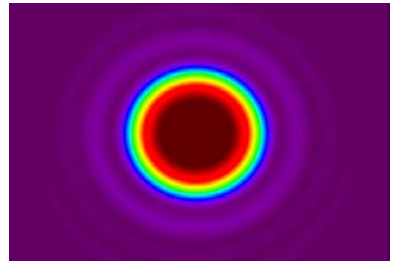


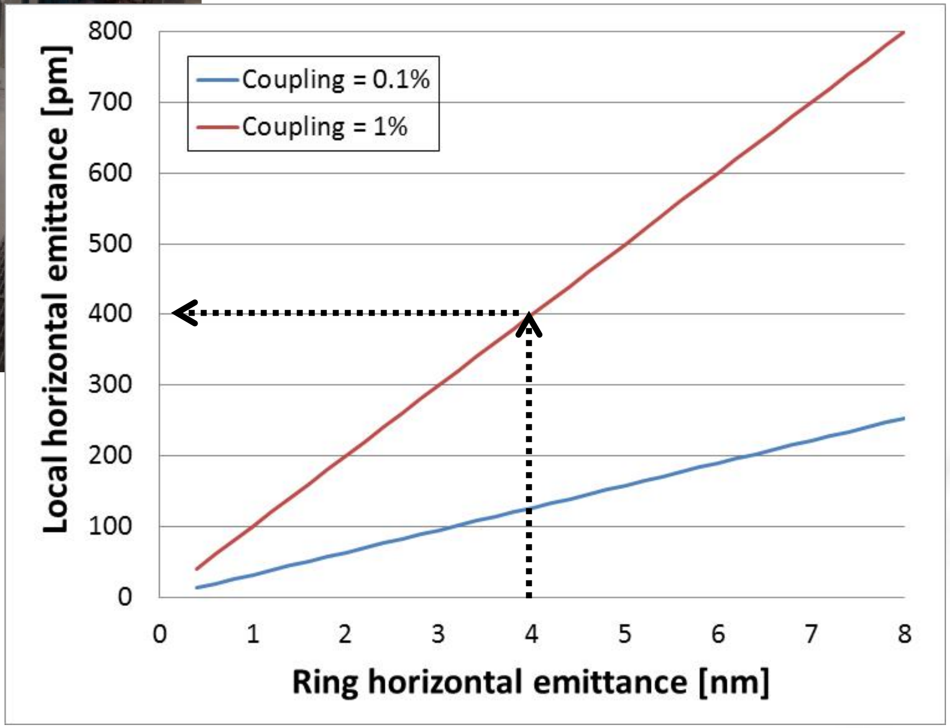
Application of the Emittance Adapter to SOLEIL and MAX IV

Pascale Brunelle
on behalf of the Round Beam Project Team

Round Beam Workshop, SOLEIL, June 14th - 15th, 2017

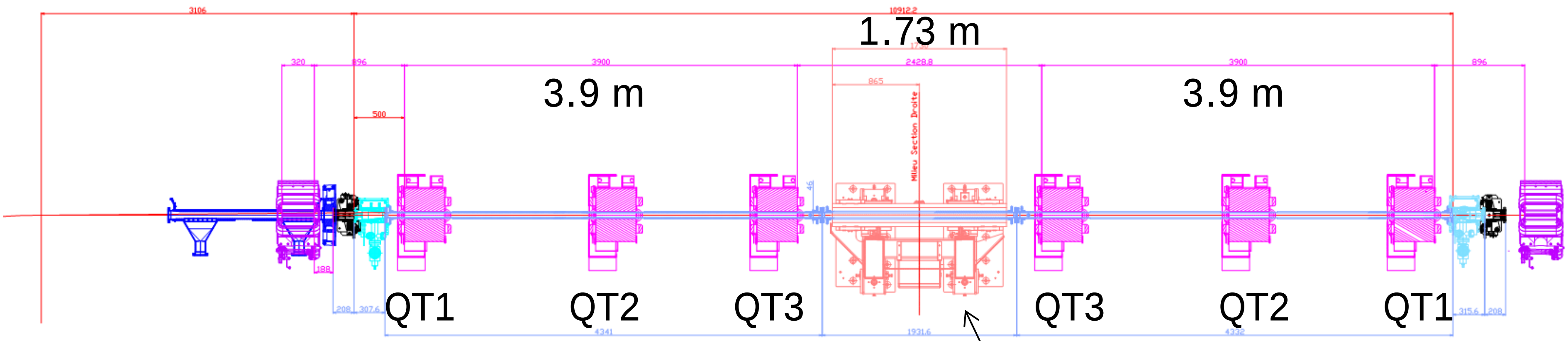
Possibility of applying the emittance adapter to a long straight section at SOLEIL

$$\left(\varepsilon_x\right)_{apparent} \sim \sqrt{\left(\varepsilon_x \cdot \varepsilon_z\right)_{ring}}$$

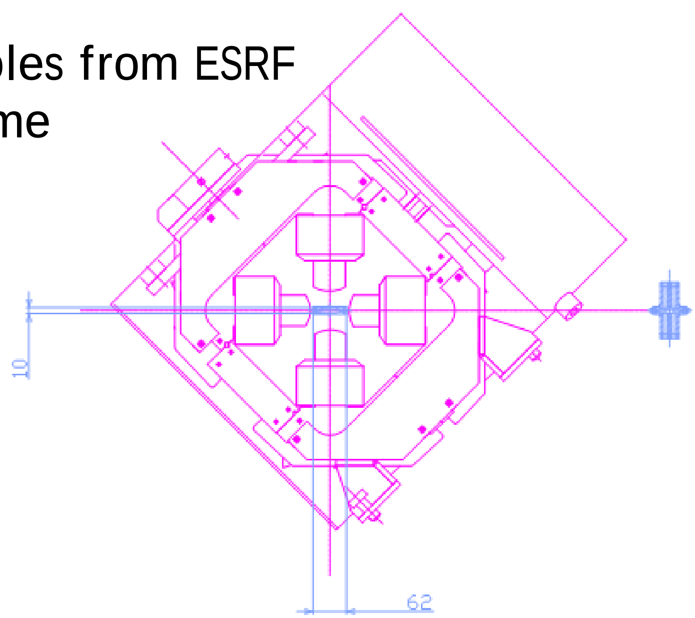


A. Chao and P. Raimondi (SLAC-PUB-14808)

SDL09 Preliminary Layout



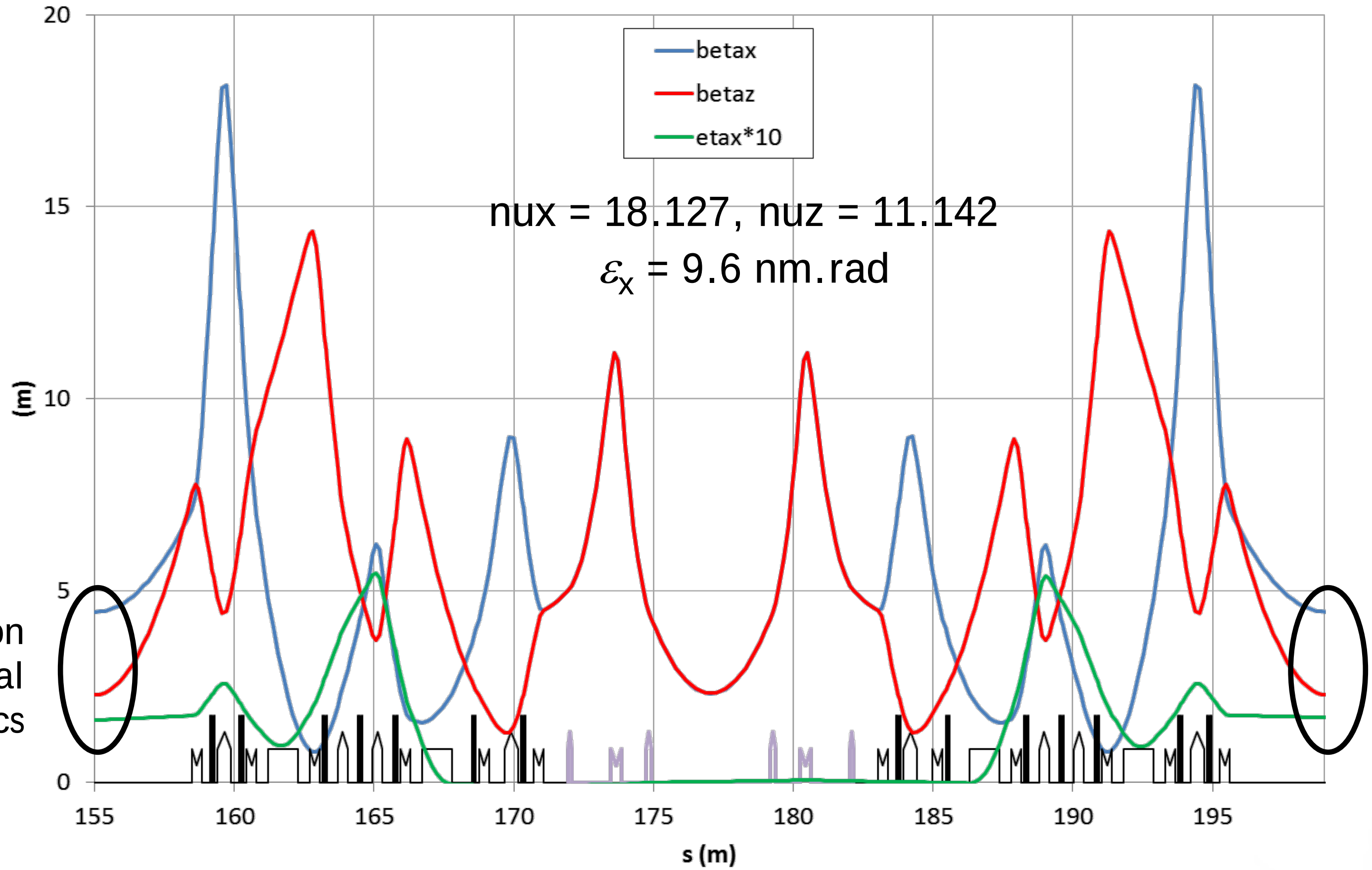
- Old quadrupoles from ESRF rotated in a frame
Gmax = 17 T/m
L = 0.40 m



- A 60 mm period Apple-II type undulator is available at SOLEIL

- An imaging system camera can be installed in the tunnel.

Optics Tuning

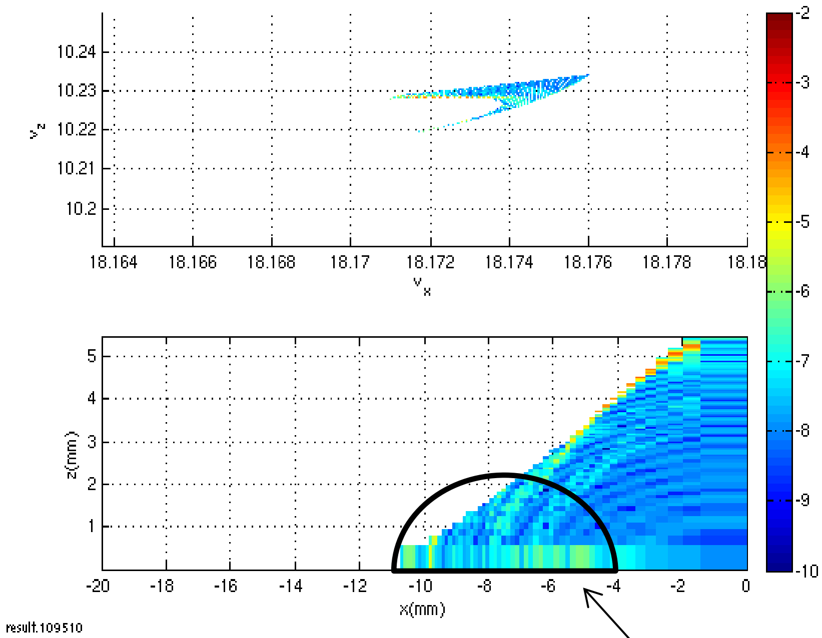


- 4.2 m available for the solenoid
- Skew quadrupoles reach 40 T/m gradient
- L = 0.14 / 0.39 / 0.20 m
- 1 quadrupole of the ring reach gradient > 20 T/m

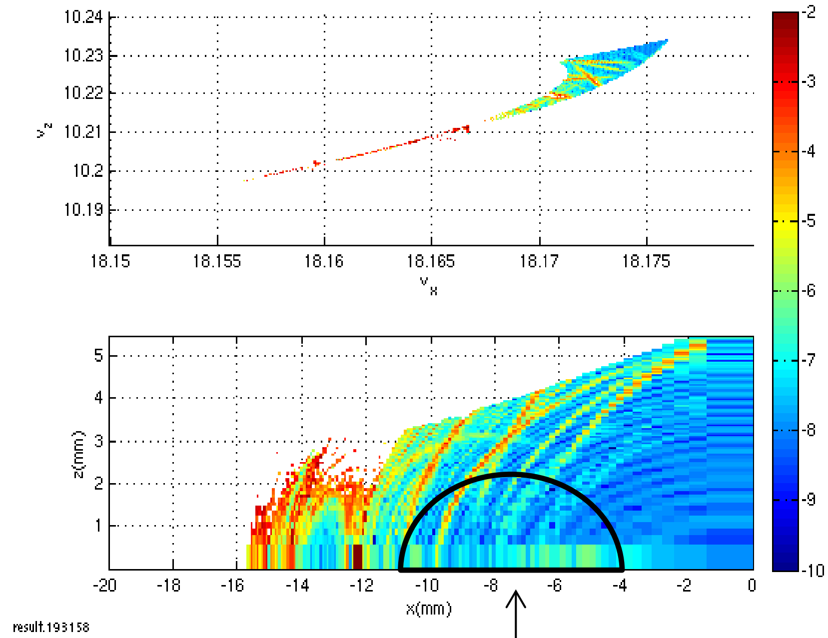
Beam Dynamics

The vacuum chamber height has to be enlarged from 14 to 24 mm to ensure good injection efficiency.

Standard chamber 56 (H) x 14 (V) mm



Enlarged QT chamber 56 (H) x 24 (V) mm



Beam coming from the booster (100% of the electrons)

Change of Direction

- The demonstration appeared to be feasible BUT the budget was increased from ~0 to 440 k€.
- Then the strategy was to study first the benefit of using a round photon beam at the sample of a beamline.
- An opportunity was given by the collaboration between MAX IV and SOLEIL.

Round Beam Project

MAXIV : Konstantin Klementiev
Christoph Quitmann

SOLEIL : José-Miguel Luque-Raigon (post-doc)
Pascale Brunelle
Nicolas Jaouen
Olivier Marcouillé
Thierry Moreno
Ryutaro Nagaoka
François Polack
William Shepard
Amor Nadji

Goal of the Round Beam Project

- Study the benefit of using a round photon beam compared to a flat one in terms of flux density at the sample.

- Round electron beam configurations based on Emittance adapter *:

  - Nominal horizontal emittance and energy spread for SOLEIL and MAX IV.
  - Coupling = 0.01.
  - Solenoid field = 10 T.

- Photon energy range:

  - HARD and SOFT X-ray beamlines

** Joël Chavanne, Some Undulator Photon Beam Properties in a Flat to Round Electron Beam Insertion, ESRF note, 2013, ESRF, Grenoble, France*

Tools

- Wave Propagation based on SRW* output
  - ➢ Photon beam reconstruction at Source.
  - ➢ Photon beam propagation to the Diaphragm
    - 2D-Gaussian distribution for emittance (H and V)
    - 1D-Gaussian distribution for energy spread.
- Calculation of the electron beam trajectory for any magnetic field
  - ➢ Calculated or measured undulator field.
  - ➢ Undulator field + solenoid field.
- **Propagation from diaphragm to sample using SPOTX** : T. Moreno.**
- **Propagation from source to sample using X-Ray-Tracer : K. Klementiev.**

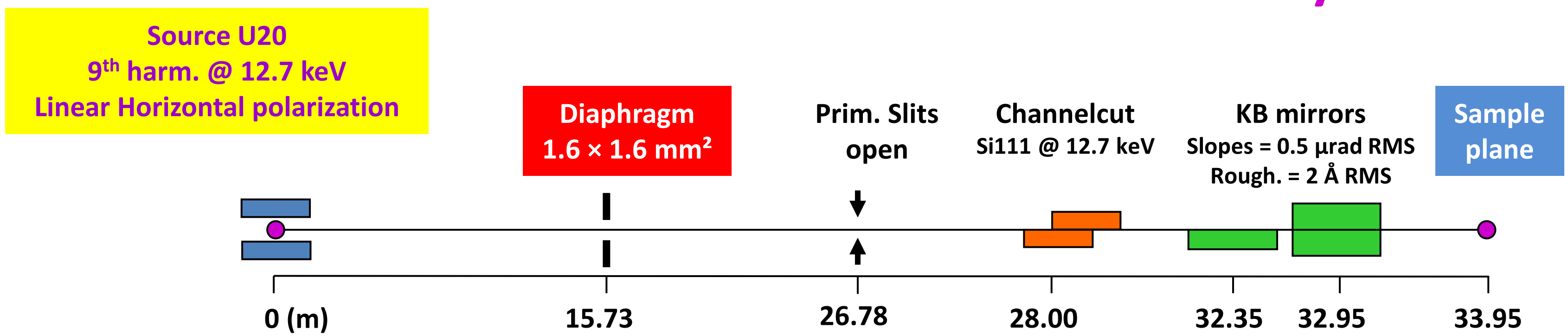
** O. Chubar, P. Elleaume, "Accurate and Efficient Computation of Synchrotron Radiation in the Near Field Region", Proceedings of the EPAC98 Conference, pp.1177-1179.*

*** Moreno, T. and Idir, M., 2001. J. Phys. IV France* ***11****, 527–531*

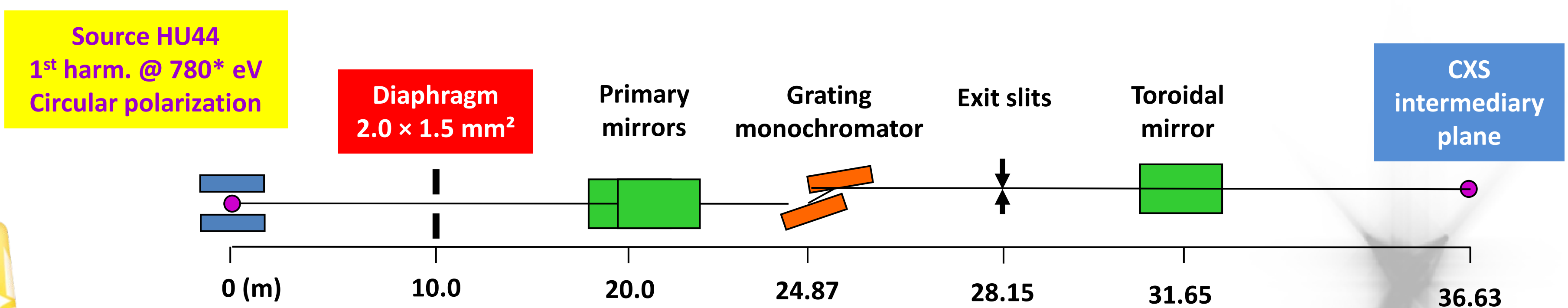
**** K. Klementiev, http://pythonhosted.org/xrt/*

Study of two beamlines with their existing configuration

HARD X-ray beamline PX2



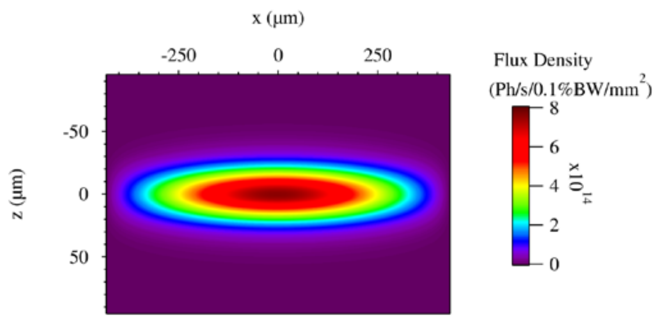
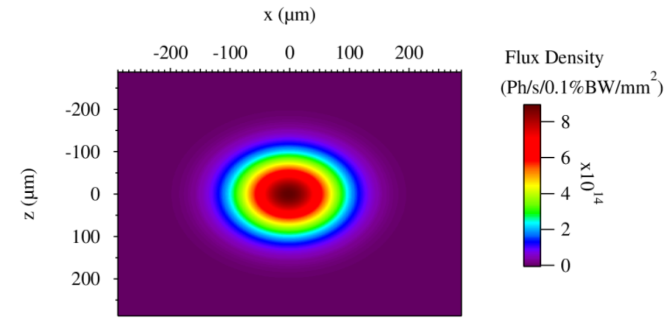
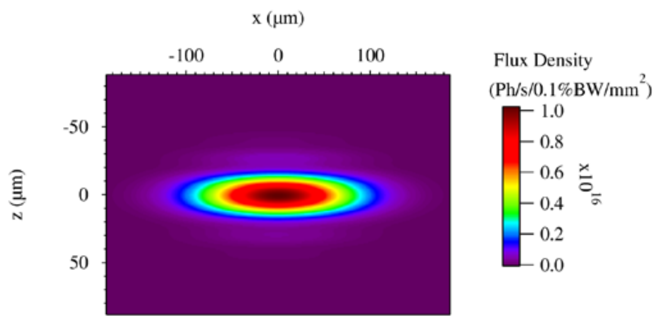
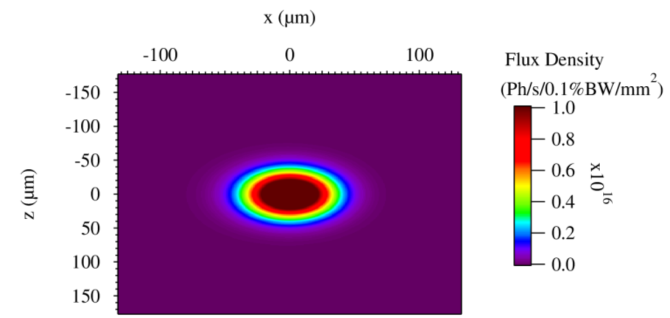
SOFT X-ray beamline SEXTANTS



* 932 eV for MAX-IV

Reconstruction at the source

Example of the Soft X-ray SEXTANTS beamline

	FLAT beam	ROUND beam
SOLEIL Electron beam		
	$\Sigma_{x,z}$ = **204.92 × 14.23 μm²** (H ×V) Flux = **2.14** $\cdot 10^{14}$ ph/s/0.1% bw	$\Sigma_{x,z}$ = **60.51 × 60.78 μm²** (H ×V) Flux = **1.59** $\cdot 10^{14}$ ph/s/0.1% bw
MAX IV Electron beam		
	$\Sigma_{x,z}$ = **54.96 × 9.12 μm²** (H ×V) Flux = **1.56** $\cdot 10^{15}$ ph/s/0.1% bw	$\Sigma_{x,z}$ = **20.58 × 20.55 μm²** (H ×V) Flux = **1.55** $\cdot 10^{15}$ ph/s/0.1% bw

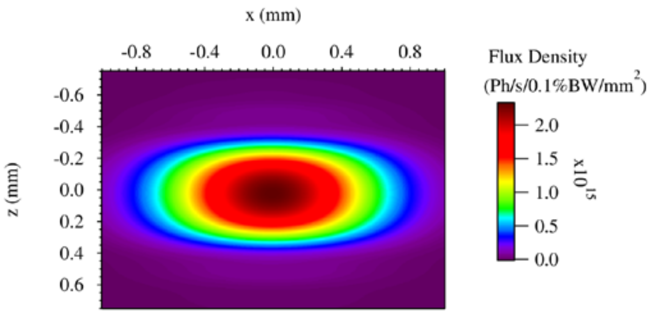
Propagation to the diaphragm

Example of the Soft X-ray SEXTANTS beamline

FLAT beam / ROUND beam

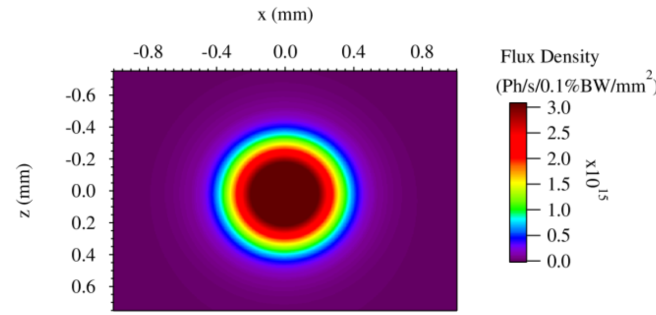
SOLEIL Electron beam

FLAT beam:



$\Sigma_{x,z}$ = **0.98 × 0.46 mm²** (H ×V)
Flux = **1.20 $\cdot 10^{15}$** ph/s/0.1% bw

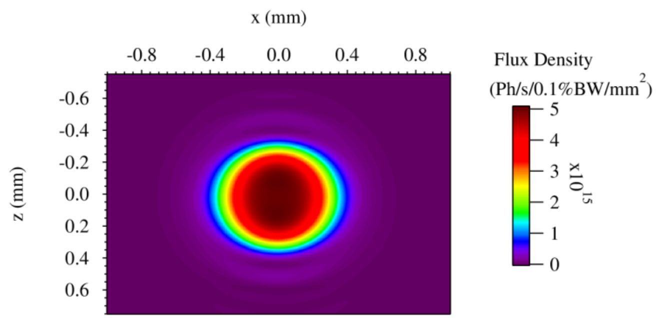
ROUND beam:



$\Sigma_{x,z}$ = **0.49 × 0.49 mm²** (H ×V)
Flux = **1.23 $\cdot 10^{15}$** ph/s/0.1% bw

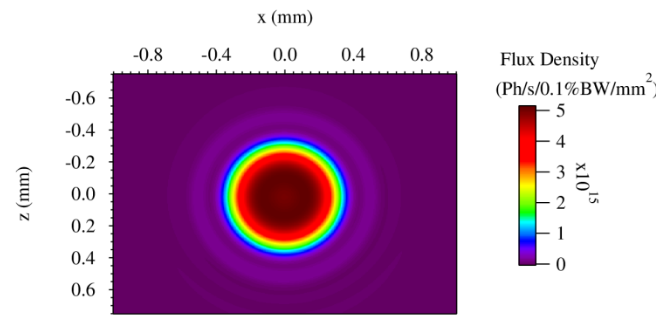
MAX IV Electron beam

FLAT beam:



$\Sigma_{x,z}$ = **0.50 × 0.47 mm²** (H ×V)
Flux = **1.54 $\cdot 10^{15}$** ph/s/0.1% bw

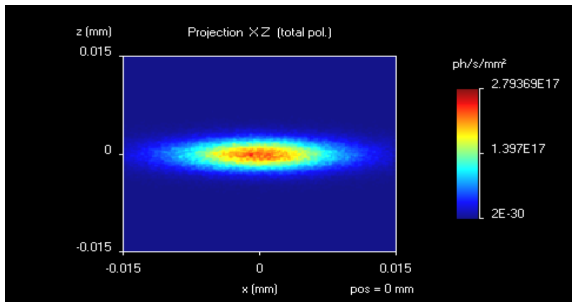
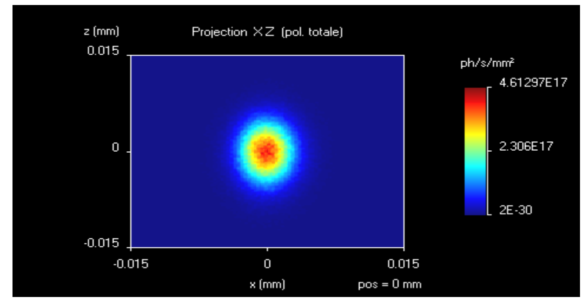
ROUND beam:



$\Sigma_{x,z}$ = **0.47 × 0.47 mm²** (H ×V)
Flux = **1.54 $\cdot 10^{15}$** ph/s/0.1% bw

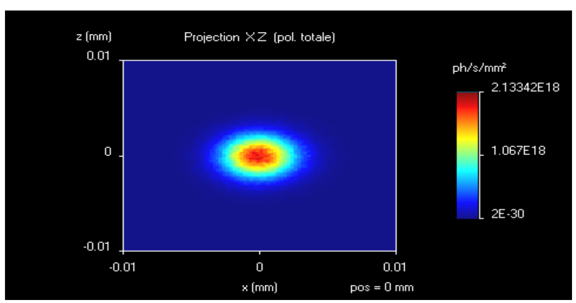
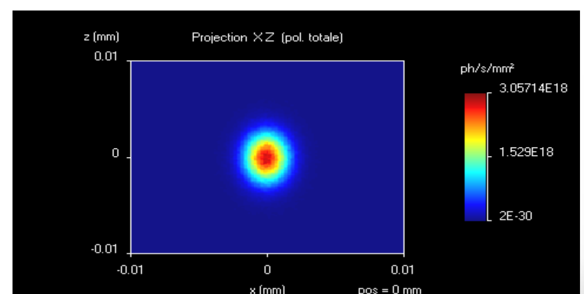
Propagation to the sample

Example of the Hard X-ray PX2 beamline

	FLAT beam	ROUND beam
SOLEIL Electron beam		

FLAT beam: **FWHM Sizes = 14.8 × 3.8 μm² (H ×V)**
Flux = 1.51 · 10^{13} ph/s

ROUND beam: **FWHM Sizes = 4.7 × 7.6 μm² (H ×V)**
Flux = 1.72 · 10^{13} ph/s

	FLAT beam	ROUND beam
MAX IV Electron beam		

FLAT beam: **FWHM Sizes = 4.4 × 3.6 μm² (H ×V)**
Flux = 3.50 · 10^{13} ph/s

ROUND beam: **FWHM Sizes = 2.6 × 4.1 μm² (H ×V)**
Flux = 3.60 · 10^{13} ph/s

Benefit of the emittance adapter on photon flux density at sample

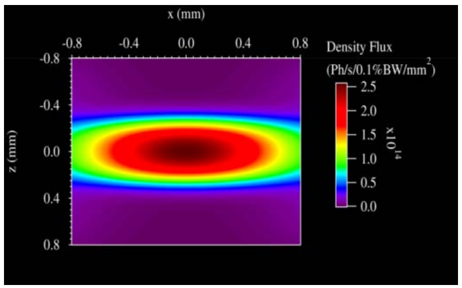
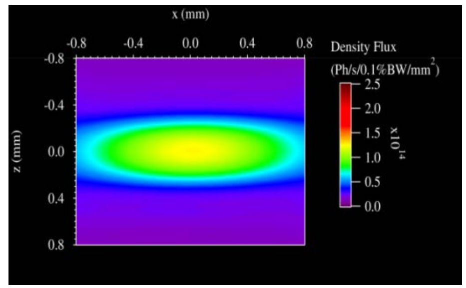
- The benefit comes mainly from the reduction of the horizontal photon beam size at source:
  - A reduction by a factor ≥ 3 is obtained for SOLEIL and ≤ 3 for MAX IV.

Gain factor in flux density at the sample	Hard X-ray beamline PX2	Soft X-ray beamline SEXTANTS
SOLEIL	1.8	2.1
MAX IV	1.5	1.2

- This gain factor is not preserved at the sample because of some effects of the beamline equipment:
  - *Losses due to horizontal mirror slope errors.*
  - *Vertical size fixed by monochromator slit.*
  - *Distance from KB to sample is large.*

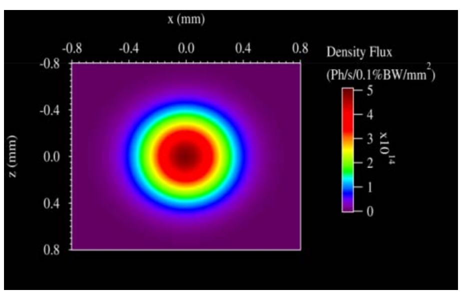
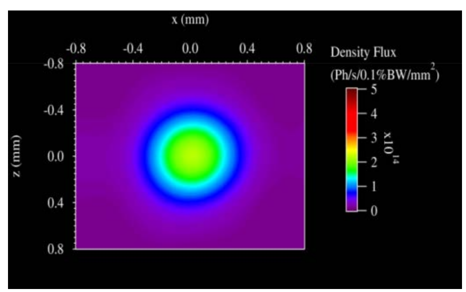
Effect of the undulator phase error

Example of the PX2 Hard X-ray beamline : SOLEIL electron beam, at the diaphragm

	PERFECT field	MEASURED field
FLAT beam		

PERFECT field, FLAT beam:
FWHM Sizes = 1.34 × 0.42 mm² (H ×V)
Flux = 1.45 · 10^{14} ph/s/0.1% bw

MEASURED field, FLAT beam:
FWHM Sizes = 1.38 × 0.44 mm² (H ×V)
Flux = 1.08 · 10^{14} ph/s/0.1% bw

	PERFECT field	MEASURED field
ROUND beam		

PERFECT field, ROUND beam:
FWHM Sizes = 0.50 × 0.57 mm² (H ×V)
Flux = 1.56 · 10^{14} ph/s/0.1% bw

MEASURED field, ROUND beam:
FWHM Sizes = 0.50 × 0.59 mm² (H ×V)
Flux = 1.09 · 10^{14} ph/s/0.1% bw

→ Flux is reduced in the same way for flat and round beams

→ Beam size is preserved

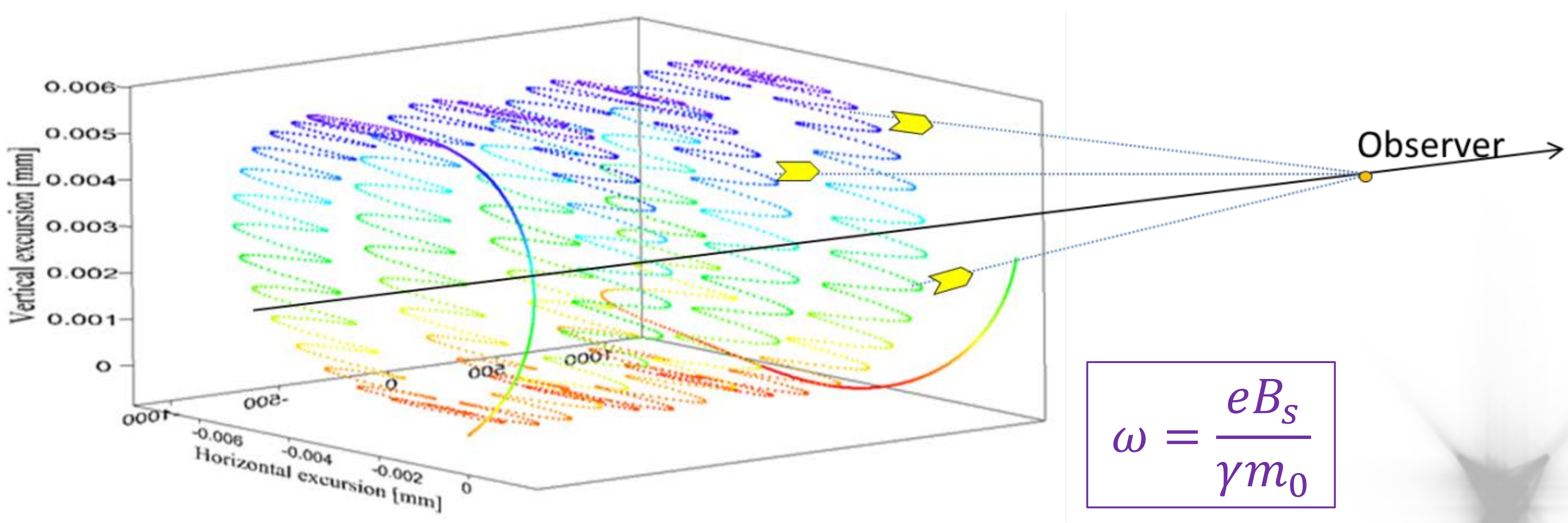
→ Benefit of the round beam is preserved

Effect of the solenoid field

Example of the PX2 Hard X-ray beamline

The effect of the solenoid field on the electron beam trajectory depends on the initial angle of the electron beam trajectory and on the solenoid field value.

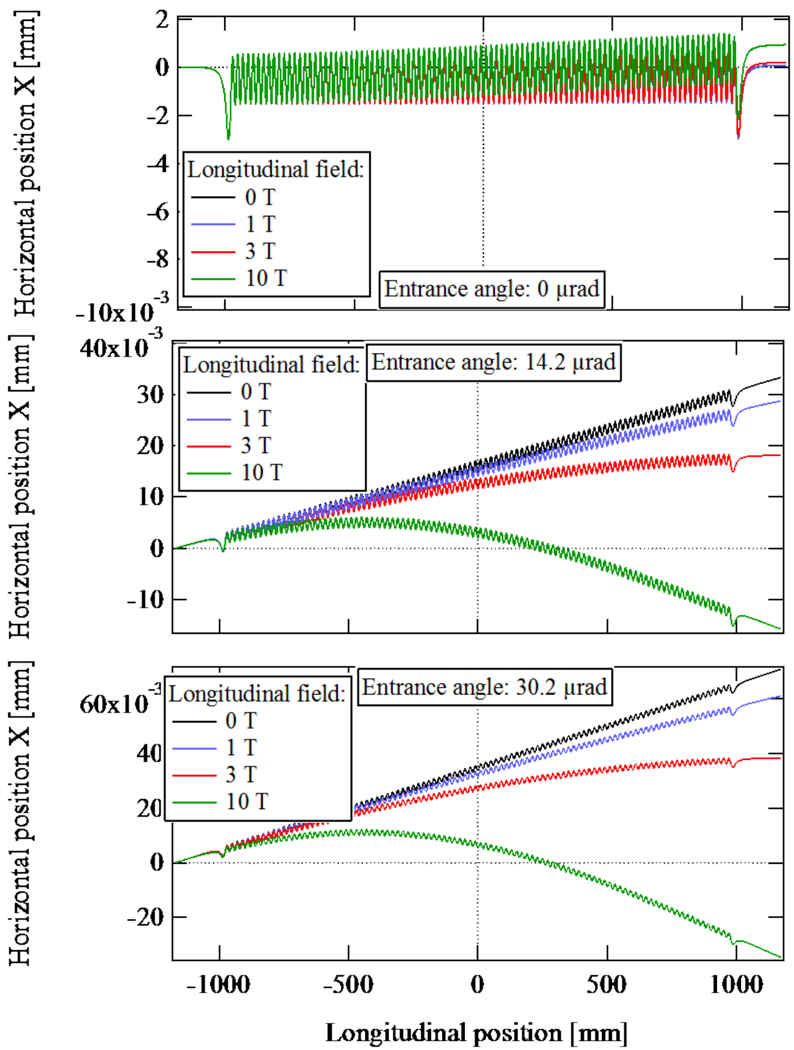
Bs = 100 T; U20 Undulator ; Entrance angle of 30 µrad in horizontal and vertical



$$\omega = \frac{eB_s}{\gamma m_0}$$

Effect of the solenoid field

Example of the PX2 Hard X-ray beamline

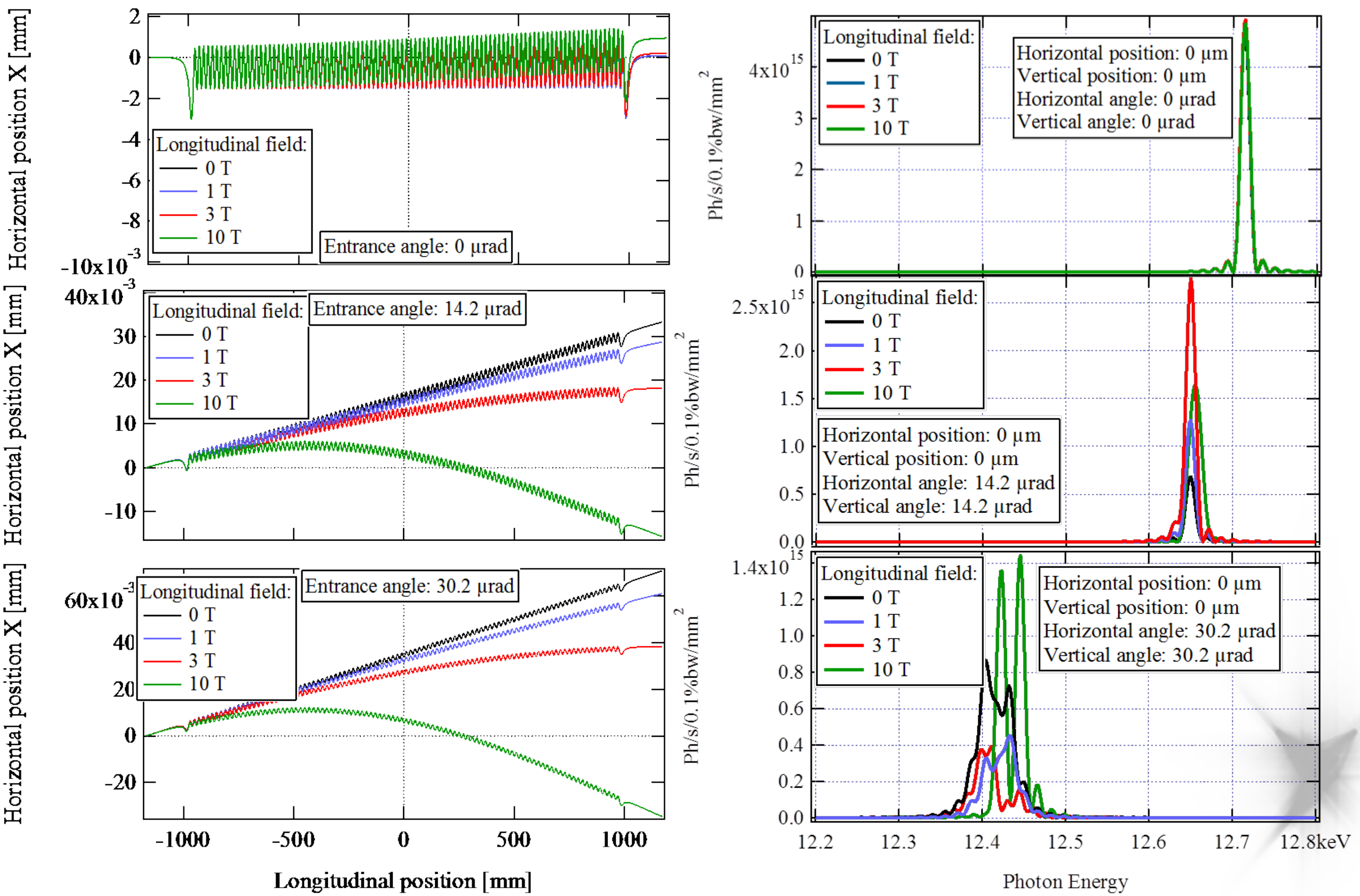


For solenoid field values ≤10 T, the number of oscillation due to the solenoid field is much smaller than 1 : the trajectory is only bended.

Effect of the solenoid field

Example of the PX2 Hard X-ray beamline

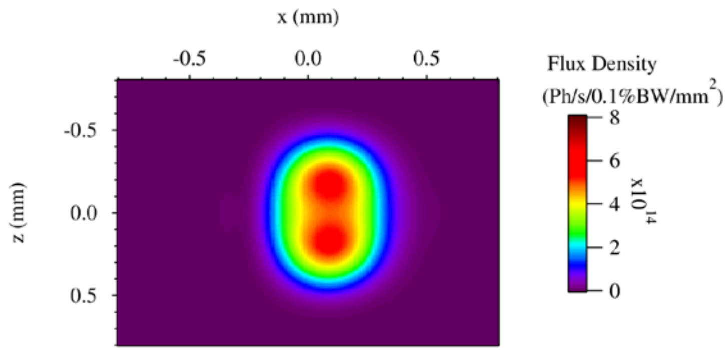
The spectrum is shifted towards lower photon energies when increasing the entrance angle.



Effect of the solenoid field

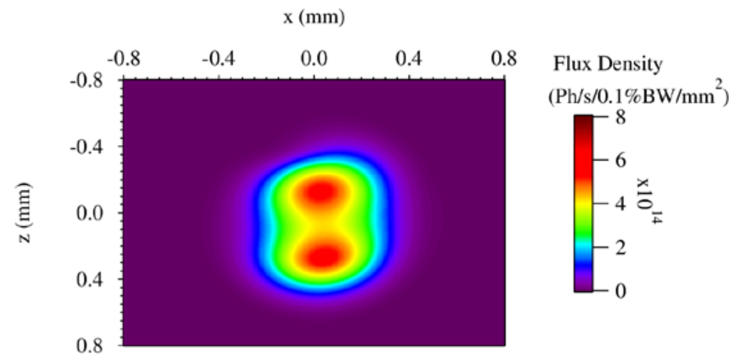
Example of the PX2 Hard X-ray beamline : SOLEIL electron beam, at the diaphragm

Bs = 0 T



FWHM Sizes = 0.34 × 0.66 mm² (H ×V)
Flux = 1.49 · 10^{14} ph/s/0.1% bw

Bs = 10 T



FWHM Sizes = 0.39 × 0.65 mm² (H ×V)
Flux = 1.49 · 10^{14} ph/s/0.1% bw

For the obtained electron beam divergences (< 10 µrad RMS), the effect of the solenoid field (10 T) on the electron trajectory and on the photon flux density is not significant. The benefit of the round beam is preserved*.

* Confirmed by Konstantin Klementiev.

Summary

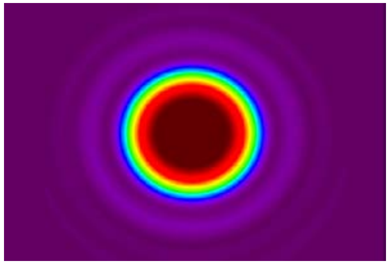
A comprehensive study has been performed to evaluate the benefit of the emittance adapter for SOLEIL and MAX IV electron beam configurations.
Dedicated tools were developed to calculate the emitted radiation and its propagation to the diaphragm.

For the two SOLEIL beamlines tested as example, it has been demonstrated that :

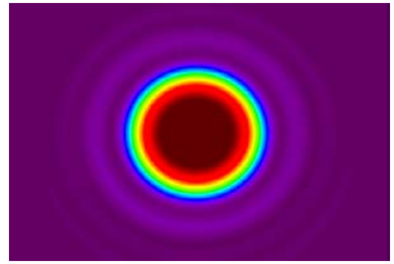
- → The gain in flux density at the sample is mainly due to the reduction of the horizontal electron beam size at source.
- → A reduction by a factor ~3 is obtained on the present SOLEIL and MAX-IV storage rings with a 10 T solenoid field (perfect adaptation is obtained with a solenoid field of ~140 T for an undulator length of 2 m).

The present design of the two beamlines should be optimized to benefit from a small horizontal photon beam size.

During this Round Beam project,
photon users, optics and radiation experts, accelerator physicists worked together in a very pleasant and efficient way.



Thank you for your attention

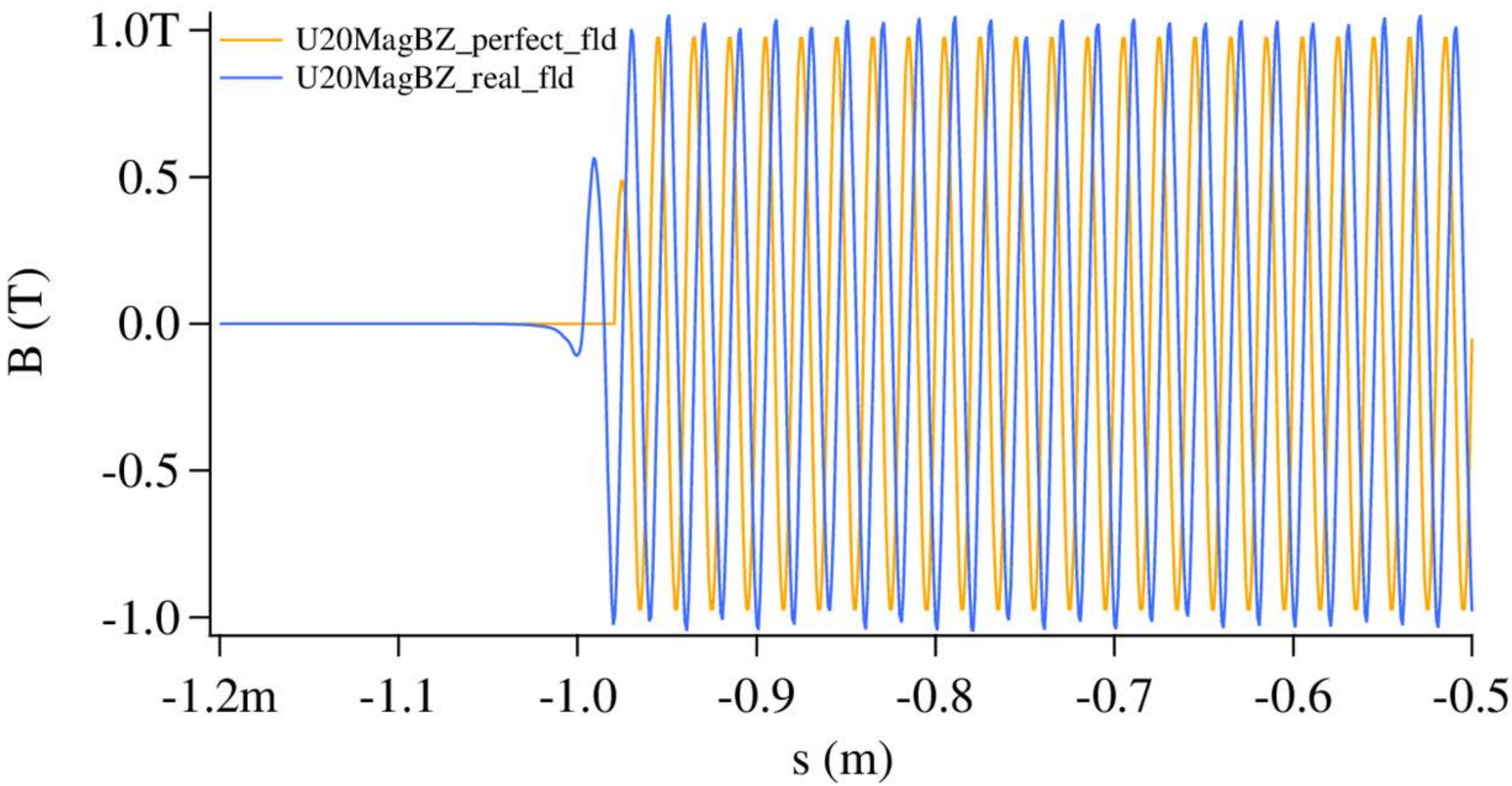


Electron beam characteristics

	SOLEIL PRESENT				SOLEIL UPGRADE			MAX IV	
	PX2	SEXTANTS			SDC			Present	
	Flat beam	**Flat beam**	**Round beam**		**Flat beam**	**Round beam**		**Flat beam**	**Round beam**
Energie (GeV)	2.739	2.739	2.739	2.739	2.739	2.739	2.739	3.0	3.0
Energy spread	1.01E-03	1.01E-03	1.01E-03	1.01E-03	1.08E-03	1.08E-03	1.08E-03	7.70E-04	7.70E-04
Emittance coupling	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**	**0.01**
Horizontal emittance (pm.rad)	**4000**	**4000**	**4000**	**4000**	**170**	**200**	**200**	**328**	**328**
Vertical emittance (pm.rad)	39.6	39.6	39.6	39.6	1.7	2.0	2.0	3.2	3.2
Solenoid field (T)	**-**	**-**	**10**	**60**	**-**	**10**	**20**	**-**	**10**
Apparent H and V emittances (pm.rad)	**-**	**-**	**398.0**	**398.0**	**-**	**19.9**	**19.9**	**-**	**32.6**
betax (m)	*4.82*	*4.23*	*9.1*	*1.5*	*0.53*	*9.1*	*4.6*	*9*	*10.0*
alphax	*-0.3708*	*0.0089*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
etax (m)	*0.1734*	*0.1673*	*0*	*0*	*0.0144*	*0*	*0*	*0*	*0*
etax'	*0.0014*	*0.0004*	*0*	*0*	*0*	*0*	*0*	*0*	*0*
betaz (m)	*3.21*	*2.28*	*9.1*	*1.5*	*0.54*	*9.1*	*4.6*	*2*	*10.0*
alphaz	*-0.7163*	*0.0126*	*0*	*1*	*0*	*0*	*0*	*0*	*0*
sigmax (µm)	**224.5**	**212.2**	**60.3**	**24.6**	**18.2**	**13.5**	**9.5**	**54.3**	**18.1**
sigmax' (µrad)	30.4	30.4	6.6	16.2	17.9	1.5	2.1	6.0	1.8
sigmaz (µm)	**11.2**	**8.3**	**60.3**	**24.6**	**1.0**	**13.5**	**9.5**	**2.5**	**18.1**
sigmaz' (µrad)	4.3	3.7	6.6	16.2	1.8	1.5	2.1	1.3	1.8

Domain n° 5 – SP n° 3
SP Title: Round Photon Beam

HARD X-ray beamline PX2 : Effect of the undulator PHASE ERROR at the diaphragm



Measured Magnetic Field

↓

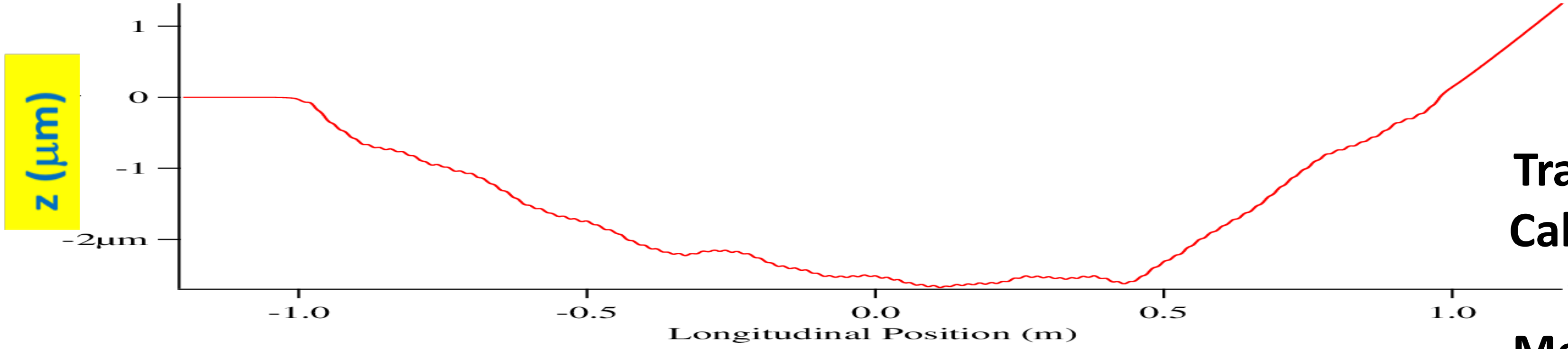
Ephoton = 11.871 keV

↓

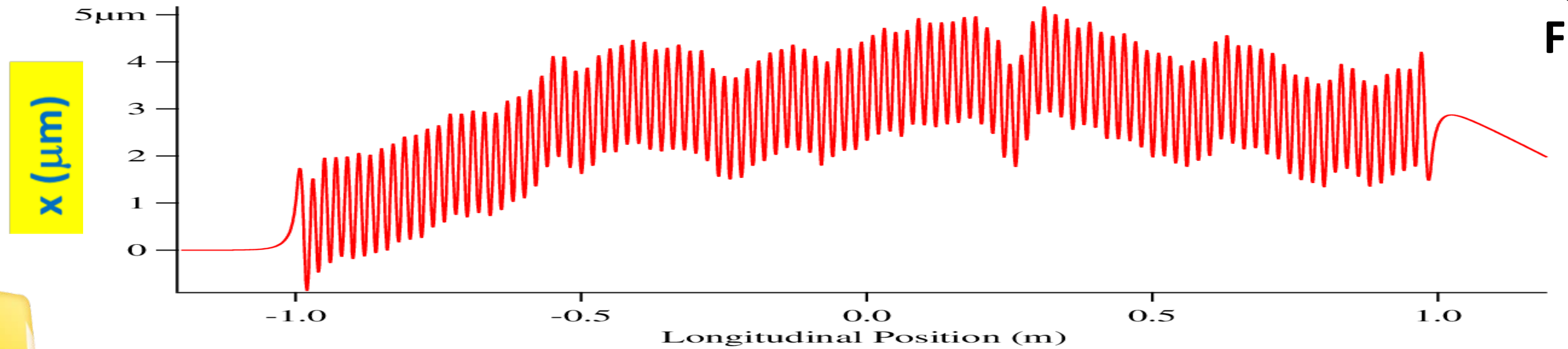
Perfect Magnetic Field = 0.9875 T

Domain n° 5 – SP n° 3
SP Title: Round Photon Beam

HARD X-ray beamline PX2 : Effect of the undulator PHASE ERROR at the diaphragm

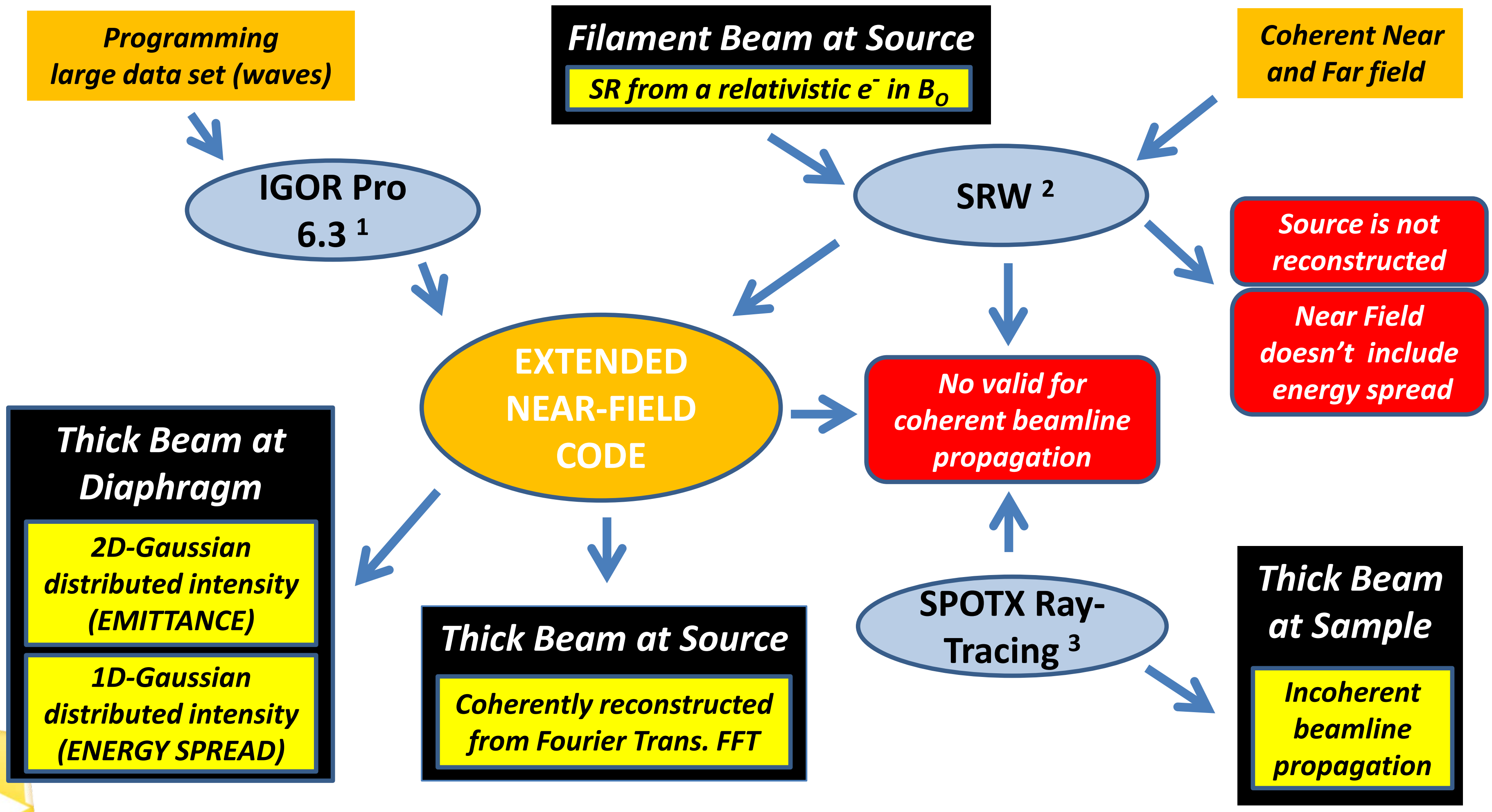


Trajectory Calculated from Measured Magnetic Field



Domain n° 5 – SP n° 3
SP Title: Round Photon Beam

Development of an Extended Near-Field code based on SRW output



1. IGOR Pro 6.3 Manual. 2013 WaveMetrics, Inc. http://www.wavemetrics.com/
2. O. Chubar, P. Elleaume, proc. of the EPAC98 Conference, 22-26 June 1998, p.1177-1179.
3. Moreno, T. & Idir, M., 2001. *J. Phys. IV France* ***11***, 527–531