SCU1 Experience at 1-ID

S. D. Shastri
Materials Physics and Engineering Group - APS

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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)
  – λ_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**
  – λ_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 ~ 8–10º at K_{max}
  – Ivanyushenkov *et al.*, *PR-STAB* (submitted, 2016)

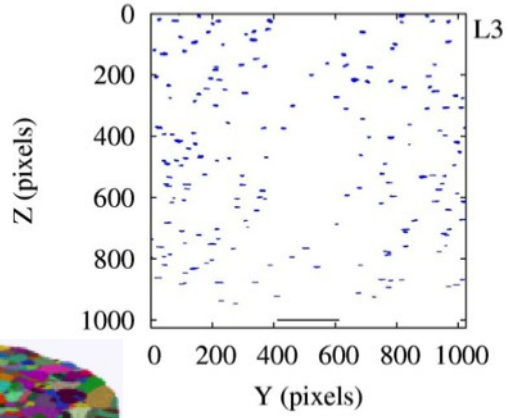
- SCU18-2 for 6-ID-D in 2016-3
  – same as SCU1 parameters, with improvements
  phase errors ~ 2º at K_{max}

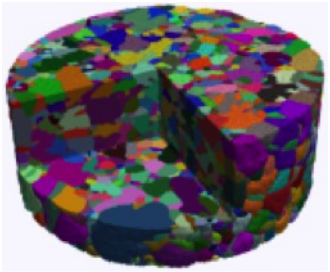
- H-SCU planned for 7-ID in 2017-3
  – helical, λ_u = 31.5 cm , N = 38 , L = 1.2 m

High-Energy X-Rays (> 40 keV)

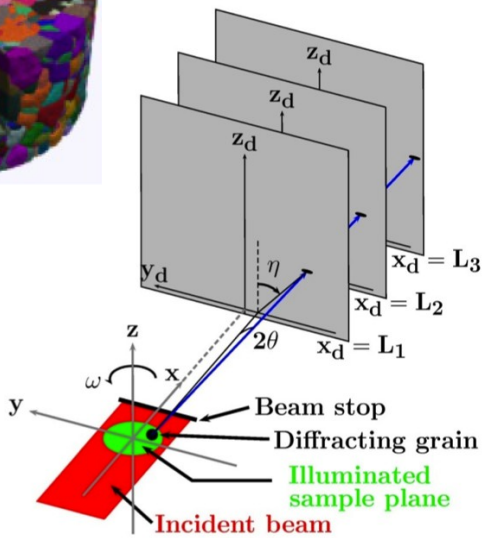
Current APS 1-ID techniques:

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





nf-HEDM method



Why high-energy x-rays?

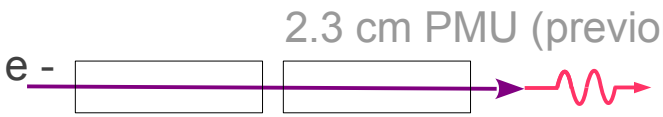
Interaction properties:

- 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

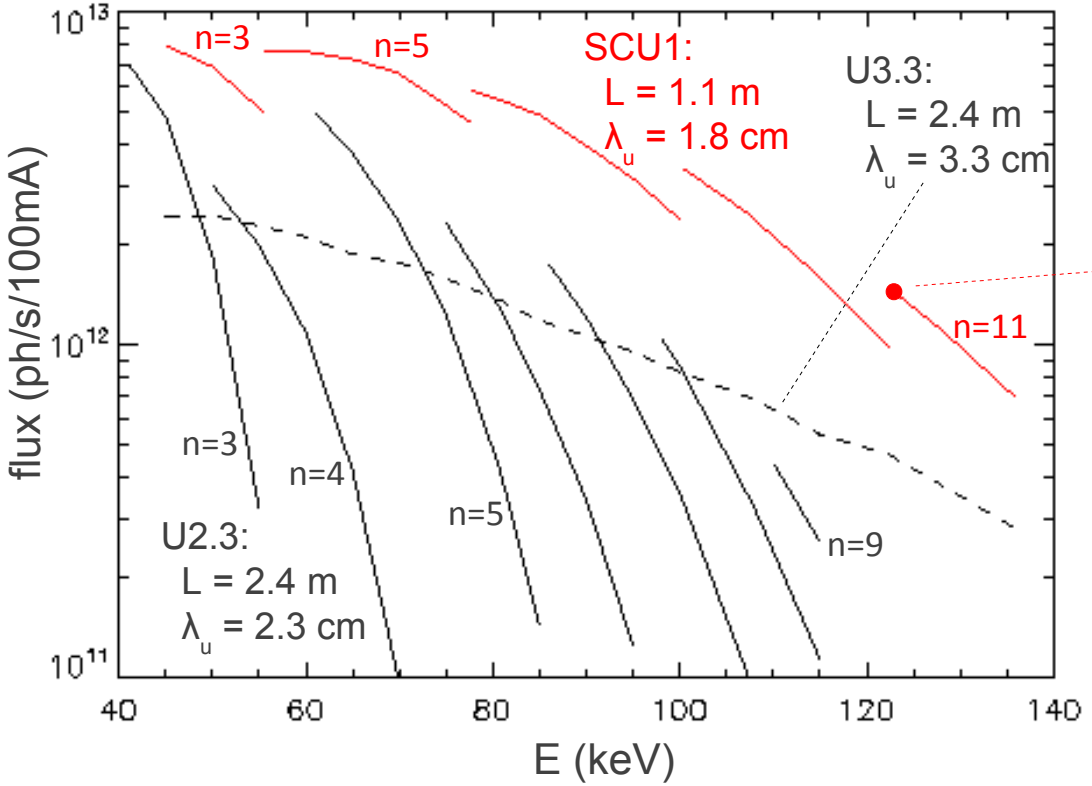
SCU1 – PMUs Comparison at 1-ID

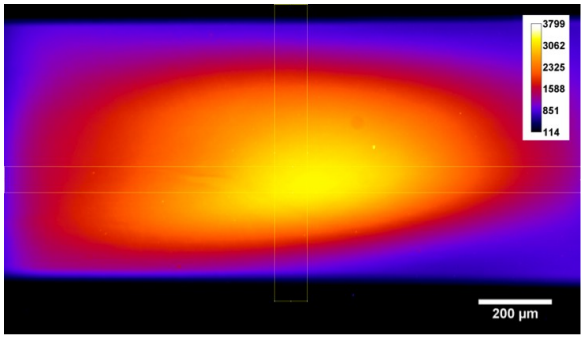


3.3 cm PMU 1.8 cm SCU (since 6/2015)

SCU1 at APS 1-ID

1-ID measured flux through 0.5 x 0.5 mm^2 at 27.5 m
monochr. b.w. ~ 0.06–0.2 % over 40–140 keV





122.7 keV , n = 11 , 448.2 A

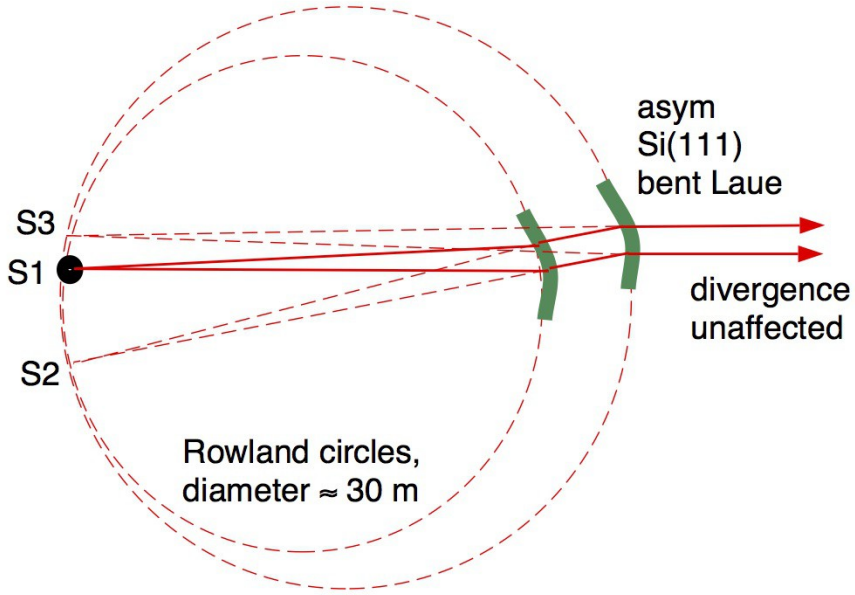
Power

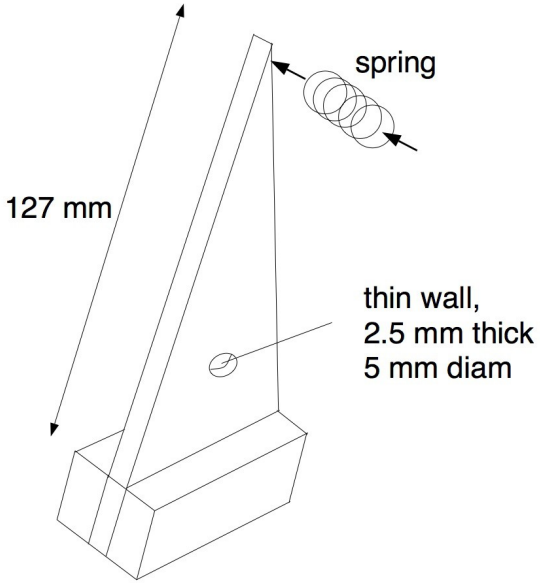
- U33 (i.e., UA) at 11 mm gap, K = 2.6
  – 5.2 kW total
  – 240 W/mm^2 at 25 m
  – 1.2 kW in 3 x 2 mm^2 at 25 m

- SCU1, K = 1.6
  – 2.9 kW total
  – 220 W/mm^2 at 25 m
  – 1.0 kW in 3 x 2 mm^2 at 25 m

- Comparable thermal loads on Si Laue-monochromator

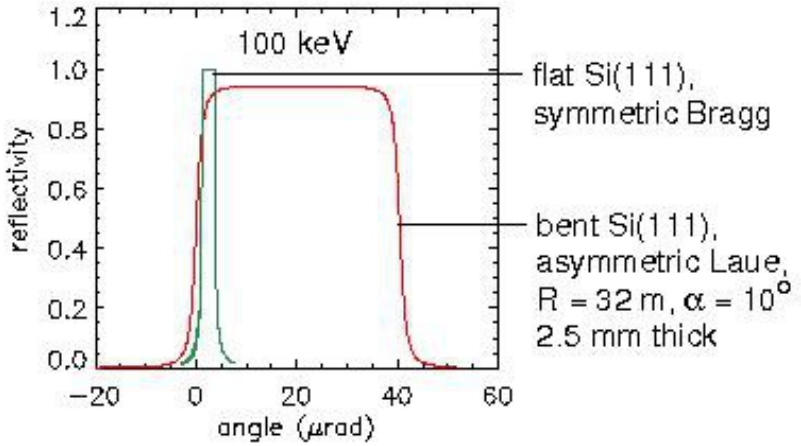
APS 1-ID High-Energy Bent Double-Laue Monochromator (40–140 keV)





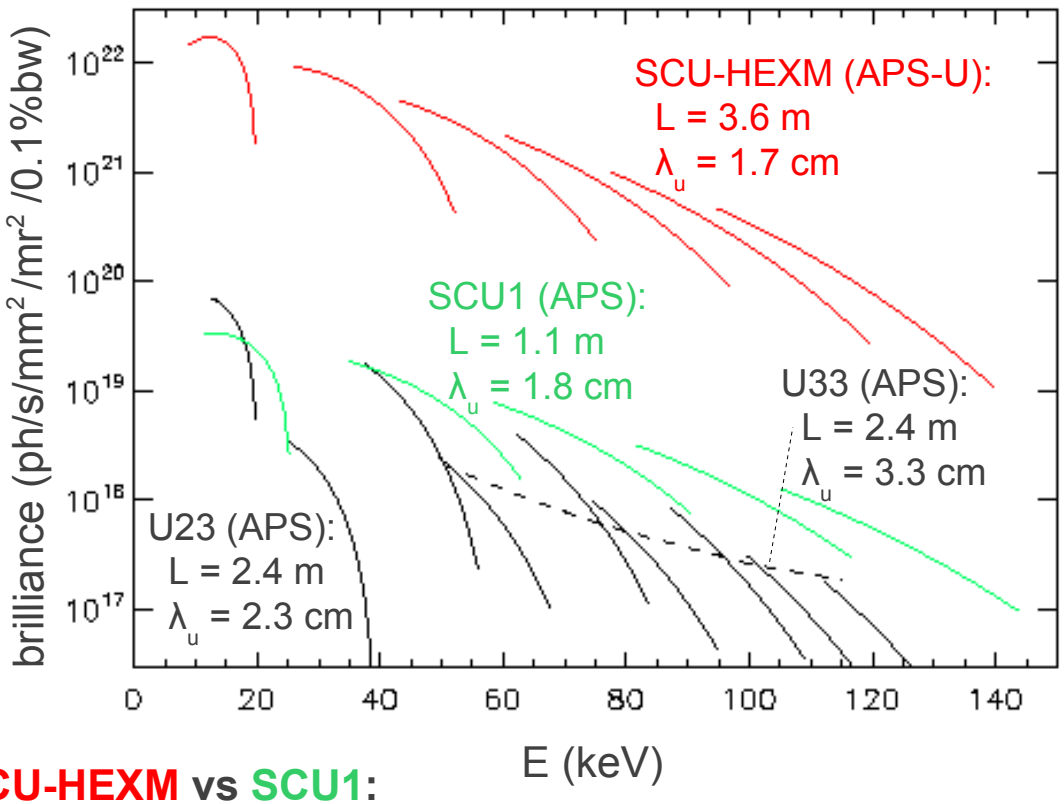
JSR **9**, 317–322 (2002)

- 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

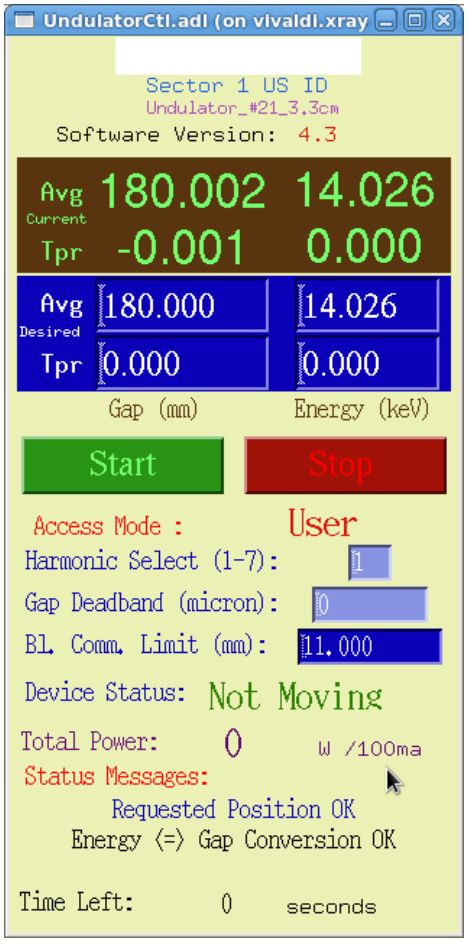
SCU1 Usage and Reliability/Downtime Since 2015-2

- 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.

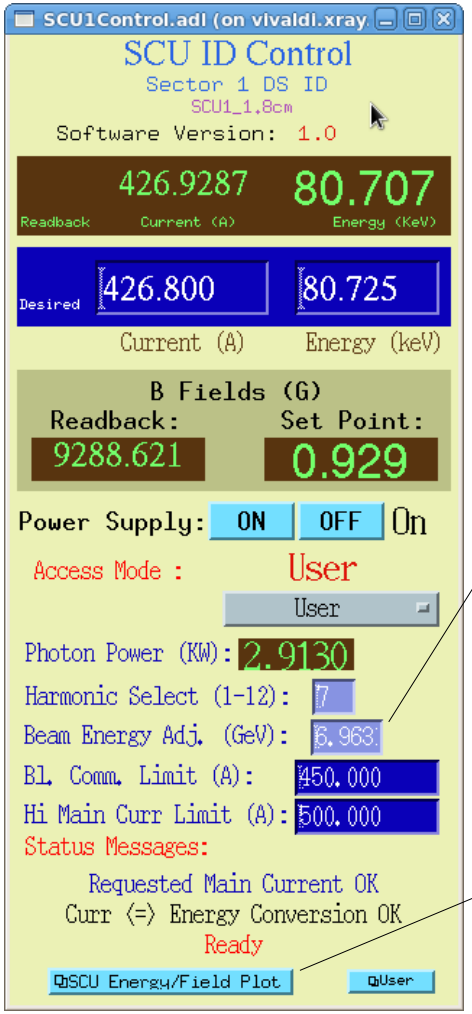
Overall excellent reliability/availability.

EPICS Control Interface for Beamline

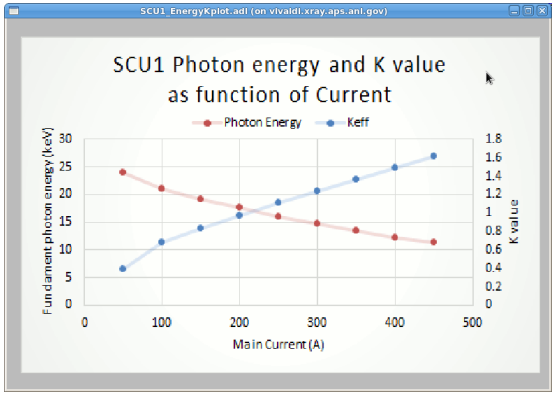
PMU control



SCU control



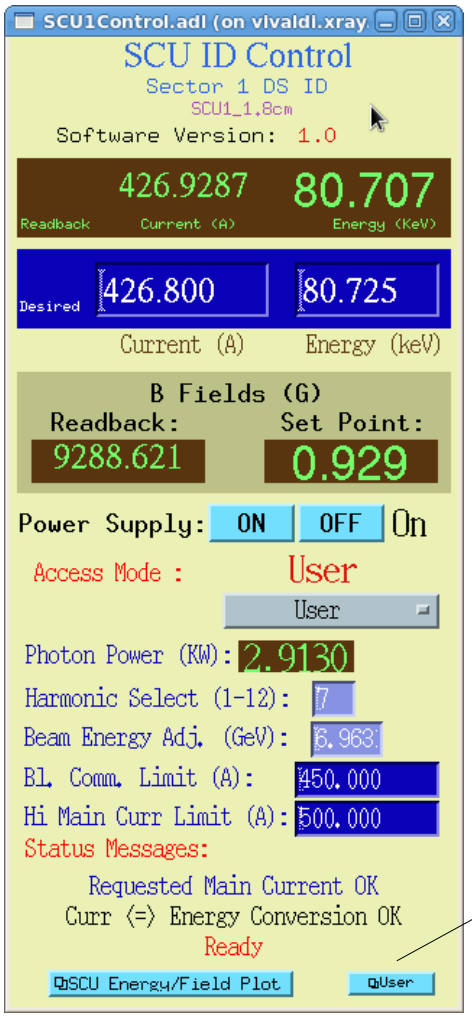
storage-ring energy

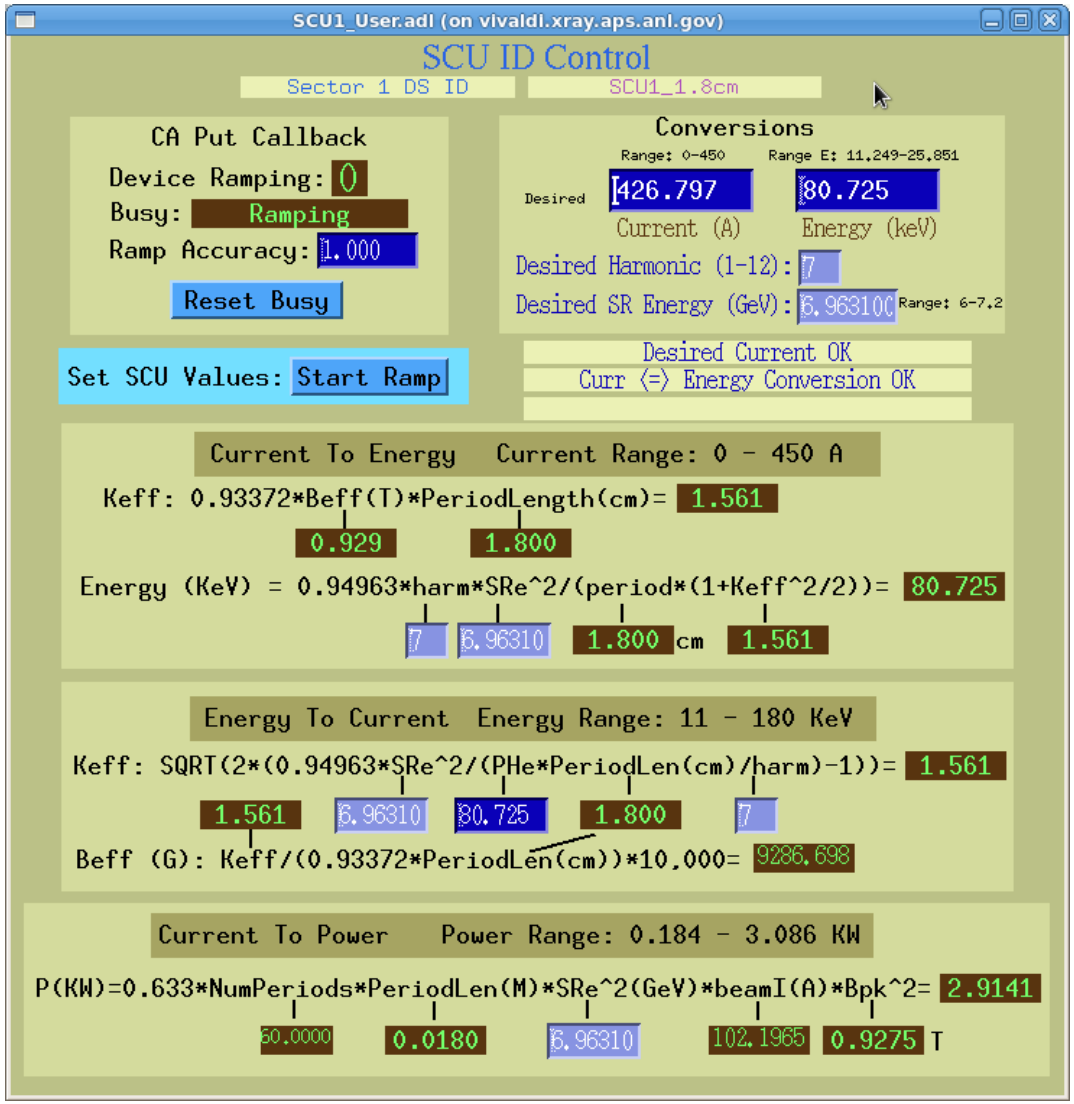


EPICS Control Interface for Beamline

SCU control

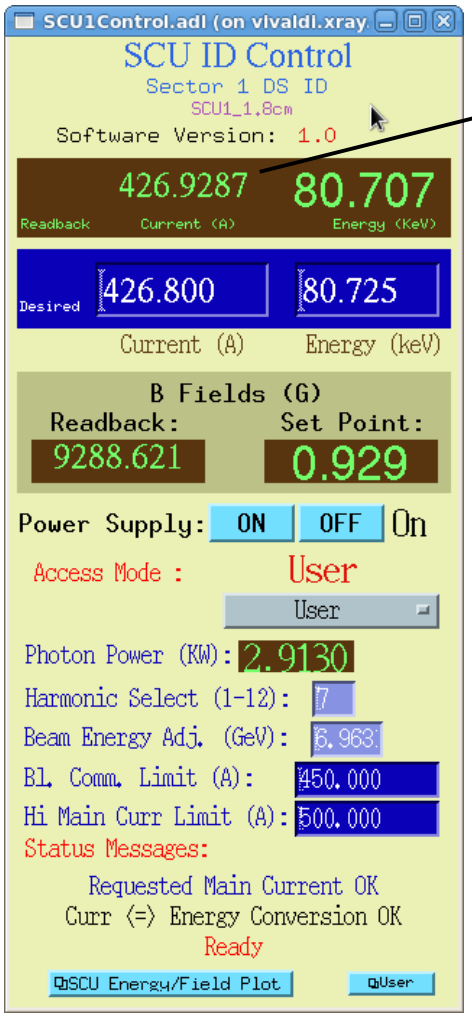
– To calculate w/o ramping
– Ramping accuracy PV





Current Readback Value Fluctuations

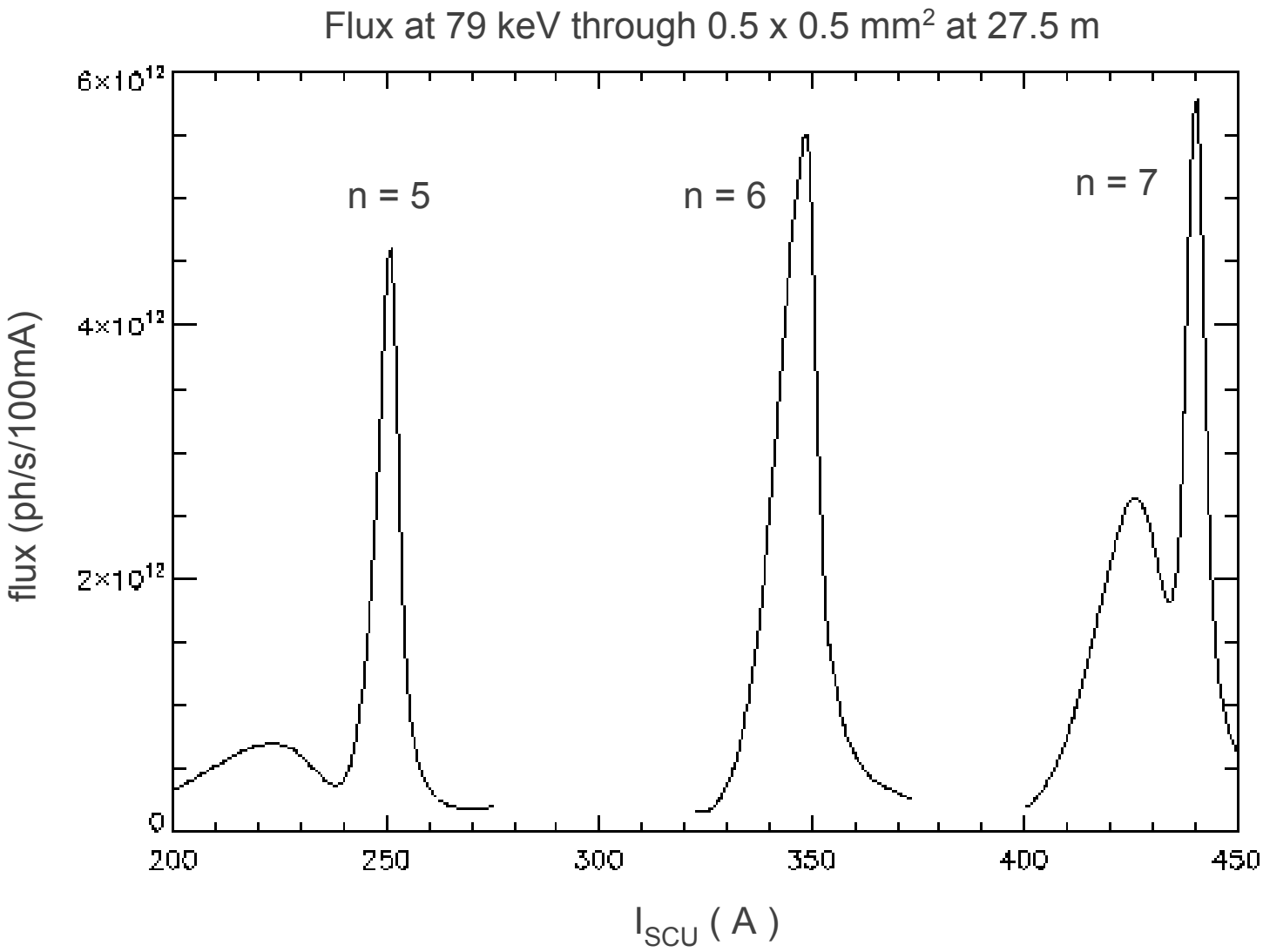
SCU control



Readback fluctuates:
- actual current is stable
- from noise in DC-CT signal
- over range ~ 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

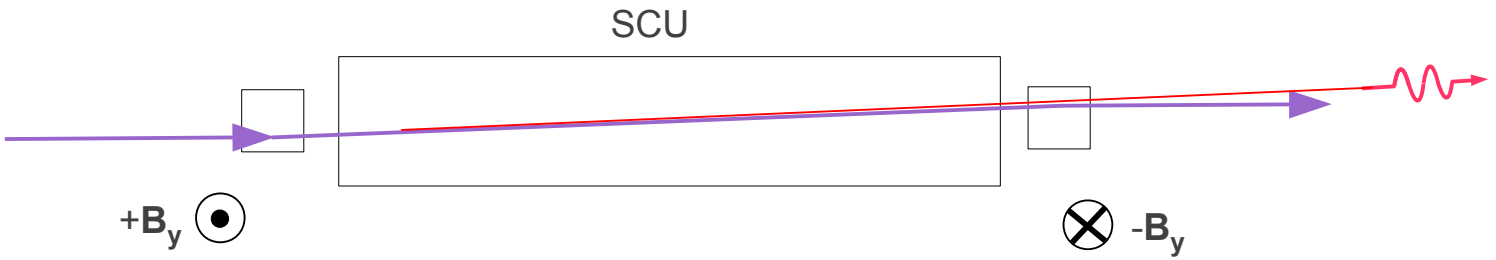
Current Scan with Monochromator Fixed



X-Ray Beam Motion with SCU Current

- Beam moves ~ 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 μm).
- Not surprising given 2nd field-integrals of tens of G 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 2nd-integral correctors to preserve electron angular trajectory, and hence, photon beam. Automated look-up table.



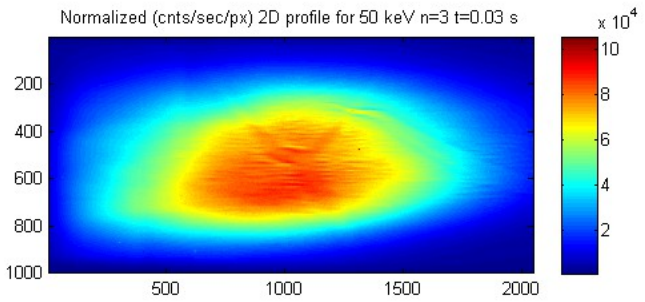
(top view)

Full Beam Profiles (P. Kenesei)

– asymmetry visible
– 1 mm x 0.5 mm FWHM at 36 m

– CoolSnap 4K interline CCD
  LuAG:Ce 25 μm scintillator
  1 μm pixels

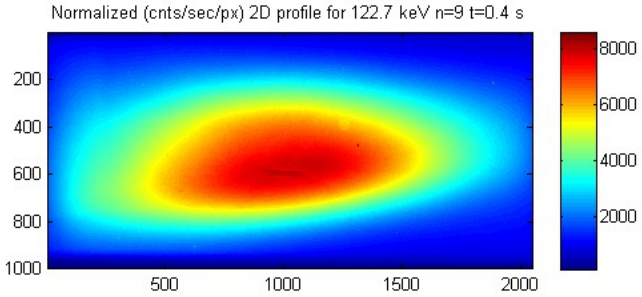
50 keV, n = 3



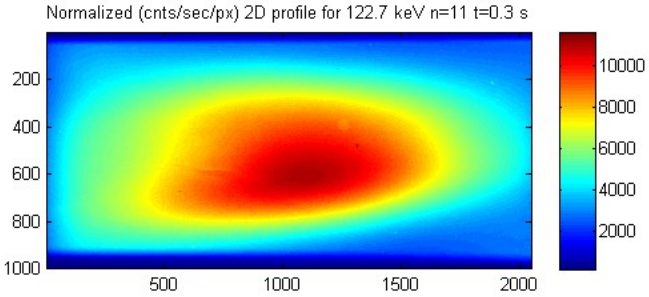
(μm)

(μm)

122.7 keV, n = 9

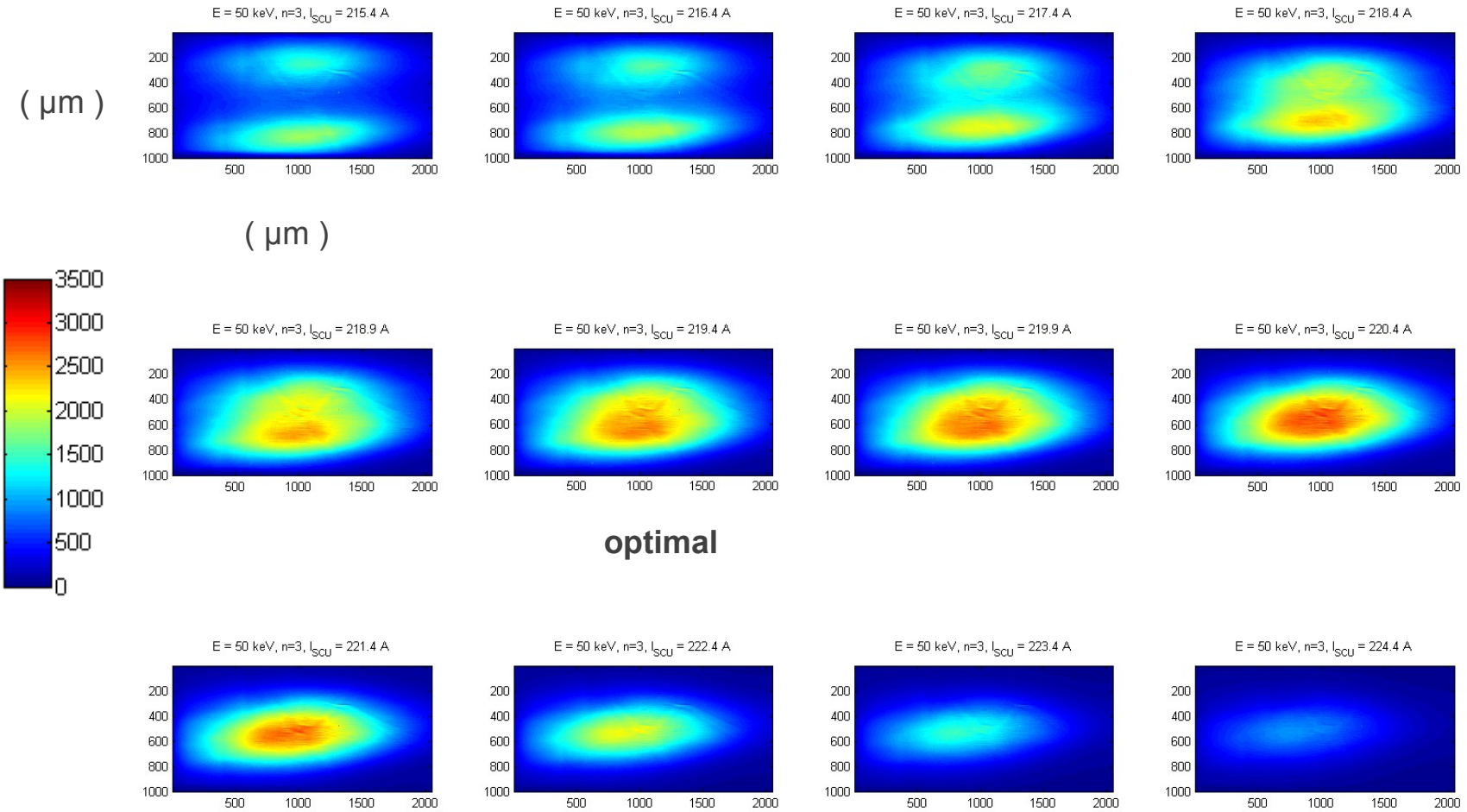


122.7 keV, n = 11



Current Tuning (P. Kenesei)

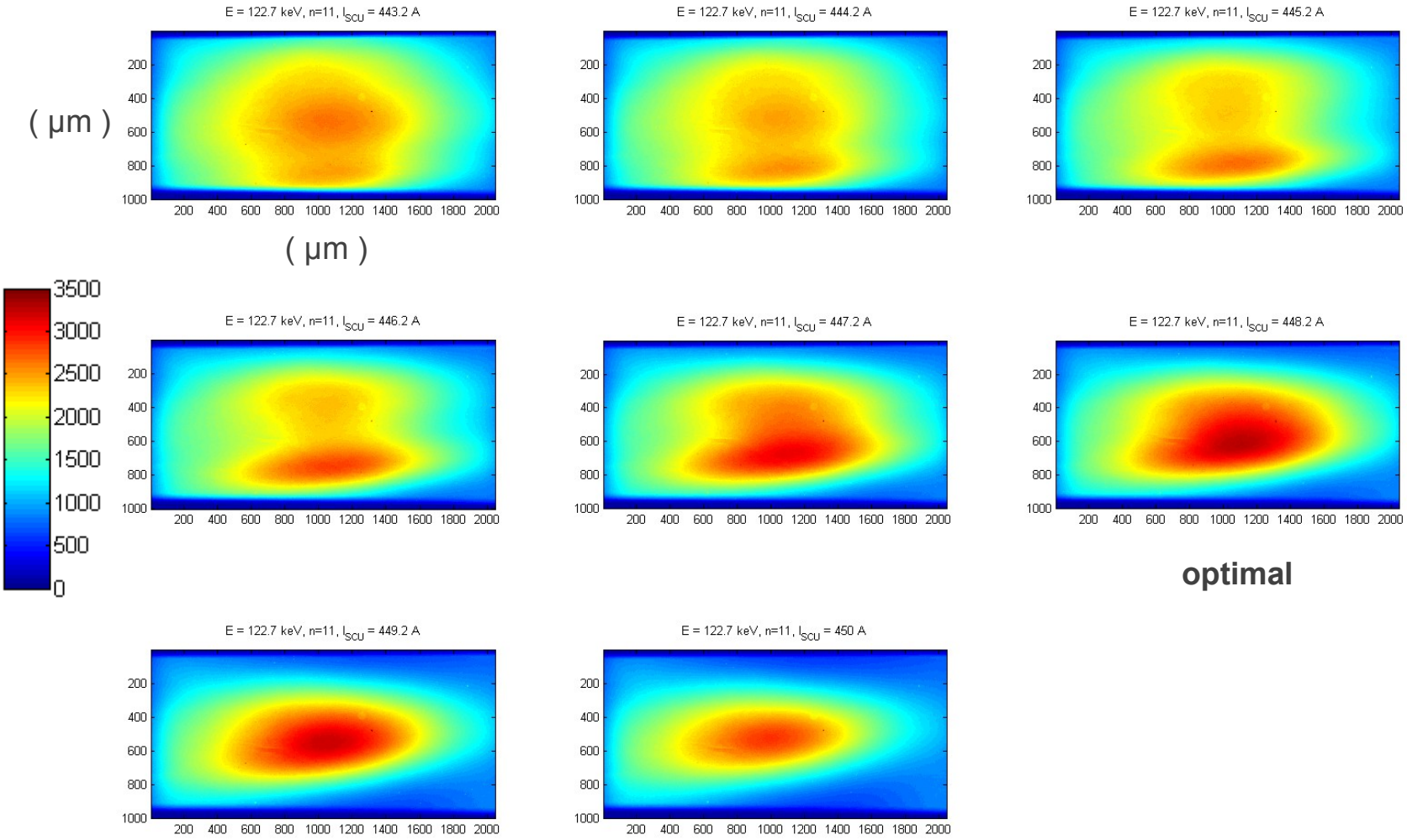
50 keV, n = 3, ~ 219 A



optimal

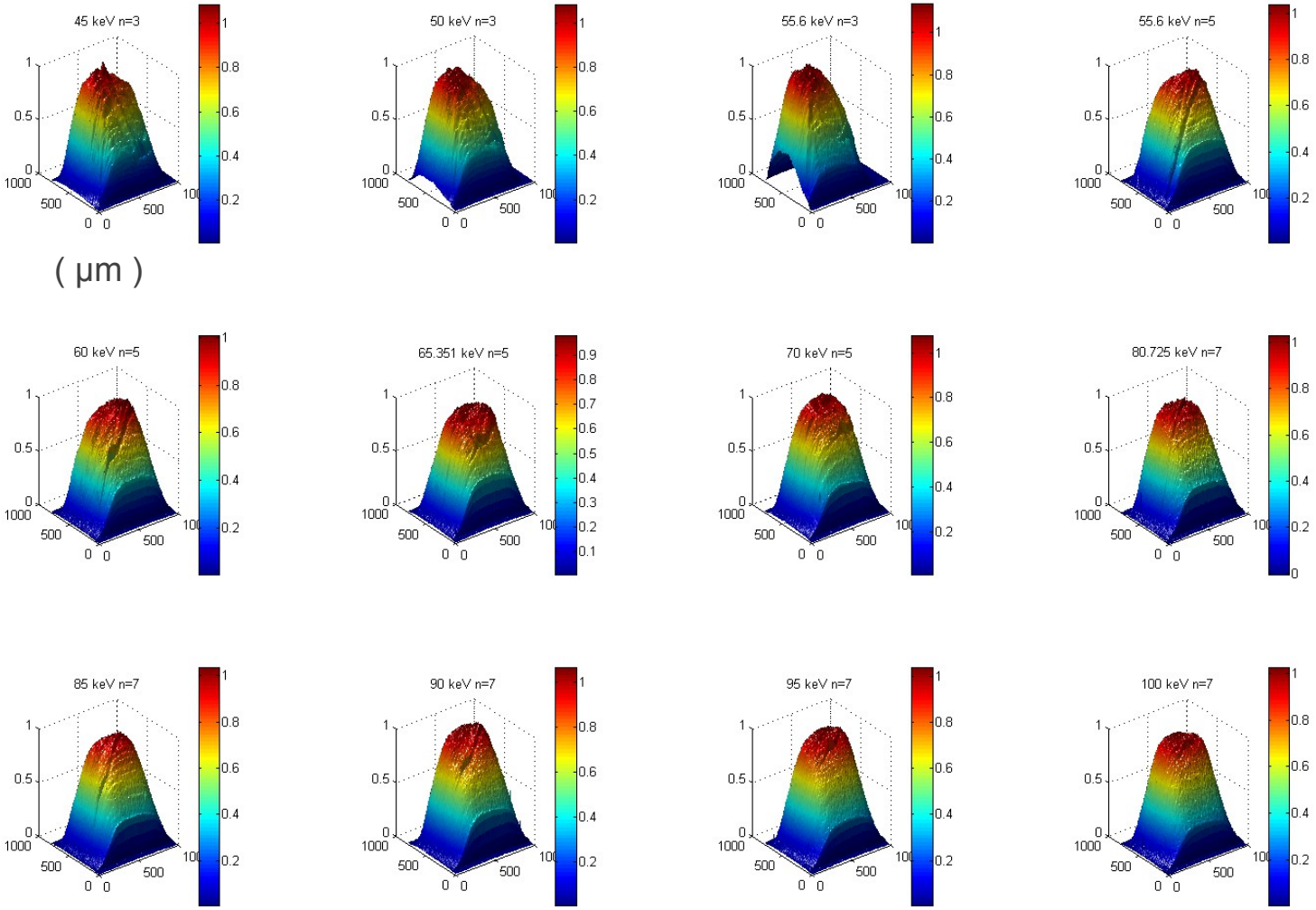
Current Tuning (P. Kenesei)

122.7 keV, n = 11, ~ 448 A



Profiles Through Aperture (P. Kenesei)

Profiles at 36 m through 0.5 x 0.5 mm^2 at 27 m



Questions