Summary of Working Group 3: Free Electron lasers

Luca Serafini - INFN/Milan
Zhirong Huang - SLAC

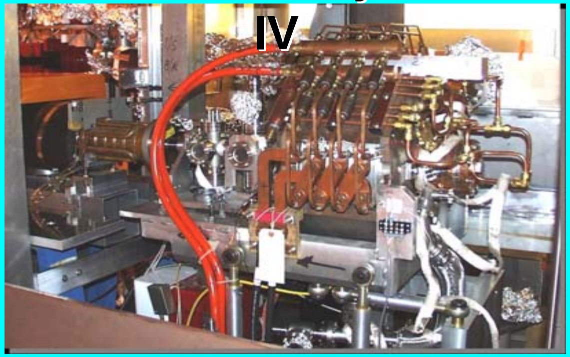
- **FEL Experiments, Facilities, Seeding and Synchronization**
  13 oral contributions

- **FEL Theory, Simulations, Novel Sources**
  13 oral contributions

- **Table Top X-ray FEL's with extreme beams**
  Joint Session with WG4 (see WG4 summary)

300 MeV S-Band Linac

BNL Photoinjector IV



10 m NISUS Wiggler

Experimental Studies of Optical Guiding, Efficiency Improvement and Femto-seconds FEL Pulse Control at the NSLS SDL

X.J. Wang, J.B. Murphy, J. Rose, Y. Shen, T. Tsang and T. Watanabe

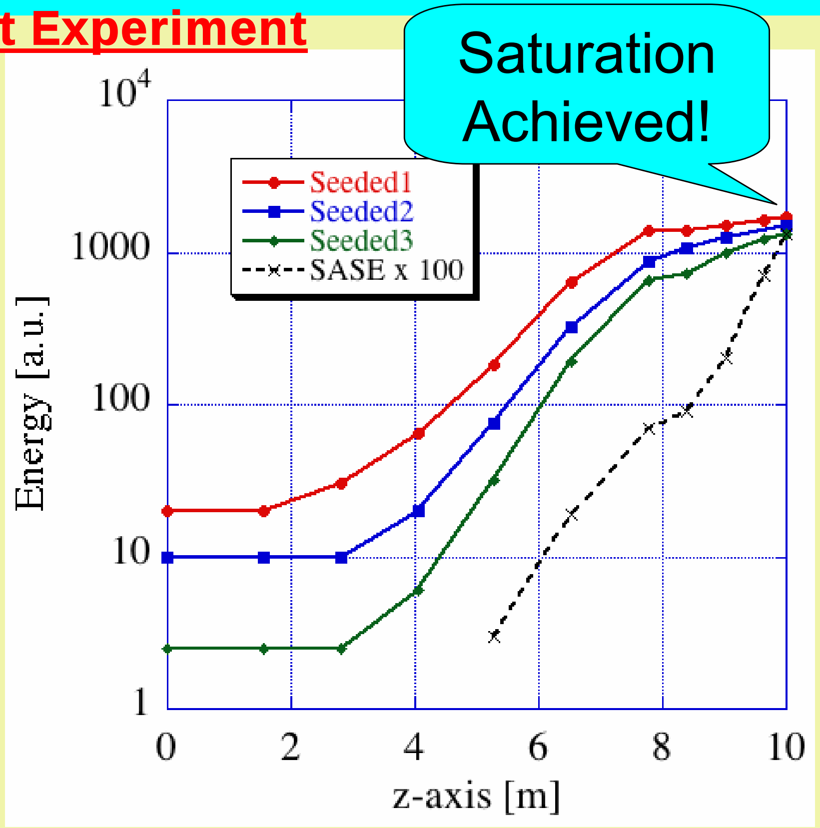
National Synchrotron Light Source
Brookhaven National Laboratory
Upton, NY 11973, USA

Office of Naval Research

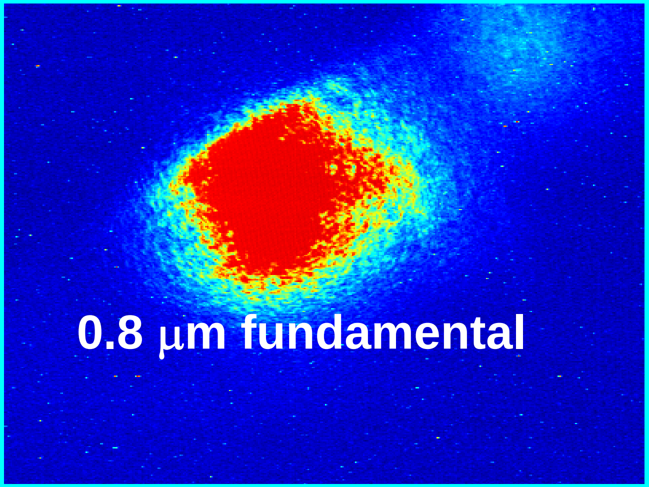
Office of Naval Research

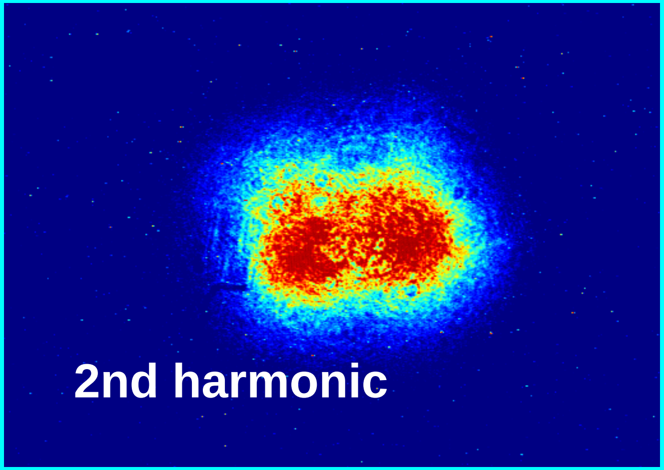
FEL Amplifier Exps:Fundamental & Harmonics

First Experiment



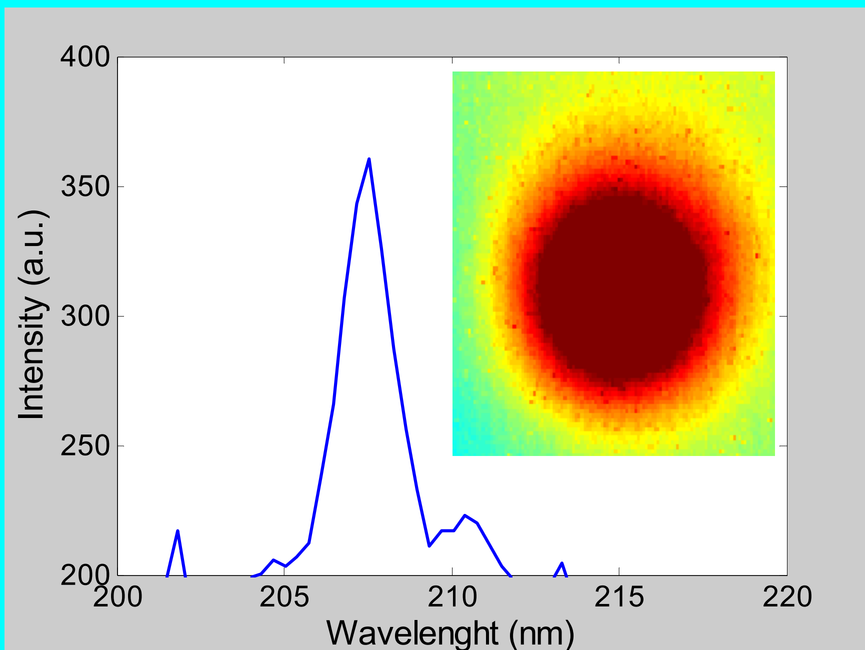
Three orders of magnitude FEL gain was observed.

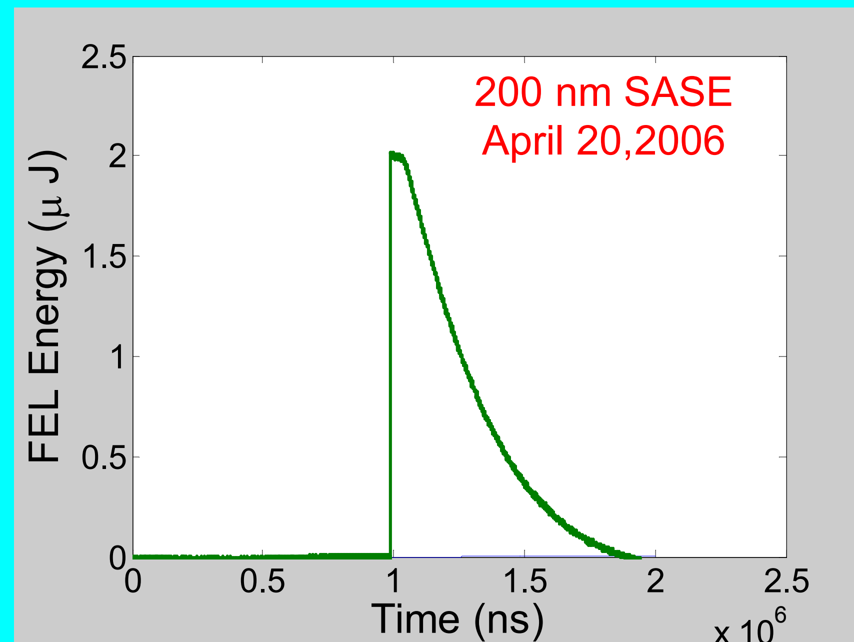




Ultra-Violet FEL Operation: 200 nm SASE

SDL Shortest Fundamental λ was 266 nm



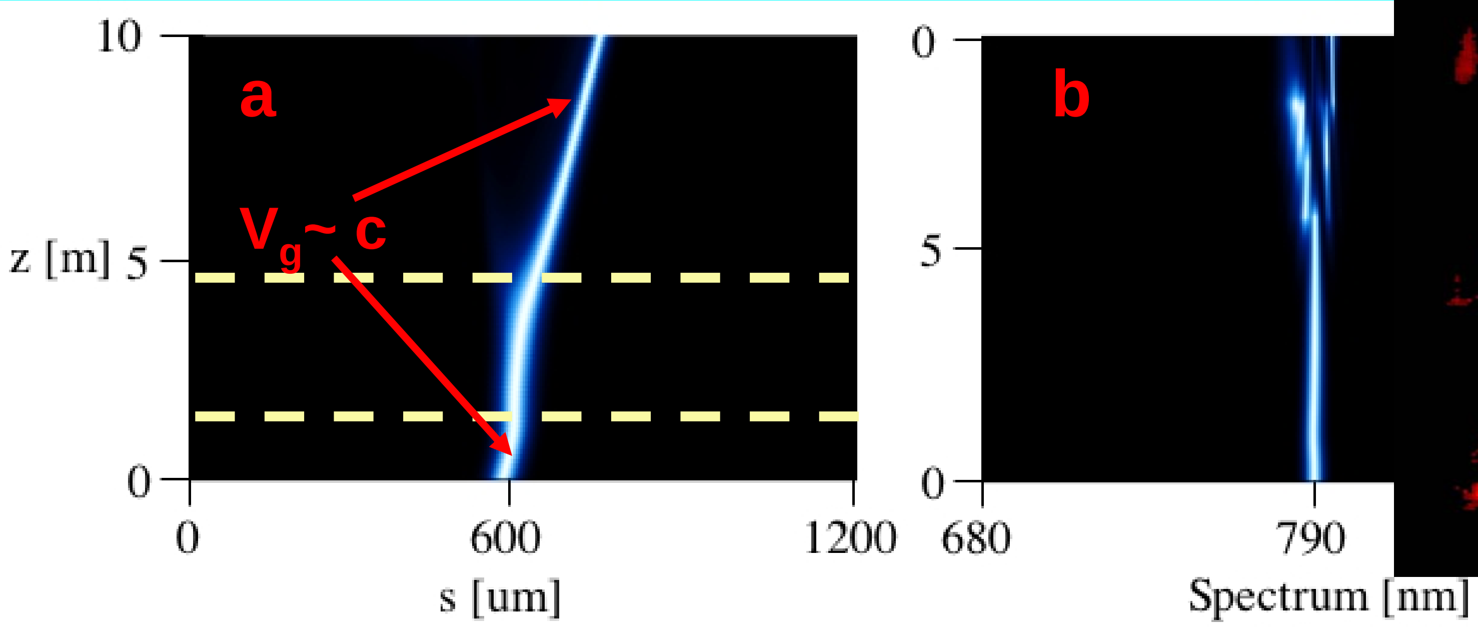


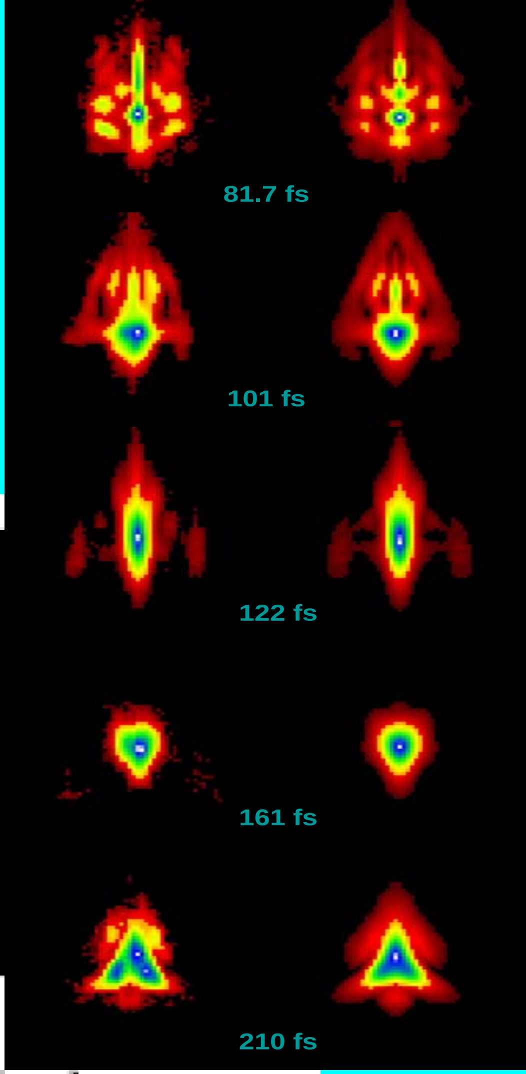
SASE below 200 nm
HGHG 795 → 198 nm with 10 µJ output

Superradiance in FEL

- R. Bonifacio and F. Casagrande, NIM A 239 (1985).
- R. Bonifacio, et al, Phys. Rev. A 40 (1989) 4467.
- L. Giannessi, et al, J. Appl. Phys. 98, 043110 (2005).

Seed laser length << E-beam length





Peak power	Pulse energy	Pulse duration
$P \propto z^2$	$E \propto z^{3/2}$	$\sigma_{sr} \propto z^{-1/2}$

High Gain Operation and Polarization Switch with a Distributed Optical Klystron FEL (DOK-1 FEL)

Y. K. Wu[*], N. A. Vinokurov[#]
S. Mikhailov[*], J. Li[*], V. Popov[*]

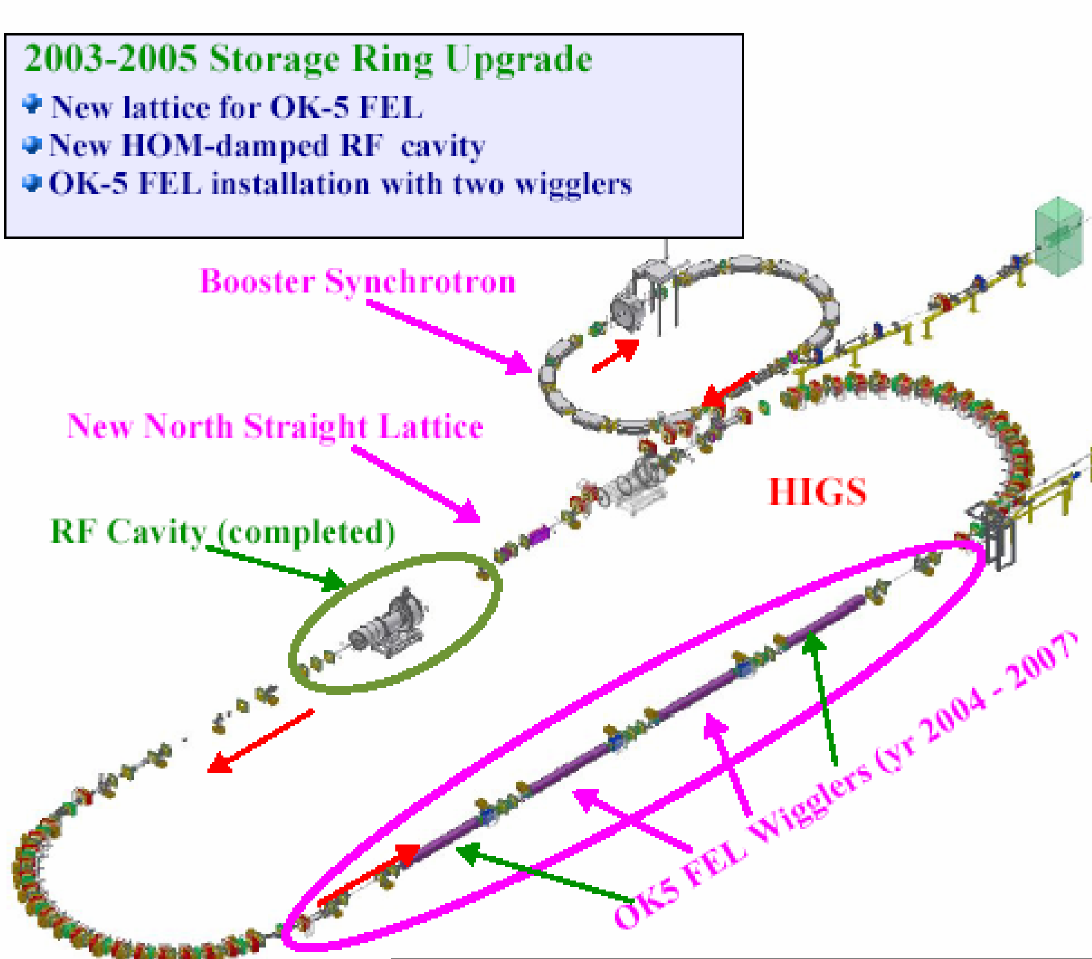
[*]FEL Lab, Department of Physics, Duke University
[#]Budker Institute of Nuclear Physics (BINP, Russia)

May 16, 2006

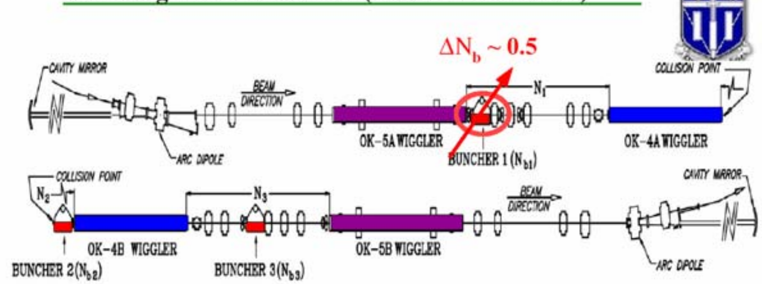
New DFELL Facility

DFELL Facility after Full Upgrades in 2006

2003-2005 Storage Ring Upgrade
- New lattice for OK-5 FEL
- New HOM-damped RF cavity
- OK-5 FEL installation with two wigglers

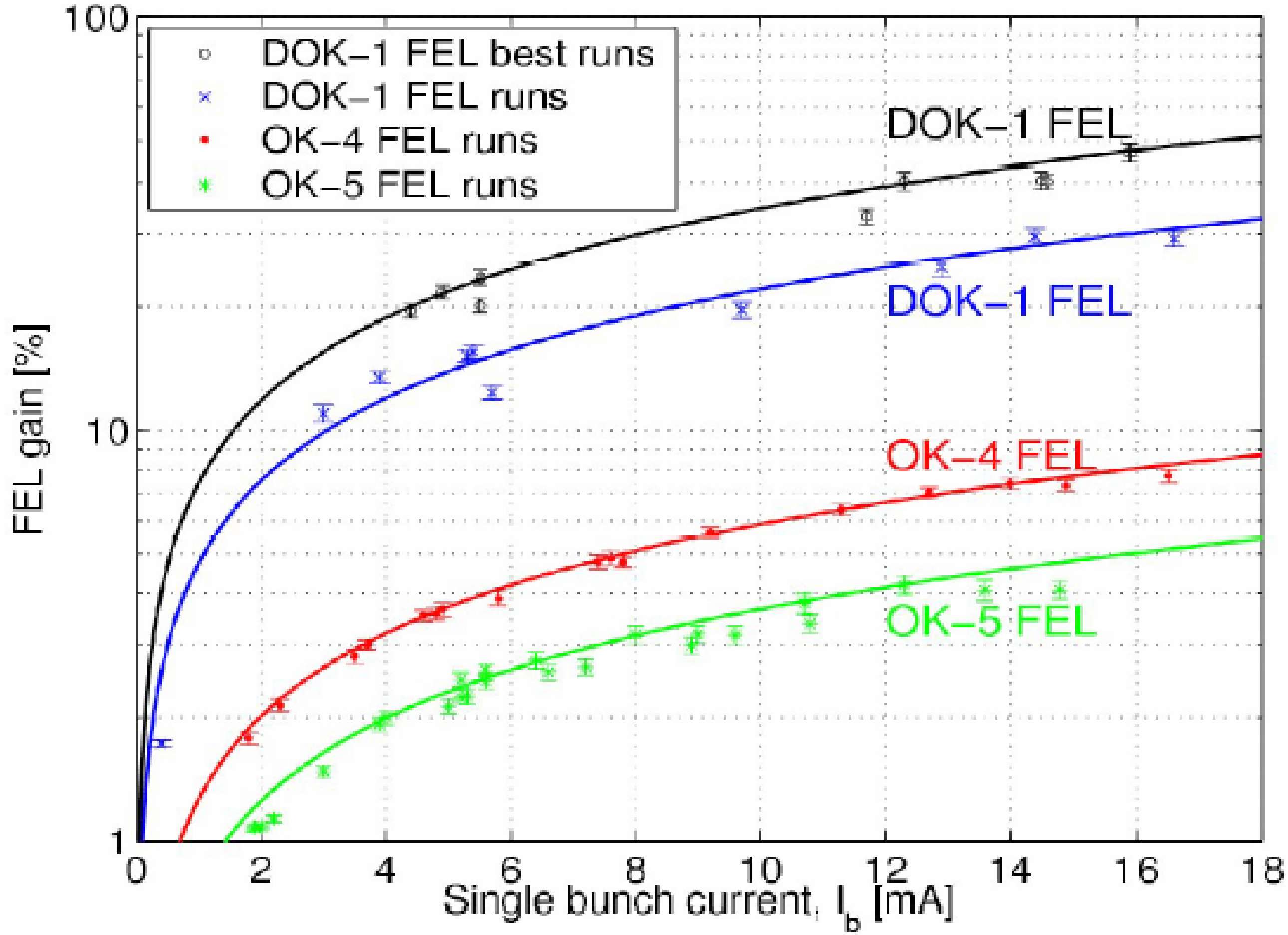


Switching FEL Polarization (One-Buncher Knob)



Fully Upgraded Facility (2006)
- Top-off injection, continuous gamma-ray operation
- Typical mode: 8-bunch, 20 mA/bunch

OK-4, OK-5, DOK-1 FEL Gain vs Current



- Microwave instability region: Gain ~ $I_b^{2/3}$
- DOK-1 gain ~2.2-2.3 times OK-4 gian + OK-5 gain

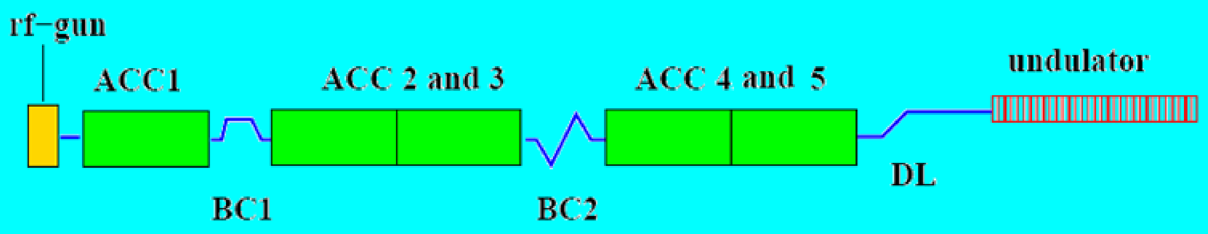
Operational experience and recent results from FLASH

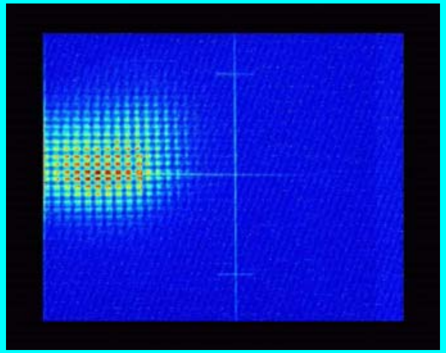
(VUV FEL at DESY)

E. Saldin, E. Schneidmiller and M. Yurkov for FLASH team

FLS2006, May 16, 2006

- Milestones
- Parameters of FEL radiation
- Beam dynamics: consequences for machine operation
- Tuning SASE: tools and general remarks
- Main problems
- Lasing at 13 nm

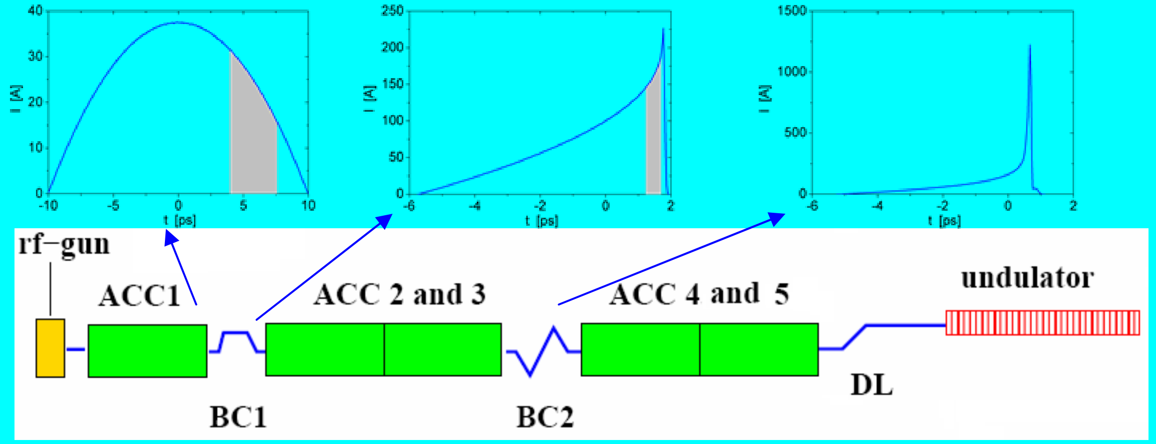




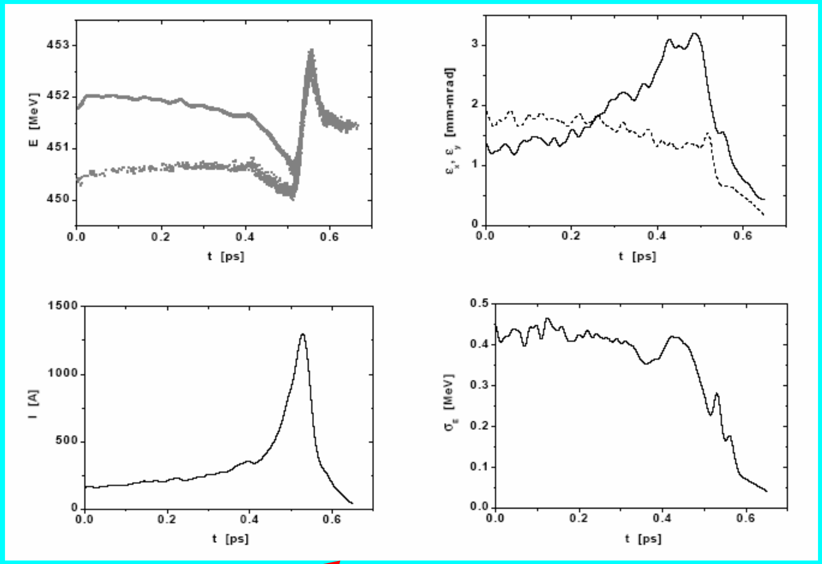
14-29.01.2005

Production of ultra-short radiation pulses

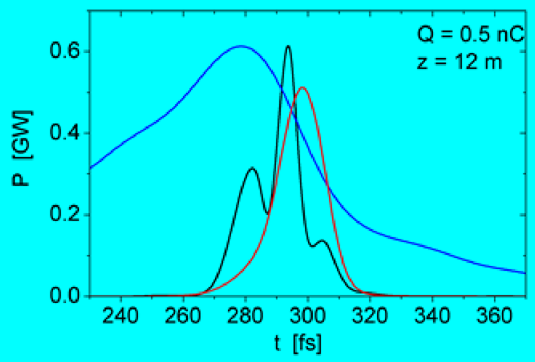
An ultra-short current spike (50-100 fs FWHM) with peak current 1-2 kA is formed in the nonlinear beam formation system of the VUV FEL



s2e simulations



radiation pulses ~20 fs



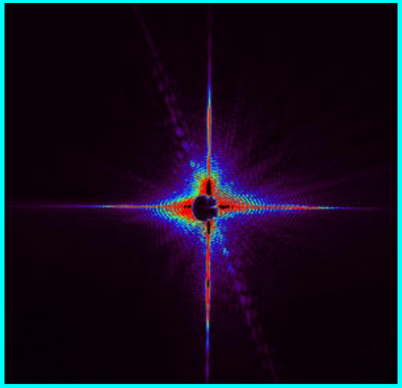
~10% of charge, properties very different from those of entire bunch

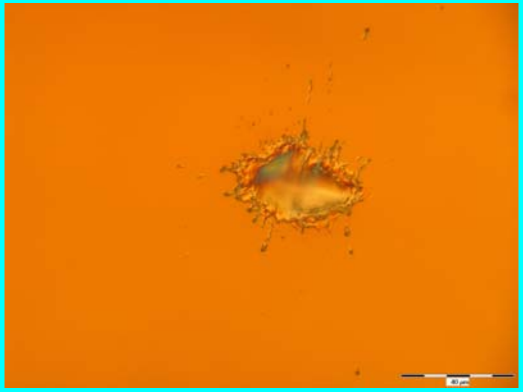
Final remarks

- The first VUV FEL user facility works. At the moment we operate unique user facility providing photon beams with ultimate peak brilliance, 100 millions times above the best SR storage rings. Users are happy:

10.02.2006: Summary from FEL users* *We loved those 15 microJ pulses! Today we measured time-delay holograms of exploding latex spheres (pump-probe, using a multilayer mirror to reflect the pulse back onto the particle). Will post picture in logbook. Thanks for all the photons. (H.Chapman et al., BL2)*

18.02.2006: Summary from FEL users* *WHAT AN EXCELLENT RUN!!! We really enjoyed the 15-22 μJ average and were able to complement our previous cluster data with higher pulse energies. This shift was very valuable to us. Hopefully we can get similar intensities tomorrow... * Chris Bostedt, TU Berlin*





DISPERSION MEASUREMENT
AND
CORRECTION IN THE VUV-FEL (FLASH)

Winni Decking, Torsten Limberg, Eduard Prat

37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources

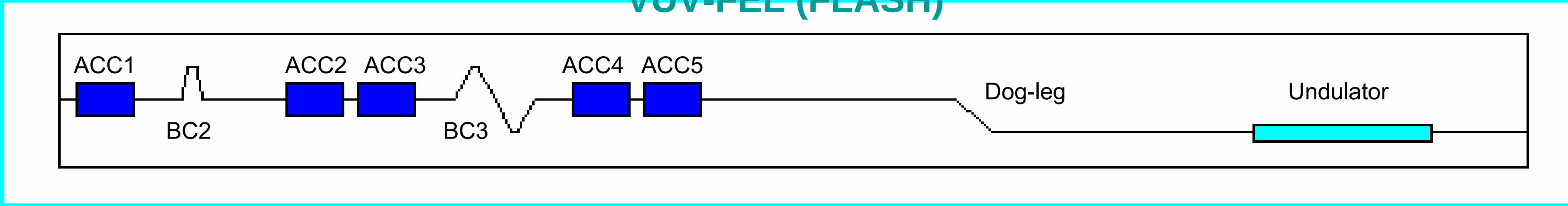
Hamburg, 16 May 2006

$$\eta_x = \frac{\Delta x}{\Delta p / p}$$

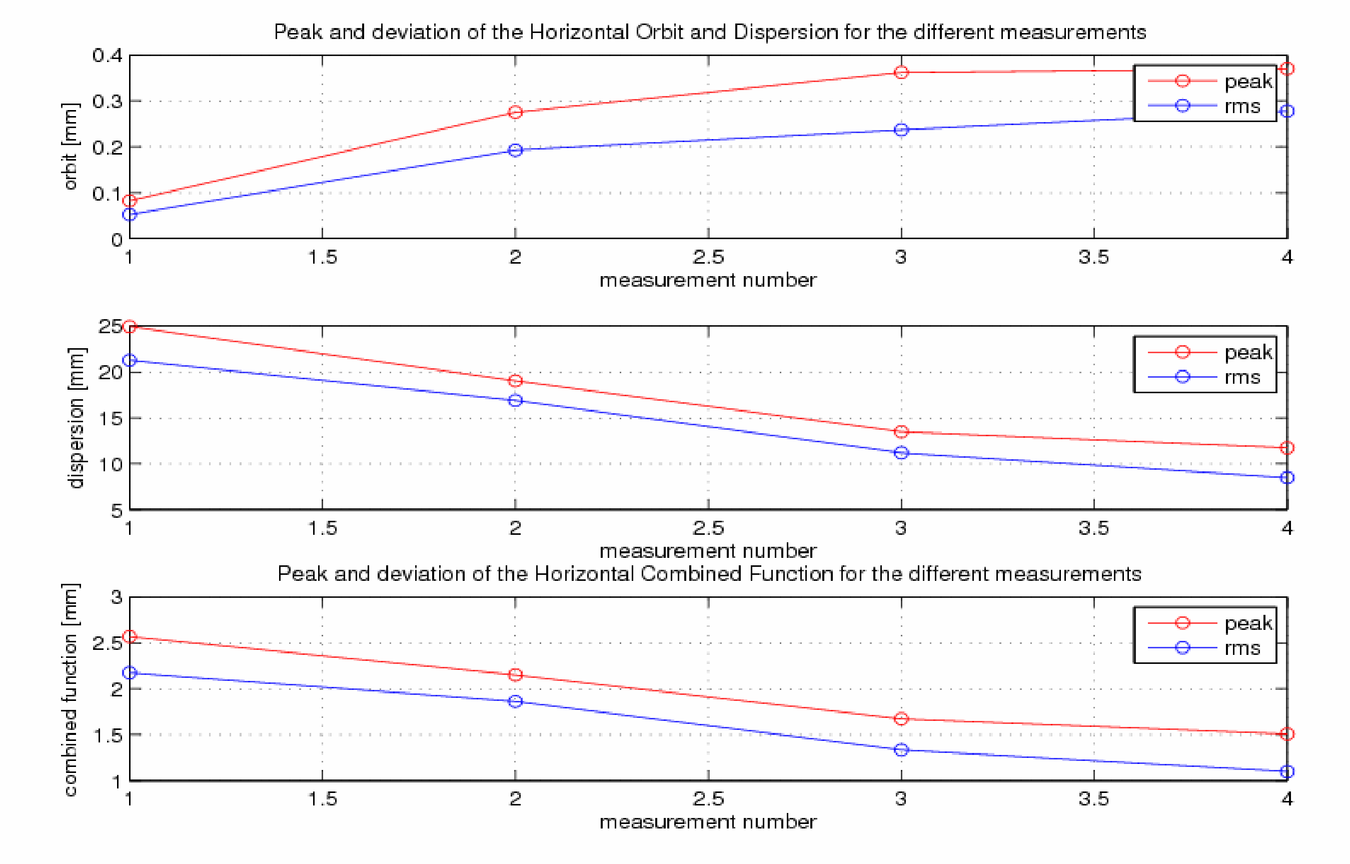
$$\sigma = \sqrt{\varepsilon \cdot \beta(s) + \eta(s)^2 \cdot \left(\frac{\Delta p}{p}\right)^2}$$

Goal: dispersion in the undulator of **1 cm**

VUV-FEL (FLASH)



1st Dispersion correction measurements (April 06)



Beam Dynamics Experiments and Analysis in FLASH on CSR and Space Charge Effects

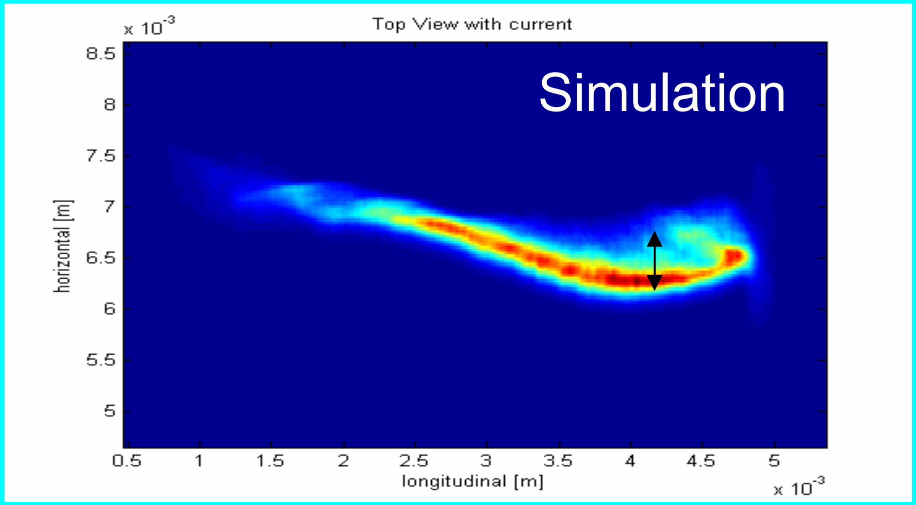
Bolko Beutner, Martin Dohlus, and Michael Röhrs

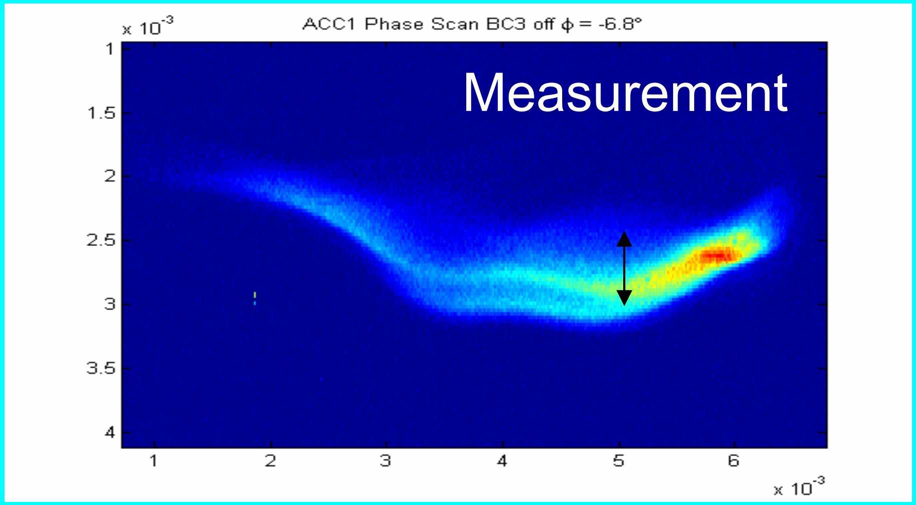
DESY Hamburg

ICFA FLS-2006 Workshop - DESY, May 19th 2006

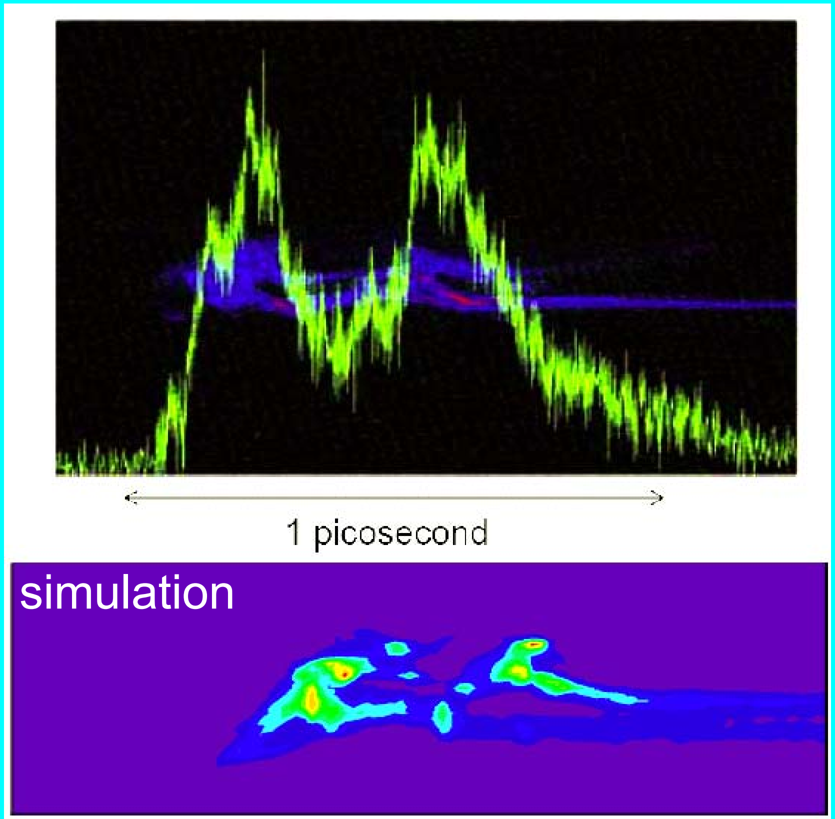
Comparison with Simulations

- Qualitative agreement
- Sag near the head is in both cases about 0.5mm
- Optics and dispersion in the machine were not measured
- Disagreements in bunch length





- The observed double peak structure of the FLASH beam is understood by simulations.
- Qualitative agreement between simulated and measured transverse profiles



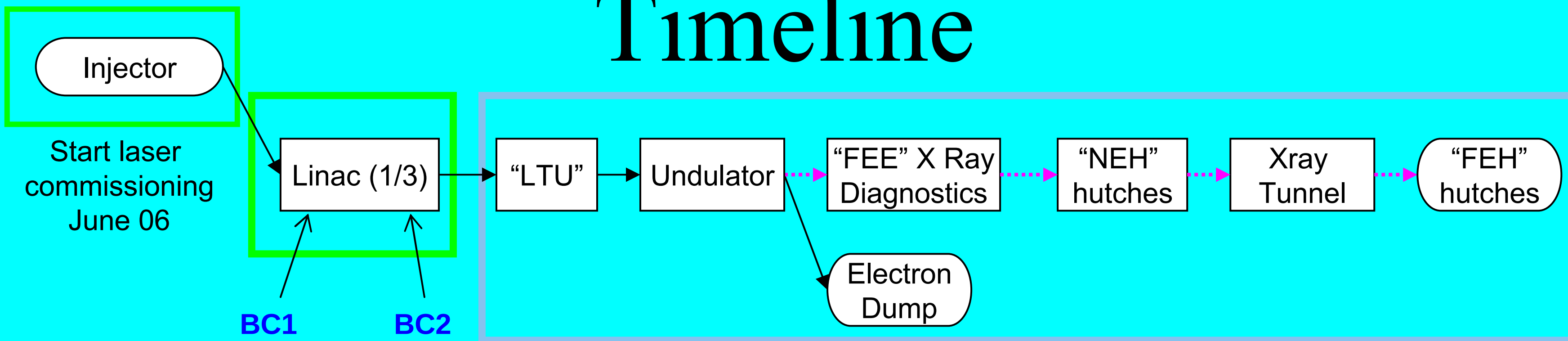
LCLS Commissioning Plans

(Dec. 1, 2006 through Mar. 30, 2009,…and beyond)

J. Welch

ICFA FLS 2006

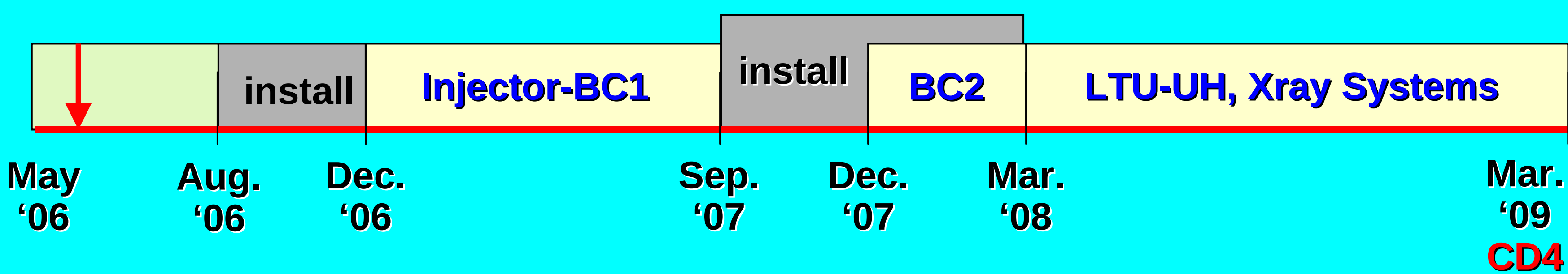
Overview of Beamlines and Timeline



Existing and refurbished housing

New housing construction. Completion by ~ Oct. 07

LTU: Linac to Undulator
FEE: Front End Enclosure
NEH: Near Experimental Hall
FEH: Far Experimental Hall
BC1(2): Bunch compressors



The SPARX project

C. Vaccarezza

on behalf of the SPARX team

2006-07: 1 year for Technical Design Report.

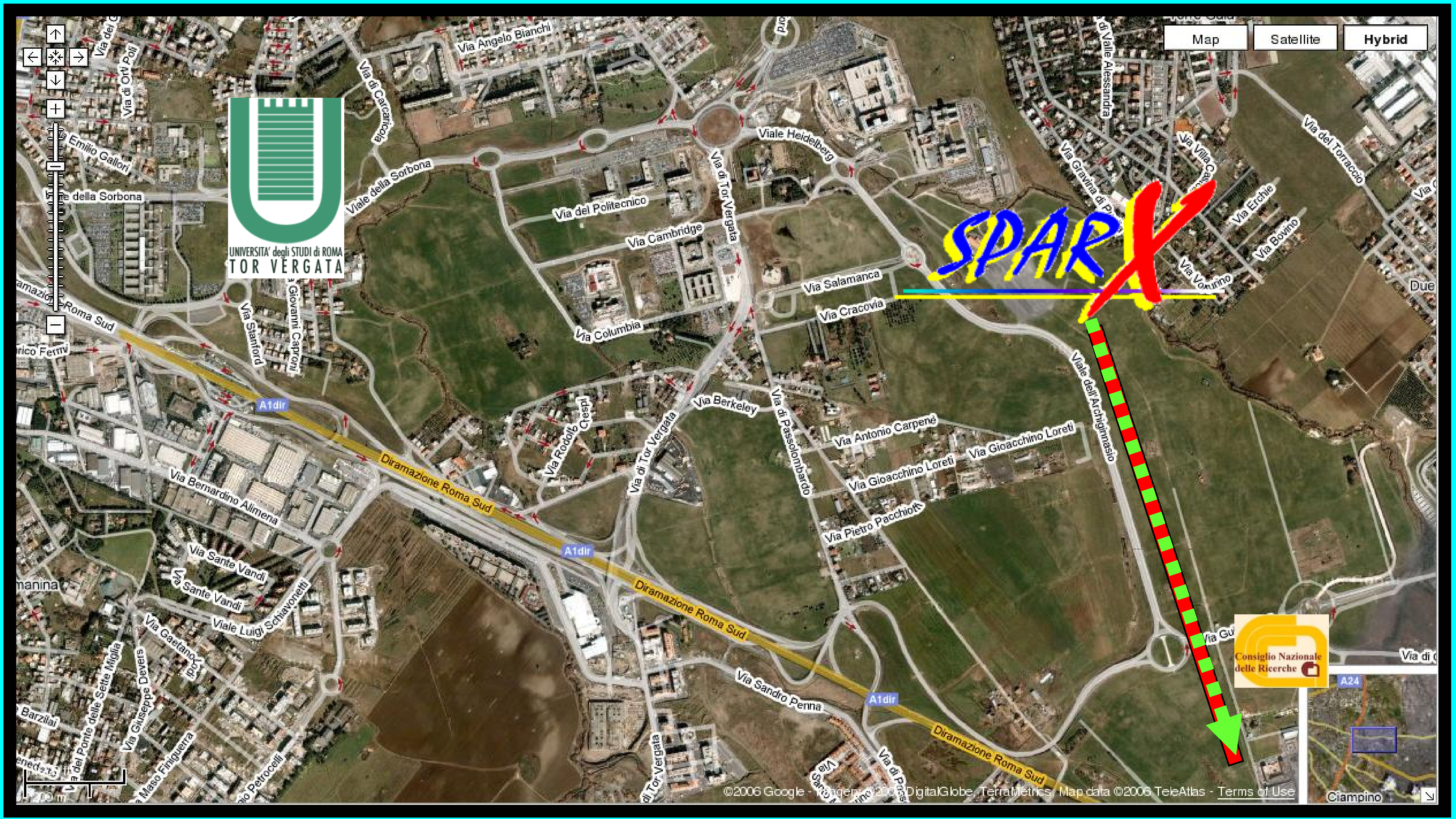
2006-09: Civil construction & site arrangement

2007-09: Device construction & procurement

2010-11: Installation & Commissioning

50 M€ 1 GeV first phase (funded!)

50 M€ 2 GeV phase



SDUV-FEL Facility Progress

Dai Zhimin
on behalf of SDUV-FEL team

2006.5.18

Current Schedule of SDUV-FEL

2002.1~2005.12	Construction and commissioning of a 100MeV Linac with grid gun as prototype of pre-injector of SSRF
2006.1~2006.9	Installation of 40MeV injector with photocathode RF gun
2006.9~2007.6	Commissioning of photocathode RF gun and 40MeV injector
2007.1~2007.12 (phase 1)	Installation of undulator system, seeding laser, and electron beam / laser diagnostic instruments; Begin on experiments of UV-FEL (262nm)
2008.1~2009.12 (in phase 2)	Upgrade Linac energy to 280MeV, and begin on experiments of DUV-FEL (88nm)

Simulation studies on the self-seeding option at FLASH

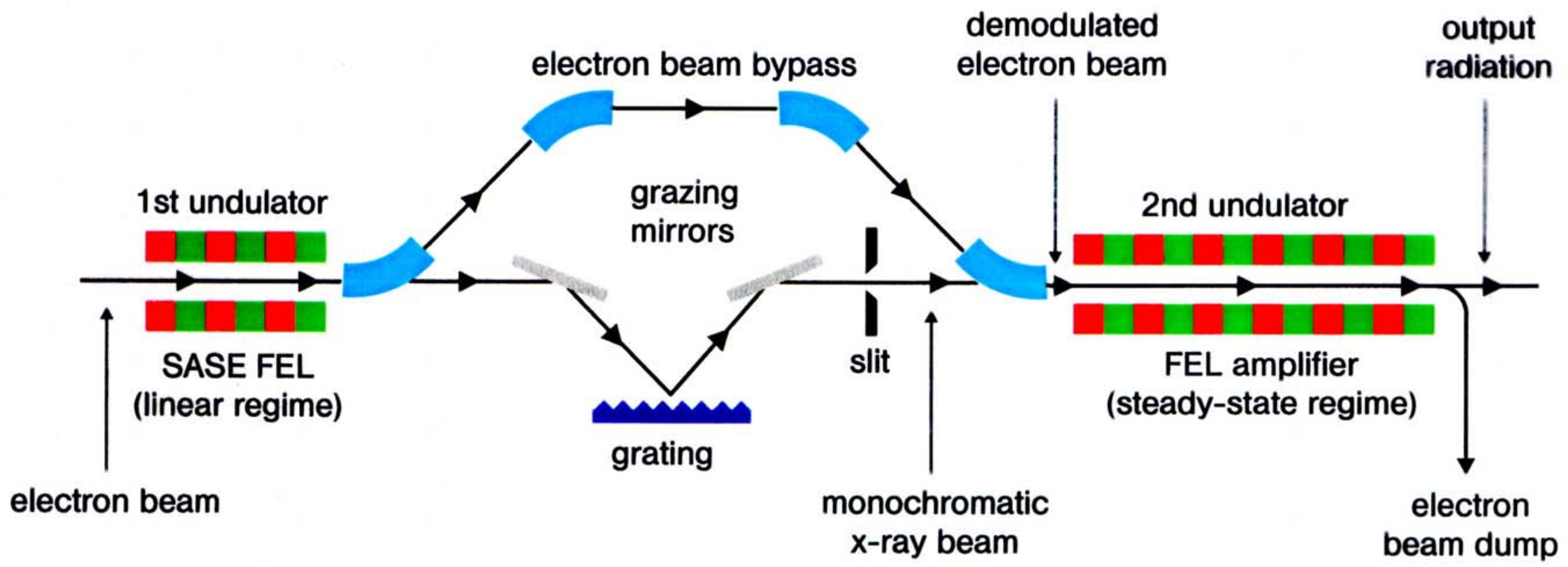
B. Faatz, V. Miltchev, J. Rossbach, R. Treusch

37th ICFA Advanced Beam Dynamics Workshop on Future Light Sources

This work has been partially supported by the EU Commission in the Sixth Framework Program, Contract No. 011935 – EUROFEL

Basic principles of the self-seeding option [1]

1) J. Feldhaus et al. / Optics Communications 140(1997) 341-352

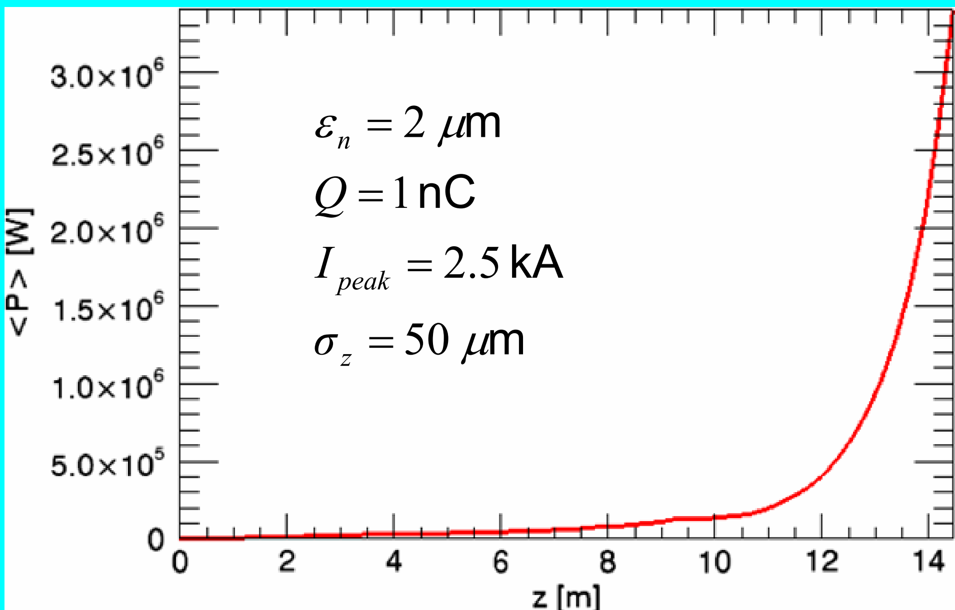


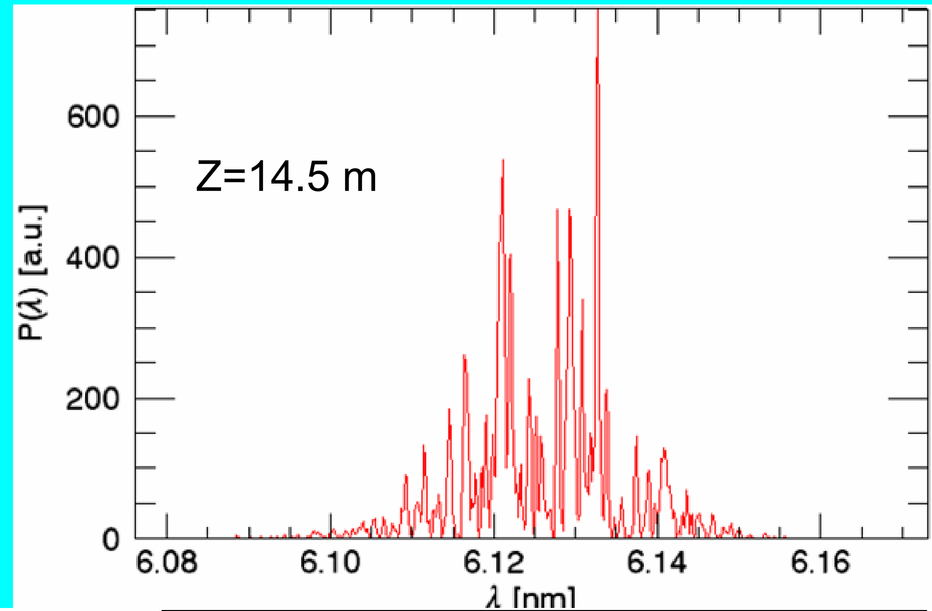
Schematic view of the seeding option for FLASH

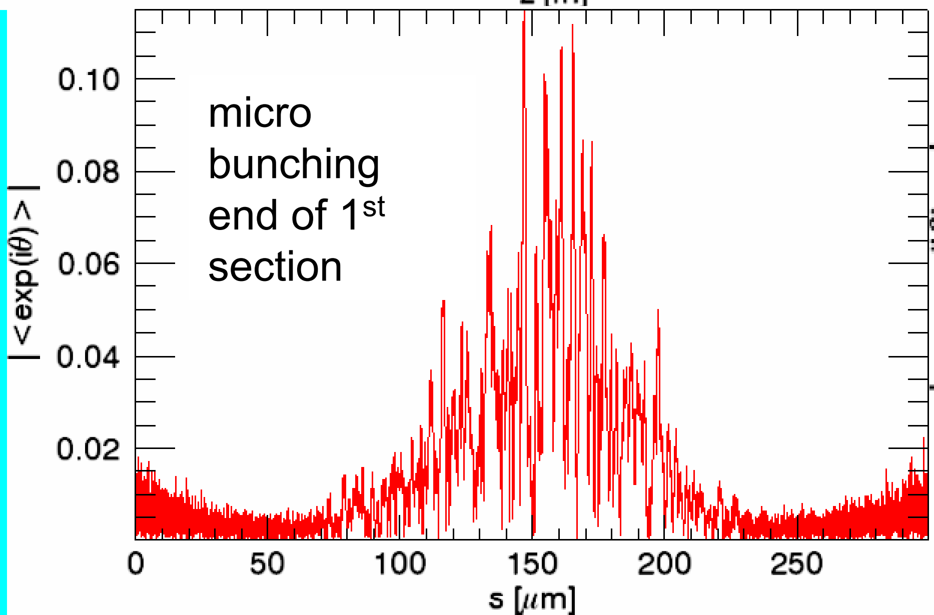
Basic requirements:

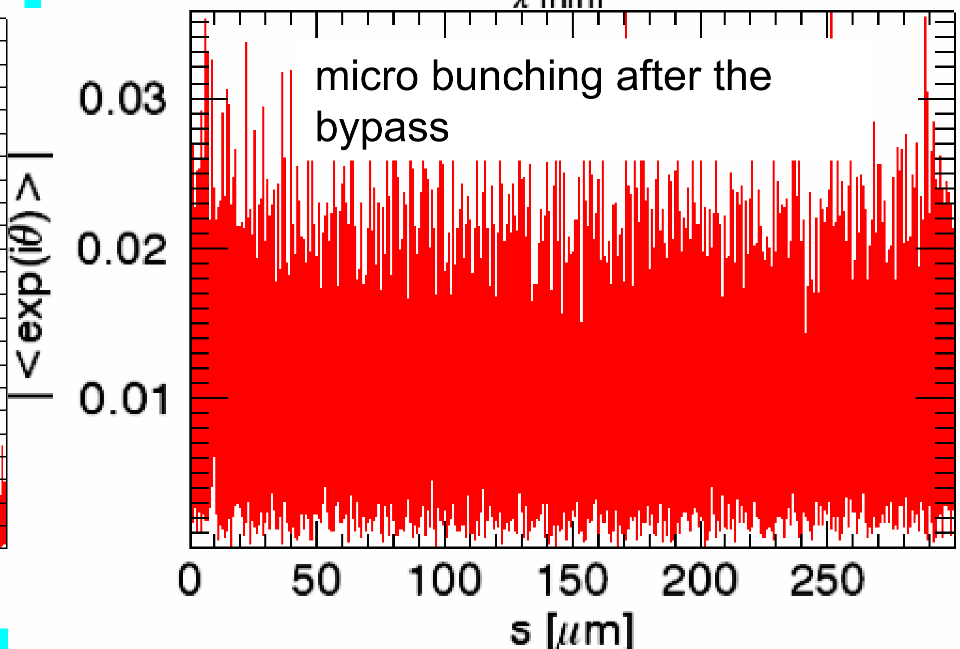
1) The 1st section operates in linear high-gain regime, $<P_{SASE}>\sim 10MW$
2) The micro bunching is smeared out after the magnetic chicane
3) The monochromator resolution $\Delta\omega/\omega \approx 5\cdot 10^{-5}$
4) The seeding power $P_{SEED} \sim 10kW$ >> shot noise power $P_{SHOT} \sim 10W$
5) The seed pulse is amplified to saturation in the 2nd undulator section

FEL calculations – 6 nm(1st section)

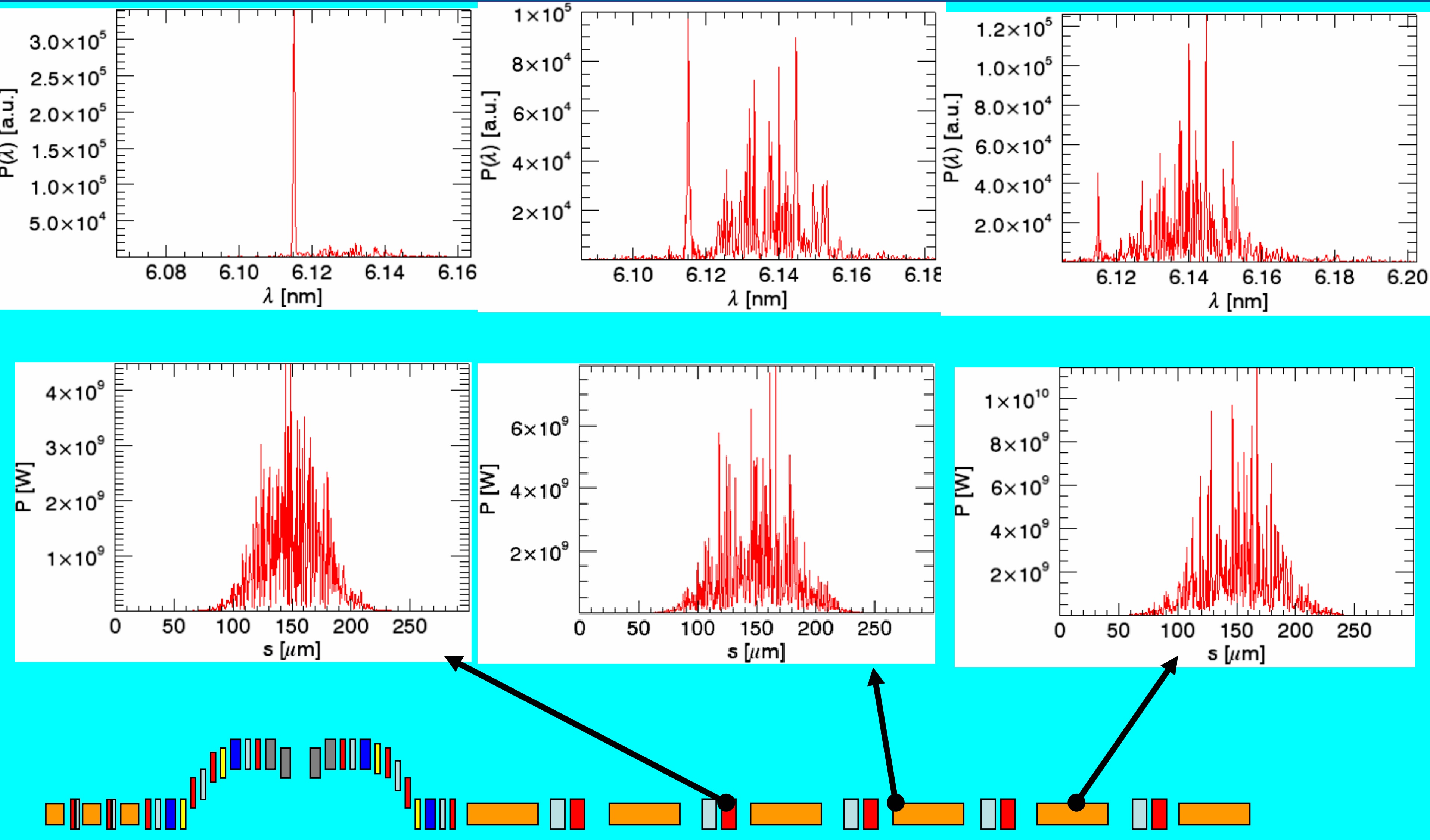




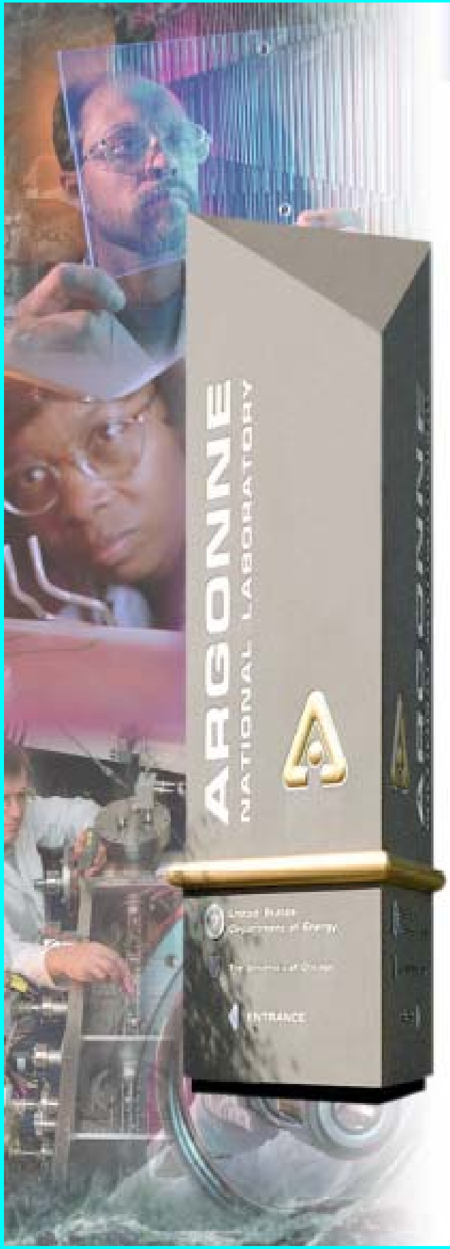




FEL performance – 6 nm(2nd section)



ARGONNE NATIONAL LABORATORY



Visible/IR light and X-Rays in Femtosecond Synchronism from an X-Ray Free-Electron Laser

B.W. Adams
APS, XOR

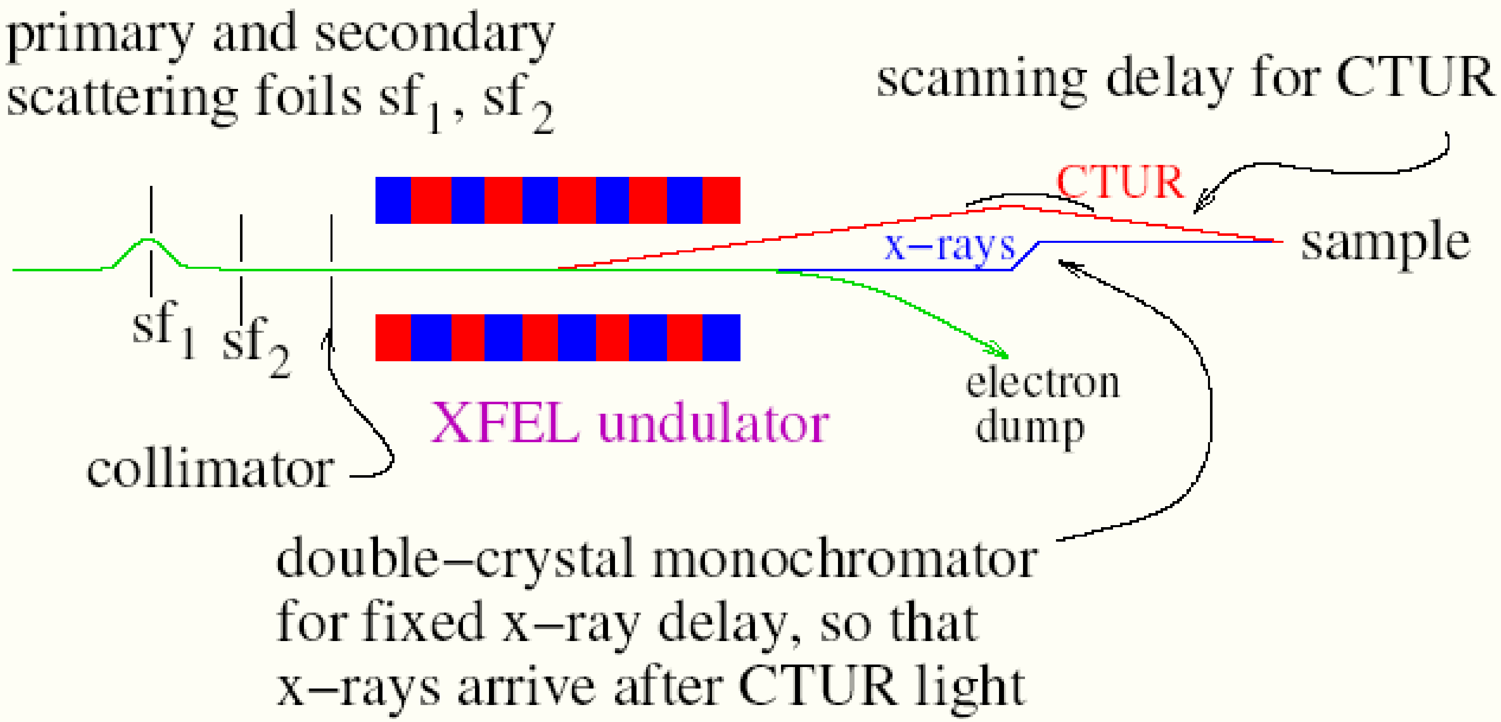
May 2006
FLS2006

THE UNIVERSITY OF CHICAGO

Office of Science
U.S. DEPARTMENT OF ENERGY

Argonne National Laboratory is managed by the University of Chicago for the U.S. Department of Energy

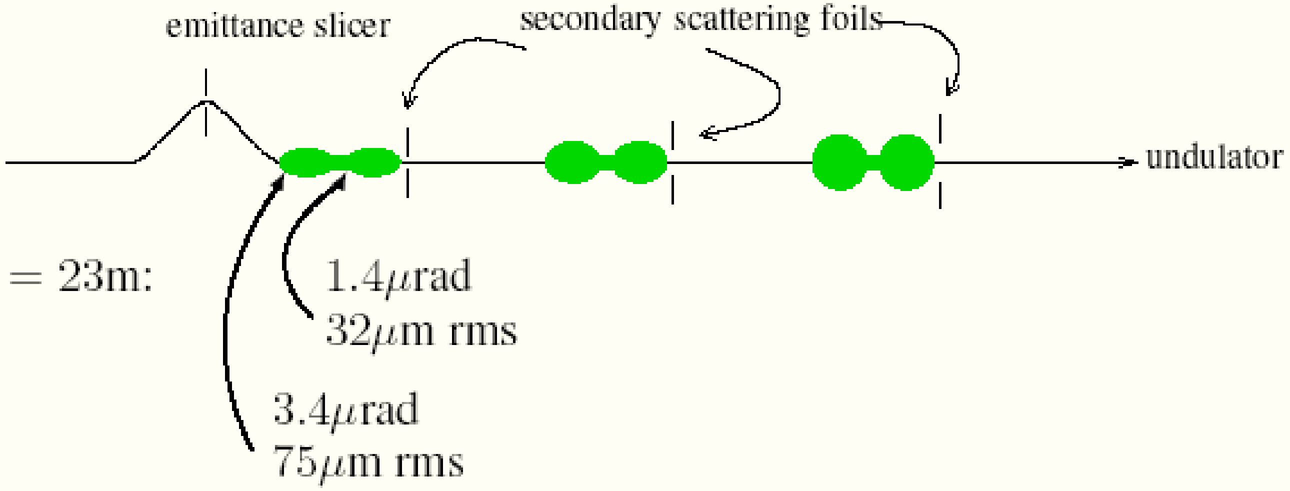
Overview



primary and secondary
scattering foils sf1, sf2
scanning delay for CTUR
CTUR
x−rays
sample
sf1
sf2
electron
dump
XFEL undulator
collimator
double−crystal monochromator
for fixed x−ray delay, so that
x−rays arrive after CTUR light

Increasing the Emittance Contrast

Emittance contrast is in both divergence and beam size:
secondary scattering foils make use of beam size contrast
to increase emittance contrast even further



with $\beta = 23$m:

1.4μrad
32μm rms

3.4μrad
75μm rms

space secondary foils at 1/2-β-function intervals to catch all electrons

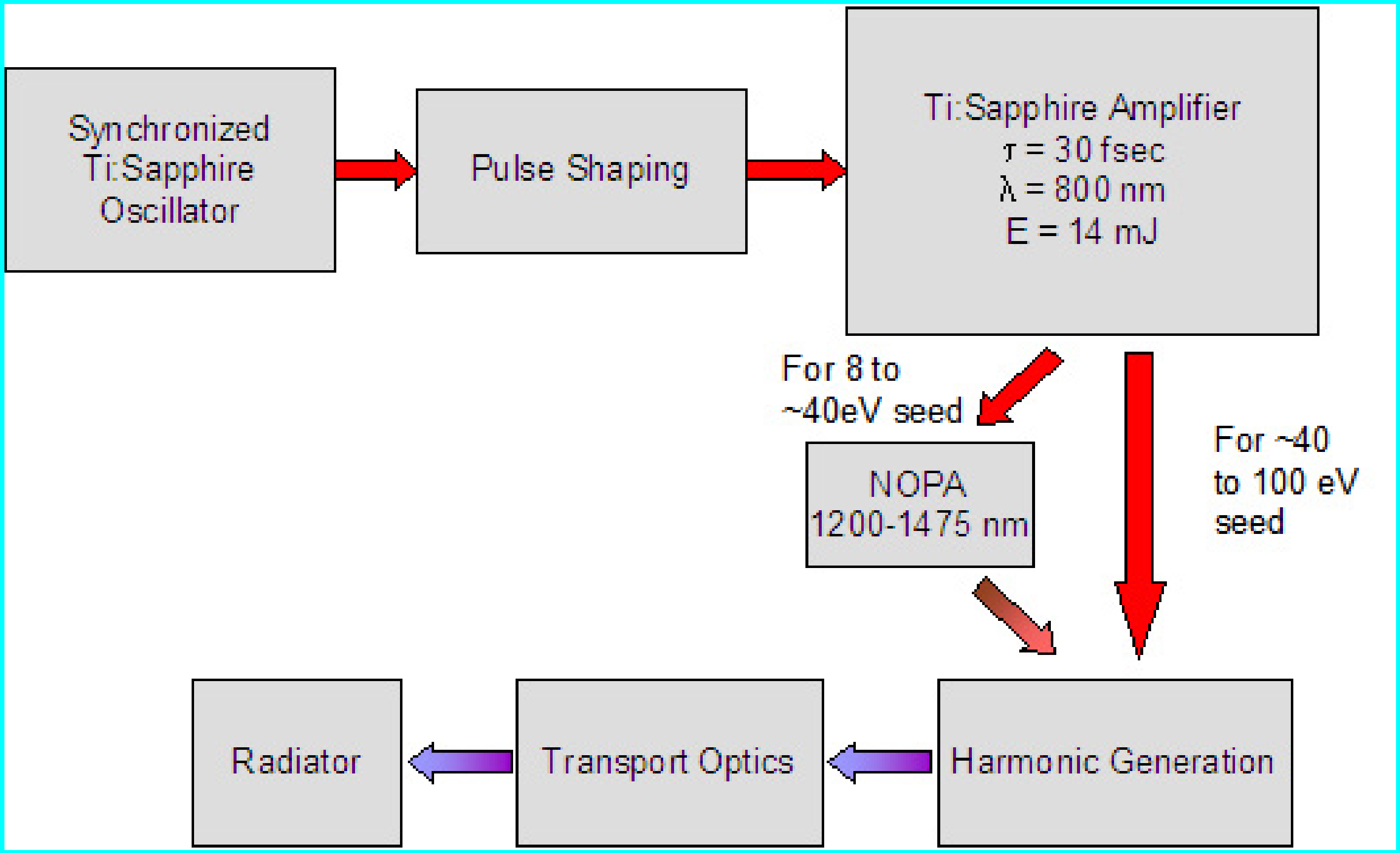
High Harmonic Seeding and the 4GLS XUV-FEL

Brian Sheehy, May 18, 2006, FLS Workshop, FEL Workgroup,

J.A. Clarke, D. J. Dunning, N. R. Thompson, CCLRC, ASTeC, Daresbury Laboratory;
B. W. J. McNeil, University of Strathclyde, Glasgow, UK

- **Energy and Efficiency Questions**
  - **how much do we need?**
  - **how much do we have today? tomorrow?**
- **Tunability**
  - **tunable fundamental**
  - **adaptive tuning**
- **Attosecond structure, contrast, & spatial coherence**
- **Layout in the facility**

Functional block diagram of the high harmonic seed generation for the XUVFEL



•Two-track system: 8 – 40 eV & 40 – 100 eV (Tunability)

• Doable with existing technology

  • expected near-term improvements in lasers, harmonic efficiency, will make it easier

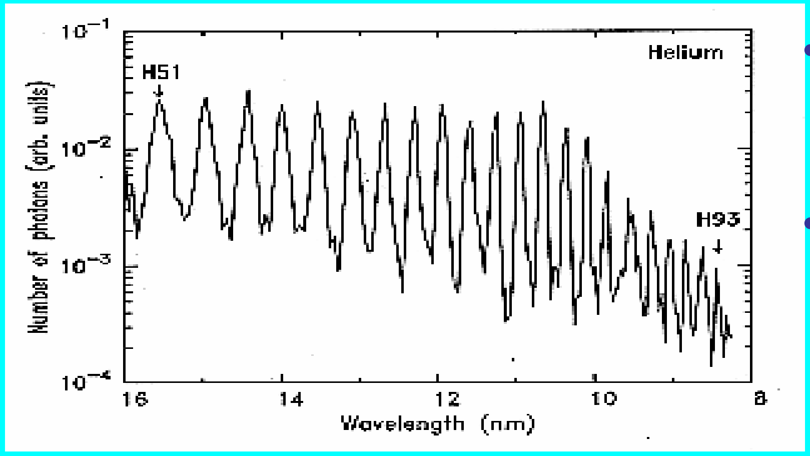
Energy, Efficiency and Repetition rate

- Required Harmonic Energy
  - 1.0E-9 J based on 30 KW, 30 fsec pulse
    - consistency among simulation efforts: GENESIS, GINGER, PERSEO
  - "spontaneous" power only ~ tens of Watts

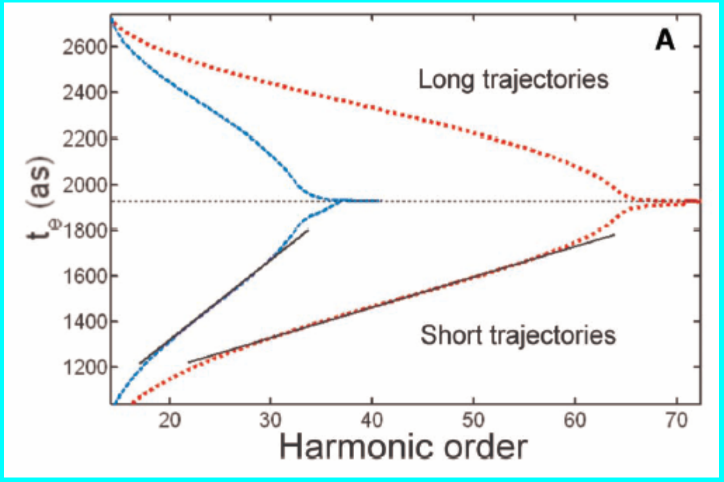
Existing Ti:Sapph systems

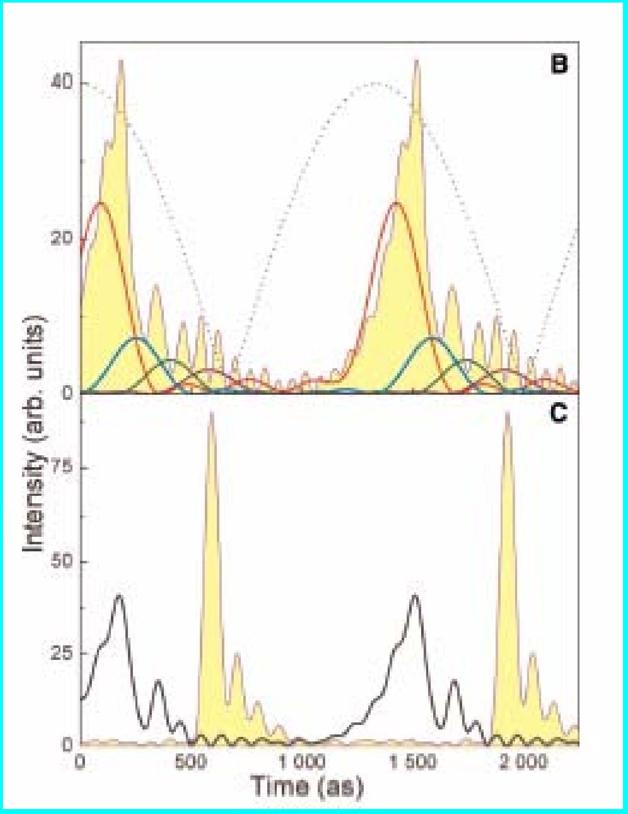
Laser Energy (mJ)	2	4	14	60
Repetition Rate (kHz)	10	5	1	0.1
harmonic energy (nJ)	0.8	2	6	24
net efficiency to target (generation, tuning, transport…) 40-100 eV			4.E-07	

Attosecond Time Structure in the harmonics



- Plateau electronics form a frequency comb
  - Well defined relative phases
  - attosecond pulse trains & attosecond pulses
- Emission time for harmonic groups distinguishable
  - chirped over the plateau



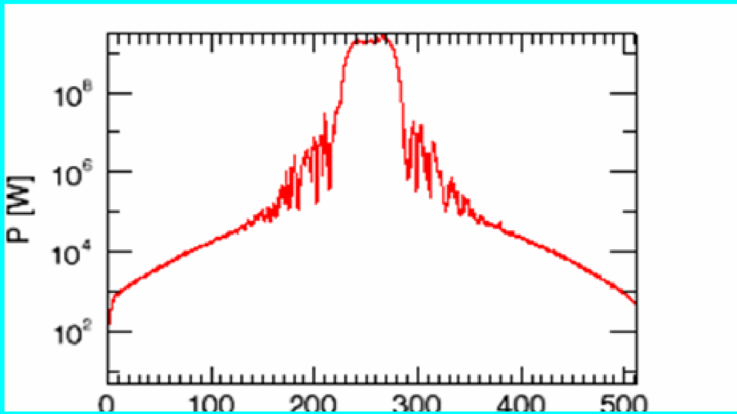


Mairesse et al Science 302, 1540 (2003)

Some Comments on Contrast

The contrast you get:

- improves with increasing seed power
- is sensitive to e^- bunch profile
  - simulations use gaussian
  - sensitive to synchronization



The contrast you need:

- is sensitive to the length of the pedestal
  - IR pedestals are nsec-psec
  - the integrated effect counts
  - sensitive to e^- bunch length/profile
- varies with the experiment

Magnetics and Radiation Sources Group

4GLS

University of Strathclyde

The 4GLS VUV-FEL:

a Regenerative Amplifier FEL (RAFEL) design

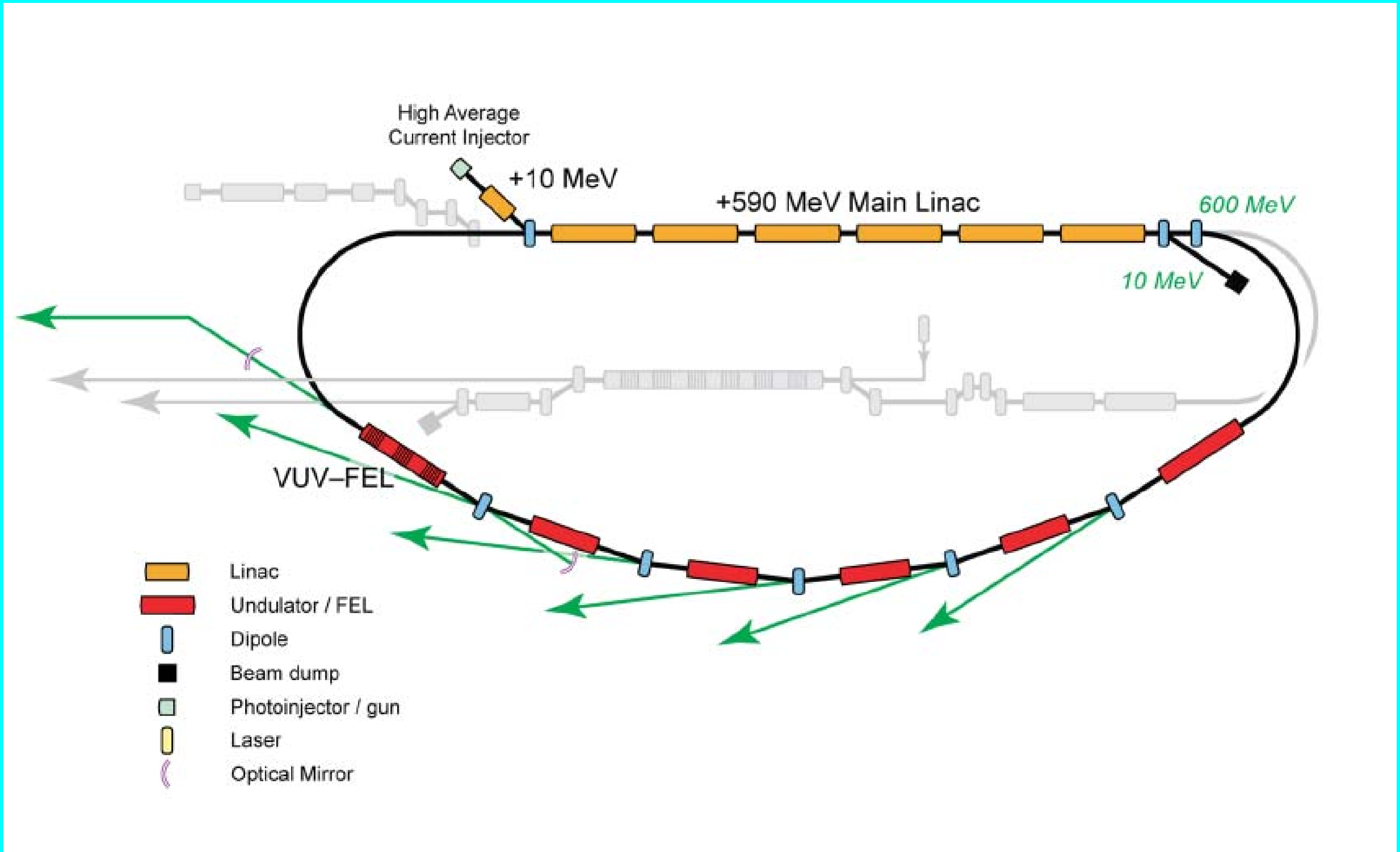
Neil Thompson & David Dunning, *MaRS Group, ASTeC*

Brian McNeil, *University of Strathclyde*

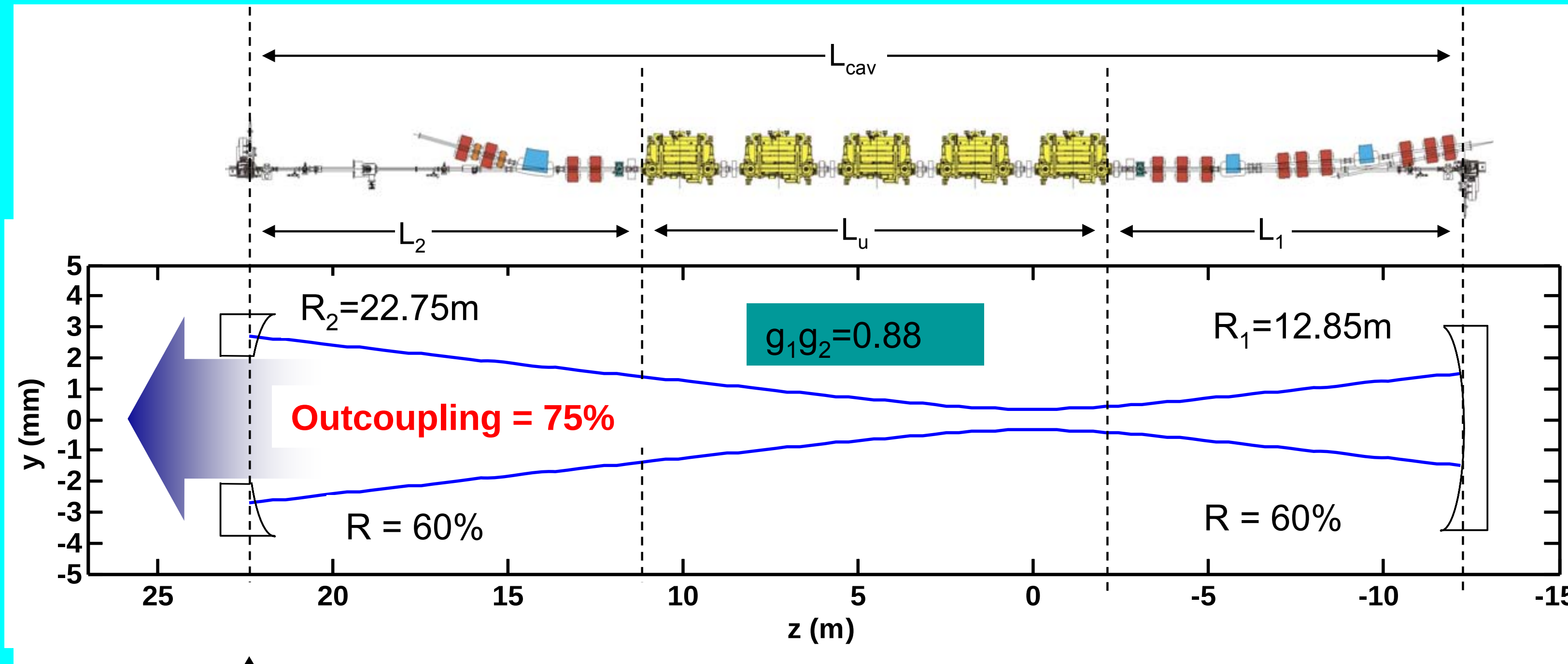
Brian Sheehy, *Sheehy Scientific Consulting*

ICFA FLS-2006 Workshop - DESY, May 19th 2006

The VUV-FEL in 4GLS



Cavity parameters in CDR



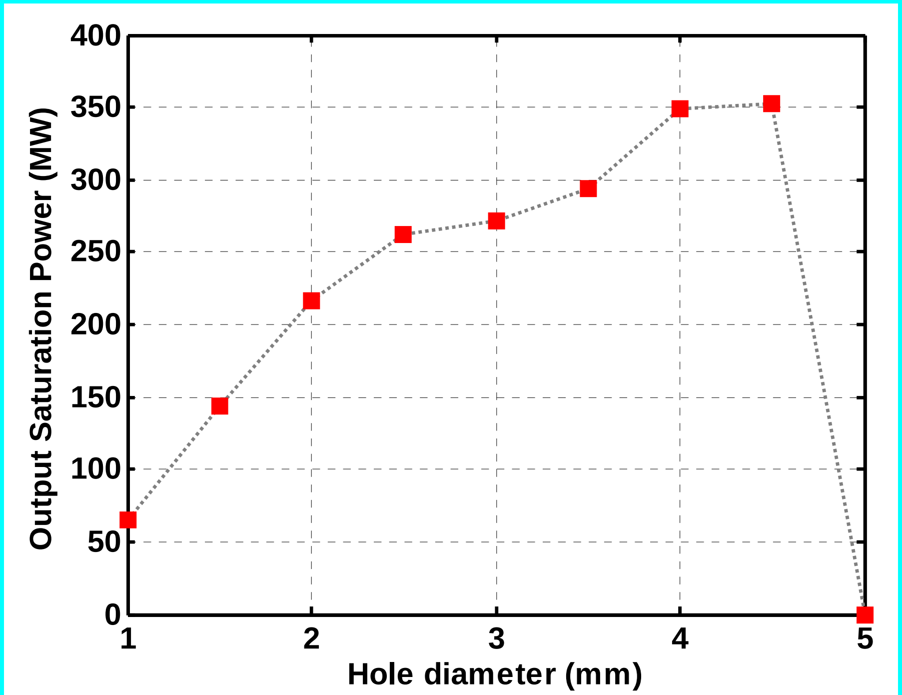
Hole size chosen to be slightly smaller than spontaneous emission spot size on first pass

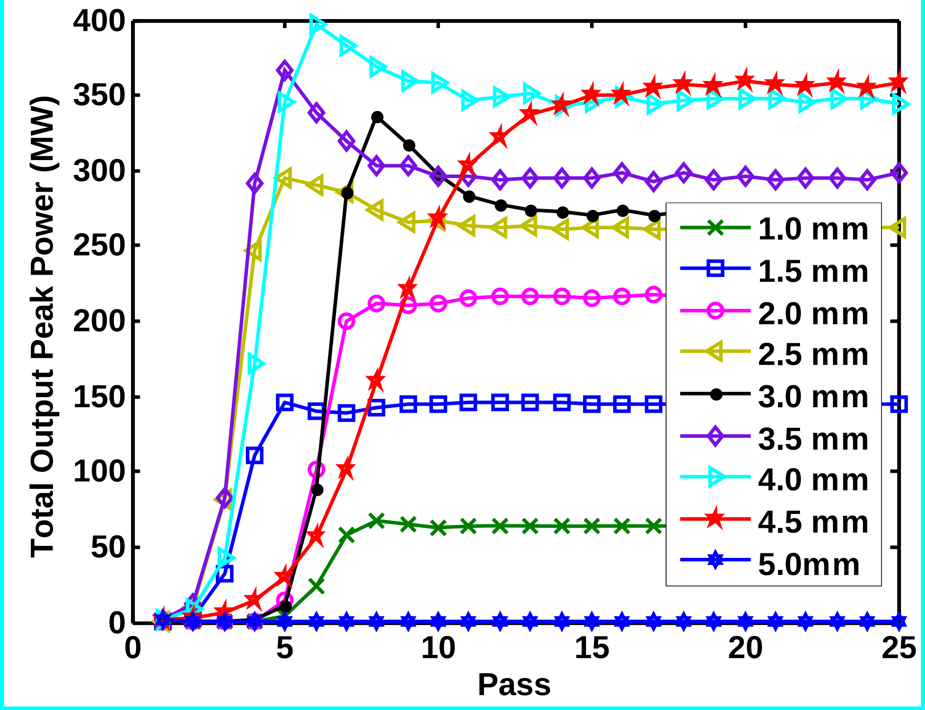
Mirror ROC then chosen, assuming cold cavity mode, to give:

- waist near entrance to undulator (to optimise seeding)
- spot size on mirror appropriate for 75% outcoupling with chosen hole size

i.e. match opening angle of spontaneous emission to divergence angle of fundamental cavity mode

Varying hole size





Fully Coherent X-ray Pulses from a Regenerative Amplifier Free Electron Laser

Zhirong Huang and Ron Ruth

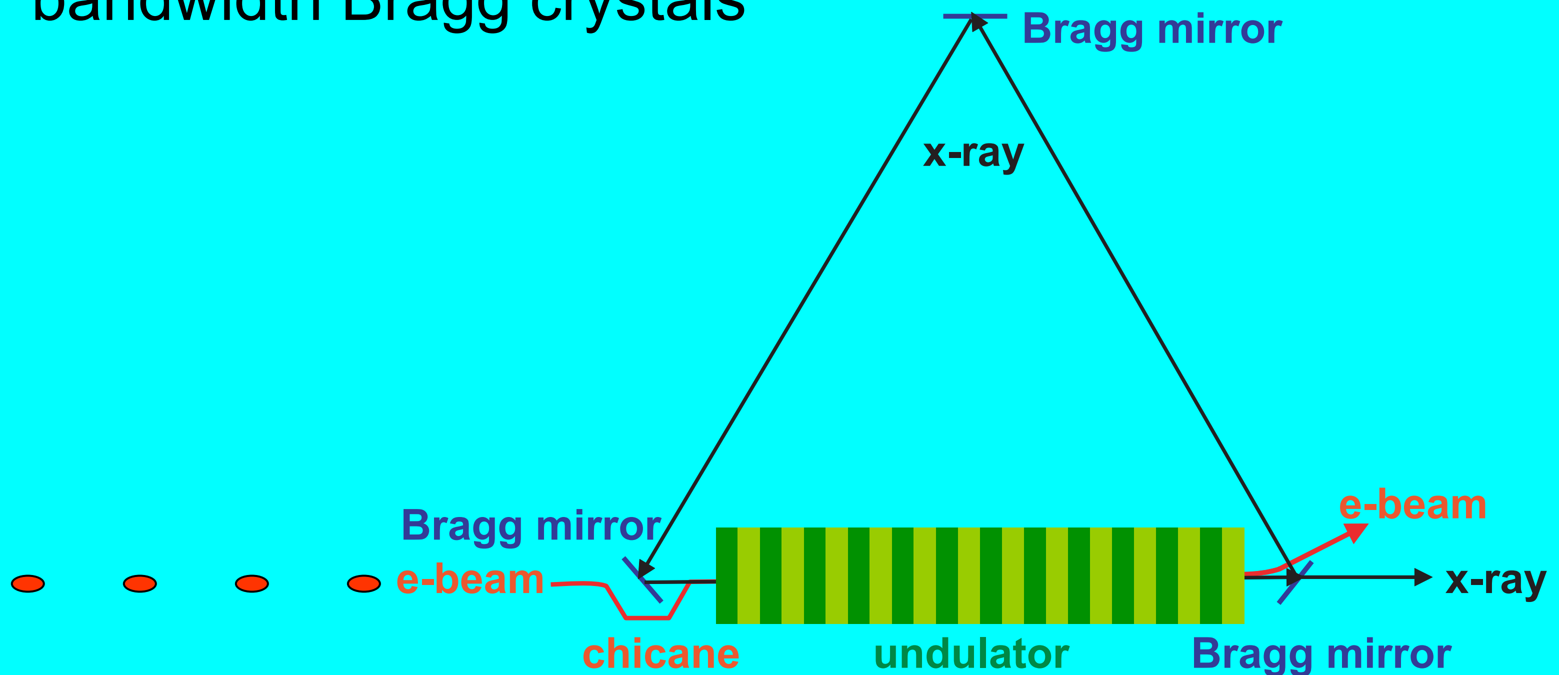
SLAC

FEL working group

(5/18/2006)

X-ray RAFEL

- We propose and analyze an x-ray RAFEL using narrow-bandwidth Bragg crystals*



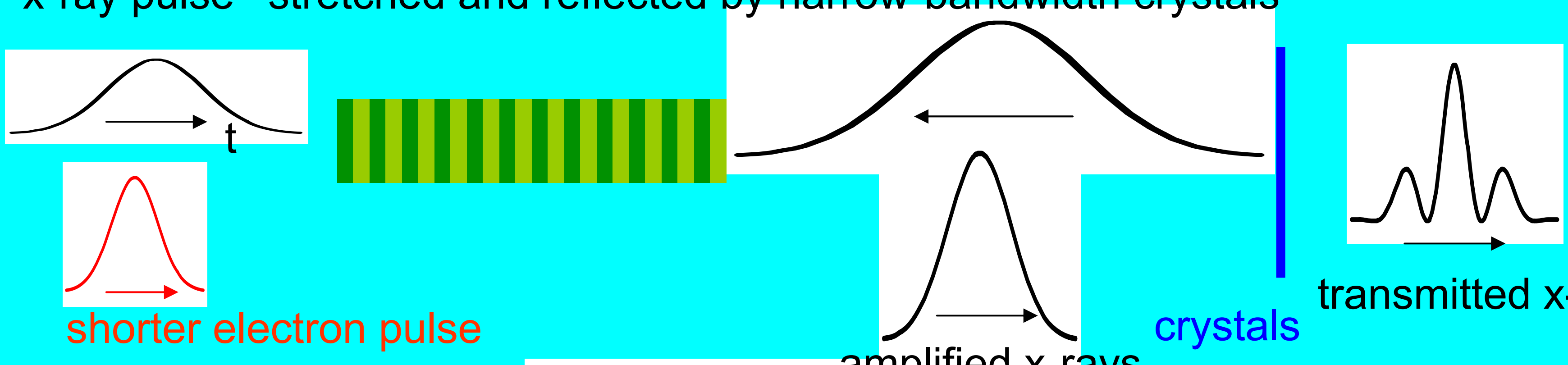
- Alternative backscattering geometry may also be used

** Z. Huang & R. Ruth, PRL96, 144801 (2006)*

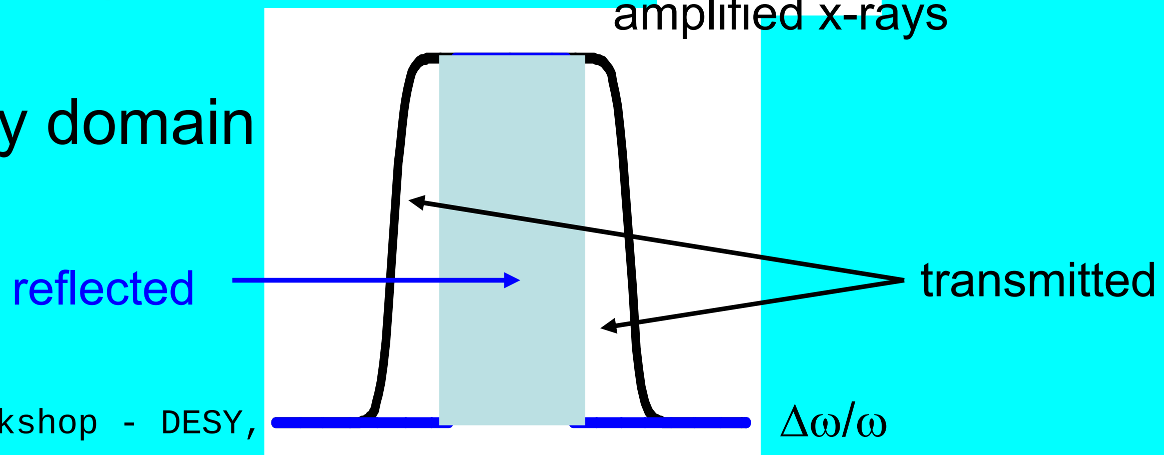
Frequency-domain extraction scheme

- If crystal reflects ~100% within narrow bandwidth, how can power be extracted out of the cavity?
- Use bunch shorter than the reflected x-ray pulse: FEL interaction ➔ amplify and spectrally broaden the radiation
➔ Power transmitted outside the feedback bandwidth

x-ray pulse stretched and reflected by narrow-bandwidth crystals



In frequency domain



Radiation energy dose and damage issue

Comparison of LCLS SASE and RAFEL power and energy

X-ray properties	**SASE**	**RAFEL**
Pulse length (fwhm)	200 fs	100 fs transmitted (150 fs reflected)
FEL pulse energy	2 mJ (one pulse)	2 mJ (last 2 saturated pulses)
FEL peak power	10 GW	4 GW out (14 GW in cavity)
FEL photon energy	~ 8 keV	8 keV
Absorption in 100-µm diamond crystal	18 % of 10 GW = 1.8 GW	18 % of 4 GW = 0.72 GW
Beam transverse area	~ $(50\ \mu m)^2$ (100 m away)	~ $(22\ \mu m)^2$
Energy dose on crystal	0.004 eV/atom	0.002 eV/atom × 2 pulses (?)
Spontaneous power (over large beam area)	70 GW	3.6 GW × 10 bunches

Melt dose level of C (graphite) is 0.9 eV/atom, more than two orders of magnitude higher than both SASE and RAFEL doses on diamond

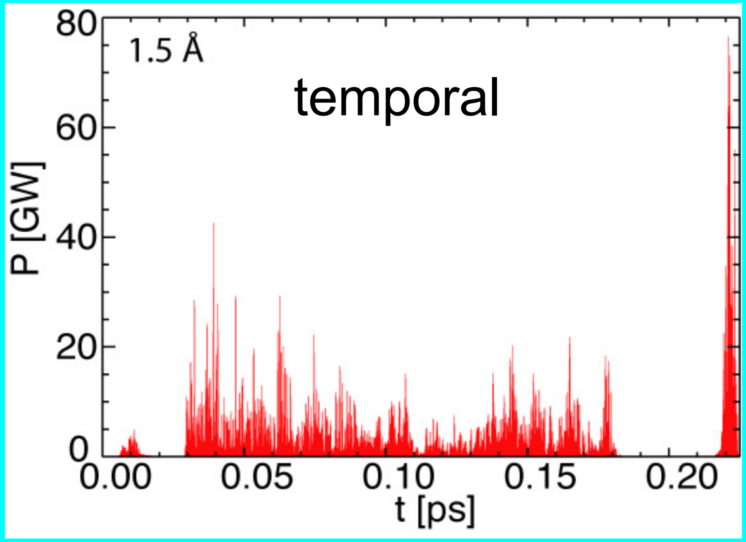
Parameter Summary

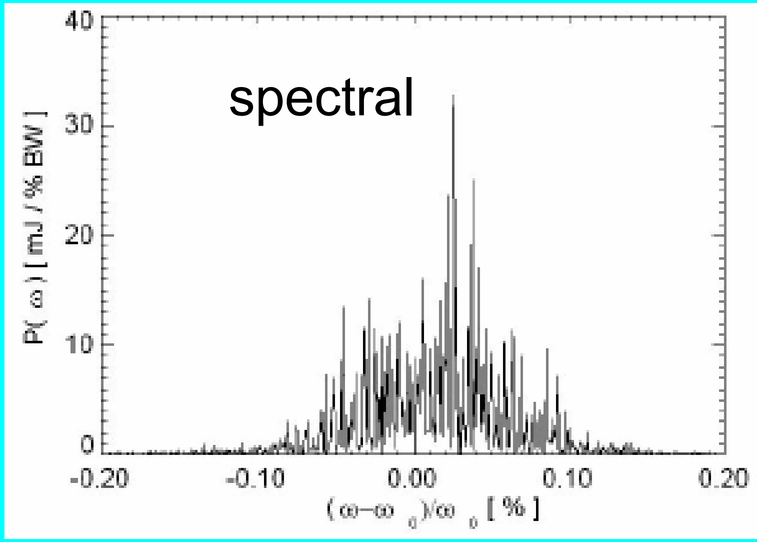
DESCRIPTION	
FEL design	Regenerative Amplifier
Seeding type	Self-seeding
Seeding mechanism	Low-Q cavity
PHOTON OUTPUT	
Tuning Range	3 - 10 eV
Peak Power	500 - 300 MW (3 GW*)
Repetition rate	$n \times 4\frac{1}{3}$ MHz (n is integer)
Polarisation	Variable elliptical
Min Pulse length FWHM	170 fs (25 fs*)
Typical ΔνΔt	~1.0
Max pulse energy	70 μJ
Maximum Average output power	$n \times 300$ W

Introduction

➢ SASE x-ray sources will lay the foundation for next-generation x-ray facilities

➢ Due to its noisy startup, SASE is transversely coherent but temporally chaotic (LCLS example, from S. Reiche)



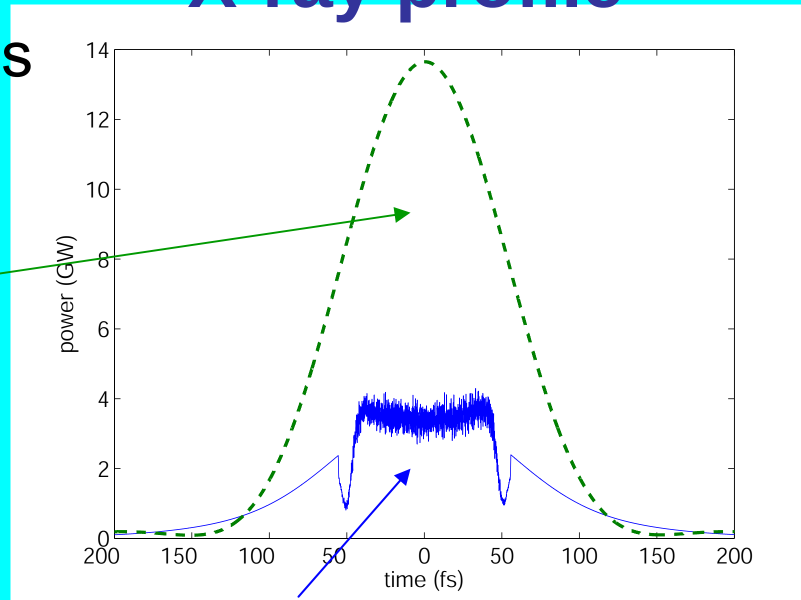


➢ Monochromator can be used to select a single mode, but flux is reduced (by ~700) and intensity fluctuates 100%

➢ Various schemes to improve temporal coherence proposed

X-ray profile

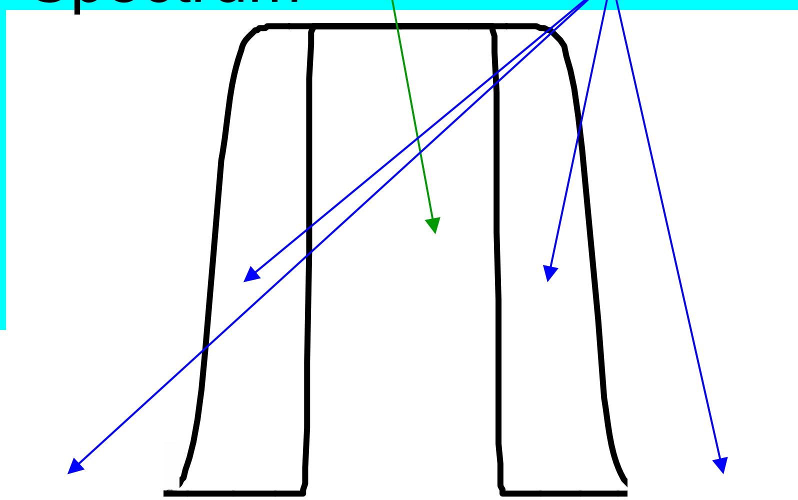
- End of 10th pass

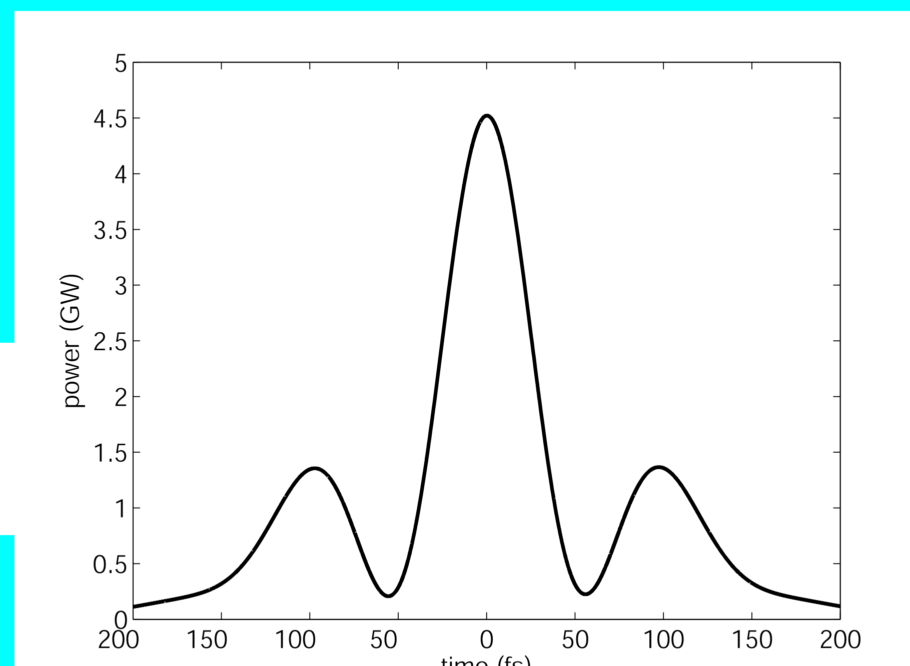


reflected x-ray

transmitted x-ray (82% transmission for a 100-μm diamond)

- Spectrum





Broadband SASE can be filtered by another monochromator

Quantum Regime of SASE-FEL

R. Bonifacio [(1)], N. Piovella [(1,2)], G.R.M. Robb [(3)], A. Schiavi [(4)]

[(1)] INFN-MI, Milan, Italy.

[(2)] Dipartimento di Fisica, Univ. of Milan, Italy

[(3)] SUPA, Dep. of Physics, Univ. of Strathclyde, Glasgow, UK

[(4)] Dipartimento di Energetica, Univ. of Rome "La Sapienza" & INFN, Italy

- In a QUANTUM REGIME an FEL behaves as a TWO-LEVEL system
- electrons emit coherent photons as in a LASER
- in the SASE mode the spectrum is intrinsically narrow ('quantum purification')
- the transition between the classical and the quantum regimes depends on a single parameter:

$$\bar{\rho} = \left(\frac{mc\ \gamma_r}{\hbar k} \right) \rho$$

> 1 classical

< 1 quantum

Analysis of spontaneous emission and its self-amplification in free-electron laser

Qika Jia (NSRL, Heifei, China)

Summary

With the time domain approach,

Spontaneous emission (incoherent and coherent)

for an arbitrary e- pulse profile.

The effective start-up power of SASE

Consist of:

the shot noise term, the incoherent spontaneous emission

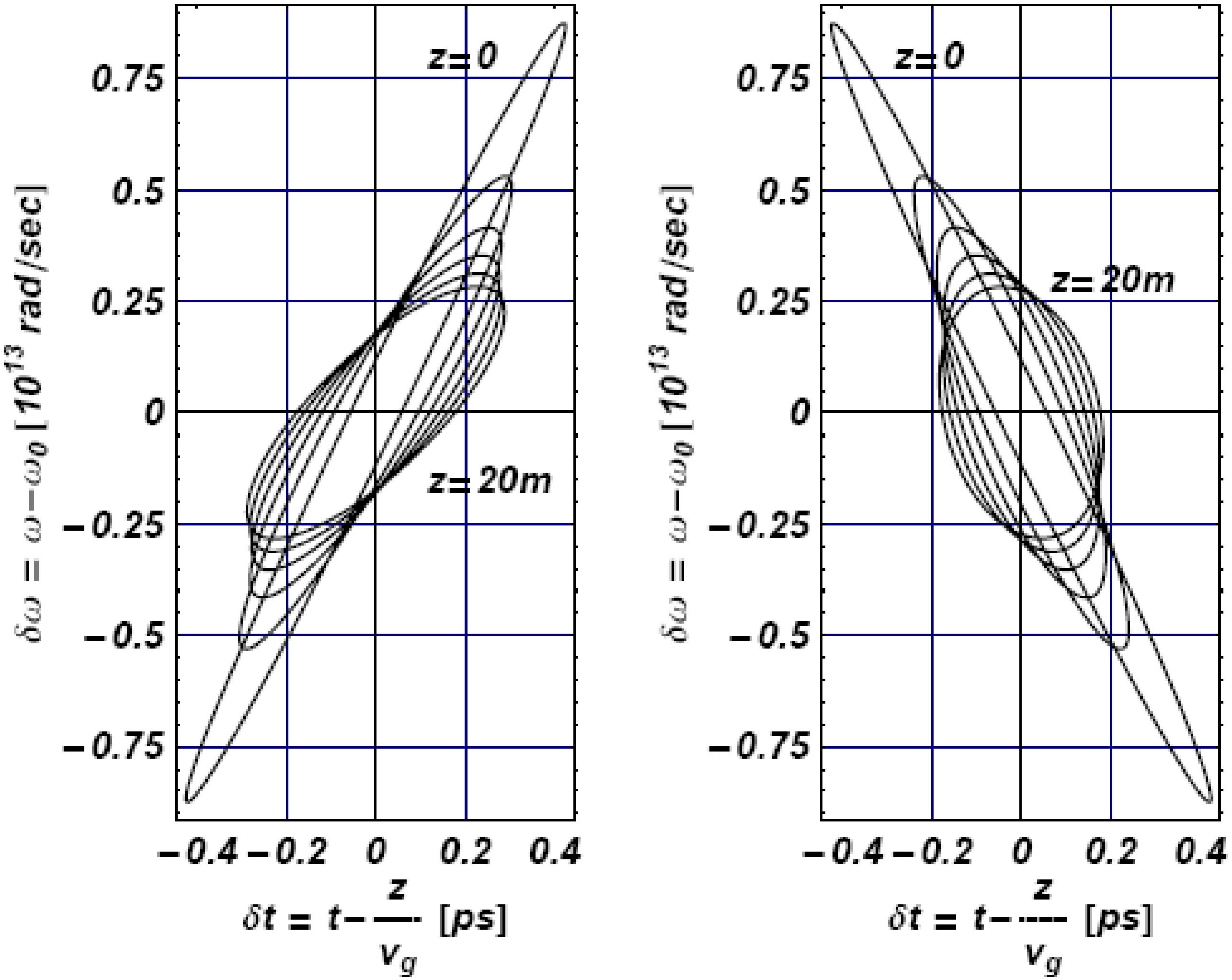
= the usual spontaneous undulator radiation in the one L_g

the super radiant term, the coherent spontaneous emission.

An analytical estimation of saturation power and length

Longitudinal Coherence Preservation & Chirp Evolution in a High Gain Laser Seeded Free Electron Laser Amplifier

<u>J.B. Murphy</u>, J. Wu, X.J. Wang & T. Watanabe, BNL & SLAC



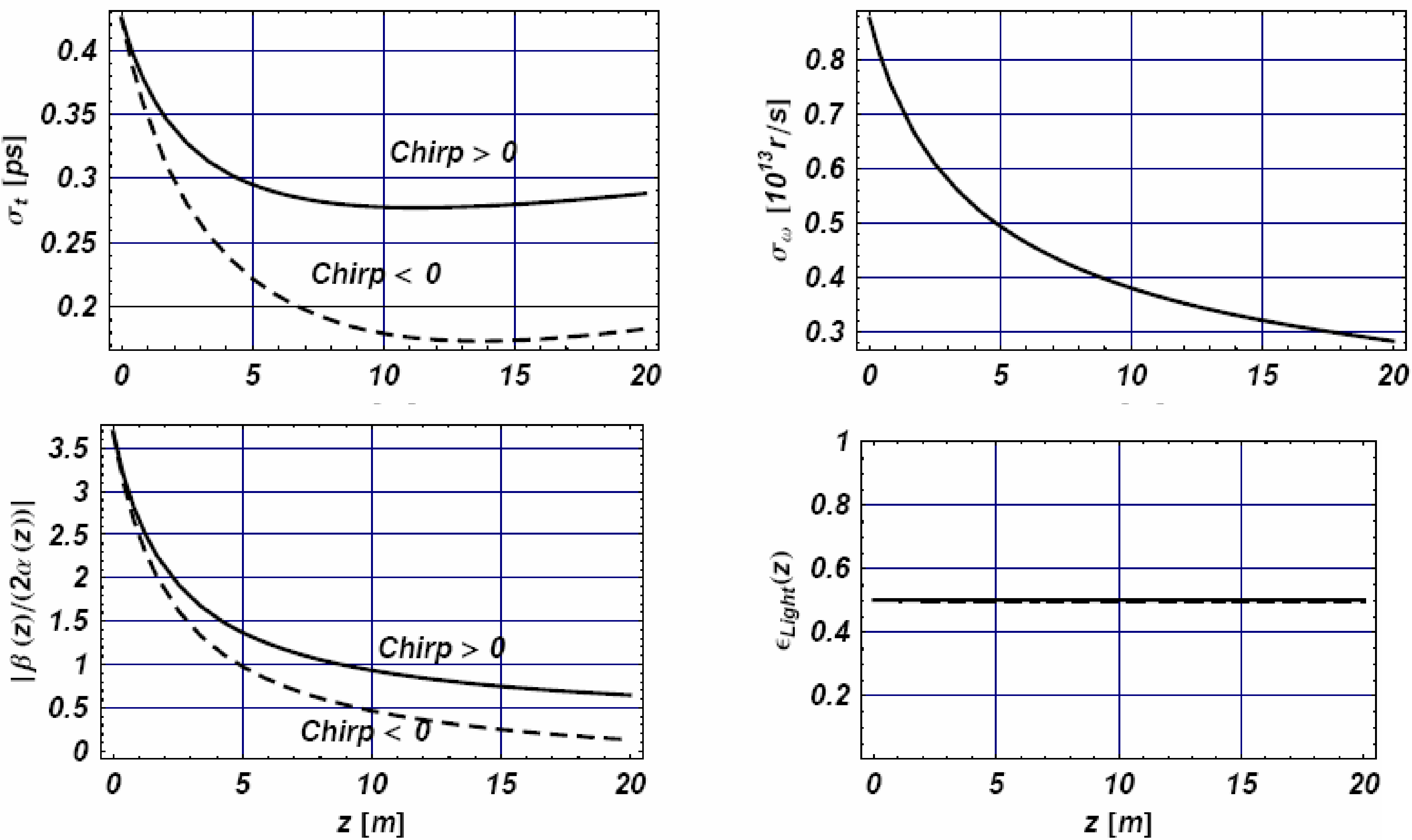
$\rho = 10^{-3}$

$\lambda = 800$ nm

$T_{FWHM} = 1$ ps

$\omega_{FWHM} = 7$ nm

Evolution of the Moments: Numerical Example



High-contrast attosecond pulses from X-ray FEL with an energy-chirped electron beam and a tapered undulator

E. Saldin, E. Schneidmiller and M. Yurkov

FLS2006, May 18, 2006

- Energy chirp in SASE FELs
- Energy chirp and undulator taper: symmetry and compensation
- An attosecond scheme
- Beyond “fundamental” limit

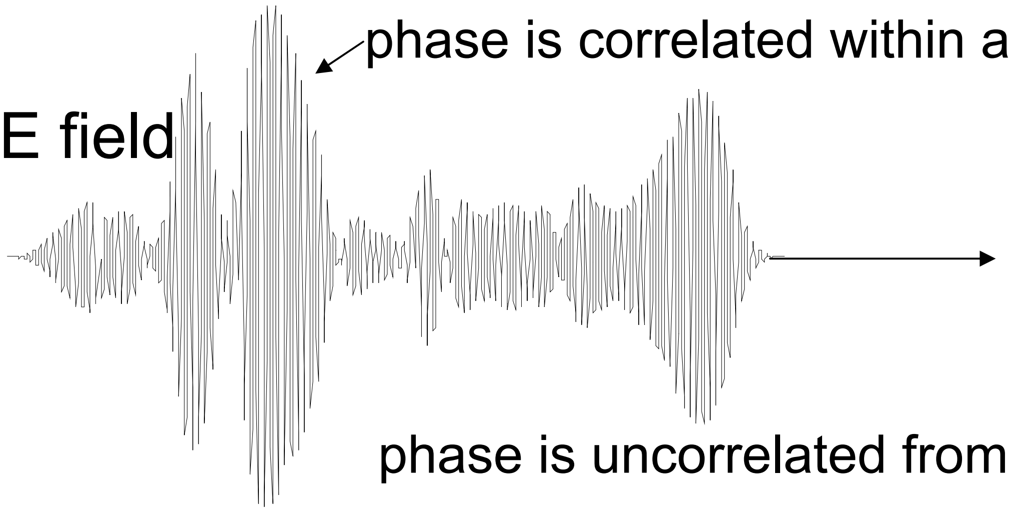
Beyond “fundamental” limit

- It was generally accepted that a natural limit for a pulse duration from SASE FEL is given by $(\rho\omega)^{-1}$, FEL coherence time (~duration of intensity spike)
- But: energy chirp + undulator taper allow to get strong frequency chirp (>> $\rho\omega$) within a spike without gain degradation
- Use monochromator to select a pulse that is much shorter than a spike
- Contrast remains high: spontaneous spectrum from the rest of the bunch gets broader due to the stronger taper

- Example: increase energy modulation by ~3 so that $\alpha \sim 6$. For optimal bandwidth of a monochromator the reduction factor is ~$(2\alpha)^{1/2}$, i.e. pulse duration is in sub-100 as range.

Optical Klystron Enhancement to SASE FEL

Y. Ding, P. Emma, Z. Huang (SLAC), V. Kumar (ANL)



- Required OK R_{56} is $kR_{56}\sigma_\delta \sim 1$

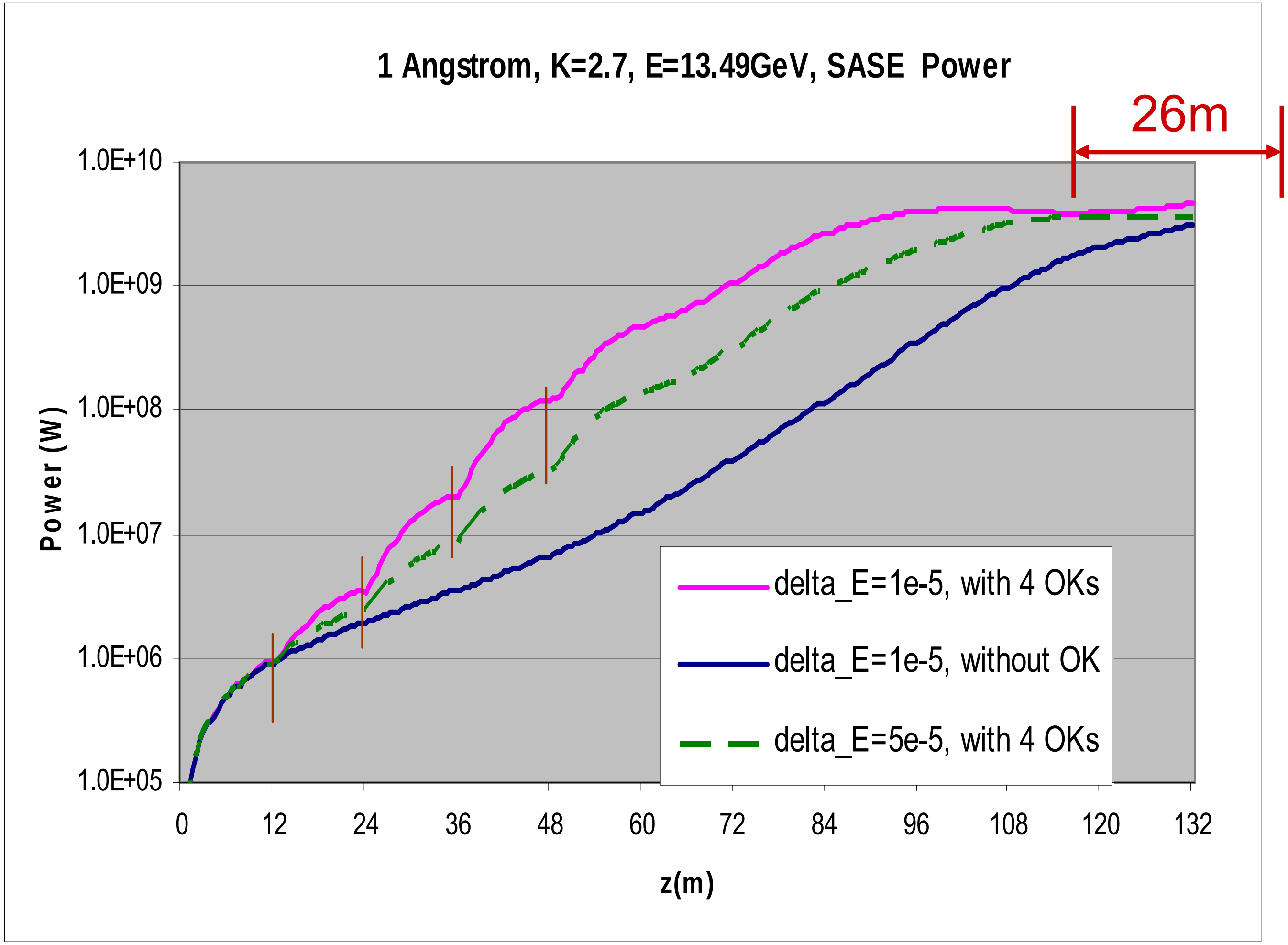
$$R_{56} \sim \frac{\lambda}{2\pi\sigma_\delta} \sim 0.5\ \mu\text{m for } \sigma_\delta = 5\times 10^{-5}$$

- Chicane delays e-beam by $R_{56}/2 = 0.25\ \mu\text{m} >>$

  SASE phase correlation length $\sim \frac{\lambda}{4\pi\rho} \sim 0.03\ \mu\text{m}$

- SASE OK not sensitive to phase mismatch

λ=1.0 Å LCLS possibility with OKs



Parameters of the chicane for delta_E=5×10^{-5}:

R_{56}~0.23μm, B~0.70T

L_B=6cm, $L_{chicane}$=51cm

Beam Physics Highlights of the FERMI@Elettra Project

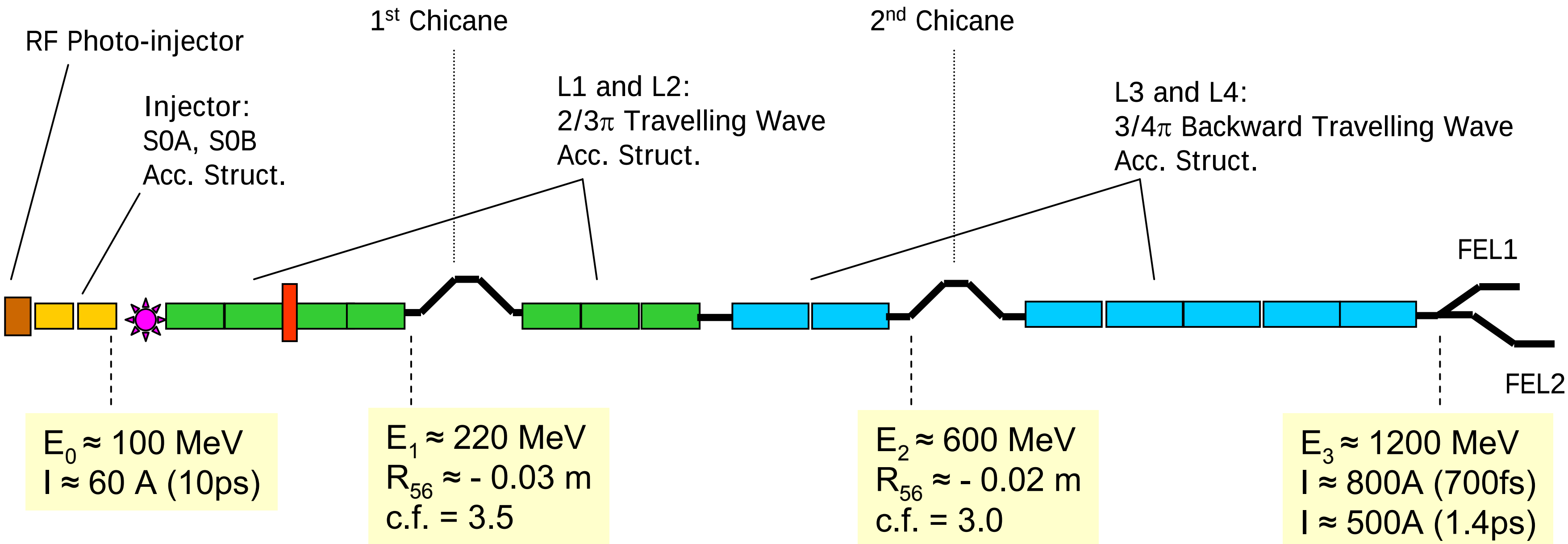
S. Di Mitri

on behalf of the Accelerator Optimization Group:

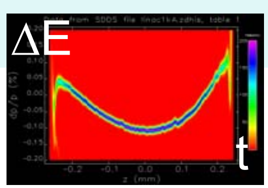
M. Cornacchia, P. Craievich, S. Di Mitri, G. Penco, M. Trovo', ST
I. Pogorelov, J. Qiang, M. Venturini, A. Zholents, LBNL
P. Emma, Z. Huang, R. Warnok, J. Wu, SLAC
D. Wang, MIT

FLS Workshop, May 2006, Hamburg

Outlook – THE ACCELERATOR

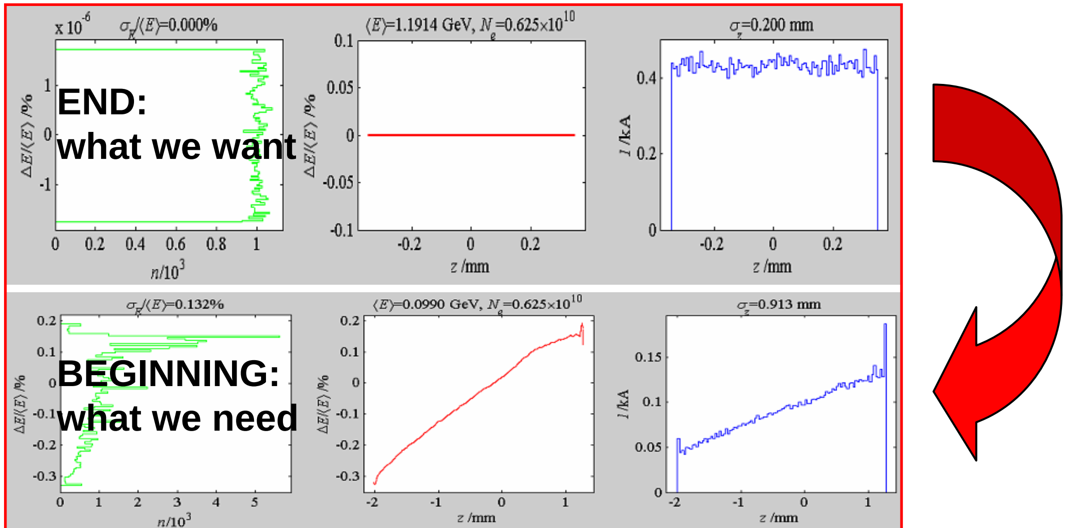


	"Short" bunch	*"Medium" bunch*	*"Long" bunch*
Bunch length	200 fs (flat part)	700 fs (flat part)	1.4 ps (flat part)
Peak current	800 A	800 A	500 A
Emittance(slice)	1.5 μm	1.5 μm	1.5 μm
Energy spread(slice)	<150 keV	<150 keV	<150 keV
Flatness, $\lvert d^2E/dt^2 \rvert$		<0.8 MeV/ps^2	<0.2 MeV/ps^2

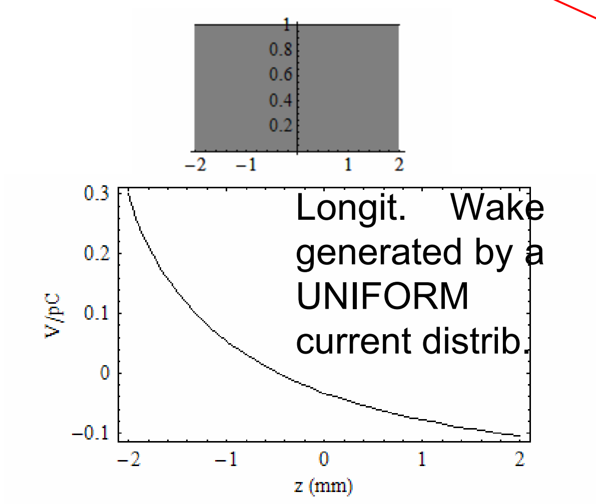


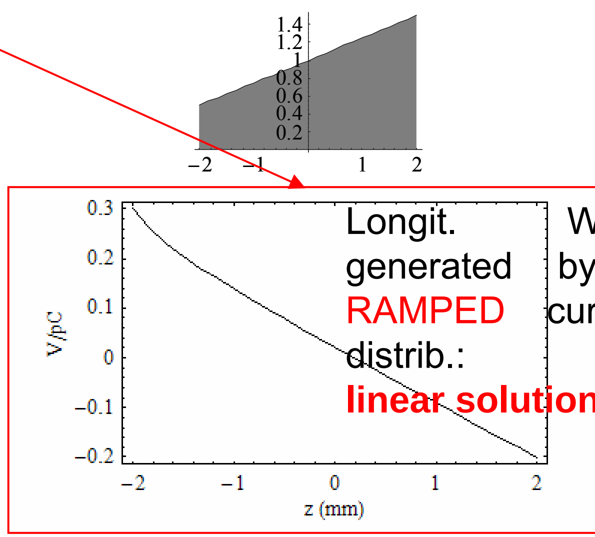
FERMI @elettra

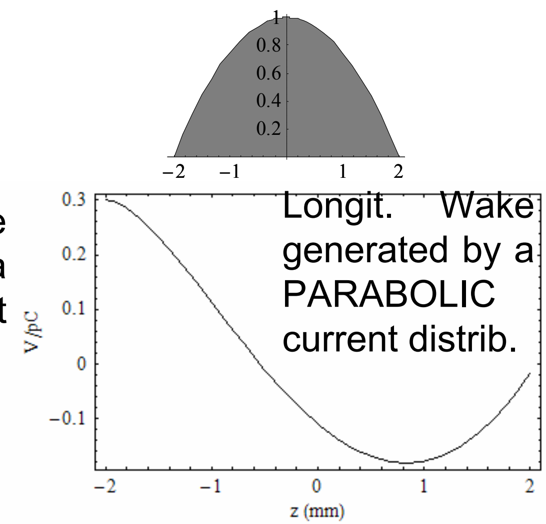
E-Beam Physics - REVERSE TRACKING



- Valid for "frozen" beams (see, Appendix)
- It predicts a ramped current profile from the Injector.
- Confirmed by the forward tracking.







 courtesy M. Cornacchia, P.Emma, G. Penco, A. Zholents

BESSY

Berliner Elektronenspeicherring-Gesellschaft
für Synchrotronstrahlung m.b.H.

Experiences with Start to End Simulations and Tolerance Studies for HGHG FEL Cascades

Bettina Kuske, Michael Abo-Bakr, Atoosa Meseck

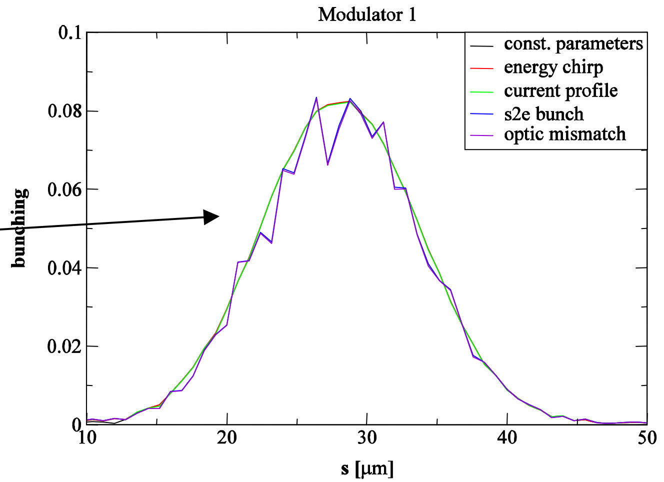
ICFA-FLS-Workshop, Hamburg, May 16th, 2006

Leibniz
Gemeinschaft

1. Example: Bunches from S2E simulations <=> constant bunch parameters

Single HGHG stage:

- 280 MeV, 200 A

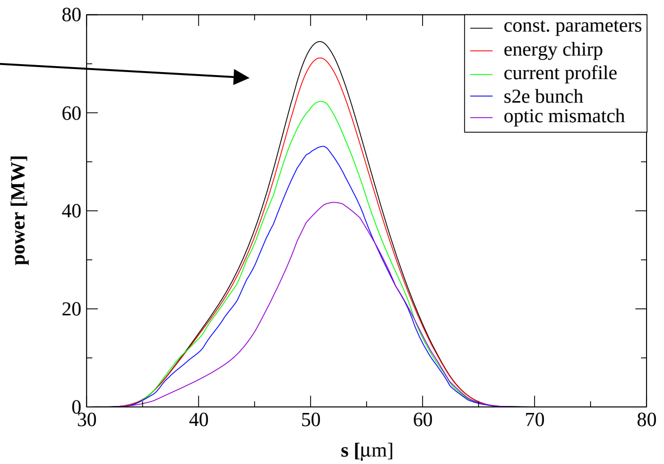


Modulator:

- bunching less smooth for s2e bunch (energy spread)
- no effect for γ-chirp, current

Radiator:

- power loss for every non-constant parameter



Colour code:

- ***bunch with constant parameters***
- ***incl. energy chirp*** **$\Delta\gamma/\gamma$ = 1e-3/100fs**
- ***incl. current profile***
- ***complete s2e bunch***
- ***optics mismatch***

Start-To-End Simulations for the European XFEL

Martin Dohlus, Igor Zagorodnov (DESY)

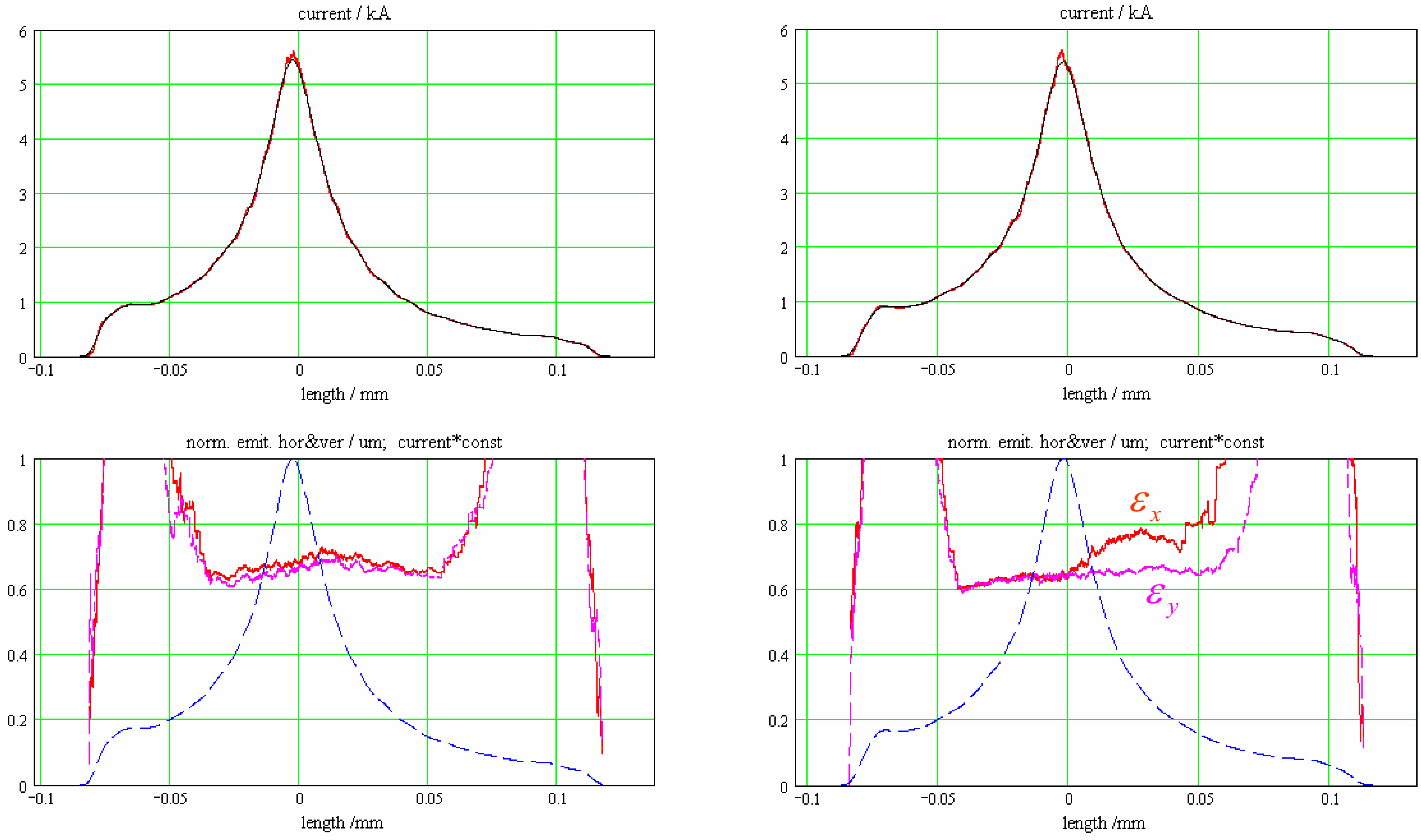
- description of European XFEL beam line
- technical aspects of simulation

  matching / codes / tools
- gun
- μ-bunch "instability"

  laser heater / technical aspects of simulation
- European XFEL – segmentation (for simulation)
- method 1 (fast)
- method 2 (reference)
- method 3 (efficient & accurate) – to be done

method 1 method 2

current & slice emittance



Single Bunch Emittance Preservation in XFEL Linac

G. Amatuni, R. Brinkmann, W. Decking, V. Tsakanov

DESY, CANDLE

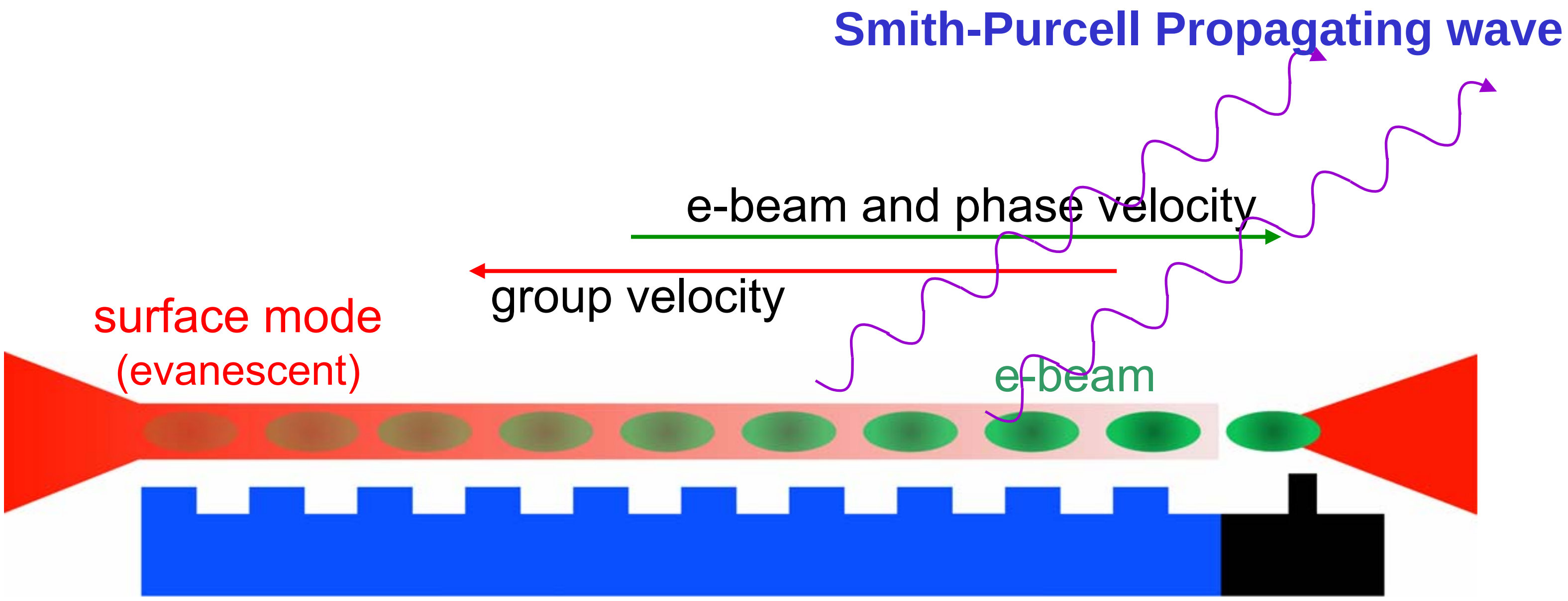
	Booster	Linac
• Coherent oscillations		
uncorrelated	$6\cdot10^{-6}$	$2\cdot10^{-4}$
correlated	$2\cdot10^{-3}$	$1.2\cdot10^{-3}$
• Cavity Misalignments	$5\cdot10^{-6}$	$3\cdot10^{-7}$
• Modules Misalignments	$4\cdot10^{-5}$	$2.5\cdot10^{-6}$
• Correlated Misal. (130°)	-	$7\cdot10^{-6}$
• Cavity tilts		
uncorrelated	$5.8\cdot10^{-5}$	0.6%
correlated	0.6%	1.9%
• One-to-One correction		
uncorrelated	$6.3\cdot10^{-5}$	0.4%
correlated	1.7%	2%

➡ Total Emittance dilution <5% with 2 Modules/Cell

A Smith-Purcell Backward Wave Oscillator for Intense Terahertz Radiation

Kwang-Je Kim and Vinit Kumar

ANL and The University of ChicagO



Example Parameters

Grating

$\lambda g = 173\ \mu m$

$h = 150\ \mu m$

$L = 1.27\ cm$

Electron Beam

$qV = 35\ keV$

$\beta = 0.352$

$\Delta y = 23.7\ \mu m$

$\varepsilon_y \leq 4.15\times10^{-9}$ m-r

$\varepsilon_x \leq 8.37\times10^{-6}$ m-r

$\Delta x = 1.1\ \mu m$

$I_s = 13.4\ mA$

$P_s^{ebeam} = 470\ W$

BWO

$\lambda = 790\ \mu$

$\lambda_z = 278\ \mu m$

$\upsilon_g = -0.1\ c$

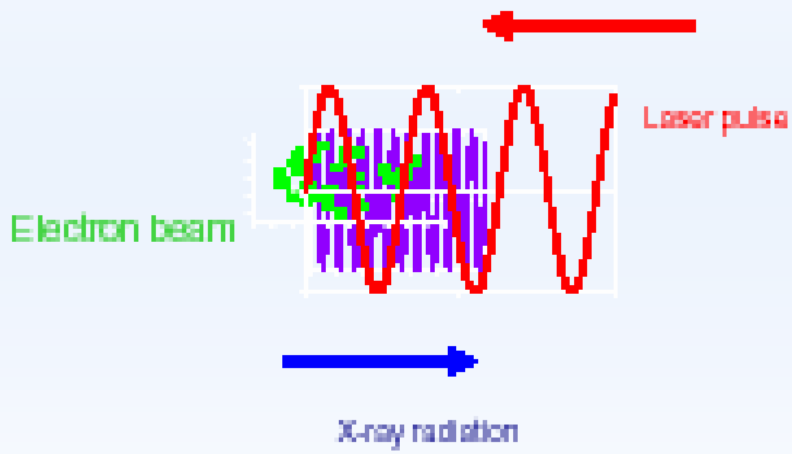
$\eta_{eff} \sim 1\%$

$P_S^{opt} \approx 5W$

Toward Coherent X-rays: exploring coherent emission mechanisms (FEL-like) in Thomson Sources

A.Bacci, M.Ferrario*,
C. Maroli, V.Petrillo, L.Serafini
Università e Sezione I.N.F.N. di Milano (Italy)
*LNF, Frascati (Italy)

The physical system



Laser pulse characteristics:

wavelength λ=0,8 μm, power 1TW, time duration T=5 ps
Circular polarization, focal spot diameter w_0 >50 micron

Electron beam characteristics:

Conterpropagating respect the lasr pulse
Energy 15 MeV (γ=30), spot size σ_0=10 μm, length L_b=100-200μm, charge Q=1 nC

Radiation characteristics:

Wavelength λ=2.2 Ang

Production of coherent X-rays with a free electron laser based on optical wiggler

by C. Maroli et al., (INFN)

First example

Laser pulse time duration up to 100 ps, power 40-100 GW, w_0=100μm, λ_L=10 μm (CO_2 laser),total laser energy 4-10J, a_{L0}=0.3, guided

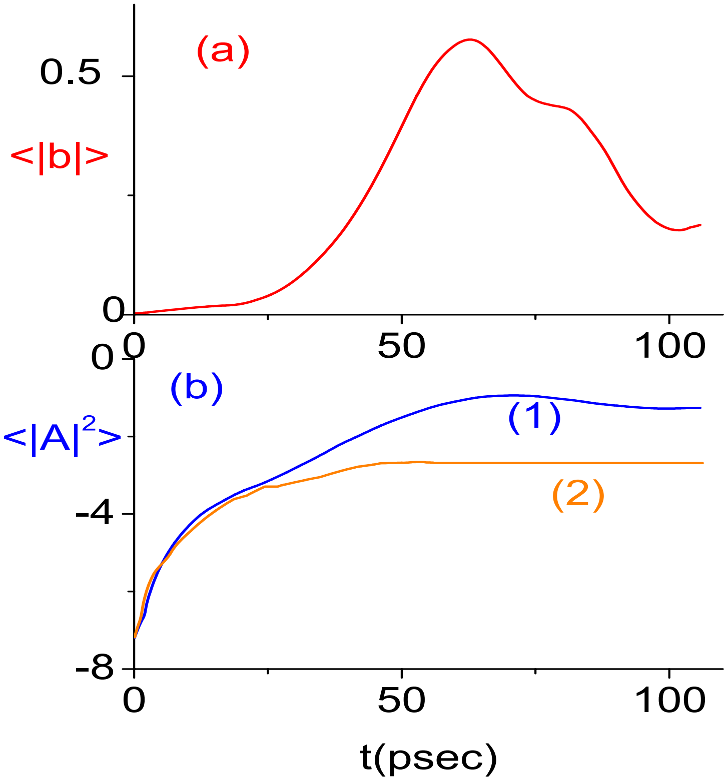
Electron beam Q=1-5nC, L_b=1mm, focal radius σ_0=25 μm, I=0.3-1.5 kA, energy=30 MeV (γ_0=60) , transverse normalized emittance up to 1 mm mrad, $\delta\gamma/\gamma=10^{-4}$.

$\rho=2.8\ 10^{-4}$ gain length L_g= 2.83 mm

Radiation λ_R=7.56 Angstrom Z_R=2.5 m

$\bar{\rho} = 41.32\rho\gamma_0\lambda_R(\mathring{A})$ = 5.25 ⟹ no appreciable quantum effects

ε_n=0.6 mmmrad at t=0, guided laser pulse



(1) Collective radiation
$2\ 10^{10}$ Photons

(1) Incoherent radiation
210^{8} photons

$|A|^2_{sat}$=0.11, saturation length about 7 L_g (70 ps) 2,36$10^{10}$ photons

(a) averaged bunching factor <|b|> in the middle of the bunch vs time, (b) logarithmic plot of $<|A|^2>$ vs time in both coherent (1) and incoherent (2) cases. w_0=50 mm with a flat laser profile, a_{L0}=0.3, Q=3 nC, I= 0.9 kA,$<\gamma>$=60, $\Delta p_z/p_z=10^{-4}$, ε_n=0.6 , $\Delta\omega/\omega= -10^{-4}$.

Conclusions

At the present state of the analysis we may say that the growth of collective effects during the back scattering Thomson process is possible provided that:

i) a low-energy , high-brigthness electron beam is available (normalized transverse emittance at t=0 preferably less than 1)

ii) the optical laser pulse is long enough to allow the electron bunching by the spontaneous (incoherent) radiation and the consequent FEL instability

iii) the laser envelope should have rather “flat” transverse and longitudinal profiles

Summary remarks of WG3

- Short-wavelength FELs are on the horizon. More excitement to come

- Start-to-end simulations are invaluable tools to understand the performance and tolerance of these machines

- Seeding can improve SASE's temporal coherence, more technical challenges to overcome

- Theoretical progress is still made in many areas

- Novel sources based on FEL-like mechanism may provide compact, coherent THz or X-rays