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Coherent Harmonic Generation on UVSOR-II storage ring

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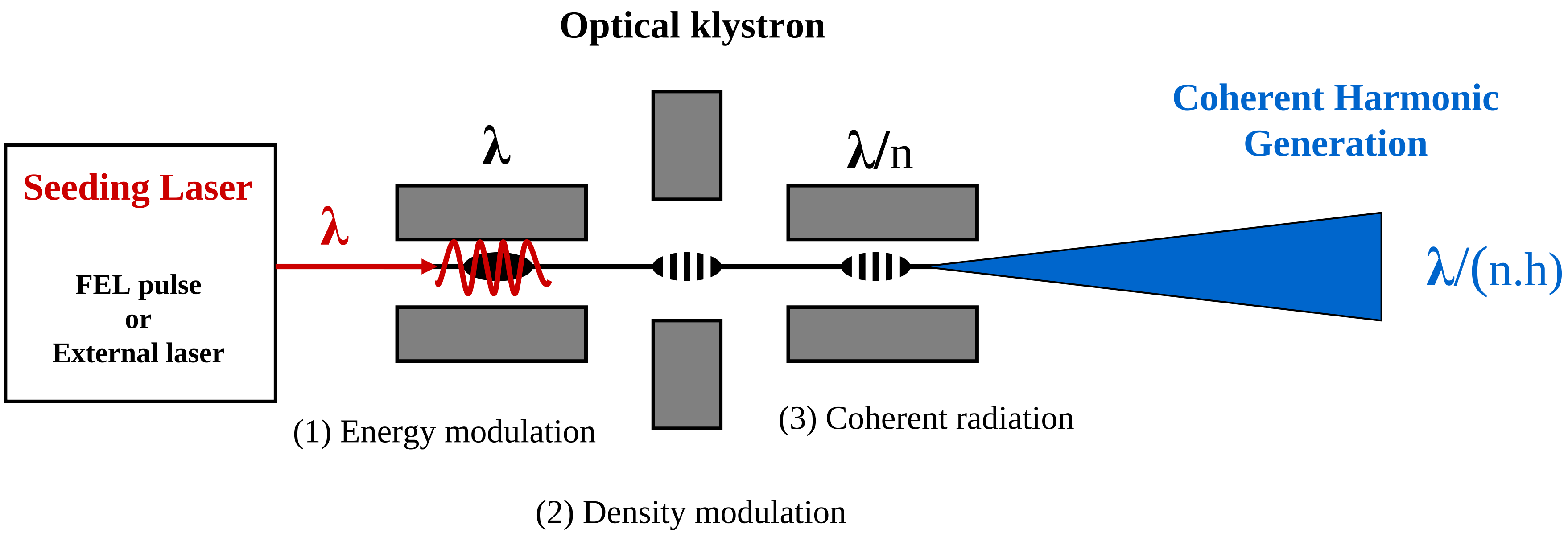
Acknowledgments: S. Bielawski, C. Szwaj, J. Yamazaki.

CHG FEL configuration



CHG FELs background

- CHG first proposed in 1982 *R. Coïsson and F. De Martini, Phys. Of Quant. Elec. 9 (1982).*
- CHG with external seed:
  - First demonstration on ACO storage ring: *R. Prazeres et al., NIM A272 (1988).*
    - Nd:Yag laser (1064.1 nm) seeded in OK
    - Generation of H3 (354.7 nm) of fund.
    - Generation of H3 (177 nm) and H5 (<u>106.4 nm</u>) of doubled laser
  - Similar results on:
    - Super ACO storage ring: *R. Prazeres et al., NIM A304 (1991).*
    - MAX-lab storage ring: *S. Werin et al., NIM A290 (1990).*
  - Present experiments (using Ti:Sa laser at 800 nm):
    - @ UVSOR-II *M. Labat et al., Euro. Phys Jour. D **44** (2007) 187.*
    - @ ELETTRA *F. Curbis et al., FEL'07.*
- CHG with internal seed (FEL pulse stored in a cavity):
  - @ DUKE: *V. Litvinenko et al., NIM A507 (2003).*
    - at 665.4 nm → H3 (221.8 nm)
    - at 236 nm → H2 to H7 (118 to 37 nm)
  - @ ELETTRA:
    - at 660 nm gives H3 (220 nm) *G. De Ninno, Proc. FEL'04 (2004) 237.*

CHG and HGHG FELs

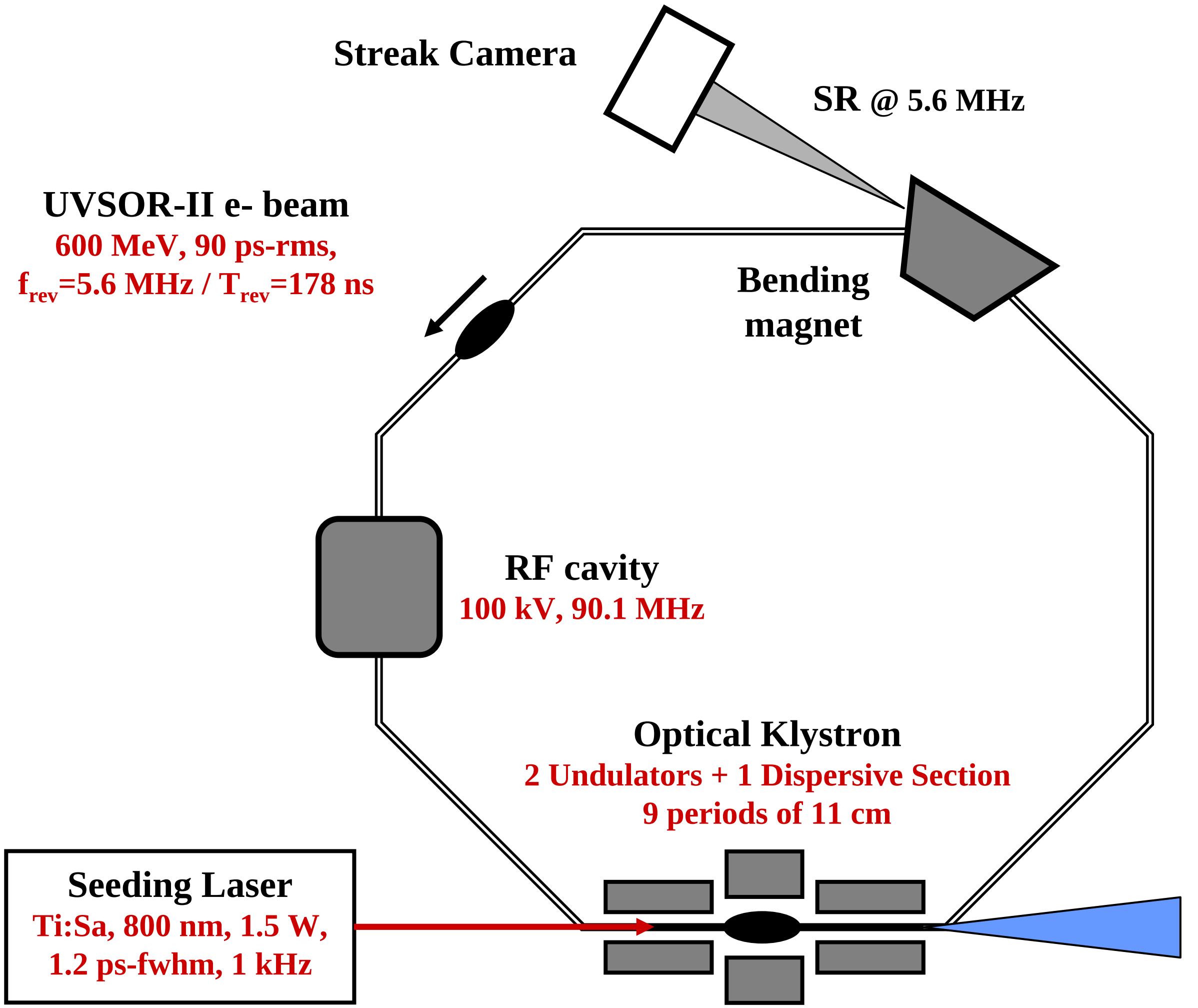
- **CHG FELs on SR:**
  - Limited undulator length + Limited beam quality
    → Limited power

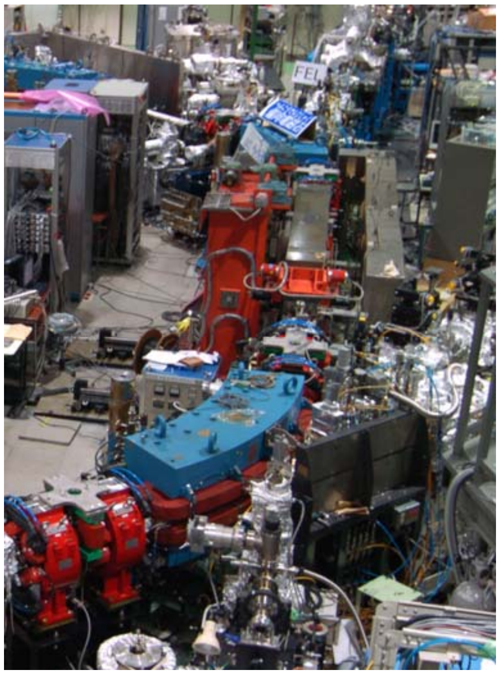
- **HGHG FELs:** *L.H. Yu et al., Science 489 (2000).*
  - Long undulators → saturation power **~ GW**
  - Short wavelengths
  - Good coherence
  - Future FEL sources (Arc-En-Ciel, BESSY-FEL, Fermi, 4GLS, MAX-Lab, …)

- **Common issues:**
  - Seeding techniques: ***synchronisation, alignement***
  - Seeding ***energy level*** to overcome shot noise
  - ***Coherence*** improvement from seeding
  - Nonlinear ***harmonic generation***

→ Investigations on CHG FELs
can be useful for future FELs sources GW @ ~ 1nm

CHG experiments on UVSOR-II SR

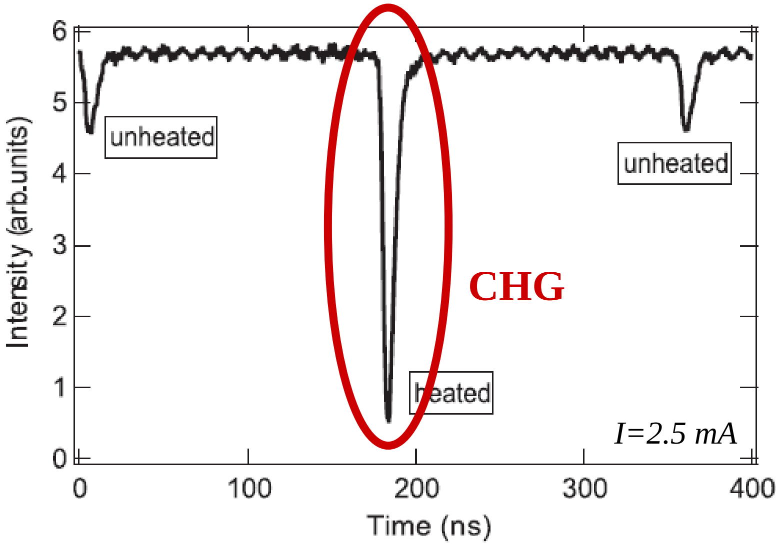




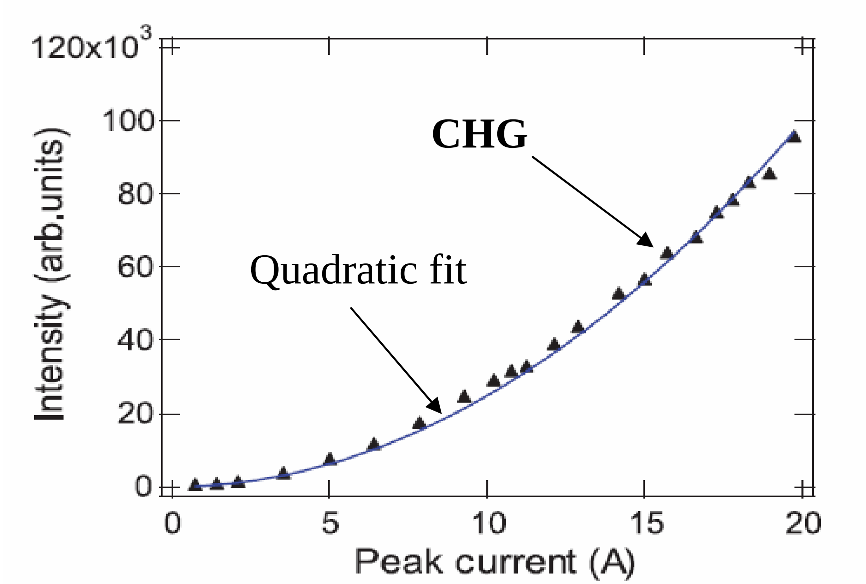
UVSOR-II FEL

<u>Commercial system:</u>
Mode-locked Ti:Sa oscillator (Coherent, Mira 900-F), and
Regenerative amplifier (Coherent, Legend HE)

1^{st} result: Coherent Generation of H3 (266 nm)



$H3_{\text{with CHG}} = H3_{SE} \times 5$

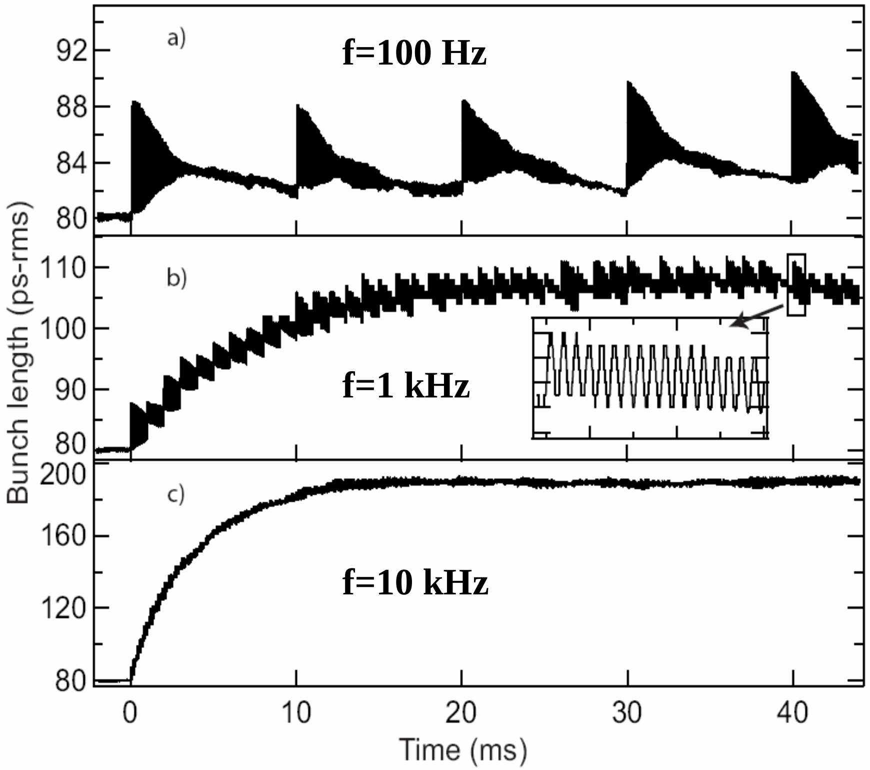


CHG α I_{peak}^{2}: signature of coherence

*M. Labat et al., Euro. Phys Jour. D **44** (2007) 187.*

Beam dynamics studies (1)

- Simulation of e- distribution:
  - **Beam heating** → Saturation
  - Double **oscillating structure**:
    - Laser repetition rate
    - Synchrotron frequency
  - **Equilibrium state** depends on laser parameters
    - → possible adjustment of heating
    - → optimisation of average/peak
- Exp. measurement:
  - → **Bunch lengthening ~ 10 %**



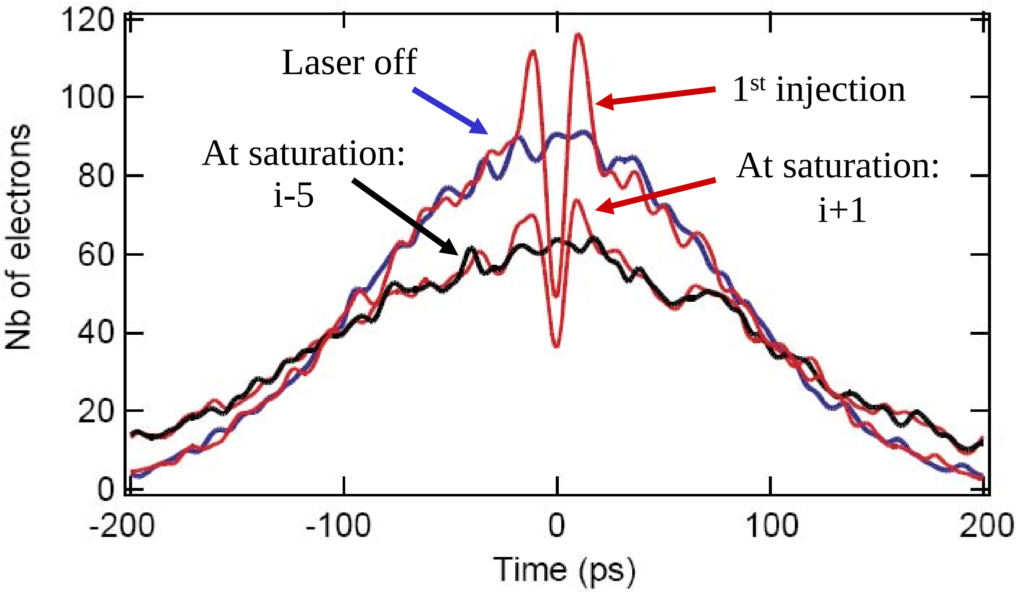
M. Labat et al., submitted to Eur. Phys. Lett. In July 2007.

Qualitative agreement with simulations

Beam dynamics studies (2)

- Simulation of beam profile evolution:
  - At each injection (i):
    - → **Hole** (< 10 turns life time)
  - Progressive diffusion
  - Progressive lengthening

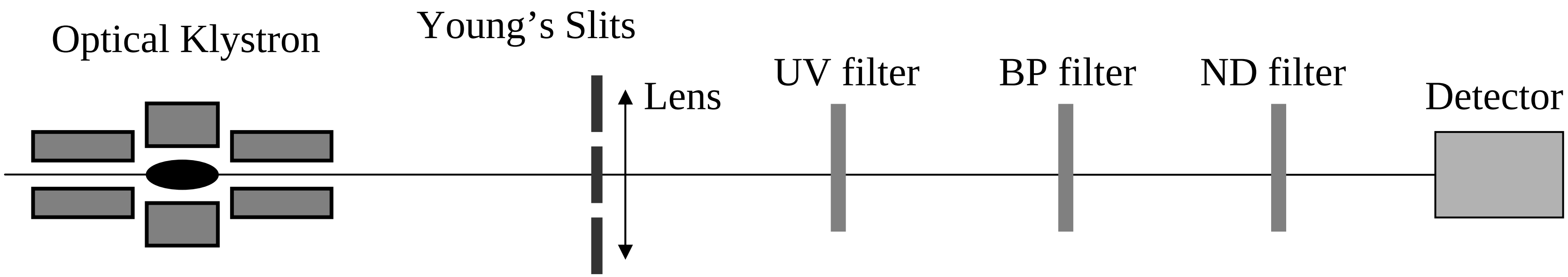
Saturation comes from
LOCAL HEATING



Rep rate= 1 kHz, P=5 W, pulse duration= 6 ps-fwhm.

CHG Transverse Coherence

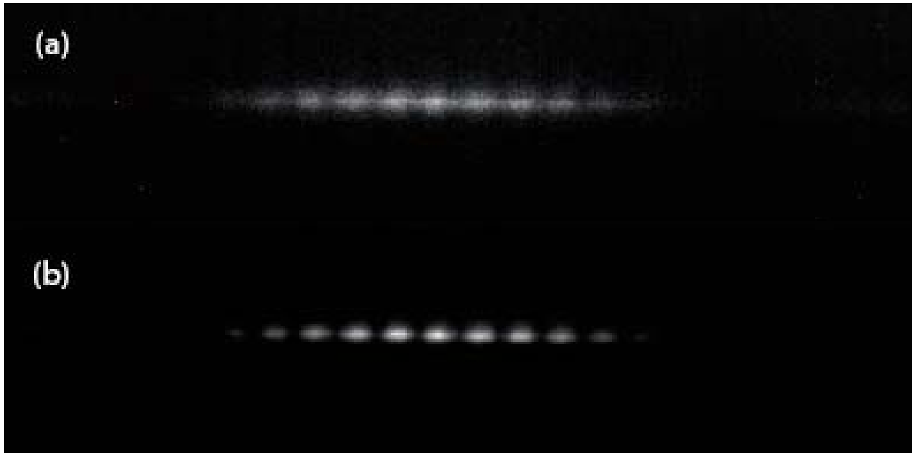
- Young slits experiment:
  - → 2D interference pattern
  - → Visibility of the fringes
  - → Mutual coherence degree → **Transverse coherence**
- 2D detector:
  - – Fast intensified CCD camera for CHG (harmonic pulse gating)

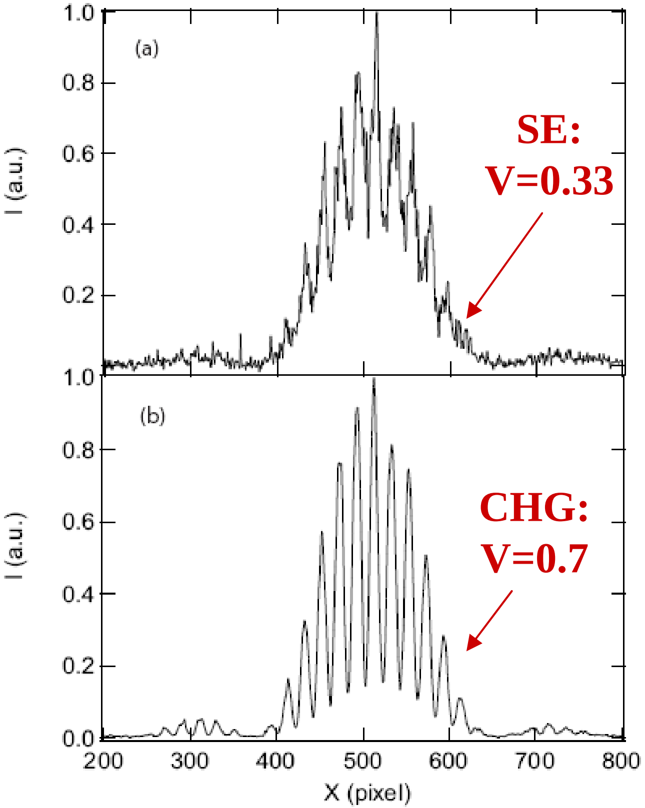


CHG transverse coherence

SE

CHG





- With seeding:

Visibility: 0.33 → 0.7

- Further FEL analysis undergoing in collaboration with G. Dattoli

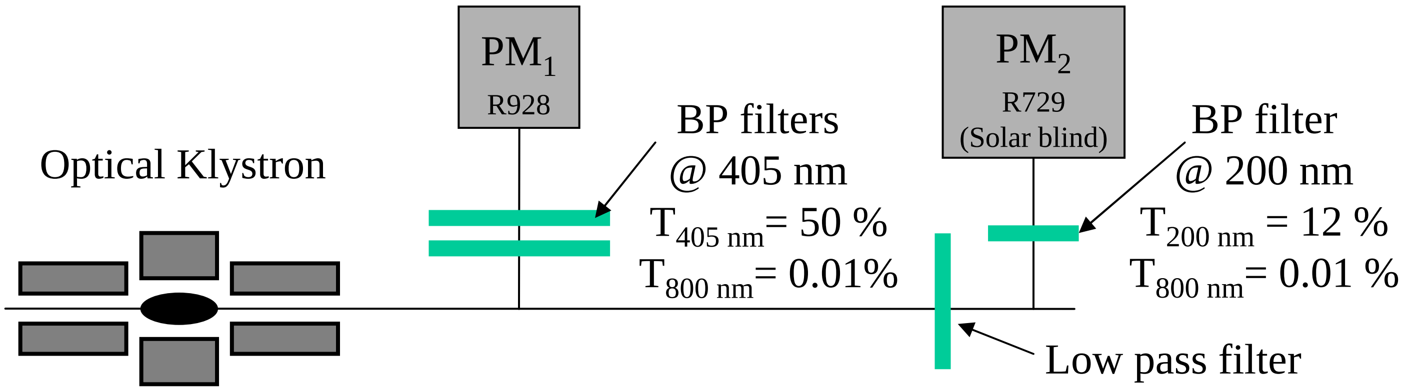
See Poster: TUPPH007

Even Harmonic Generation with planar undulators

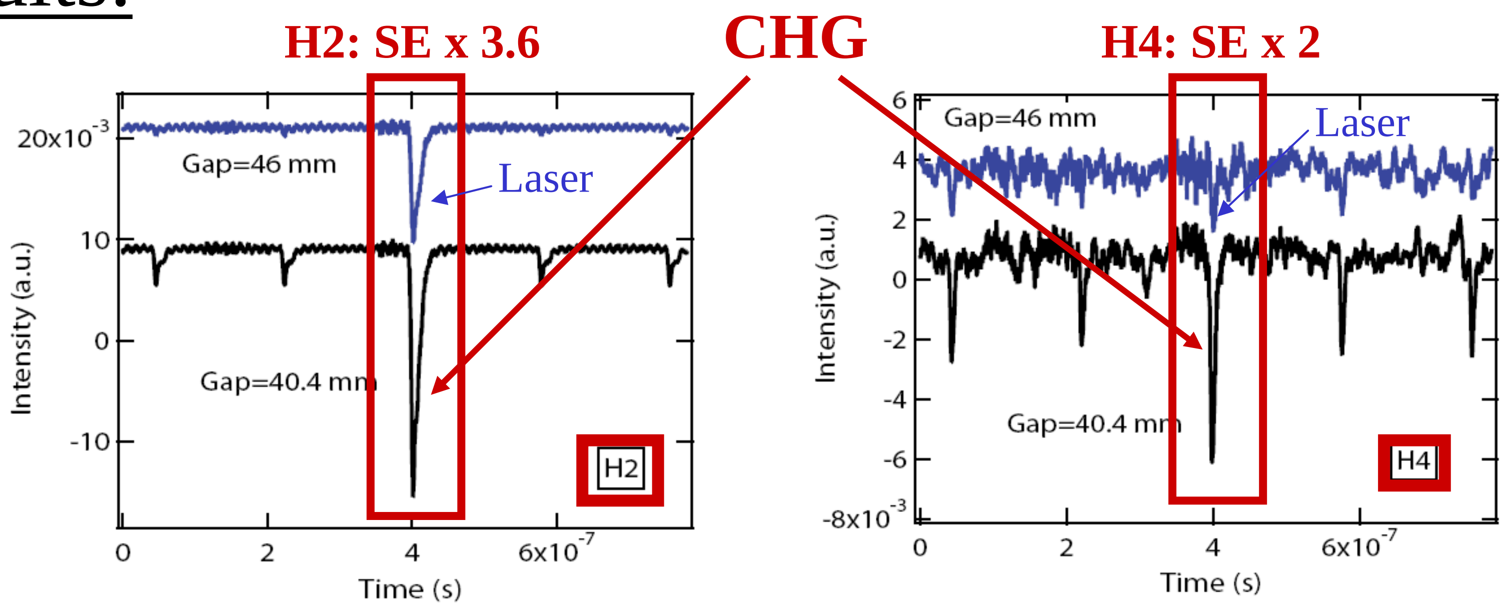
- Oscillator FELs:
  - Select efficient coupling coef. between transverse cavity modes and harmonics *M.J. Schmitt et al., PRA 34 (1986) 4843*
  - Wave guides *H. Bluem et al., PRL67 (1991) 824*
- CHG FELs:
  - No cavity → no possible mode selection
  - SE even harmonics: off-axis
  - CHG even harmonics expected: strong off axis radiation

Even Harmonic Generation with planar undulators

Exp. setup:



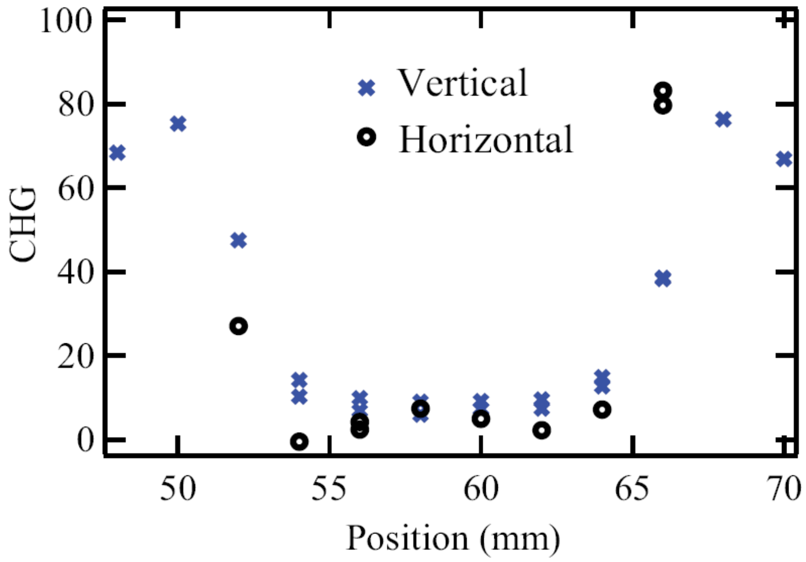
1st results:

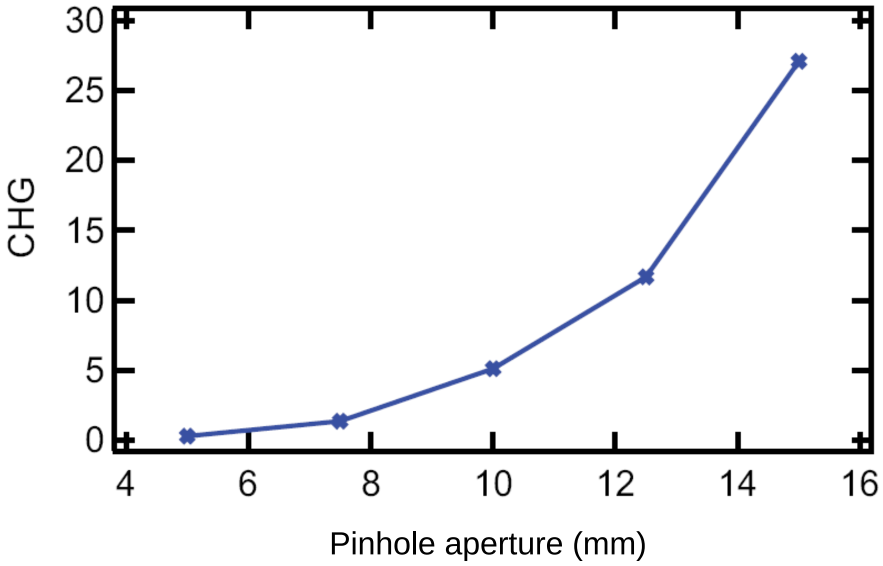


Even Harmonic Generation with planar undulators

- Angular distribution of H2:
  → Clear off-axis distribution

Transverse scan with a 3 mm pinhole





Even Harmonic Generation with planar undulators

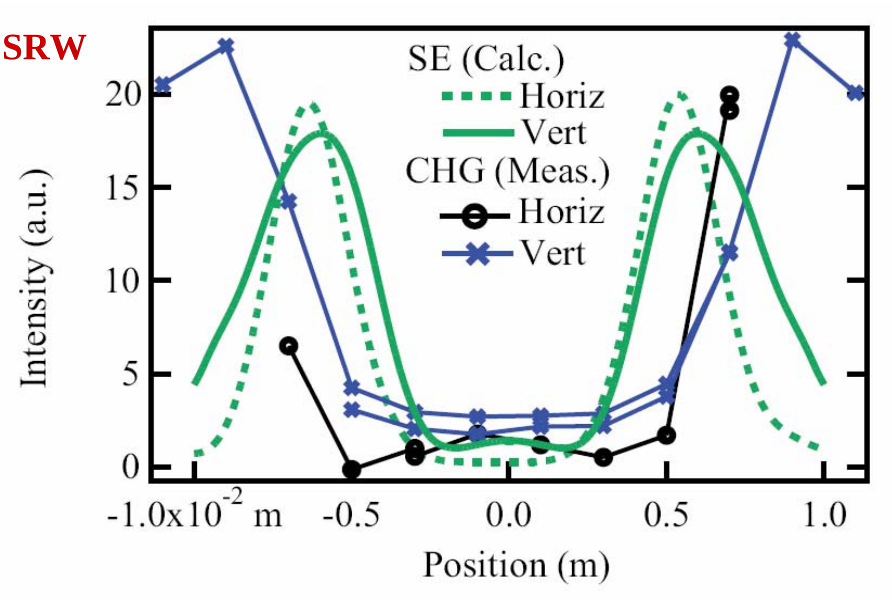
- Comparison to SE calculated with SRW & SPECTRA.

→ CHG <u>appears</u>:

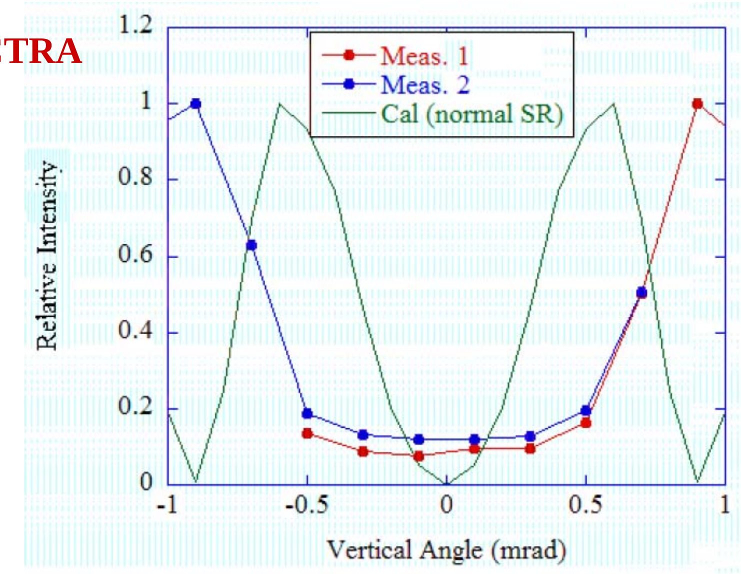
  – More divergent

To be confirmed with
MEDUSA simulations
(H. Freund, Private Communications)

SRW



SPECTRA



CHG with helical undulators

- Helical undulators enable:
  - **Circular polarisation** → various users experiments
- Debated issue:
  - "Azymuthal resonance"

    → **HG on-axis** *H.P. Freund et al., PRL 94 (2005).*
  - Usual resonance

    → **HG off-axis** …

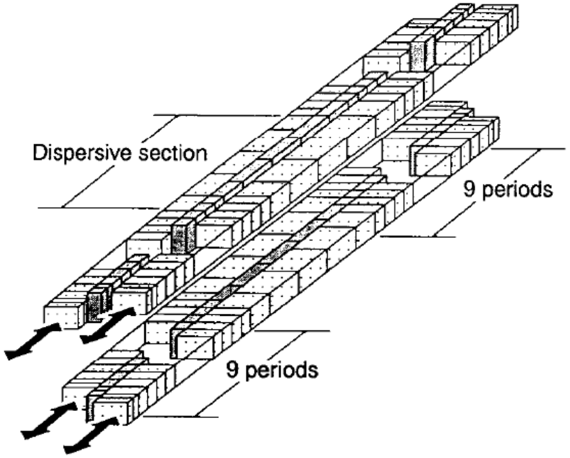
G. Geloni et al., Opt. Comm. 271 (2007).

CHG with helical undulators

- Experimental setup @ UVSOR:
  - **OK** → helical configuration
  - **e- beam** → E=500 MeV

    for resonance matching @ 800 nm
  - **Laser** → variable polarisation

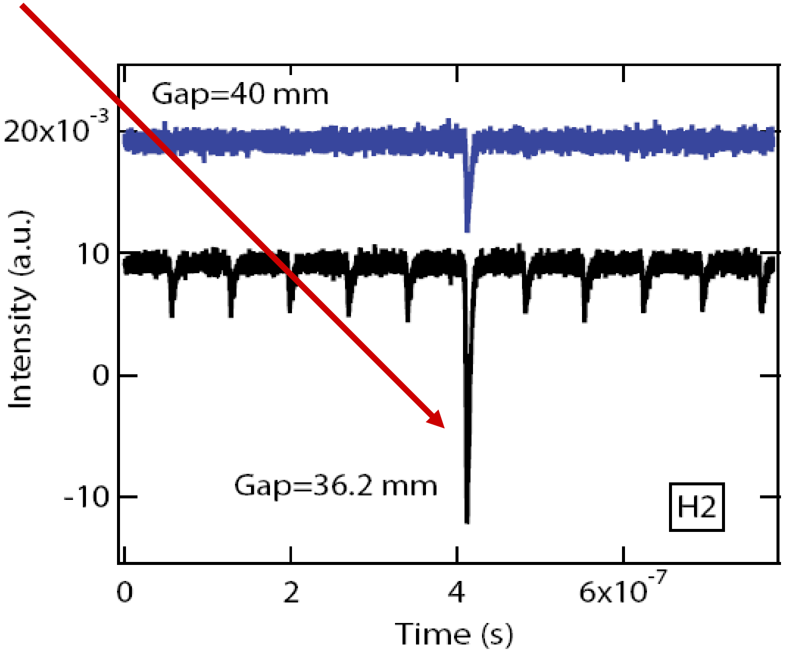
    using a λ/4



CHG with helical undulators

- Results:
  - **Coherent Harmonic Generation on H2:**

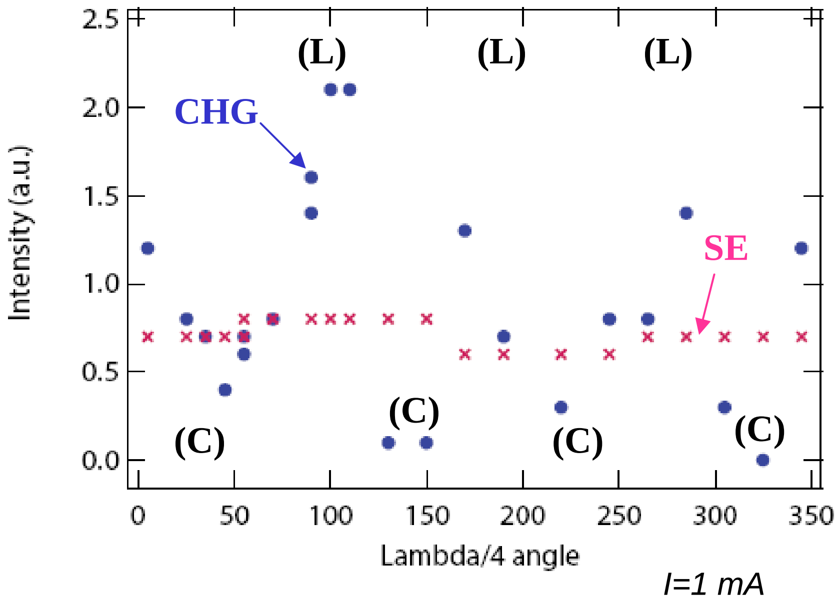
    H2 intensity = SE x 3
  - Still CHG on H3



I=2.8 mA

CHG with helical undulators

- Angular distribution of H2:
  → Off-axis
- Laser polarisation dependency of H2:
  – (L) → max CHG
  – (C) → min CHG
  – Expected/Unpexted
  – Further checking on:
    - Alignment
    - Over bunching
- Next: HG efficiency vs n_H



To be compared with both approaches' expectation

Conclusion

- Experimental work on CHG FEL @ UVSOR-II:
  - → Beam dynamics under laser heating
  - → Seeding effect on transverse coherence
  - → Harmonic Generation possibilities:
    - * Even HG
    - * HG with helical undulators

→ Step forward in CHG FEL understanding

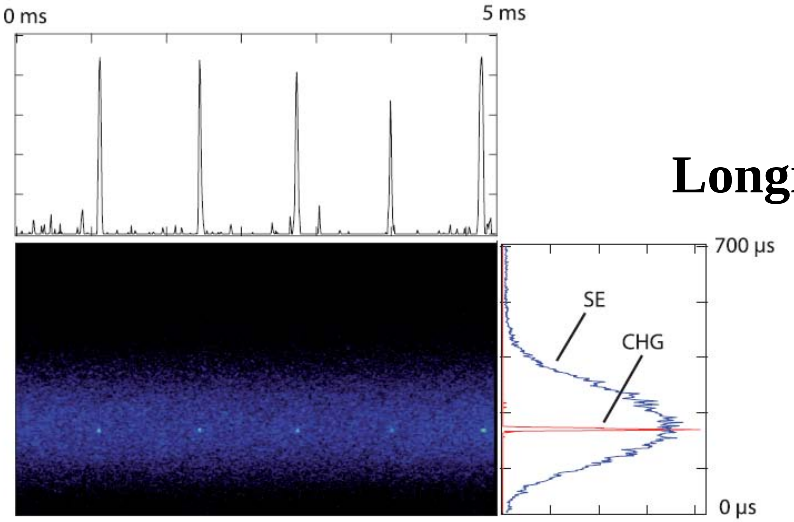
→ Encouraging/Useful results for HGHG FELs

CHG energy per pulse

- Calculation of SE level with SPECTRA:
  - 1.8 pJ @ 2.4 mA on detector
  - 7.2 pJ before filter
- Amplification of SE by factor 5
- Estimation of CHG energy: SE x 5 x 2.4
  - CHG ~ 87.5 pJ

CHG ~ 0.1 µJ

Longitudinal coherence



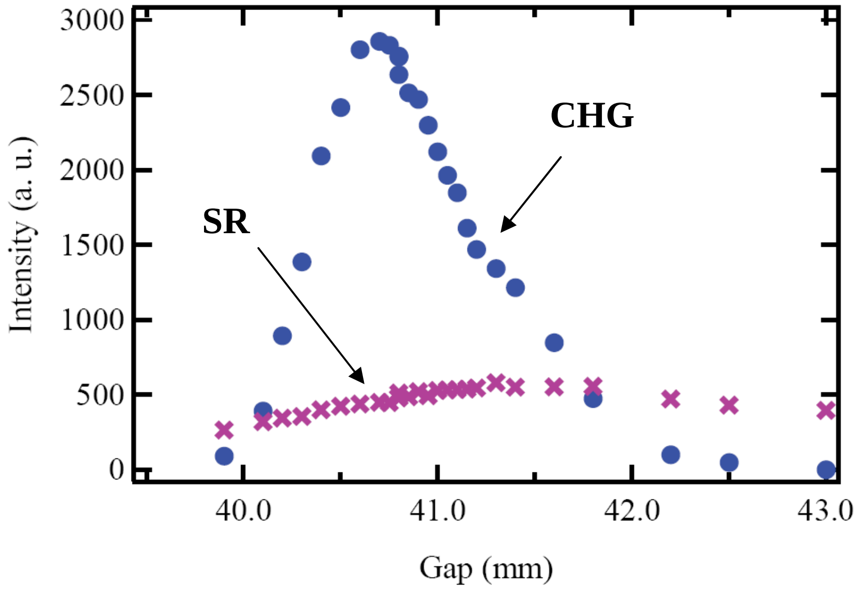
Longitudinal coherence:

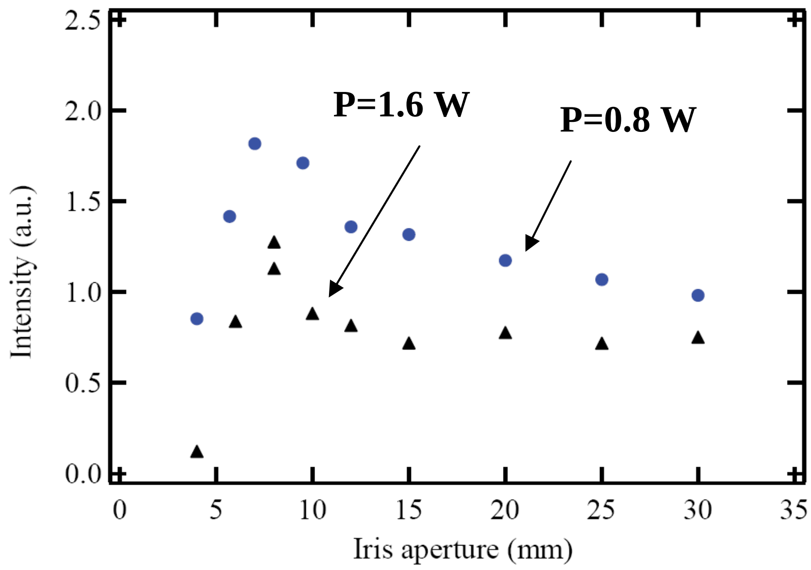
* Pulse length: **< 3 ps-rms**
(SC resolution)
* Spectral width: **< 2.5 nm**
(spectrometer resolution)

CHG intensity optimisation

- Systematic measurements versus:
  - Undulator gap
  - Laser parameters (power, pulse duration, diameter)

→ Optimisation of H3





Harmonic Generation

- Future investigations :
  - Compare planar/helical configurations in terms of :
    - HG efficiency vs n_H

BP filter @ 400 nm:

* Opto sigma corporation: VPF-25C-40-40-4000
  - Centered @ 405 nm
  - $\Delta\lambda_{fwhm}$=40 nm
  - $T_{405\ nm}$=50 %
  - $T_{800\ nm}$=0.01%
* Corion: P10405A-H972
  - Centered @ 405 nm
  - $\Delta\lambda_{fwhm}$=10 nm
  - $T_{405\ nm}$=50 % ??
  - $T_{800\ nm}$=0.01%

BP filter @ 200 nm:

MA200nm

T_{200nm} = 12 %

$\Delta\lambda$fwhm=10 nm

T_{800nm} = 0.01%

Low pass filter:

Sigma Kouki UTVAF-50S-34U

$T_{\lambda<340\ nm}$ < 0.01 %

- Dear Marie-san,
-
- Actually the filter is very old one and I do not know from which company it is bought.
- Yesterday I checked removing from the filter holder and found
- it is just labeled "MA200nm".
- The filter size is 30mm and we have a lot of similar ones.
- I am not very sure but the typical values of specification of that kind of filters are
-
- Peak transmission 12%
- Band width FWHM = 10nm
-
- I think in case of the filter @200 nm these values is not far.
-
-
- Best Regar

- Dear Marie-san,
-
-
- The reference of the filter is
- Sigma Kouki UTVAF-50S-34U
- You can find information of the filter here.
-
- http://www.sigma-koki.com/english/B/Filters/ColoredGlassFilters/UTVAF/UTVAF.html#0.
-
- The 200 nm filter is very old one and I am not sure that I can find the reference.
-
- Best regards,
- Masahito Hosaka