

# SCU1 Experience at 1-ID



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# Superconducting Undulators (SCUs) at APS—Installations

- To elevate energies of x-ray harmonics by providing large fields at small periods and at more open magnetic gaps (out of beam-vacuum).
- SCU0 prototype for 6-ID-D in 2013-1 (until 2016-2)
  - $\lambda_u = 1.6$  cm ,  $N = 21$  ,  $L = 0.33$  m
  - Ivanyushenkov *et al.*, *PR-STAB* **18**, 040703 (2015)
- **SCU1 (or SCU18-1) for 1-ID in 2015-2**
  - $\lambda_u = 1.8$  cm ,  $N = 60$  ,  $L = 1.08$  m ,  $K_{max} = 1.62$  ( $B_{max} = 0.96$  T, 450 A) , 9.5 mm gap
  - phase errors  $\sim 8\text{--}10^\circ$  at  $K_{max}$
  - Ivanyushenkov *et al.*, *PR-STAB* (submitted, 2016)
- SCU18-2 for 6-ID-D in 2016-3
  - same as SCU1 parameters, with improvements
  - phase errors  $\sim 2^\circ$  at  $K_{max}$
- H-SCU planned for 7-ID in 2017-3
  - helical,  $\lambda_u = 31.5$  cm ,  $N = 38$  ,  $L = 1.2$  m

# High-Energy X-Rays (> 40 keV)

## Current APS 1-ID techniques:

- **HEDM** - high-energy diffraction microscopy (ff- and nf-)
- **$\mu$ -CT**, e.g., voids, cracks
- **ST** (scattering tomography)
- **SAXS**
- **PDF, WAXS**
- **resonant scattering** near heavy-element K edges

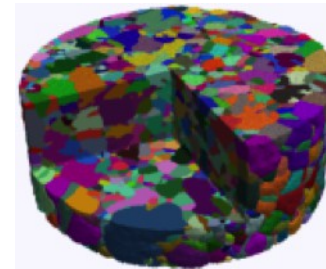
## Why high-energy x-rays?

### Interaction properties:

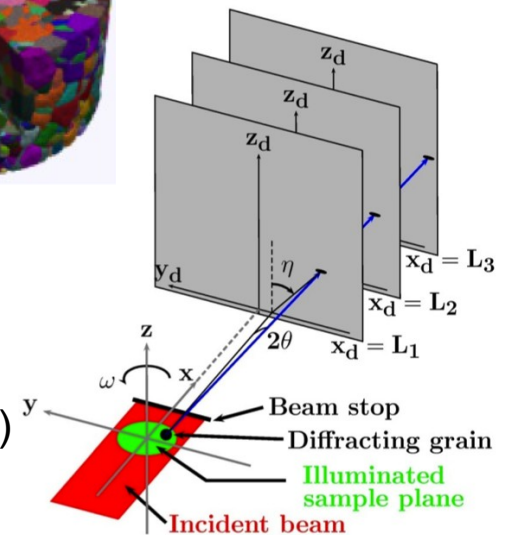
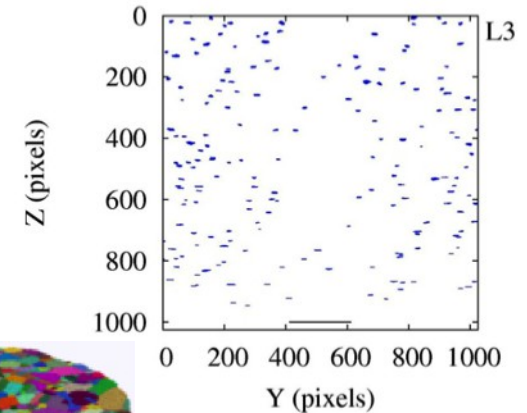
- low attenuation
- small scattering angles
- accessibility of high  $Q$
- improved validity of Born approximation (no multiple scattering)

### Enables:

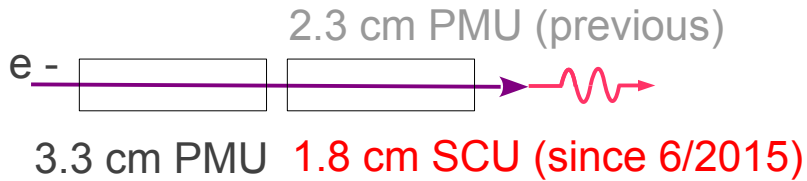
- extreme environments, e.g. thick walled containment: furnace/high-pressure cells
- scattering from bulk / away from surface in thick or high-Z samples
- high direct-space resolution



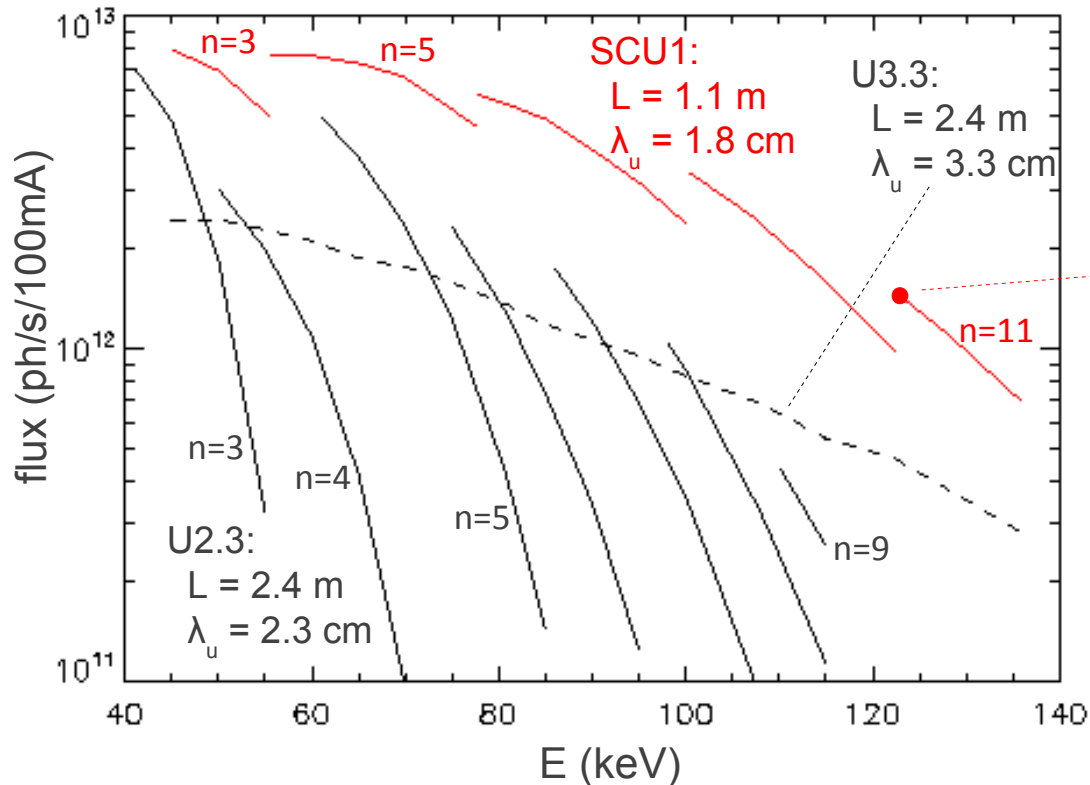
nf-HEDM method



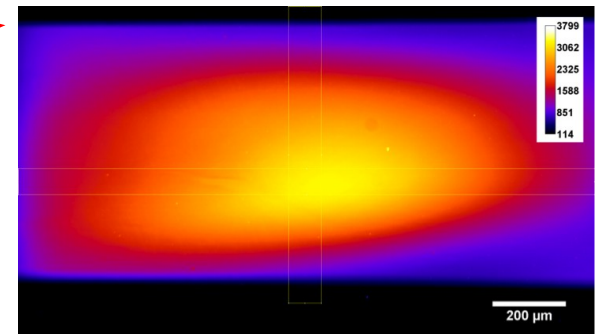
# SCU1 – PMUs Comparison at 1-ID



1-ID measured flux through  $0.5 \times 0.5 \text{ mm}^2$  at 27.5 m  
monochr. b.w.  $\sim 0.06\text{--}0.2 \%$  over 40–140 keV



SCU1 at APS 1-ID

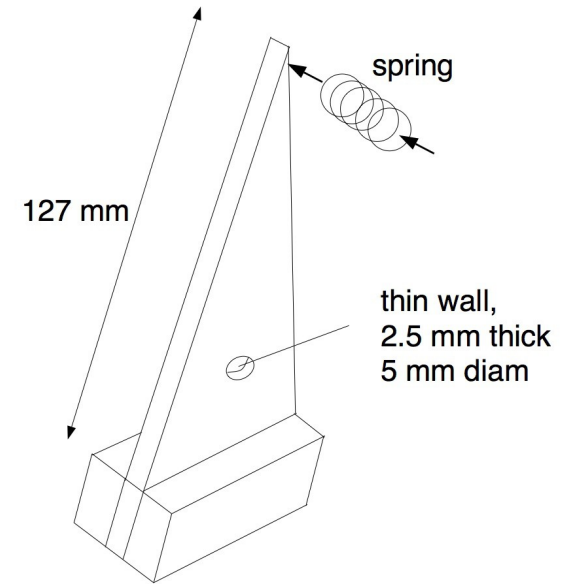
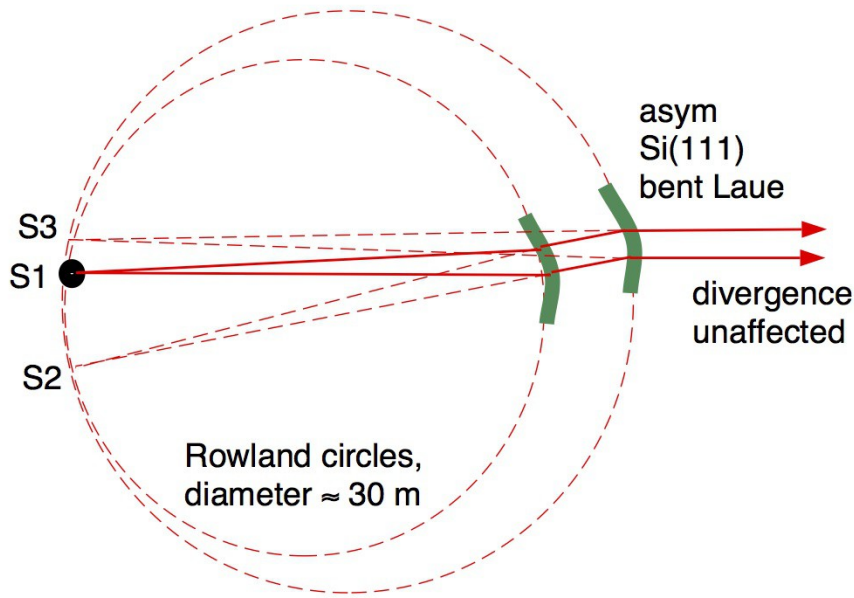


122.7 keV , n = 11 , 448.2 A

# Power

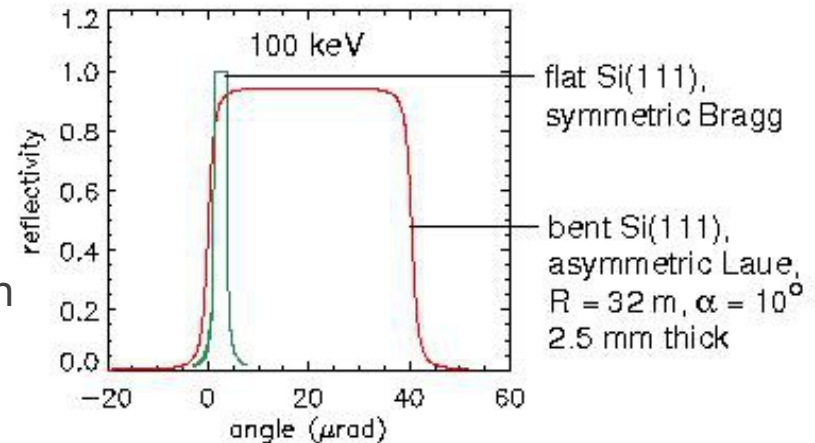
- U33 (i.e., UA) at 11 mm gap,  $K = 2.6$ 
  - 5.2 kW total
  - 240 W/mm<sup>2</sup> at 25 m
  - 1.2 kW in 3 x 2 mm<sup>2</sup> at 25 m
- SCU1,  $K = 1.6$ 
  - 2.9 kW total
  - 220 W/mm<sup>2</sup> at 25 m
  - 1.0 kW in 3 x 2 mm<sup>2</sup> at 25 m
- Comparable thermal loads on Si Laue-monochromator

# APS 1-ID High-Energy Bent Double-Laue Monochromator (40–140 keV)



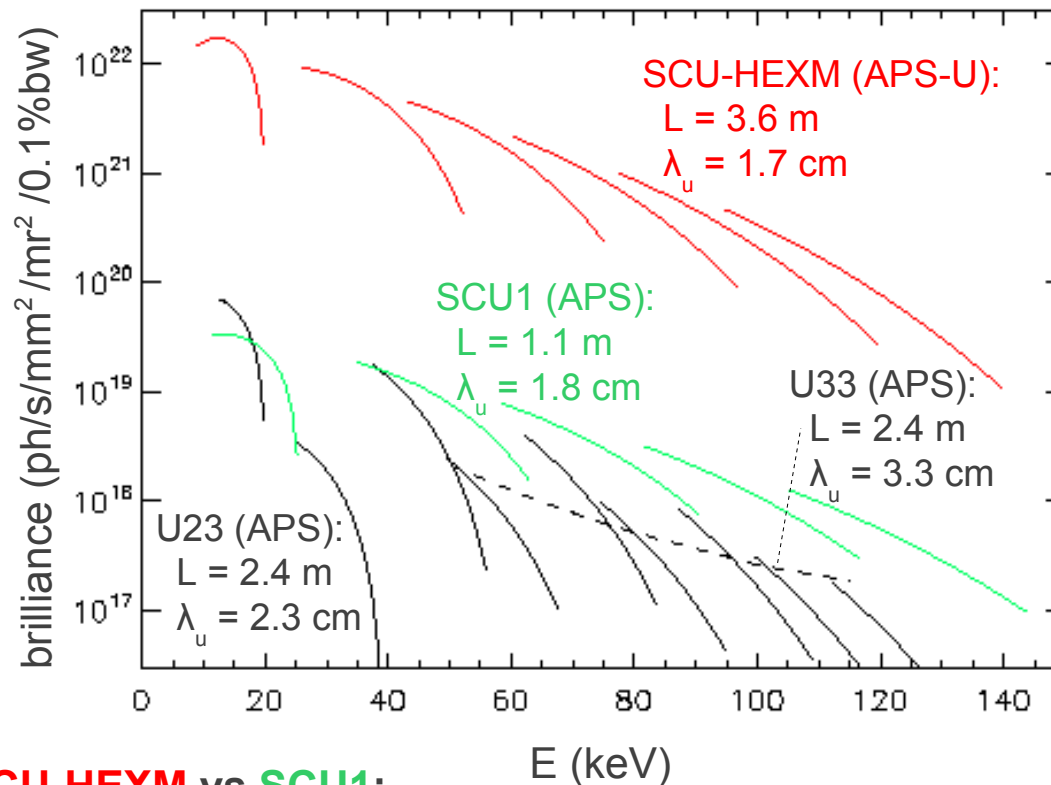
*JSR 9, 317–322 (2002)*

- cryogenically cooled (LN2)
- sequential Rowland conditions
- high flux, > 10 times over flat crystals, without increase in energy spread ( $\Delta E/E \sim 10^{-3}$ )
- brilliance/phase-space preserving (compensation effect)
- fully tunable
- in-line / fixed vertical offset



# Going Towards APS-U (1-ID and HEXM Beamlines)

Past PMUs / Present SCU1 / Future SCU-HEXM



Future **SCU-HEXM** vs **SCU1**:

- 3.6 m long, 1.7 cm period, 6 GeV
- 2x flux in central cone
- 10x flux density
- 300x brilliance

## SCU1 Usage and Reliability/Downtime Since 2015-2

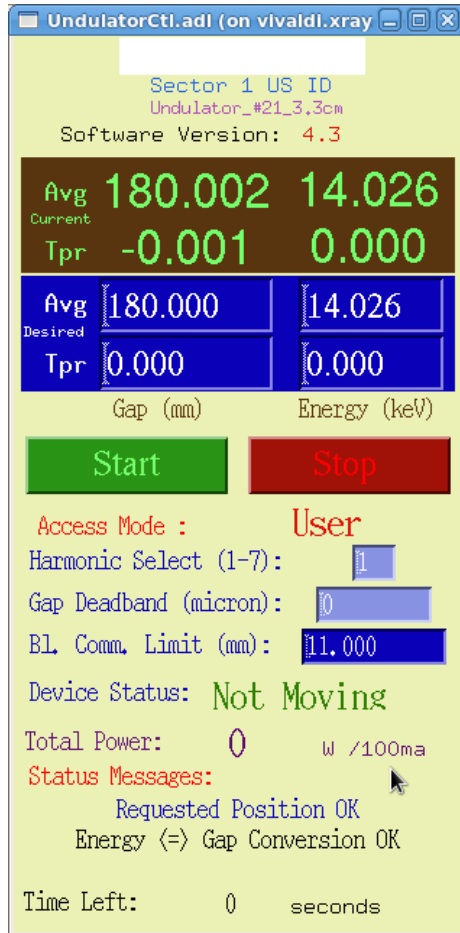
- Usage in 1-ID experiments: SCU1 > 90% , U33 < 10%
- No storage-ring beam losses caused by SCU1
- SCU1 quenches without stored beam loss—once, downtime few hours.
- SCU1 quenches accompanying beam losses from other causes (~ 24%). No impact (transparent) as SCU1 recovers in parallel with re-injection.
- Controls issues—once, 12/19/2016. Communication loss(es) between various components resulted in SCU being sent to 0 A current. Few hours lost overnight. Notifications now implemented.

**Overall excellent reliability/availability.**

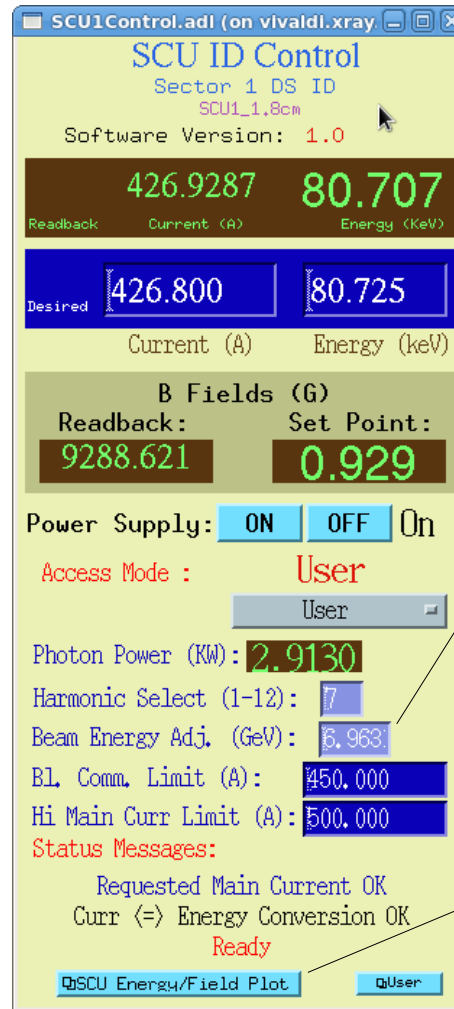


# EPICS Control Interface for Beamline

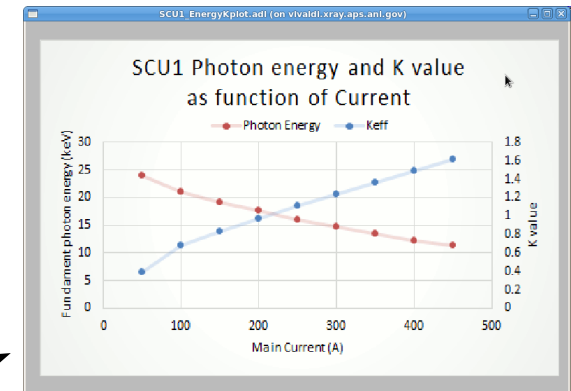
## PMU control



## SCU control



storage-ring energy



# EPICS Control Interface for Beamline

## SCU control

- To calculate w/o ramping
- Ramping accuracy PV

SCU1Control.adl (on vivaldi.xray)

### SCU ID Control

Sector 1 DS ID  
SCU1\_1.8cm

Software Version: 1.0

Readback: **426.9287** **80.707**  
Current (A) Energy (keV)

Desired: **426.800** **80.725**  
Current (A) Energy (keV)

B Fields (G)  
Readback: **9288.621** Set Point: **0.929**

Power Supply: **ON** **OFF** On

Access Mode: **User**  
User

Photon Power (KW): **2.9130**

Harmonic Select (1-12): **7**

Beam Energy Adj. (GeV): **6.963**

BL. Curr. Limit (A): **450.000**

Hi Main Curr Limit (A): **500.000**

Status Messages:  
Requested Main Current OK  
Curr (<=>) Energy Conversion OK  
**Ready**

SCU Energy/Field Plot User

SCU1\_User.adl (on vivaldi.xray.aps.anl.gov)

### SCU ID Control

Sector 1 DS ID SCU1\_1.8cm

CA Put Callback

Device Ramping: **0**

Busy: **Ramping**

Ramp Accuracy: **1.000**

Reset Busy

Conversions

Range: 0-450 Range Et: 11,249-25,851

Desired: **426.797** **80.725**  
Current (A) Energy (keV)

Desired Harmonic (1-12): **7**

Desired SR Energy (GeV): **6.963100** Range: 6-7.2

Desired Current OK  
Curr (<=>) Energy Conversion OK

Set SCU Values: **Start Ramp**

Current To Energy Current Range: 0 - 450 A

$K_{eff} = 0.93372 * B_{eff}(T) * PeriodLength(cm) = 1.561$

**0.929** **1.800**

Energy (KeV) =  $0.94963 * harm * SRe^2 / (period * (1 + K_{eff}^2/2)) = 80.725$

**7** **6.96310** **1.800** cm **1.561**

Energy To Current Energy Range: 11 - 180 KeV

$K_{eff} = \sqrt{2 * (0.94963 * SRe^2 / (PHe * PeriodLen(cm) / harm) - 1)} = 1.561$

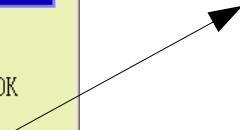
**1.561** **6.96310** **80.725** **1.800** **7**

$B_{eff}(G) = K_{eff} / (0.93372 * PeriodLen(cm)) * 10,000 = 9286.698$

Current To Power Power Range: 0.184 - 3.086 KW

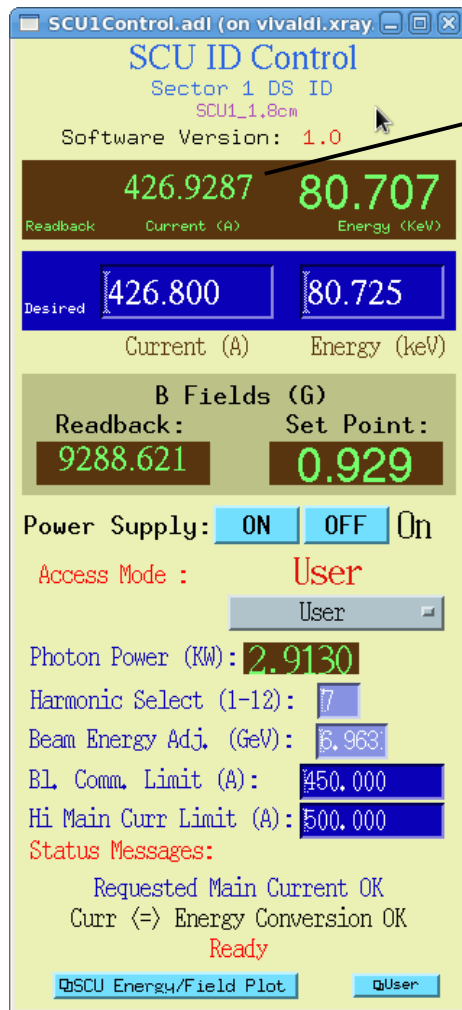
$P(KW) = 0.633 * NumPeriods * PeriodLen(M) * SRe^2(GeV) * beamI(A) * Bpk^2 = 2.9141$

**50.0000** **0.0180** **6.96310** **102.1965** **0.9275** T



# Current Readback Value Fluctuations

## SCU control



Readback fluctuates:

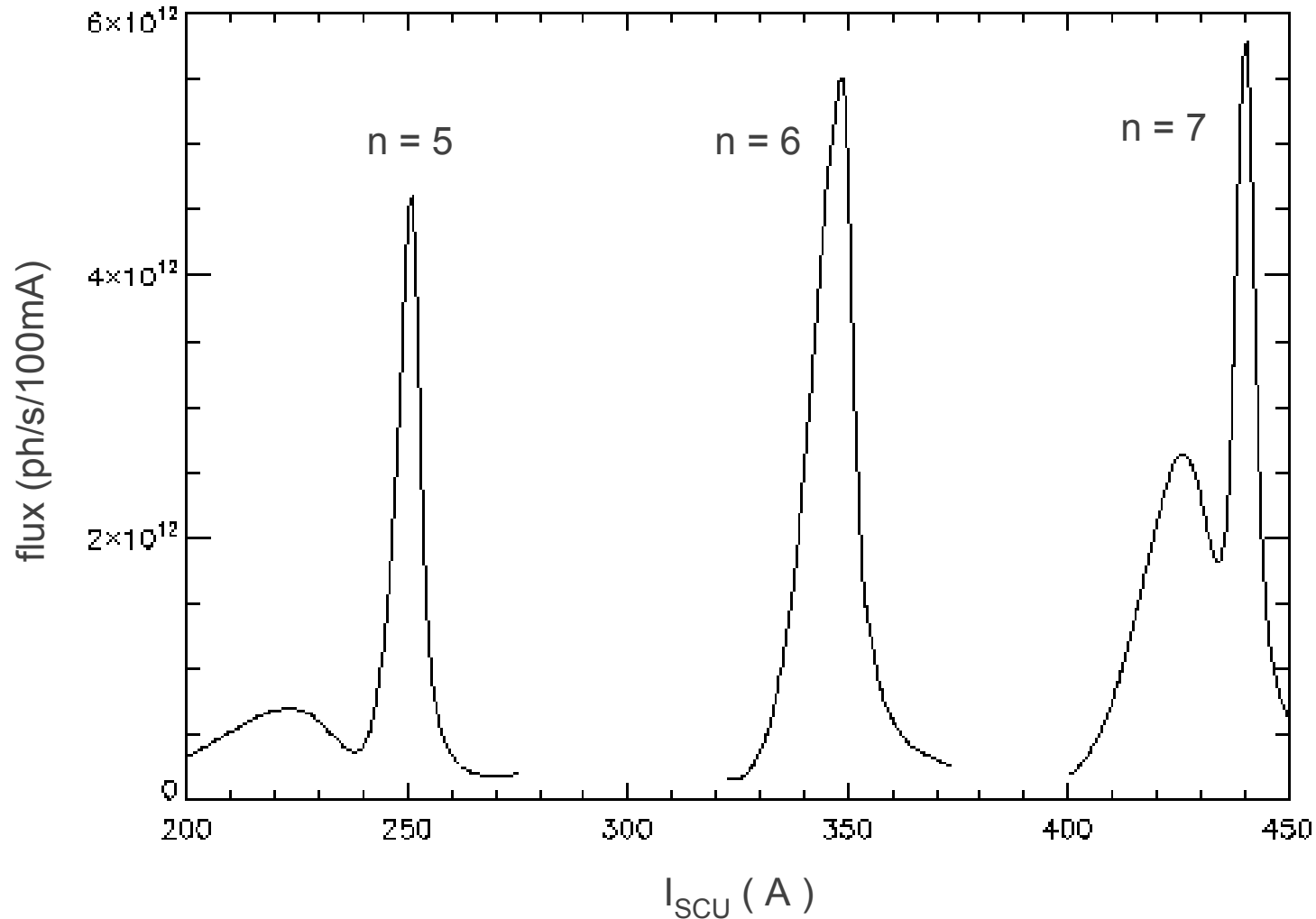
- actual current is stable
- from noise in DC-CT signal
- over range  $\sim 0.8$  A
- off-centered about requested value,  $+0 / -0.8$  A
- recently improved

Makes scanning tricky:

- EPICS Busy/Done Record with ramping-accuracy-PV set carefully, e.g., to 0.6 A
- current steps no less than 0.5 A
- adequate positioner settling time, e.g., 1 s

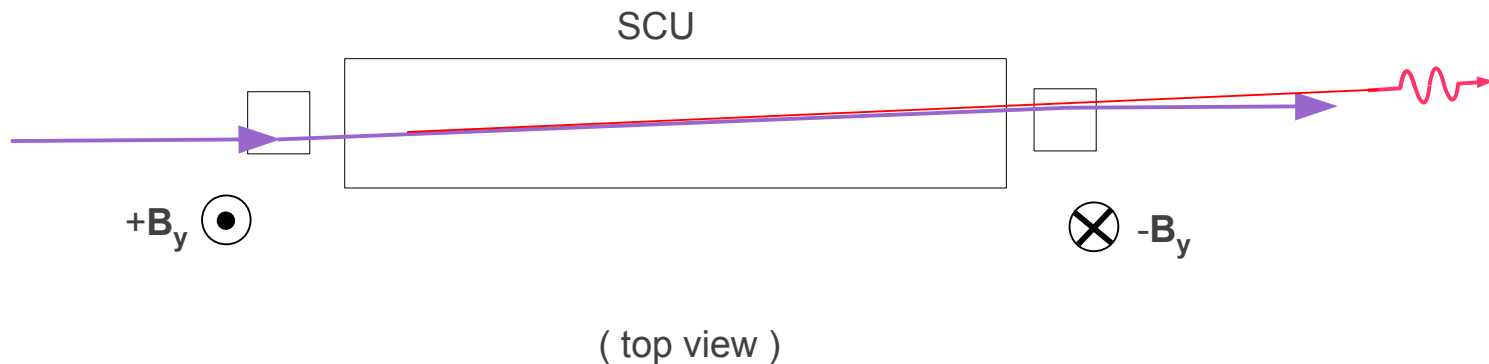
# Current Scan with Monochromator Fixed

Flux at 79 keV through  $0.5 \times 0.5 \text{ mm}^2$  at 27.5 m



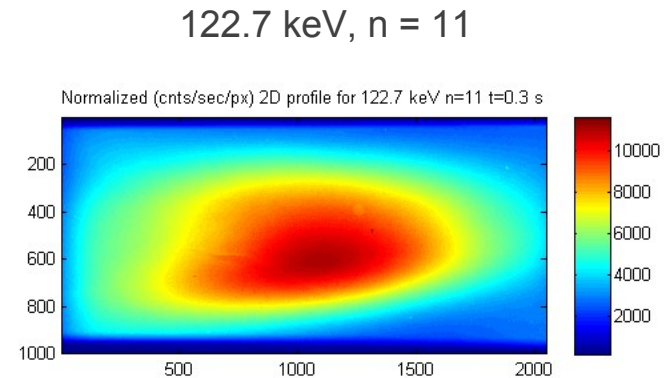
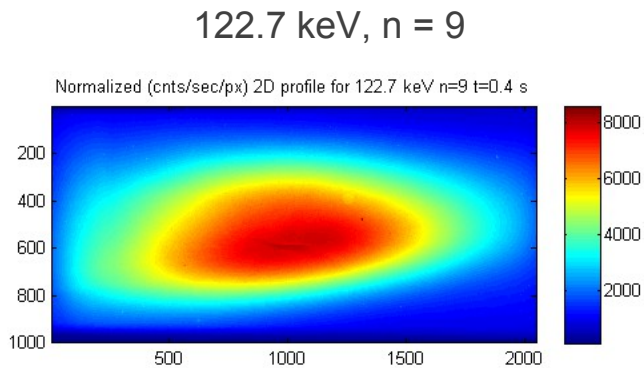
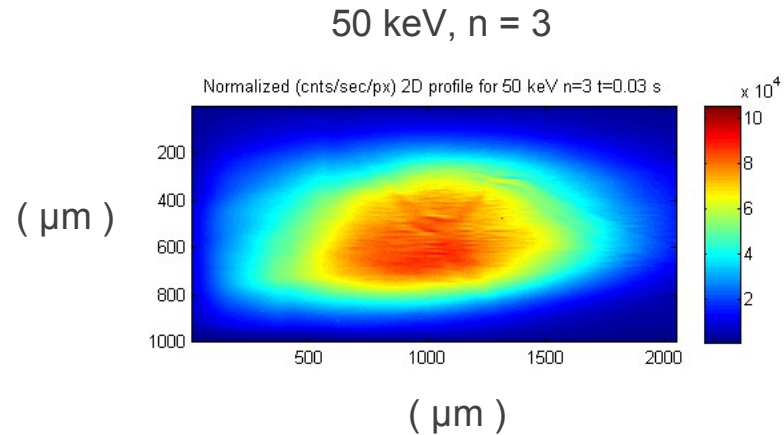
# X-Ray Beam Motion with SCU Current

- Beam moves  $\sim 0.5$  mm at white-beam slits (27 m) over 200–450 A, with most taking place at 350–400 A.
  - Horizontal only—vertical is steady ( $< 20$   $\mu\text{m}$ ).
  - Not surprising given 2<sup>nd</sup> field-integrals of tens of G  $\text{cm}^2$  and short 1 m device.
  - At 1-ID-E end-station (sample at 70 m), horizontal motion can be over 1 mm.
  - Results in realignment time during operations (energy changes).
  - Can re-steer, but takes XBPMs out of orbit feedback, requiring current-scan for recalibration of XBPM offsets.
- **Strategy:** Use SCU field 2<sup>nd</sup>-integral correctors to preserve electron angular trajectory, and hence, photon beam. Automated look-up table.



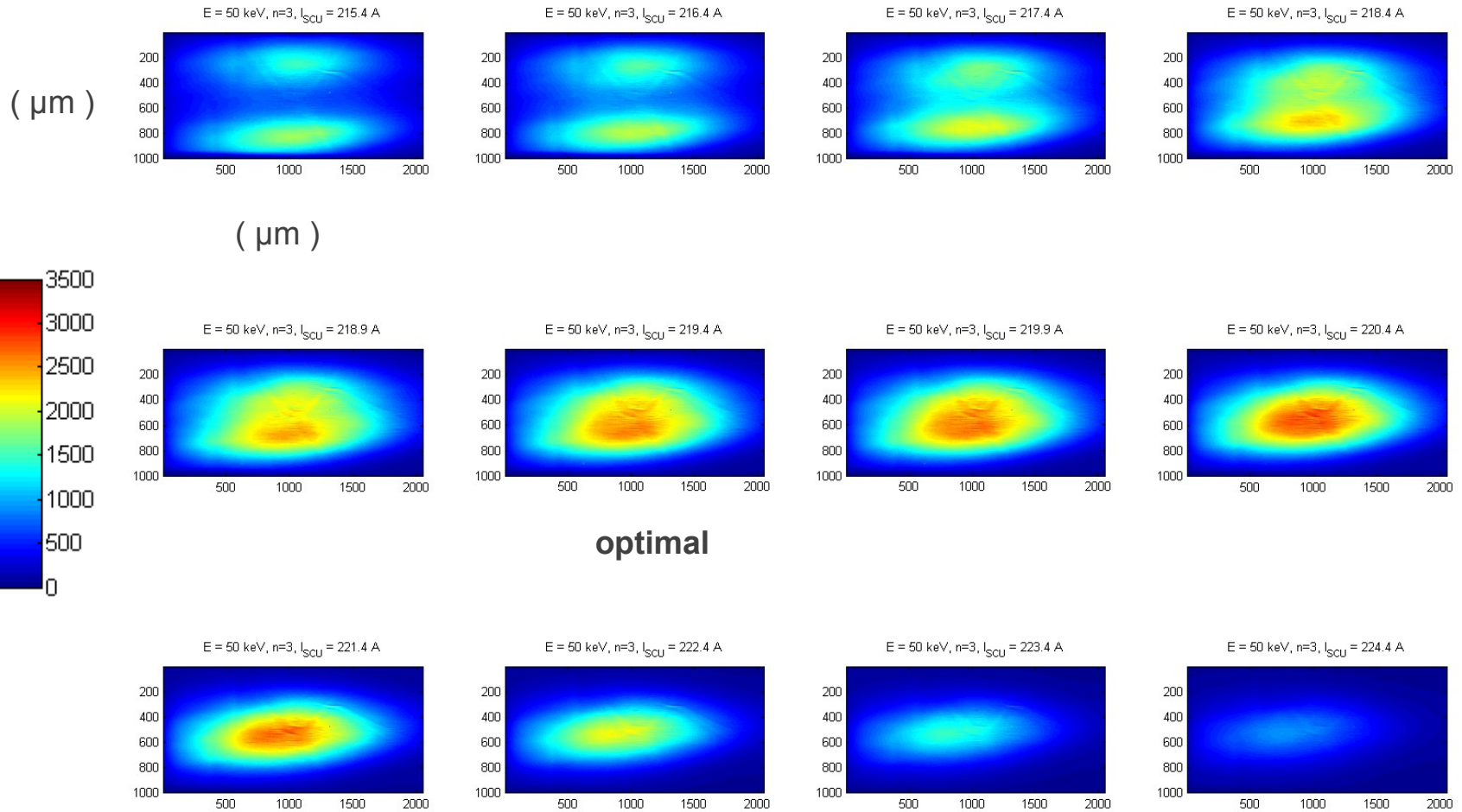
# Full Beam Profiles (P. Kenesei)

- asymmetry visible
- 1 mm x 0.5 mm FWHM at 36 m
- CoolSnap 4K interline CCD  
LuAG:Ce 25  $\mu\text{m}$  scintillator  
1  $\mu\text{m}$  pixels



# Current Tuning (P. Kenesei)

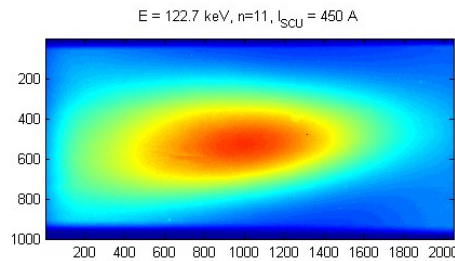
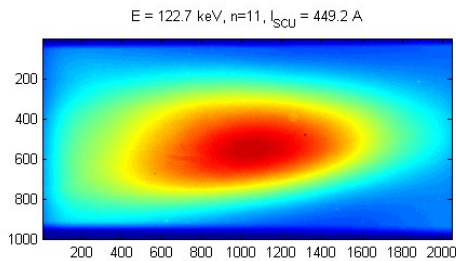
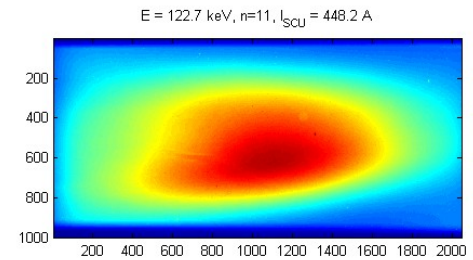
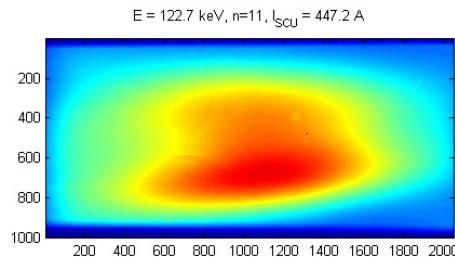
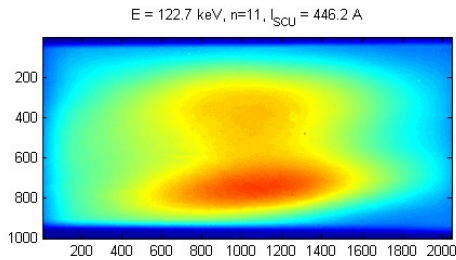
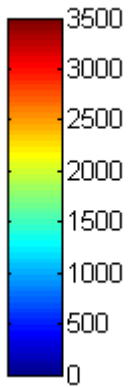
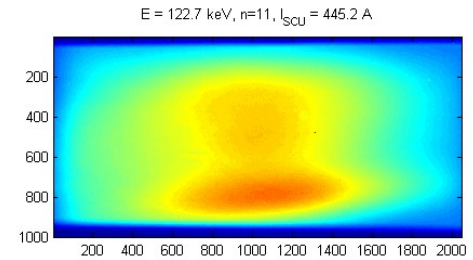
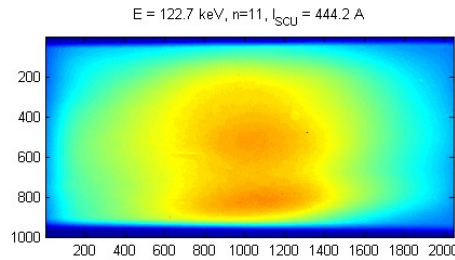
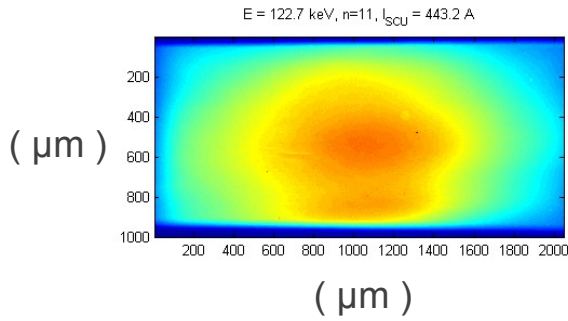
50 keV,  $n = 3$ ,  $\sim 219$  A





# Current Tuning (P. Kenesei)

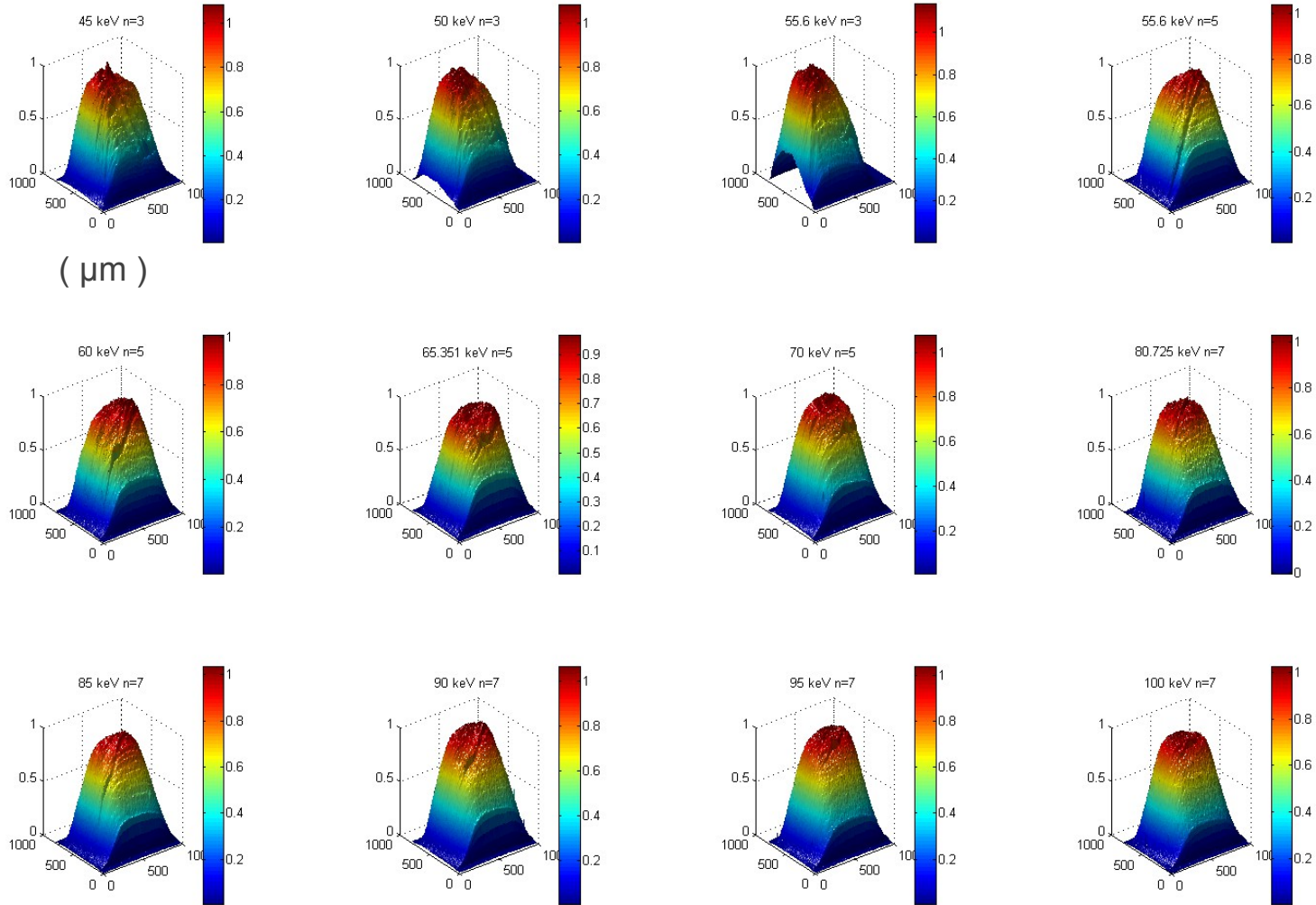
122.7 keV, n = 11, ~ 448 A





# Profiles Through Aperture (P. Kenesei)

Profiles at 36 m through 0.5 x 0.5 mm<sup>2</sup> at 27 m



# Questions

