The ORS section: Plans for 2011 and 2012

Kirsten Hacker*, Shaukat Khan, TU Dortmund
Gergana Angelova Hamberg, Volker Ziemann, Uppsala University
Peter Salen, Peter Van der Meulen, University of Stockholm
Florian Gruener, Benno Zeitler, LMU Munich
Atoosa Mesek, Helmholtz Zentrum Berlin
Jens Osterhoff, University of Hamburg
Holger Schlarb, Franz Tavella, DESY

Goal:
get permission (& 20-30k€) for new laser transport line for ORS section experiments

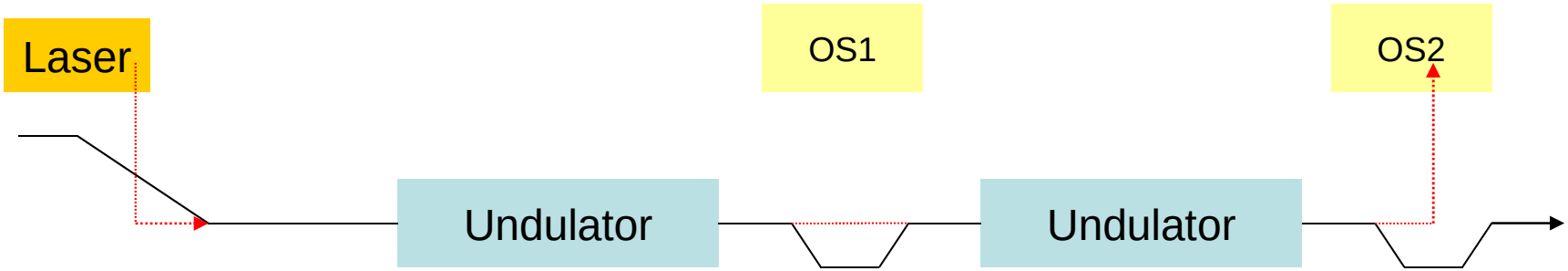
- Diagnostics

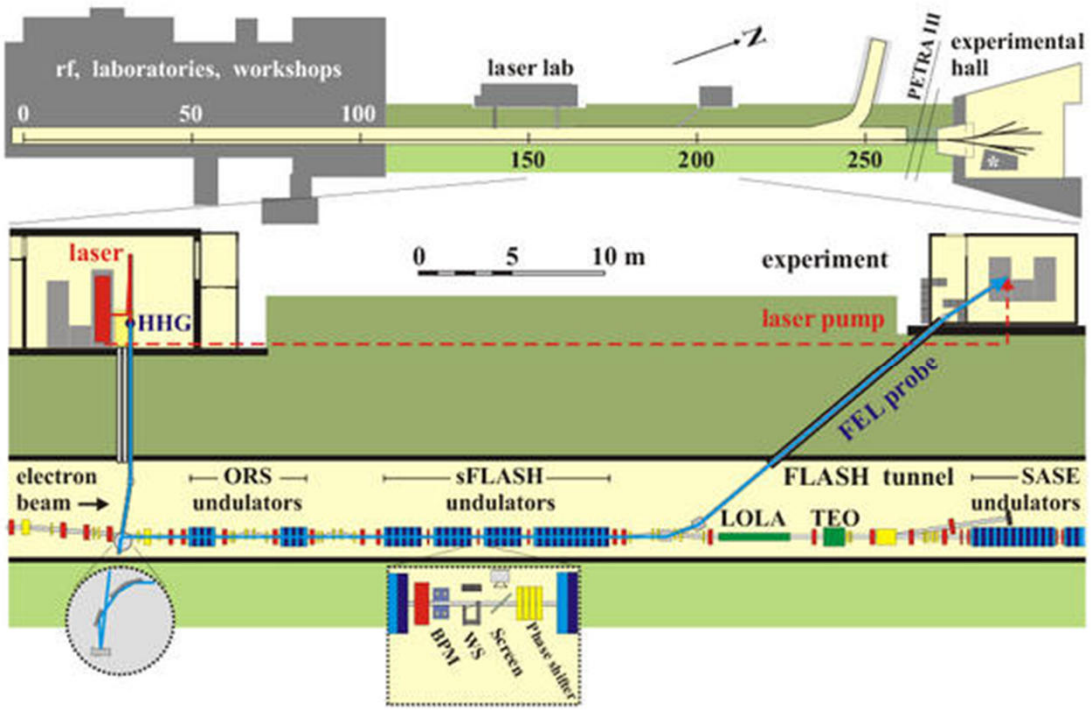
  (many you haven’t heard about before)
- Seeding and slicing

  (echo enabled harmonic generation)

The ORS section:

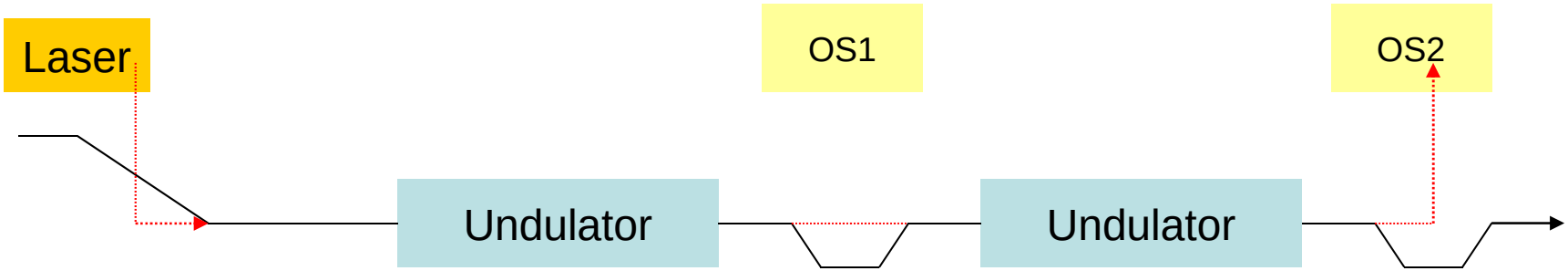
Optical Replica Synthesizer





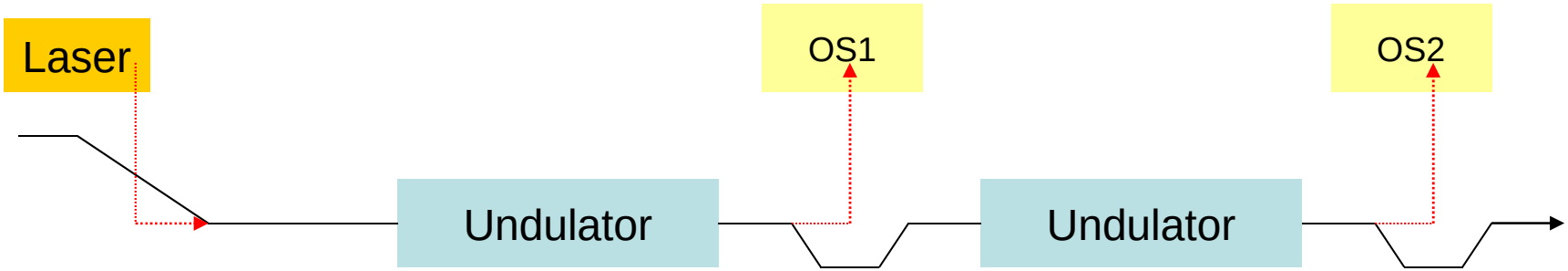
sFLASH added Spring 2010

Not just ORS…



- Laser Timing Diagnostic (current use)
- Optical Replica method 1: (the original)
- Optical Replica method 2: (new concept)
- EO sampling with a FROG (proof-of-principle)
- Attosecond Beam Slicing
- Echo-Enabled Harmonic Generation

Agenda for 2011



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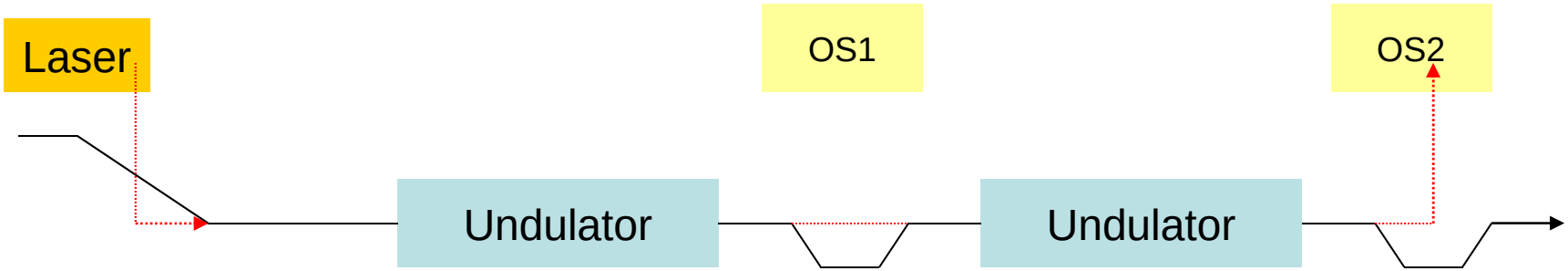
Agenda for 2012



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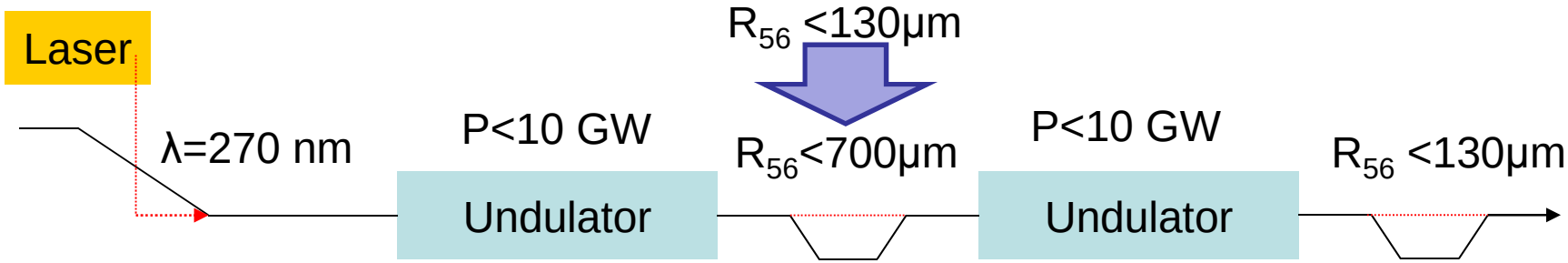
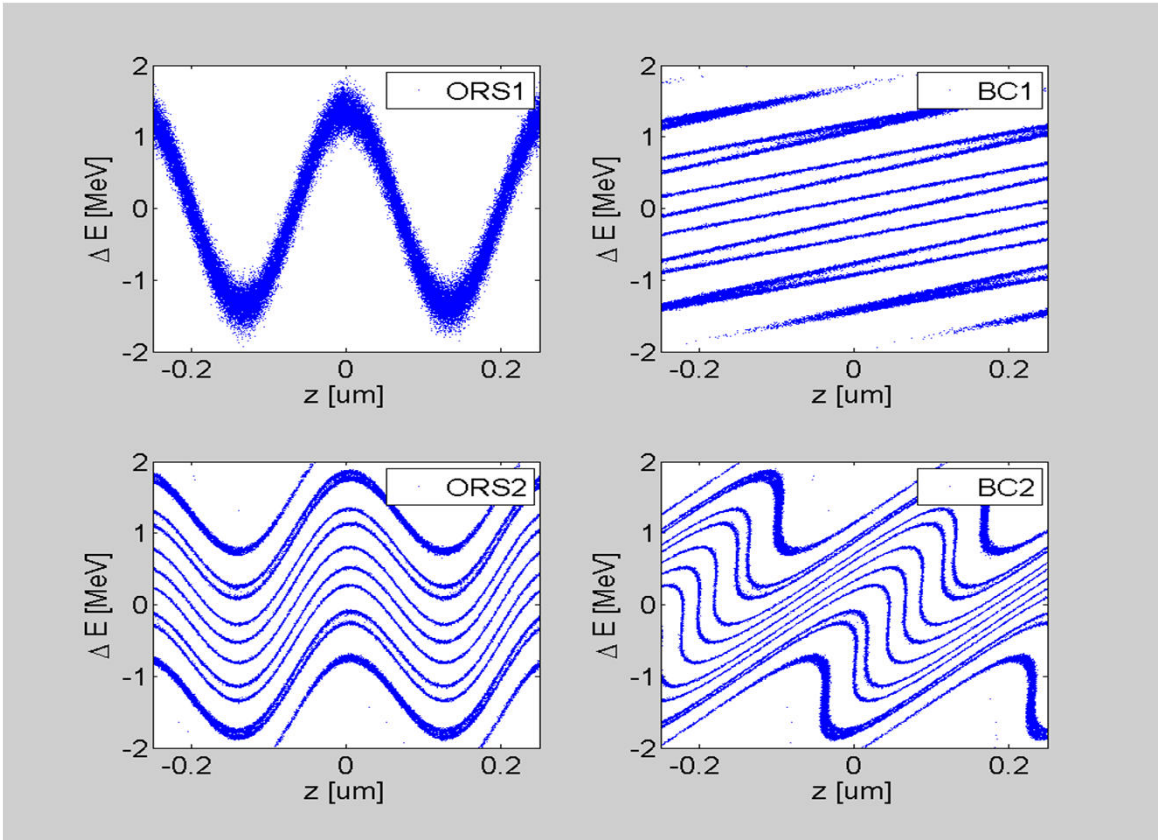
EEHG in ORS section

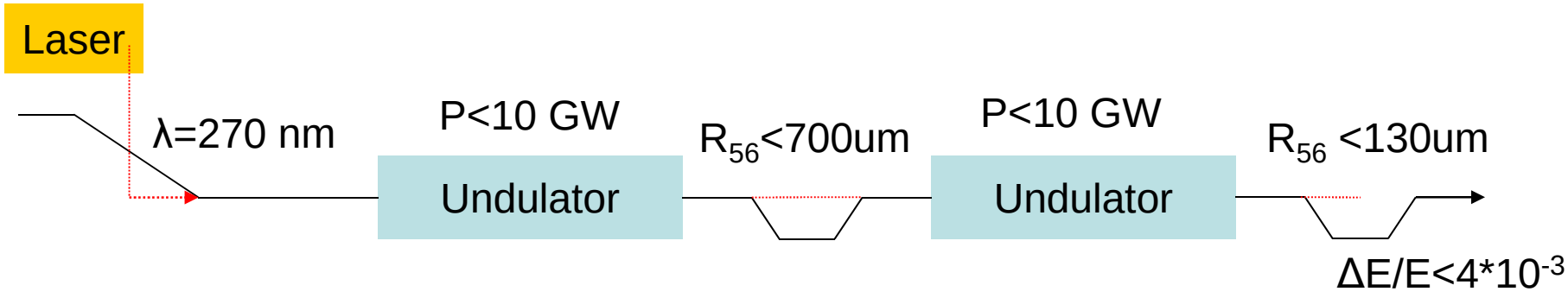




$\Delta E/E<4*10^{-3}$

1-D particle tracking
With Matlab

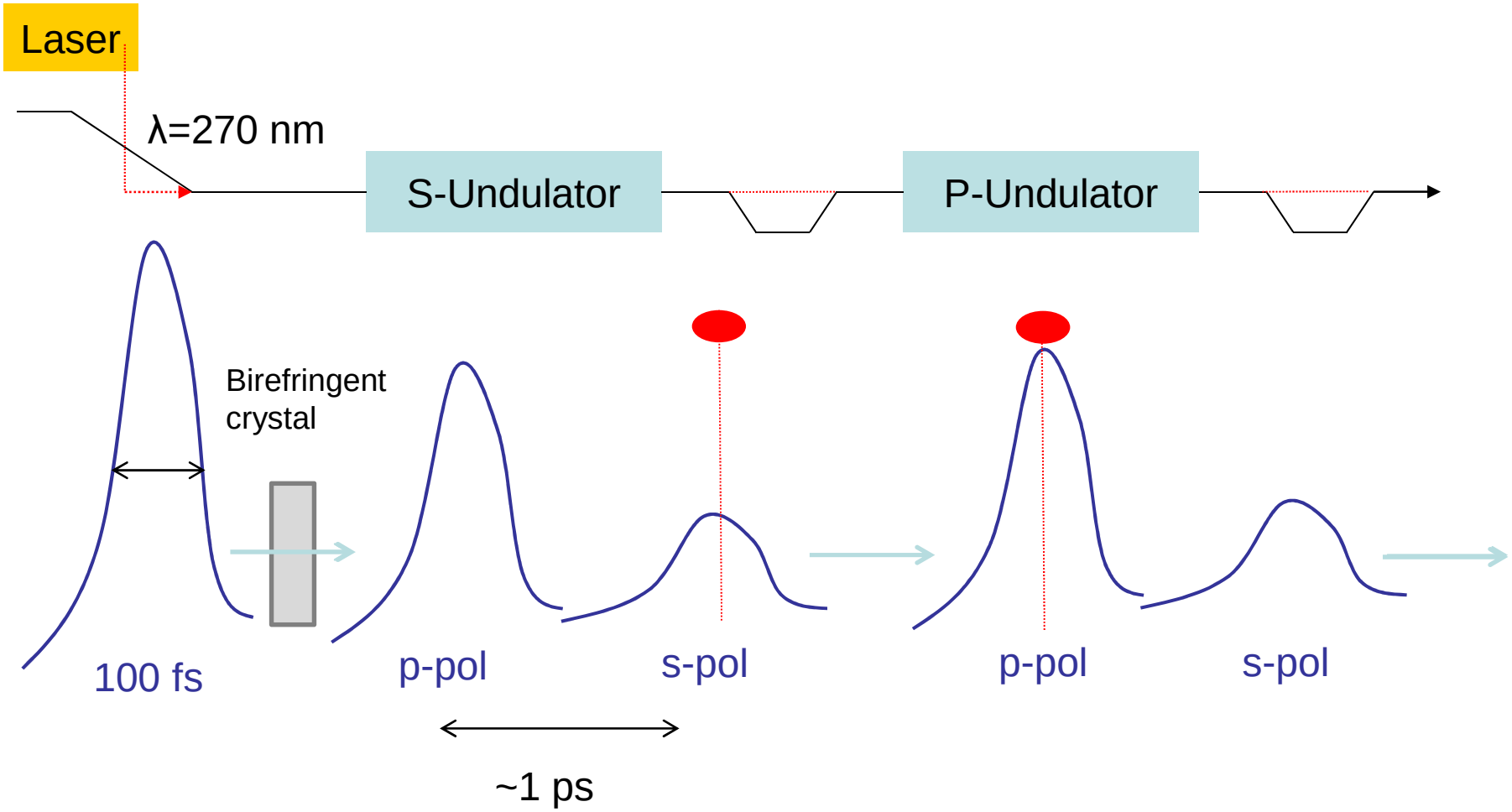
Other EEHG schemes



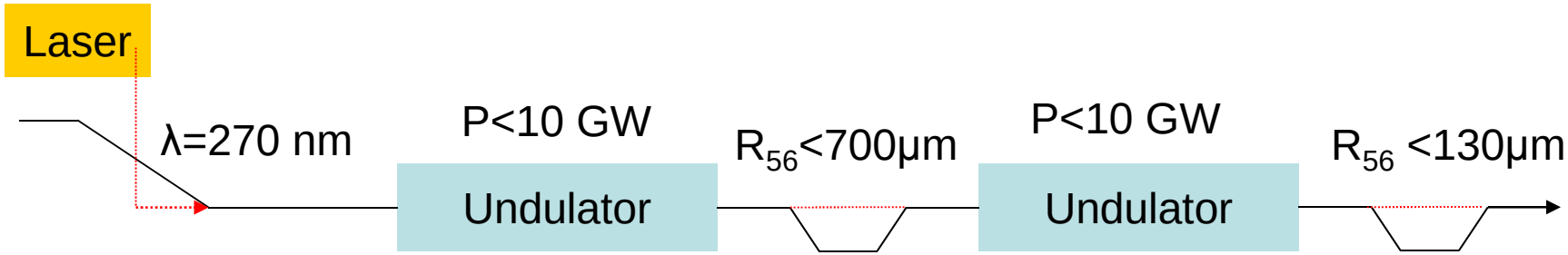
facility	E_0 (GeV)	$R_{56}^{(1)}$ (mm)	$R_{56}^{(2)}$ (mm)	λ(nm)
FERMI FEL2	1.2	8.2	0.35	4
FERMI FEL2	1.2	2.5	0.12	10
FLASH II	1.2	5.2	0.09	4
FLASH II	0.7	1.1	0.06	13
FLASH I ORS	1.15	0.7	0.03	14
FLASH I ORS	0.7	0.6	0.05	14

-FERMI FEL2 [250 MW]
-FLASH II [1.5 GW]
-FLASH I ORS [10 GW]

EEHG with one laser



EEHG theory



$\Delta E/E<4*10^{-3}$

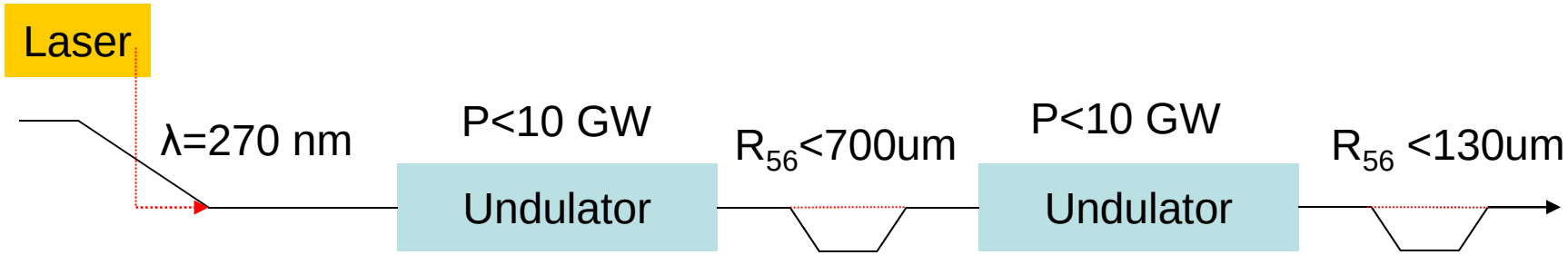
$$b_{n,m} = \left| J_m(-A_2 B_2(km+n)) J_n(-A_1(B_1 n + B_2(km+n)) e^{-\frac{1}{2}(nB_1 + B_2(m+n))^2} \right|$$

$$b_{n=-1,m} = \left| J_m(A_2 B_2(m-1)) J_1(B_1 - B_2(m-1)) e^{-\frac{1}{2}(B_1 - B_2(m-1))^2} \right|$$

$A=\Delta E/\sigma_E$ and $B=2\pi R_{56}\sigma_E/(E_0\lambda)$

PhysRevSTAB.12.030702 2009

Low-R56 EEHG theory



$\Delta E/E<4*10^{-3}$

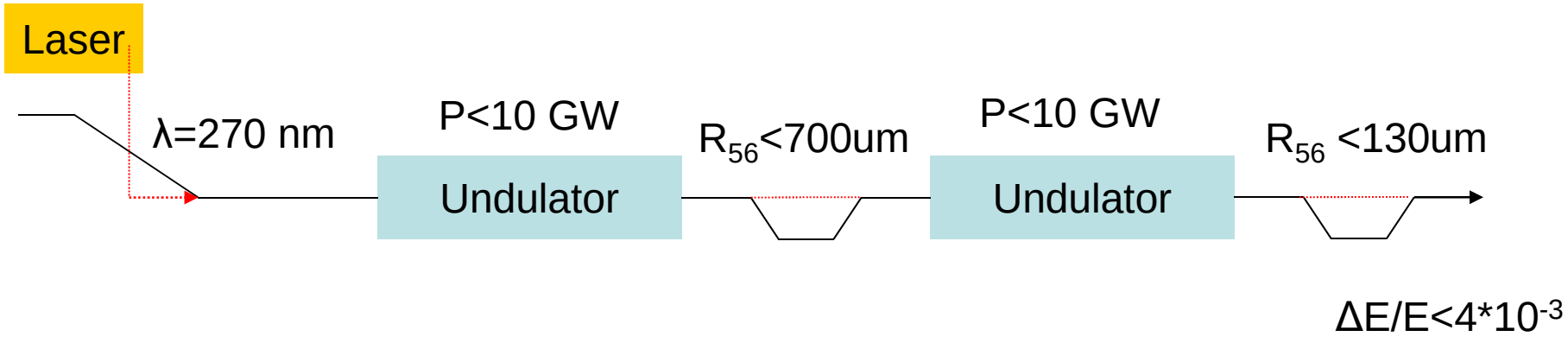
$$b_{n,m} = \left| J_m(-A_2 B_2(km+n)) J_n(-A_1(B_1 n + B_2(km+n)) e^{-\frac{1}{2}(nB_1 + B_2(m+n))^2} \right|$$

$$b_{n=-1,m} = \left| J_m(A_2 B_2(m-1)) J_1(B_1 - B_2(m-1)) e^{-\frac{1}{2}(B_1 - B_2(m-1))^2} \right|$$

$A=\Delta E/\sigma_E$ and $B=2\pi R_{56}\sigma_E/(E_0\lambda)$
$k=1$

PhysRevSTAB.12.030702 2009

Phase Dependent EEHG Theory



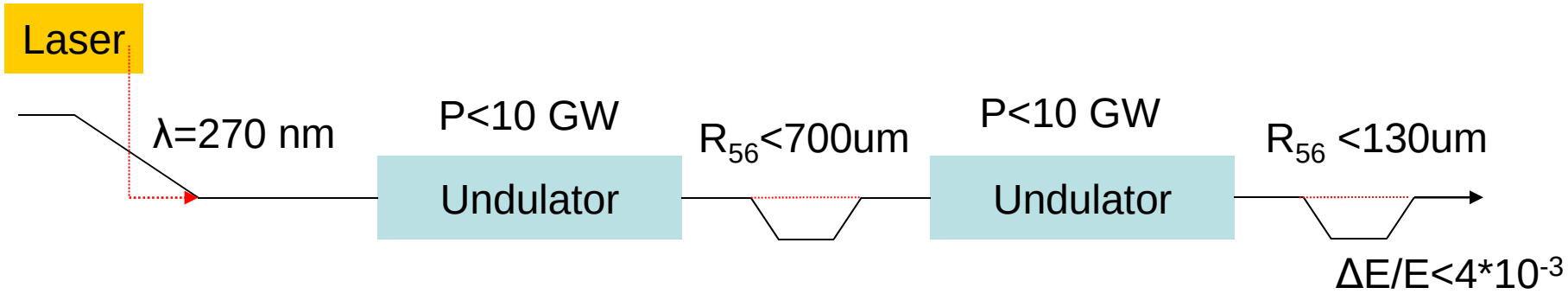
$$b_a(\varphi) = \sum_n e^{in\varphi} J_m(-A_2 B_2(km+n)) J_n(-A_1(B_1 n + B_2(km+n)) e^{-\frac{1}{2}(nB_1 + B_2(km+n))^2}$$

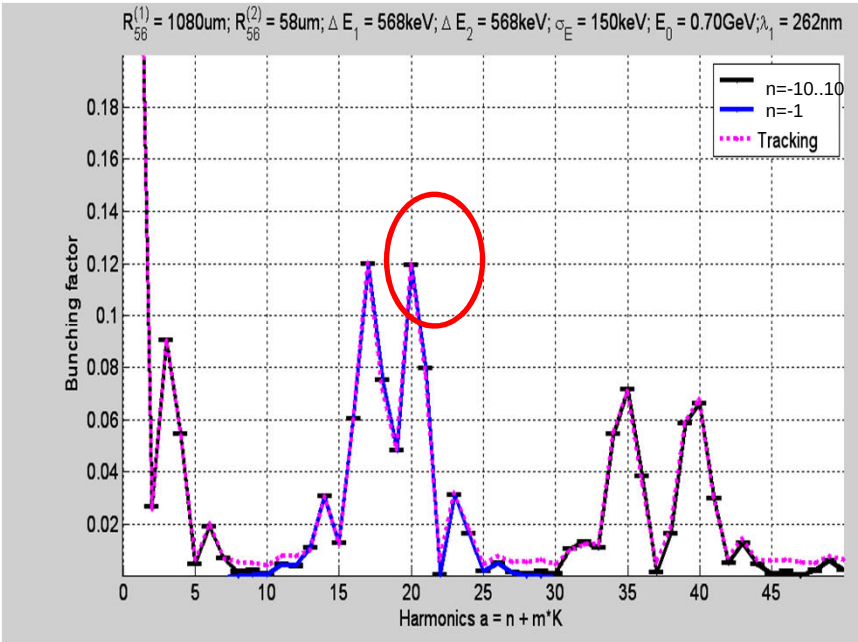
$A = \Delta E/\sigma_E$ and $B = 2\pi R_{56}\sigma_E/(E_0\lambda)$

$a = m + nk$, k=1

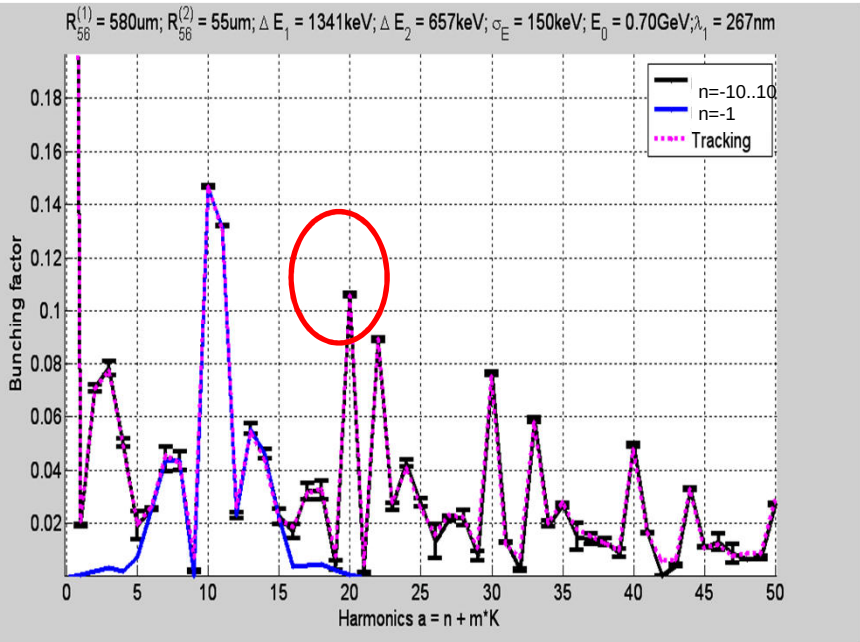
Compare with FLASH II

0.7 GeV 20th harmonic scheme



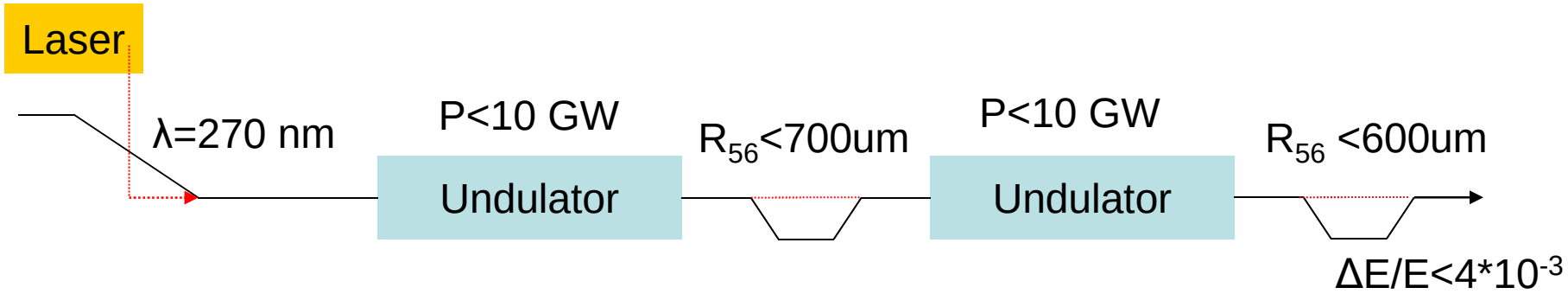


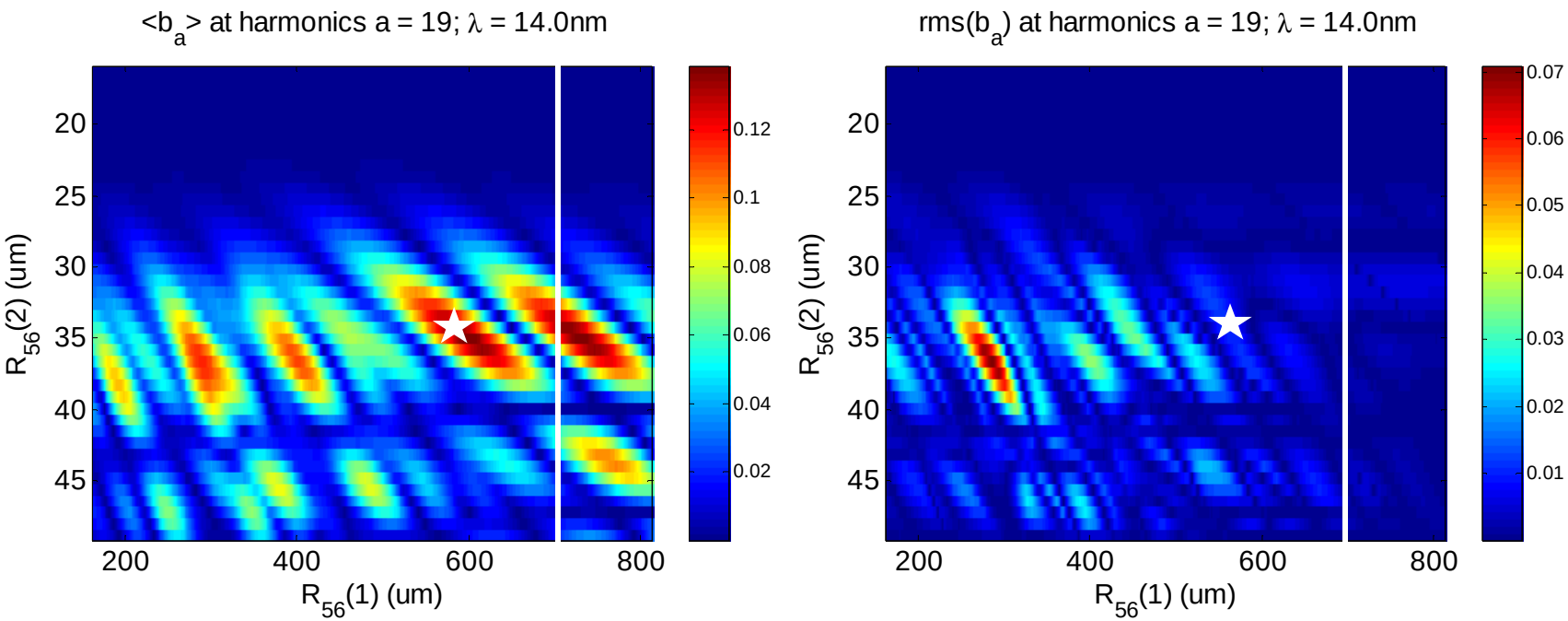
FLASH II



FLASH I ORS section

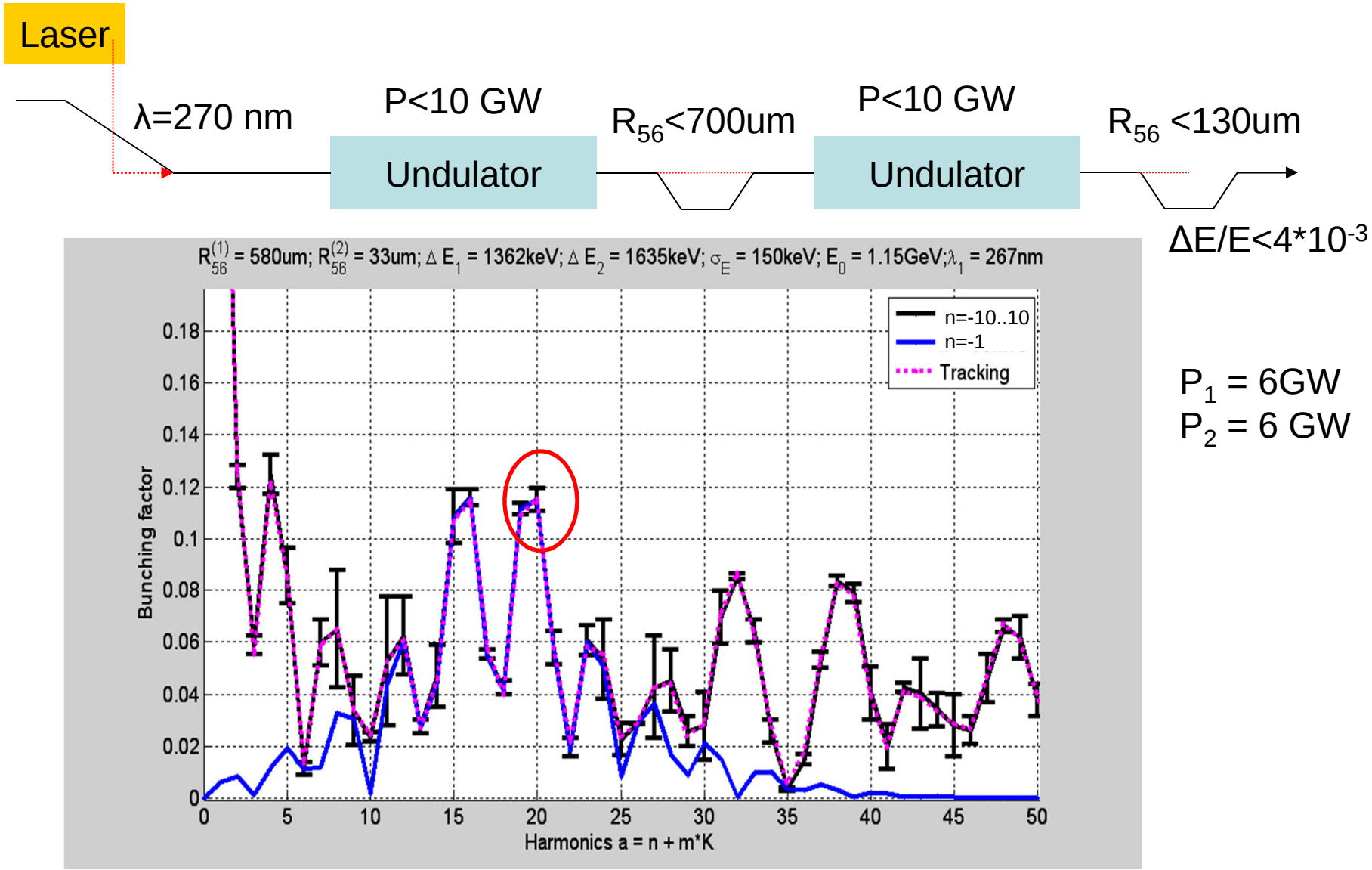
14 nm @ 1.15 GeV





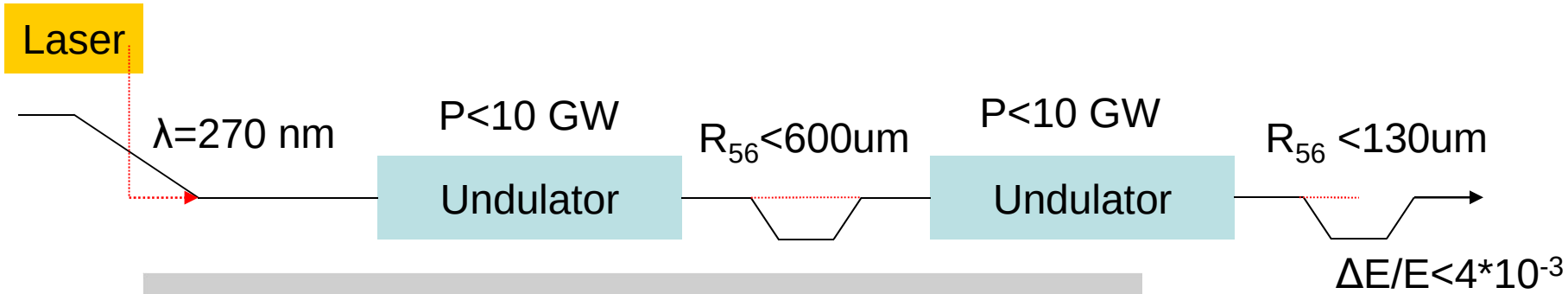
P_1 = 6 GW P_2 = 6 GW

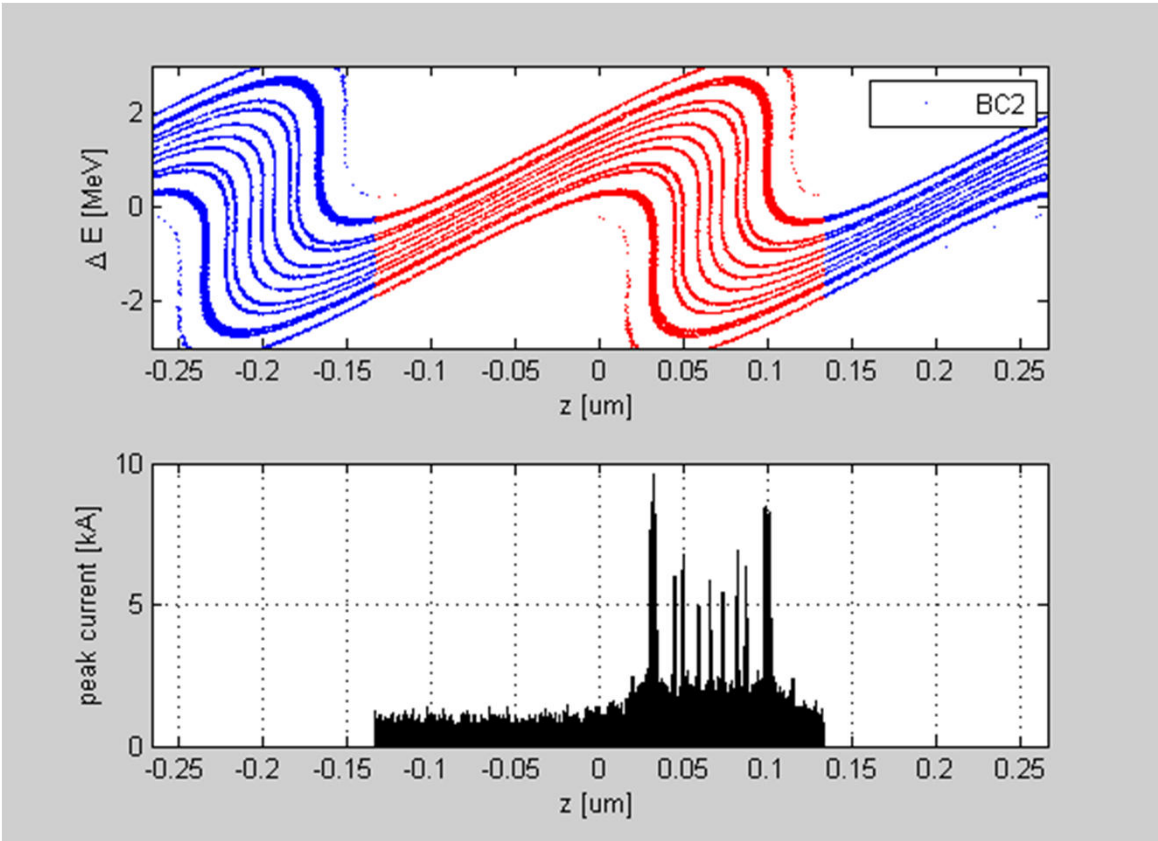
14 nm @ 1.15 GeV



P_1 = 6GW
P_2 = 6 GW

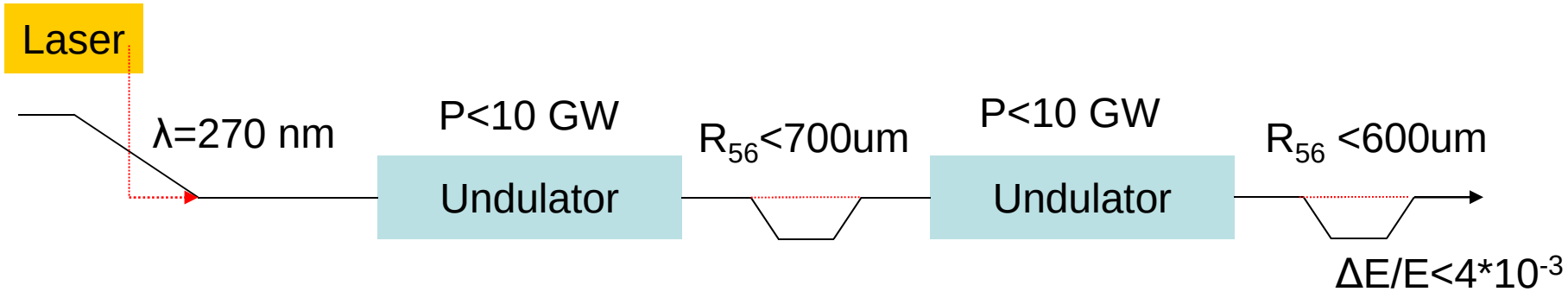
14 nm @ 1.15 GeV

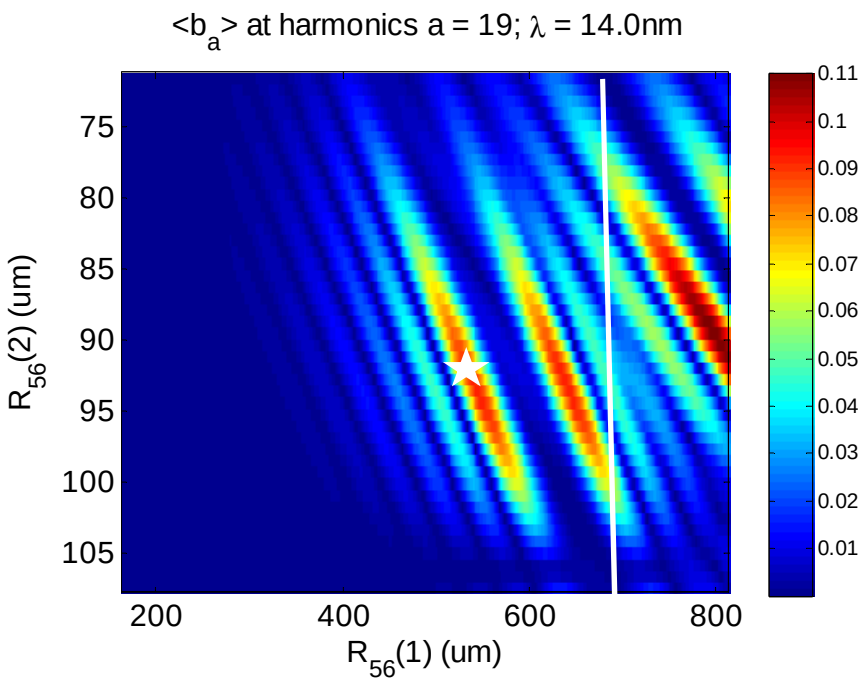


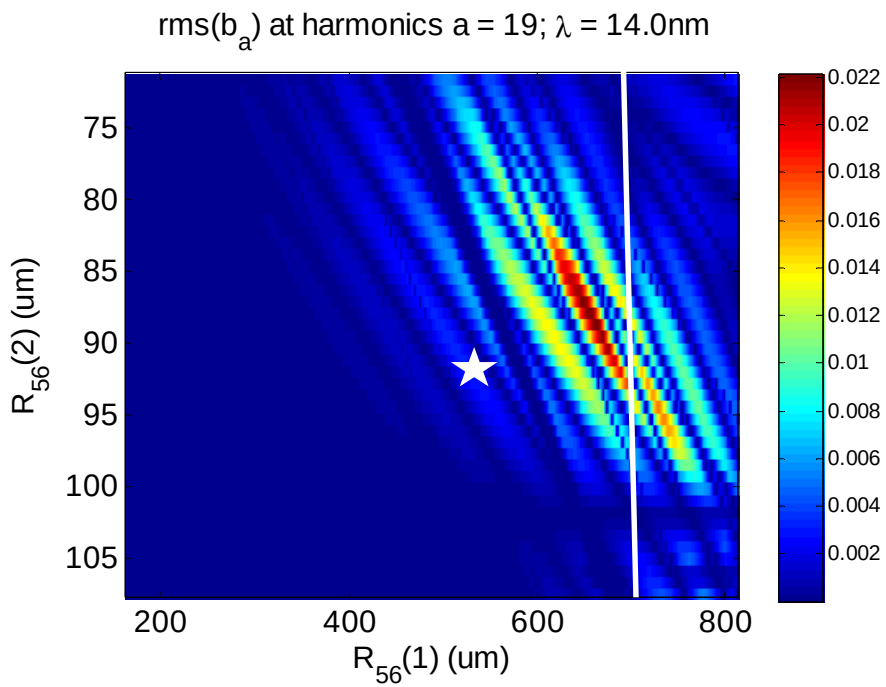


P_1 = 6GW
P_2 = 6 GW
$R_{56}1$=580um
$R_{56}2$=33um

14 nm @ 1.15 GeV

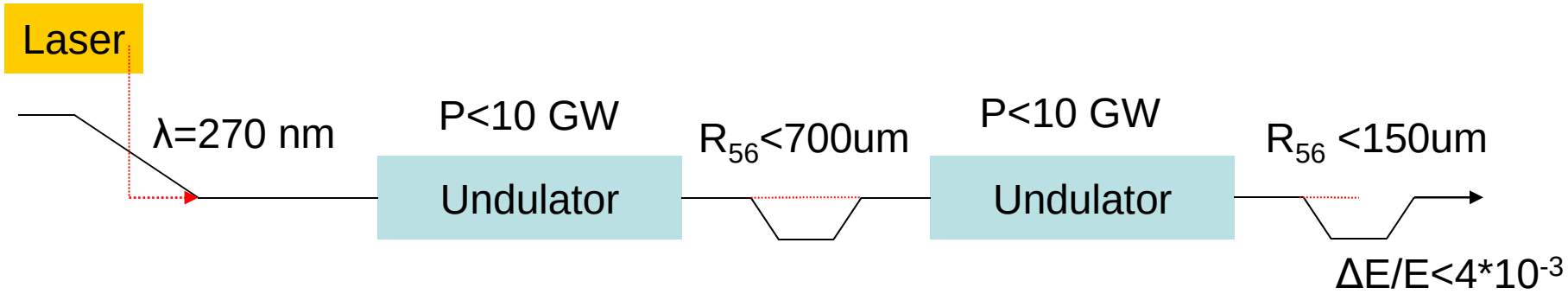


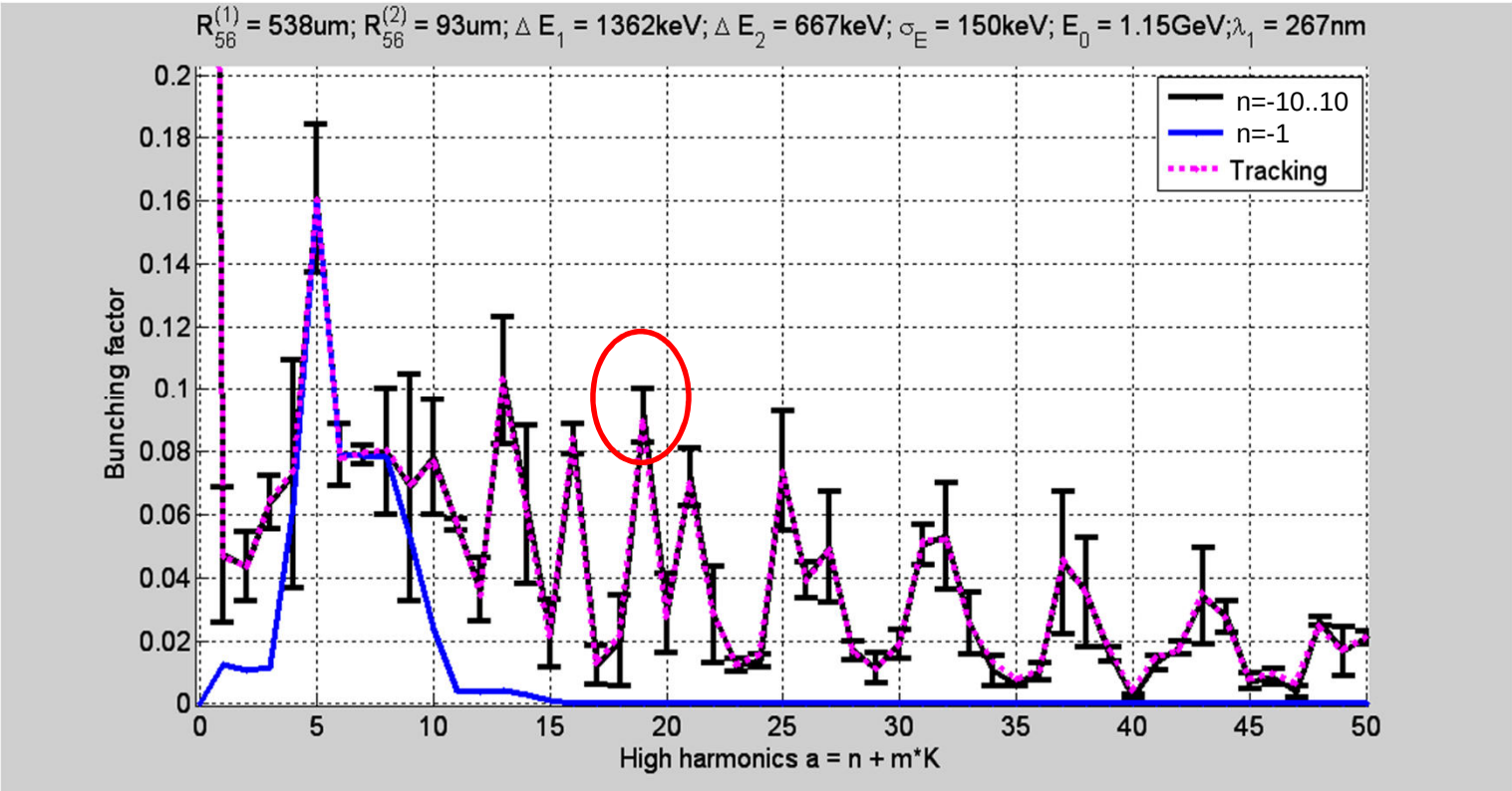




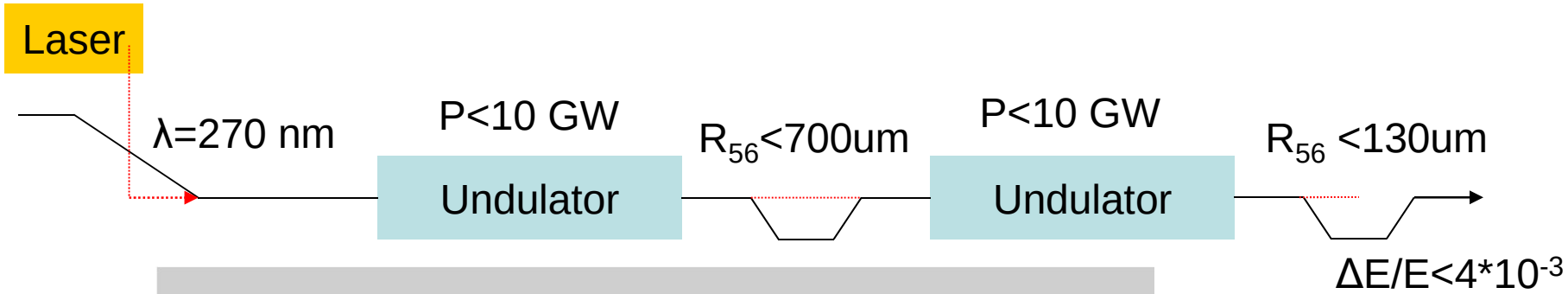
P_1 = 6 GW P_2 = 1 GW

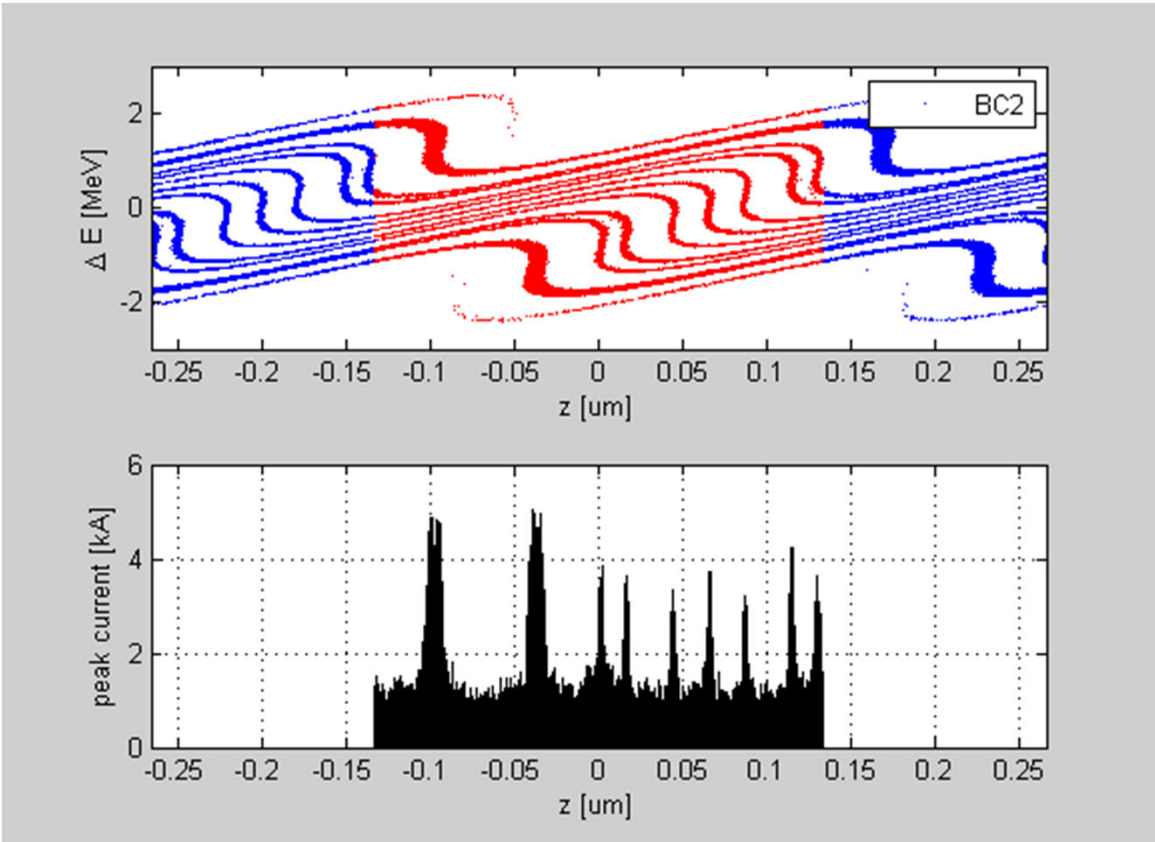
14 nm @ 1.15 GeV


Laser
λ=270 nm
P<10 GW
Undulator
R_{56}<700um
P<10 GW
Undulator
R_{56} <150um
$\Delta E/E<4*10^{-3}$


$R_{56}^{(1)}$ = 538um; $R_{56}^{(2)}$ = 93um; ΔE_1 = 1362keV; ΔE_2 = 667keV; σ_E = 150keV; E_0 = 1.15GeV; λ_1 = 267nm
n=-10..10
n=-1
Tracking
Bunching factor
High harmonics a = n + m*K
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
0.18
0.2
0
5
10
15
20
25
30
35
40
45
50

14 nm @ 1.15 GeV

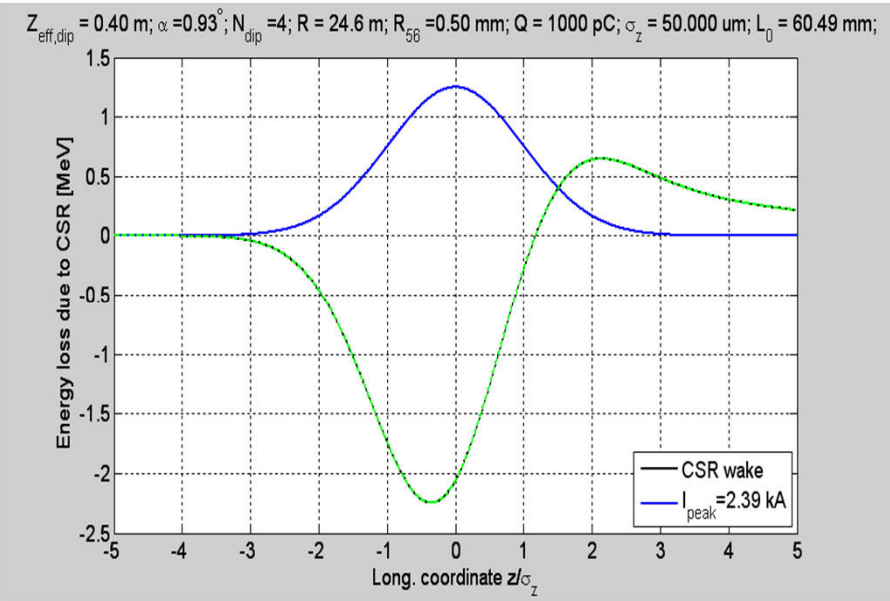




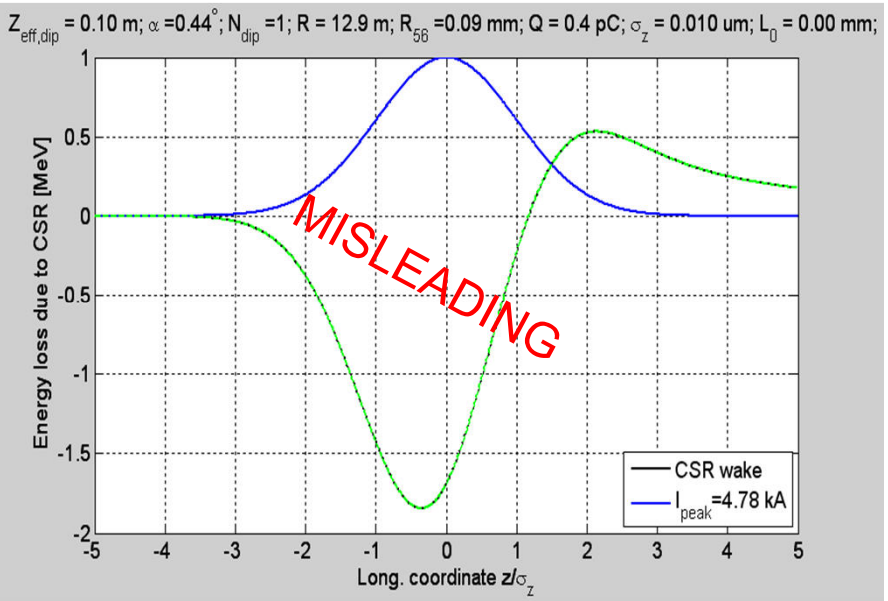
P_1 = 6GW
P_2 = 1 GW
$R_{56}1$=538um
$R_{56}2$=93um

CSR wakes

1-D macro bunch
In first chicane

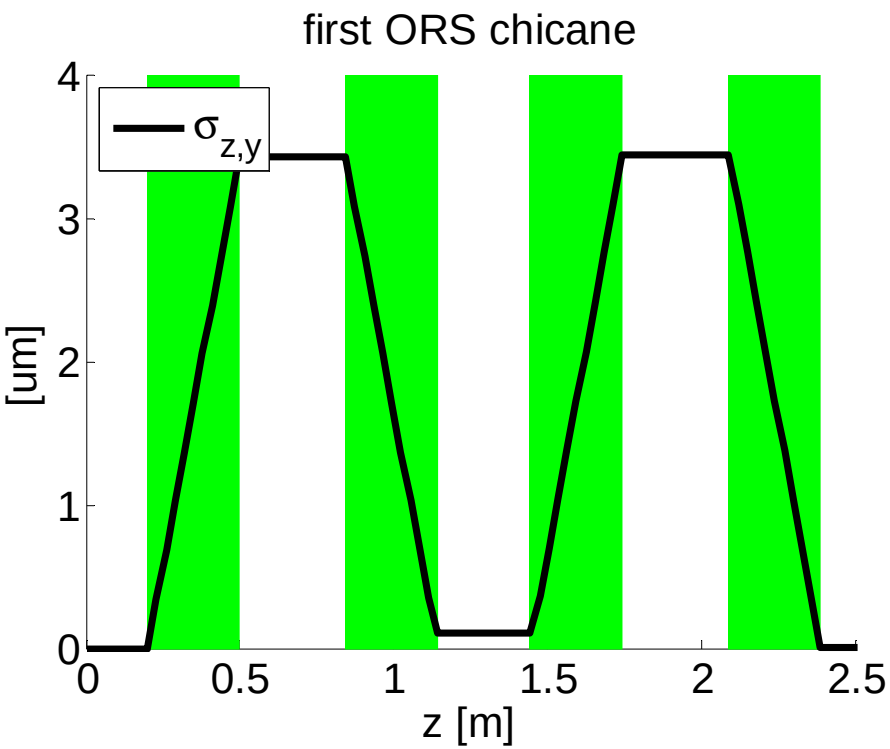


1-D micro bunch
In last chicane

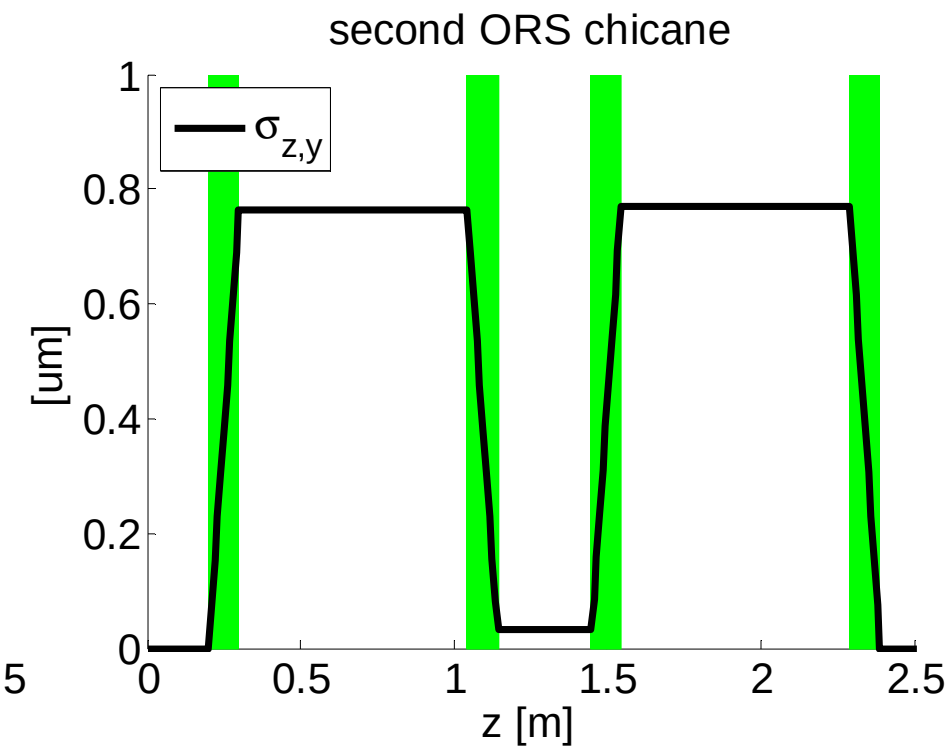


R_{53} & R_{54} smearing out spikes

$$\sigma_{z,y}^2 = R_{53}^2 \sigma_y^2 + R_{54}^2 \sigma_{y'}^2$$

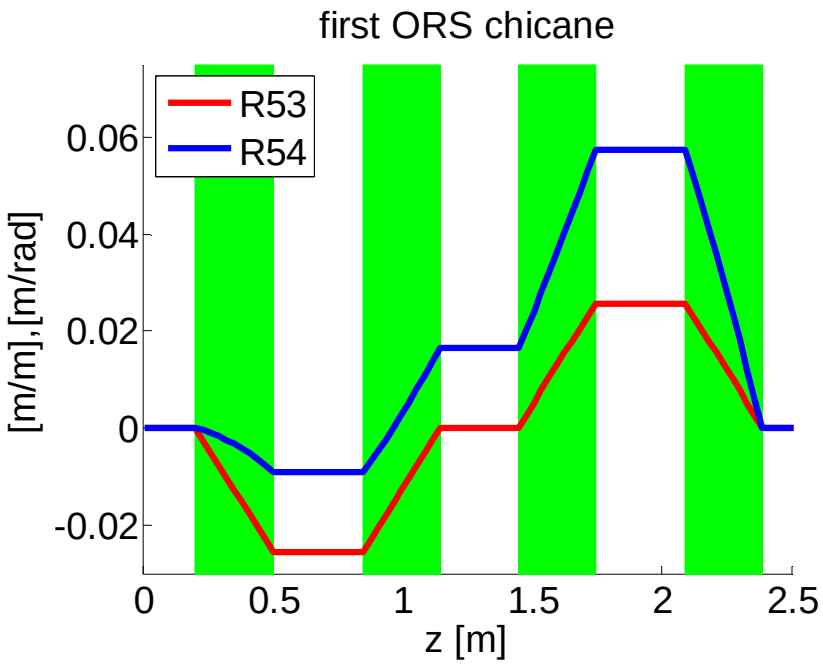


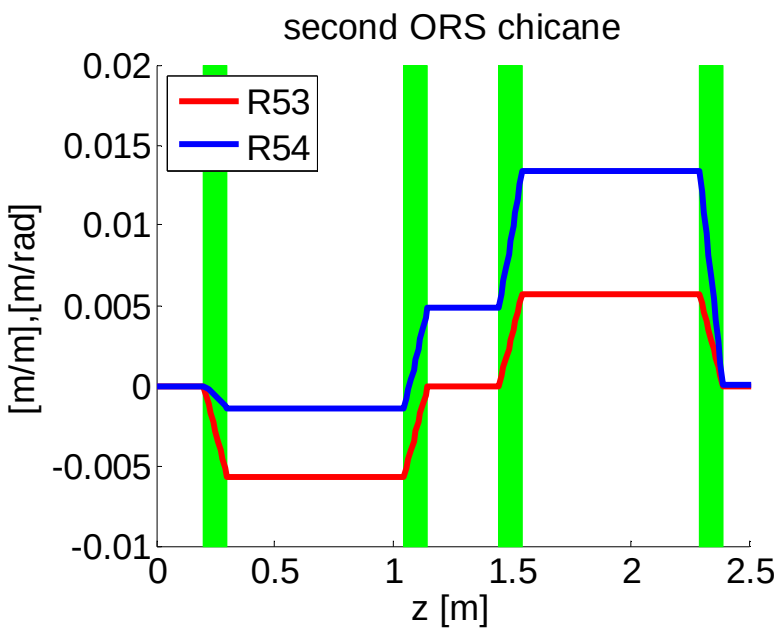
100 nm minimum



30 nm minimum

R_{53} & R_{54} leakage due to CSR





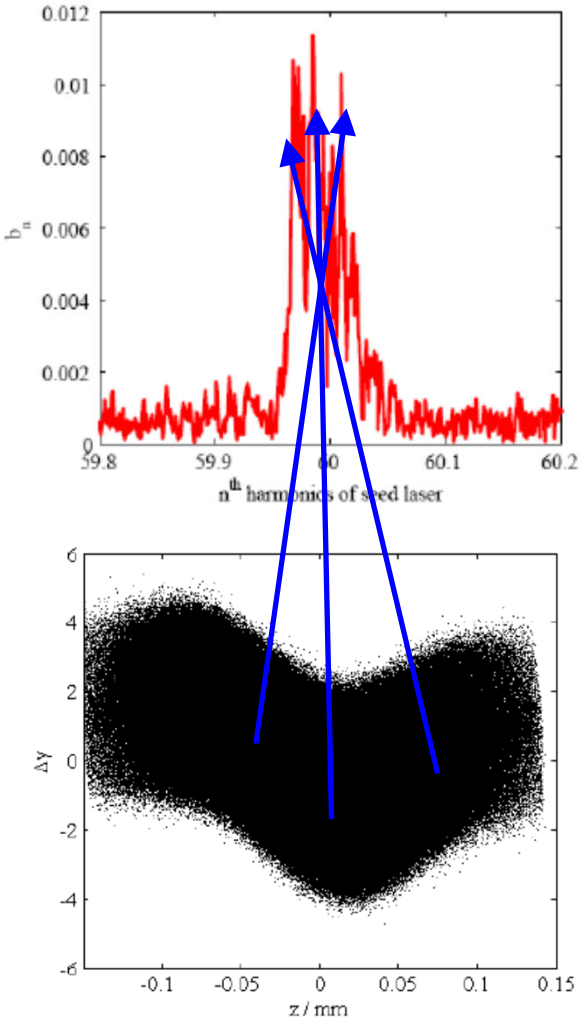
$\sim\exp(k^2 R_{53}^2 \sigma_y^2/2)$

$\Rightarrow$ Magnetic field of first chicane must be tuned to within 0.05%

$\Rightarrow$ Magnetic field of second chicane must be tuned to within 0.20%

CSR -> bunching factor

ORS EEHG wakes are same magnitude as FLASH II wakes for 20th harmonic scheme



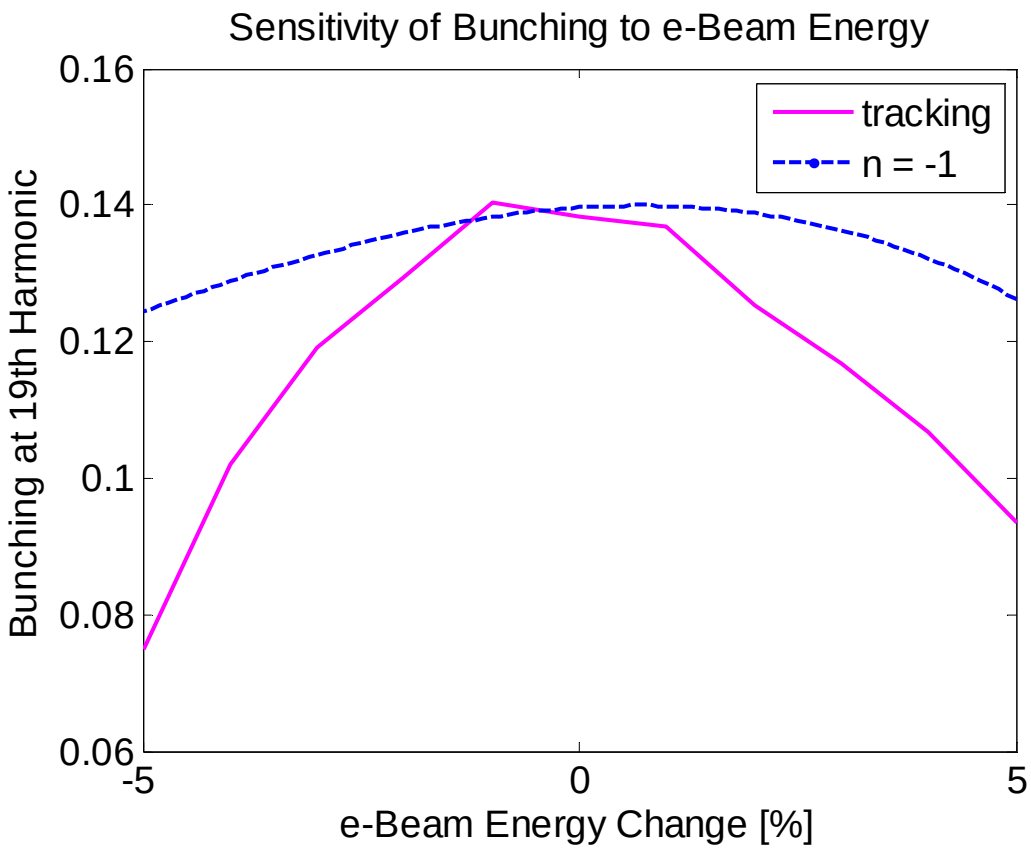
CSRtrack/Elegant=> 50% reduction in bunching

Interpretation?
R53, R54 leakage or something else?

"different parts of the electron beam shift to different microbunching wavelength.
Thus, the projected microbunching bandwidth is broadened and the bunching factor is degraded."

Plot from
FEL beam dynamics seminar
Dec 06

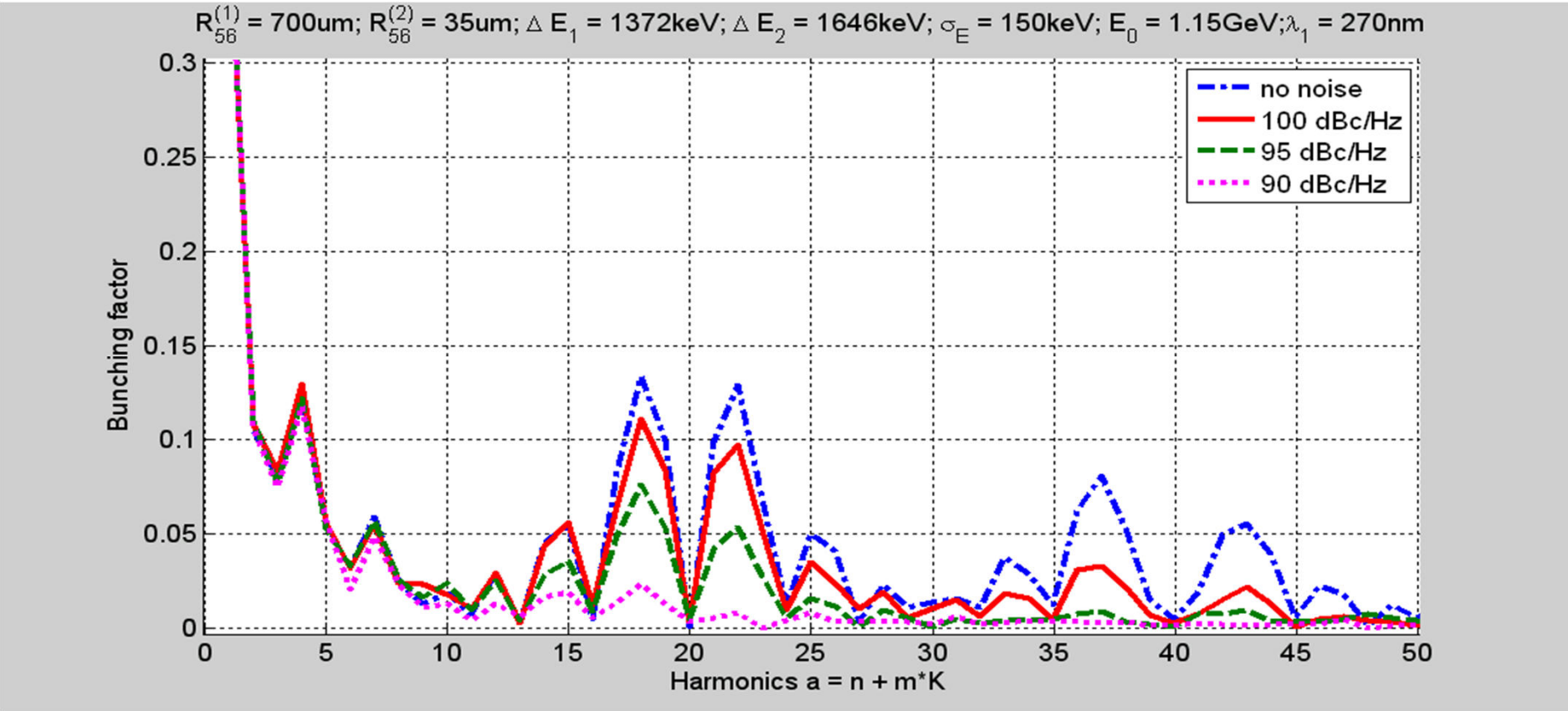
Beam Energy Sensitivity



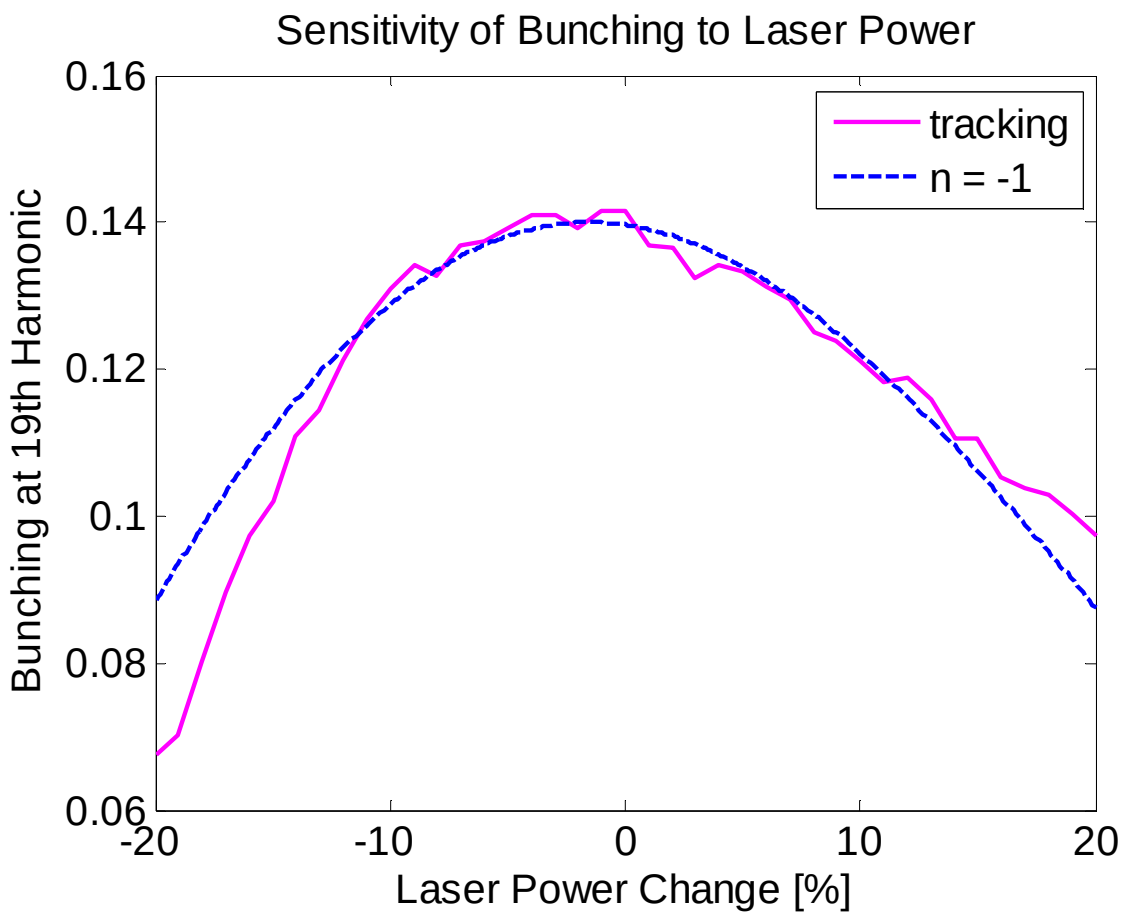
Phase Noise Sensitivity

EEHG & HGHG
Same rule?

$$\left(\frac{P_s}{P_n}\right)_{out} = \frac{1}{n^2}\left(\frac{P_s}{P_n}\right)_{in}$$



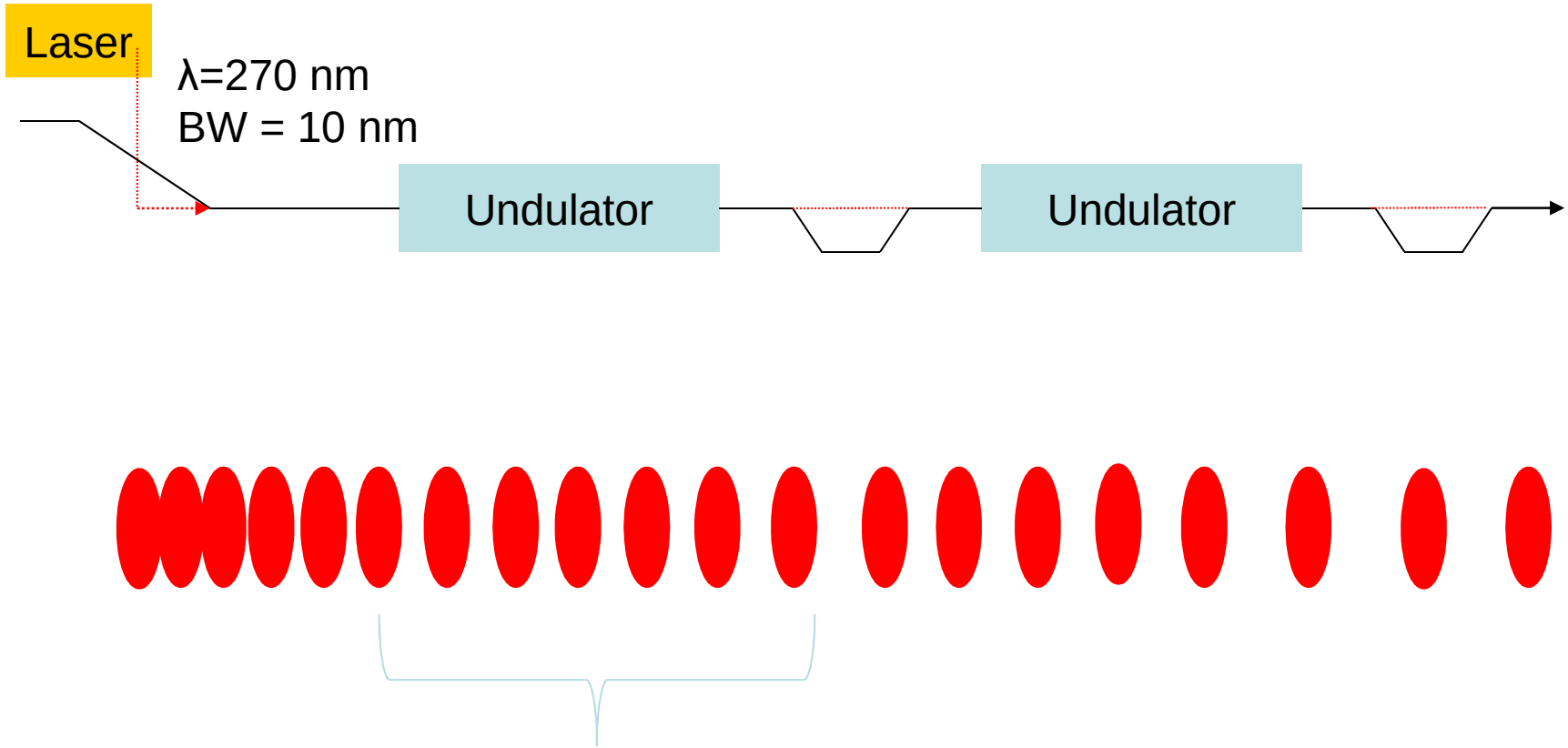
Laser Power Sensitivity



Laser pulse front tilt

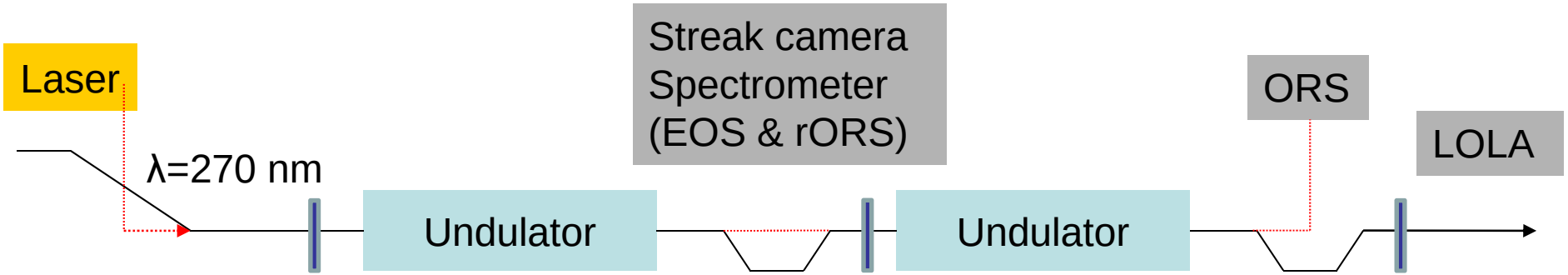
We probably need a way to tune it.

EEHG with chirped laser pulse



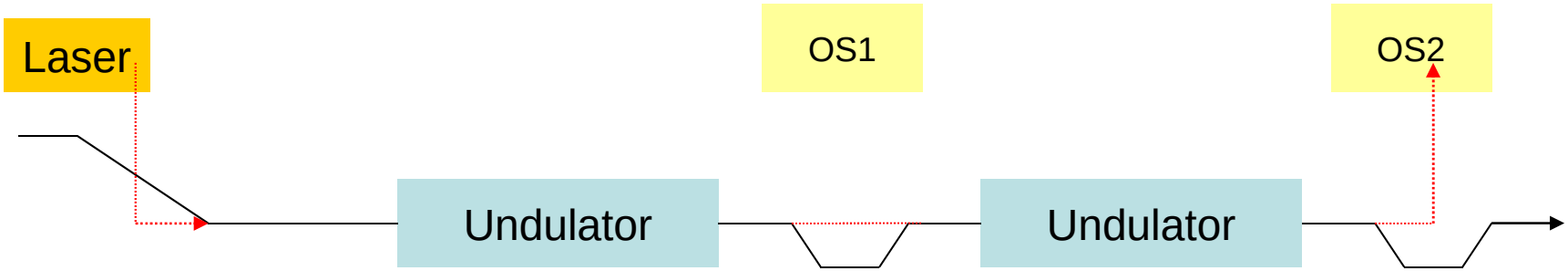
Bandwidth of bunching (~0.5 nm) > bandwidth of undulator radiation (0.05 nm)
=>
Only a slice of the beam lases

EEHG diagnostics



- YAG/OTR screens for transverse overlap
- Streak camera for (ps) longitudinal overlap
- LOLA (check for energy spread changes -> bunching)
- ORS for longitudinal overlap and profile
- sFLASH spectrometer

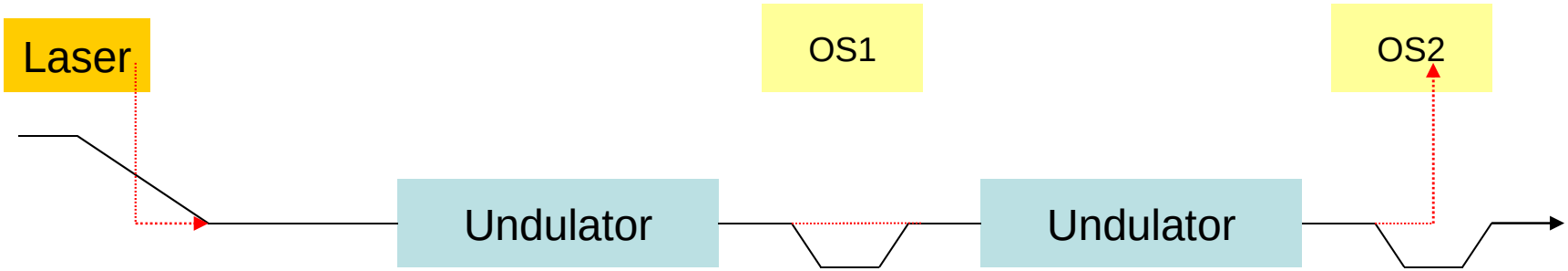
ORS: the original

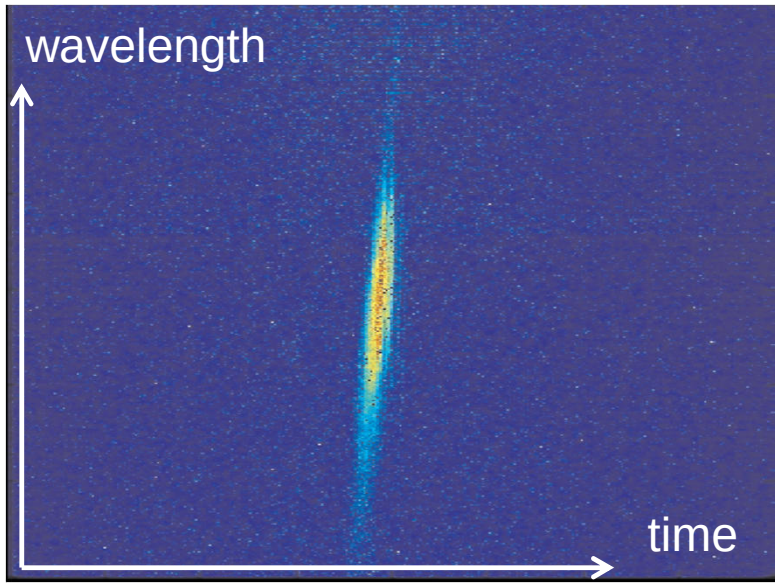


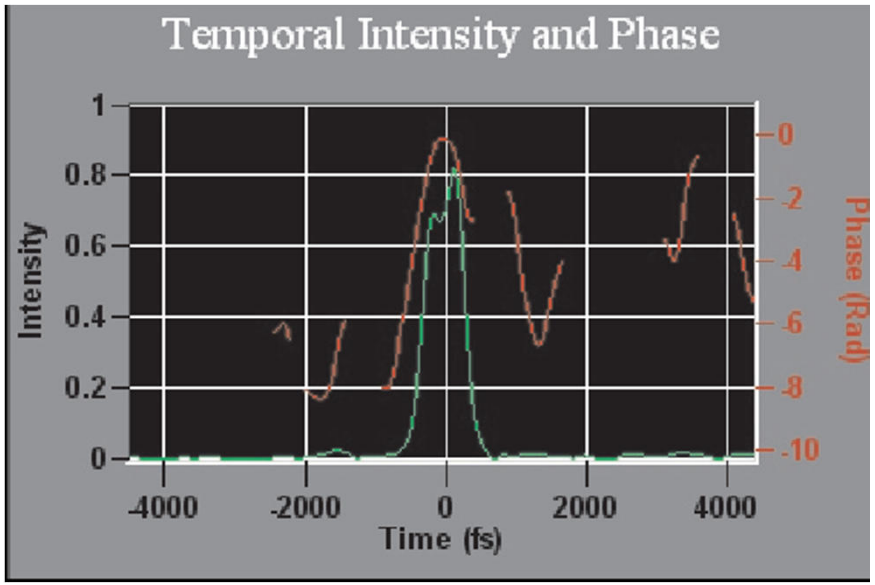
- e-beam is modulated by laser pulse in first undulator
- e-beam radiates optical replica in second undulator
- FROG installed in OS2 measures longitudinal profile of optical replica

Idea from Saldin, Schneidmiller, & Yurkov
Experiment supported by Uni. Uppsala & Uni. Stockholm

ORS: success in 2007

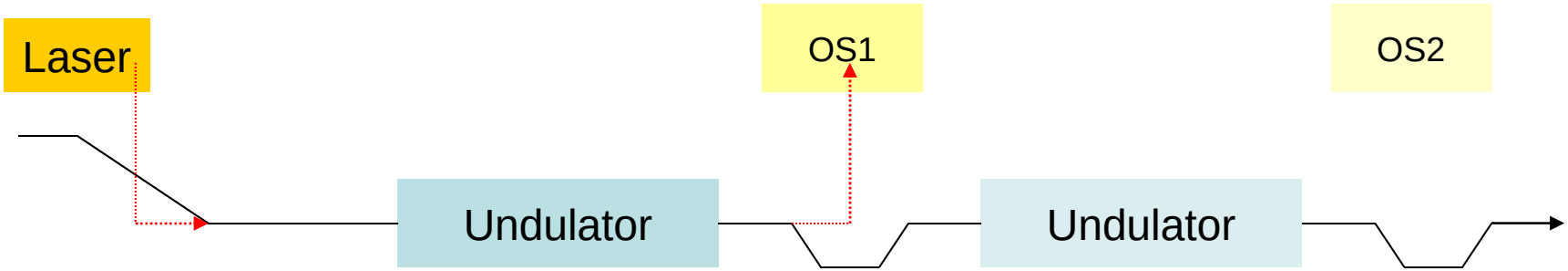






FEL08-THBAU04 (Boedewadt)

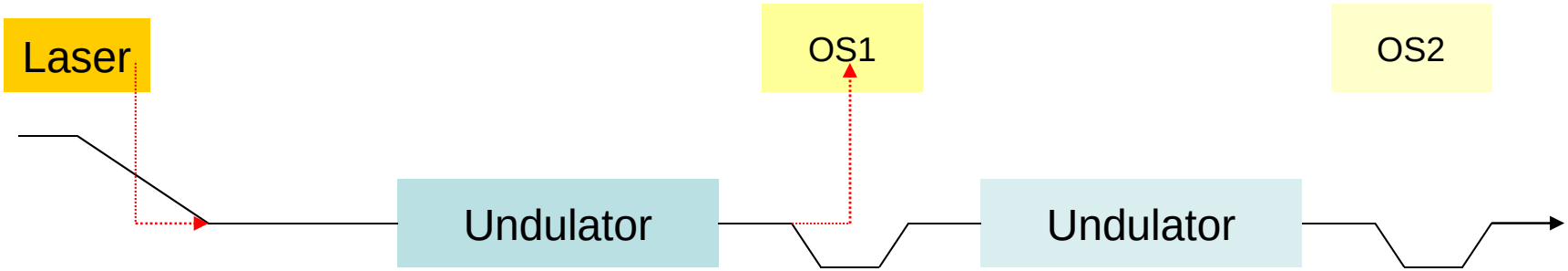
rORS: new concept

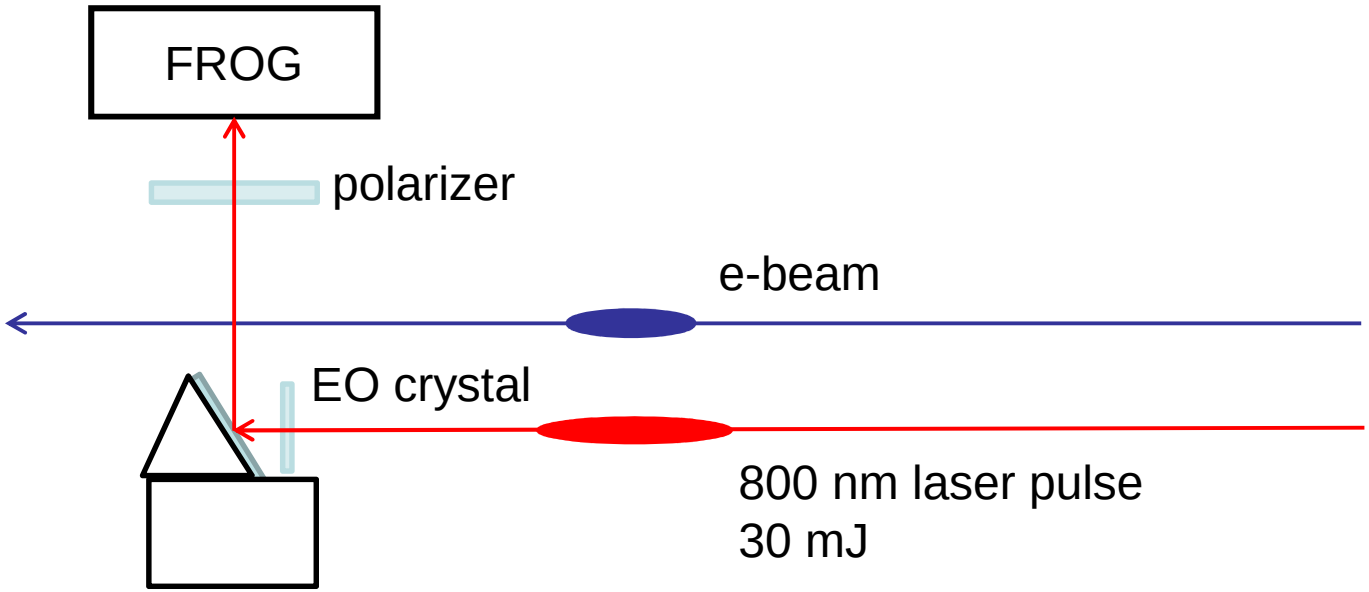


- Beam is modulated by laser pulse in first undulator
- Longitudinal profile is derived from measurements done with a FROG and a spectrometer installed in OS1
- Should be especially good for ultra-short, fs beams

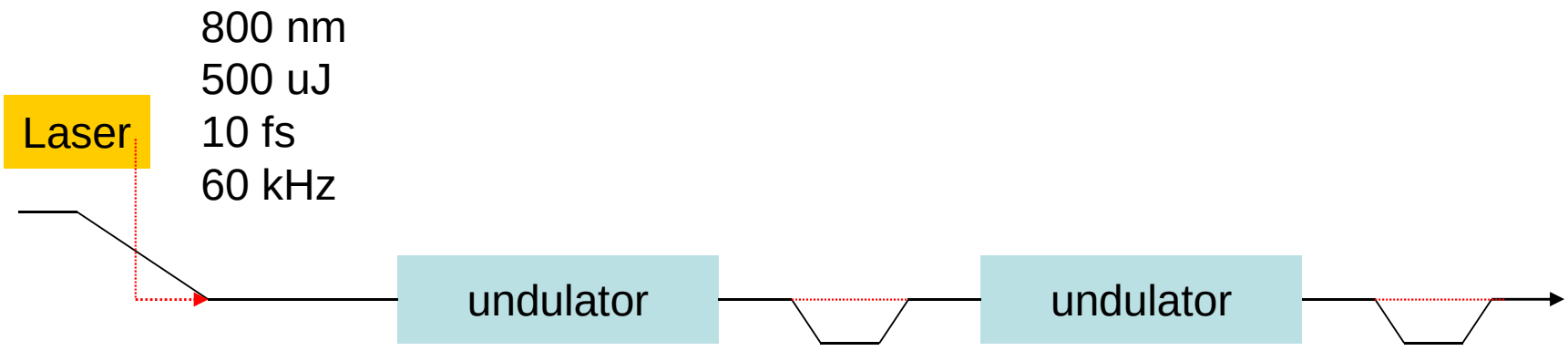
Proposed by Jens Osterhoff & Florian Gruener

Electro-optical sampling with a FROG in OS1





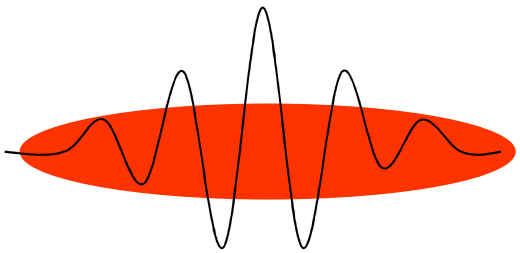
Attosecond beam Slicing



Use laser pulse in undulator to give a slice a different energy

Use chicane to separate slice from rest of beam

=> perfectly synchronized beam slice



Use few cycle 800/2400 nm laser pulse
From Tavella

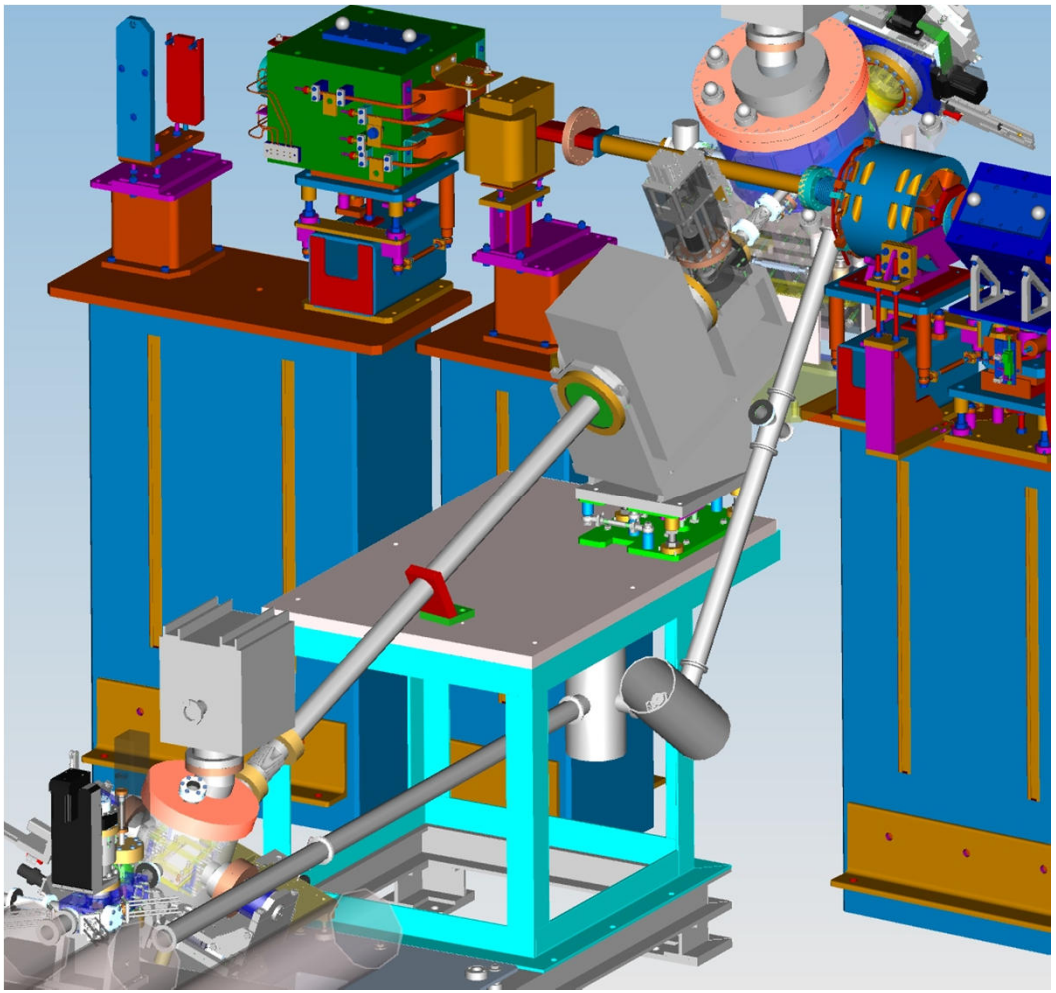
Experiment checklist:

- ✓ laser beams and optics
- ✓ undulators and chicanes
- ✓ laser/e-beam diagnostics
- ▪ in-vacuum transport for laser beam

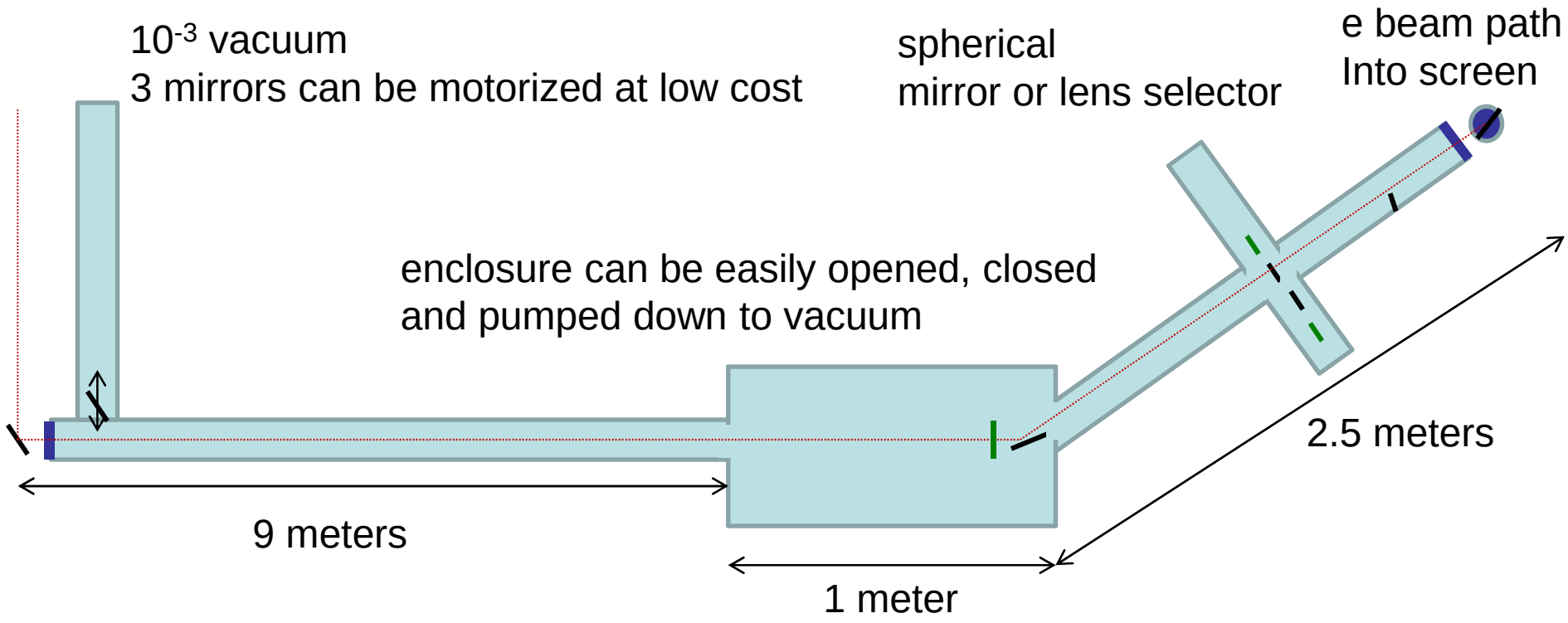
In-vacuum laser transport?

- 270 nm (~100 fs FWHM) for EEHG
- Few-cycle 800 nm pulse for beam slicing

3-D tunnel model



In-vacuum laser path



Experiment checklist:

- ✓ laser beams and optics
- ✓ undulators and chicanes
- ✓ laser/e-beam diagnostics
- ▪ In-vacuum transport for laser beam

Could be installed during the shutdown in the last 3 months of 2011 and ready for experiments in 2012!!

Thank you for your time

ORS: lessons learned

More laser power needed

- 10 mJ
- 1 ps FWHM
- 10 GW
- 500 um FWHM

Use 800 nm HHG laser

- 30 mJ
- 30 fs FWHM
- 1000 GW
- 13 mm FWHM

XUV mirrors are bad for 800 nm beam

- 30 uJ
- 30 fs FWHM
- 1 GW
- >13 mm FWHM

Add telescope and bypass pumping stage irises

- 1 mJ
- 300 fs FWHM
- 10 GW
- 500 um FWHM

Build new laser transport line to bypass XUV mirrors

- 30 mJ
- 1 ps FWHM
- 30 GW
- 500 um FWHM

270 nm beam

Start with 811 nm HHG laser beam
- 33 mJ
- 300 fsFWHM
- 100 GW
- 13 mm FWHM

Compress it from 300 fs to 30 fs
- 30 mJ
- 30 fs FWHM
- 1000 GW
- 13 mm FWHM

Frequency triple it with 10-15% efficiency
- 3 - 4.5 mJ
- 30 fs FWHM
- 100 - 150 GW
- 13 mm FWHM

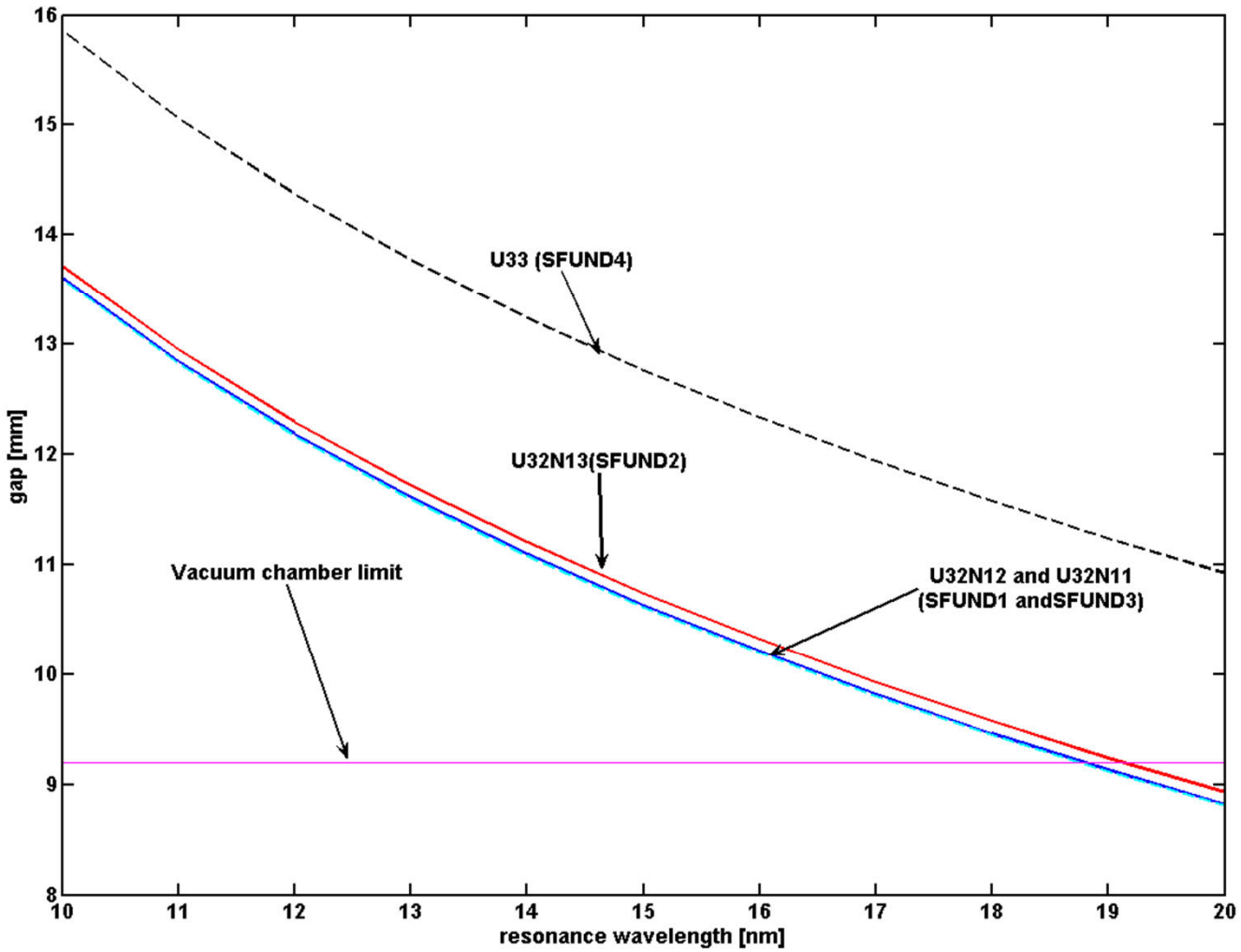
Birefringent crystal
- 2.7 - 4.0 mJ
- 30 fs FWHM
- 90 - 135 GW
- 13 mm FWHM

½ waveplate & 2 mirrors
- 2.0 - 3.0 mJ
- 30 fs FWHM
- 65 - 100 GW
- 13 mm FWHM

Sufficient Laser Power

EEHG with sFLASH undulators

For 1GeV beam energy



Plot courtesy of Delsim-Hashimi