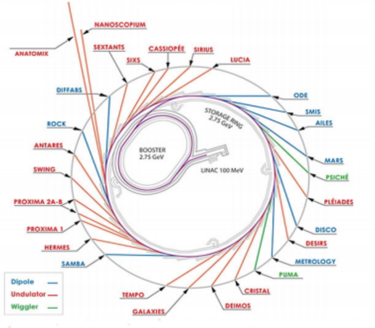
Optical Diagnostics for SOLEIL–Upgrade

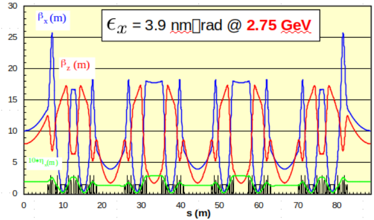
Transverse beam sizes and emittance measurement

M. Labat, N. Hubert

Workshop @IFAST, April 2022

SOLEIL present storage ring

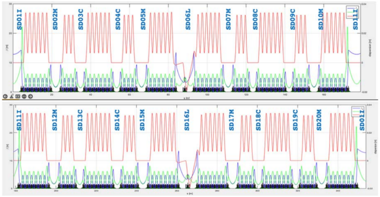


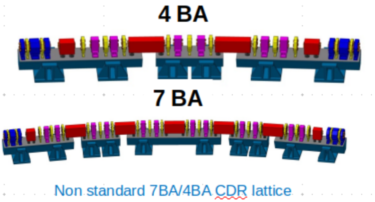


SOLEIL present storage ring

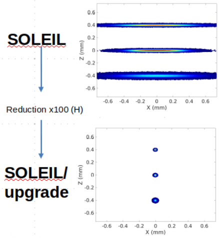
- Storage ring: 354 m circumference
- Lattice: DBA + distributed dispersion
- ϵ_x=3.9 nm.rad ; ϵ_y=40 pm.rad
- 29 beamlines

SOLEIL–Upgrade project





SOLEIL–Upgrade lattice



- Lattice: non–standard 7 DBA + 4 DBA
- ϵ_x=84.4 pm.rad ; ϵ_y=25.3 pm.rad
- Presently in TDR phase...

Beam size and emittance for SOLEIL–U

- Present vs. future parameters:

Machine	SOLEIL	SOLEIL–Upgrade Nominal / Machine tuning
ϵ_x (pm.rad)	4000	84.4 / 90
ϵ_y (pm.rad)	40	25.3 / 1
σ_x in dipoles (μm–RMS)	45–75	8.3 / 8–17
σ_y in dipoles (μm–RMS)	25	12.5 / 2–3

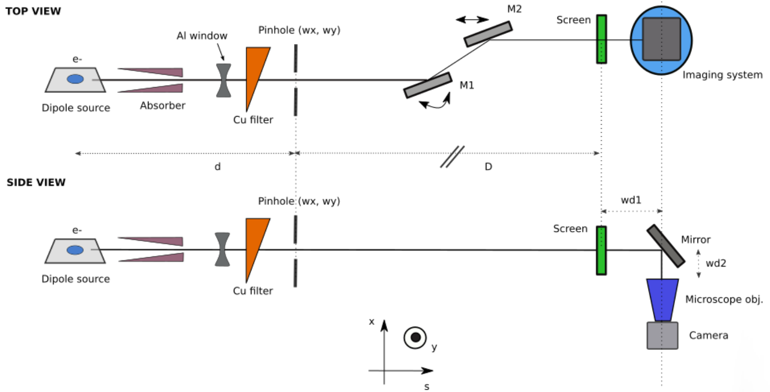
- Specifications for $\epsilon_{x,y}$ ($\sigma_{x,y}$) measurement:
  - $\epsilon_{x,y}$ measurement with sub–pm resolution
    $\rightarrow$ $\sigma_{x,y}$ measurement with sub–μm resolution
  - $\epsilon_{x,y}$ (nominal) measurement at >100 Hz repetition rate
  - High reliability for $\epsilon_{x,y}$ (nominal) measurement
  - At least 2 measurements of $\epsilon_{x,y}$ with different $\eta_{x,y}$

Strategy for $\epsilon_{x,y}$ measurement

- Development of 2 types of optical diagnostics beamline:
  - X-ray range beamline(s):
    - Based on high–field dipole(s)
    - + Pinhole camera → ≈ 5 μm–RMS resolution at > 100 Hz
      (for users' operation)
    - + Fresnel diffraction → ≈ 1 μm–RMS resolution at > 10 Hz
      (for machine tuning)
  - Near–UV / visible beamline:
    - Based on low–field dipole
    - + Polarized imaging → ≈ 5 μm–RMS resolution at > 100 Hz
      (for users' operation)
    - + Polarized diffraction imaging → ≈ 1 μm–RMS resolution at > 10 Hz
      (for machine tuning)

→ The beamlines design will ensure to swap from one technique to the other

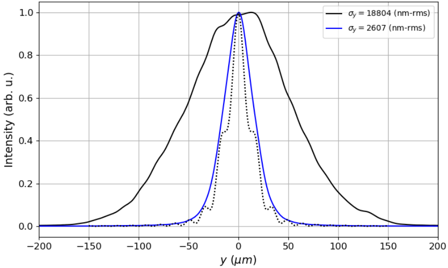
X–ray beamline(s) >> Principle



- Principle: flip from users' to machine tuning mode removing M1–M2 specular mirrors
- Main components:
  - Easy: Aluminium window, copper absorber, scintillator, objective
  - Tricky: High–field dipole, absorber, adjustable pinhole, specular mirrors, camera

X–ray beamline(s) >> SRW simulations

- Expected performances of the pinhole camera ($E_{phot} > 50$ keV):

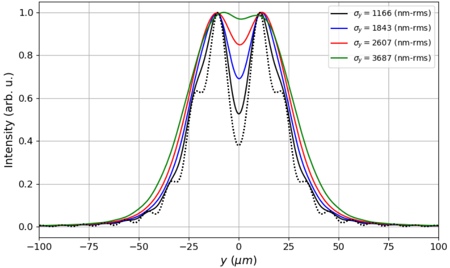


B=3 T, d=3 m, M_W=2.66, E_ν=50 keV, w_y=14 μm

→ Should resolve down to $\sigma_{x,y} \approx 5$ μm–RMS

X–ray beamline(s) >> SRW simulations

- Expected performances of Fresnel diffraction ($E_{phot} > 50$ keV):



B=3 T, d=3 m, M_W=2.66, E_ν=50 keV, w_y=19 μm

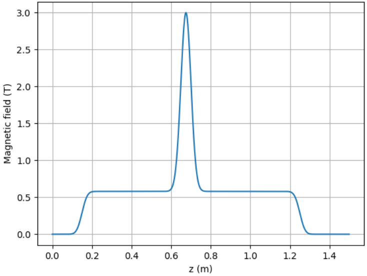
$\rightarrow$ Should resolve down to $\sigma_{x,y} \approx 1$ μm–RMS

X–ray beamline(s) >> SRW simulations

- Expected performances in the X–ray range ($E_{phot} > 50$ keV):
  - The dipole field has little influence on ultimate resolution
  - BUT... a strong impact on photon flux !!!

  → For 100 Hz (?) repetition rate → B=3 T mandatory.

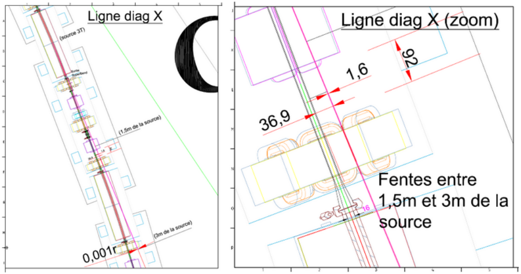
- Source dipole:
  - To enable 100 Hz measurements @ $E_{phot} > 50$ keV $\rightarrow B > 2.5$ T
  - Target: use one of the *long* dipoles with central field @ B=3 T



Long dipole longitudinal magnetic field with central field @ 3 T. Courtesy A. Loulergue. PRELIMINAR DESIGN.

X–ray beamline(s) >> Main components

- Beamline(s) integration:
  - Source dipole = long + free dipole
  - To enable high resolution: $M > 2.5 \rightarrow d_{source-pinhole} < 3$ m

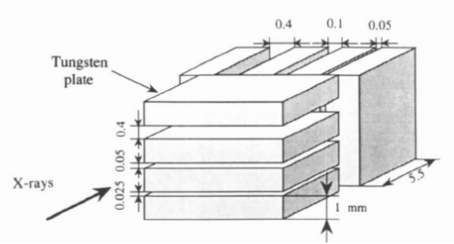


Integration of X–ray beamline on a 3 T long dipole. PRELIMINAR DESIGN.

- So: pinhole will still be *in between* DBA magnets.... = tiny space !

X–ray beamline(s) >> Main components

- Pinhole design: (1) Stacking of blades + shims

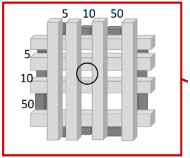


Pinhole design from P. Elleaume et al., J. Syncrotron Rad. (1995) 2, 209-214.

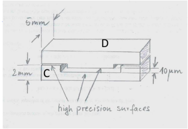
- Pros: Proven, compact, cheap, reliable
- Cons: Fixed set of hole sizes, no or non–acurate metrology, painfull assembly

→ Alternative ?

- Pinhole design: (2) Alternatives investigated
  - LIGA >> no. Not enough attenuation power.
  - Motorized micro–slits >> no. Too expensive, not reliable enough.
  - Other mechanical design based on ESRF / ALBA experience >> yes.



New "CD shaped" pinhole design

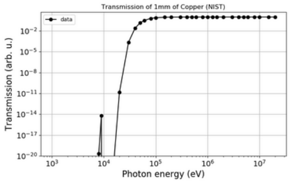


Pinhole model from ALBA and ESRF. Courtesy U. Iriso and F. Ewald.

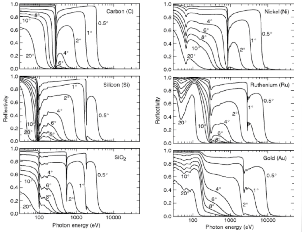
→ Study of a new mechanical design to be soon started

X–ray beamline(s) >> Main components

- Monochromator (for Fresnel diffraction ONLY): just an idea...
  - Statements:
    - We only need XX linewidth to reach 1 μm resolution in Fresnel diffraction
    - No need to implement XX linewidth standard monochromator: it will kill flux: see Diamond and ESRF....
  - Alternative idea: make a band–pass filter ?
    - High–pass filter = Copper attenuator
    - Low–pass filter = Pair of mirrors in specular reflection



Copper transmission = High–pas filter



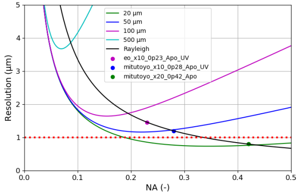
Specular mirror reflectivity = Low–pass filter

- Many critical issues still: x offset ? final flux ? alignement ? x_{camera} ?

- Scintillator:
  - Specifications:
    - Short time response (<0.1 ms)
    - Spatial resolution <1 μm
    - High yield
    - Emission around 500 nm to match camera efficiency
    - Linear response
    - Thickness = compromise output yield / resolution decrease from d.o.f.

      $\rightarrow$ between 0.02 and 0.1 μm

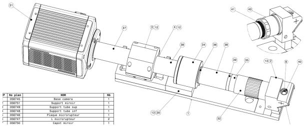
$\rightarrow$ CdW04, Yag:Ce, LuAg:Ce, GaGG



Resolution versus Numerical Aperture for different scitillator thickness.

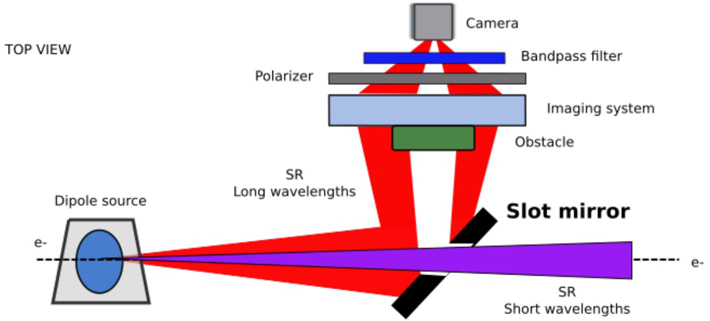
X–ray beamline(s) >> Main components

- Imaging system:
  - Compact + stable mechanics
    from Detetor Group design
    (housing: scintillator + mirror + objective + camera + focus stage)
  - Objective = microscope
    (EdmundOptics + Mitutoyo to be tested)
  - Camera = ?
    (not defined yet)



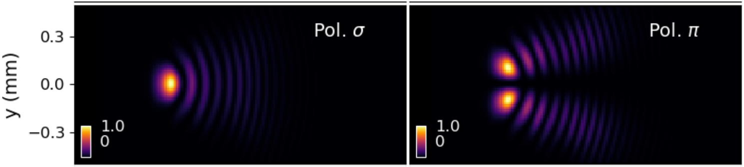
X–ray beam imager prototype.

Near–UV / Visible beamline >> Principle



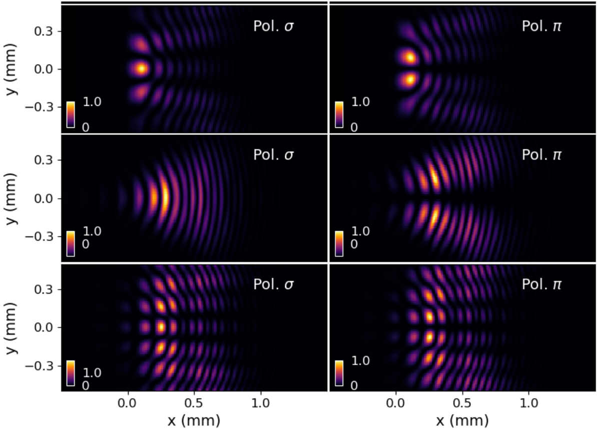
- Principle: flip from users' to machine tuning mode adding an obstacle
- Main components:
  - Easy: Low–field dipole, thin obstacle, focussing lens, polarizer, objective
  - Tricky: Extraction mirror, camera

- Expected performances of the polarized imaging (@λ=200 nm):



$\rightarrow$ Should resolve down to $\sigma_{x,y} \approx 5$ μm–RMS

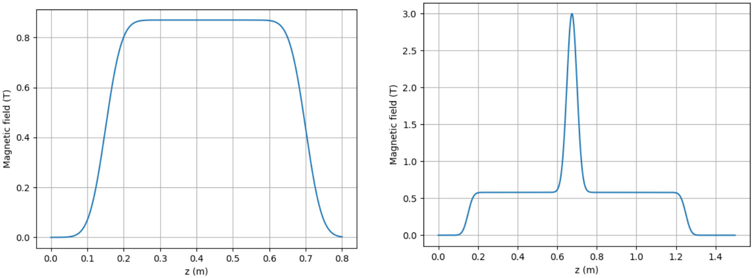
- Expected performances of the obstacle + polarized imaging (@λ=200 nm):



→ Should resolve down to $\sigma_{x,y} \approx 2\ \mu$m–RMS → to be more optimized...

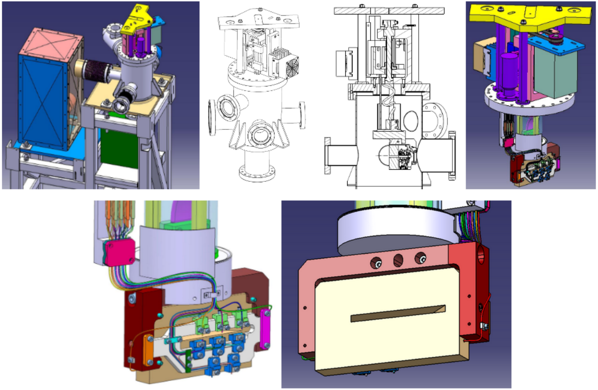
- Expected performances in near–UV / visible range (down to 200 nm):
  - Since we'll work with large θ_x:
    $\rightarrow$ B longitudinal distribution will be important (flat / not)
  - The lower the field... the higher the photon flux
    $\rightarrow$ For 100 Hz (?) repetition rate $\rightarrow$ B <1.7 T mandatory

- Source dipole:
  - To enable 100 Hz measurements @ 200 nm$< \lambda < 1$ μm $\rightarrow B < 1.7$ T
  - Target: use one of the *short* dipoles @ B=0.87 T,
    or first/last part of a *long* dipole @ B=0.58 T



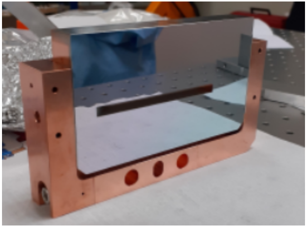
Short and long dipole longitudinal magnetic field. Courtesy A. Loulergue. PRELIMINAR DESIGN.

- Extraction mirror:
  - Principle: Slotted mirror + air–cooling system
  - To test high resolution polarized imaging with such system:



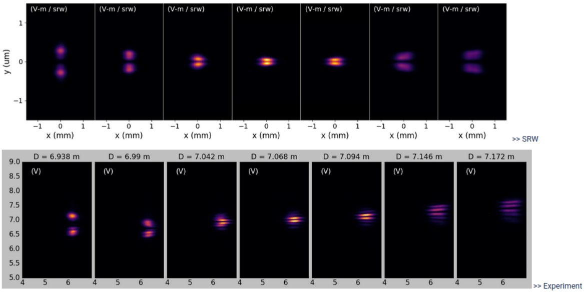
→ Installation in January 2022 of a new extraction mirror on our visible beamline

- Preliminar results with our new extraction mirror:
  - Mirror performances:
    - Mirror made of Copper + enhanced Alumium deposition
    - Very high surface quality even around the slot !!
      (flatness $<$ 250 nm PV, roughness $<$3 nm–rms)
    - Excellent thermal stability up to 500 mA stored: no image distorsion !!



→ High quality mirrors are feasible on copper :-)

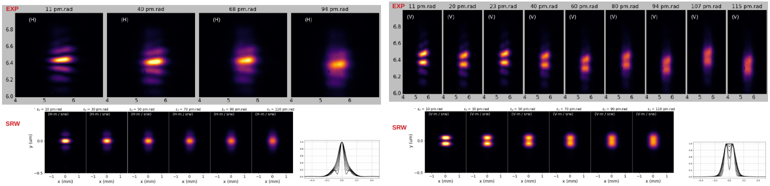
- Preliminar results with our new extraction mirror:
  - Images measured and simulated vs. distance lens–camera (pol. V):



Images vs distance to lens. θ_X=3.5 mrad, Pol. V.

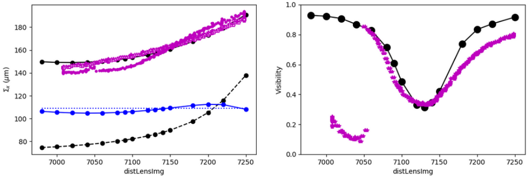
→ Good agreement "by eye" SRW / measurements :-)

- Preliminar results with our new extraction mirror:
  - Images measured and simulated vs. ϵ_y:

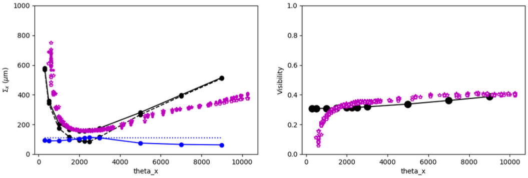


→ Sensitivity "by–eye" seems very good in both σ/π pol. :-)

- Preliminar results with our new extraction mirror:
    - Horizontal beam size Σ_x and Visibility in image plane (pol. V):



Vs. distance lens–camera

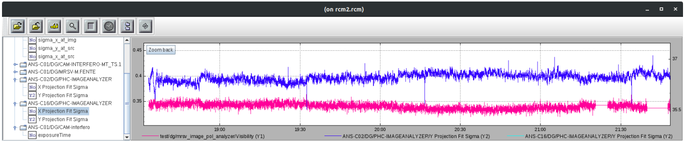


Vs θ_X collection angle

Experiment / SRW with: d=5940 mm, f_X=3200mm, f_Y=3240 mm

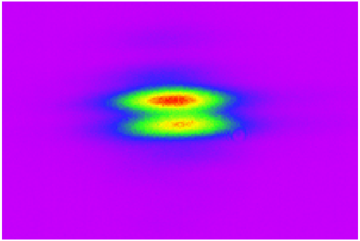
→ Quite good absolute agreement SRW / measurements... but to be improved

- Preliminar results with our new extraction mirror:
  - Sensitivity Visility vs. ϵ_y from Pinhole Cameras:

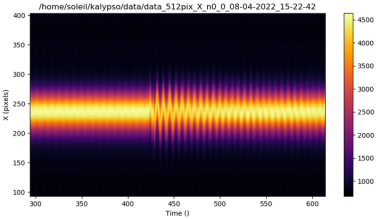


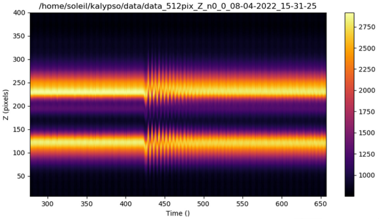
→ Good sensitivity in pol. V seems confirmed.

- Preliminar results with our new extraction mirror: TO BE DONE
  - Check experimental magnification with bumps at source point
  - Check vertical alignment of mirror
  - Improve beamline stability (N_2 or vacuum transport)
  - Improve periscope alignment
  - Improve SRW/measuremnt agreement



- Other development on our present visible beamline: ultra–fast imaging
  - Kalypso (KIT) camera implemented on σ pol. branch
  - Ultra–fast acquisition (up to 3 MHz) $\rightarrow$ turn–by–turn (846 kHz) imaging
  - Allows to follow injection effect on stored beam for instance

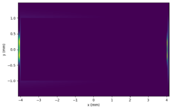




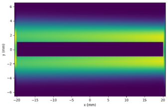
  - Even if not yet absolute beam size measurement...

$\rightarrow$ Very usefull for recent commissioning of MIK (to be published)

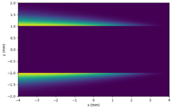
- Extraction mirror: back to SOLEIL–Upgrade topic...
  - For machine operation $\rightarrow$ slot height > 2 mm
  - For large large θ_x measurements $\rightarrow$ θ_x >20 mrad
  - For photon collection down to 200 nm $\rightarrow$ $d_{source-mirror}$ >3 m
  - But deposited power rapidly increases with $d_{source-mirror}\ldots$
  - And power density slowly decreases with $d_{source-mirror}\ldots$



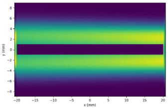
(a) D=400 mm, λ=200 nm.



(b) D=2000 mm, λ=200 nm.



(c) D=400 mm, λ=500 nm.

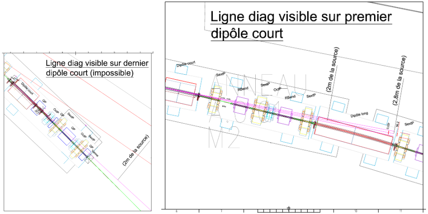


(d) D=2000 mm, λ=500 nm.

Intensity distribution at 200 and 500 nm at 0.4 and 2 m from source point. θ_X=20 mrad, θ_X=10 mrad.

$\rightarrow$ Extraction mirror design IS an issue... working on it...

- Beamline(s) integration:
    - Source dipole = short + free dipole
    - To enable large collection angle + limited power deposition on mirror:
      → extraction at *d* >2 m from source point.... with *free* path....



Integration of near–UV / visible beamline on short dipole. PRELIMINAR DESIGN.

→ Beamline integration IS ALSO an issue... working on it...

- Other components:
  - Transport mirrors, lenses, polarizer, bandpass filters, etc....
    → should be easy...
  - Fast computation of beam size (100 Hz):
    → could be more tricky... → to be tested on our visible beamline

→ A lot of preliminar work can be done on our visible beamline

Conclusion

- For $\epsilon_{x,y}$ ($\sigma_{x,y}$) measurements:
  - Pinhole + Fresnel diffraction in the X–ray range
  - Polarized + obstacle imaging in the near–UV/visible range

- Announcement: two post–doc positions opened at SOLEIL
  - Beam diagnostics for the new booster

    https://www.synchrotron-soleil.fr/en/job-offers/post-doctoral-position-boosters-diagnostics
  - Photon BPMs for the new storage ring front–ends

    https://www.synchrotron-soleil.fr/en/job-offers/post-doctorat-photon-bpm

$\rightarrow$ to work on diagnostics for SOLEIL–Upgrade