"FLS2006"

High Harmonic Seeding and the 4GLS XUV-FEL

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

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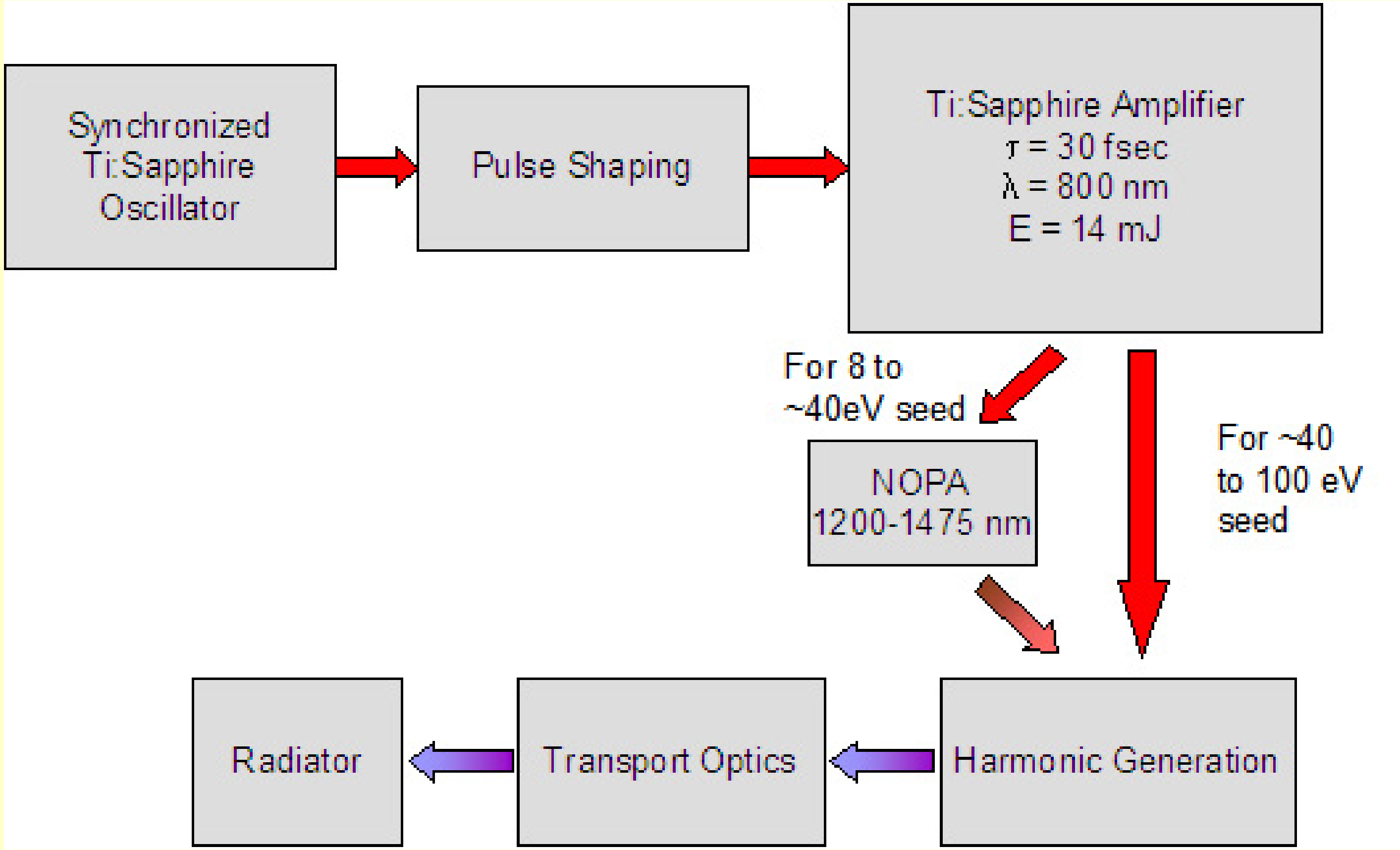
- **Energy and Efficiency Questions**
  - **how much do we need?**
  - **how much do we have today? tomorrow?**
- **Tunability**
  - **tunable fundamental**
  - **adaptive tuning**
- **Attosecond structure, contrast, & spatial coherence**
- **Layout in the facility**

4GLS

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



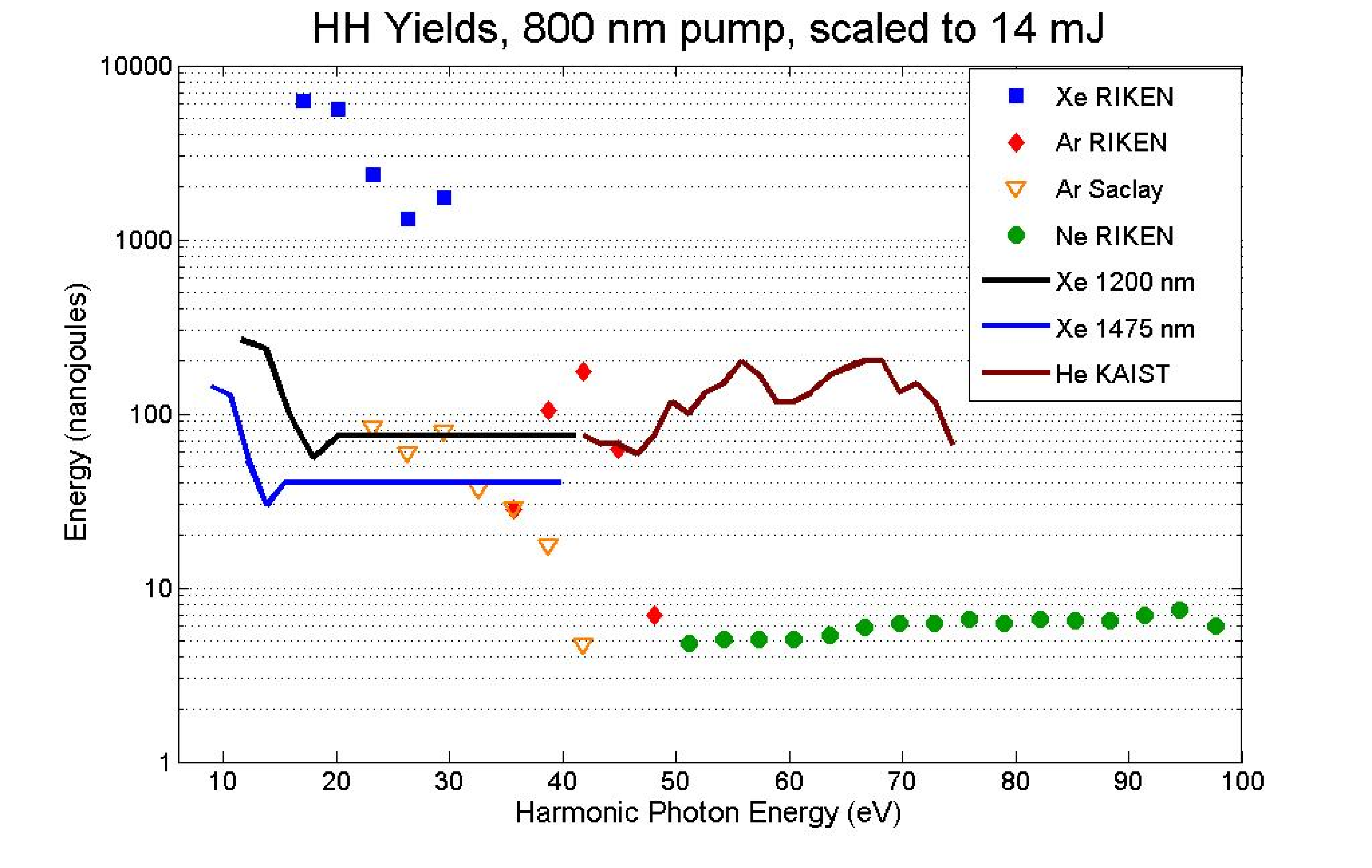
- Two-track system: 8 – 40 eV & 40 – 100 eV (Tunability)
- Doable with existing technology
  - expected near-term improvements in lasers, harmonic efficiency, will make it easier

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

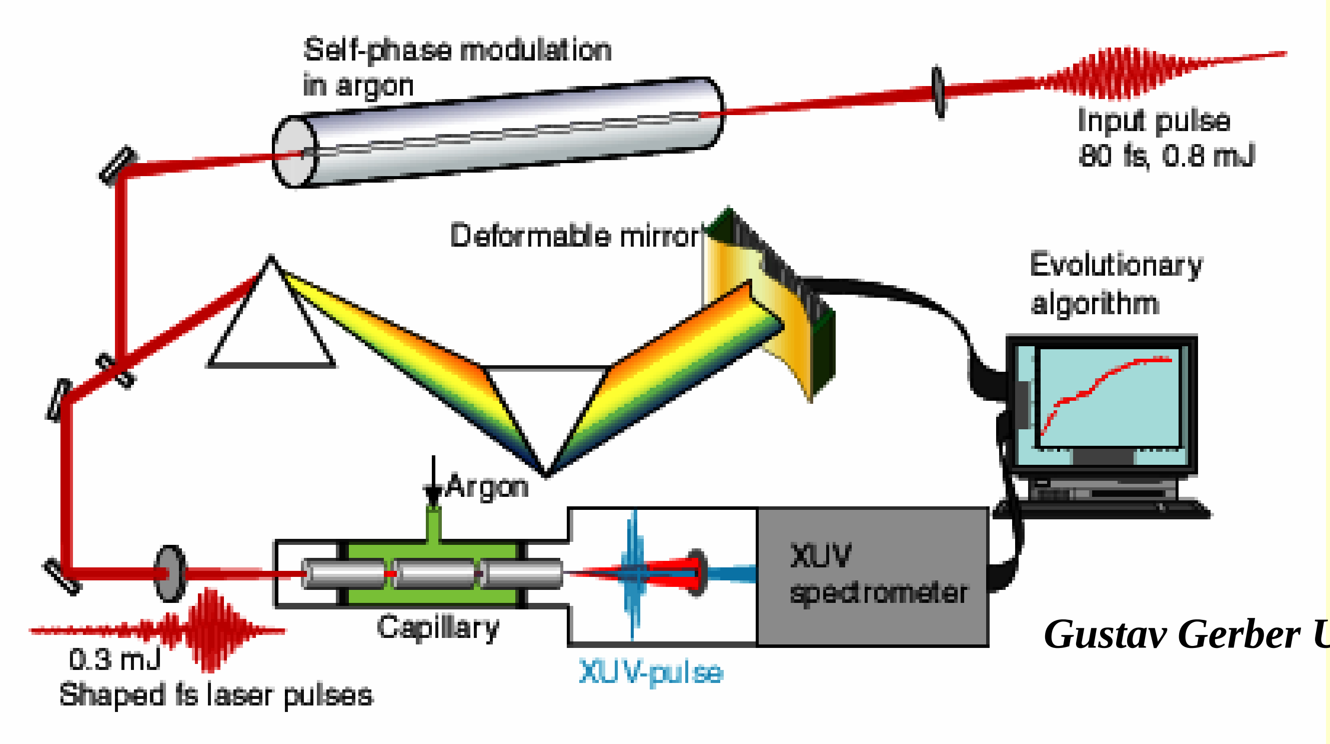
Existing Ti:Sapph systems

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	



- **15% conversion efficiency in NOPA – noncollinear optical parametric amplifier**
- **harmonic efficiency scales as λ^{-3}**
- **XUVFEL simulations being run with 1-3 nJ pulses**

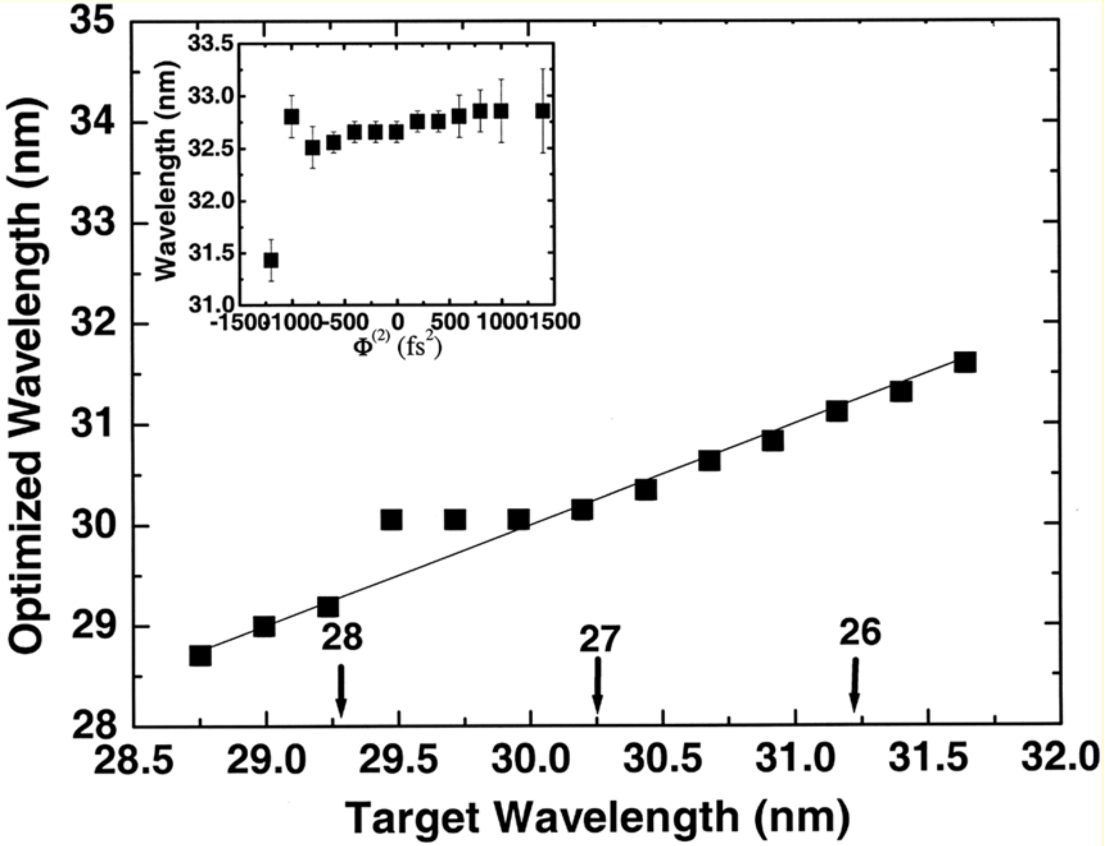
Tunability: Chirping/Adaptive control



Gustav Gerber Uni Wuerzburg

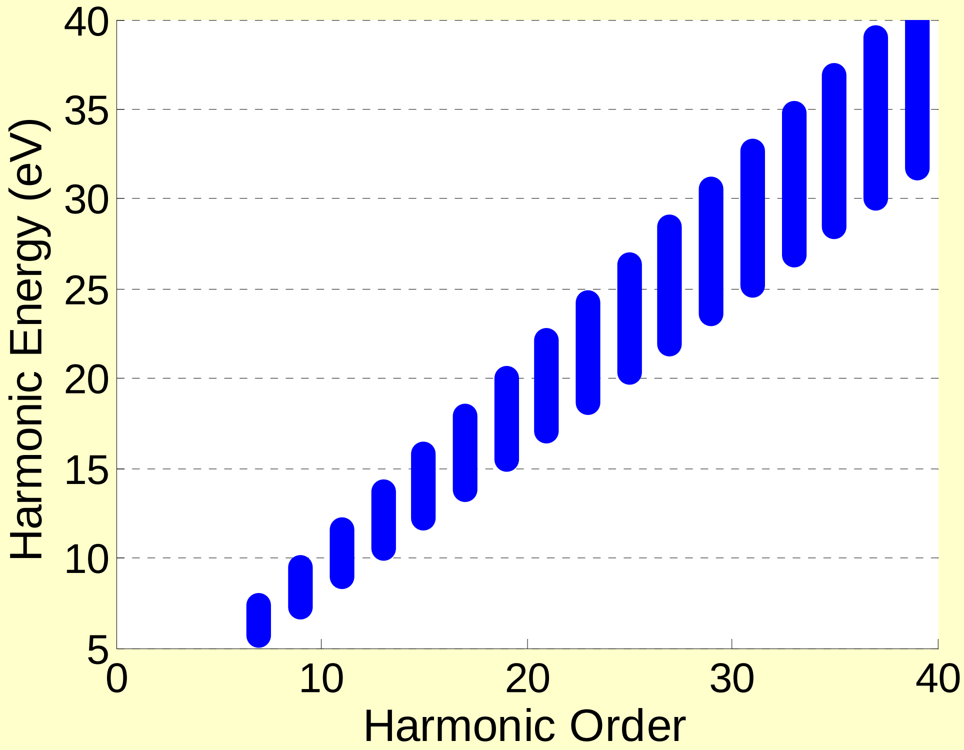
- Shaping fundamental pulse to shift frequency of the harmonic
- Range is ~$2q\Delta\nu_f$. $\Delta\nu_f$=fundamental bw, q=harmonic order
- Can also use a Dazzler before the amplifier chain
    - minimal perturbation to synchronization

Adaptive Tuning in Argon (Reitze et al Opt Lett 2004)



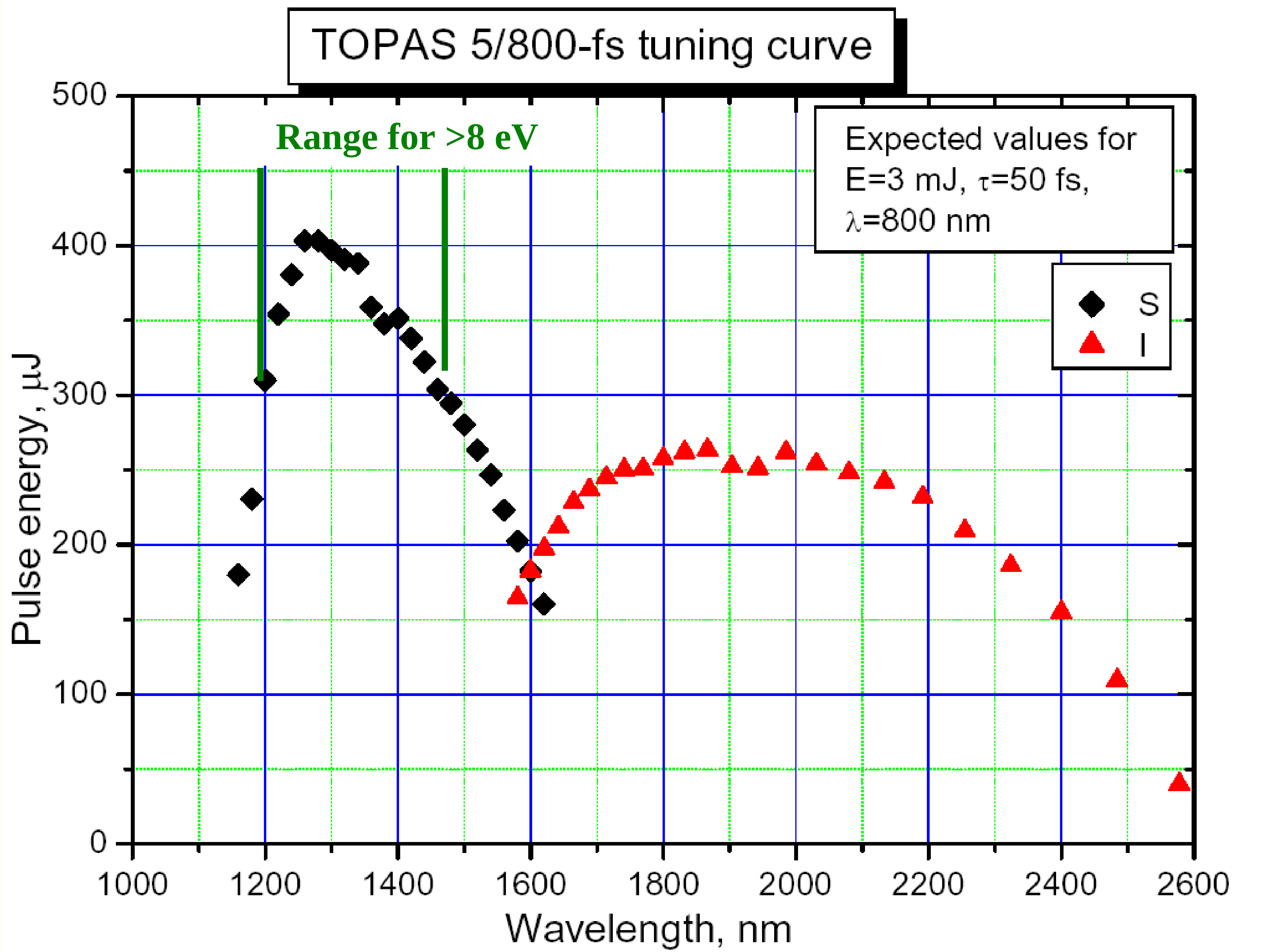
•Complete tuning (between harmonic orders) at 40 eV
•Both range and efficiency dramatically enhanced relative to simple chirping

Tunable fundamental



Tuning range of harmonics 7-39 for a fundamental that is tunable from 1175-1525 nm

- tuning range ≺ harmonic order
  - longer wavelength fundamental means higher order
- the lowest energy required determines the required tuning range of the fundamental



Commercial OPA Systems 10-13%, laboratory system 20%

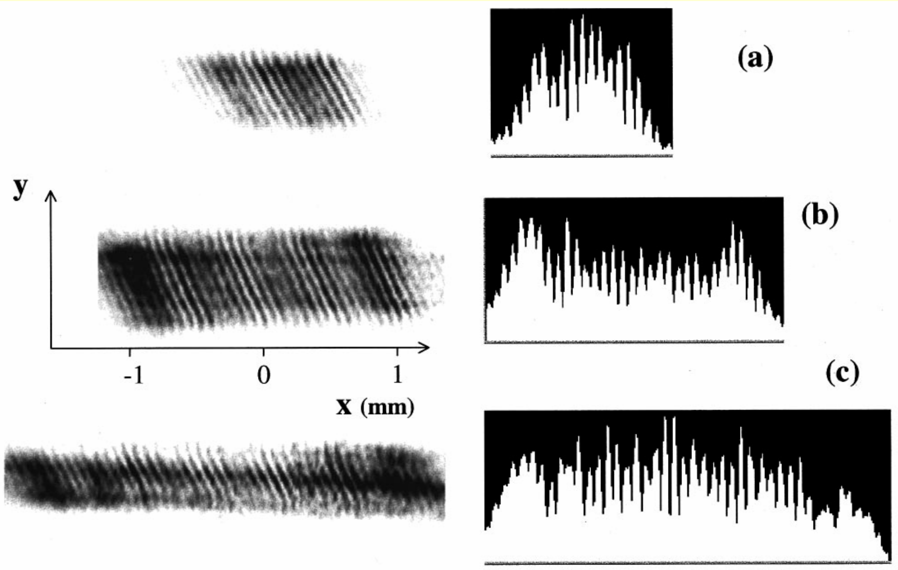
Near-Term Improvements

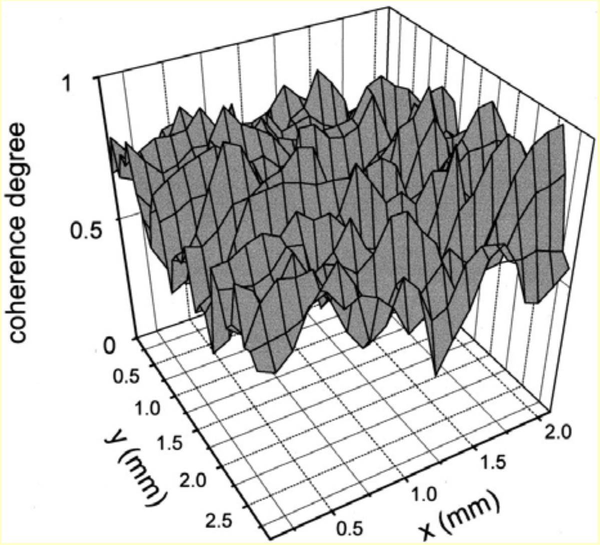
- HH Generation Techniques
  - still surprises in *exploiting* the dynamics: e.g. 2-color results of KAIST in 2005 demonstrated $>10^2$ enhancement in HH yield in Helium
  - Quasi phase-matched waveguides
  - HH generation in photonic bandgap fibers

- Lasers
  - Ti:Sapphire scalable in power
  - OPCPA systems (Optical Parametric Chirped Pulse Amplification)
  - High power Yb:YAG lasers
  - a number of 100 Watt laser designs were discussed at 2004 MIT workshop
    - longer wavelength (~2 μm) removes need for two-track system

Strong Drivers: HH for table top ultrashort X-ray source and attosecond science

Spatial Coherence

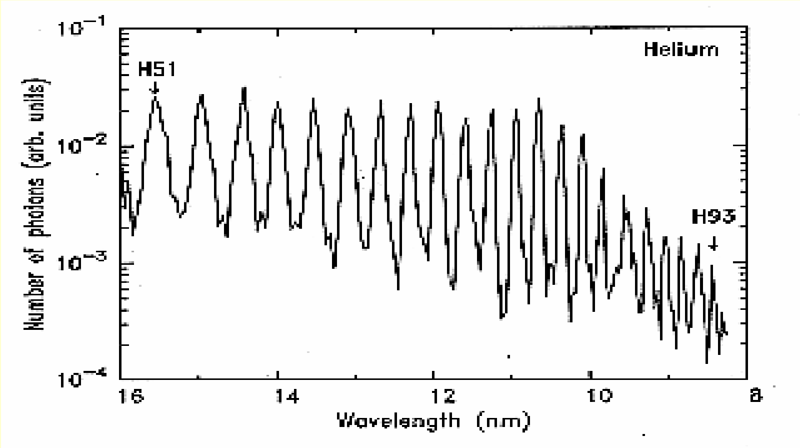




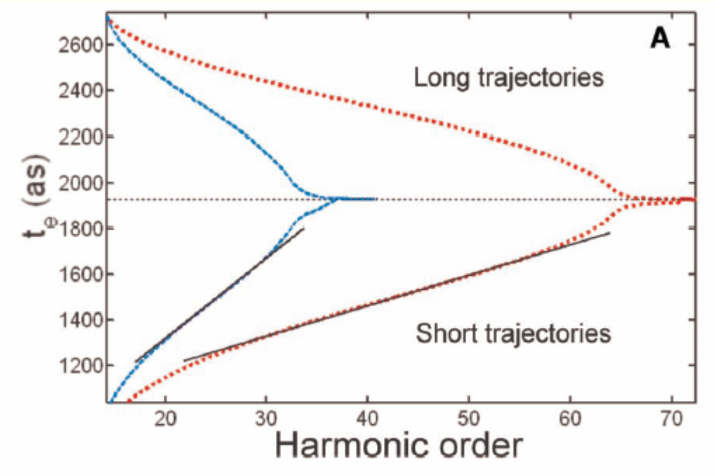
Saclay (Le Deroff et al) PRA 61, 043802

- High spatial coherence
- Sensitive to phase matching conditions
- Consistent with 3 step model

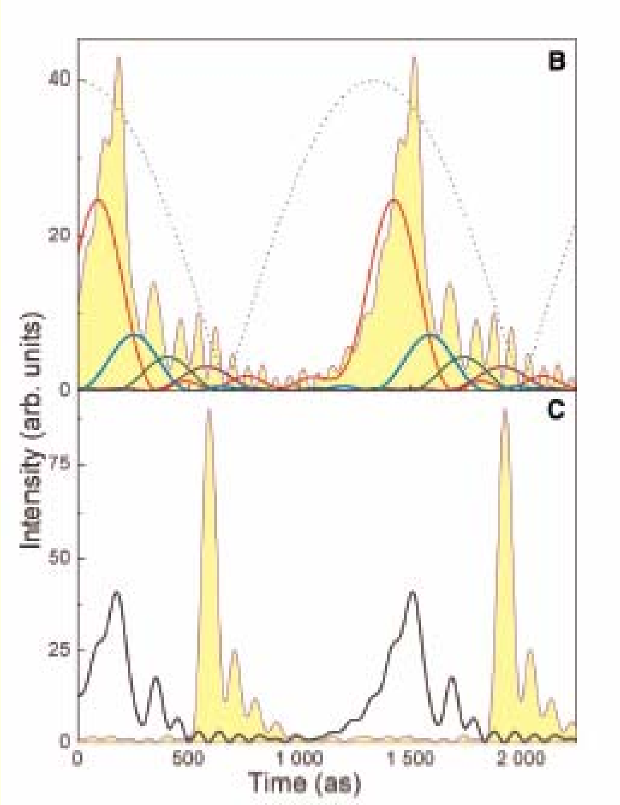
Attosecond Time Structure in the harmonics



- 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

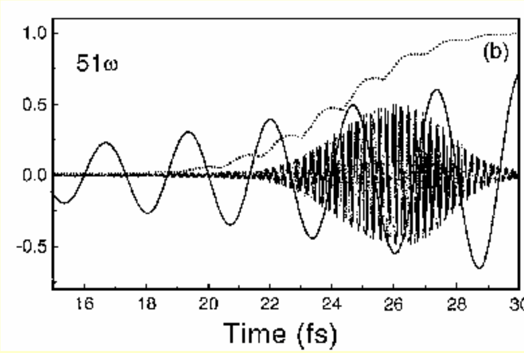


Mairesse et al Science
302, 1540 (2003)



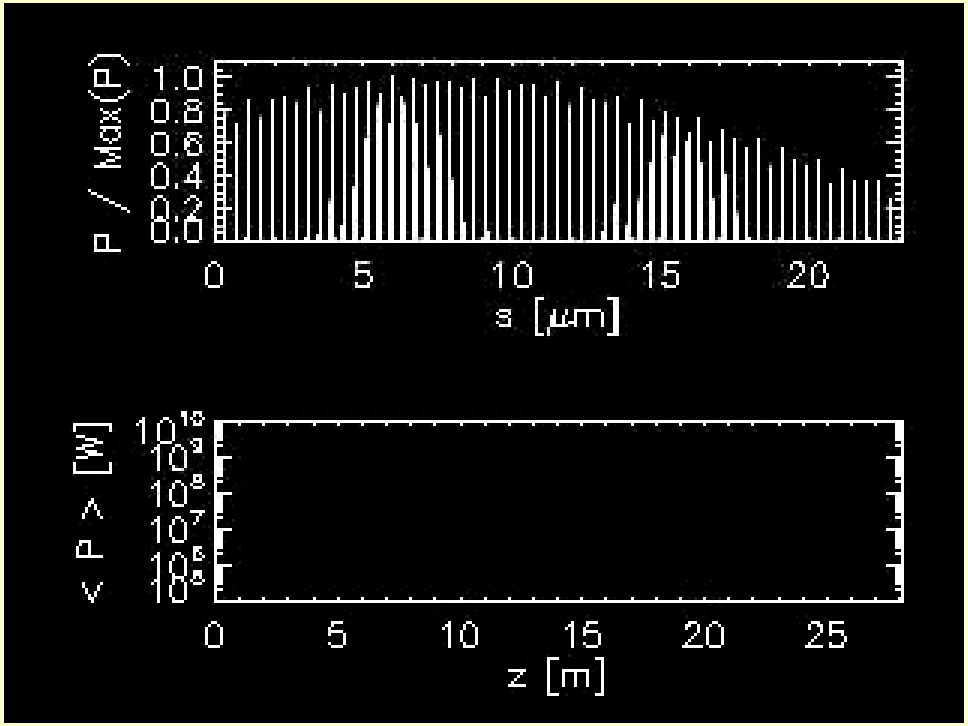
Is attosecond structure a problem for seeding?

- slippage over one-half optical cycle -1.3 fs -will average over the structure
  - at 100 eV in the XUV-FEL this slippage takes ~1 gain length
  - GENESIS simulation: B. McNeil
- Only a single harmonic lies within the gain bandwidth of the radiator
  - attosecond structure arises from multiple harmonics interfering
  - single harmonic has smooth temporal profile
- **This Workshop:** conversations with Luca and Ati
  - GENESIS simulations show some effect
  - still some questions about how to handle the large bandwidth/fast modulations in GENESIS
  - differences? wiggler length, seeding length, HGHG vs amplifying the fundamental



Kapteyn-Murnane group
PRL 78, 1271 (1997)

4GLS



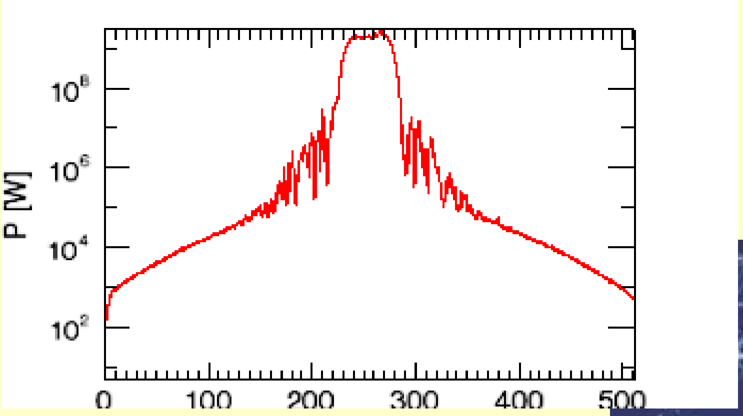
Genesis simulation by Brian McNeil

Seed with 240 attosecond pulses separated by 1.3 fsec (T/2).

- photon energy 100 eV
- slippage ~ 15 fsec
- structure is washed out

Contrast: Even though seed power dominates the shot noise power, SASE still occurs.

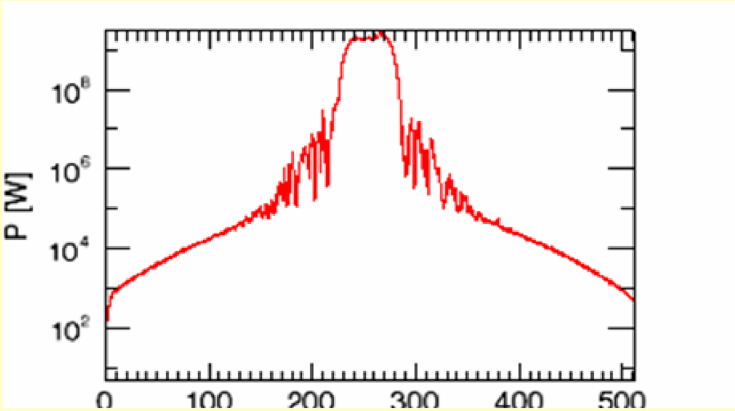
- problem in experiments concerned with nonlinear interactions
- ratio ~ 10^{-3} acceptable
- improves with increasing seed power
    - shown is with 1 nJ seed



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

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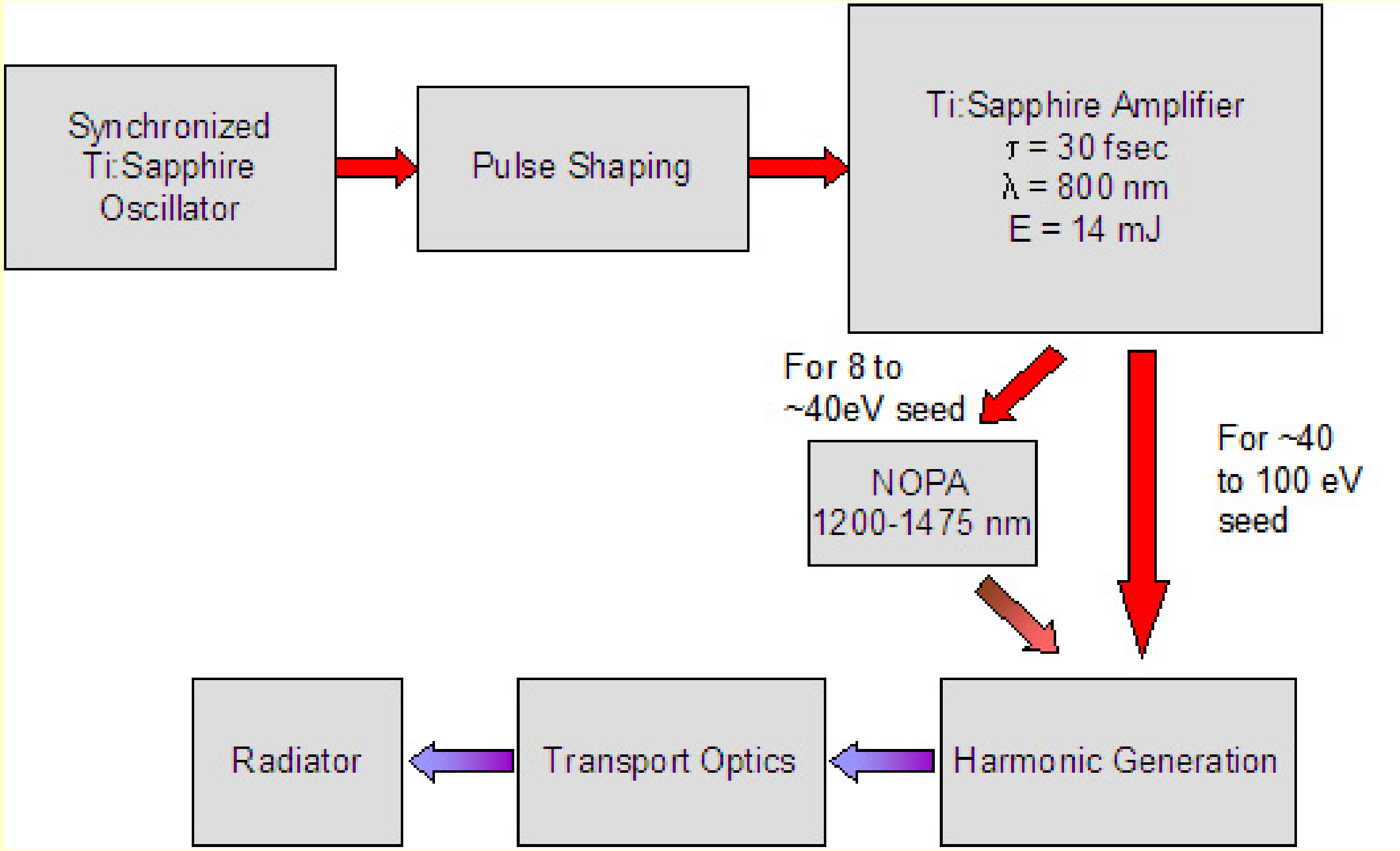
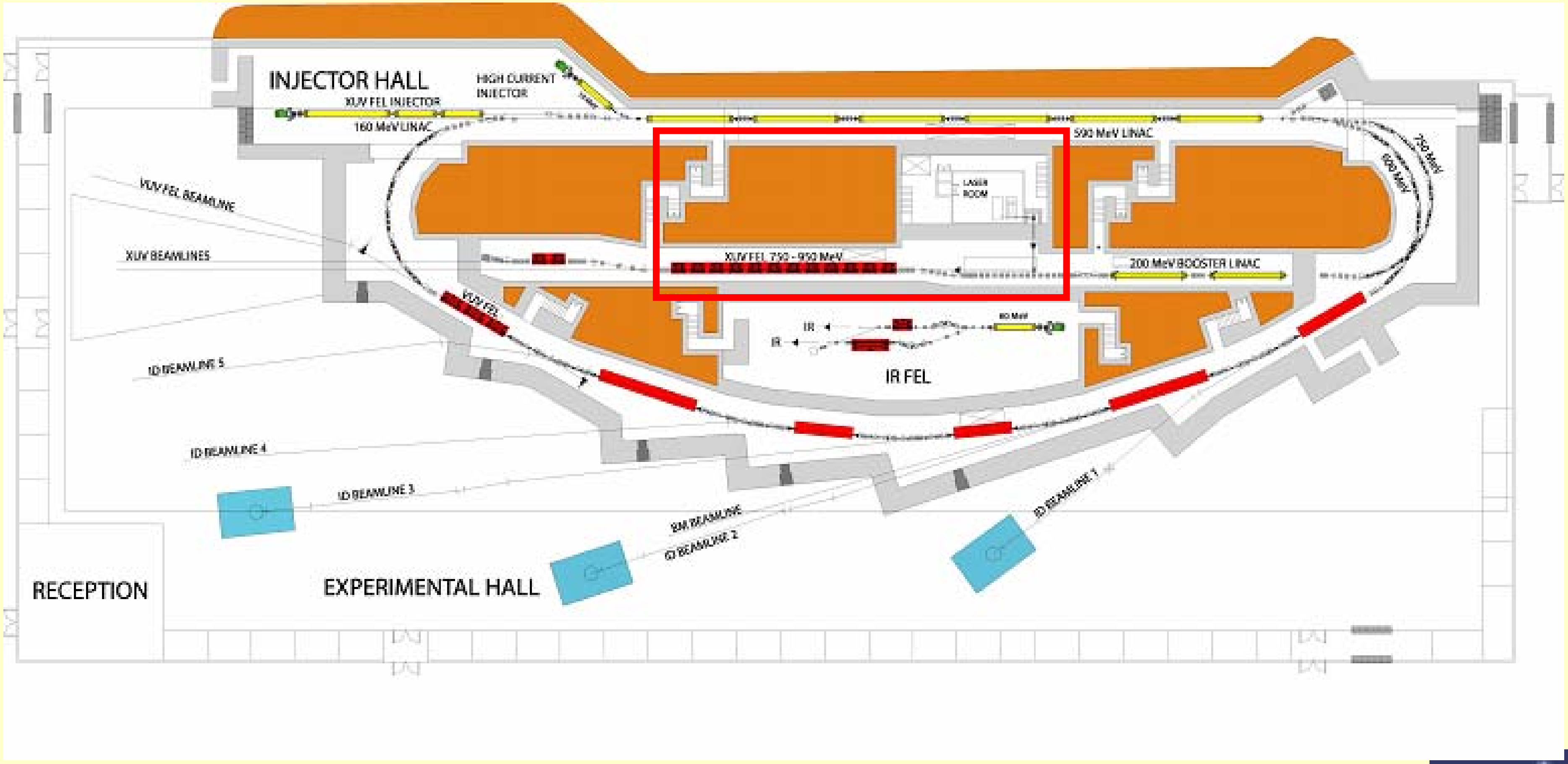
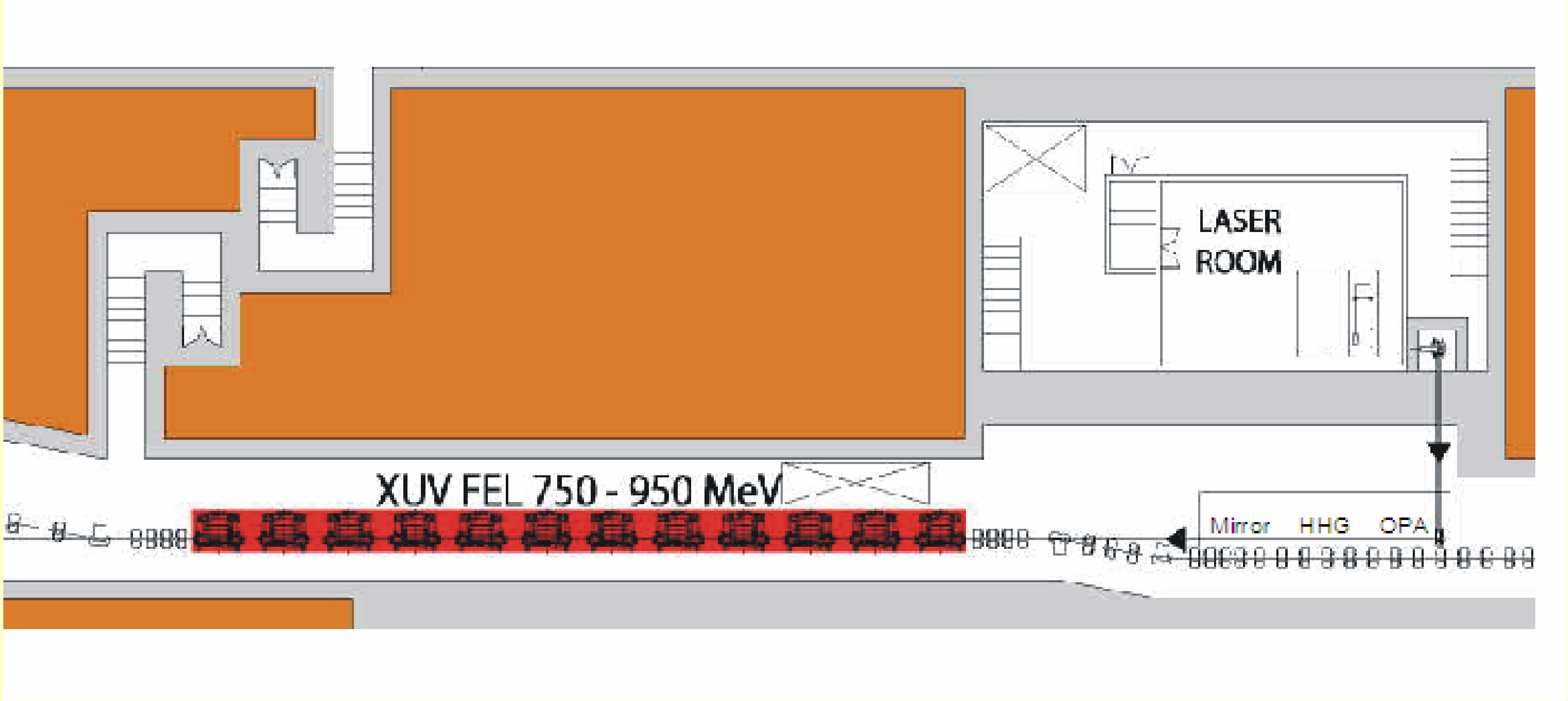



INJECTOR HALL
HIGH CURRENT INJECTOR
XUV FEL INJECTOR
160 MeV LINAC
590 MeV LINAC
750 MeV
600 MeV
LASER ROOM
VUV FEL BEAMLINE
XUV BEAMLINES
XUV FEL 750 - 950 MeV
200 MeV BOOSTER LINAC
VUV FEL
IR
IR
IR FEL
ID BEAMLINE 5
ID BEAMLINE 4
ID BEAMLINE 3
BM BEAMLINE
ID BEAMLINE 2
ID BEAMLINE 1
RECEPTION
EXPERIMENTAL HALL



- transport fundamental into enclosure
- tunable fundamental generated inside
- HHG inside
- grazing incidence optics image pulse into radiator

4GLS

Summary

HHG seeding is feasible with present day technology and parameters will improve with laser technology in the next few years

- Higher power
  - higher repetition rate
  - better contrast

- Longer wavelength
  - simpler & more robust design
  - higher energies reachable 1-2 keV (not currently in 4GLS plan but of interest to this group)