Characterization of Second Harmonic Afterburner Radiation at the LCLS

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MAX-lab

SLAC NATIONAL ACCELERATOR LABORATORY

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LELAND STANFORD JUNIOR UNIVERSITY

Utilizing the Micro-Bunched Electron Beam

- At FEL saturation, the electron beam is highly micro-bunched at odd and even harmonics.
- Adding extra undulators (resonant at any of these harmonics but with different parameters) can be used to produce an additional FEL quality photon beam with properties such as
  - Enhanced harmonics content
  - Various types of planar and circular polarization (fundamental or 2nd harmonic)
  - …

R. *Bonifacio*, L. De Salvo Souza, P. Perini and E.T. Scharlemann, *Nucl. Instr. Meth. A* ***296*** (1990), p. 787

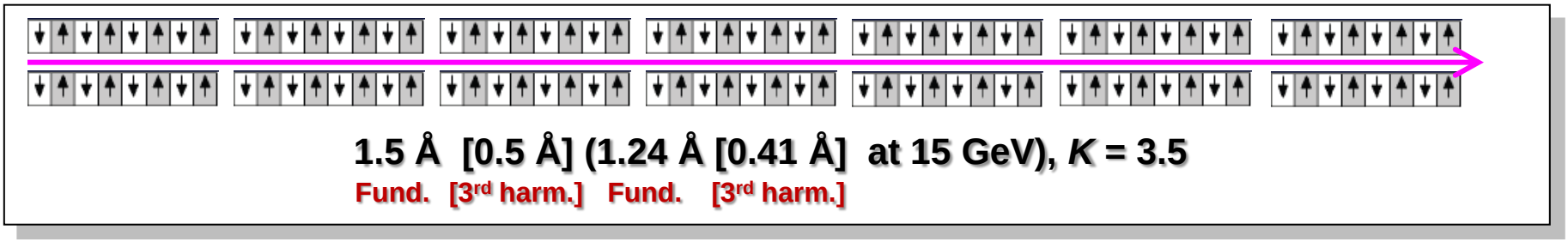
W.M. Fawley, H.-D. Nuhn, R. Bonifacio, E.T. Scharlemann, in Proceedings of the 1995 Particle Accelerator Conference, p. 219

- Those extra undulators are generally referred to as “After-Burners”, AB.
- The After-Burner concept is being tested at the LCLS in the form of a Second Harmonic After-Burner (SHAB).

Z. Huang and S. Reiche, *in Proceedings of the 2004 FEL Conference*, 201-204

Testing the After-Burner Concept

- In the LCLS, saturation occurs well before the end of the undulator even at the shortest wavelength.
- The last 10 of the 33 LCLS undulator segments have been set aside for the SHAB test.

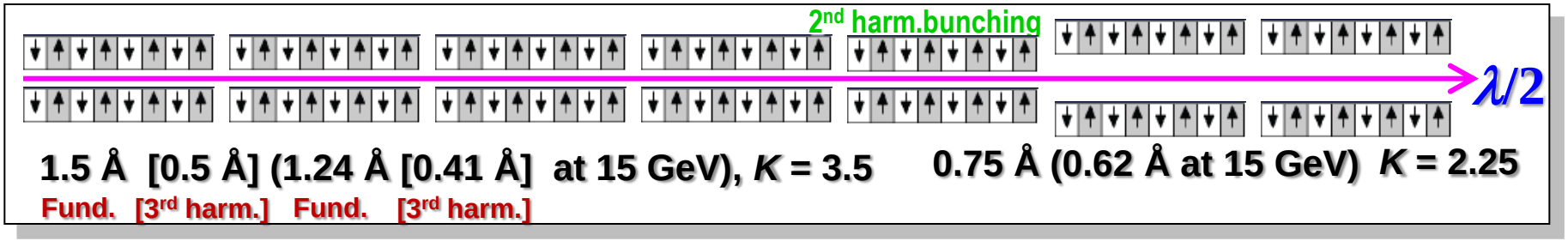


existing LCLS undulator

Testing the After-Burner Concept

- In the LCLS, saturation occurs well before the end of the undulator even at the shortest wavelength.
- The last 10 of the 33 LCLS undulator segments have been set aside for the SHAB test.

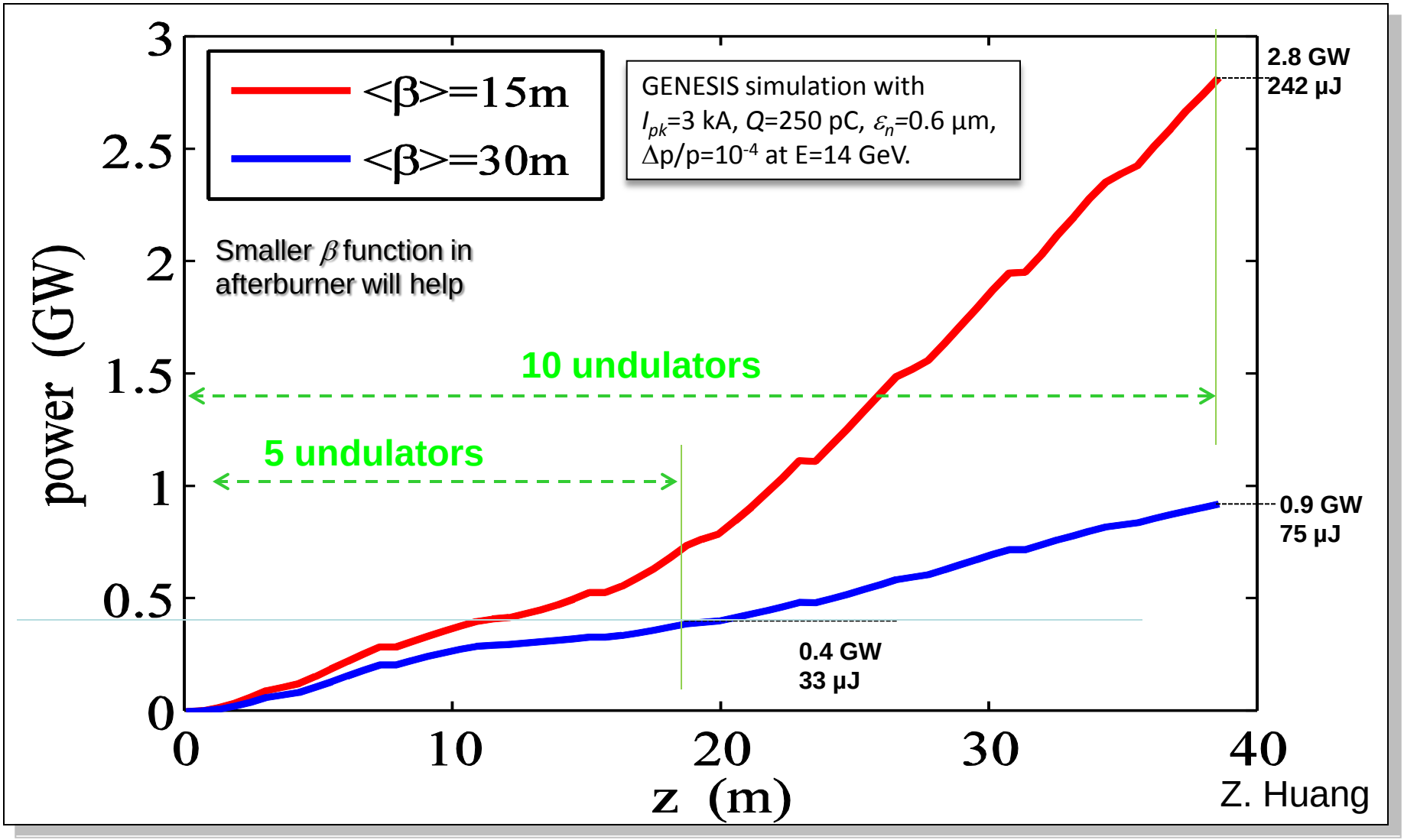
16 keV = 0.75 Å (up to 20 keV = 0.62 Å at 15 GeV)



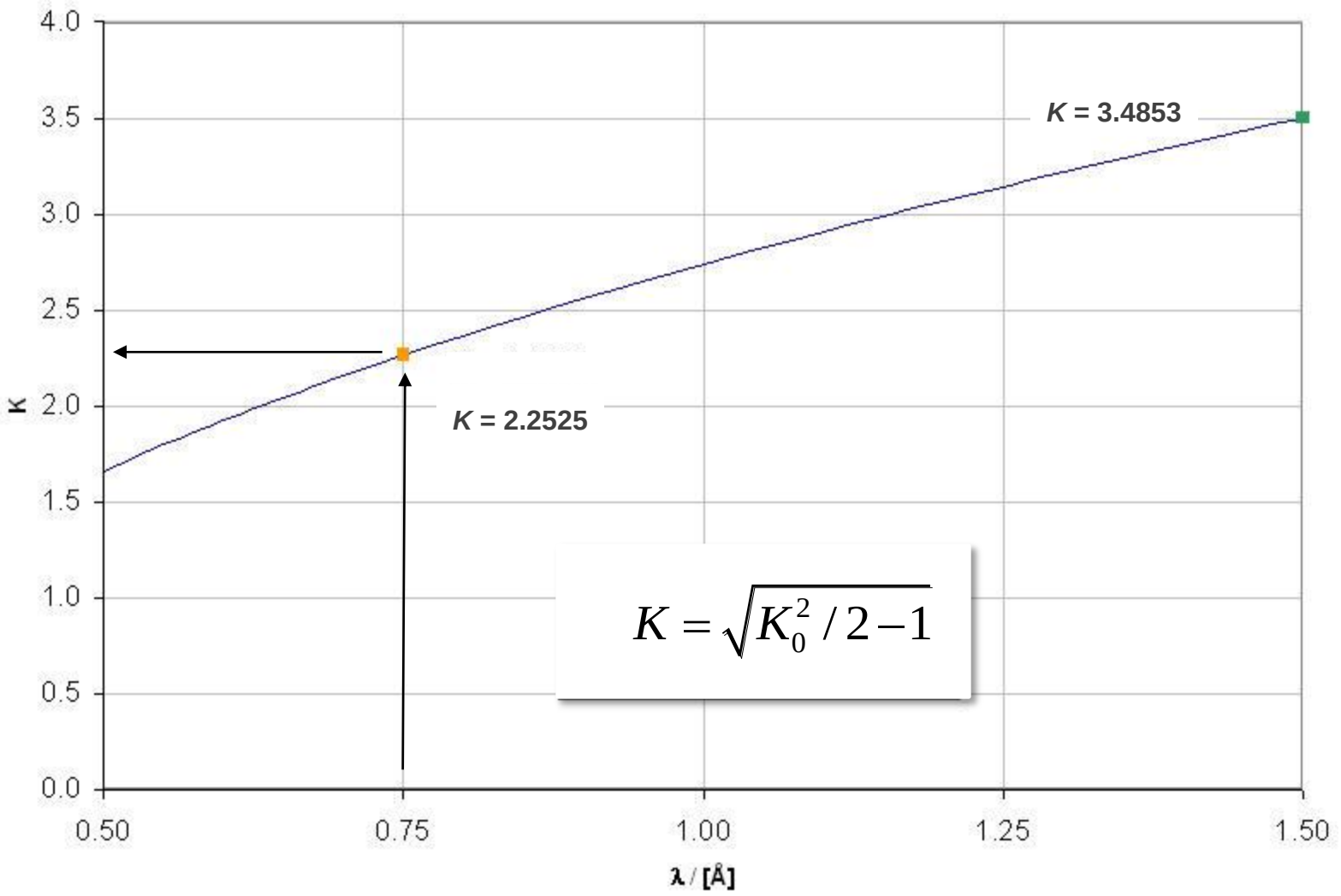
existing LCLS undulator **2nd harmonic after-burner**

- Presently, the last 5 undulator segments (U29 – U33) have been converted to SHABs

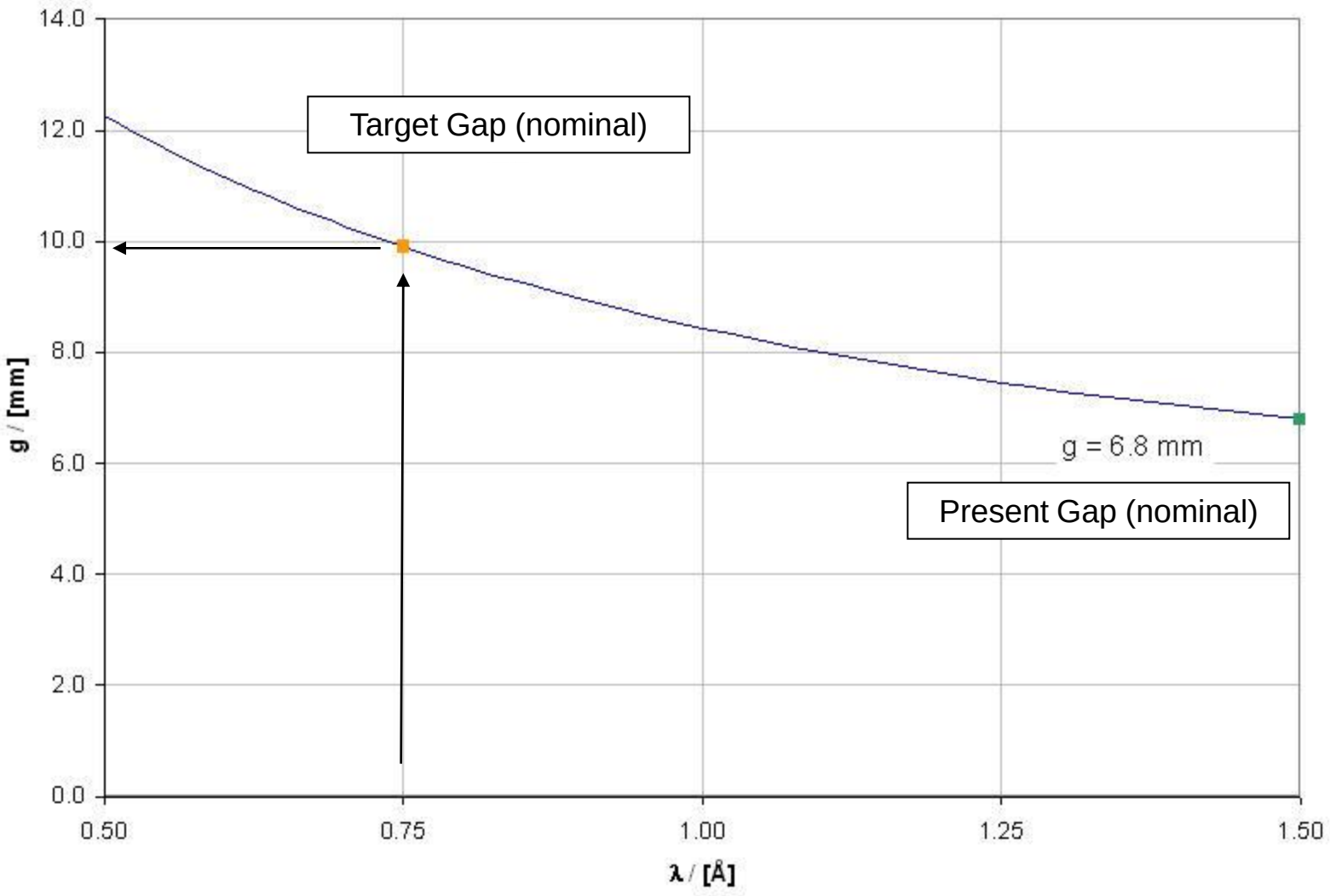
Expected Second-Harmonic Afterburner Yield



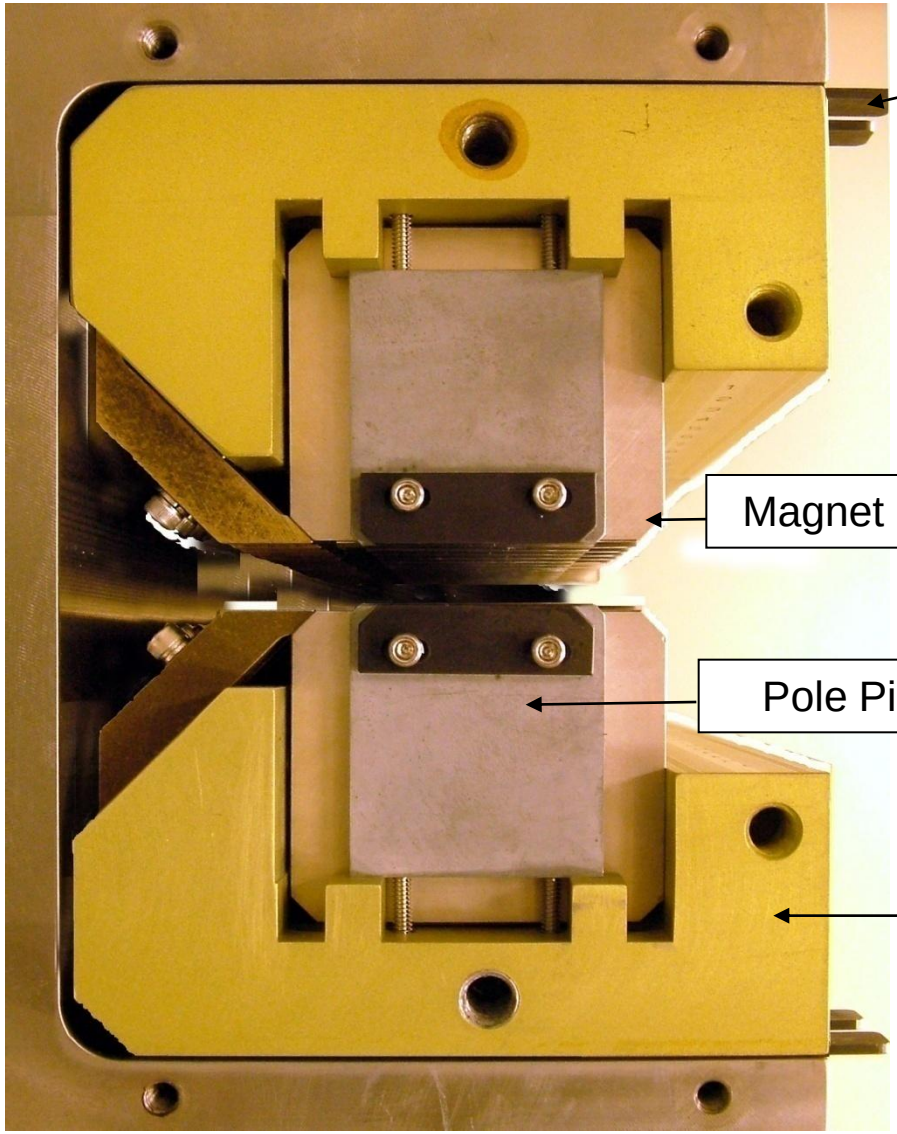
K Requirement



Gap Requirement



Gap Change Visualization

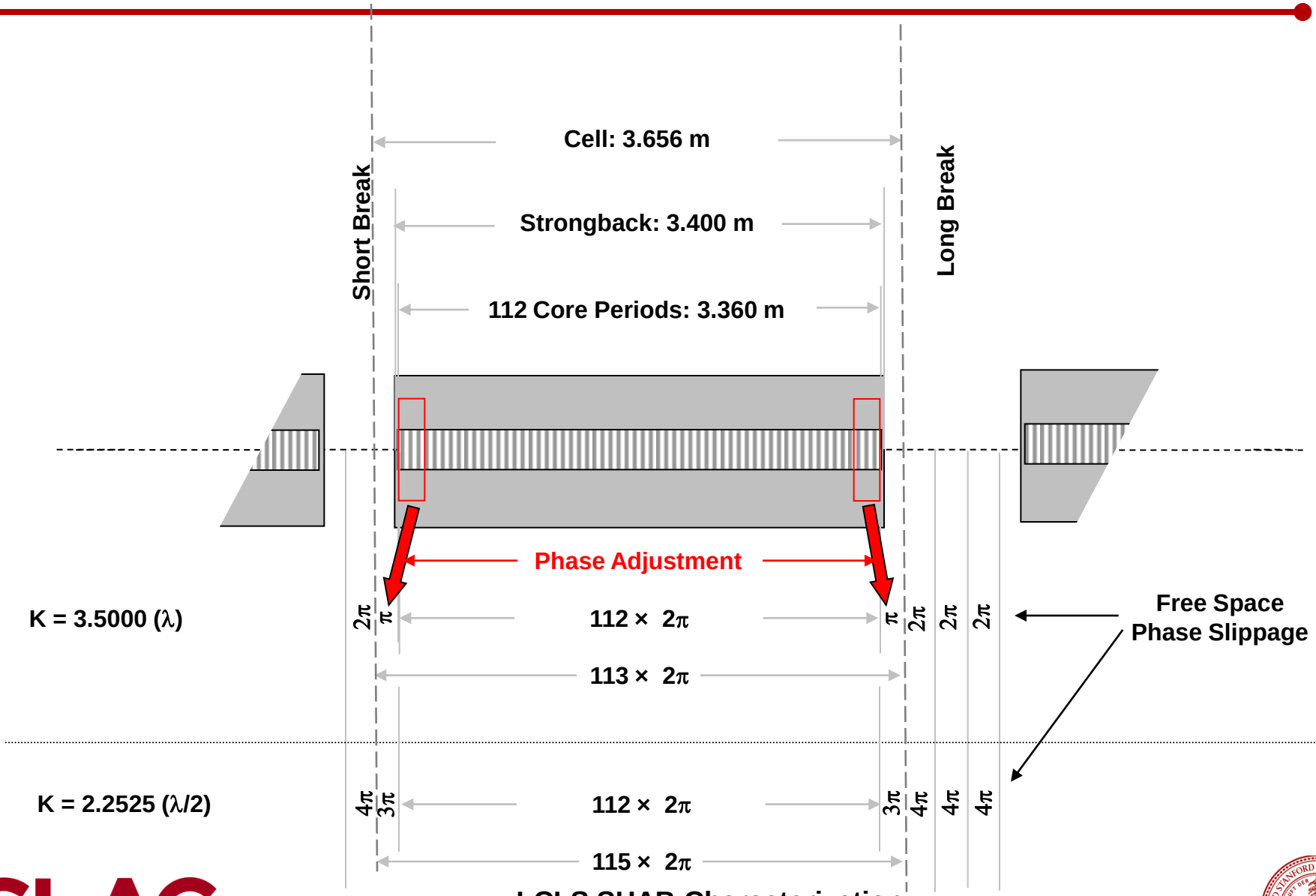


Present Undulator

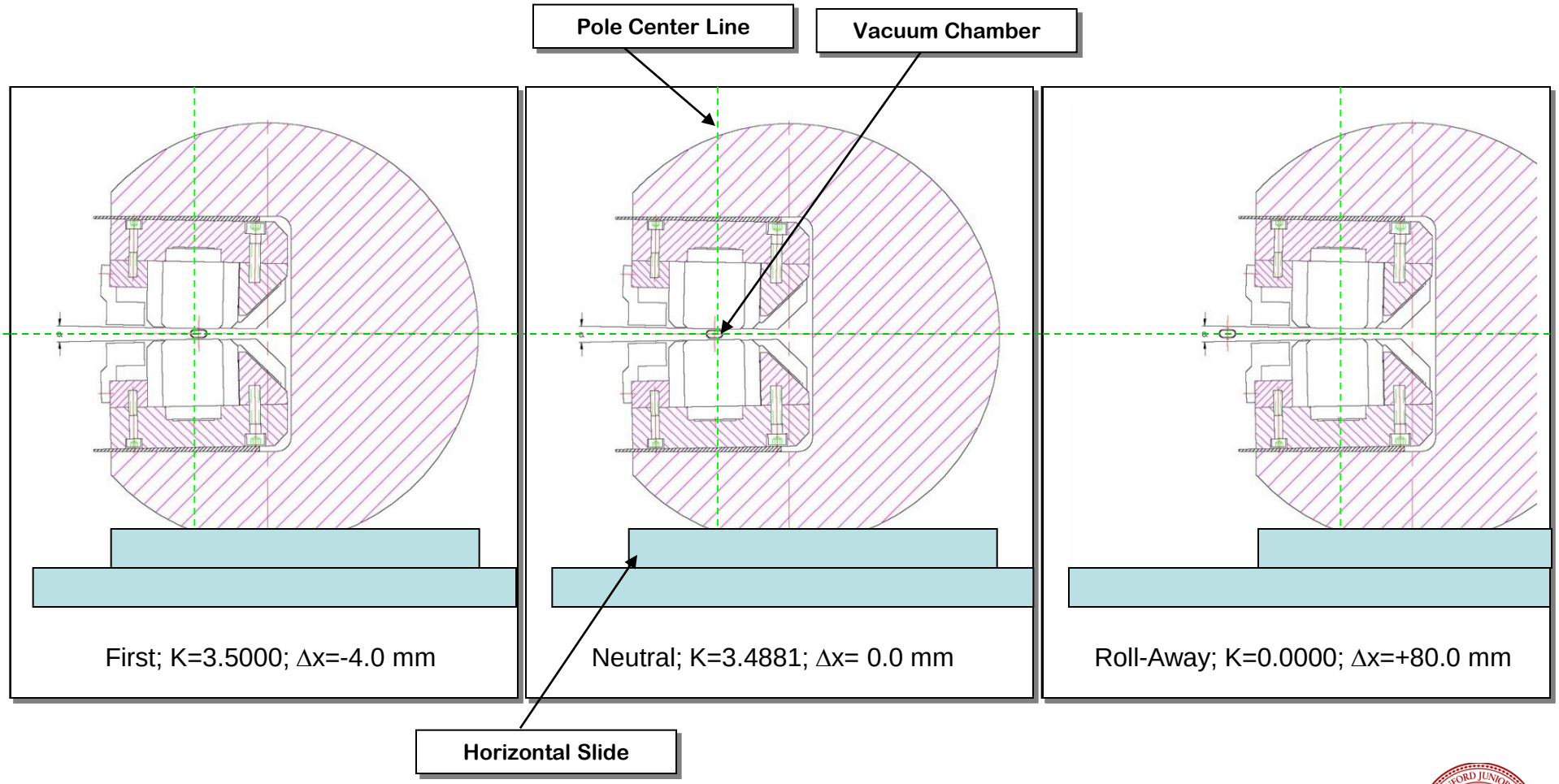
2nd Harmonic Undulator

Shim Size not changed in visulization

LCLS Undulator Phase Scheme



Undulator Roll-Away and K Adjustment Function

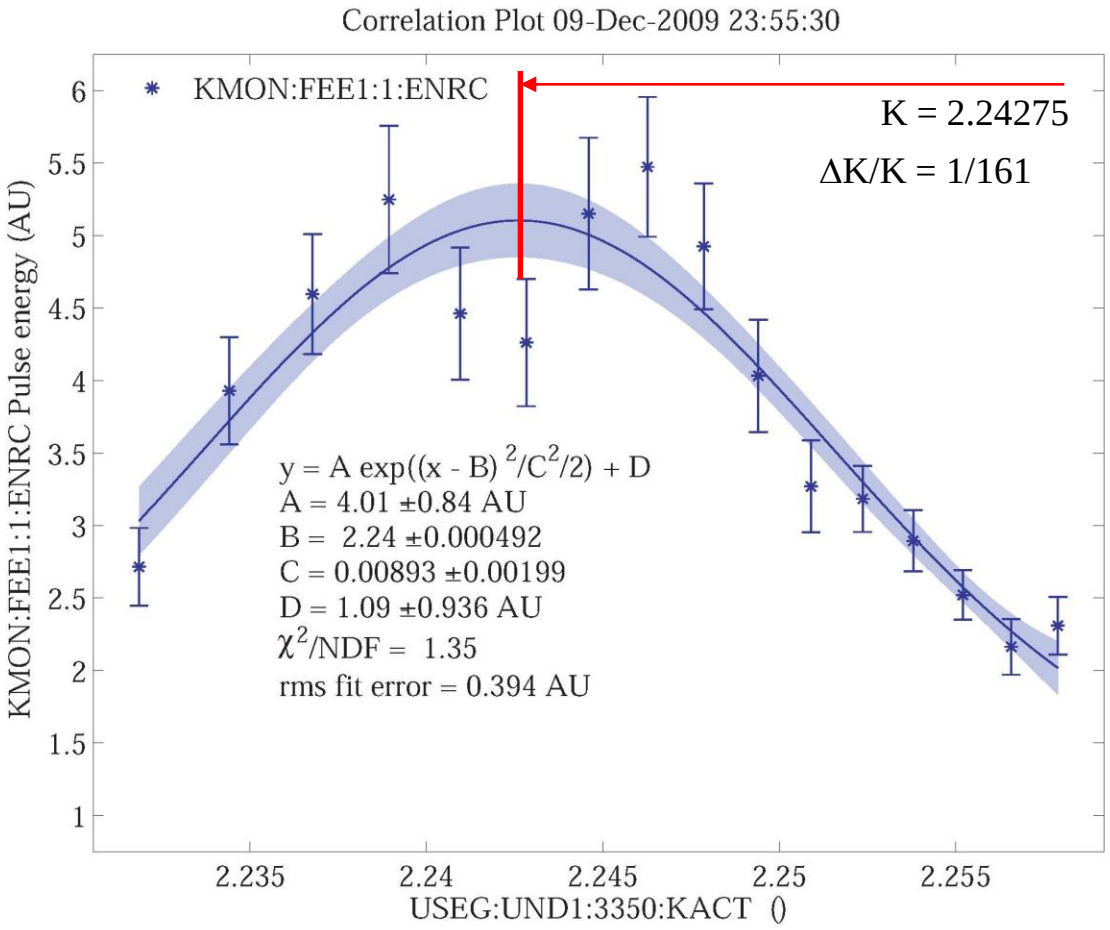


First SHAB Undulator Installed and Tested

- Gap of one undulator was increased and installed in slot U33 on 12/9/2009.
- Beam measurements done with the K-Mono

2009-12-09

E_e = 9.6 GeV
$E_{x\text{-}ray}$ = 8.19 keV
Required by K-Mono



Installation and Test Schedule

- December 9, 2009
  SHAB U33 installed and tested @ 8.2 keV SHAB energy

- January – May 2010
  SHABs U29 – U32 modified, tuned, and installed

- May 2010 – August 2010
  SHABs commissioned as discussed in this talk

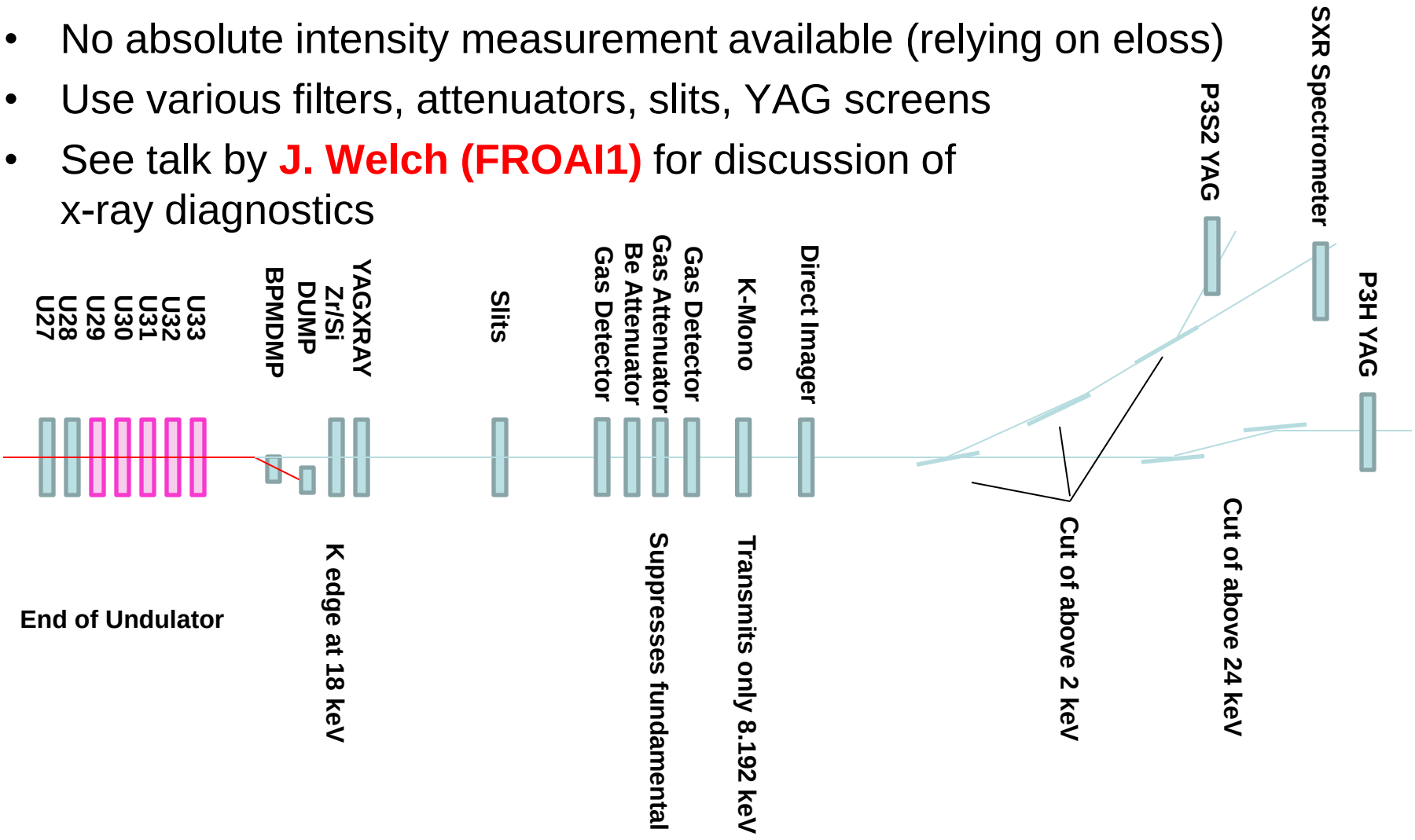
- Three more SHABs are ready to be installed

- Presently a maximum of 10 SHABs is considered

- Next steps are not yet decided

Diagnostics

- No absolute intensity measurement available (relying on eloss)
- Use various filters, attenuators, slits, YAG screens
- See talk by **J. Welch (FROAI1)** for discussion of x-ray diagnostics

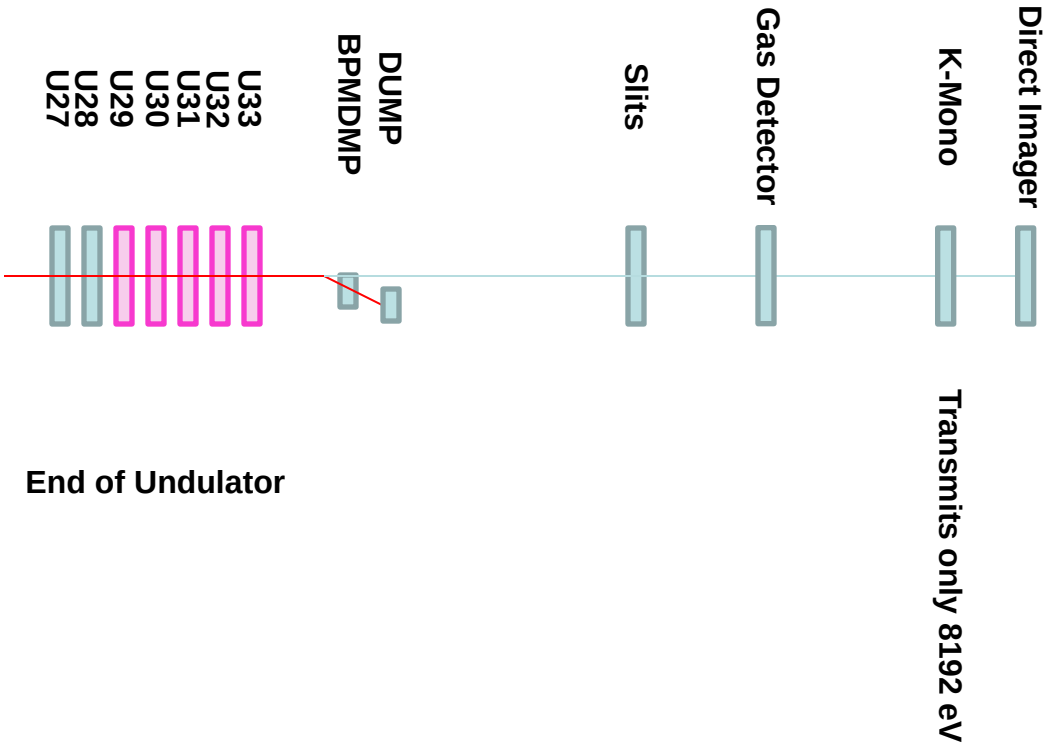


Setup Steps

- Start with BBA (all undulator segments inserted)
- Set electron energy to target energy
  - 4.3 GeV (for 900 eV / 1800 eV) 2 keV 3rd harmonic mirror cutoff
  - 6.2 GeV (for 4096 eV / 8192 eV) K-Mono
  - 14.2 GeV (for 9000 eV / 18000 eV) Zr K edge
- Setting a linear taper
- Remove SHABs
- Adjust electron energy to set 2nd FEL harmonic to exact energy
- Insert 1 SHAB at a time and scan K and set to optimum
- Measure saturation point and set desired number of bunching undulators

Diagnostics for SHAB Energy = 8192 eV

- Use K Mono to remove fundamental and third harmonic.
- Use NFOV (Direct Imager) for observation.
- PROBLEM:
  K Mono very difficult to adjust



As example of use see K scan of U33, in earlier slide

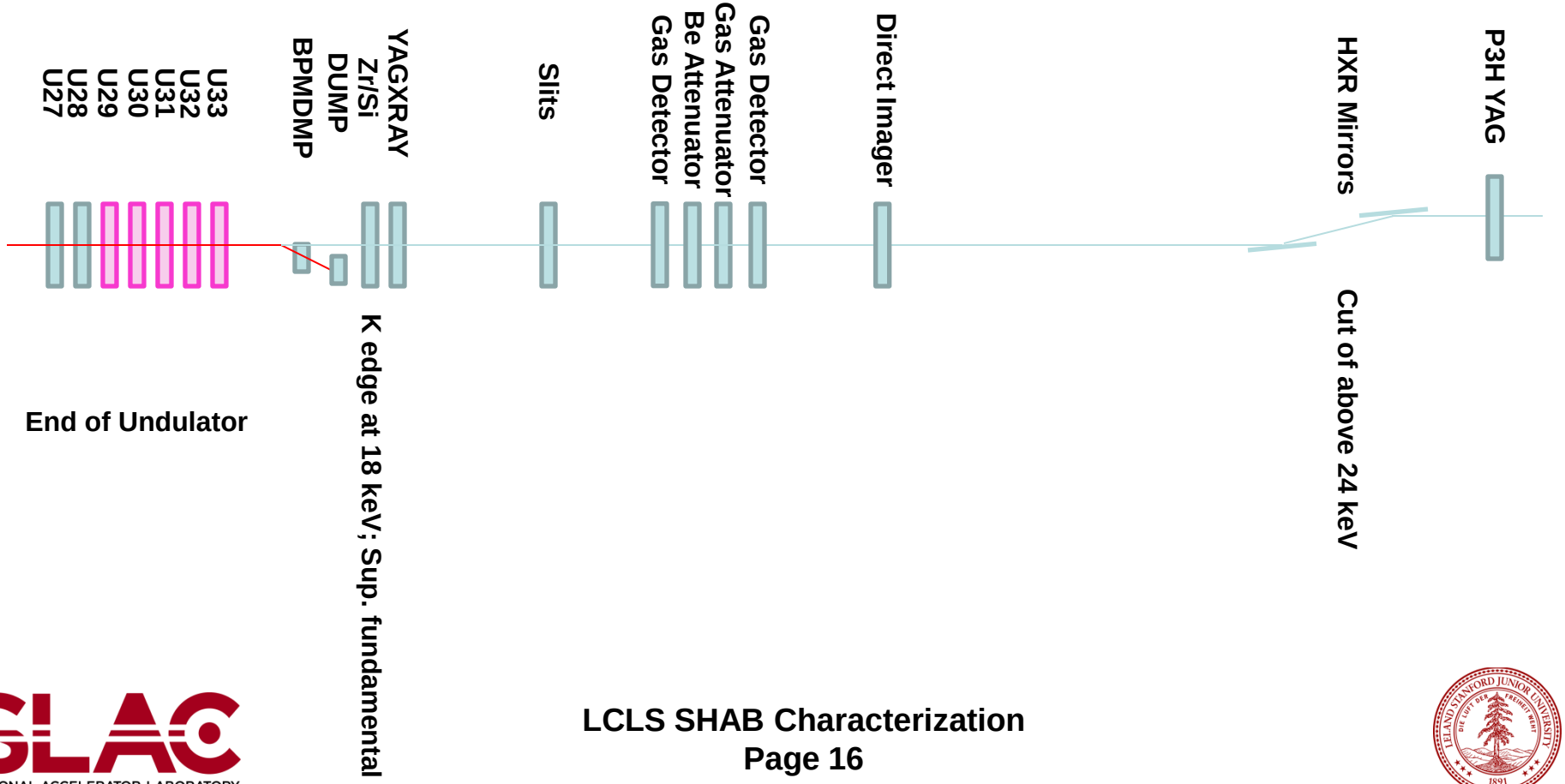
Diagnostics for SHAB Energy = 18000 eV

- Use Zr/Si foil to remove fundamental.
- Use deflection on HXR mirror pair to remove 3rd harmonic.
- PROBLEM:

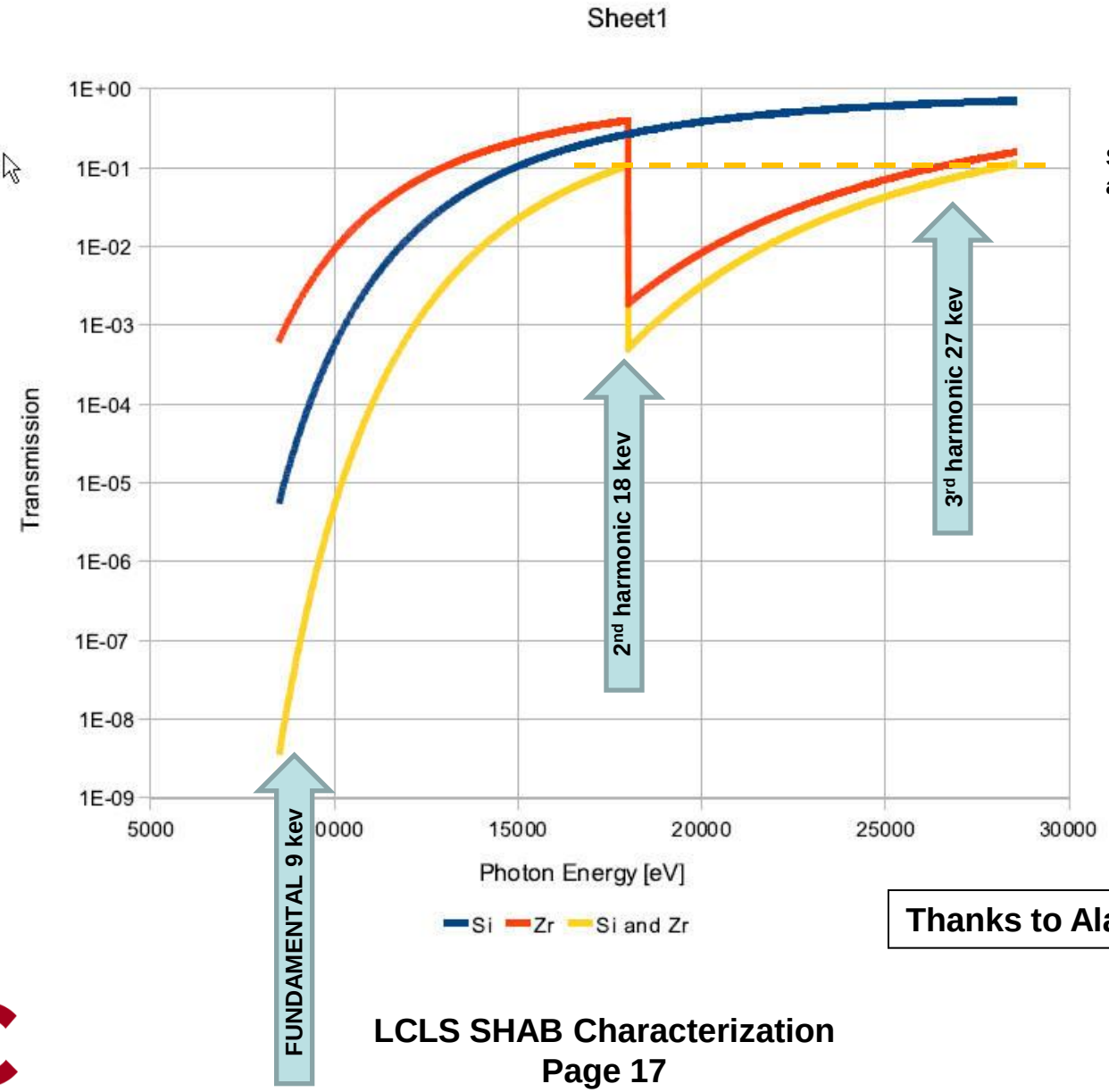
  HXR mirrors are too small for the beam.

  They are difficult to align to guarantee good 3rd harmonic suppression.

  MD time too short to change machine energy from <2keV operation and tune.



Zr + Si Spectrum



Similar absorption at 2nd and 3rd harmonic

Thanks to Alan Fisher!

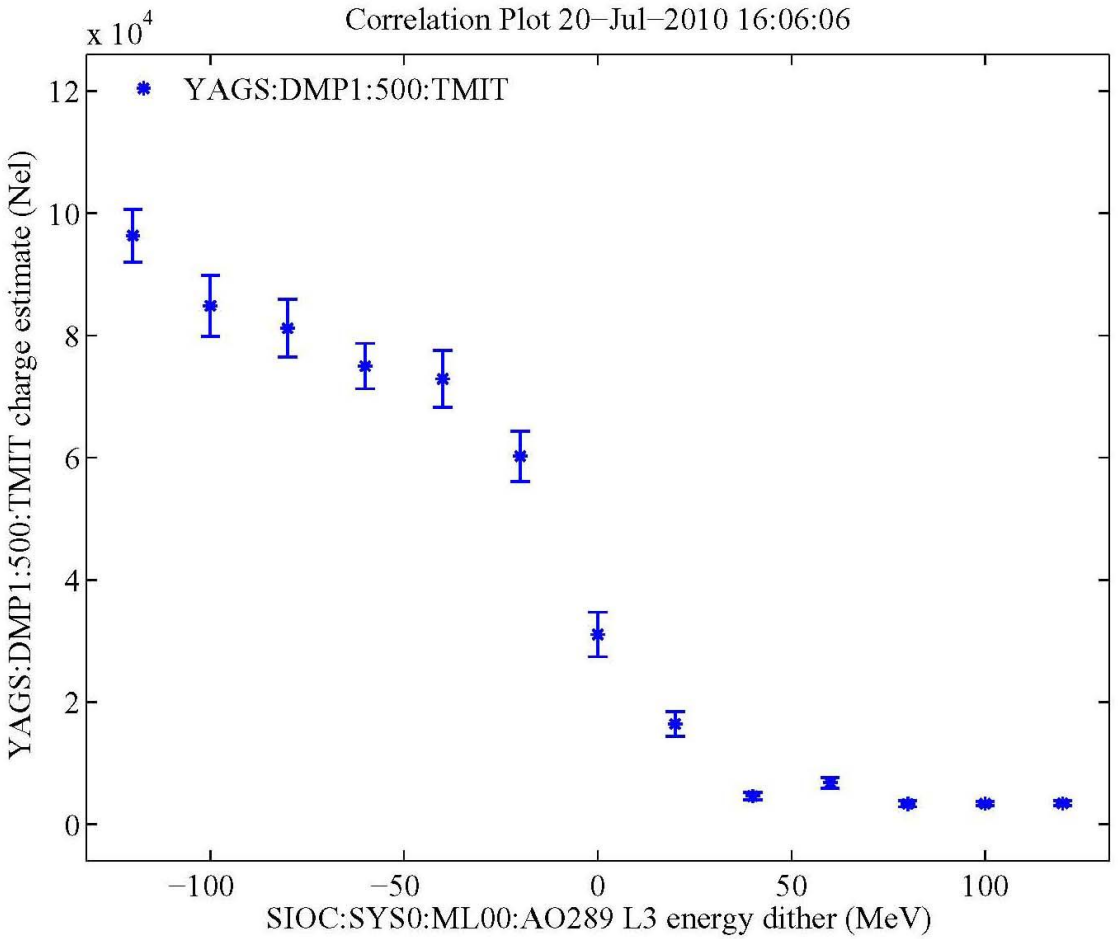
YAGXRAY vernier scan across Zr K edge

U01:U33; SHAB at optimum 6/29/10 taper

Bend energy 14.232 GeV

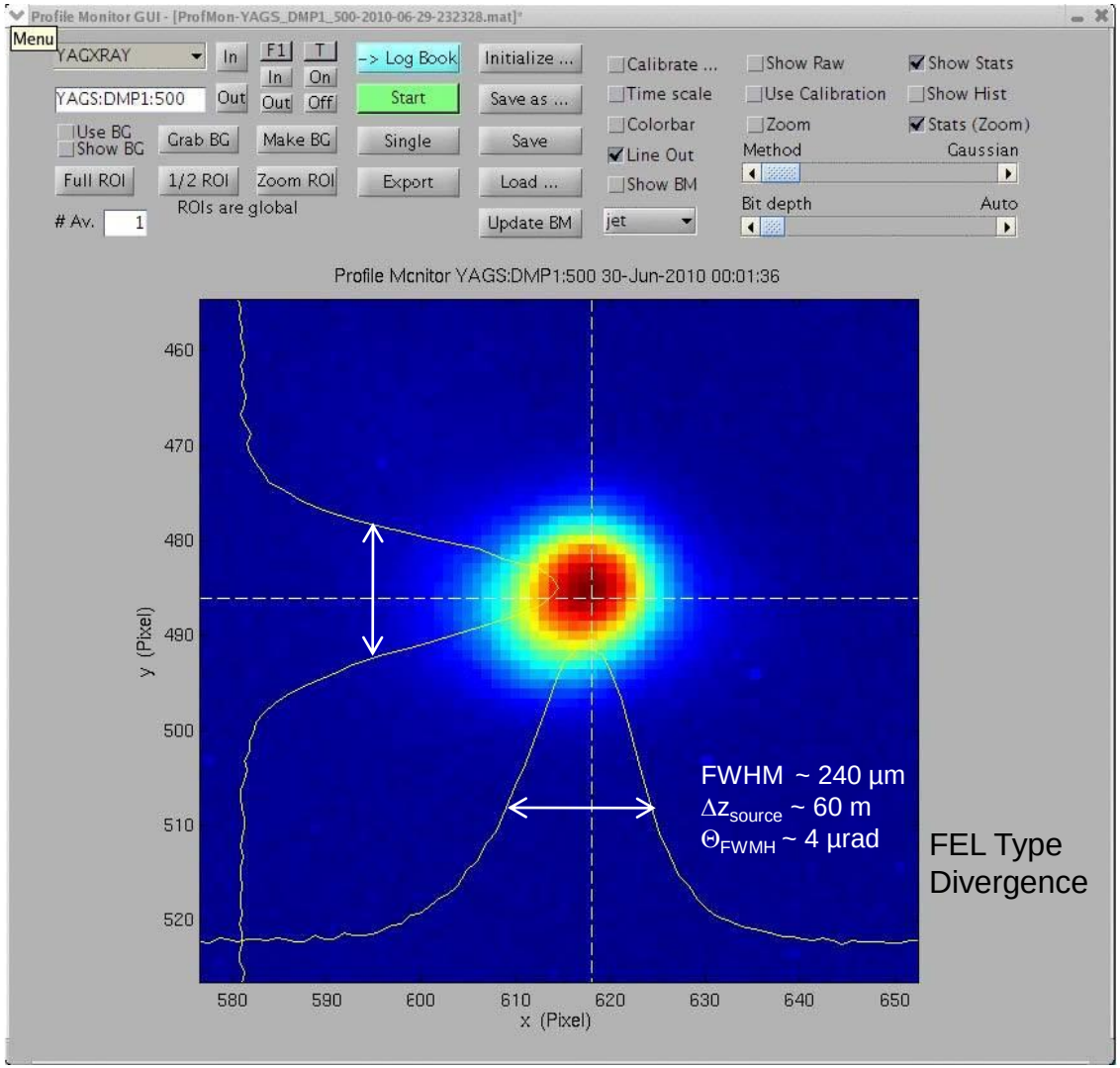
Background subtraction effectively removed non-beam background.

Above K edge intensity from 3rd harmonic and leakage is quite low.



Observing SHAB Beam on YAGXRAY after Zr/Si

18 keV SHAB Energy

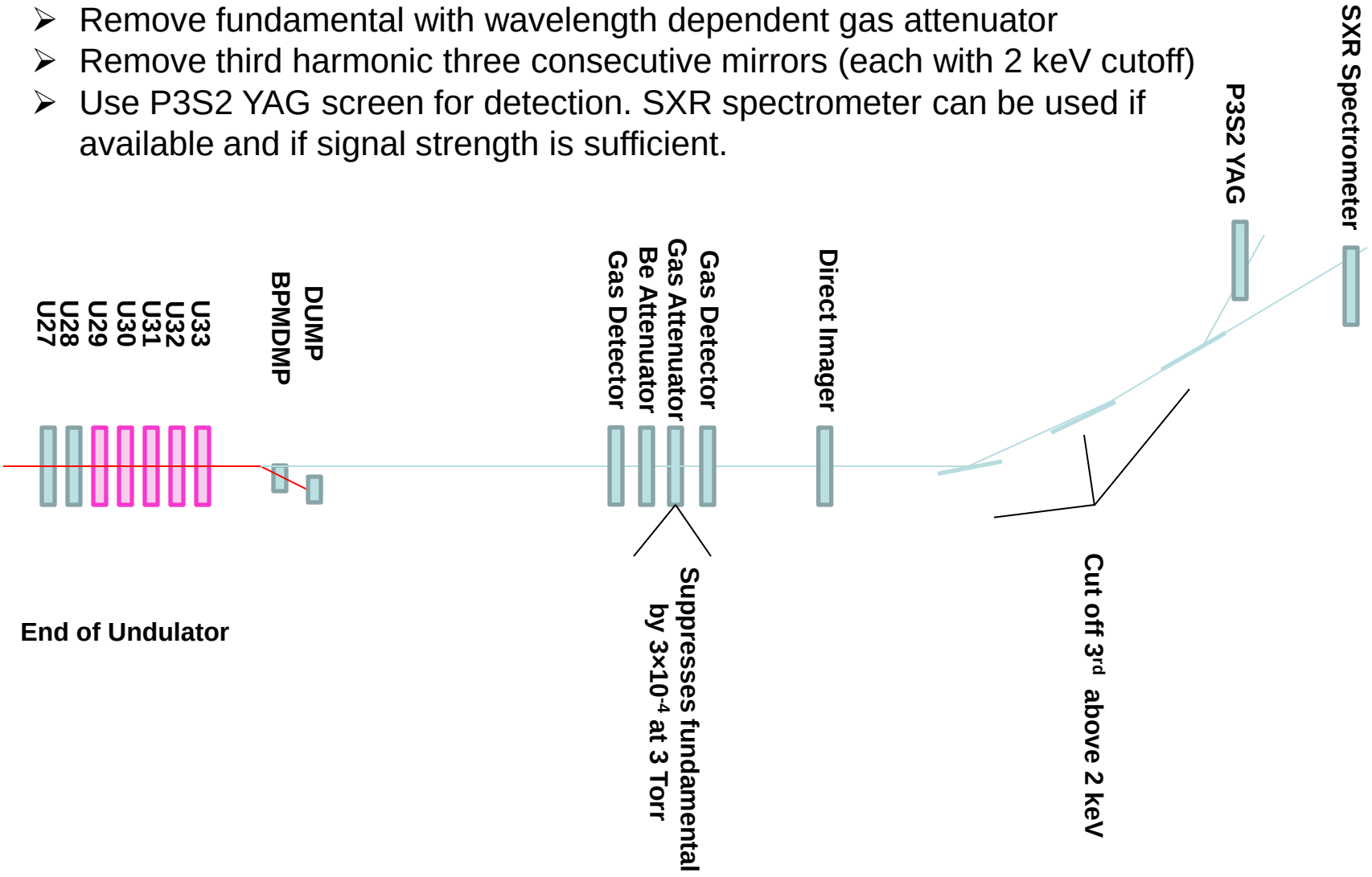


FEL Type Divergence

U1-33 all in (28+5 SHABs)

Diagnostics for SHAB Energy = 1800 eV Beam

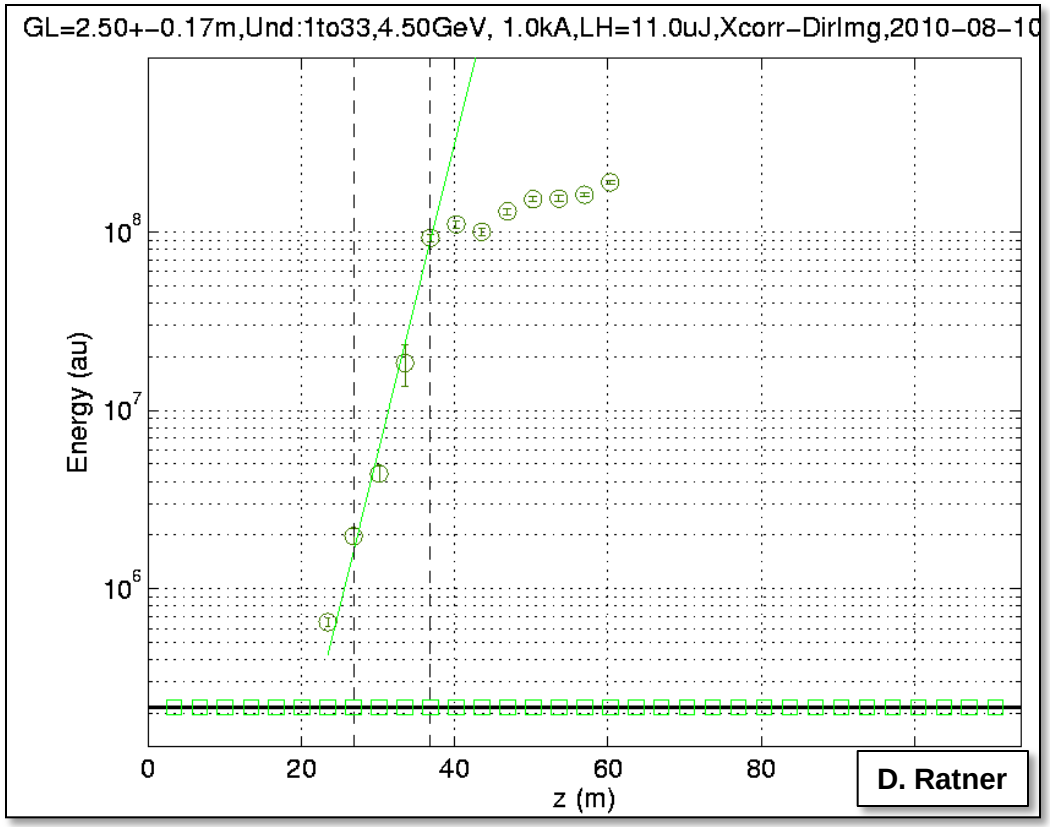
- Remove fundamental with wavelength dependent gas attenuator
- Remove third harmonic three consecutive mirrors (each with 2 keV cutoff)
- Use P3S2 YAG screen for detection. SXR spectrometer can be used if available and if signal strength is sufficient.



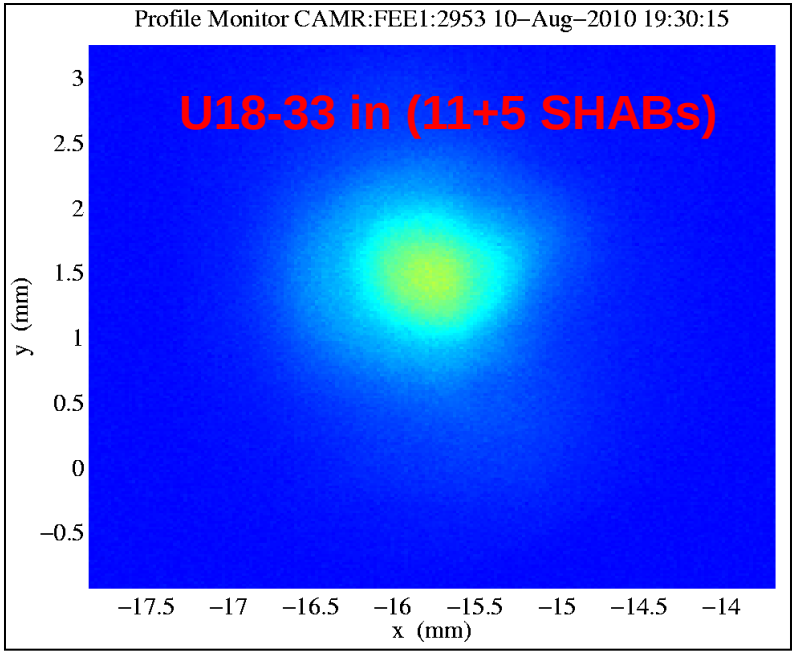
GainLength Gui

1800 eV SHAB Energy

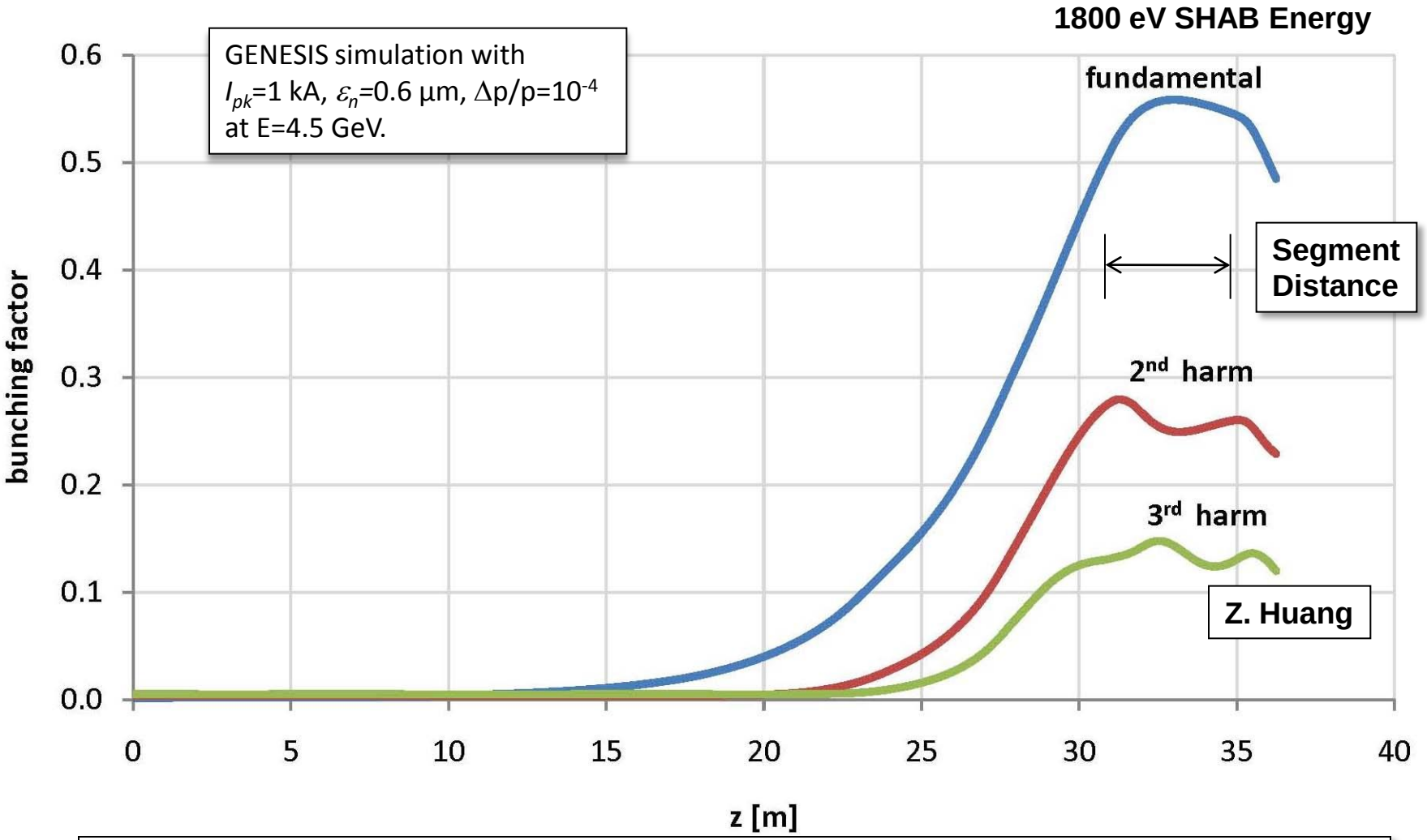
determine FEL saturation at ~11 undulator sections at SHAB energy of 1800 eV:



Remove first 17 undulators ➔



Harmonic Bunching



Adjust number of regular undulators to optimize 2nd harmonic microbunching in SHABs. Granularity is given by Segment Distance.

Debunching in SHABs due to Undulator R_{56}

J. Wu

- *The FEL induced energy spread in the regular undulator is heating the electron beam*
  - *SHABs have an R_{56}*
  - *In an undulator* $R_{56} = -\frac{K^2 L_u}{2\gamma_0^2} \approx -2N_u\lambda_r$
  - *When the R_{56} of the SHABs spreads electrons by more than $\lambda_r/4$, the microbunching, built in the regular undulator, diffuses in the SHABs* $R_{56}\frac{\Delta\gamma}{\gamma} \approx \frac{\lambda_r}{4} \Rightarrow N_u \approx \frac{1}{8\Delta\gamma/\gamma} \approx \frac{1}{8\rho}$
  - *Take $\rho = 5\times10^{-4}$ → $N_u \sim 250$ → about **2** SHABs*
  - *Of course, one can **taper** the SHABs to use more segments*
  - ***Higher** energy FEL can have **more** SHABs, since ρ is smaller*
- *The ratio of energy spread to bunching amplitude can be improved with a dispersive section acting on the pre-saturated bunch. (similar to HGHG scheme)*

L.H. Yu, Phys. Rev. A **44**, 5178 (1991)

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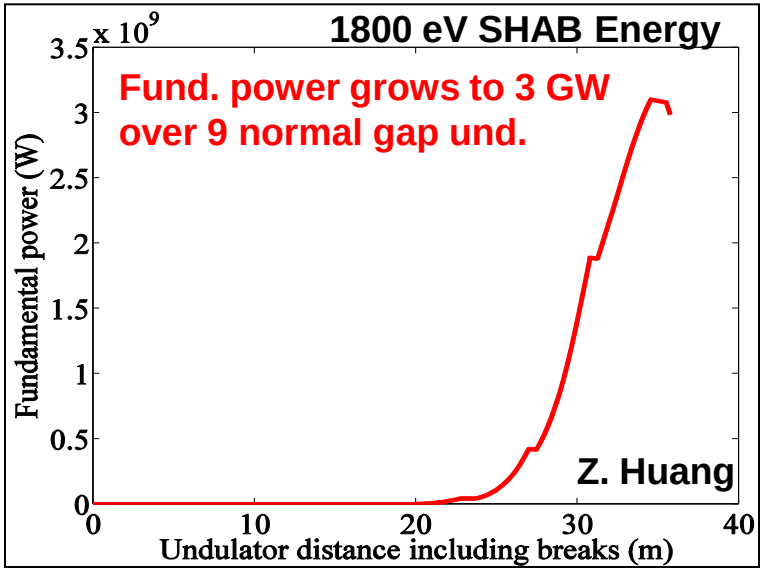
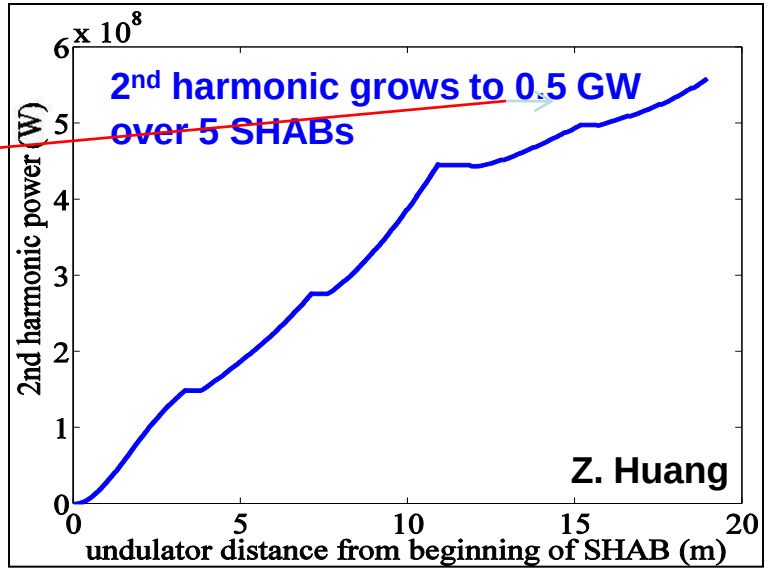
Not yet done in this experiment

L.H. Yu, Phys. Rev. A **44**, 5178 (1991)

Predicted SHAB Performance

GENESIS simulation with
I_{pk}=1 kA, ε_n=0.6 μm, $\Delta p/p=10^{-4}$
at E=4.5 GeV.



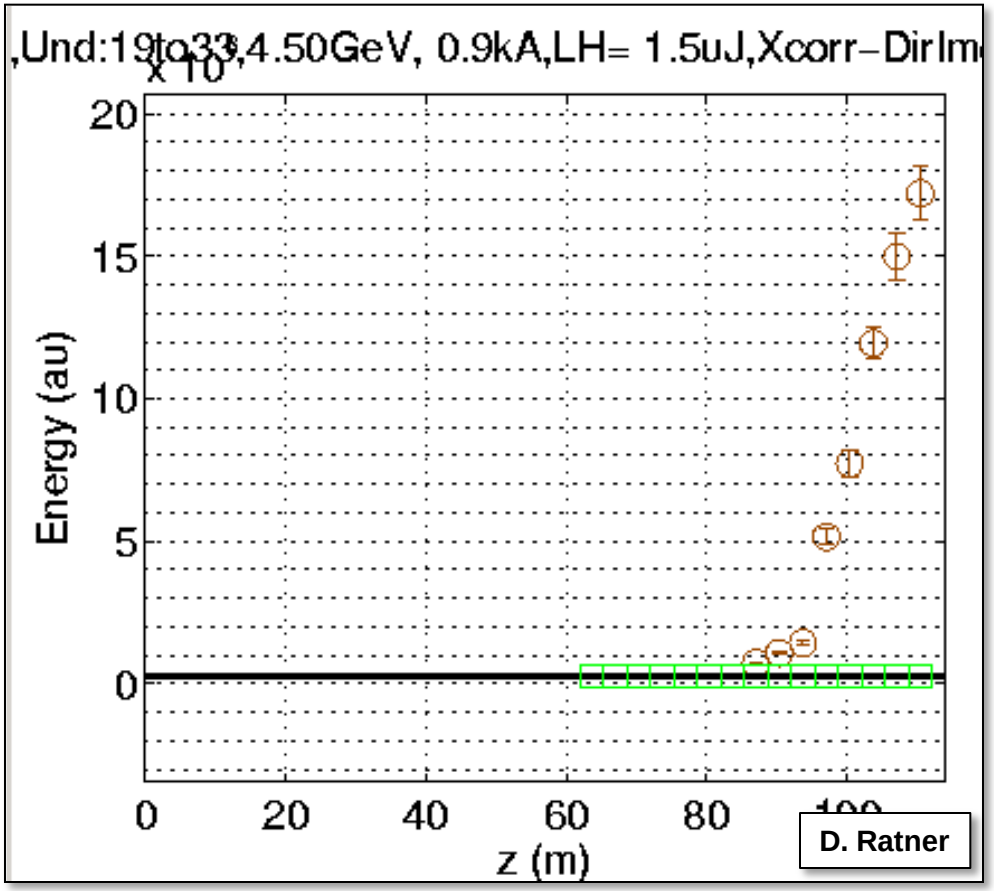


2nd harmonic intensity
0.5 GW * 250 fs = 0.12 mJ

Prediction for 1800 eV SHAB Energy

SHAB Gain Curve on Direct Imager

1800 eV SHAB Energy



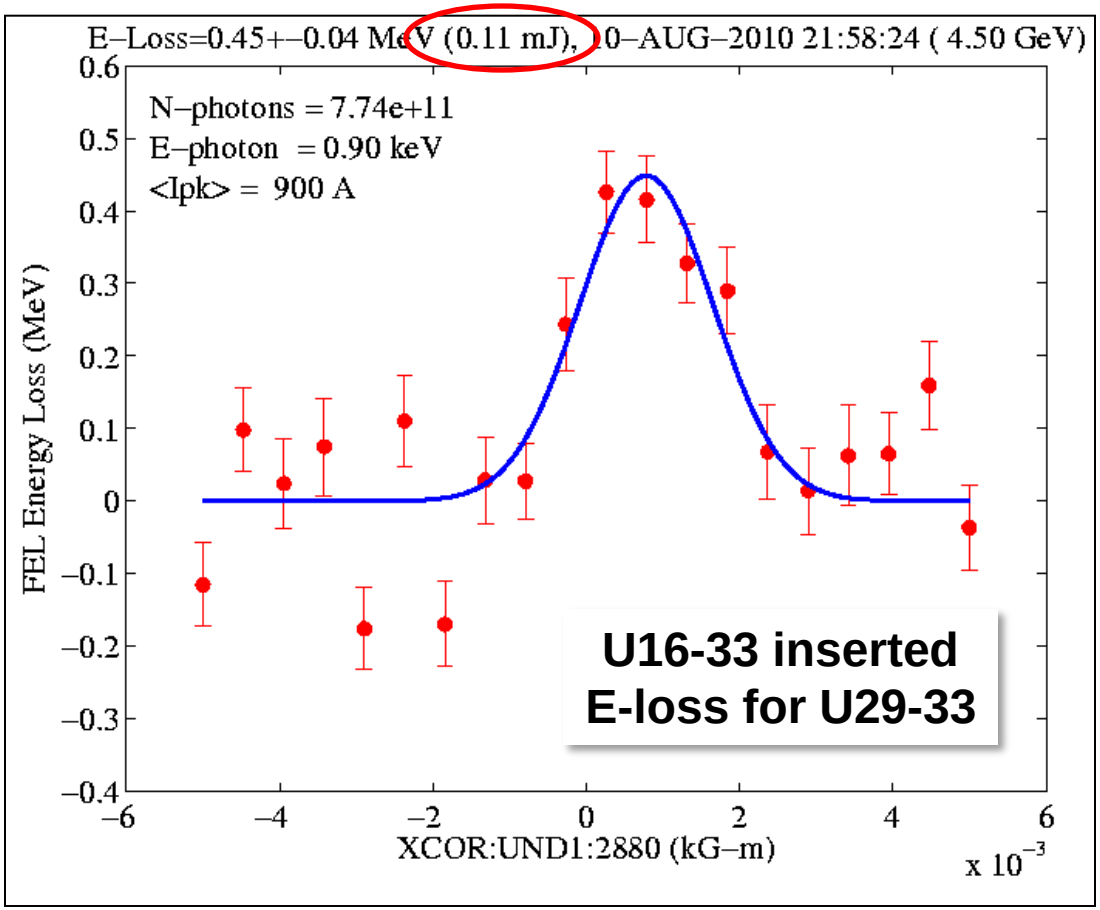
- First three data points are Und 26-28 (mostly 3rd harmonic)
- Last five are SHABs (increase due to 2nd harmonic bunching)

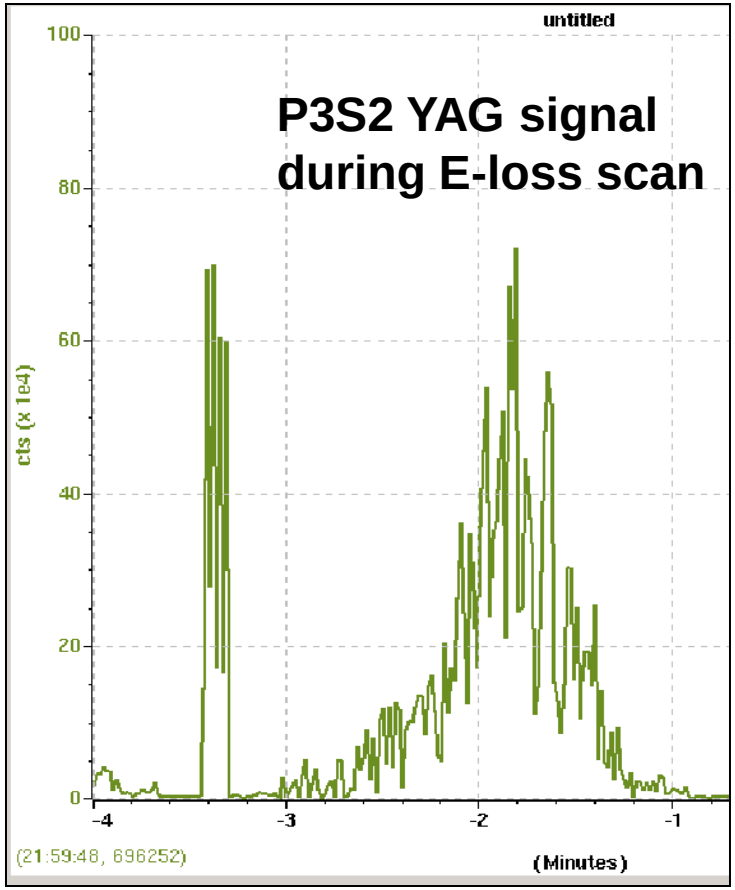
Eloss Scans

P. Emma

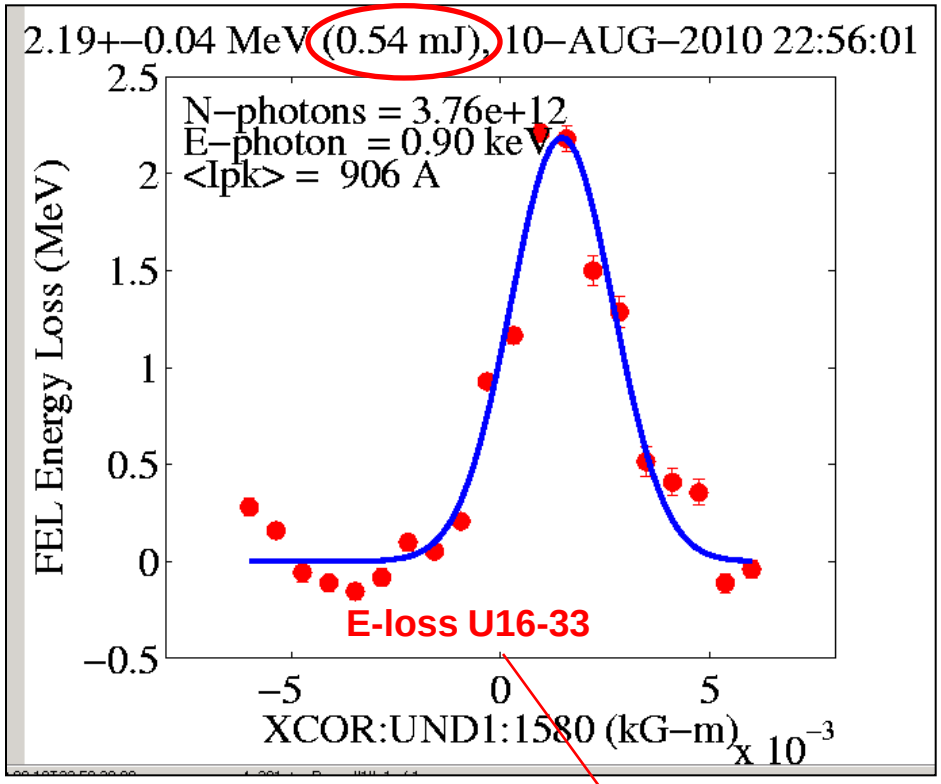
Kick electron beam transversely to destroy FEL and micro-bunching at selected point.
Measure energy loss at dump BPM

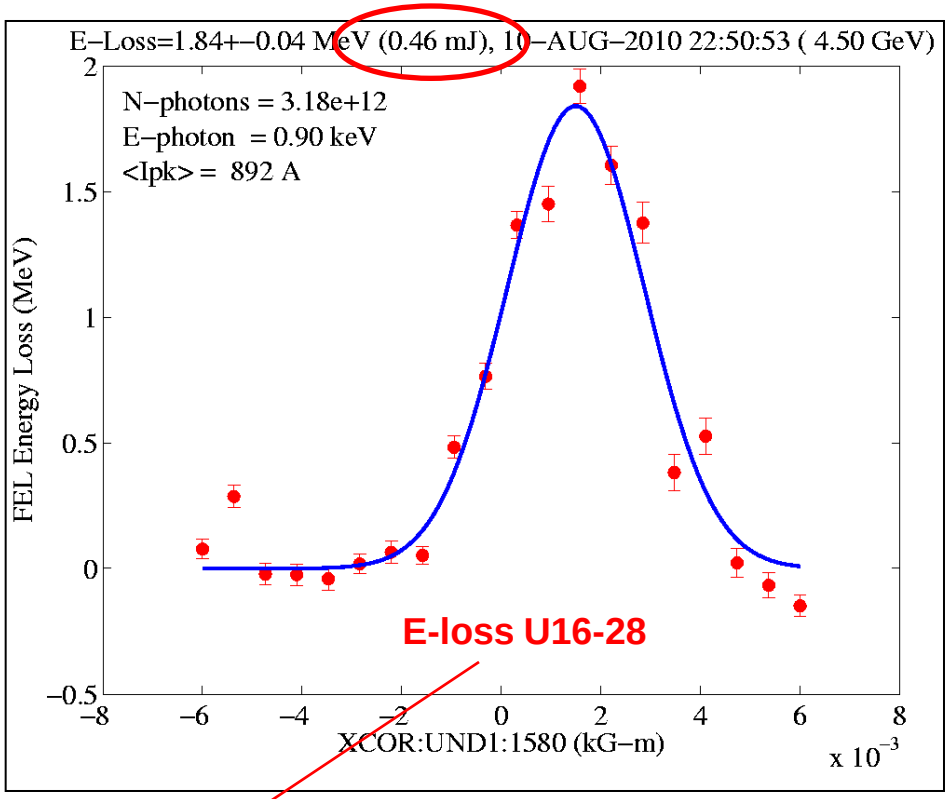
1800 eV SHAB Energy





More Exotic Eloss Scans





E-loss for U16-33

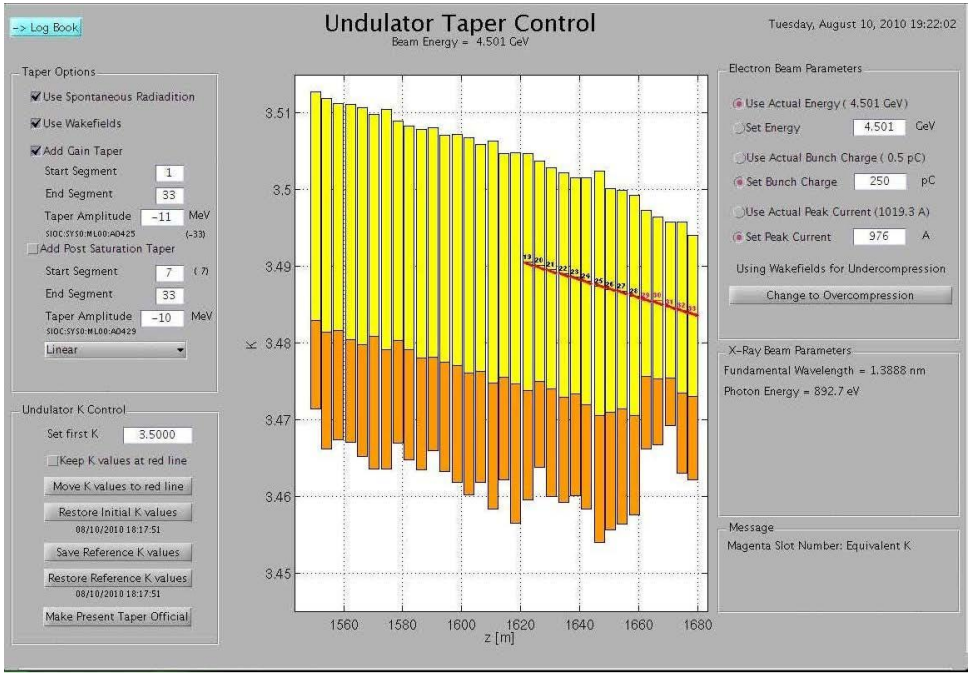
E-loss for U16-33 but place another kick at beginning of SHABs

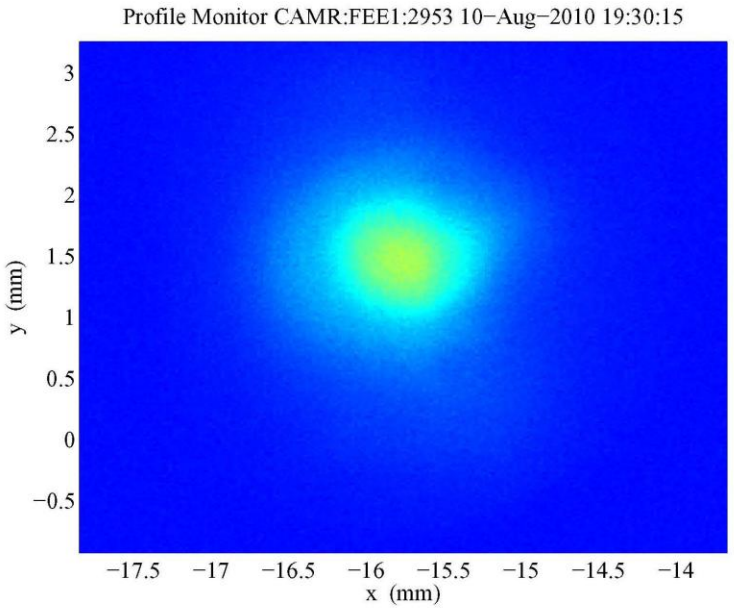
- Difference of two E-loss scan should be SHAB E-loss

0.54-0.46 = 0.08 mJ

SHAB Taper improves 2nd harmonic signal by a factor of 2

1800 eV SHAB Energy



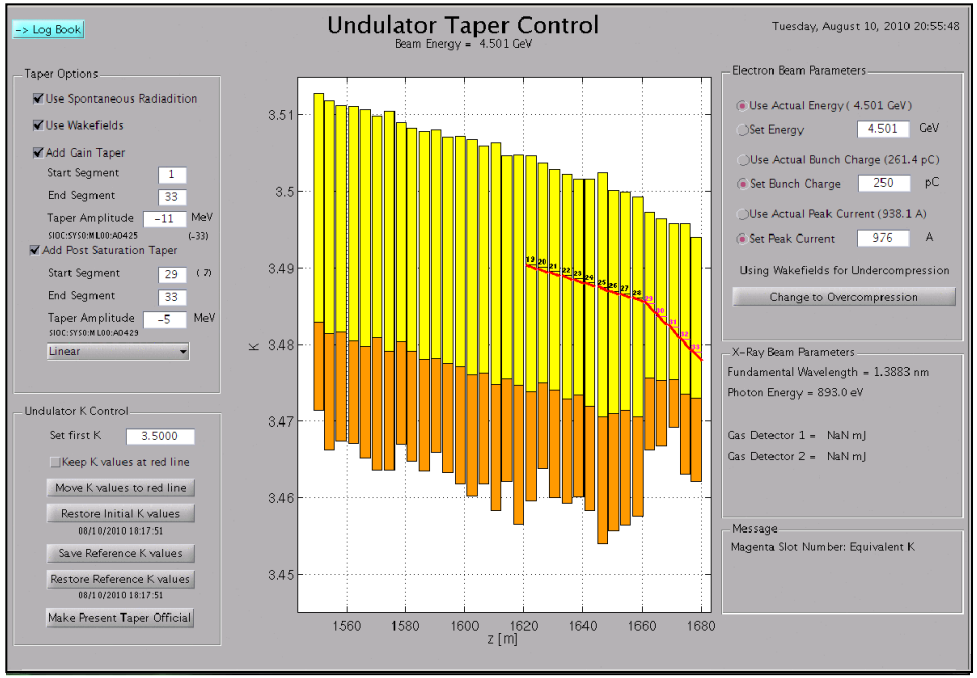


SHAB Signal on P3S2 YAG

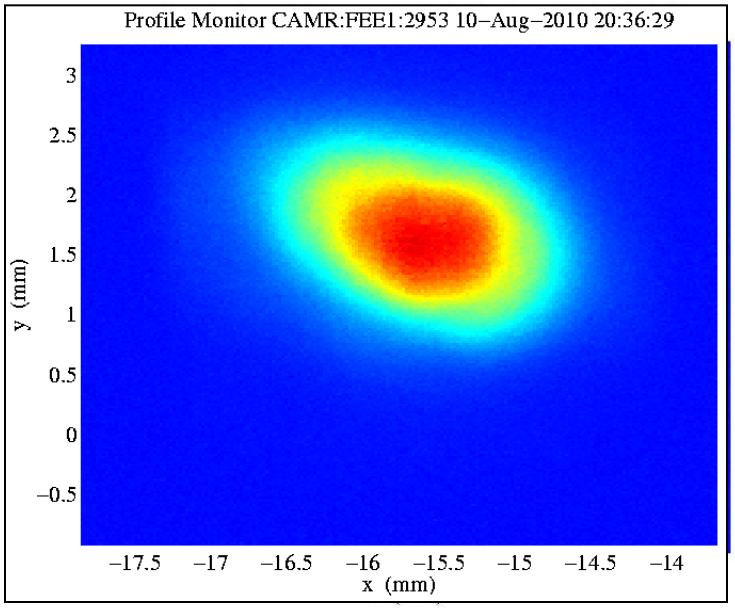
CONSTANT TAPER

SHAB Taper improves 2nd harmonic signal by a factor of 2

1800 eV SHAB Energy



DOUBLE INTENSITY

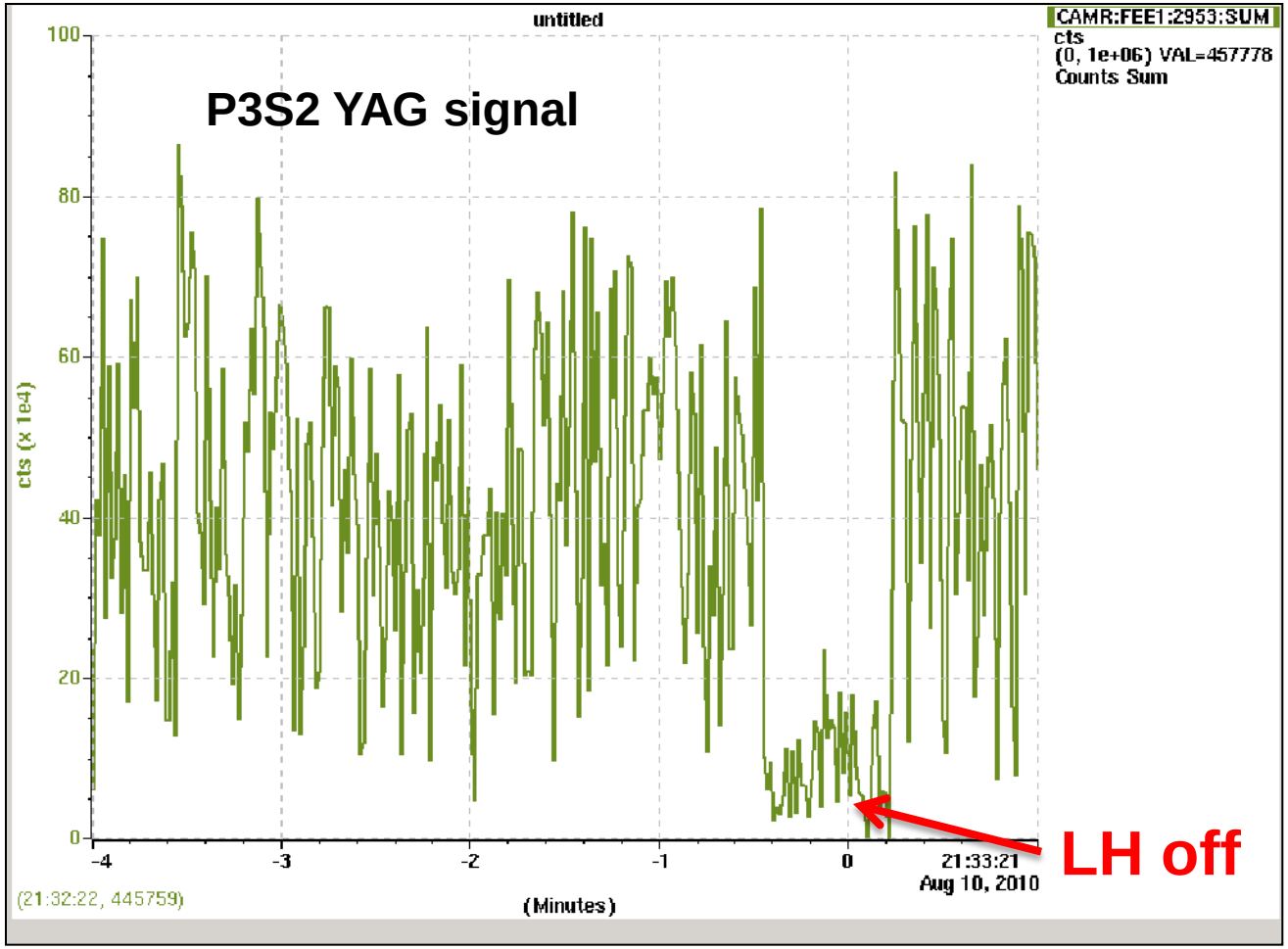


SHAB Signal on P3S2 YAG

EXTRA SHAB TAPER

Turning off the heater kills SHAB signal

1800 eV SHAB Energy



Shows that SHABs act on microbunching; also demonstrates the importance of the Laser Heater

Summary

- Five SHABs generate ~0.1 mJ of 2nd harmonic power at 1.8 keV (barely detectable with E-loss method)
- Found increasing power over all five SHABs
- Reasonable agreement with simulations
- Signal is sensitive to Laser Heater setting
- Found that SHAB intensity at 18 keV (14.2 GeV) exceeds that of 3rd harmonic at same photon energy (11.6 GeV) by at least factor 2
  - Measurement was suggested by J. Frisch
  - This factor should increase to 10+ if more SHABs are installed and beta-function is reduced.
- More SHABs are ready to be installed
- May wait until somebody can use the radiation before we install them

FEL
- MMX Sweden -

THANK YOU FOR YOUR ATTENTION!

End of Presentation