(*Undulator*) Wakefield Measurements at *LCLS*

J. Wu (SLAC)

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SLAC

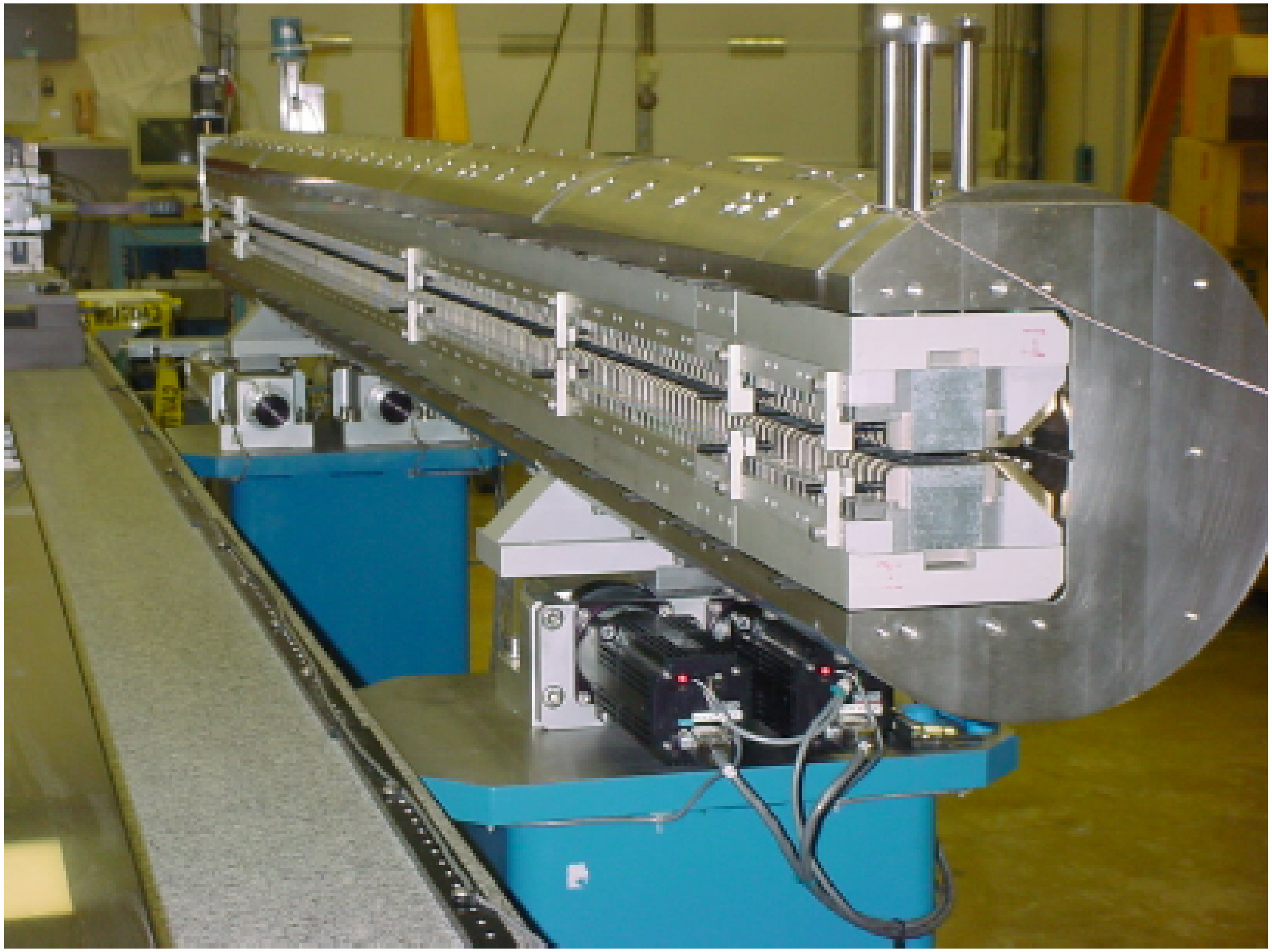
Compact X-Ray FELs using High-Brightness Beams

Aug. 5-6, 2010

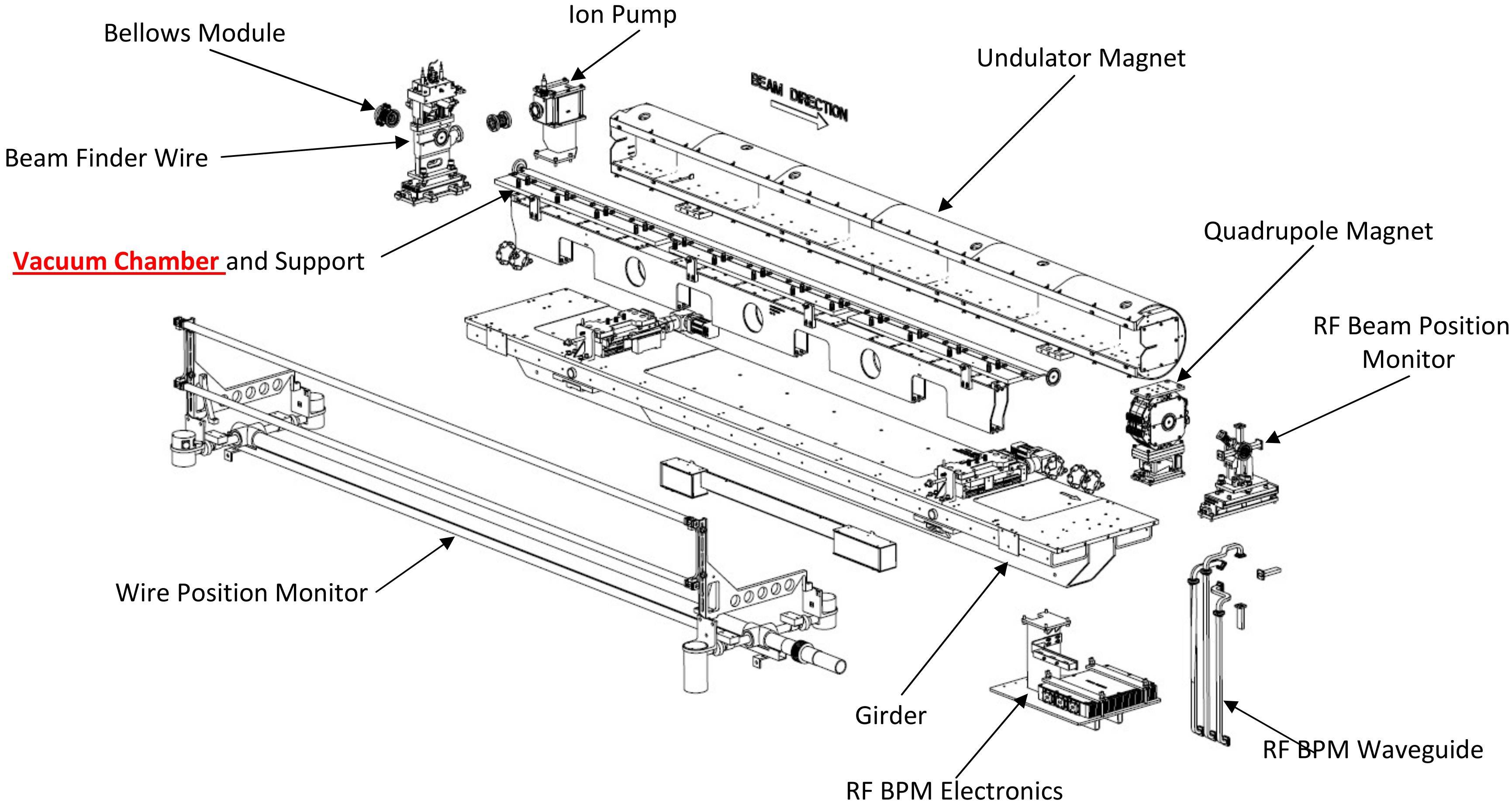
LBNL

LCLS Undulator Segment

- ***Interest: mostly about the vacuum chamber, due to its impact on FEL***

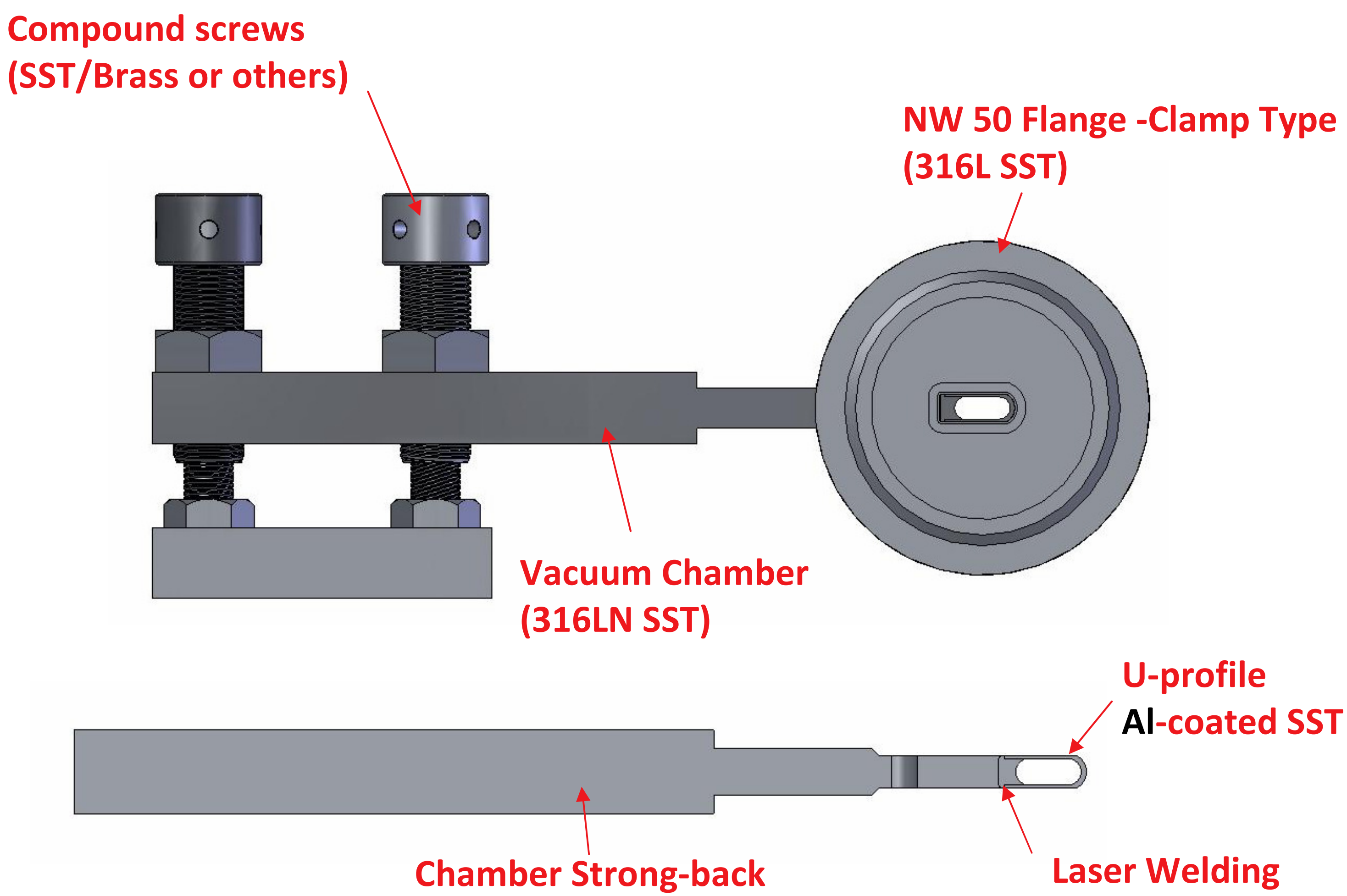


Sub-Assemblies in the Undulator Vacuum System



Courtesy D. Walters, ANL

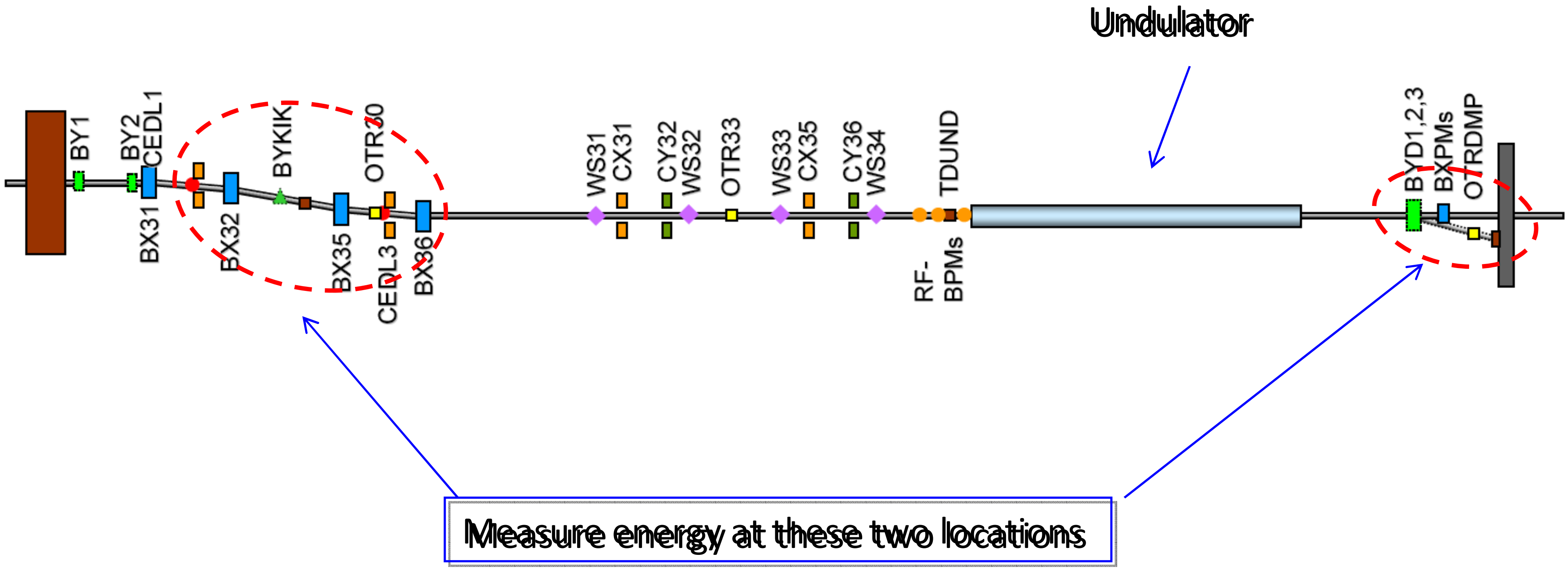
Vacuum Chamber Cross Section



Courtesy H.-D., Nuhn

Some Details

- *Machine elements before and after the undulator*



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Longitudinal Wakefield effects

- *In the following, we discuss 250 pC case.*
- *Identify Longitudinal Wakefields, and other effects lead to energy Loss in LTU and Undulator:*
  - *Stainless Steel Resistive Wall wake before DL2*
  - *CSR in DL2*
  - *Copper Resistive Wall Wake in LTU*
  - *Undulator vacuum chamber Aluminum Resistive Wall Wake*
  - *Undulator vacuum chamber Surface Roughness Wake*
  - *Undulator Spontaneous Radiation*
  - *Undulator FEL induced energy loss*
  - *Dump CSR*

(Short-range) Resistive Wall

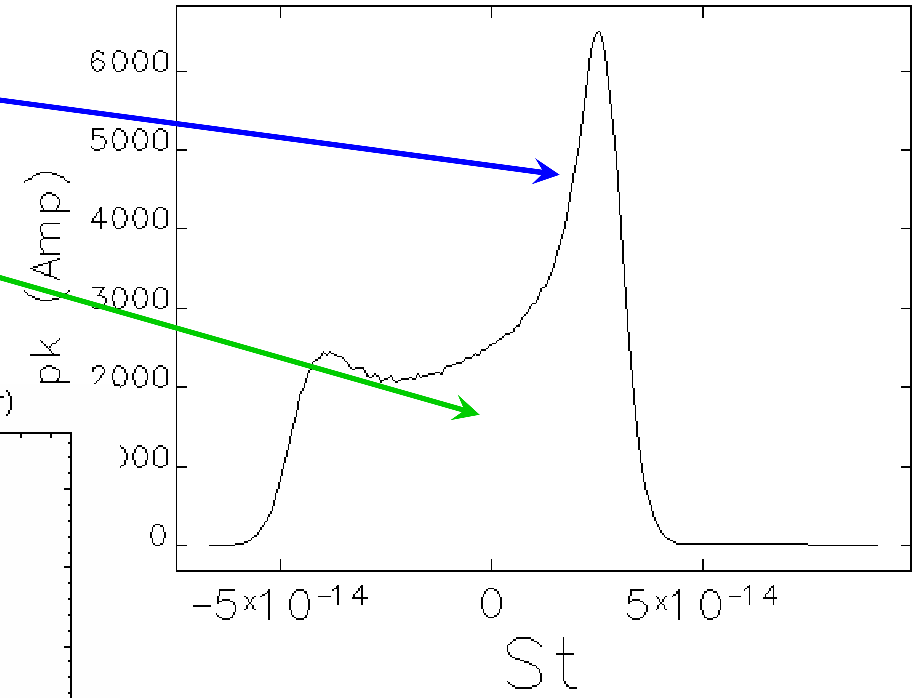
- *The vacuum pipe before DL2:*
  - Cylindrical 1 inch diameter
  - Stainless Steel
  - 76 meters
- *LTU vacuum pipe:*
  - Cylindrical 1 and 3/8 inch diameter
  - Copper
  - 275 meters total
- *The undulator vacuum pipe:*
  - Square chamber 5 mm X 11 mm
  - Aluminum
  - 4 meters X 33 segments

References: Chao, 1993; Bane-Sands, 1995; Bane-Stupakov, PAC2005; Bane-Stupakov-Tu, EPAC2006; Wu-Chao-Delayen, PAC2007; Lutman- Vescovo-Craievich, PRSTAB 2008

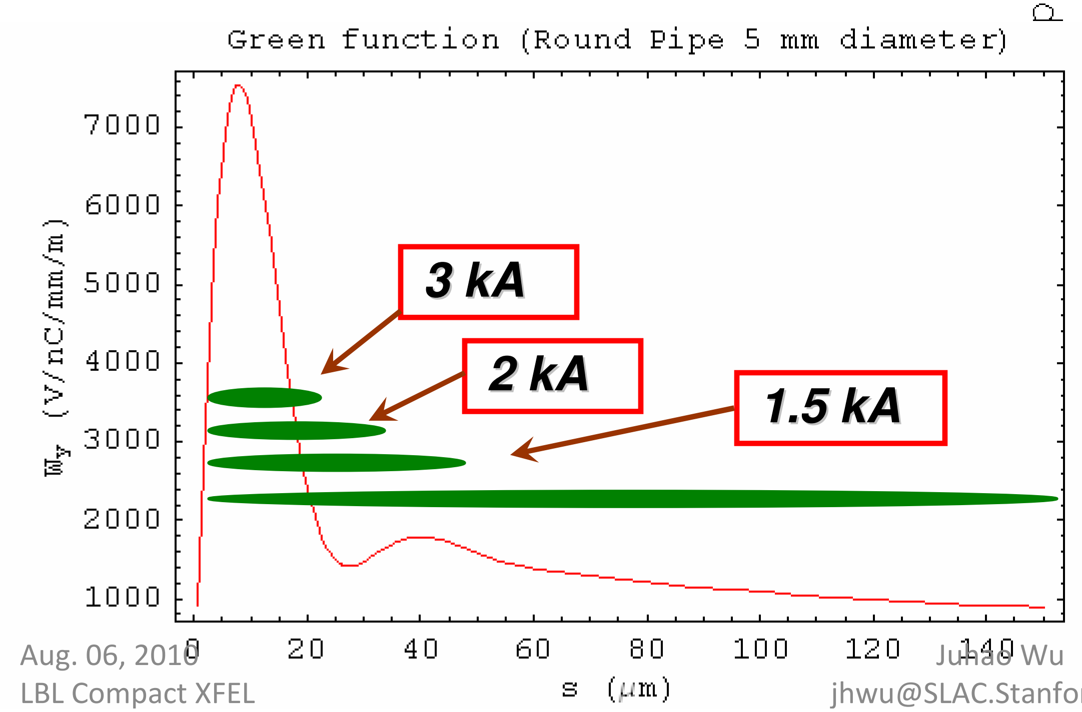
Transverse and longitudinal wakefield

- LCLS ultra-short beam and double-horn start to sample the short-range resistive-wall wake

Horns : 10 fs → 3 microns;
Overall: 100 fs → 30 microns



Example: transverse



500 A

For 250 pC charge

CSR and Undulator Radiation

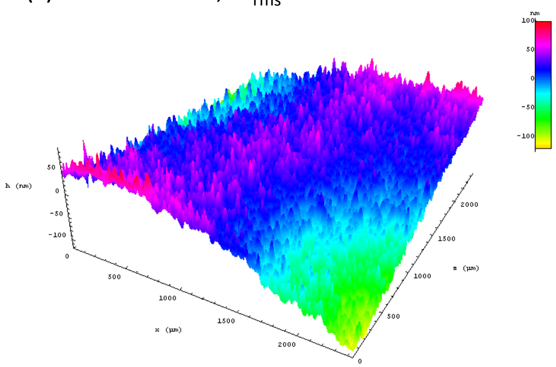
- *DL2 and Dump CSR (1-D with transient, included in Elegant)*
- *Undulator Spontaneous radiation (Analytical results)*
- *FEL induced energy loss (Simulation with Genesis)*

Surface Roughness

Sample: #8 Mode: PM Objective: 5x Size: 2.438 x 2.438 mm^2

 # 1

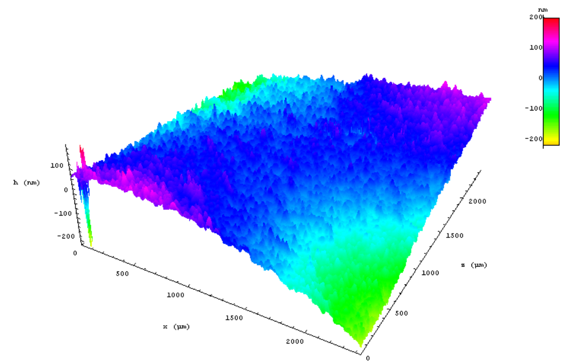
r(z): 3560 mm; h_{rms}: 34 nm



x'_{rms}: 0.6 mrad; z'_{rms}: 0.7 mrad

 # 2

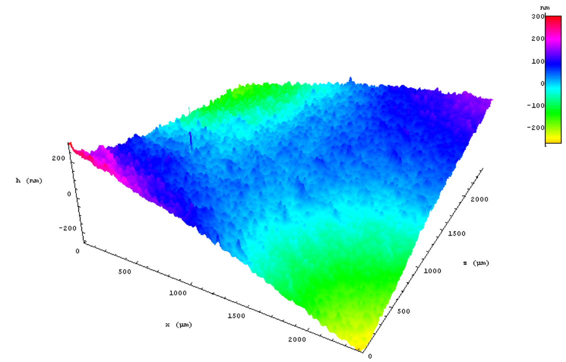
r(z): 3690 mm; h_{rms}: 50 nm



x'_{rms}: 0.8 mrad; z'_{rms}: 1.0 mrad

 # 3

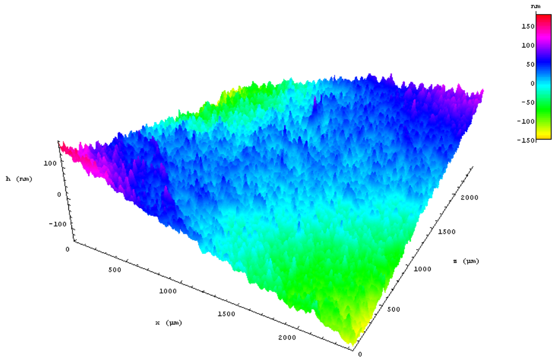
r(z): 4700 mm; h_{rms}: 77 nm



x'_{rms}: 0.7 mrad; z'_{rms}: 0.7 mrad

 # 4

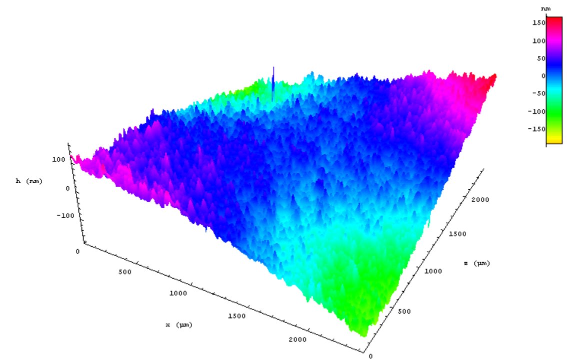
r(z): 6530 mm; h_{rms}: 45 nm



x'_{rms}: 0.6 mrad; z'_{rms}: 0.7 mrad

 # 5

r(z): 5740 mm; h_{rms}: 52 nm



x'_{rms}: 0.7 mrad; z'_{rms}: 0.8 mrad

Comments:

Flat area.

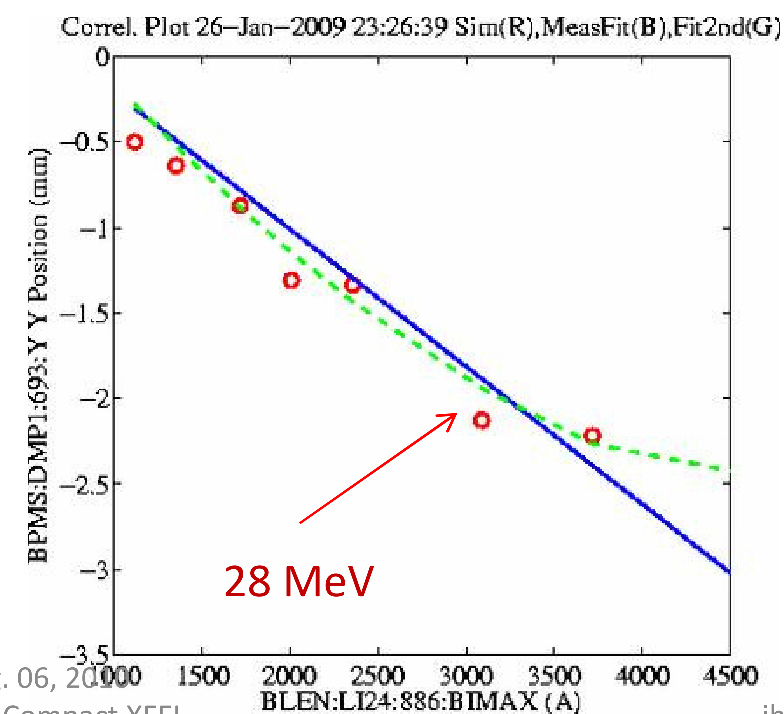
rms derivatives << 10 mrad

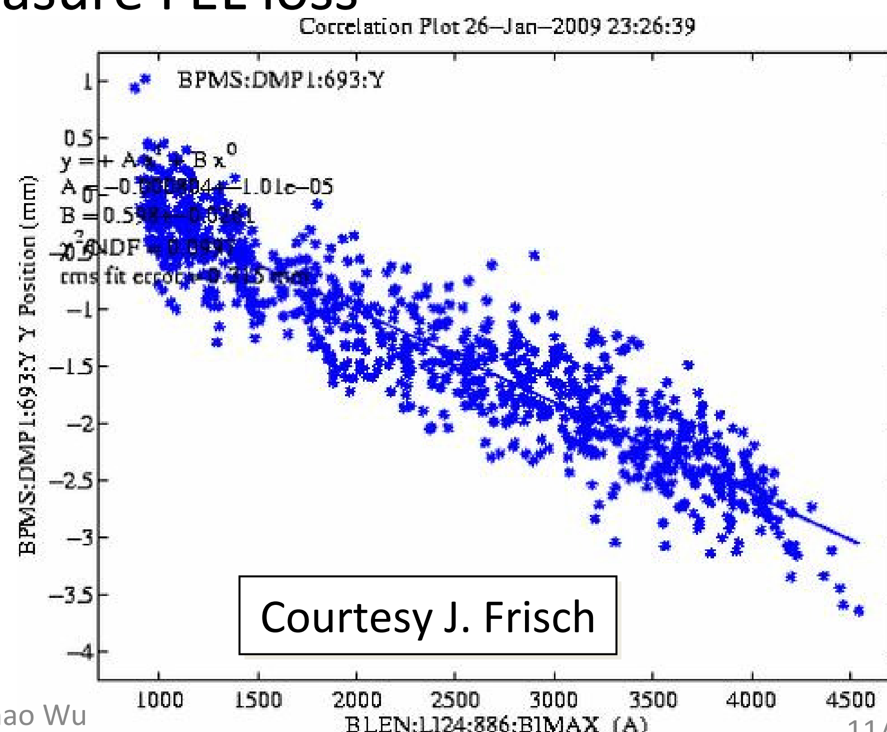
Well within tolerance.

Courtesy H.-D., Nuhn

Longitudinal without undulator: example

- Measurement (before undulator installed) compared to simulation (*Elegant*): Electron energy 9.3 GeV
  - Red circle: simulation with resistive-wall wakefield and CSR as above described geometry and material;
  - Blue solid line: linear fit of the measurement; Green dashed curve: second order fit of the measurement
  - Important to known when measure FEL loss





Longitudinal with FEL: example

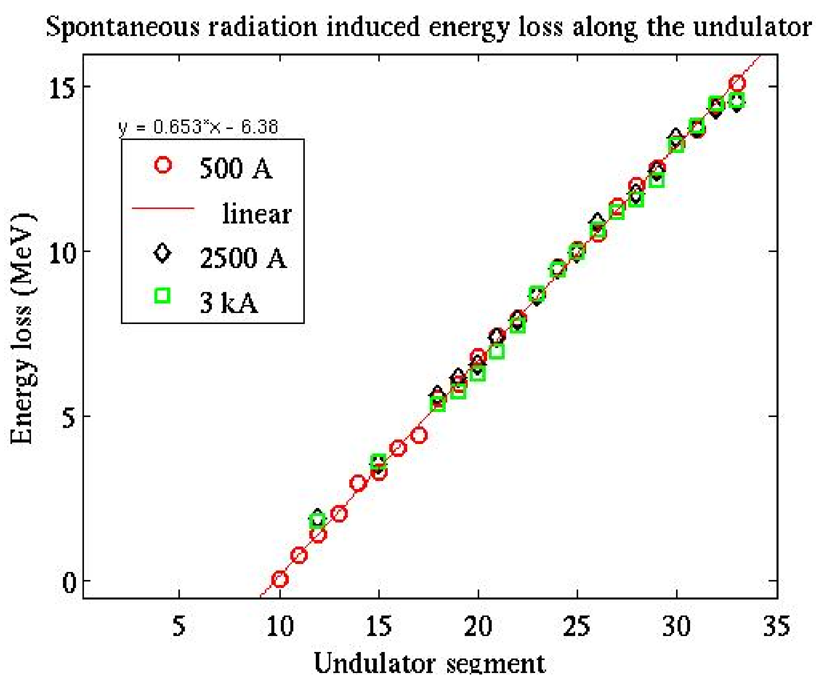
- FEL at 1.5 Å, electron energy 13.64 GeV, 3 kA current
  - For the spontaneous radiation contribution: move each of the undulator section (set to “out” status, *i.e.*, 80 mm movement) and measure the energy loss as function of the number of undulator segments.
  - For the FEL induced energy loss: kick the electron bunch using the kicker in the undulator. The FEL will be turned off, but the spontaneous radiation is still almost the same with this small orbit on the order of 1 mm excursion.
  - By comparing the above two approaches, we find the contribution of the spontaneous radiation, and the left wakefield loss in the latter case.

Longitudinal with FEL: example (cont'd)

- FEL at 1.5 Å, electron energy 13.64 GeV, 3 kA current
  - Similarly, by comparing the energy loss scan without kicking the electron bunch to that when kicking the electron bunch, the additional FEL induced energy loss is found
  - Measurement: the wakefield loss is about 40 MeV (0.3 %), the spontaneous radiation is about 16 MeV (0.1 %) for 25 undulator sections, and the FEL is about ~ 10 MeV (0.07 %) [about 2.5 mJ FEL for this 250 pC case].

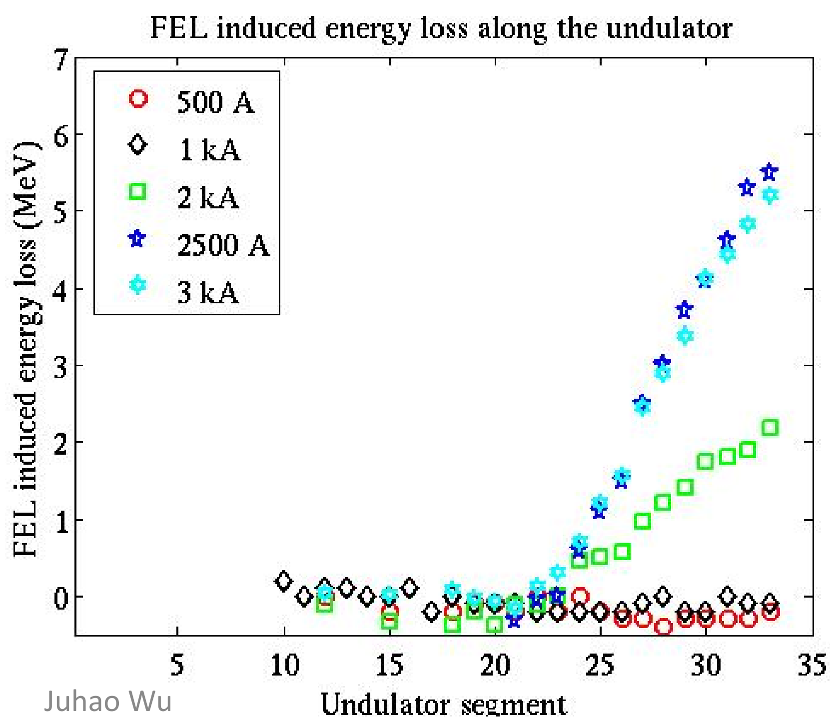
Spontaneous radiation

- The resulting spontaneous radiation agrees with the theoretical calculation with a difference of about 6%.
- Notice that the wakefield loss relies on the peak current, but the spontaneous radiation does not.

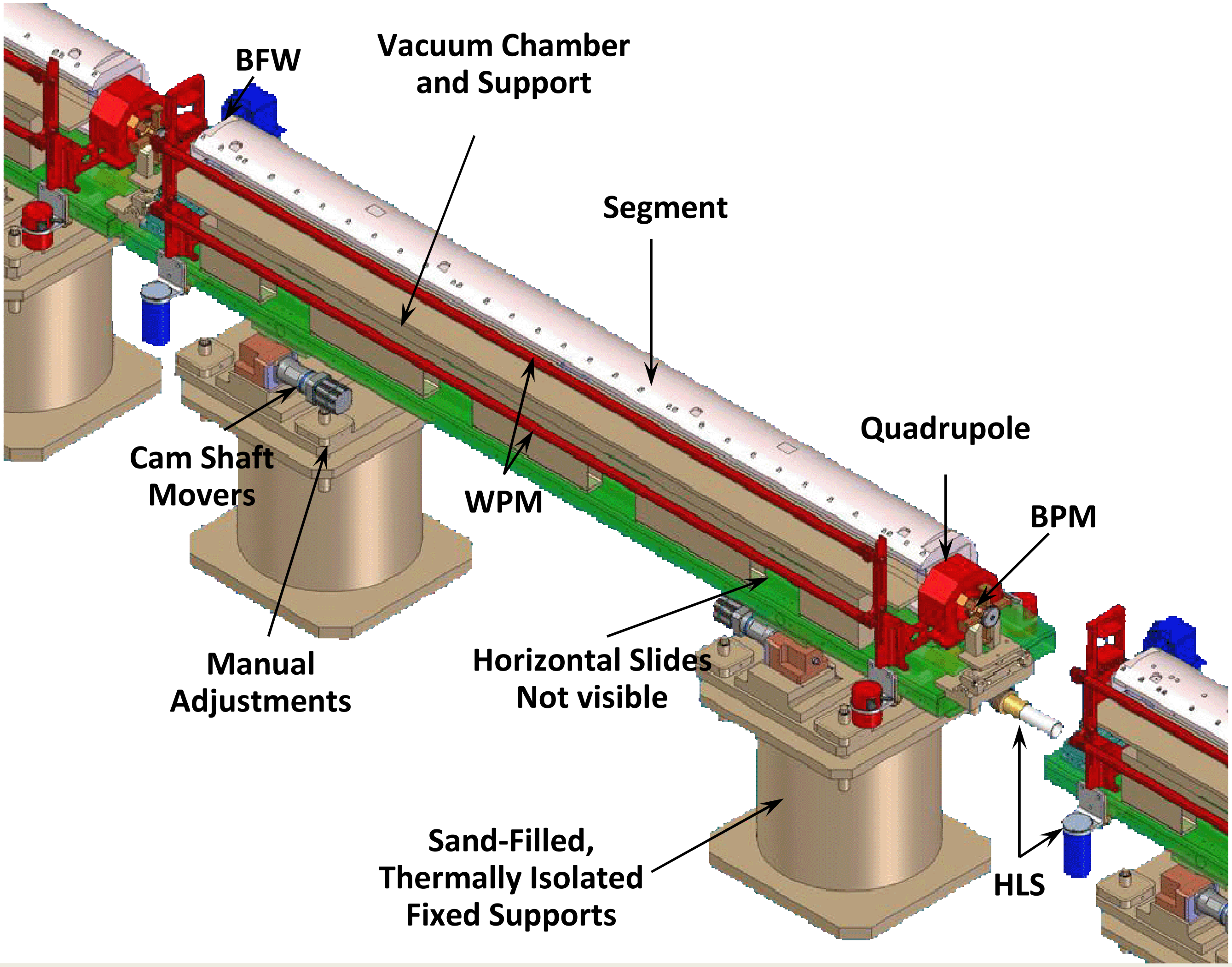


FEL induced energy loss

- We kick the electron bunch using the kicker in the undulator. The FEL is turned off, but the spontaneous radiation is still almost the same with a small orbit on the order of 1 mm excursion.
- Measurement was done with taper configuration optimized for 3 kA case



LCLS Undulator Components

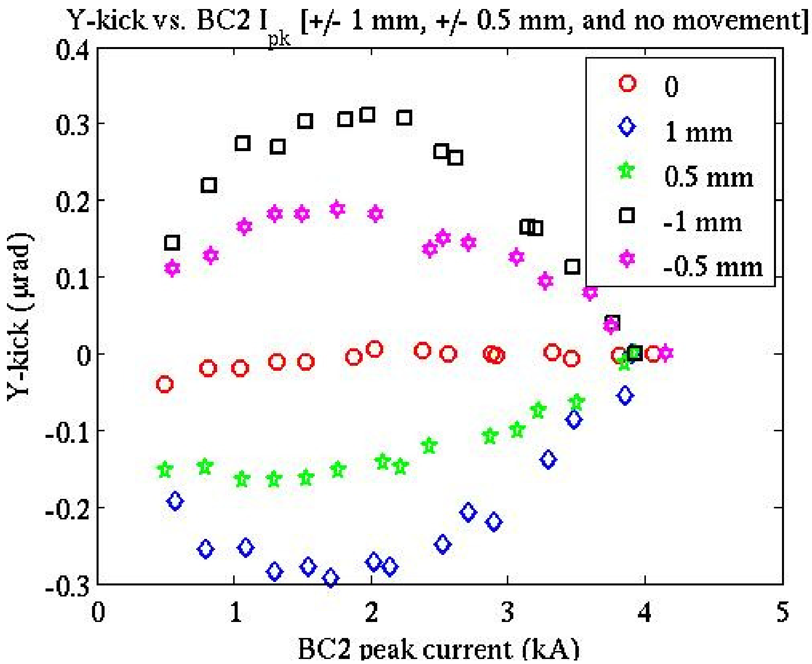


Transverse Kicks Measurement Details

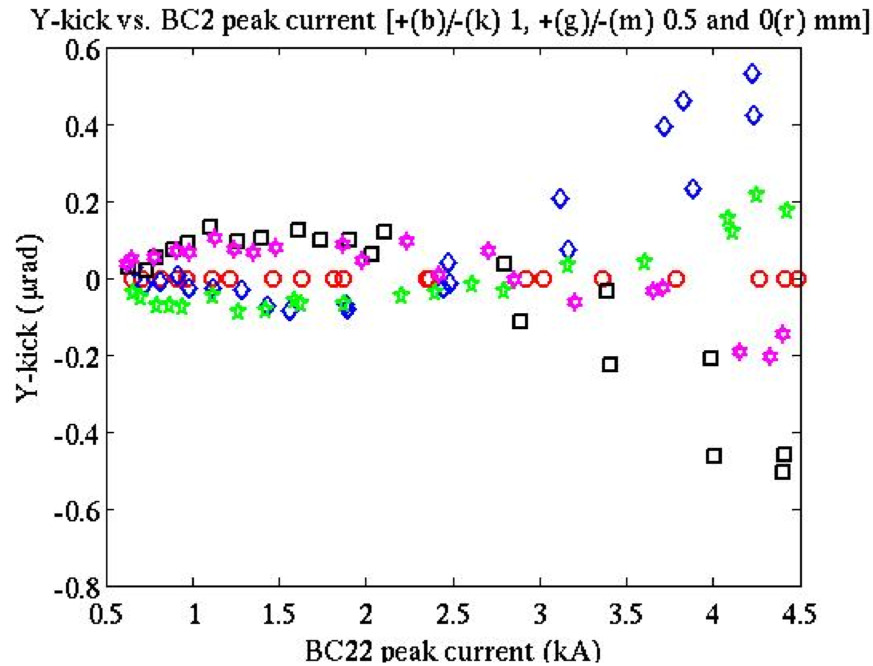
- Move 10 vacuum chamber on the one side in *y* by +/- 500 micron and +/- 1 mm
- This excite an absolute trajectory with excursion on the order of 100 micron only
- Take a reference orbit when the peak current is 3 kA
- Vary the peak current and find the difference orbit with respect to the 3 kA reference orbit
- Find the additional wake induce *y*-kick at middle of the 10 vacuum chambers (thin lens approximation)

Transverse Kicks

- Two typical measurements
  - Left for reference orbit taken for 4 kA, right for 3 kA



Jun 21, 2009 data



Jun 29, 2009 data

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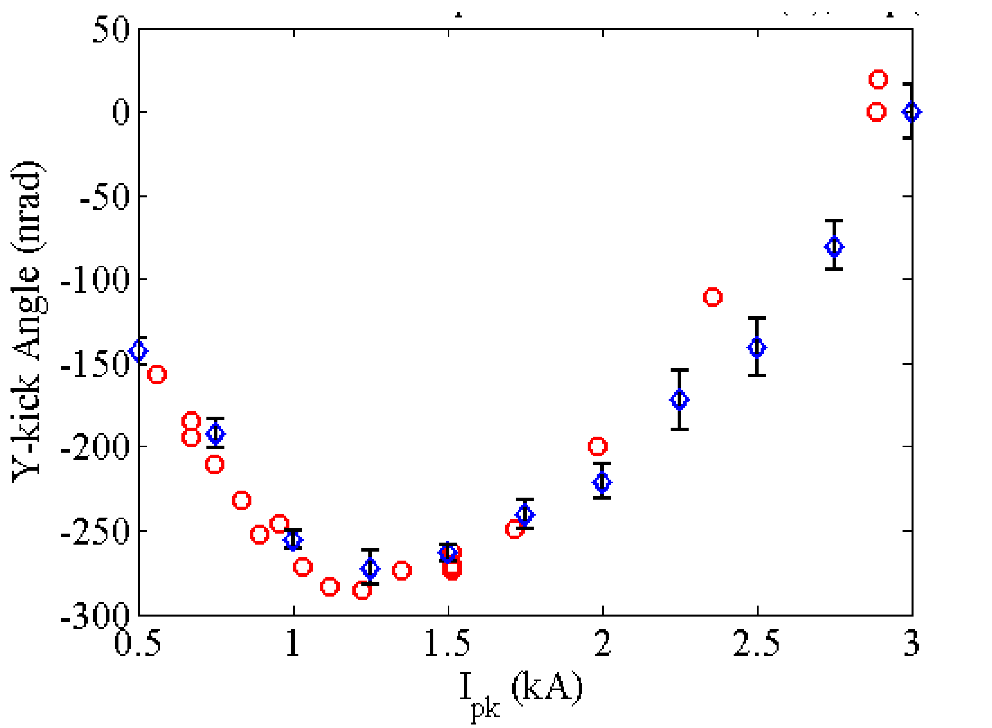
Transverse Kicks

- Measurement compared to simulation (*Elegant*)
  - one example: red circle for simulation (x3) and blue diamond with error bar is experiment data



Comments

- The wakefield effects are mixed with other components, which makes the measurement rather complicated, in particular when FEL is on
- Able to measure the spontaneous, the FEL, both agree with theoretical calculation well
- Able to measure the short-range resistive wall wakefield effects (together with surface roughness), both longitudinal and transverse, agree with simulation reasonably well within a factor of 2
- Surface roughness wakefield effect seems to be not too strong with the final machining of the LCLS undulator surface
- Study was done for 250 pC