Timing and Phase Jitter Creating Energy, Transverse, and Intensity Jitter at LCLS

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- LCLS-II and LCLS comparison
- FEL jitter brightness
- Factors of 2
- Finding and quantifying sources
- FEH, NEH Time Slot (TS = 60 Hz difference at 120 Hz)
- BC2 delay
- Injector laser timing
- Transverse jitter: HUGE and small

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Electron Beam RMS Stability Goals for SCRF at LCLS-II

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	from Requirements	relative to σ	LCLS (achieved)
Electron energy:	$\Delta E/E$ < 0.01%	40 %	40 %
Peak current:	$\Delta I/I$ < 5 %	5 %	3-8 %
Bunch arrival time:	Δt < 20 fs	40 %	200 % (1000%)
Transverse:	$\Delta x / \sigma_x$ < 10 %	10 %	3-12 %

- Longitudinal jitter is typically worse than transverse
  (due to the enormous compression to shorter bunches for FELs)
- 1.2 mm → 120 μm → 12 μm (FWHM)
  4 ps → 400 fs → 40 fs (FWHM)

20 %	→	+2 %
40 %	→	+8 %
80 %	→	+28 %
100 %	→	+41 %
rms/σ		$\sqrt{\sigma^2 + \text{rms}^2}/\sigma$

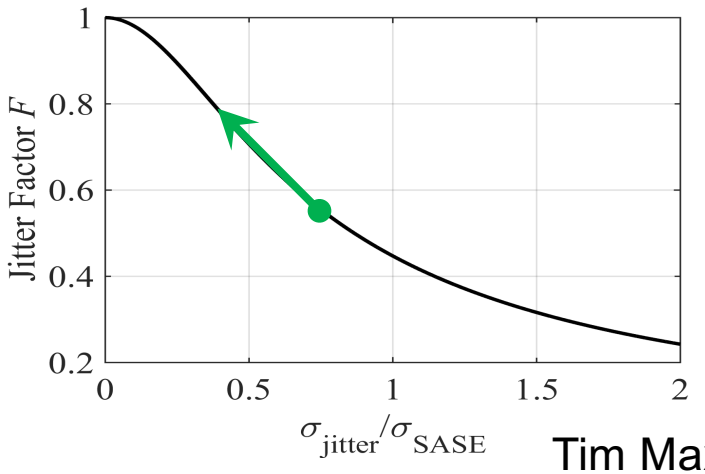
Timing and Phase Jitter at LCLS

FEL Jitter Brightness improved due to Energy Stability

FEL Jitter Factor = Frac. average FEL brightness through a monochromator due to jitter

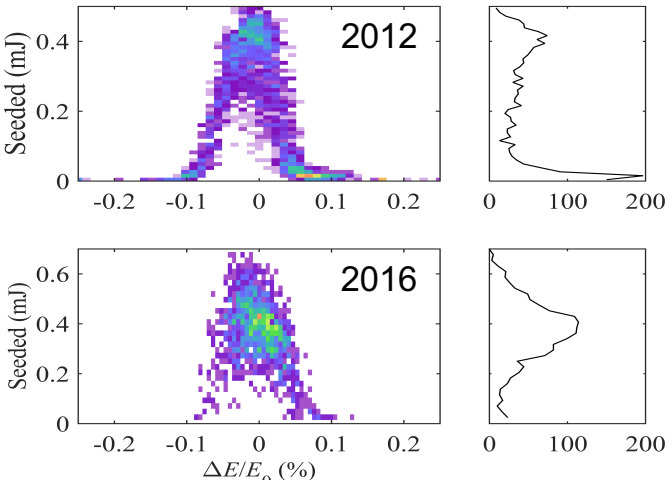
$$F = \frac{1}{\sqrt{1+4\left(\sigma^2_{JITTER}/\sigma^2_{SASE}\right)}}$$

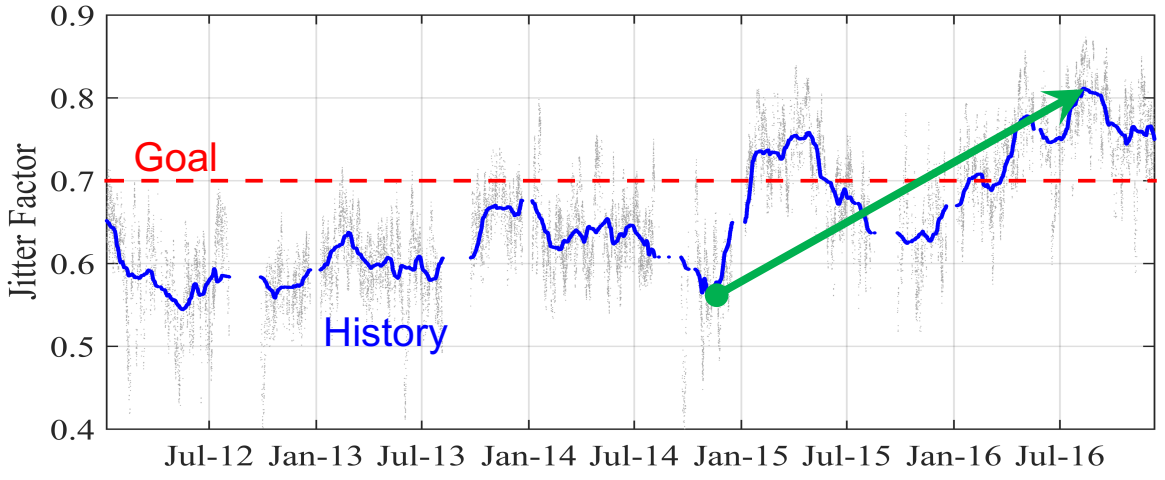
2x lower energy jitter, 40% more on-energy photons for monochromatic/self-seeded experiments



Tim Maxwell

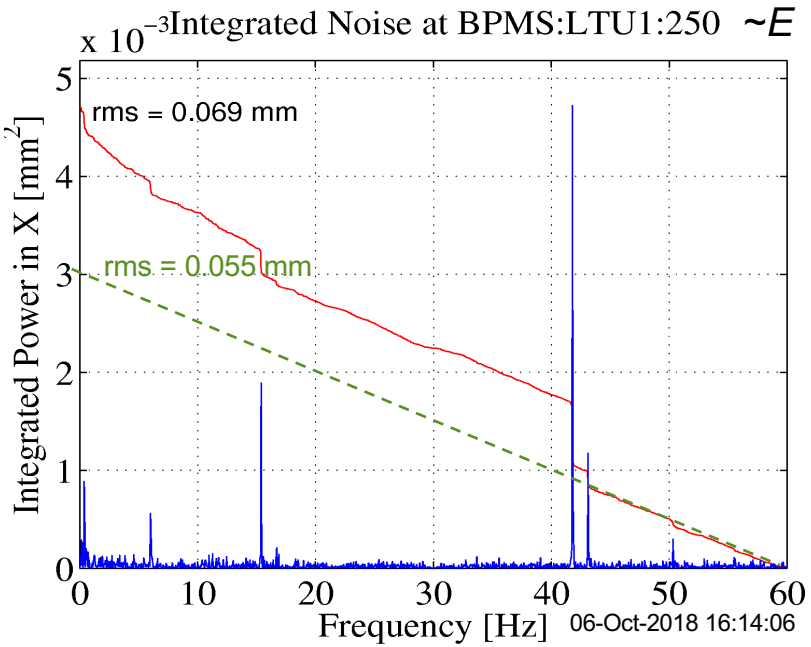
HXRSS Improvement





Some Factors of "2" Problems with Jitter

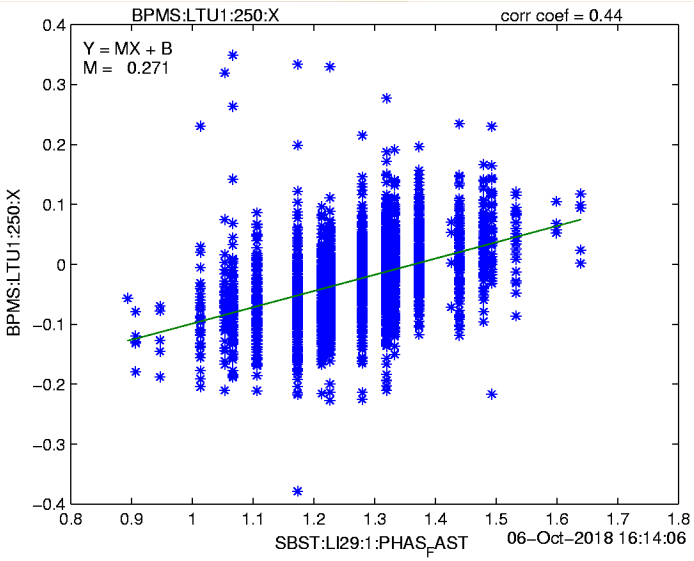
- Electron vs photon energy, factor: 2.0 due to $\lambda_1 = \frac{\lambda_u}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$
- σ (rms) vs FWHM, factor: 2.35
- Reduction of 20% in power is 10% in amplitude
- Power spectrum integral = rms^2 (we have it wrong by a factor of 2)
  - σ_E / E = 69 μm / 125 mm = 0.055%
  - by identifying and fixing the lines in frequency
    we can get 55 μm / 125 mm = 0.044%
    or 20 % better in σ_E / E (80% of amplitude)
    or 36% better in power (0.8^2 = 0.64 in power)



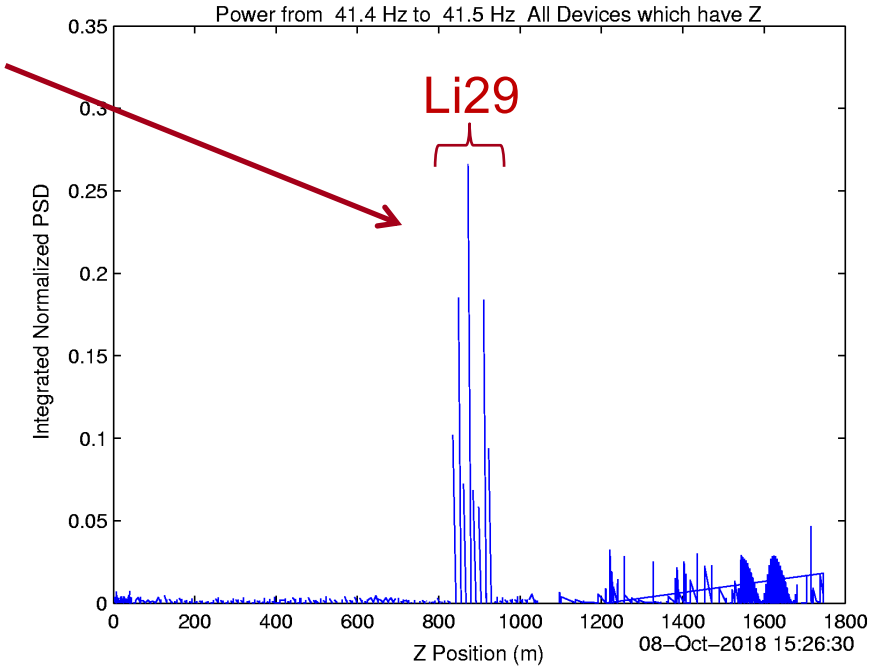
How to Find and Quantify Jitter Sources

- Pure luck, black magic, red alarms, …
- Correlations
  - corrcoef^2 = 0.44^2 = 19.4% (in power)

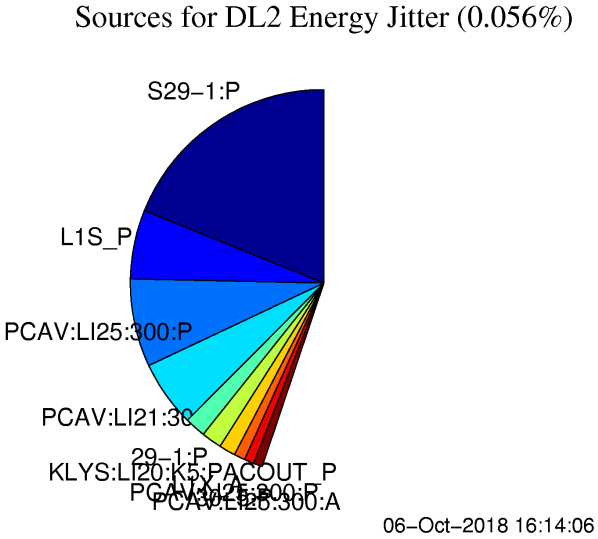
    19.4% or more comes from SBST Li29 (switch tube replacement fixed it)



- Lines in frequency spectrum vs *z*

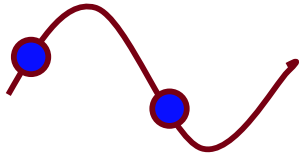


- Jitter Pie



High Power RF for Reference vs PCAV (Phase Cavity)

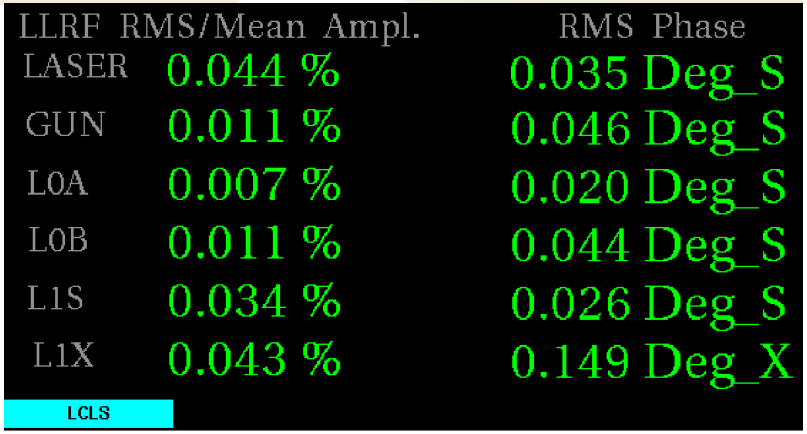
- RF: 0.030 degS = 30 fs
- PCAV timing
- one time-slot only [fs]

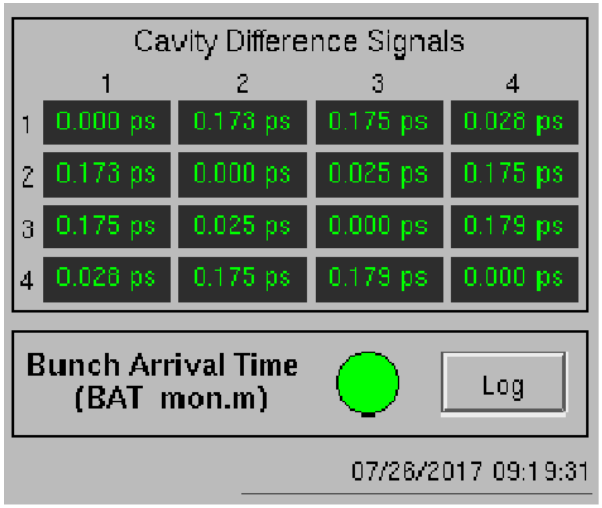


	1	2	3	4	
					NEH
1		55	53	12	PCAV
2			12	72	FEH
3				72	

- Time slot differences

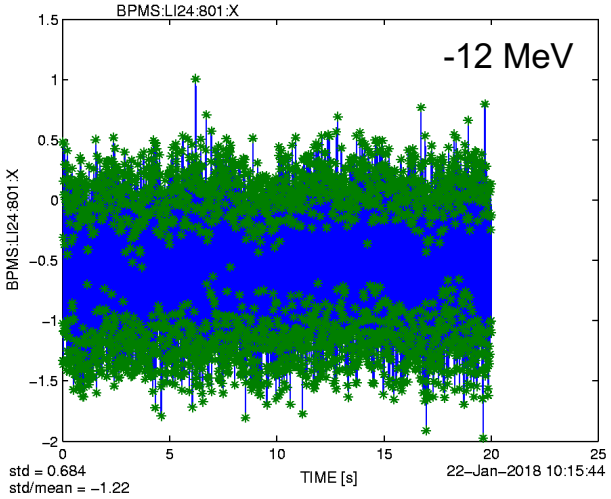
	NEH	FEH
It was (before Jul 2017)	350	500 fs
Improved (DC PS of FANOut):	310	9 fs
Aug 2018	1000	270 fs

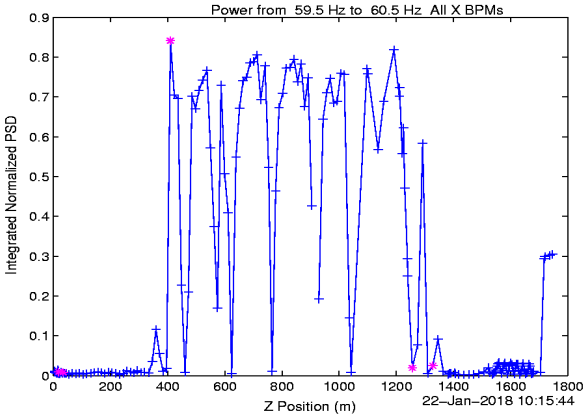


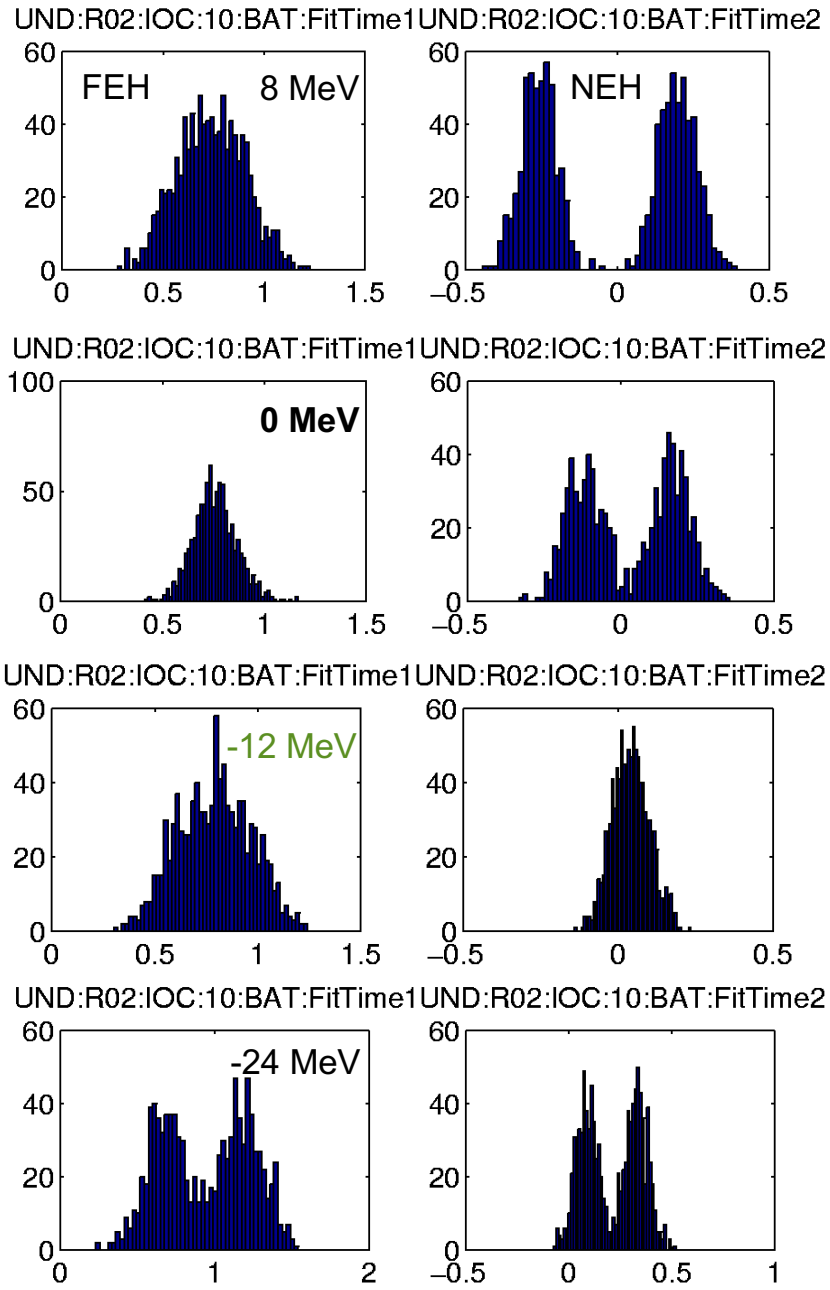


BC2 energy TS difference can correct timing TS

- BC2 *E* offsets +8, 0, -12, -24 MeV



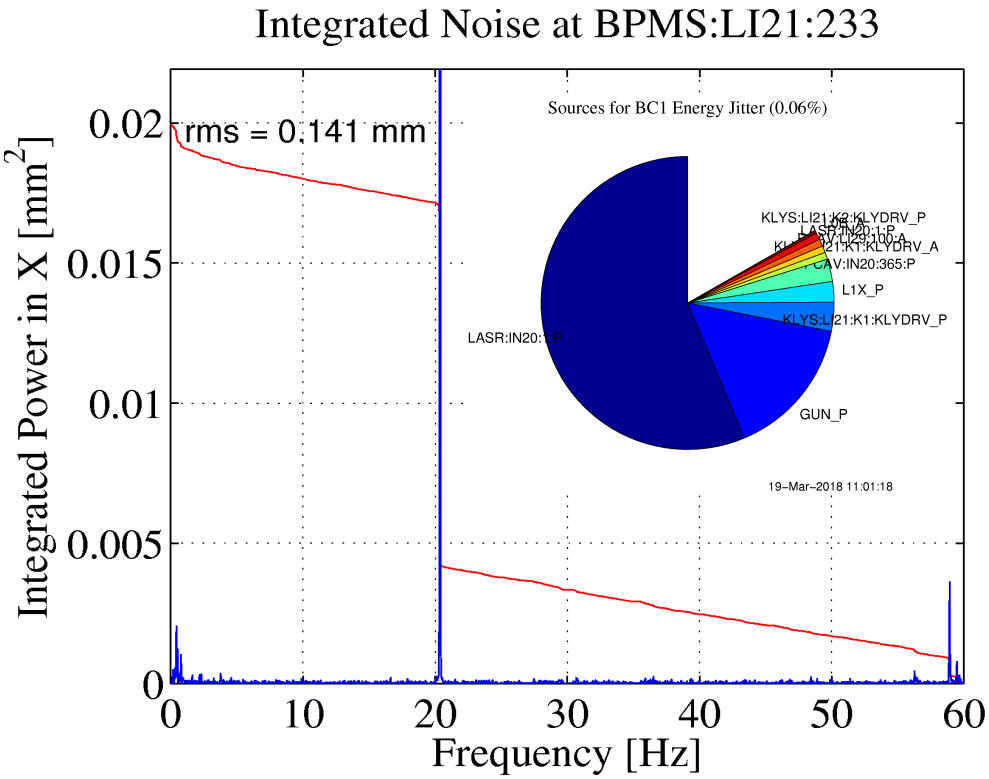




- All TS fallout corrected by FBs (DL2, LTU)

Injector Laser Timing

- Vitara 2 shows 20.35 Hz line (since Oct 1st 2013)
- "Power track dither" is at that frequency
- History: 2015: Sep (5%), Dec 10th (10%), Dec 12th after laser work (50% of BC1 jitter), …
  2016: Mar 3rd "CEP" settings changed on Vitara 2 (2%)
  Carrier Envelope Phase stabilization
- 2018: Jan-Mar (60%) same as Oct 1st 2013, without it laser jitter reduces from 95 to 55 fs



Two Bunch: Second Bunch Gets Kicked by “warmed” KMONO

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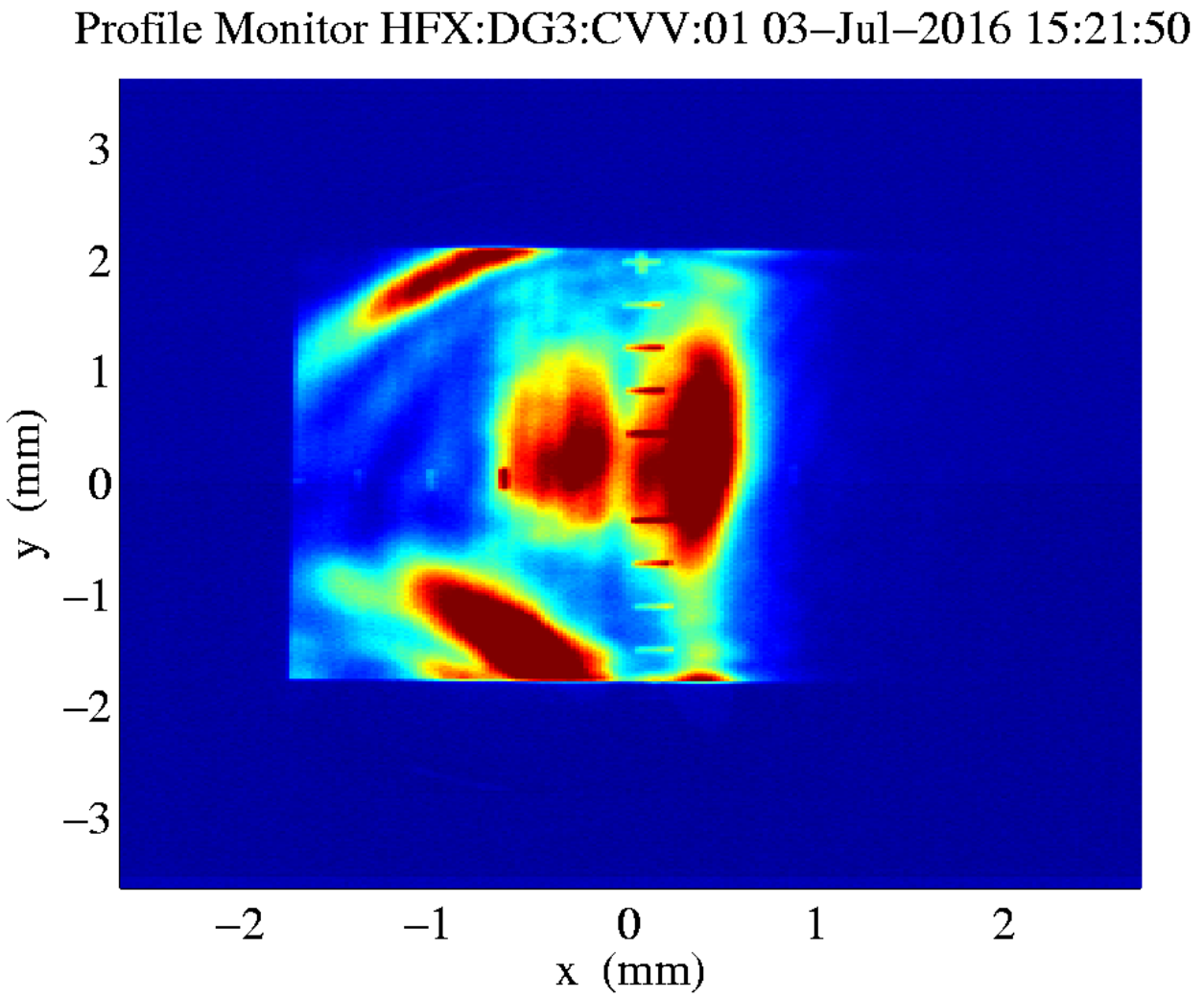
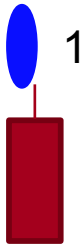
- Bunch 2 at 23.8 ns allover the place
- 1 minute of shots:
- “detuned” a little peak current

- Oct 2016 we found attenuation of 10 fixes it (210 ns)



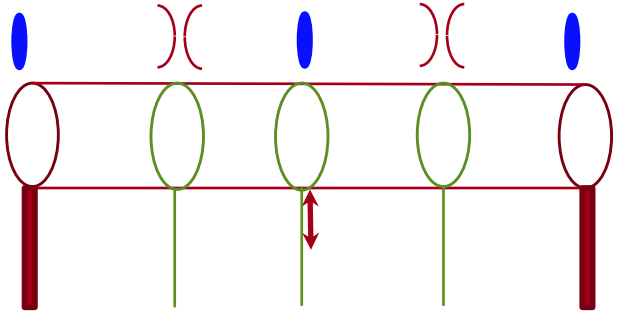
Transverse Jitter Improvements over the Years

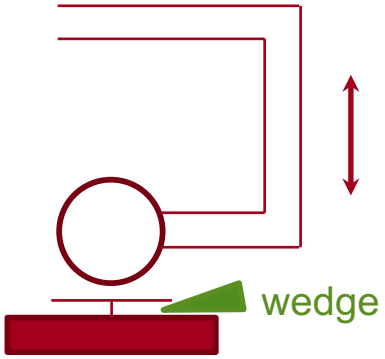
- Injector laser spot is wandering (slowly), reduced by fast Gun Launch feedback for electrons
- Structural vibrations
  - 42 Hz was RF waveguide (water-cooled) to gun
  - 10.6 Hz from 12 m girder (21-1) with quads
  - Quad to wall (x)
  - Quad clamps (y)



150 mm off center

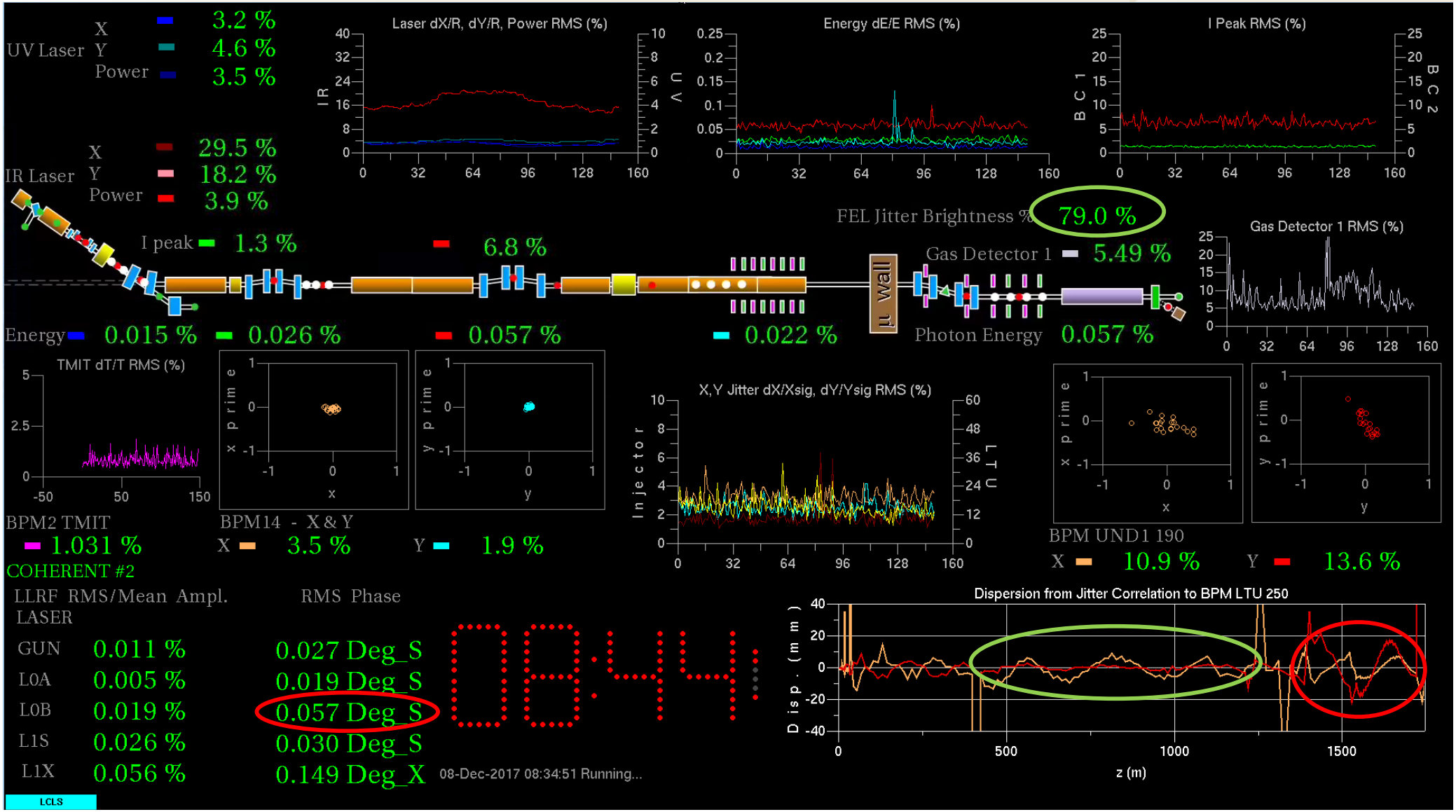
100∗ worse in y





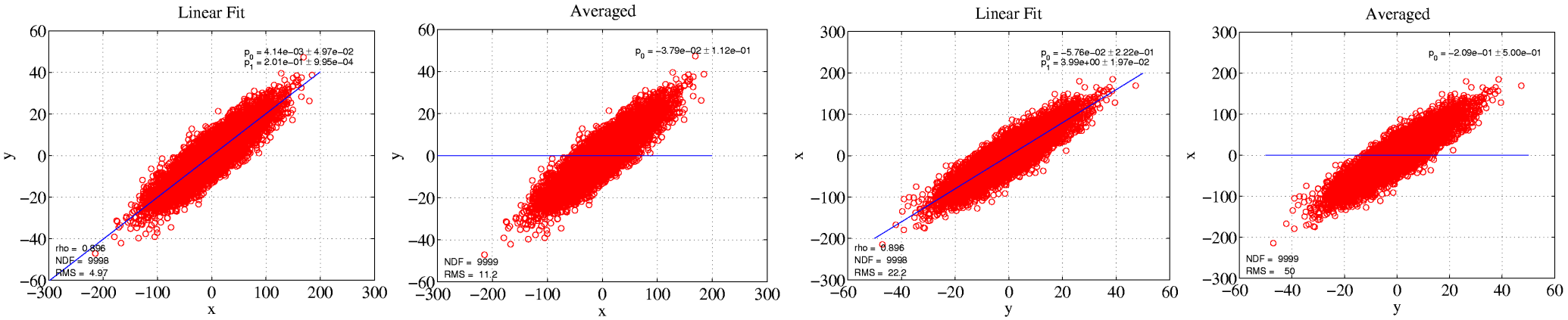
LCLS Jitter Summary Display

William Colocho



Transverse from Energy + Dispersion

- Transverse jitter creates FEL intensity variations
- Quadratic fit gives a reduced “fit_rms”, which can be used like corr-coef for a linear system, since:
  fit_rms(linear)^2 = (1-corrcoef^2) ∗ fit_rms(average)^2
- Also: p1xm = 1/p1ym ∗ corrcoef^2 [here 5:1 goes into 4:1]
- So different quadratic sources can be identified and quantified



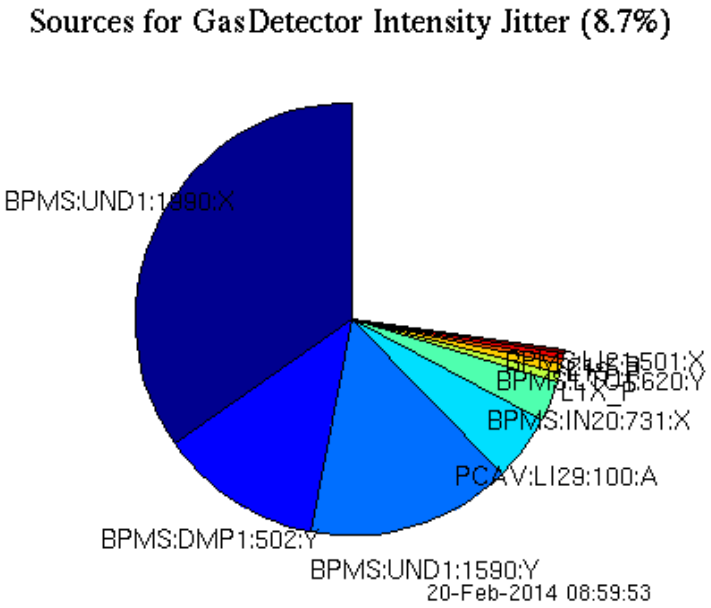
Gas Detector Intensity Jitter Quantification

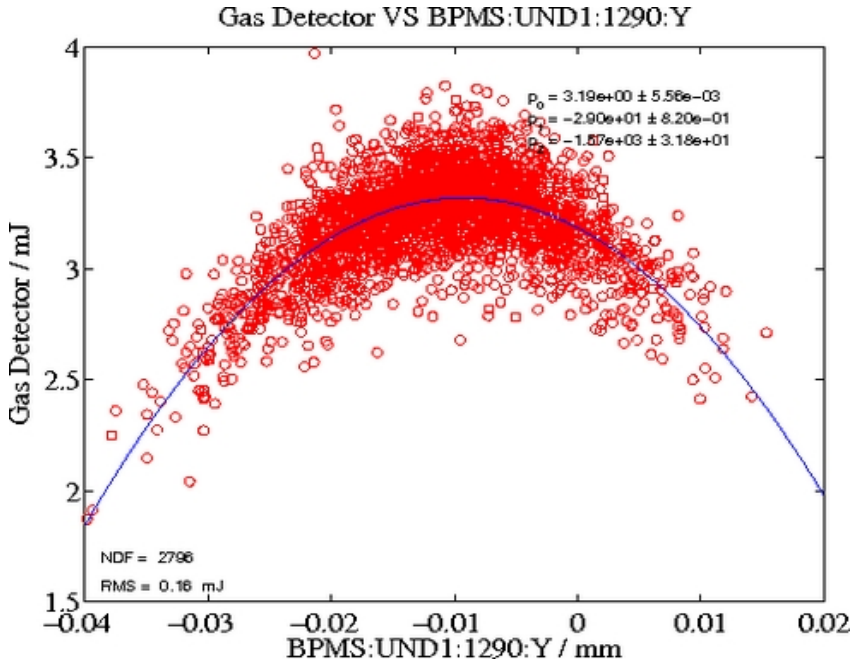
38 % of the jitter power is from **x** movement in undulator

23 % is from **y** movement

5 % is from TMIT jitter

So we understand 66 % of the jitter.





Summary

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- LCLS-II to LCLS comparison
- Timing can be as good as 50 fs rms compared to 30 fs RF
- Many factors of 2 to watch out
- We need time slot feedback in the timing system, like RF
  - NEH: 300 to now 1000 fs time slot ("fixed" with BC2 offset)
- Timing of Laser especially Vitara 2 bad with 20.35 Hz line
- Transverse jitter, fixes, and coming from energy jitter and dispersion, creating intensity jitter