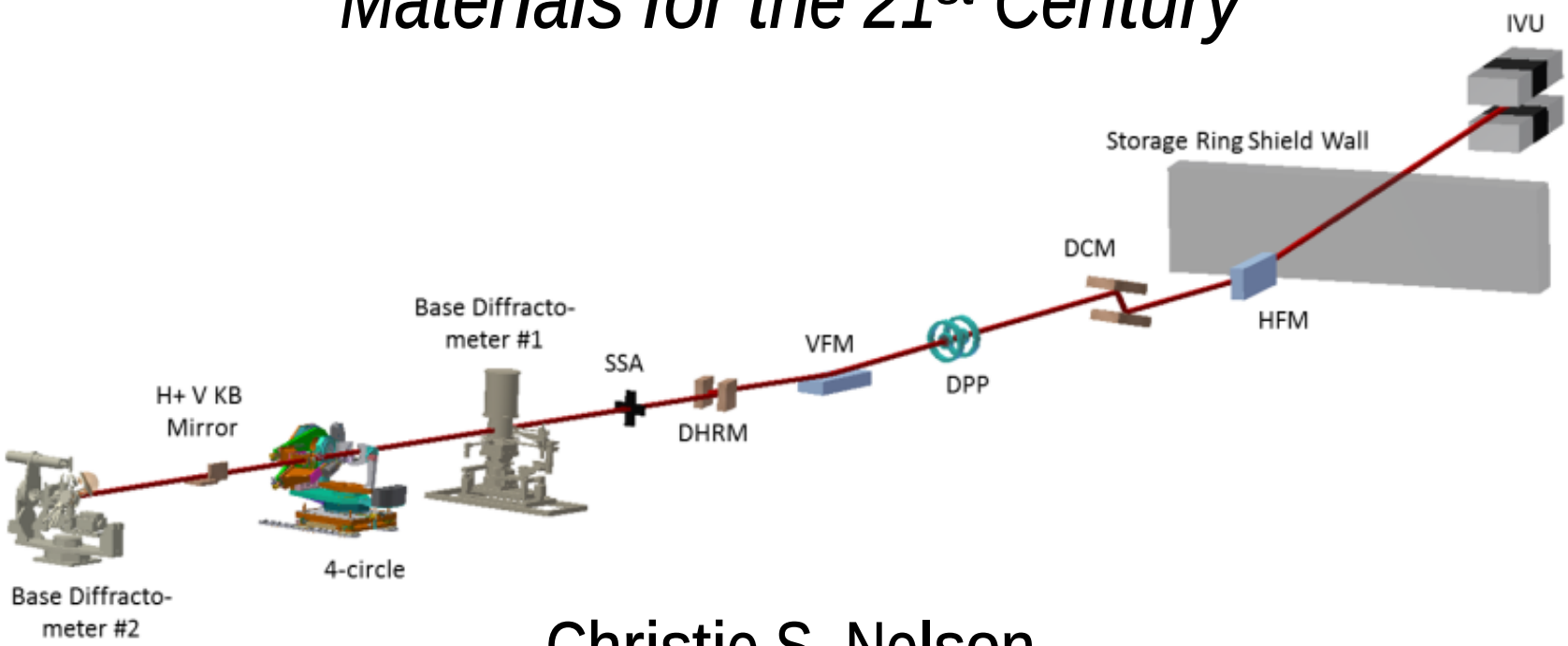
In-Situ and Resonant Scattering (ISR):

an NSLS-II Beamline for Illuminating the Physics of Materials for the 21st Century



Christie S. Nelson

ISR Group, Photon Division, Photon Sciences Directorate, BNL

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ISR Team

Beamline Advisory Team

Karl Ludwig (chair), Boston University

Joel Brock, Cornell University

Randy Headrick, University of Vermont

Jean Jordan-Sweet, IBM

Valery Kiryukhin, Rutgers University

Jonathan Lang, APS, ANL

Paul Lyman, University of Wisconsin – Milwaukee

Jörg Strempfer, Petra-III, DESY

and with input from: Roy Clarke, Matt Dawber, John Hill, Michael Pierce, Oleg Shpyrko, Barrett Wells, Phil Willmott, Arthur Woll, . . .

Beamline Development Team at NSLS-II

Kenneth Evans-Lutterodt

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Zhijian Yin

and with help from: Andrew Ackerman, Chris Amundsen, Andy Broadbent, Oleg Chubar, Lewis Doom, Andrei Fluerasu, Eugene Hu, Steve Hulbert, Mourad Idir, Steve LaMarra, Steve O'Hara, Ron Pindak, Sal Pjerov, Viswanath Ravindranath, Ruben Reininger, Lori Stiegler, Paul Zschack, . . .

2010 Beamline Development Proposal Team Members

Materials Physics Challenge

Novel Materials Enhance Devices Addressing Societal Needs in Energy and Information Technology

Solid State Lighting	***Fuel Cells***	***Solar Energy Conversion***	***Thermoelectrics***	***Information Processing & Storage***

Top-Down & Bottom-Up Atomic-Level Growth Strategies Used to Produce Novel Device Materials

Control Chemical Reactions at Surfaces	*Develop High Functionality Organic Films*	*Engineer Interfaces for Novel Properties*	*Develop Materials with Multi-Functionality*	*Grow Materials with Spin Control*	*Nanostructure Growth via Self-Assembled Processes*

DOE Grand Challenges

- ***How do we characterize and control matter away – especially very far away – from equilibrium?***
- ***How do remarkable properties of matter emerge from complex correlations of the atomic or electronic constituents and how can we control these properties?***
- ***How do we design and perfect atom- and energy-efficient synthesis of revolutionary new forms of matter with tailored properties?***

ISR Capabilities

- Resonant scattering with energies 2.4-23 keV, and ~10^{-4} $\Delta E/E$
- Controllable incident polarization and polarization analysis
- Microfocusing with large (~1 m) working distance
- Highly flexible range of sample environments
- On-the-fly scanning
- Large area detectors
- Provision for future expansion:
  - Canted build-out
  - Partnership with MPP

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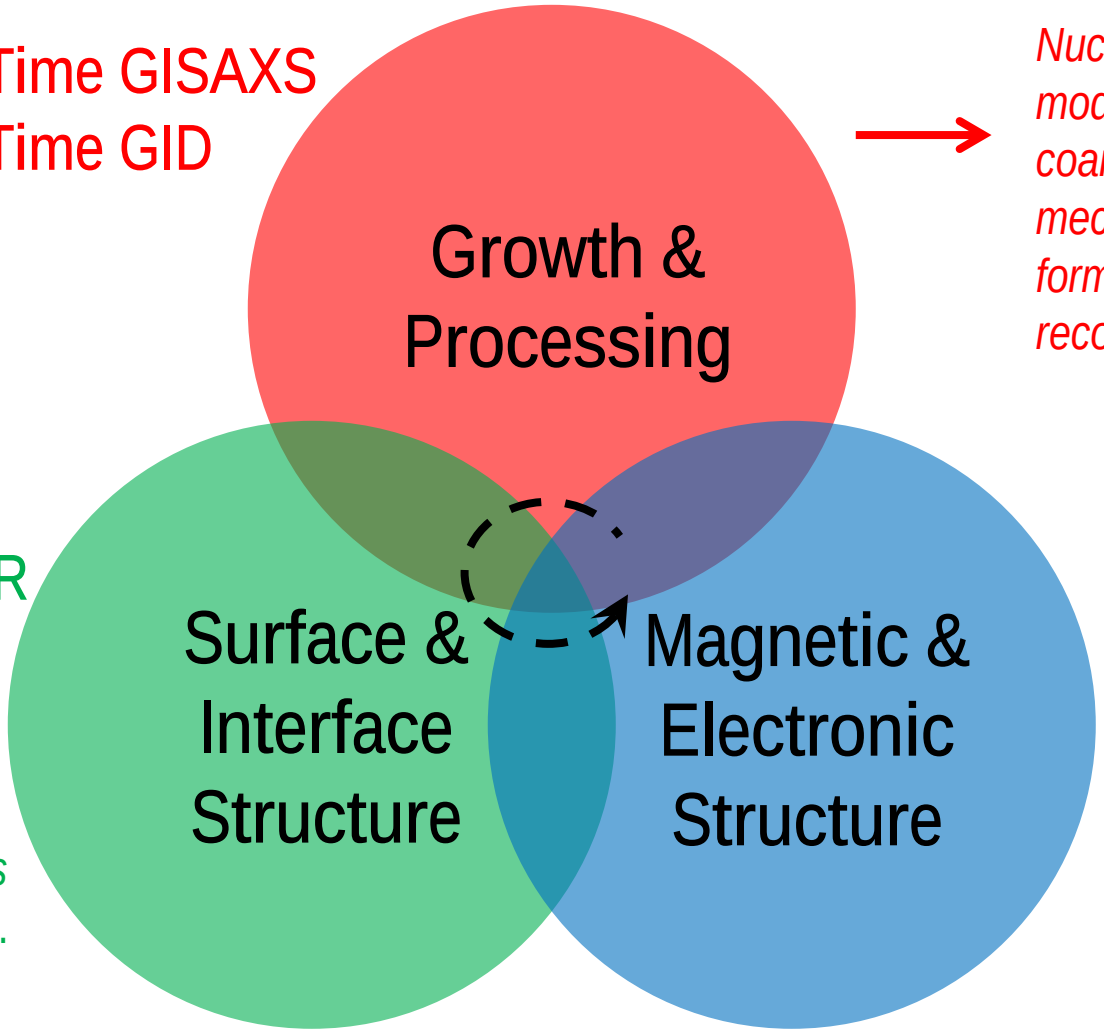
ISR Scientific Mission

Real-Time GISAXS
Real-Time GID
XRIM

Nucleation, growth modes, roughening and coarsening mechanisms, interface formation, surface reconstruction, etc.



CTR
Anomalous CTR
XRR

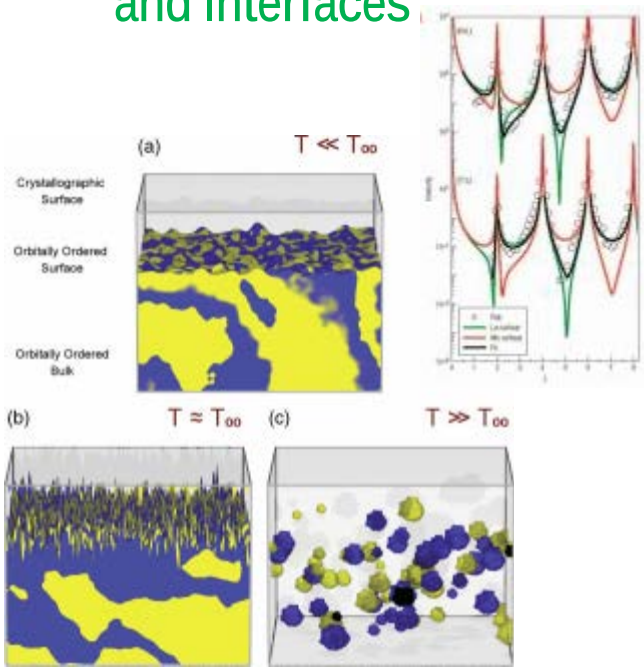
Electron density maps with atomic resolution.

RXS
Polarized XRD

Magnetic order, anisotropic charge distributions, and higher order multi-pole order.

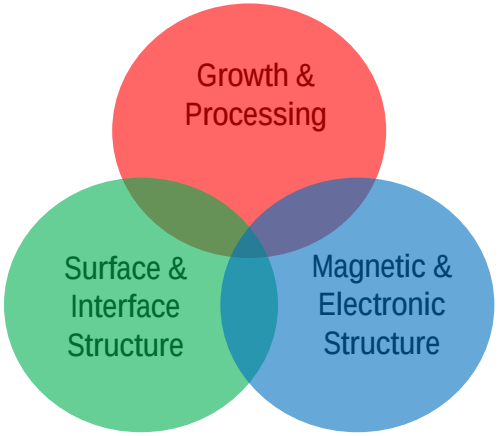
ISR Scientific Mission

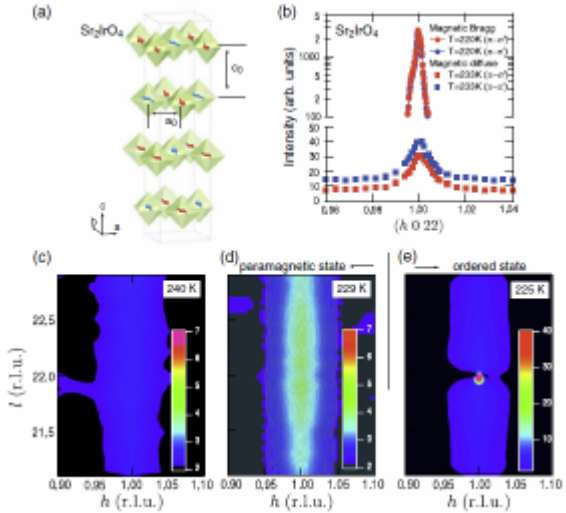
Functional Surfaces and Interfaces

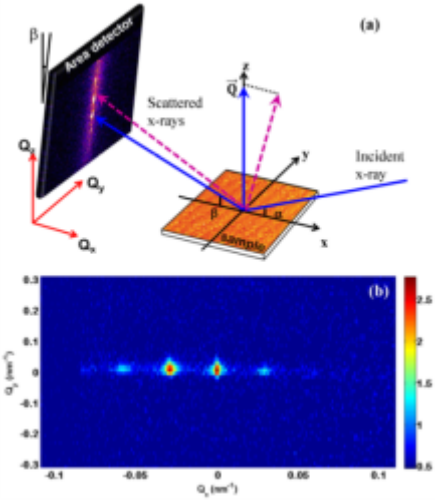


Surface orbital order in $La_{0.5}Sr_{1.5}MnO_4$, Wakabayashi *et al.*, Nature Materials 6, 972 (2007) and Wilkins *et al.*, PRB 84, 165103 (2011)

Surface and Thin-Film Growth Processes







Growth modes of $BiFeO_3$ during PLD and sputter deposition, Chinta *et al.*, APL 101, 201602 (2012) and PRL 112, 075503 (2014)

Correlated Electron Materials

Two-dimensional fluctuations of J_{eff} = ½ isospins in the paramagnetic phase of Sr_2IrO_4, Fujiyama *et al.*, PRL 108, 247212 (2012)

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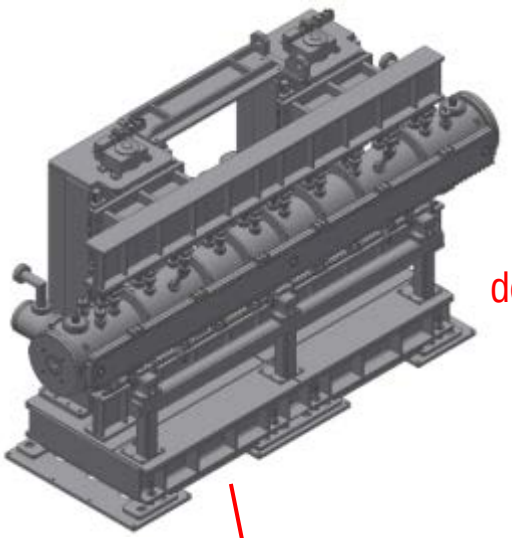
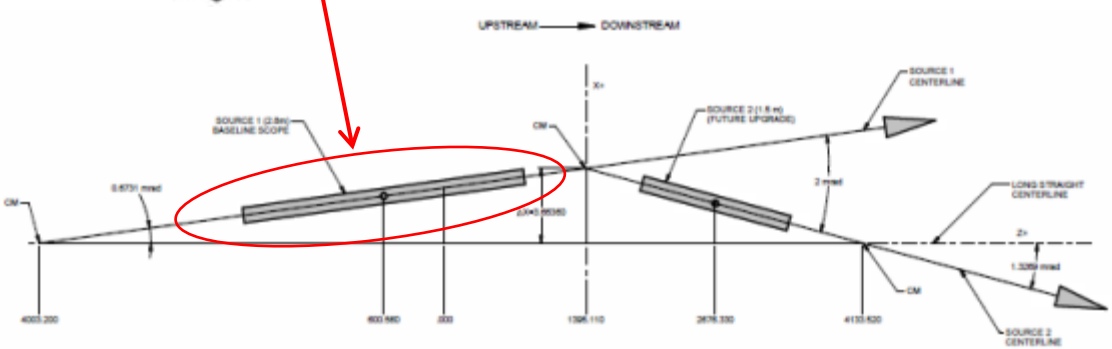
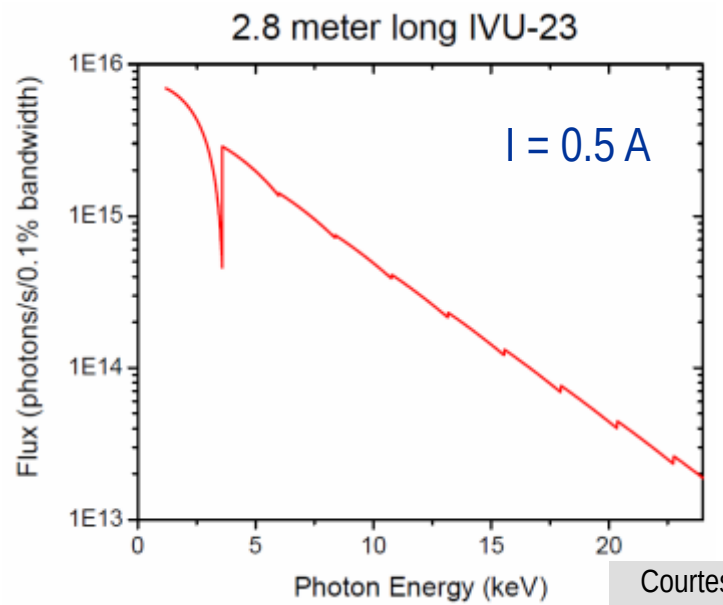
ISR Source: IVU-23 in a long straight

23 mm period, 116 periods, 5.9 mm minimum gap (K_{max} = 2.10)



NEOMAX Engineering (Hitachi) with delivery scheduled for July 2014





Courtesy Oleg Chubar

Gain compared to X21 wiggler (at 10 keV):

Flux = factor of ~3

Brightness = factor of ~3000

>10^{13} photons/s on the sample at 10 keV

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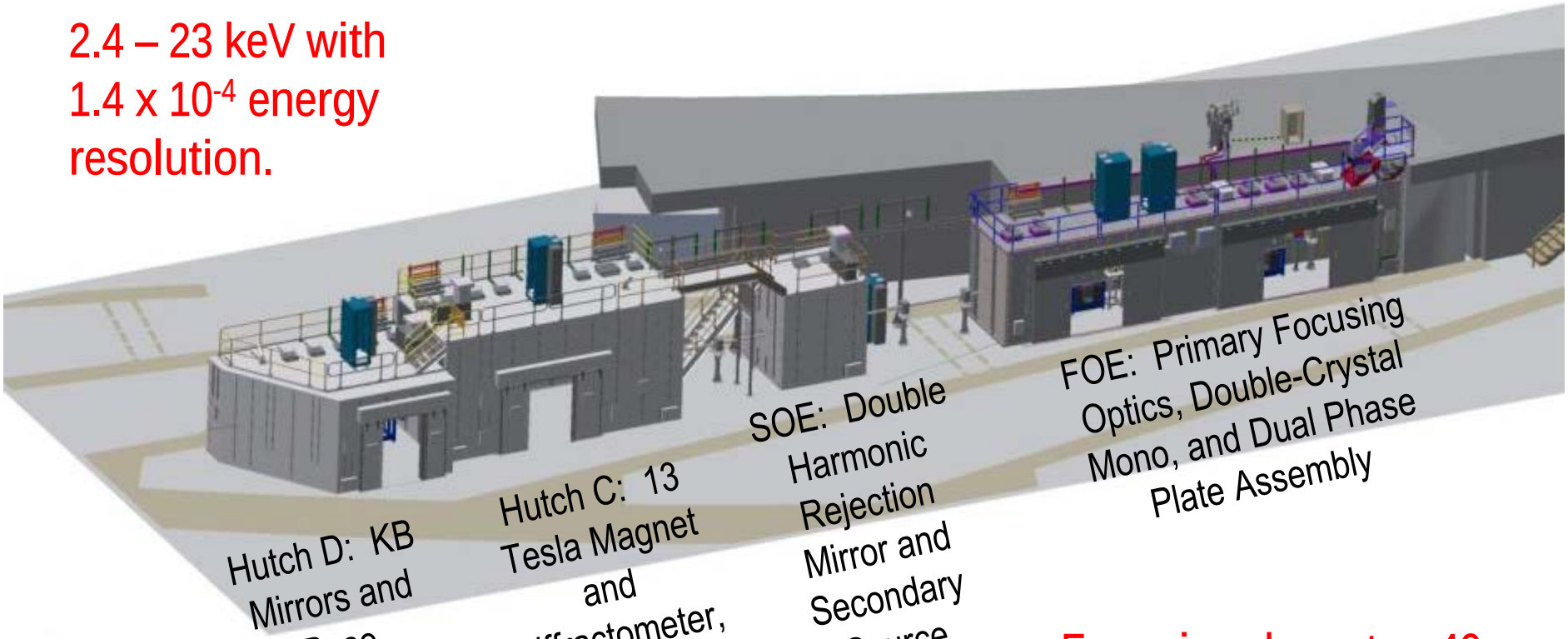
ISR Design

2.4 – 23 keV with 1.4×10^{-4} energy resolution.



Focusing down to ~40 μm (V) x 200 μm (H) in Hutch C, and ~2 μm (V) x 20 μm (H) in Hutch D.

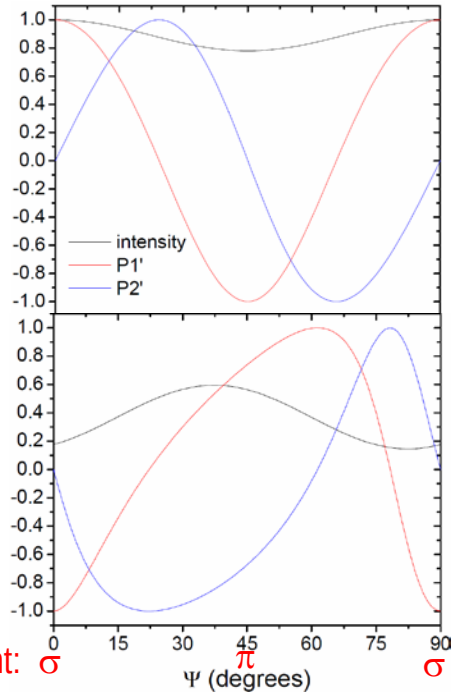
Polarization Control

Polarized x-rays provide access to different scattering channels. Scattering from magnetic order, anisotropic charge distributions, and higher order multipole order has a different polarization dependence than conventional x-ray scattering:

Scattered Intensity and Polarization at 2θ = 28˚

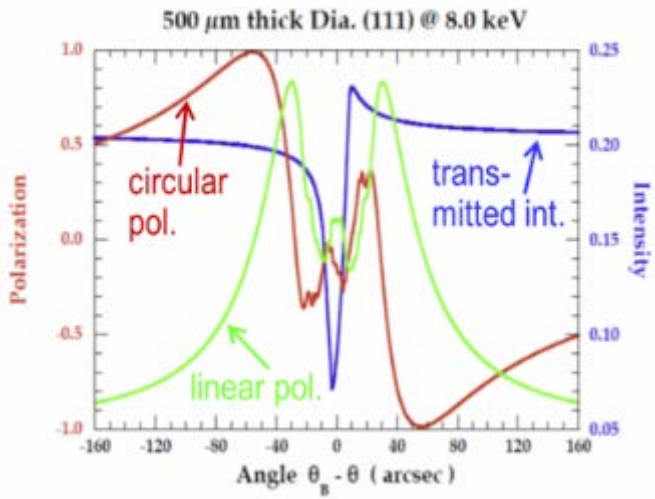
charge

resonant magnetic with M || [111]



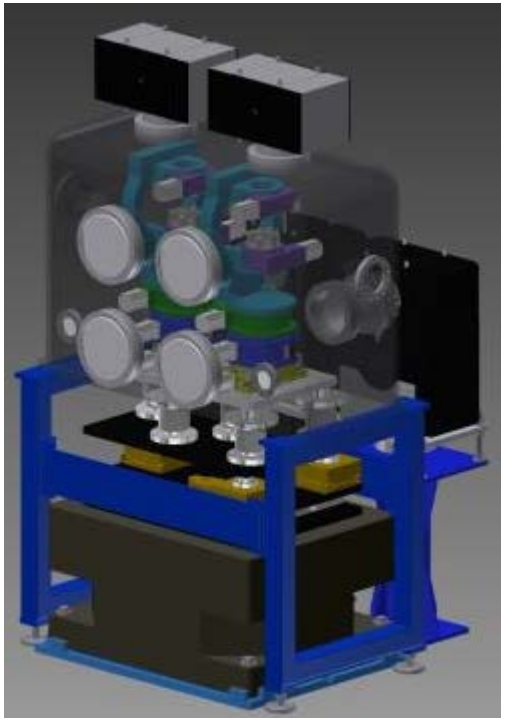
incident: σ π σ

Bragg Transmission Phase Plate



Courtesy Jonathan Lang

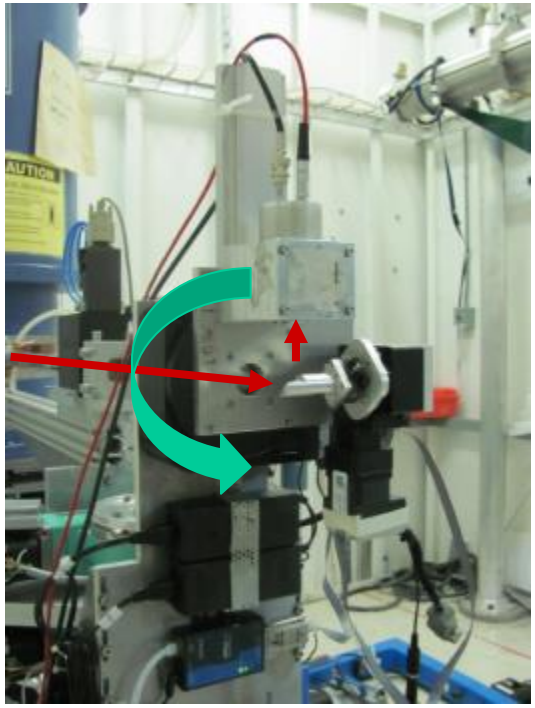
Conceptual Design of ISR Dual Phase Plate Assembly



Variable linear and circular incident polarization for 2.4 – 14 keV. Polarization analysis using analyzer crystals.

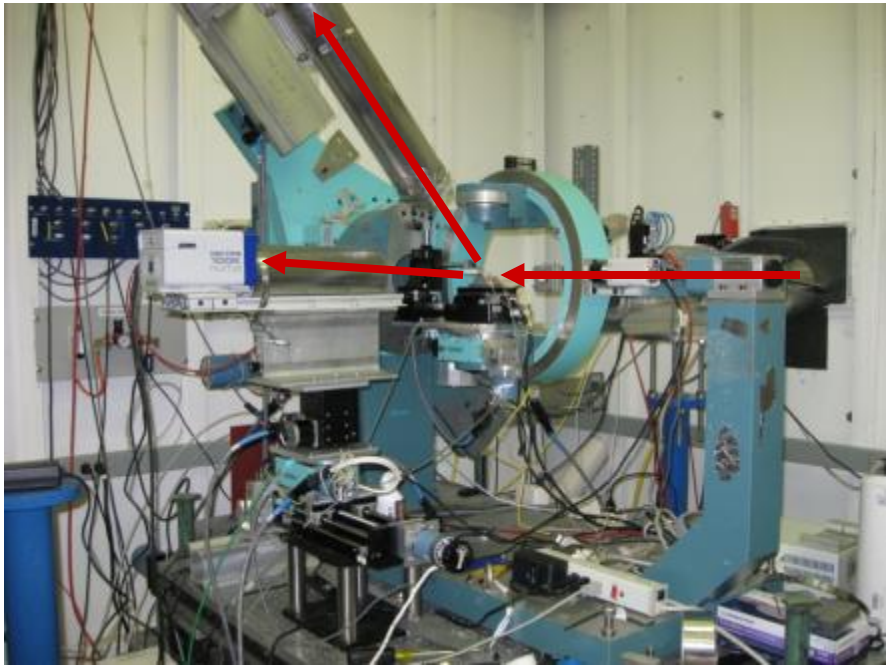
Magnet and Diffractometer in Hutch C

Polarization Analyzer



- H: 0-13 Tesla
- T: 1.8-300 Kelvin
- X-ray energies: $\gtrsim$ 6 keV

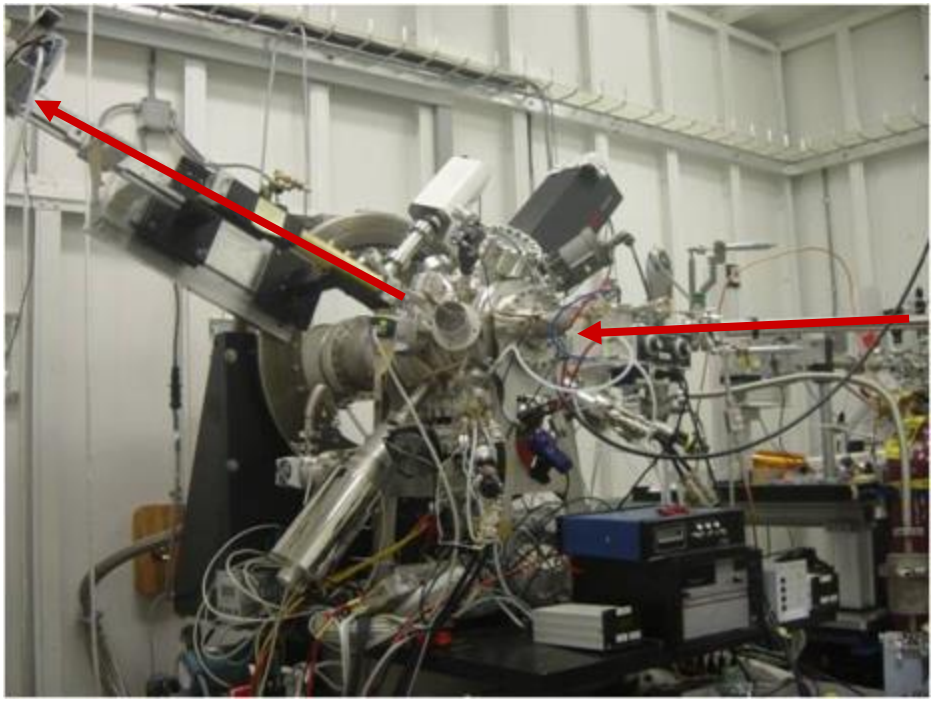
4-Circle Diffractometer in Hutch C



- ~40 (V) μm x 200 (H) μm spot size
- X-ray energies: 2.4 – 23 keV
- Additional endstation equipment:
  - Displex cryostat (temperature range of 6.5 – 350 K)
  - Pilatus area detector
  - Vortex detector

We anticipate replacing the 4-circle with an instrumented 6-circle, which will have a motorized displex mount and in-vacuum polarization analyzer.

In-Situ Endstation in Hutch D



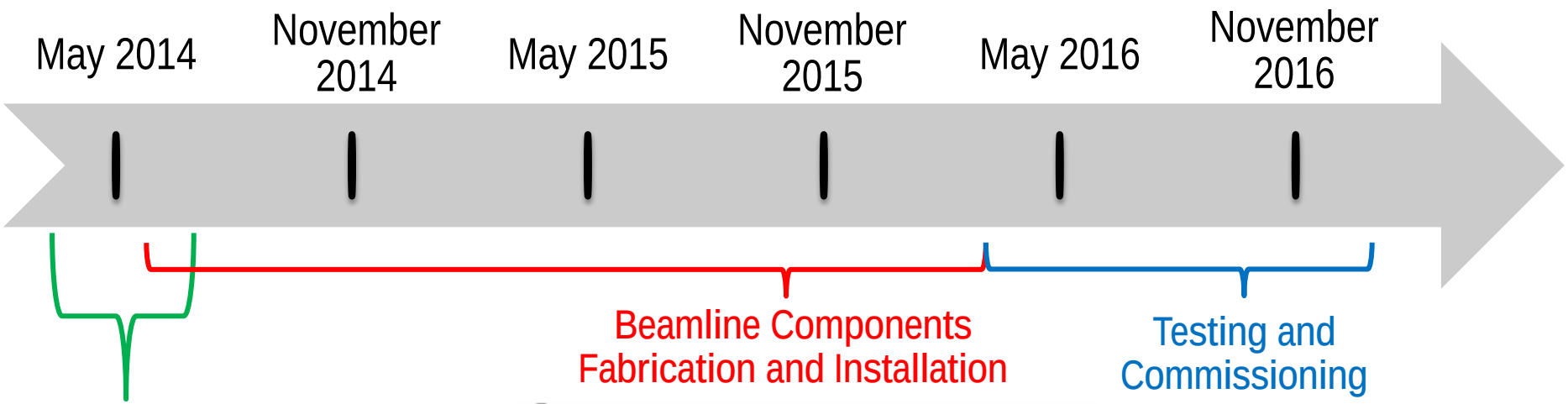
- ~2 (V) μm x 20 (H) μm spot size
- X-ray energies: 2.4 – 23 keV
- On-the-fly scanning capability
- Gas handling/exhaust infrastructure

PLD Laser

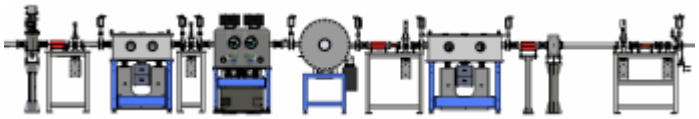
Endstation contributed by prospective Partner Users Karl Ludwig (BU), Randy Headrick (U of VT), and Matt Dawber (Stony Brook).

ISR Status

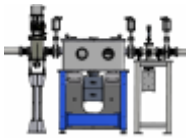
ISR is one of the NEXT Project beamlines. We have CD-2/3a approval, and are in the midst of long-lead procurements, which includes the ISR FOE optical components package.



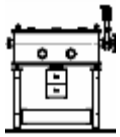
FOE:



SOE:



KB in D:



First experiments anticipated in early 2017.

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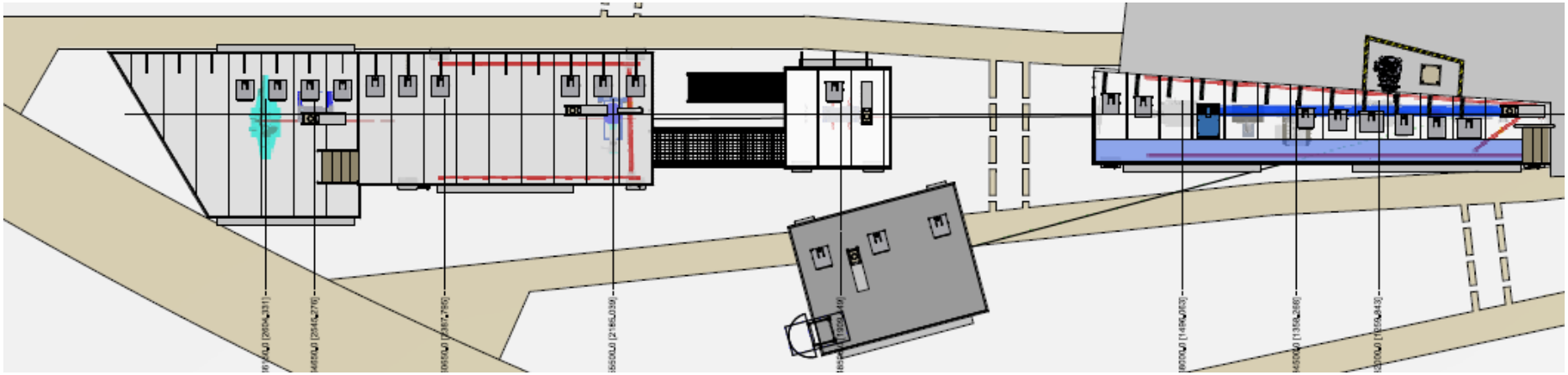
Planned ISR Upgrades

- KB mirrors in Hutch C for microfocusing at the 4/6-circle

Canted Build-out



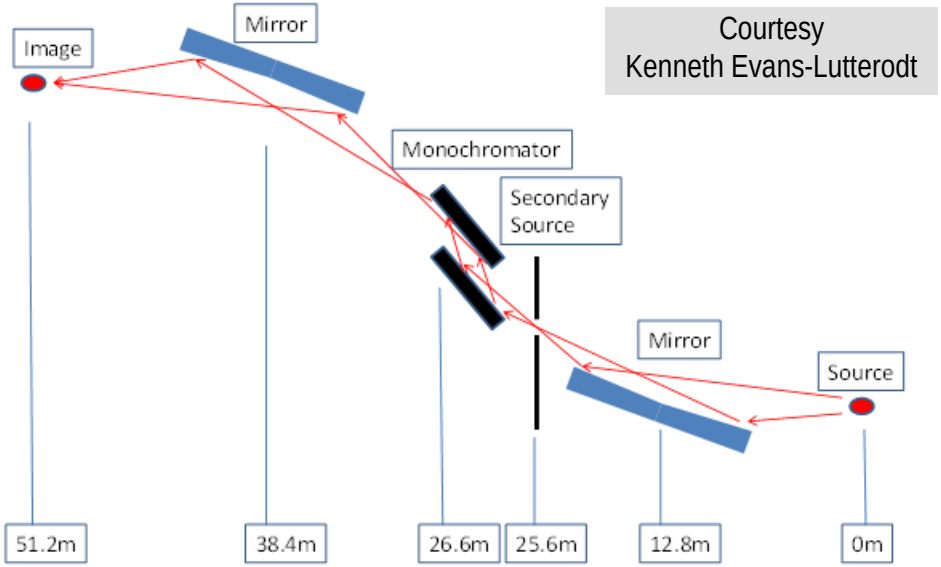
- Install second IVU in downstream section of long straight
- Install side-bounce monochromator in upstream part of FOE
- Build an outboard hutch that can accommodate two fixed-energy endstations

Partnership with MPP Beamline

MPP Scope

- Real-time, *in-situ* studies of phase transformations of thin blanket films, stacks, and nanopatterned samples
- X-ray diffraction and scattering techniques on solids, including thin films, stacks, nanopatterned samples, and bulk materials, with the capability for mounting small environmental chambers, magnets, bending jigs, and displexes

- 3-pole wiggler source
- dual-bandpass monochomator (high-flux *vs.* high resolution)
- tandem endstations for *in-situ* RTA and XRD
- rapid switch-over (mono and end-stations) and remote running



MPP anticipated to be operational in 2018

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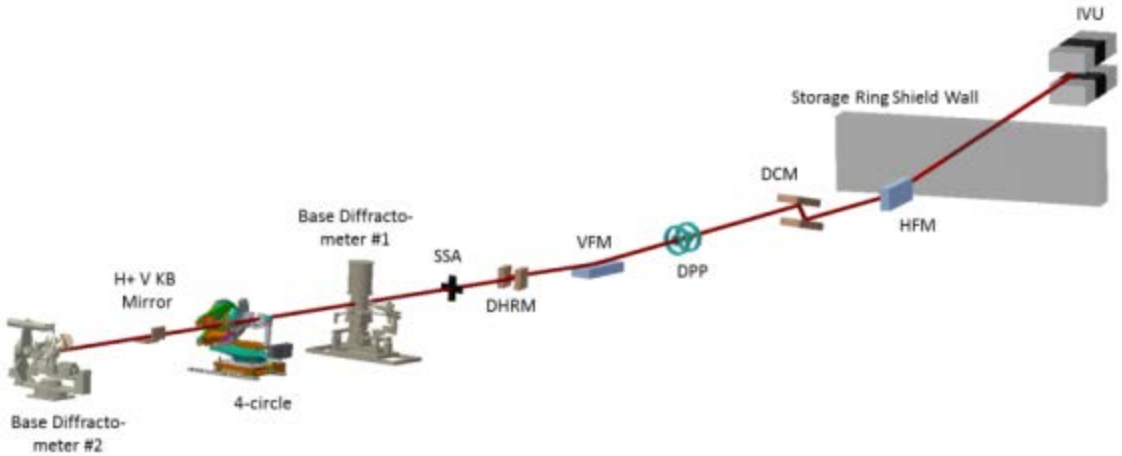
Conclusion

- ISR will have a flexible range of sample environments, and:
  - Energy range of 2.4 – 23 keV with 1.4 x 10^{-4} energy resolution
  - >10^{13} photons/s on the sample at 10 keV
  - Tunable focusing down to ~2 μm (V) x 20 μm (H)
  - Polarization control

Entire beam intercepted by 1 cm long sample at grazing incidence!



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Kenneth Evans-Lutterodt, kenne@bnl.gov

- Important Dates:
  - September – December 2016, ISR Commissioning
  - Calendar year 2017, ISR First Experiments