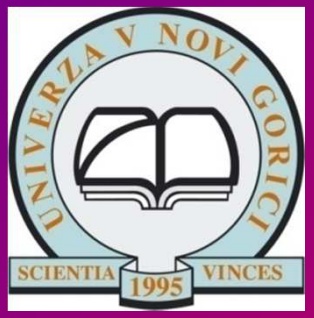


HHG tunability in the VUV-XUV spectral range aimed at FEL seeding

Benoît Mahieu

Introduction

- Seeded FELs are tunable only in a short extent
  - Amplification of harmonics of the seed
  - Frequency pulling (shift between gain bandwidth & seeded wavelength)
- Full tunability from seeded FELs can be reached through the tunability of the seed
- Seed wavelengths are not fully tunable up to now
- Seeding at low wavelengths (XUV) is accessible by the use of High-order Harmonics Generation technique (HHG)

Outline

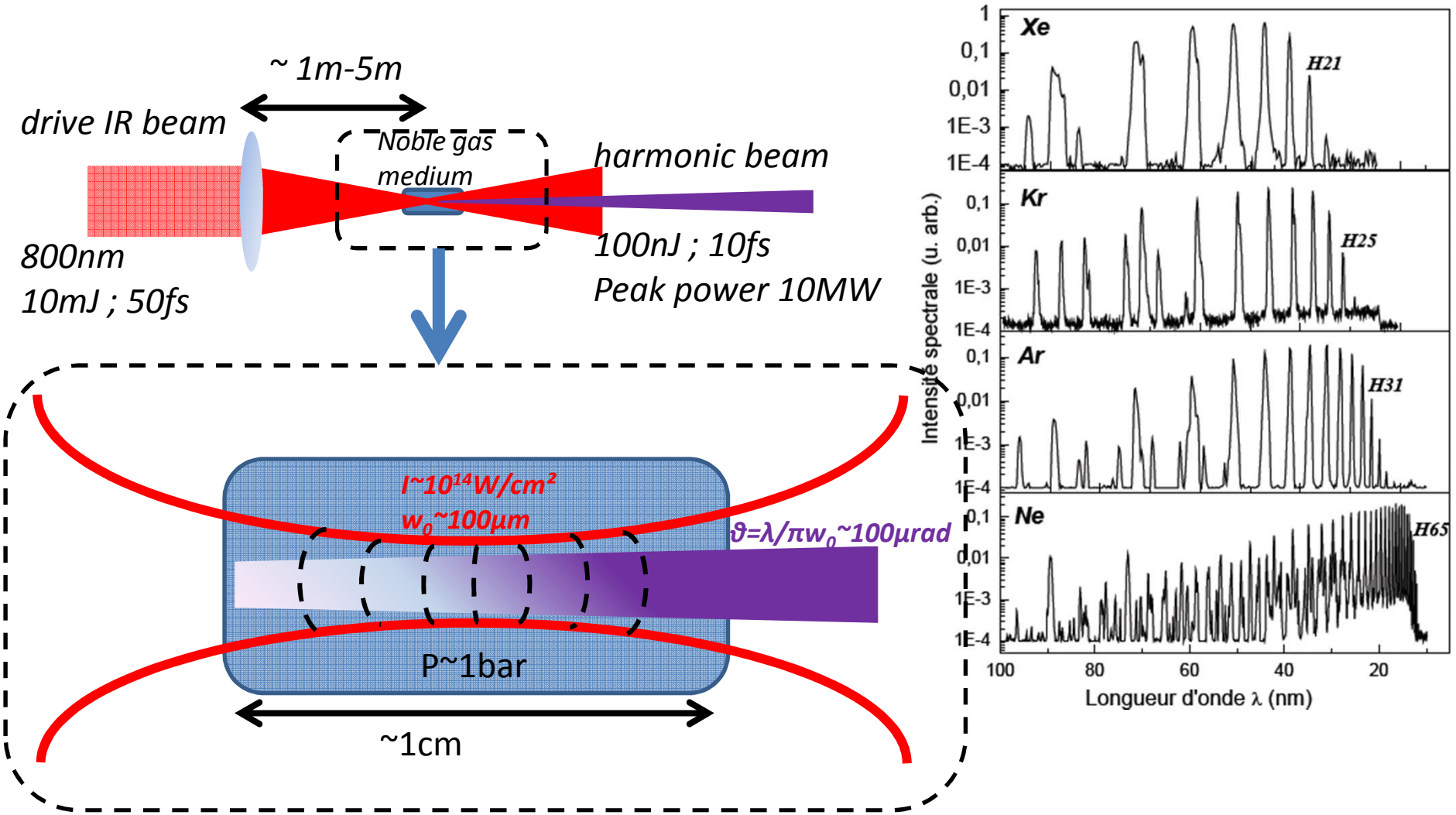
1. Recall about High-order Harmonic Generation (HHG)
   => Generation of coherent VUV/XUV femtosecond pulses

2. HHG from a source fully tunable in the near-IR spectral range
   => Full tunability of VUV/XUV beam

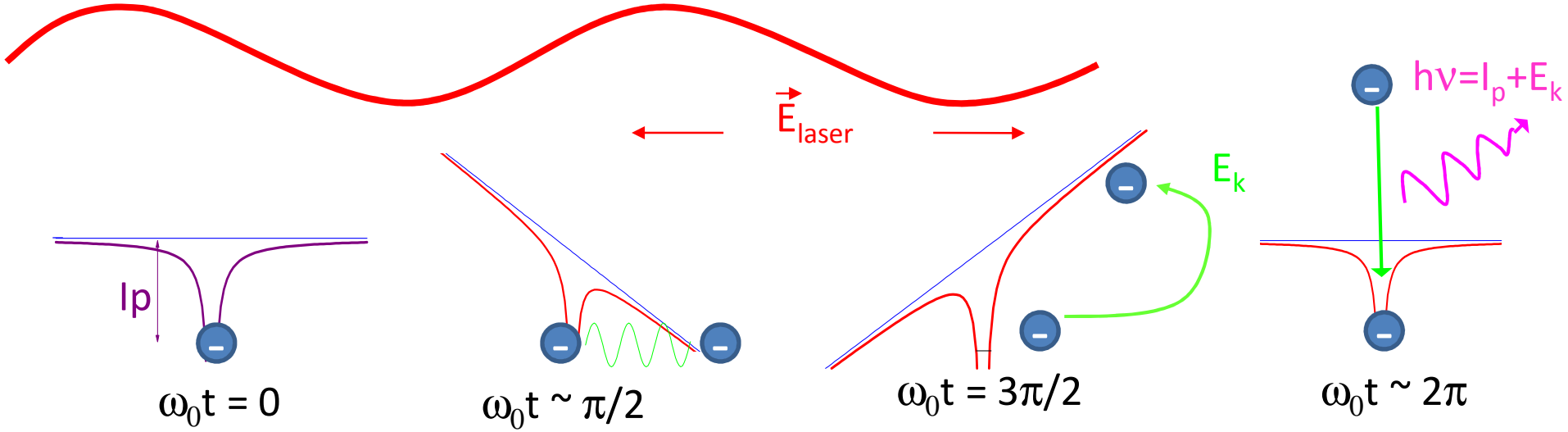
3. HHG driven by a frequency mixed source
   & prospects for full VUV/XUV tunability, at µJ level, aimed at FEL seeding

4. Seeding (UV & XUV) of FERMI@Elettra
   & status of the commissioning

High-order Harmonic Generation (HHG) in noble gases



Semi-classical model



Electron of a gas atom
Fundamental state

1 Tunnel ionization

2 Acceleration in the electric LASER field

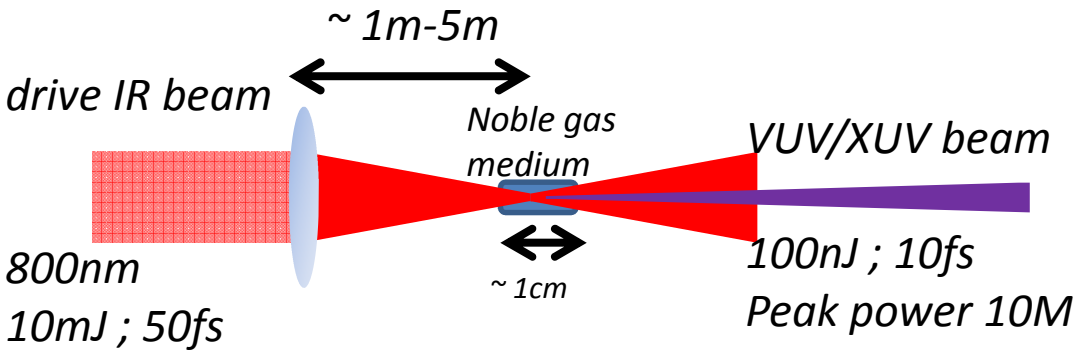
3 Recombination to fundamental state

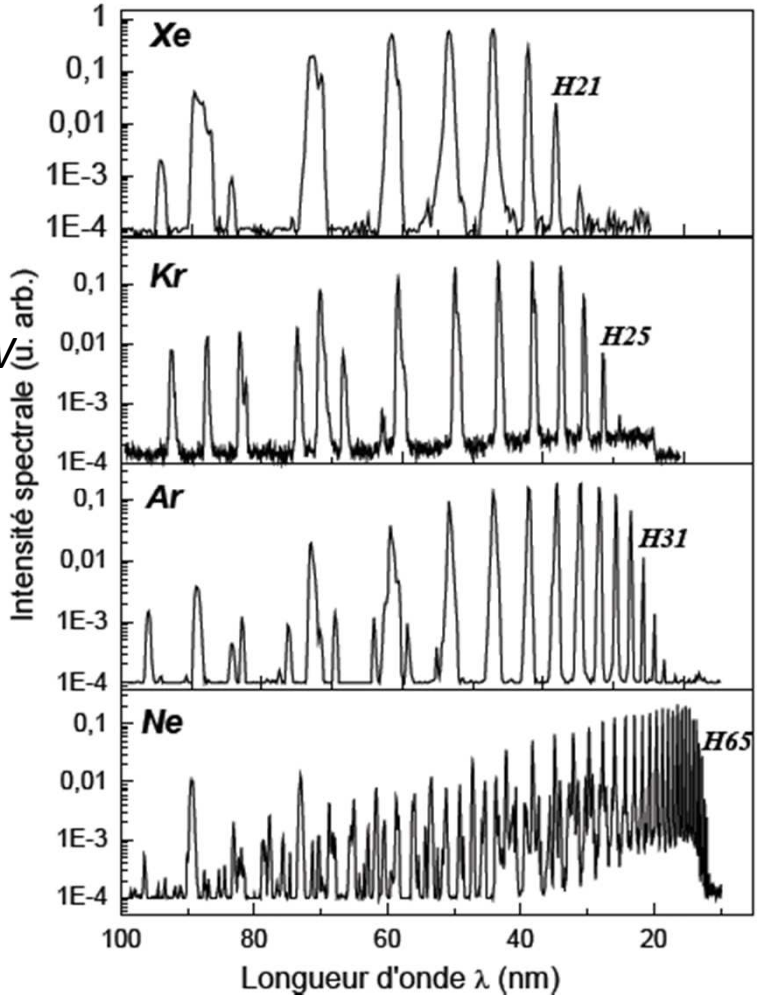
P.B. Corkum PRL 71, 1994 (1993)

K. Kulander et al. SILAP (1993)

Periodicity $T_0/2$ → harmonics are separated by 2ω in Fourier space
i.e. no even harmonics (nonlinear optics in centrosymmetric media)

Lack of HHG tunability





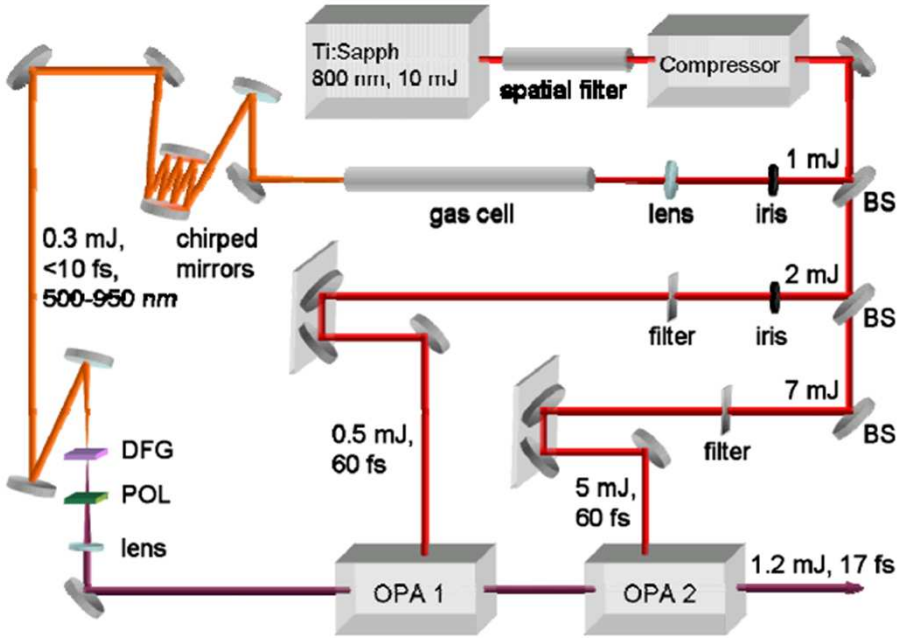
- Coherent VUV/XUV femtosecond pulses that can be used to seed a FEL
- Only odd harmonics
  => (low-order) harmonic peaks are « far away » one from the other
- Solutions: IR pulse shaper (fine adjustment), multicolour drive beam, **tunable IR source (OPA)**

HHG from a source fully tunable in the near-IR spectral range

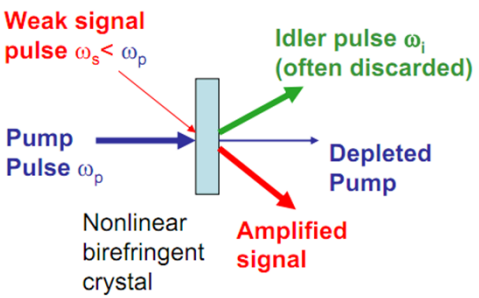
Experiments performed at Politecnico di Milano in February 2011

Femtosecond parametric source tunable in the near-IR spectral range

- Unique facility available at Politecnico di Milano [Vozzi et al. 2007]



Parametric amplification

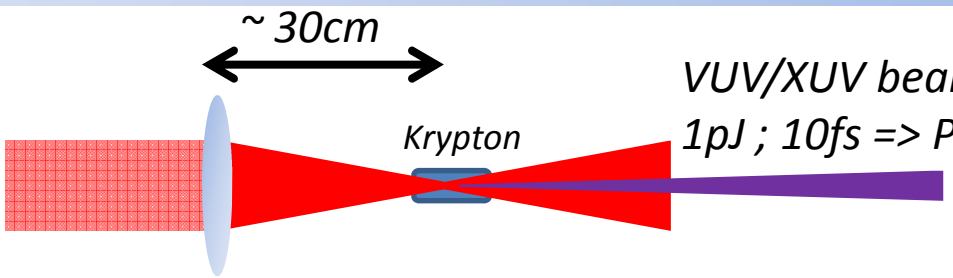


- Energy conservation
  $\hbar\omega_p = \hbar\omega_s + \hbar\omega_i$
- Momentum conservation
  $\hbar\mathbf{k}_p = \hbar\mathbf{k}_s + \hbar\mathbf{k}_i$

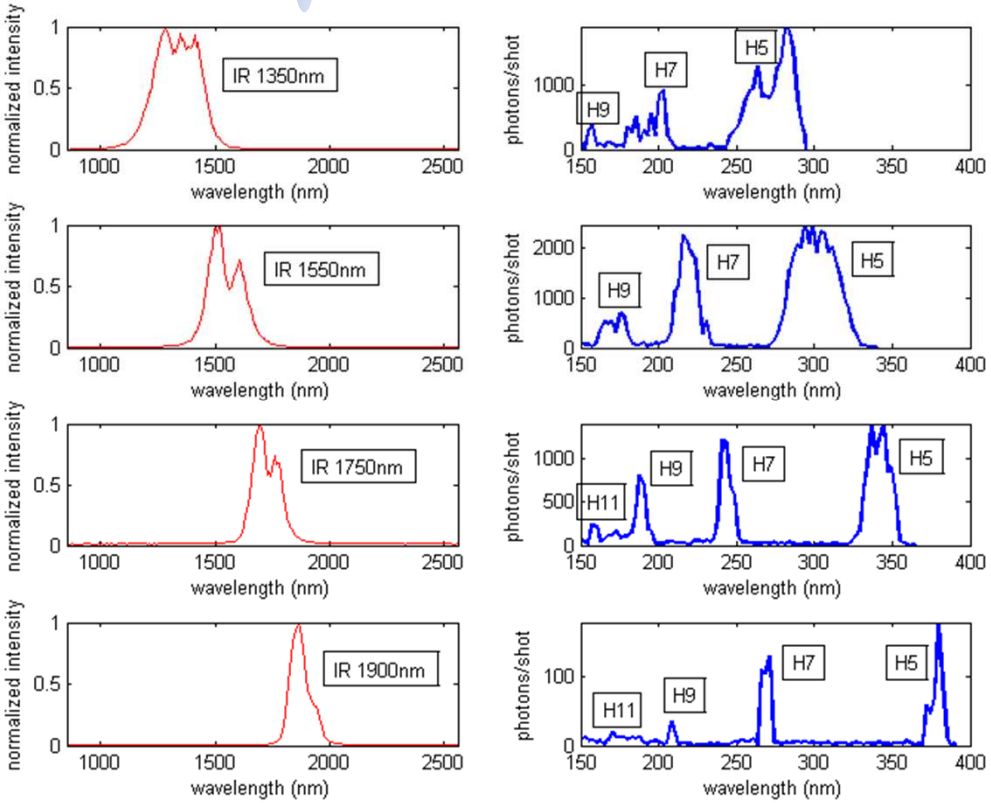
- Output beam : femtosecond pulses (1mJ), tunable from 1300nm to 1900nm used to generate tunable VUV/XUV photons through HHG

HHG driven by a tunable IR source (1/2)

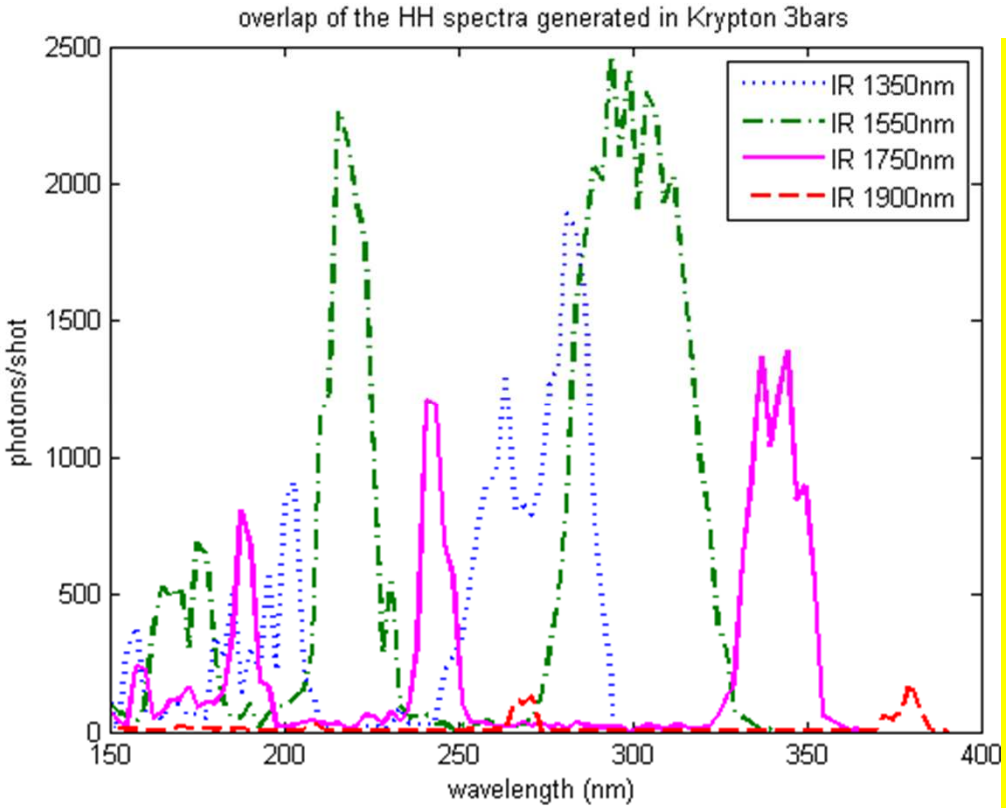
drive IR beam
1300-1900nm ; 1mJ ; 20fs



VUV/XUV beam
1pJ ; 10fs => Peak power <1kW



HHG driven by a tunable IR source (2/2)



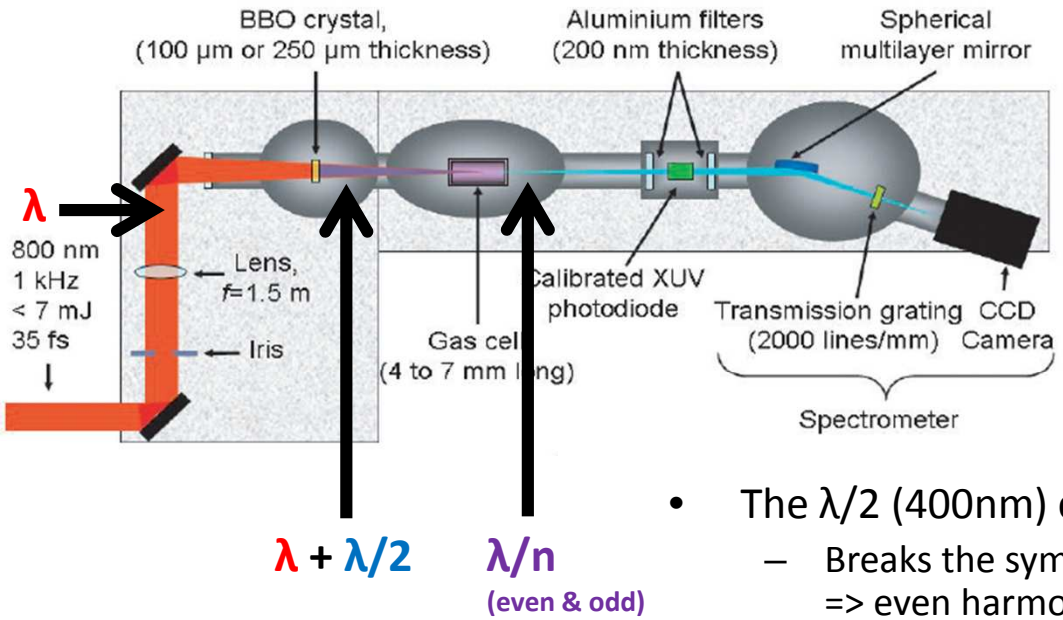
- Full tunability down to XUV
- Problem : the energy of harmonic beam is too low (for FEL seeding) because the drive wavelength is too long
- HHG Efficieny $\propto \lambda_{IR}^{-6.5}$ [Shiner 2009] 10^{-5}@800nm ; 10^{-7}@1600nm

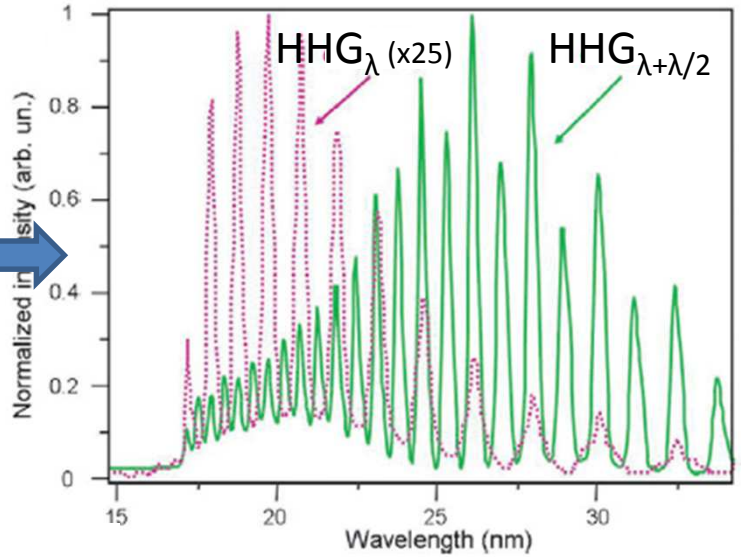
HHG driven by a frequency mixed source

& Prospects for a seed source, fully tunable in the VUV/XUV spectral range

HHG driven by a 2 colors source

[Lambert et al. 2009]

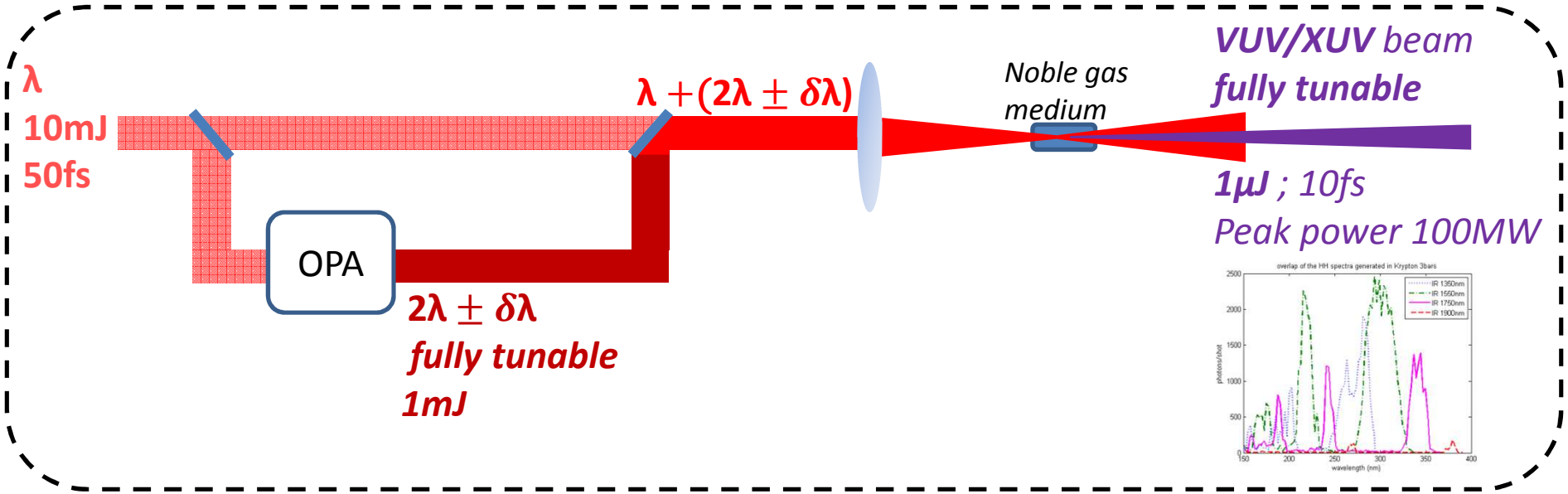




- The λ/2 (400nm) component:
  - Breaks the symmetry of the HHG
    => even harmonics are generated
  - Enhances the process
  - Redshifts the harmonics
- A small amount of energy from λ/2 is sufficient (1mJ)
- $HHG_{\lambda+\lambda/2} \neq HHG_\lambda + HHG_{\lambda/2}$
- No full tunability

Prospects for a tunable VUV/XUV source aimed at FEL seeding

- HHG driven by a mix of:
  - λ (800nm)
  - $2\lambda \pm \delta\lambda$ (1300nm-1900nm fully tunable parametric source)



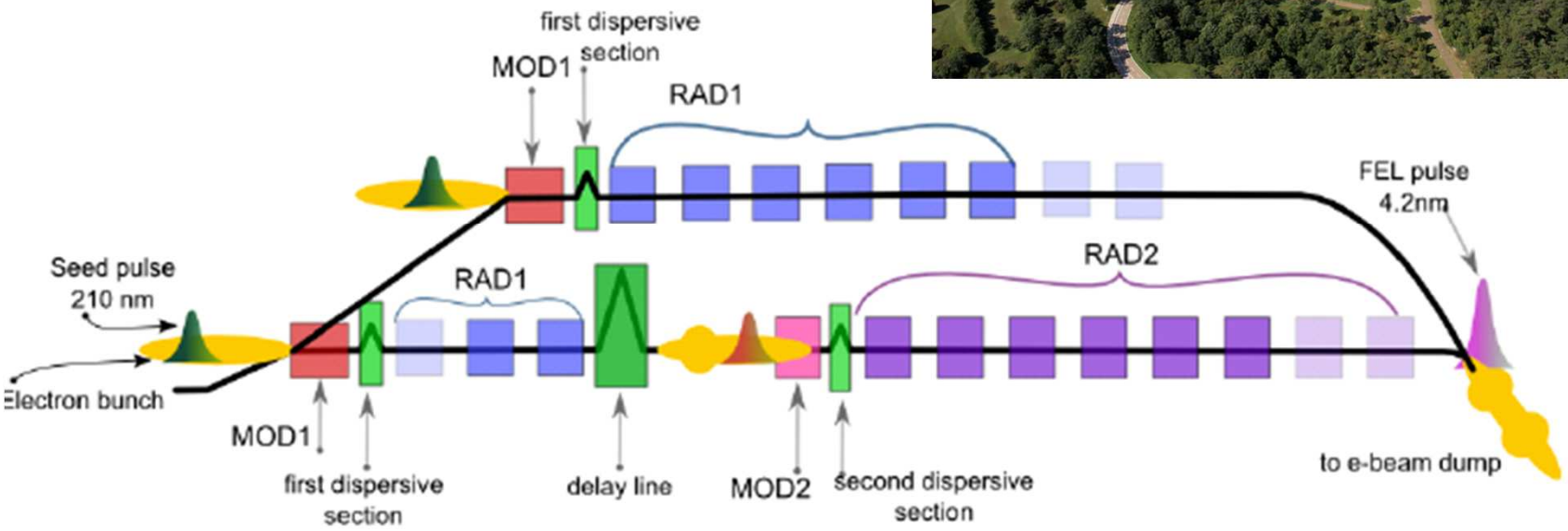
- Tunability of OPA + Efficiency enhanced by the frequency mixing
- Could be soon tested at CEA Saclay

Seeding of FERMI@Elettra & status of the commissioning

FERMI@Elettra layout

- Both SASE & Seeded mode
- FEL1: down to 20nm, **experiment of HHG seeding**
- FEL2: down to 3nm, cascade
- 10^{13}photons/pulse

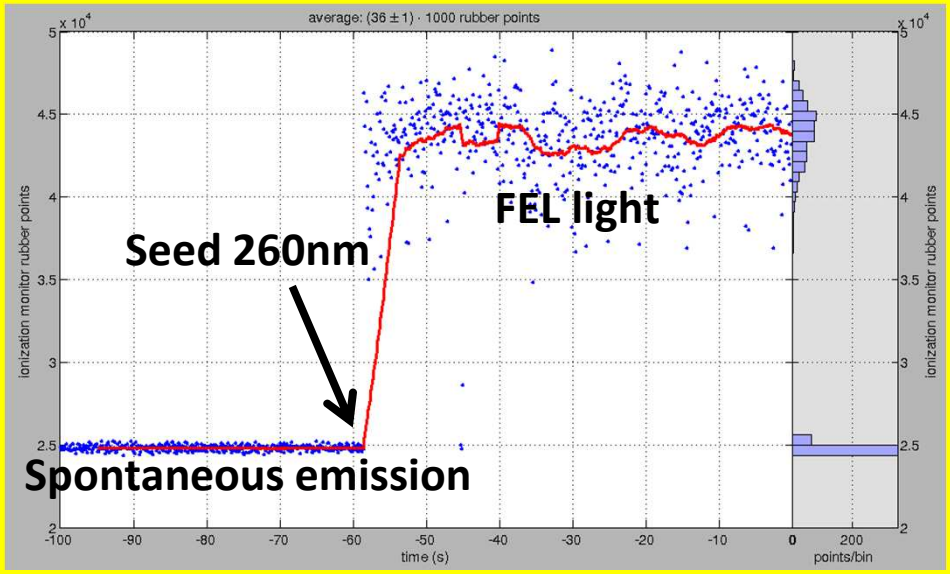
=> ***Can we get similar performances for FEL2 and FEL1 seeded with HHG?***



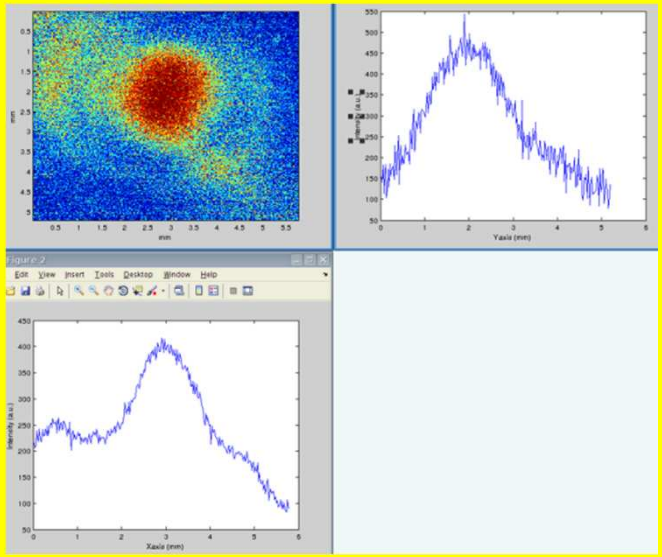
Status of the commissioning

- Start of commissioning of the machine in 2009
- First FEL light in december 2010
- Beam is already sent to users
- Last results, to be improved:
  10^{11} photons/pulse, beam stability

@43nm:

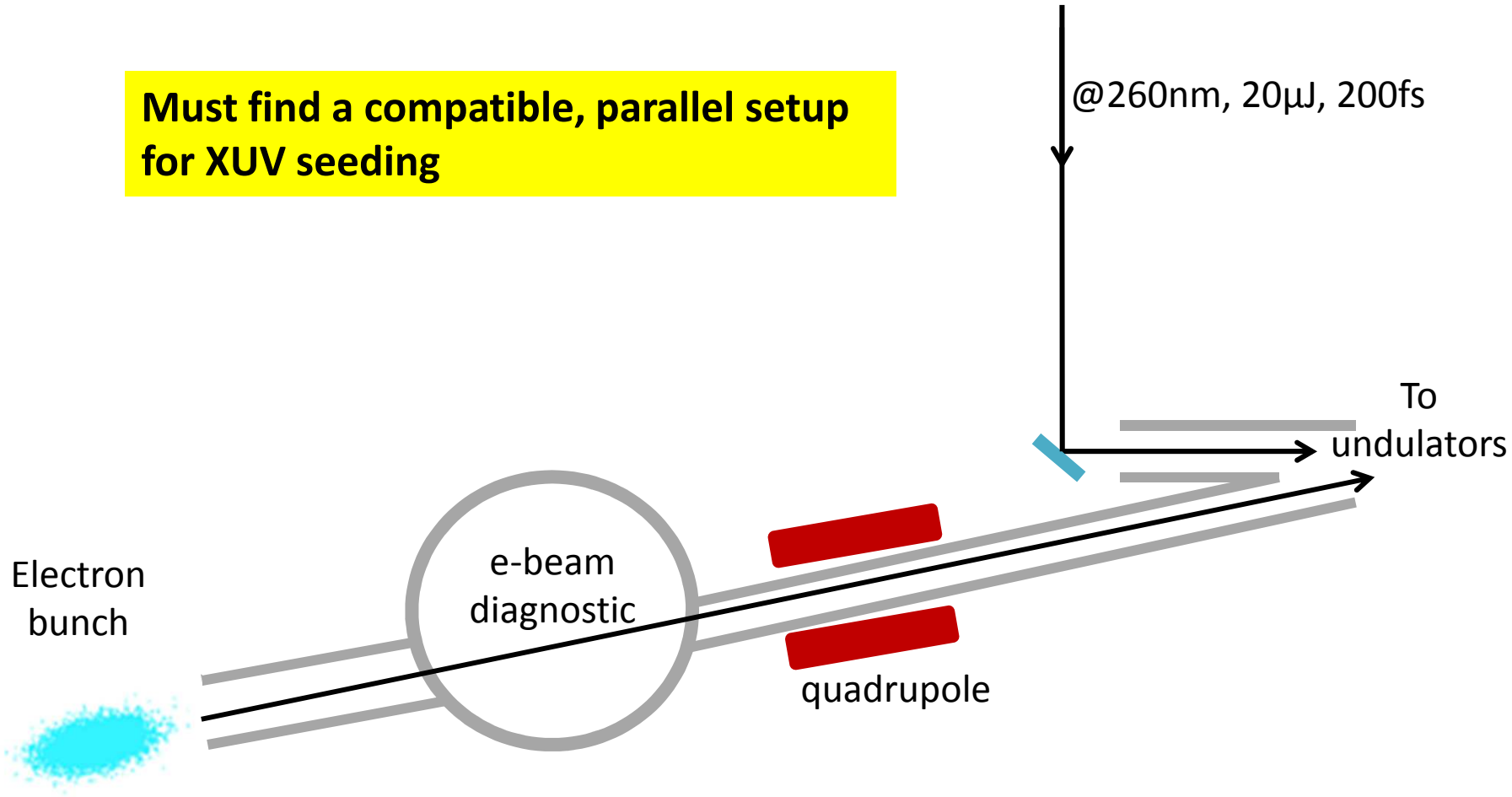


Transverse profiles

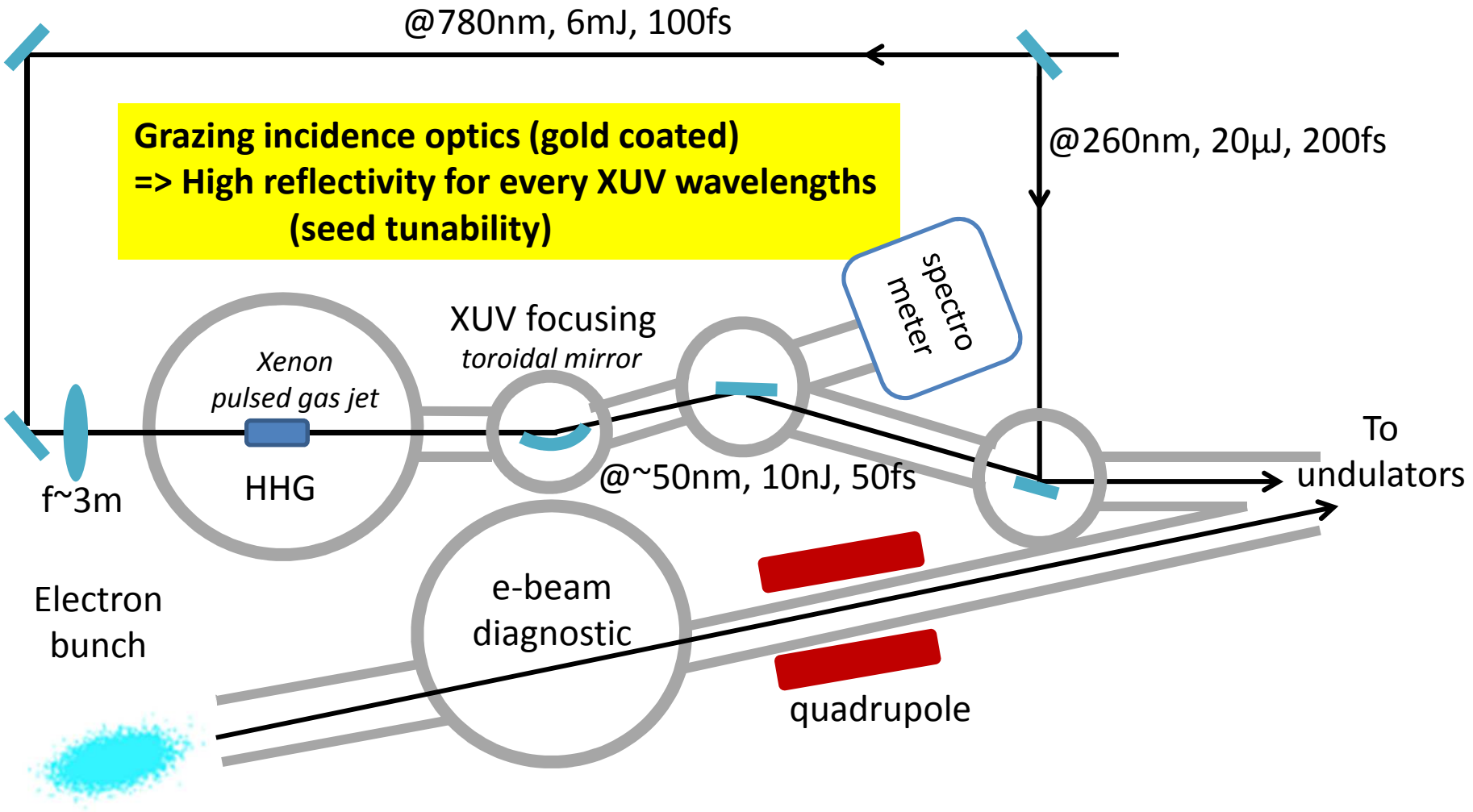


« Standard » UV seeding of FERMI@Elettra (current setup)

Must find a compatible, parallel setup for XUV seeding



HHG seeding experiment to be designed & implemented



Conclusion

- Tunability of the FEL can be reached through the tunability of the seed.
- HHG driven by an IR parametric amplifier (tunable femtosecond source) provides VUV/XUV tunability.
- The lack of energy can be overcome by mixing this source with a classical 800nm drive laser.
- The new FERMI@Elettra facility already gives light to users, and FEL experiments will start when standard parameters will be found.
- XUV seeding of FERMI@Elettra will soon be implemented then tested from beginning of 2012.

Acknowledgements

- Politecnico di Milano: Salvatore Stagira, Matteo Negro, Caterina Vozzi
- LUXOR Padova: Luca Poletto, Stefano Coraggia, Fabio Frassetto
- Sincrotrone Trieste: Marcello Coreno, Giovanni de Ninno… and all FERMI@Elettra team
- CEA Saclay: David Garzella, Willem Boutu, Hamed Merdji
- Laboratoire d'Optique Appliquée Palaiseau: Guillaume Lambert