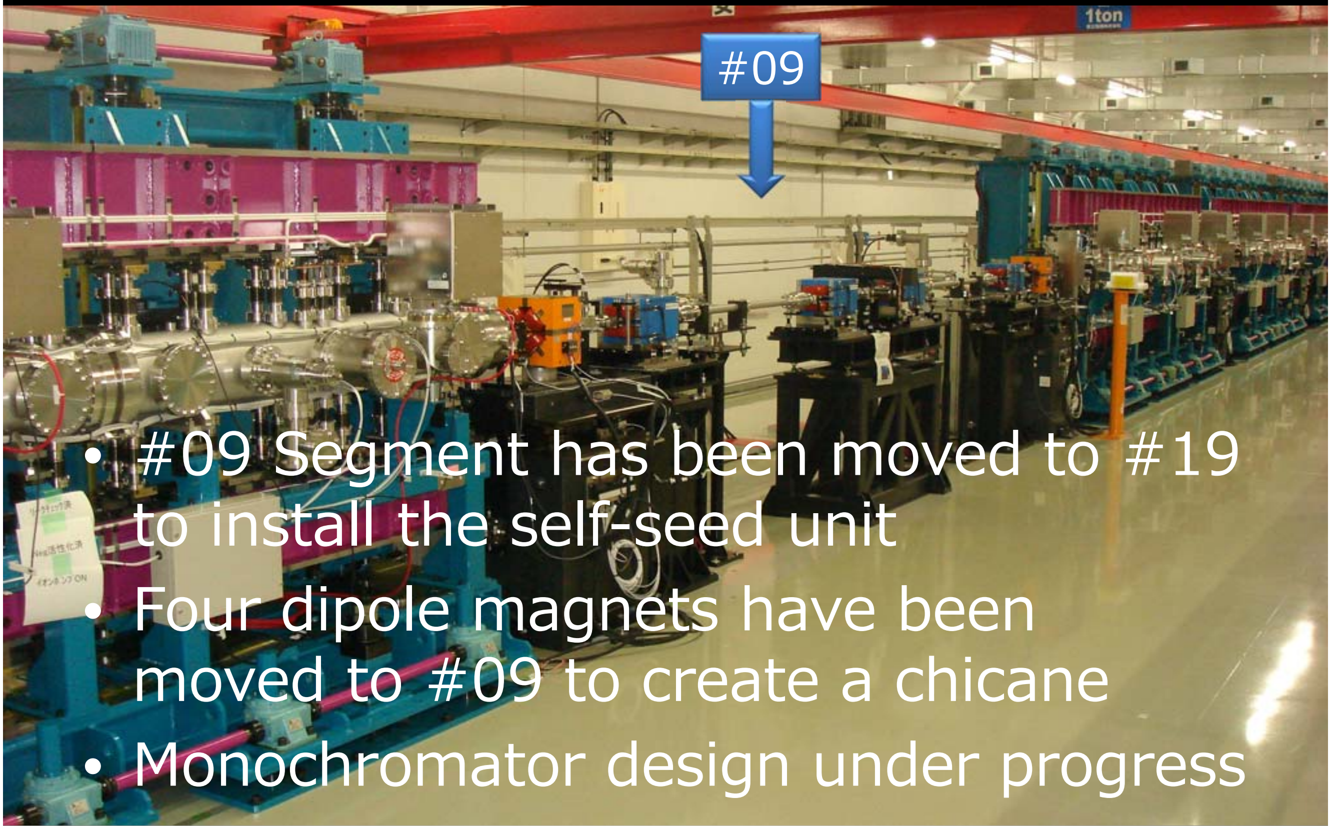
Seeding Option at SACLA

- Upgrade program at SACLA for HXR-seeding in progress
- Successful demonstration of the self-seeding scheme at LCLS urges us to go ahead with the same (?) scheme
- Numerical study to optimize the self-seeding configuration finished (preliminary)

SACLA Beamline



Current Status toward Self-Seeding



- #09 Segment has been moved to #19 to install the self-seed unit
- Four dipole magnets have been moved to #09 to create a chicane
- Monochromator design under progress

Summary

- In SACLA, two seeding options have been explored intensively :
  - EUV and SXR-region: HHG Seeding
  - HXR-region: Self seeding
- Recent R&D to improve the hit rate at the SCSS test accelerator has proven the capability of HHG seeding
- Commissioning for HXR-self seeding is scheduled this September, after installation of the monochromator