NanoMAX
Hard X-Ray Nanoprobe
@ MAX IV

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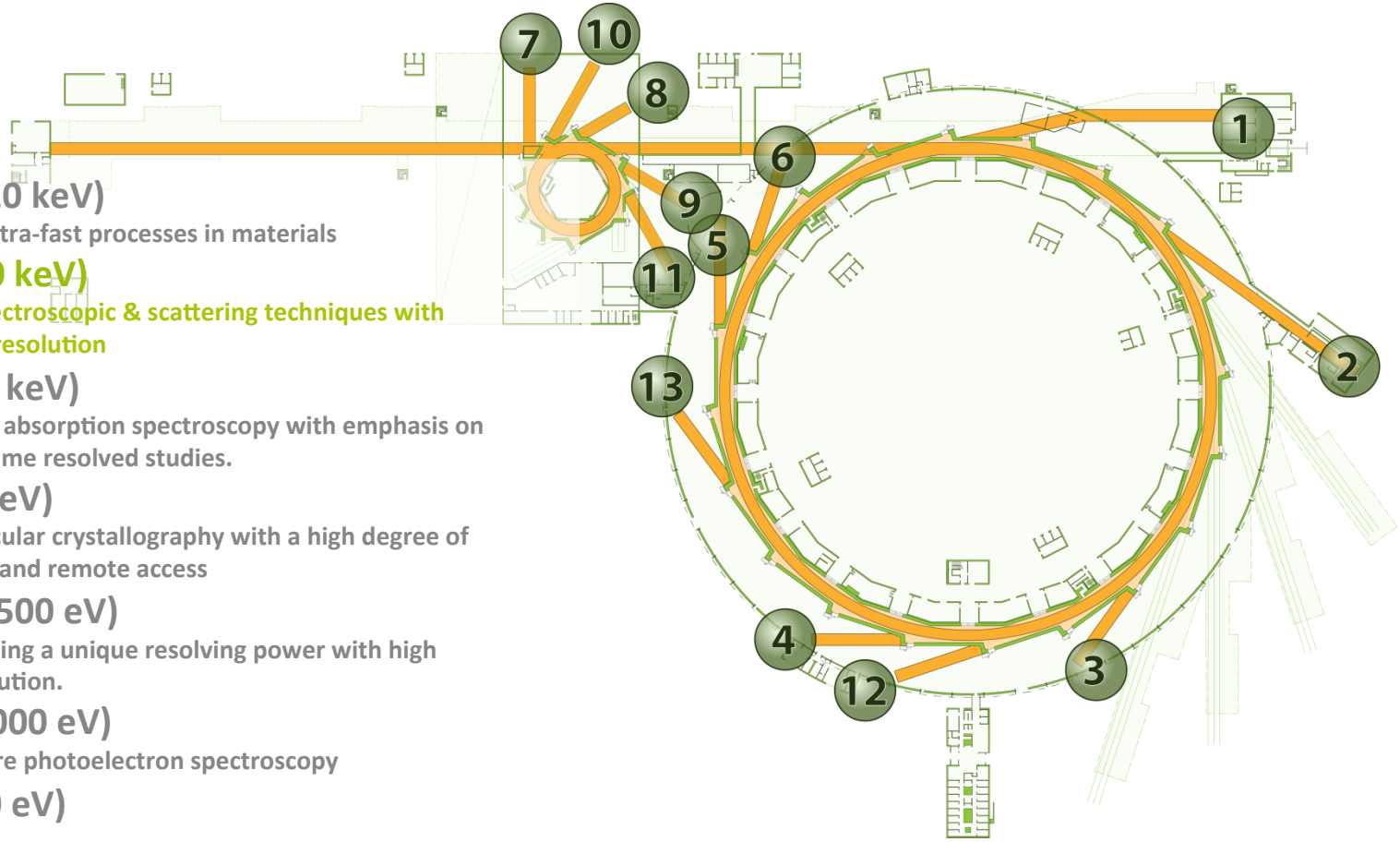
MAX IV

The 13 funded beamlines (photon energy)



1. FemtoMAX (2-20 keV)
   Studies of ultra-fast processes in materials
2. NanoMAX (5-30 keV)
   Imaging, spectroscopic & scattering techniques with nanometer resolution
3. BALDER (2.4-40 keV)
   (Hard) X-ray absorption spectroscopy with emphasis on *in-situ* and time resolved studies.
4. BioMAX (5-25 keV)
   Macromolecular crystallography with a high degree of automation and remote access
5. VERITAS (275-1500 eV)
   RIXS combining a unique resolving power with high spatial resolution.
6. HIPPIE (263—2000 eV)
   High-pressure photoelectron spectroscopy
7. ARPES (10-1000 eV)
   Angle resolved photoelectron spectroscopy for detailed studies of the electronic structure.
7. FinEstBeaMS (4-1000 eV)
   Estonian-Finnish Beamline for Materials Science
8. SPECIES (27-1000 eV) [Transfer]
   VUV High-pressure photoelectron spectroscopy and RIXS
10. FlexPES (40-1500 eV) [Transfer]
    Photoelectron Spectroscopy and NEXAFS
11. MAXPeem (30-1500 eV) [Transfer]
12. CoSAXS (4-18 keV)
13. SoftiMAX (250-2500 eV)
    Coherent Soft X-Ray Scattering, Holography…

NanoMAX Goals

- Utilize the **unique coherence** properties of MAX IV to produce an intense hard X-ray nanoprobe.
- Provide the smallest useful X-ray probe by using the best focusing X-ray optics available. Spatial resolution in **10-100 nm** range.
- Allow user configurable, flexible **sample environments**.
- Provide **various detection** methods, e.g. diffraction, fluorescence, absorption, phase contrast, coherent diffractive imaging methods.
- **Support** the users with efficient data analysis tools.
- The beamline should be adaptable to future developments in nano-**focusing optics**.

NanoMAX - Main specifications

Energy range	5 – 30 keV (3rd -17th harmonic from undulator)
Photon source	In-vacuum undulator, 2.0 meter magnetic length, 1.8 mm period, full harmonic overlap
Monochromator	Cryogenically-cooled silicon double crystal monochromator. Horizontal diffraction geometry
Focusing optics #1	Spatial resolution 30 – 50 nm (Fresnel zone plates), final goal ~10 nm, estimated flux on sample 3 10^{10} photons/second at 10 keV.
Focusing optics #2	Spatial resolution ≈100 nm (Kirkpatrick-Baez mirror system), estimated flux on sample ≈ $3 \cdot 10^{11}$ photons/second at 10 keV.
Main experimental methods	Scanning X-ray microscopy (SXM), X-ray Diffraction (XRD), X-ray fluorescence (XRF), Coherent Diffractive Imaging (CDI)

NanoMAX - Main issues

Stability	At all levels: environment, equipment units, sample, optics
Control	Beam & sample degrees of freedom
Access	Still be able to perform experiments
Science	Which experiments / techniques?
Data / Results	Users support for data analysis (as well)

Coherent flux at sample positions

Photon energy (keV)	5.0	8.3	10.0	11.6	25.0
Secondary source aperture for coherent illumination (mm)	19.09	11.46	9.55	8.18	3.82
Flux incident on 200 μm ZP at 35 m from SSA (ph/s)	3.7E+11	4.2E+11	2.9E+11	2.0E+11	9.6E+09
Flux after KB optics (300 μm) at 47 m from SSA (ph/s)	2.9E+11	3.3E+11	2.3E+11	1.3E+11	5.7E+09

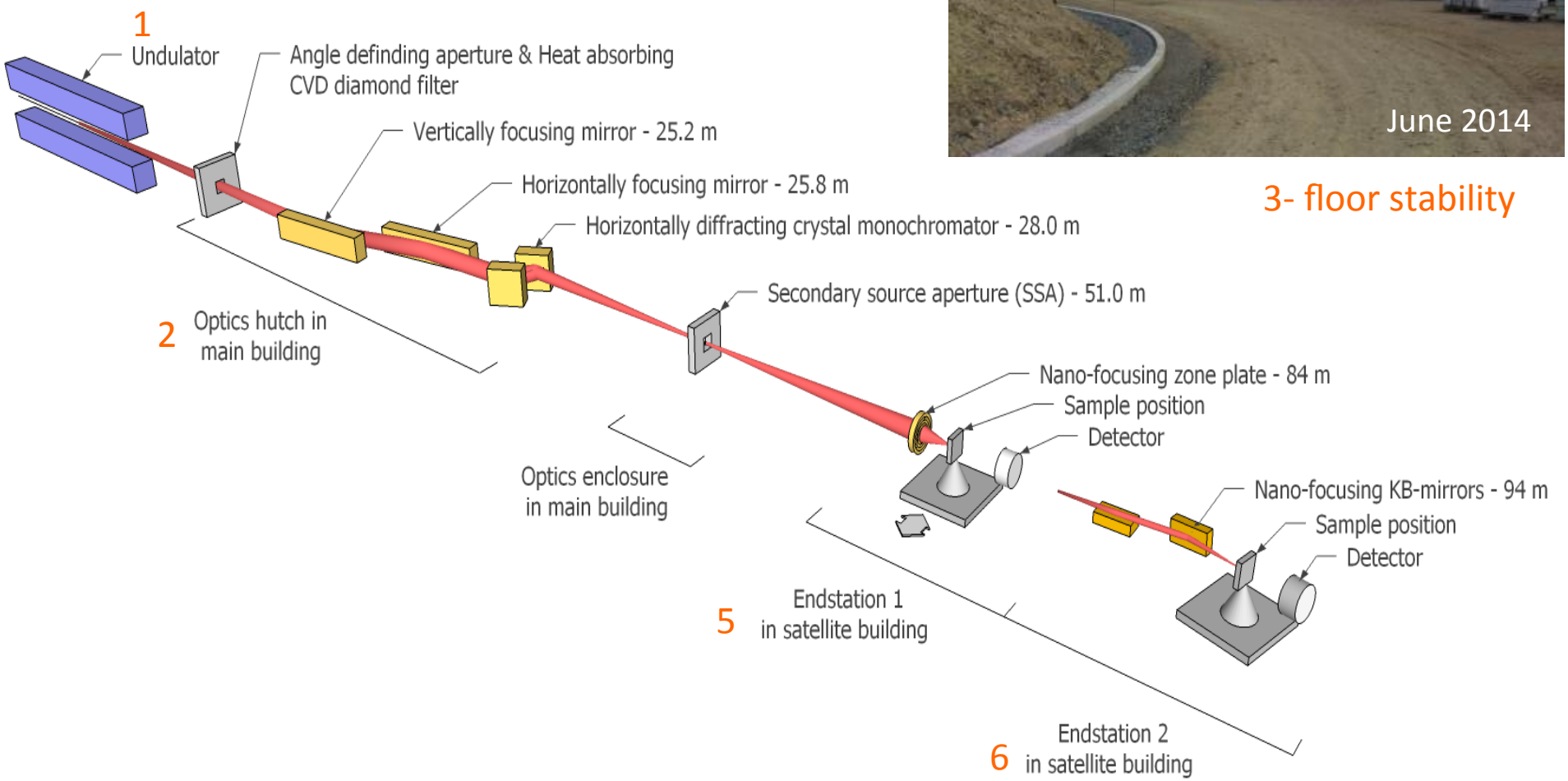
The numbers are calculated by Shadow ray-tracing taking into account:

- Heat load on Si(111) monochromator and mirrors
- Realistic reflectivity values on all optical components
- 2 meter in-vacuum undulator with K_{max} = 1.95 and 18 mm period length
- Note: The flux numbers are not for 0.1% BW but the actual Si(111) transmission
- Note: The flux numbers for ZP are not accounting for any ZP efficiency.

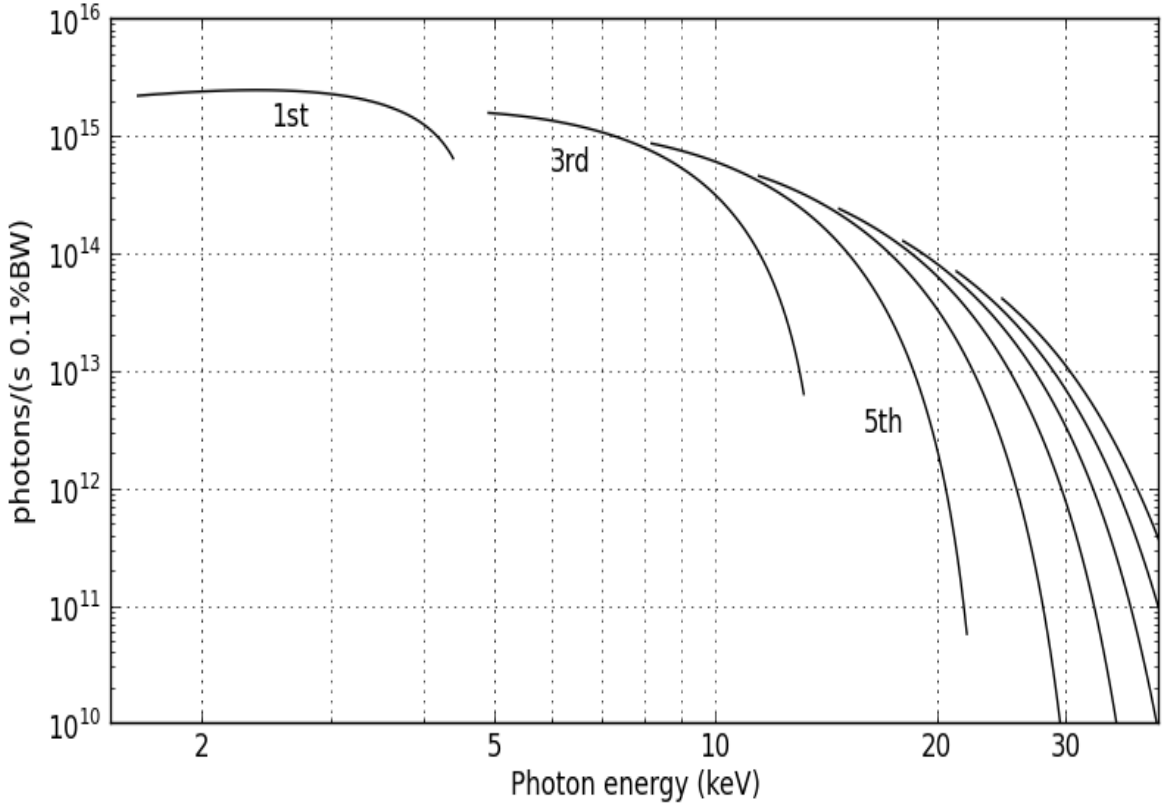
NanoMAX beamline

4
infrastructures

3- floor stability

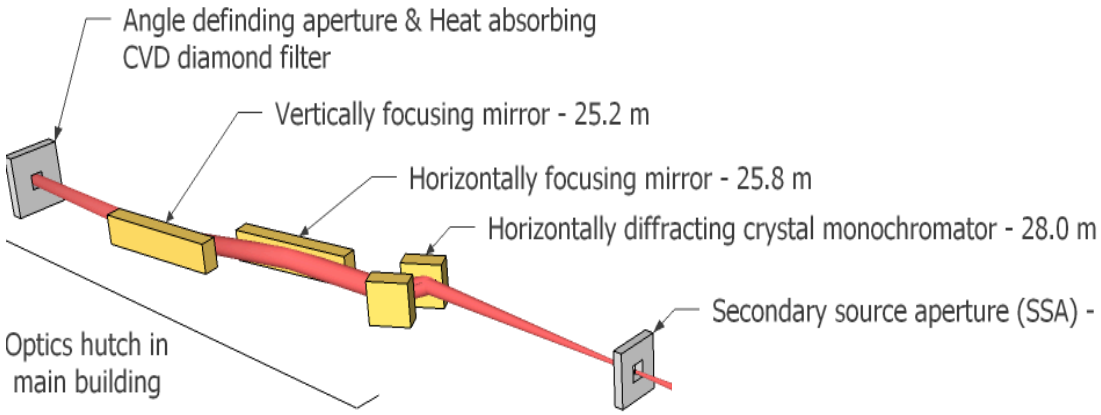


1. Undulator



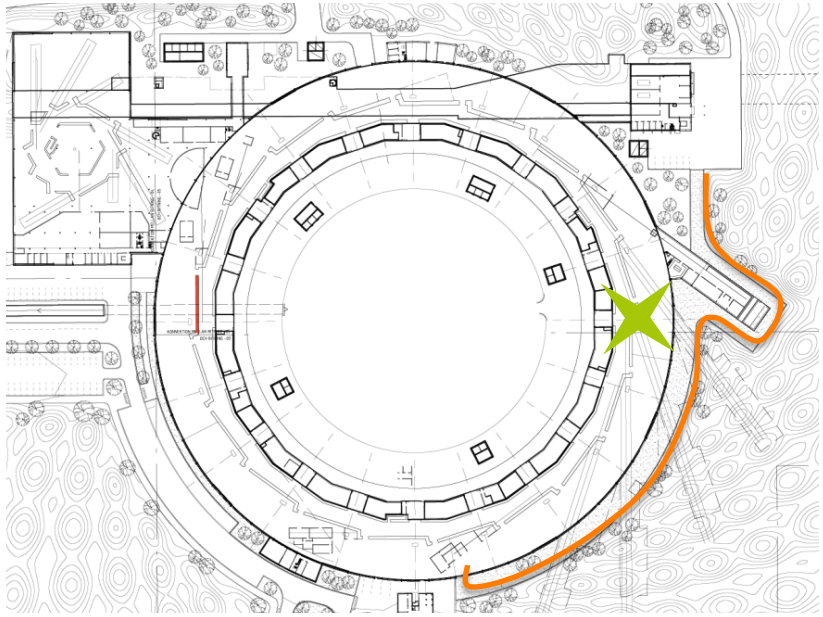
- In-vacuum undulator
- From HITACHI
- 2.0 meter magnetic length, 18 mm period
- Delilvery 2015

2. Optics



- Diagnostic module 1: fluo screen, heat-load mask 50 μrad(H) x 40 μrad(V)
- Mirrors: fixed curvature VFM (& flatVM) and bendable HFM (Si, Rh, Pt coating) by Zeiss
  - Supported on granite, decoupled from metallic frame, water cooled
- DM 2
- Mono: Si(111) cryo-cooled, horizontal geometry, high stability
- DM 3
- SSA: NanoBPM & sub-micron precision slits for beam definition
- NanoBPM & active feed-back on mirrors (?)
- FMB Oxford. Procurement 2014, delivery May 2015 (well on track)

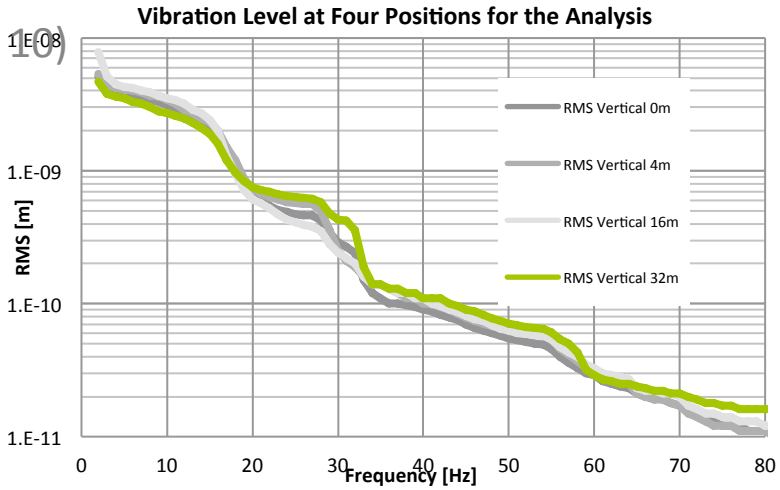
3. Floor stability and test



- NanoMAX is built on the *same* slab as MAX IV ring
- On this sector there is space for 4 more long BL

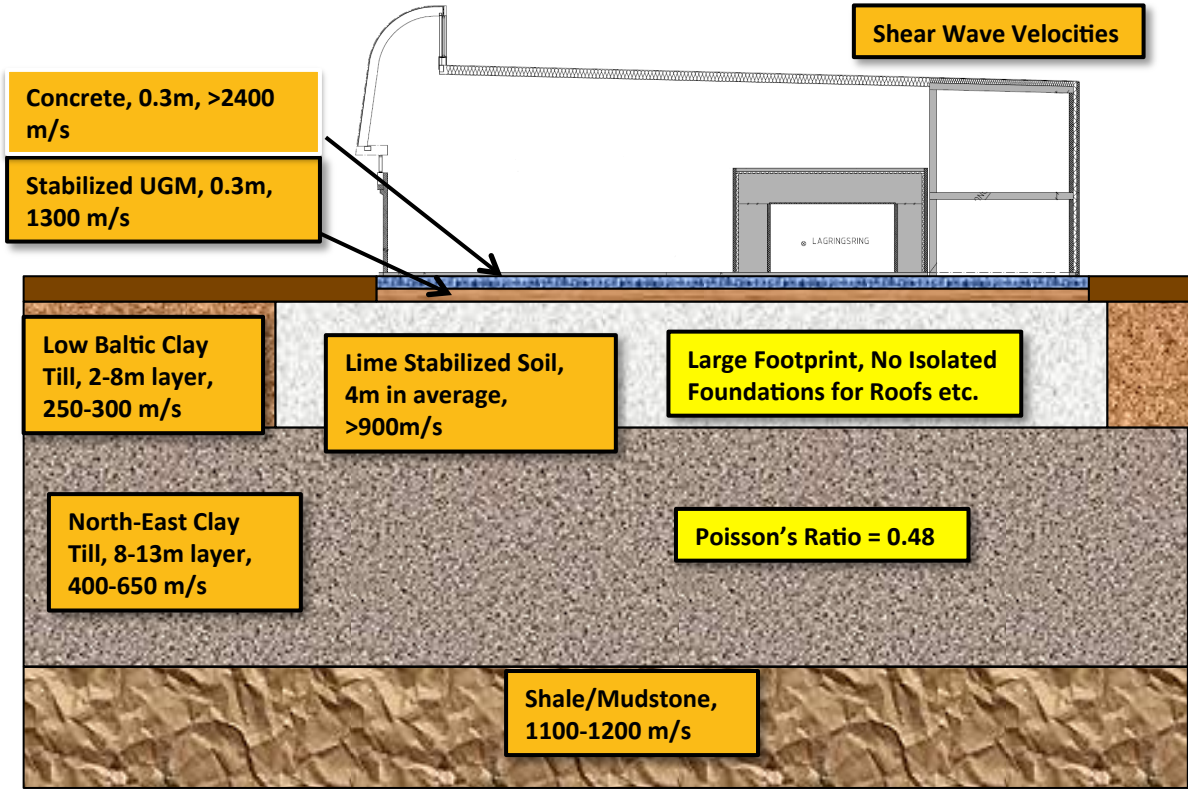
- MAX IV is near highway (but NanoMAX is far ☺)

- Floor specs: 10 nm amplitude (machine amp. factor 10)
  - Magnet vibrating in phase -> AF = 3.5
  - Magnet vibrate independently-> AF= 15
- Test on vibration levels near NanoMAX:
  - RMS ~ 3-5 nm for f < 10 Hz
  - RMS ~ 1-2 nm for 10 < f < 20 Hz
  - RMS < 1 nm for f > 20 Hz
- Tests on vibration @ NanoMAX are planned



Courtesy of Brian Norsk Jensen – Nils Rydén

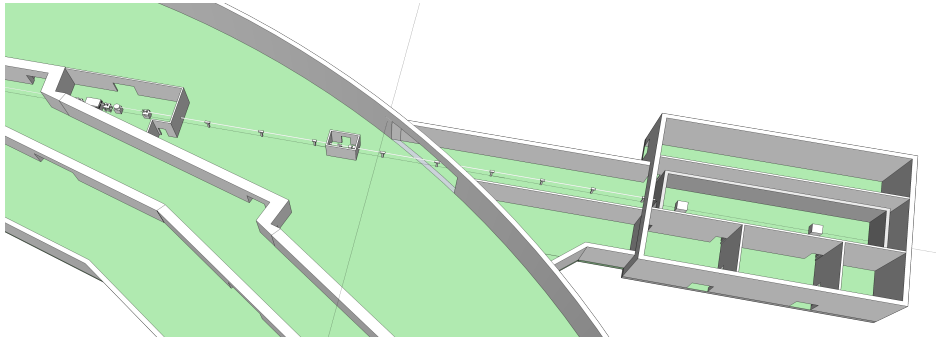
3. Floor stability



Courtesy of Brian Norsk Jensen , Nils Rydén

- Soil characteristics give a vibration amplitudes ratio of H ~2 x V
  - Stiff concrete slab reduces horizontal (compressive) waves
  - Reduced sensitivity to external vibration is measured
  - Large height correlation at " long" distances (30 m)
- Highway traffic: cars background and trucks events
  - 100nm peak values and 20-30 nm RMS averaged on truck events

4. Infrastructure



- Satellite building 50 m outwards
- Hutch with double enclosure, thermally insulated from external building
- Large hutch (5m x 20m x 4m)
- Large volume air conditioning system (temperature control $^{+}$/- 0.1^{o}C)
- Policy for keeping stability and minimise thermal gradients (in space and time)
  - No entrance near satellite building (only safety exit)
  - Small windows in control cabins (just for design / architecture purposes!)
  - Electronics racks in ventilated & temp-controlled cabinets
  - Double-door to access EXP Hutches
  - Vacuum: ion pumps (central system for " rough" pumping decoupled from floor)

5. Experimental Hutch #1 (10 nm - FZP)

- Xyz-scanning + rotation
- Interferometry control
- continuous (fast) acquisition
- cryo-cooling (at a later stage)
- on-chip sample environment

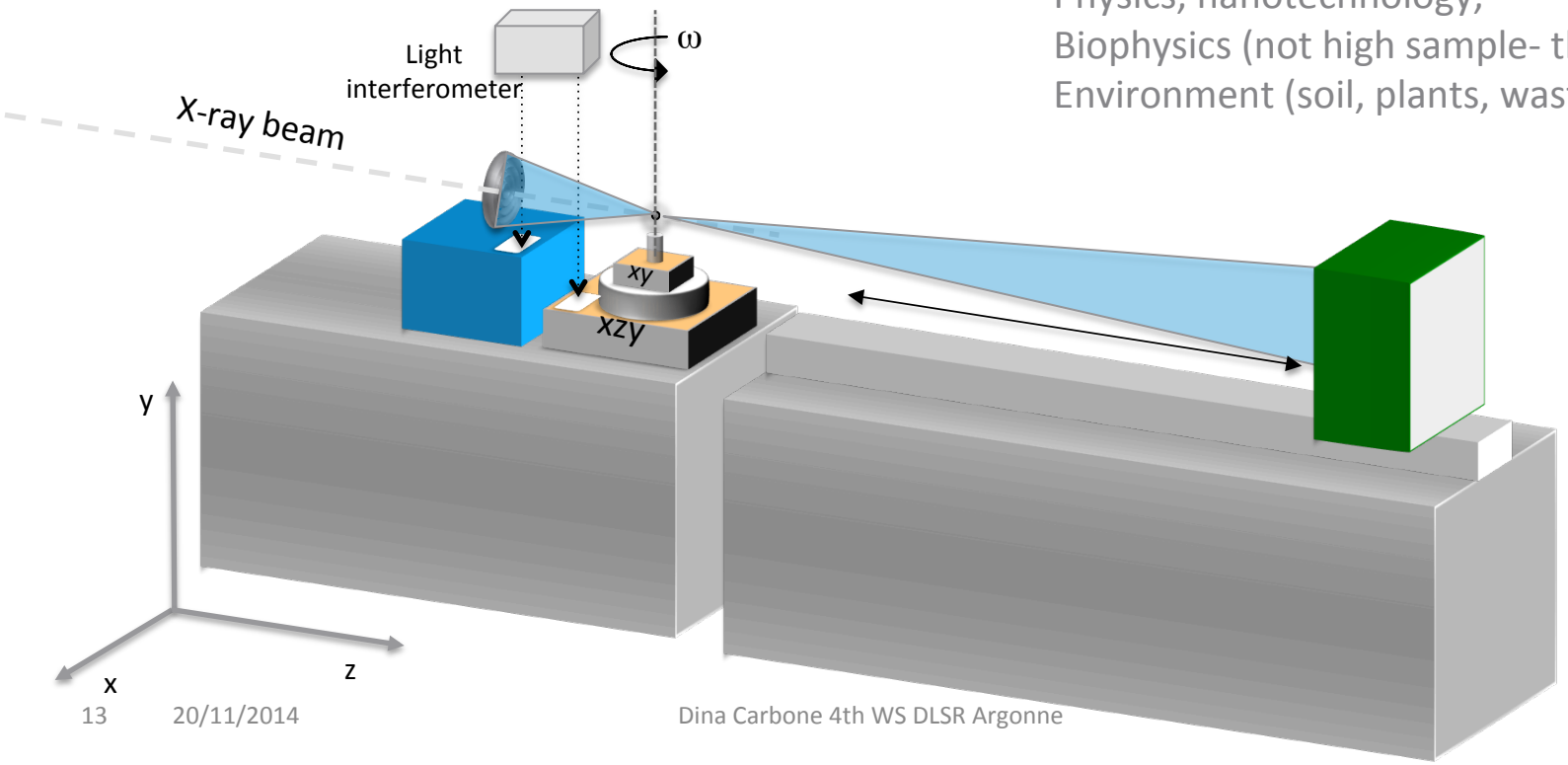
- pxl detector -adjustable distance
- fluorescence detector
- In-plane detector rotation (Bragg) ?

3D imaging Tomography

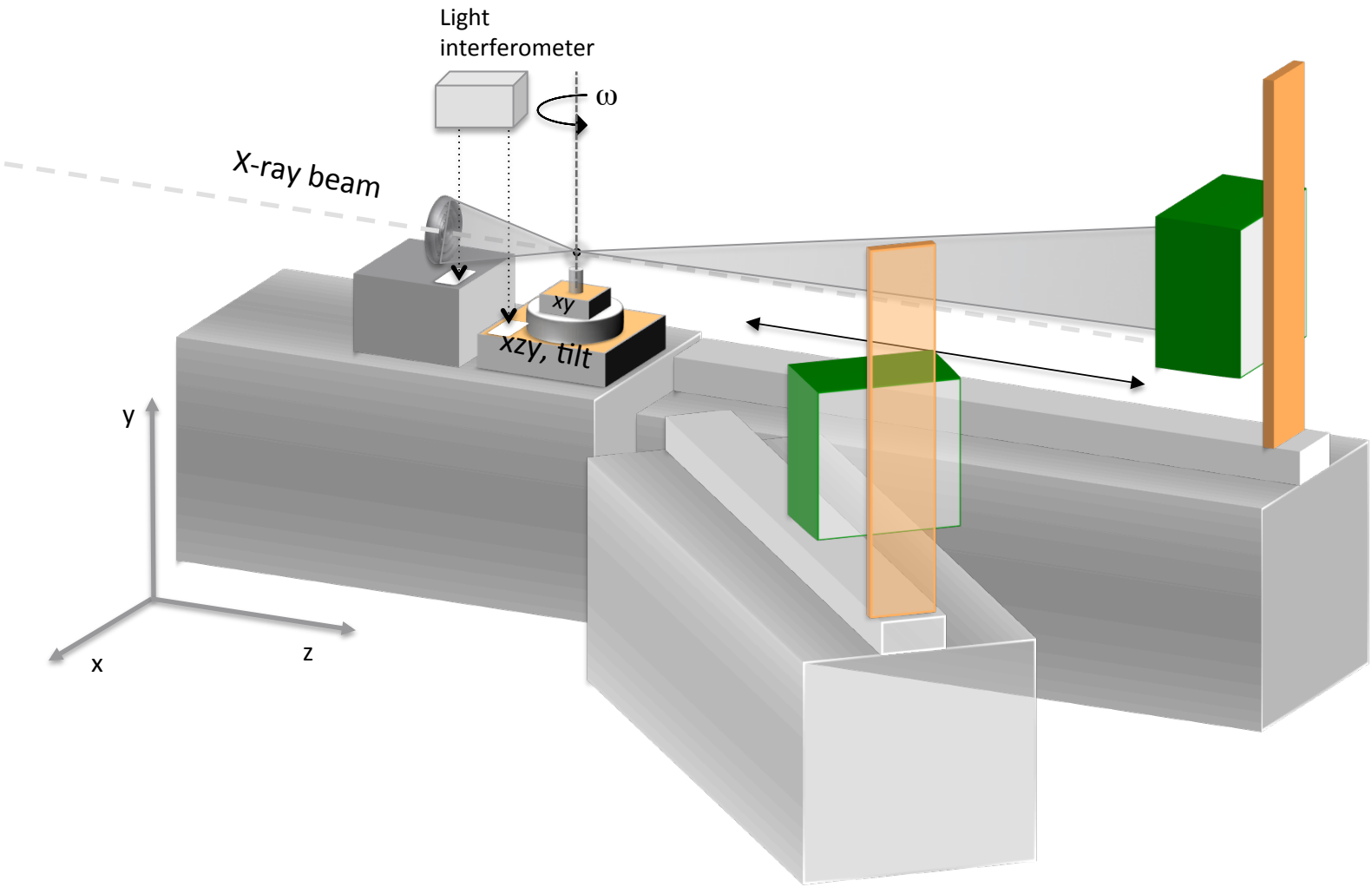
- fluorescence
- absorption
- ptychography

Materials science

Physics, nanotechnology,
Biophysics (not high sample- throughput)
Environment (soil, plants, waste)



Nano_2



6. Experimental Hutch #2 (100nm - KB)

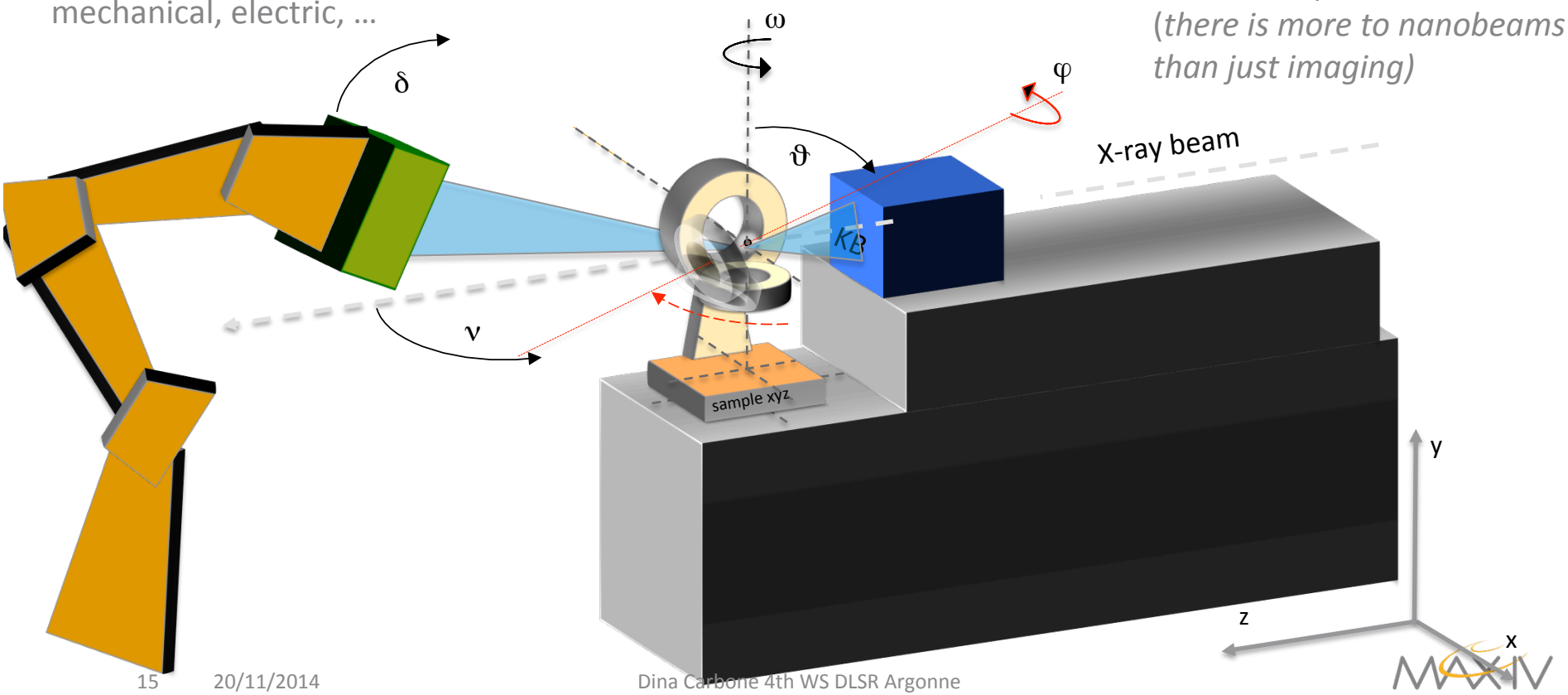
- 3 - circle goniometer
- Robot (2-circle detector arm)
- high precision Hexapod
- "complex" sample environment: controlled atmosphere and temperature, external applied fields, mechanical, electric, …

- pxl detector (Merlin ? QD)
- fluorescence detector
- space available for users equipment
- option of FZP

2D and 3D imaging in Bragg

- Scanning diffraction
- Bragg Ptychography
- fluorescence
- local XRD probe

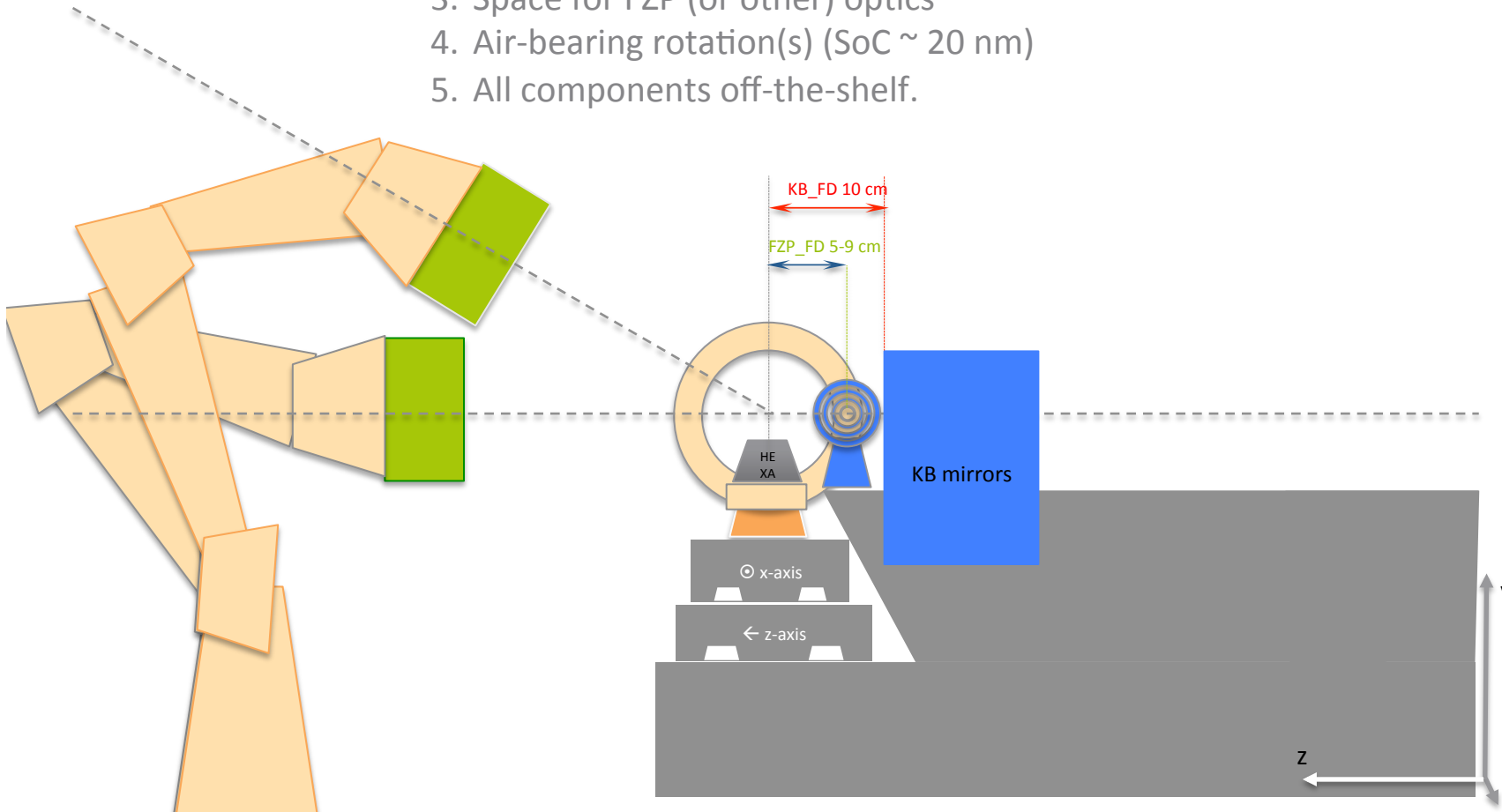
(*there is more to nanobeams than just imaging)*



6. Experimental Hutch #2 (100nm - KB)

Design:

1. KB systems heavily embedded in the granite support (not z-axis adjustment)
2. Goniometer on granite block (on air-bearing translations)
3. Space for FZP (or other) optics
4. Air-bearing rotation(s) (SoC ~ 20 nm)
5. All components off-the-shelf.



Data

- High-flux ==> high data-rate
- Data handling, 3D on-line rendering
- Software: easy access/use for users

- Establish a platform for (Imaging) data analysis
- Collaboration (methods, math, software, analysis-visualisation tools)

- Need to coordinate efforts towards a " global approach" from SR facilities worldwide? (data format, acquisition schemes) for the user's sake

Example of data flow

research papers

Journal of
Applied
Crystallography
ISSN 1600-5767

Received 13 December 2013
Accepted 26 February 2014

Imaging of strain and lattice orientation by quick scanning X-ray microscopy combined with three-dimensional reciprocal space mapping

Gilbert André Chahine,[a]* Marie-Ingrid Richard,[b,a] Roberto Arturo Homs-Regojo,[a] Thu Nhi Tran-Caliste,[a] Dina Carbone,[a] Vincent Louis Robert Jaques,[a] Raphael Grifone,[a] Peter Boesecke,[a] Jens Katzer,[c] Ioan Costina,[c] Hamid Djazouli,[a] Thomas Schroeder[c] and Tobias Urs Schülli[a]

- A Maxipix fast readout photon counting

(frame rates of up to 300 Hz full frame) detector of 516 x 516 pixels *and 55µm pixel size*

- For this measurement, 17 2D maps (35 x 90 points) were recorded for 17 incidence angles, leading to 907 256 detector images

(data volume of about 1 TB recorded in 3 h) **(0.012s per point, 0.01s exposure)**

- "[...]. At data rates of a few gigabytes per minute*, the bottleneck for this type of scanning probe technique is the data treatment*, especially to achieve real time visualization. "

Example of data analysis

SCIENTIFIC REPORTS

OPEN

SUBJECT AREAS:
TECHNIQUES AND INSTRUMENTATION
IMAGING TECHNIQUES

Received

X-ray ptychographic computed tomography at 16 nm isotropic 3D resolution

M. Holler[1], A. Diaz[1], M. Guizar-Sicairos[1], P. Karvinen[1], Elina Färm[2], Emma Härkönen[2], Mikko Ritala[2], A. Menzel[1], J. Raabe[1] & O. Bunk[1]

- **720 projections** with ptychographic scans of **343 exposures** for a total of **246 960 images** (**0.81 s per point**, **exposure 0.6 s)**

Data volume of about 5 Giga/hours for about 56 hours

*at Nanomax could go up to 25GB/***1 h** *(not crucial...)*

Data Analysis!!!

Bragg case: N x M **3D** matrices of 516 x 516 x 300 pixels
Have to be used for every iteration!!

- 343 matrices of 516 x 516 pixels
- 200 - 300 iterations of the Ptycho-engine for every one of the 720 projections
- for every iteration 4 x 2D matrices are used for computation