# LPA electron beam transport experiment

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On behalf the COXINEL team

ESLS 2017 Workshop
21-22 November
Dortmund

# OUTLINE

- LPA beam properties

- Beam transfer line

- Experiment

- Conclusion

# COXINEL

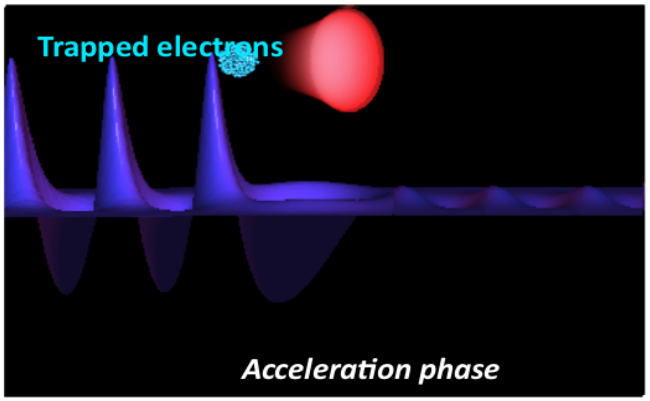
COXINEL : COherent X-ray source INferred from Electrons accelerated by Laser

Grant : ERC COXINEL (340015, PI: M.-E. Couprie)

Goal : First observation of an FEL amplification with laser plasma wakefield electron source

Setup : Installation of a dedicated transfer line with an undulator at the LOA Laboratory « «salle jaune » where LPA experiments are in operation (Victor Malka team)
2 x 40 TW laser

# LPA BEAMS




*T. Tajima and J. M. Dawson,*
*Phys. Rev. Lett. 43, 267 (1979).*

Main present characteristics :

Few hundreds MeV to 1 GeV energy

Few kA to 10 kA peak current

Short bunches ~ fs level

Large energy spread ~ percent level

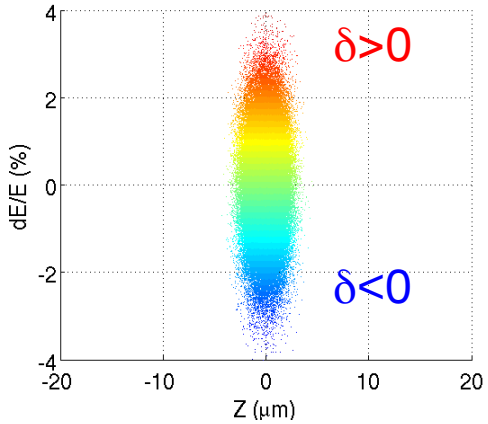
Large initial divergence ~ mrad level

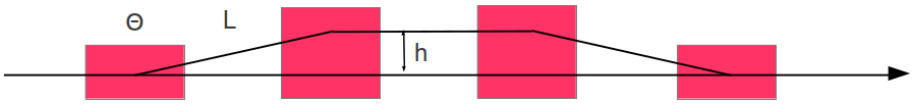
} They complicate the transfer and FEL

# BEAM DECOMPRESSION

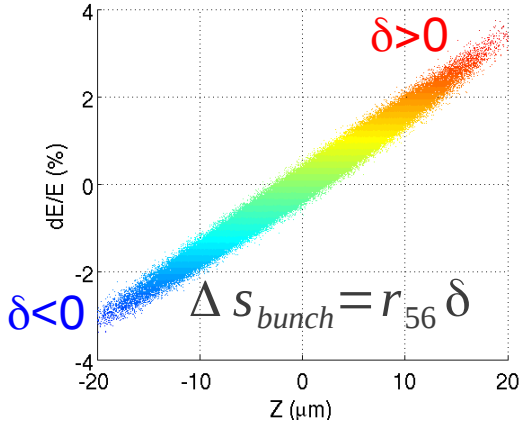
*A. R. Maier et al., PRX 2012*

Decompress the bunch to cope with the large energy spread

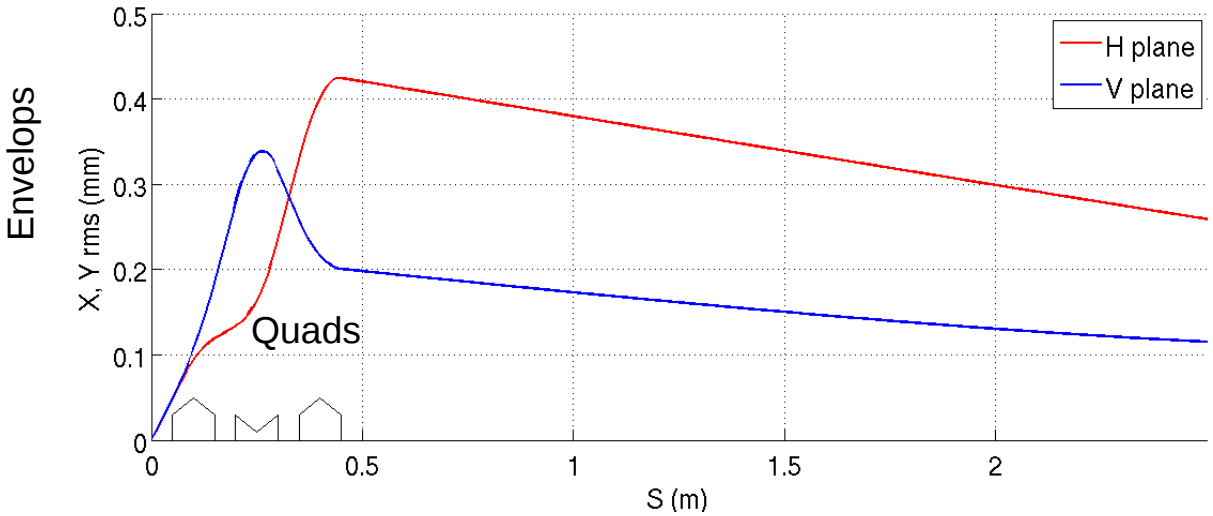


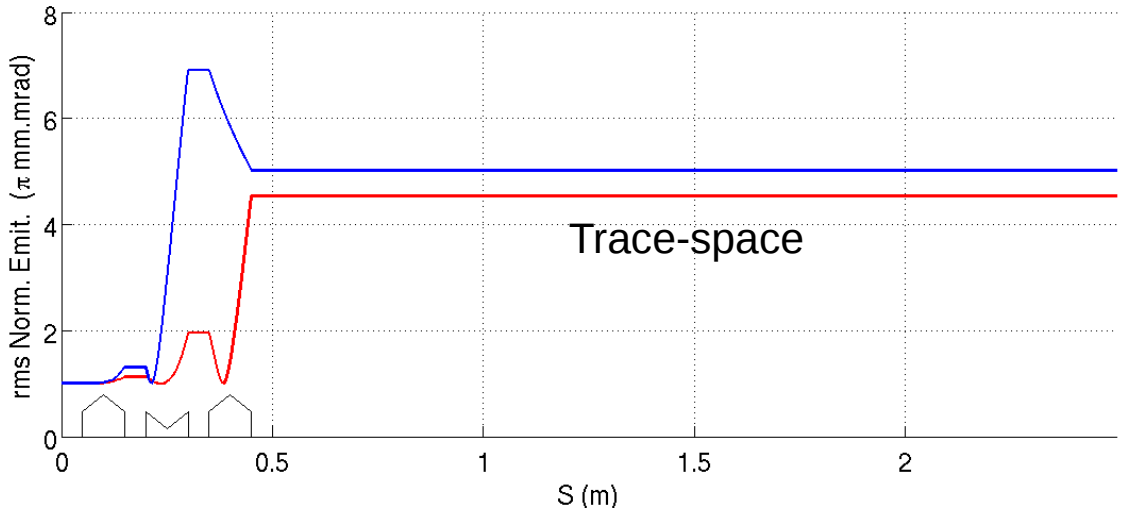




Decompression
or
slice energy de-mixing



# Chromatic emittance

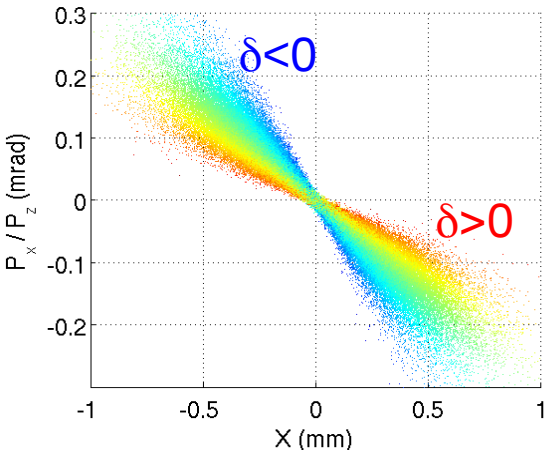



The large diverging beam needs to be refocused by means of compact and strong quadrupoles

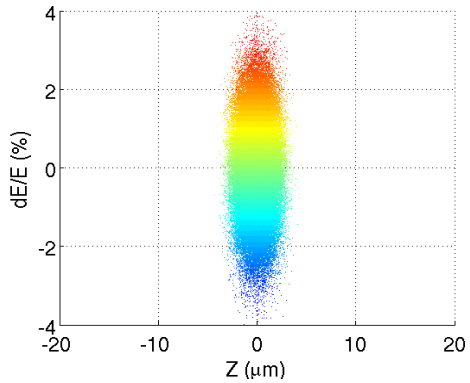
$$\gamma\,\epsilon_{chrom} \sim \gamma\,\sigma_x^2, \sigma_\delta$$

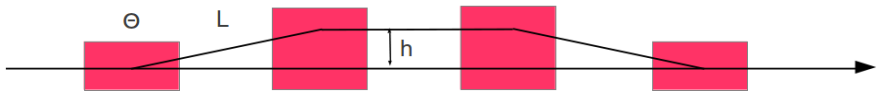
*K. Floettmann, PRSTAB 2003*
*P. Antici et al., JAP 2012*
*M. Migliotari et al., PRSTAB 2013*



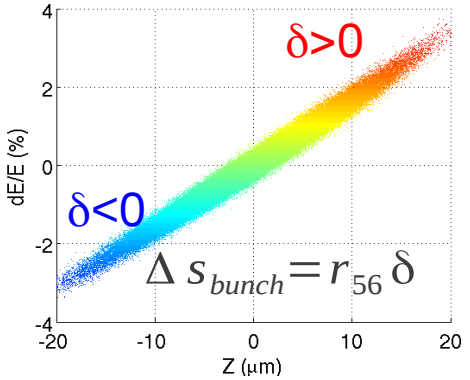
# Chromatic matching

## Longitudinal phase space



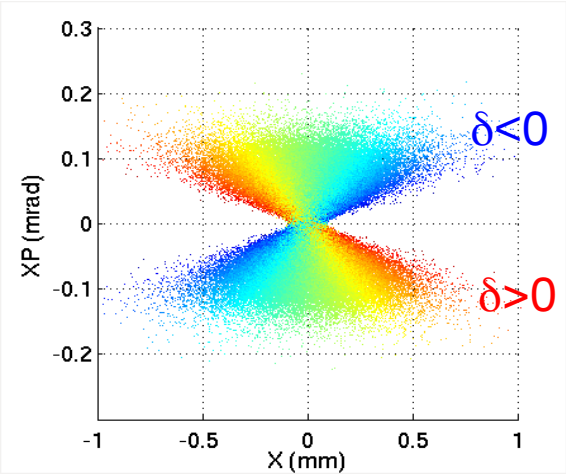

Energy de-mixing Chicane



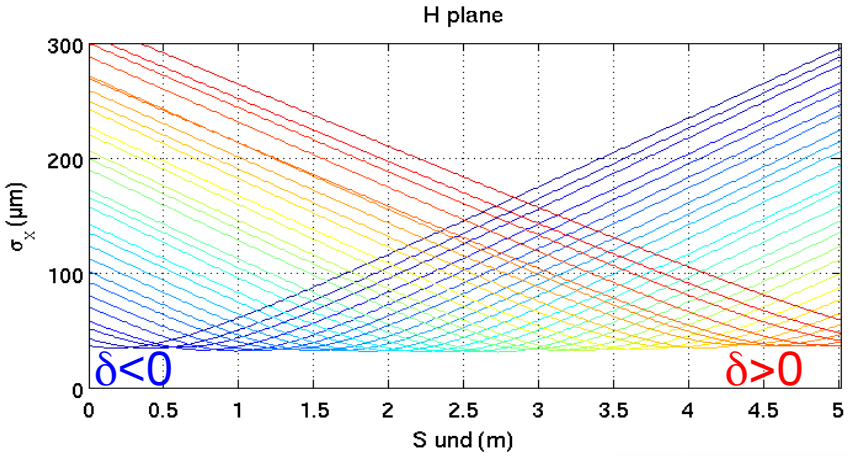

$$\Delta s_{bunch} = r_{56}\,\delta$$

## Transverse phase spaces

(In both H & V planes)




Chromatic matching



# Chromatic matching

Channel of quadrupoles from source to undulator centre

Linear Chromatic

$$\begin{pmatrix} x \\ x' \end{pmatrix} = \left[ \begin{pmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{pmatrix} + \delta \begin{pmatrix} r_{116} & r_{126} \\ r_{216} & r_{226} \end{pmatrix} \right] \begin{pmatrix} x_0 \\ x'_0 = \dfrac{p_{x0}}{p_{z0}} \end{pmatrix}$$

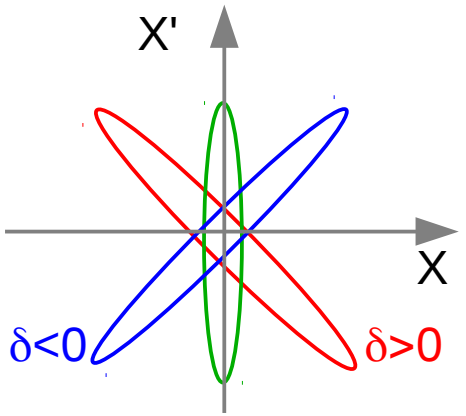
$r_{12} = 0$

Source to Image

$r_{226} = 0$

For large divergence
No initial correlation

TRANSPORT code notation 2nd order



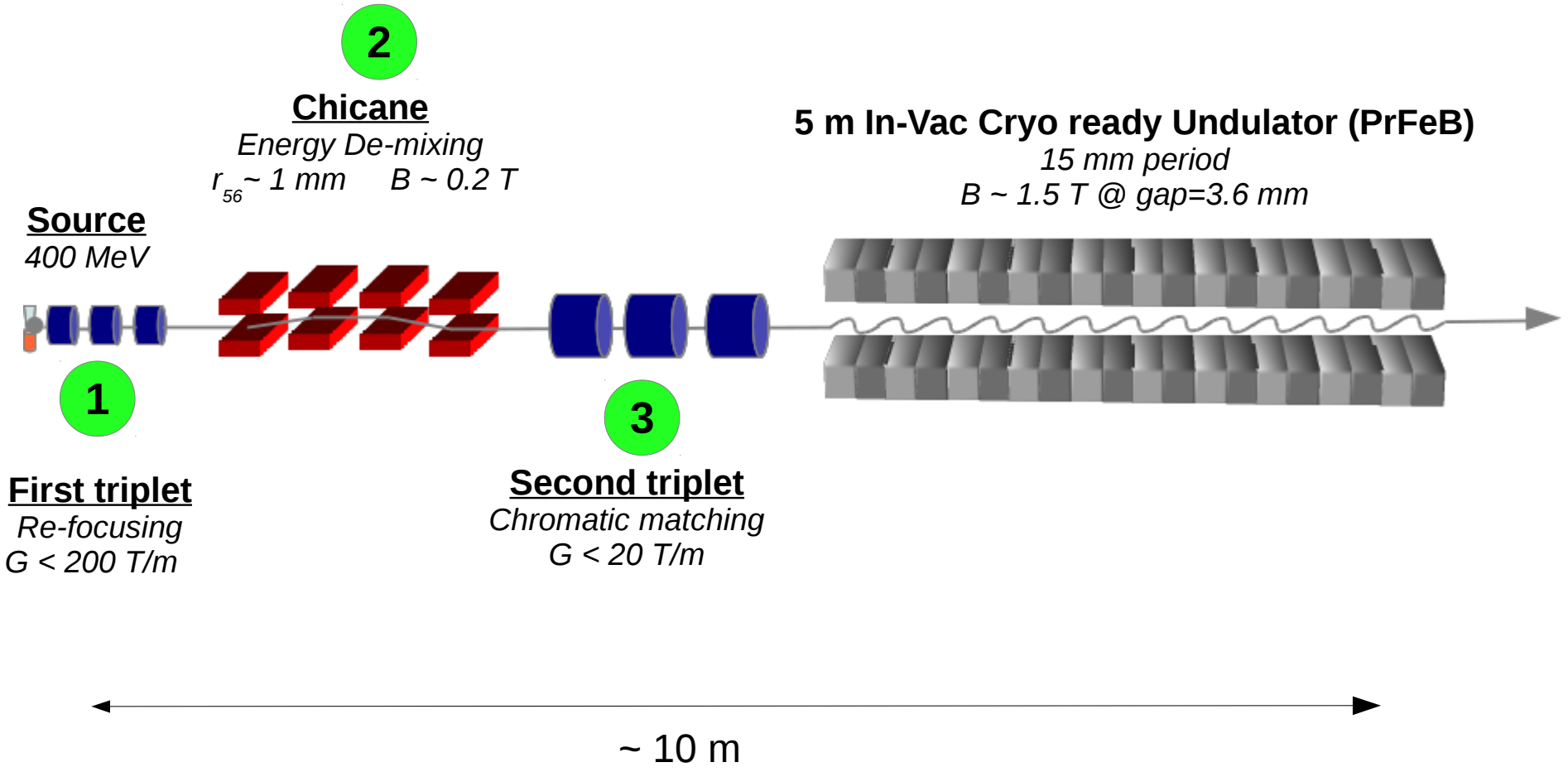

Just quadrupole settings
Independent from the initial beam

Works in both planes …

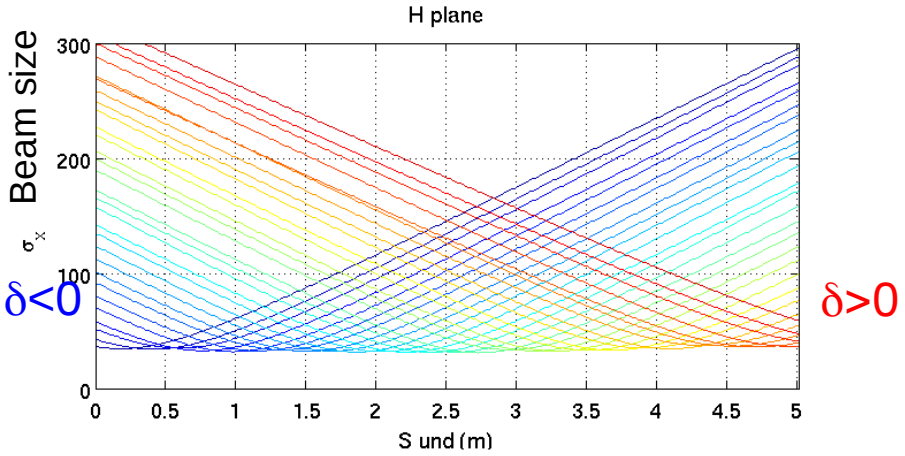
$$\gamma \epsilon_{chrom} = \gamma \frac{r_{126}}{r_{11}} \sigma_{x'}^2 \sigma_\delta$$

# Chromatic matching

An second triplet of quadrupole (at least) is mandatory to operate the chromatic tuning



# Chromatic matching



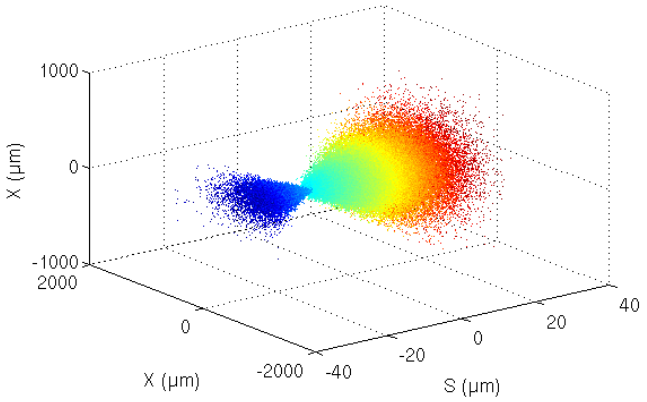

δ<0 δ>0

<= undulator =>

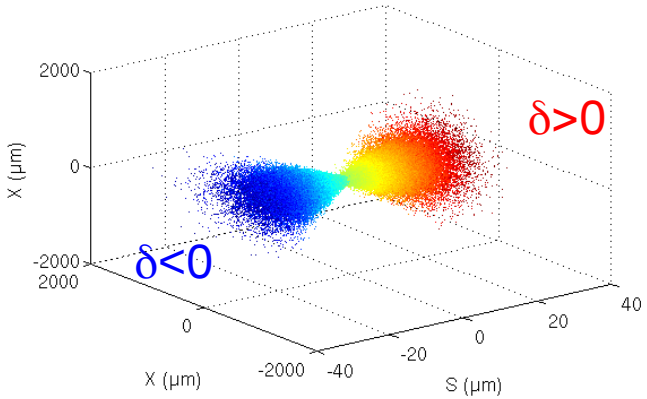
View of the slipping focusing
from the tail toward the head

**Bunch 3D view ...**

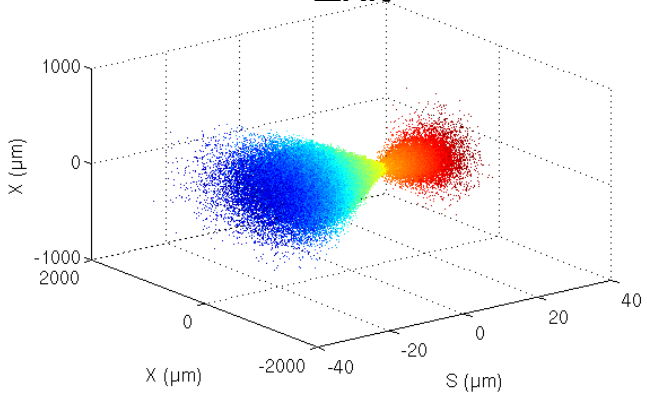
Undulator entrance




Centre




Exit




==> The chromatic matching provides a high electron density + a constant transverse size

# Chromatic matching

*A. Loulergue et al., NJP 2015*

Synchronization slippage : Electron slice waist = Photon FEL wave

Fix the chicane strength : $r_{56} = -\frac{1}{3} r_{11} r_{126} \frac{\lambda_{photon}}{\lambda_{undulator}} = -\frac{1}{3} r_{11}^2 c_{11} \frac{\lambda_{photon}}{\lambda_{undulator}}$ } Naturally positive

Up to second order, with large divergence, this relation is independent from the electron source :

==> Not sensitive to initial divergence, energy spread, pointing ...

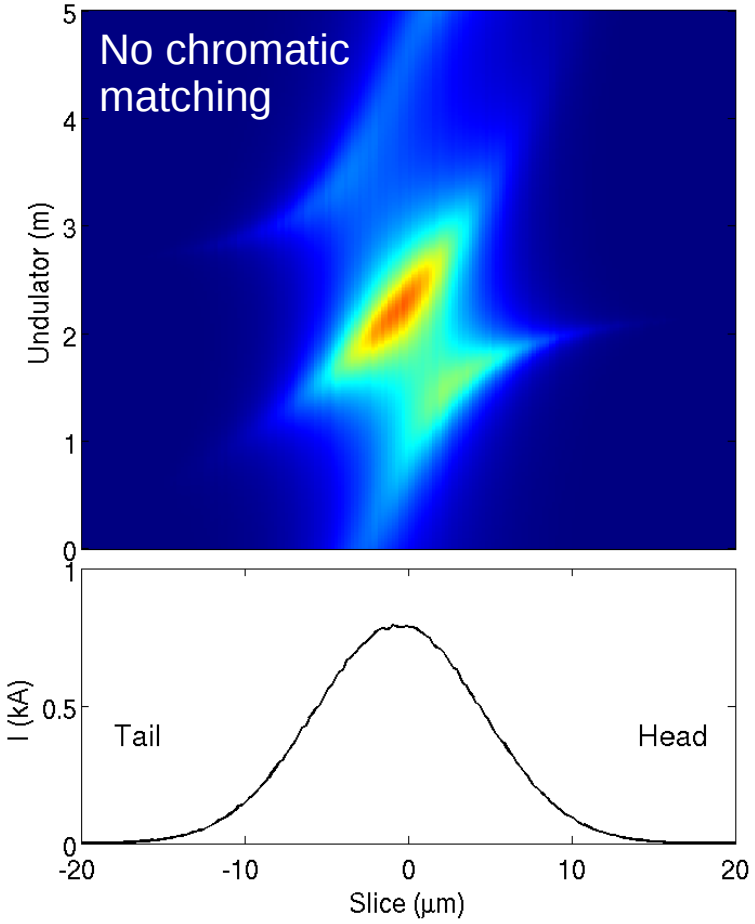
The chicane has a weak effect on the transverse focusing (1st and higher order)

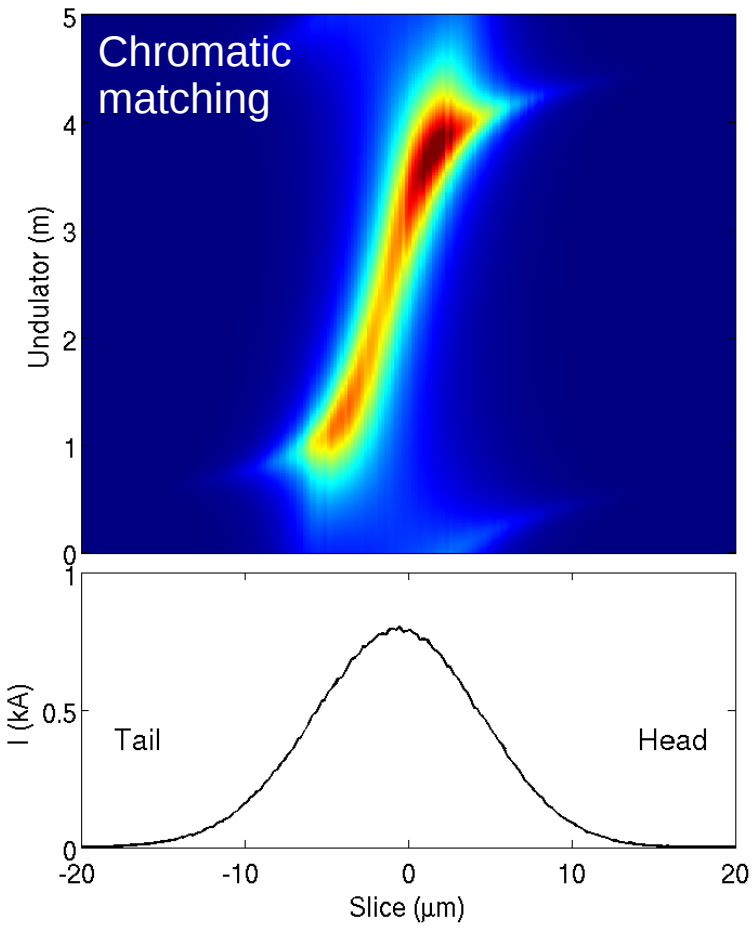
==> ~ Act only on the longitudinal plane

In practice : Set the quadrupoles and scan the chicane strength $r_{56}$

# Chromatic matching

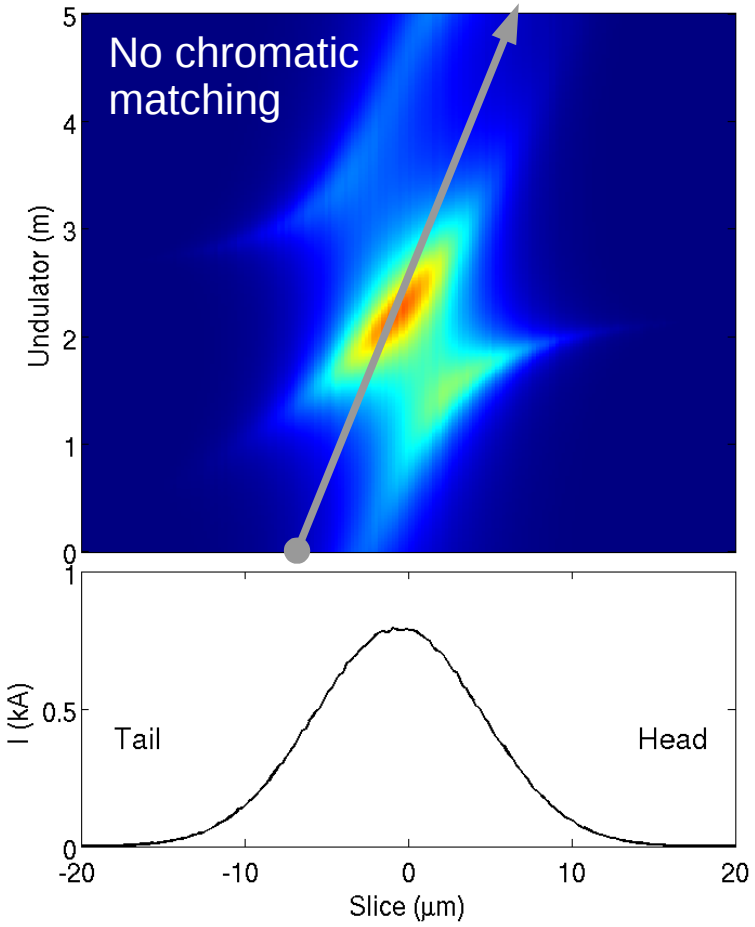
Electron transverse density pattern $\frac{I_{slice}}{\sigma_x \sigma_z}$ along the undulator (A/mm$^2$)

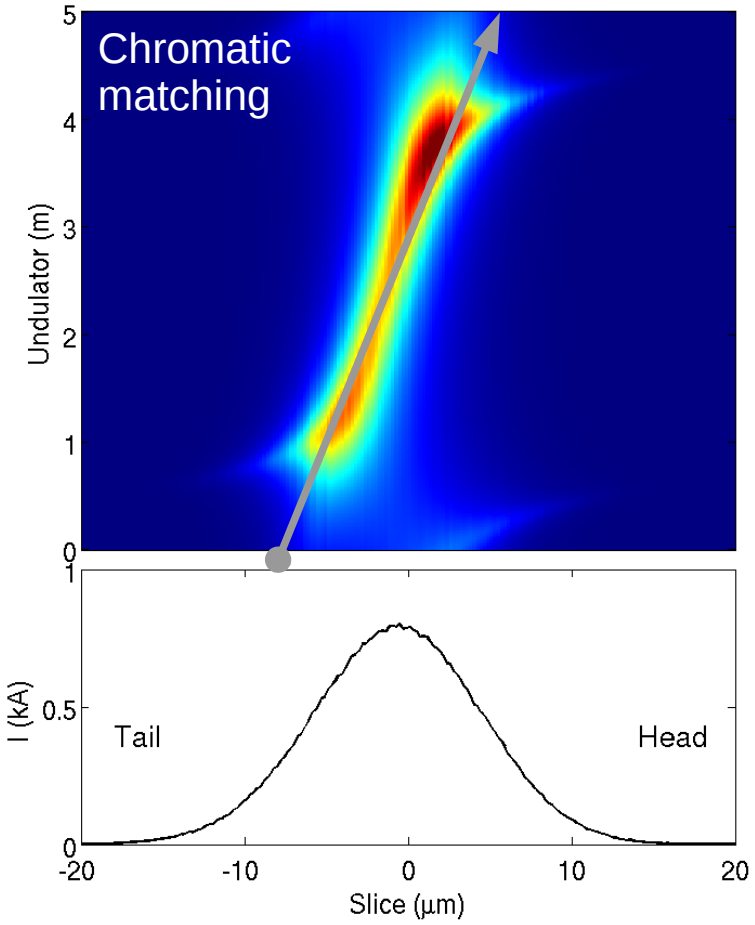


# Chromatic matching

Electron density pattern $\frac{I_{slice}}{\sigma_x \sigma_z}$ along the undulator (A/mm$^2$)

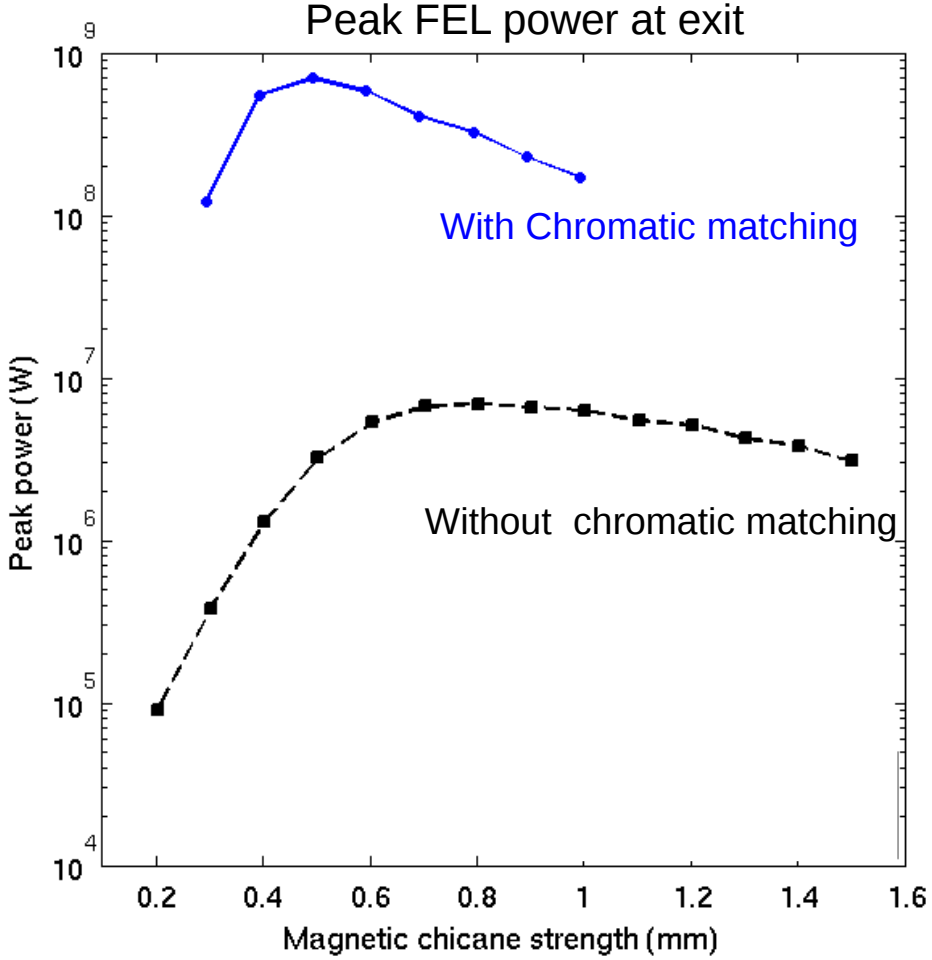


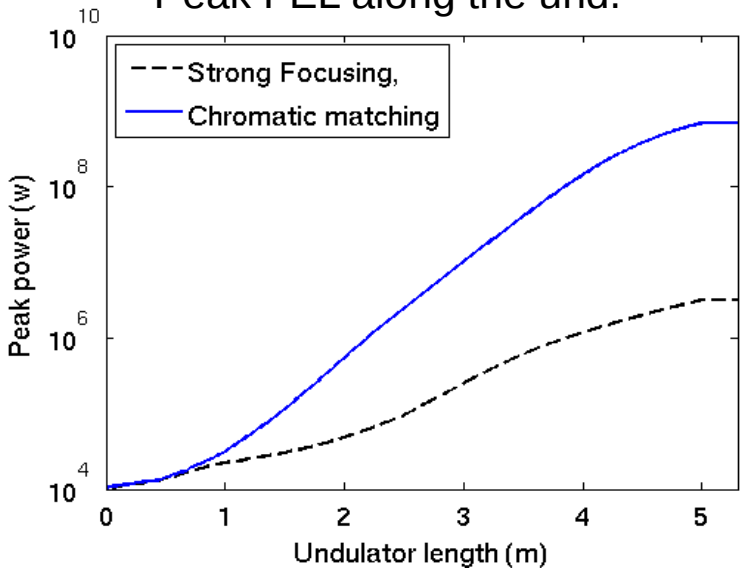
# Chromatic matching

400 MeV – 10 kW SEED at 40 nm over 5 m

Peak FEL power at exit




Peak FEL along the und.




GENESIS code
*S. Reiche, NIM 1999*

Linear Field Tapering
*N. M. Kroll et al., PQE, 1980*
*L. Giannessi et al., PRL 2011*

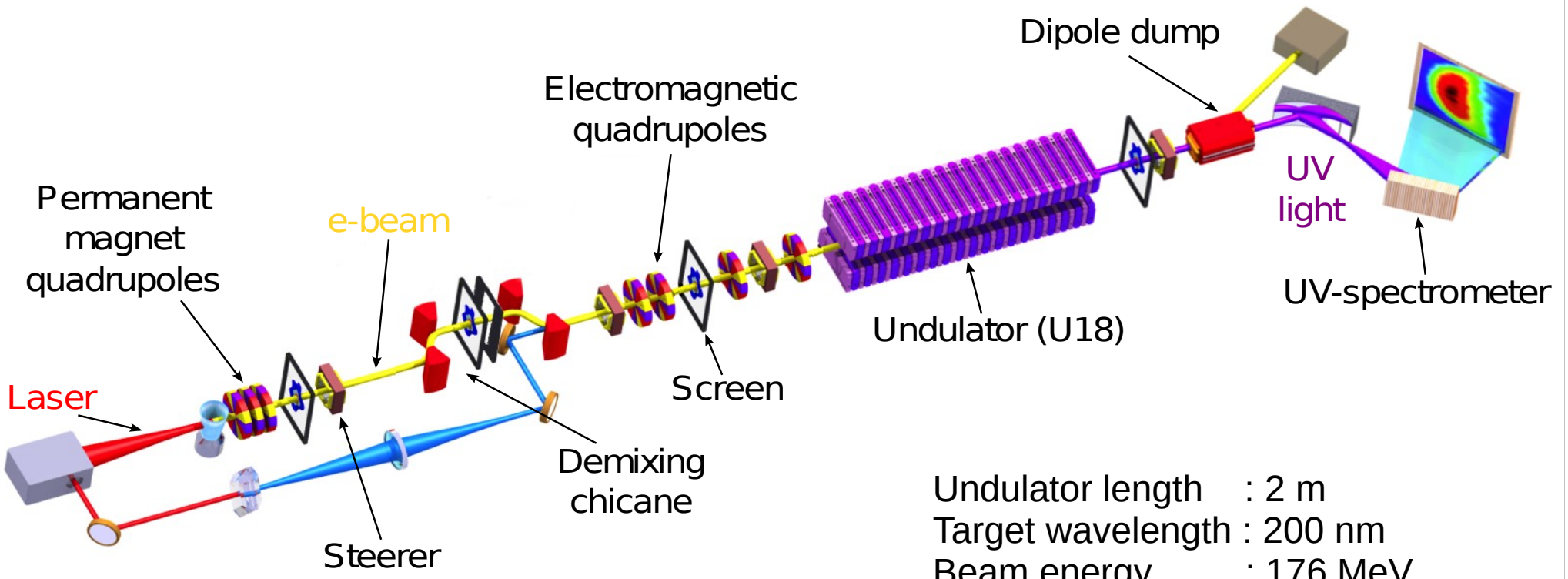
Seeded with 10 kW at 40 nm

==> The chromatic matching provides a significant increase of FEL peak power

# Experiment

**COXINEL**

Salle jaune, LOA

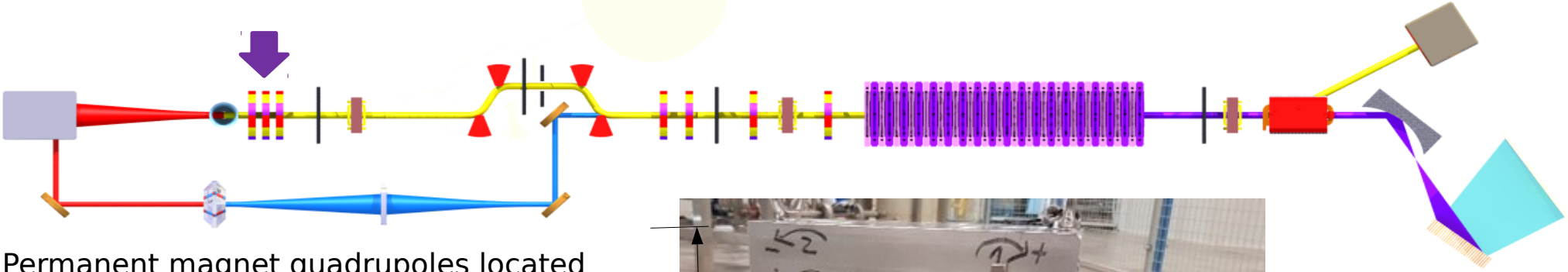



Undulator length : 2 m
Target wavelength : 200 nm
Beam energy : 176 MeV

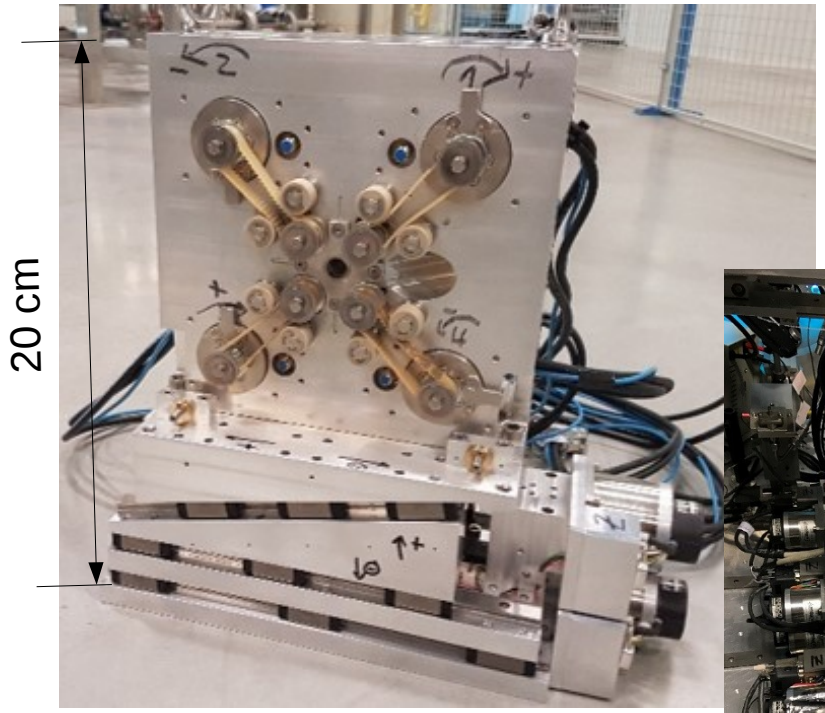
# Experiment

Salle jaune, LOA

# PMQ : Quapeva



- Permanent magnet quadrupoles located at 50 mm from the beam source
- Variable gradient (100 to 200 T/m)
  Rotating magnet
- Harmonic few % at pole tip
- Refocus the highly diverging beam from the source
- Hor. & Vert. motorized translation to fine alignment tuning
  => Mandatory to control the beam




Accepted to Applied Physic Letter

# Conclusion

First photons observed
Incoherent emission from the undulator at 200 nm

On axis X-ray camera
with 200 nm optical filter

We ~mastered the beam transfer through 7 quadrupoles and one low gap undulator

Exp. Ongoing :

Use a slit in the chicane together with a dedicated optics
for a good energy selection ~ few % fwhm

Measurement of undulator spectral emission

Thank you for your attention ...

Acknowledgements support of the Agence Nationale pour la Recherche (DYNACO), Triangle de la physique and support of the European Research Council for COXINEL (340015) and X-Five (339128) advanced grants.