Microbunching observations at LCLS

Z. Huang for the *LCLS* commissioning team

SLAC

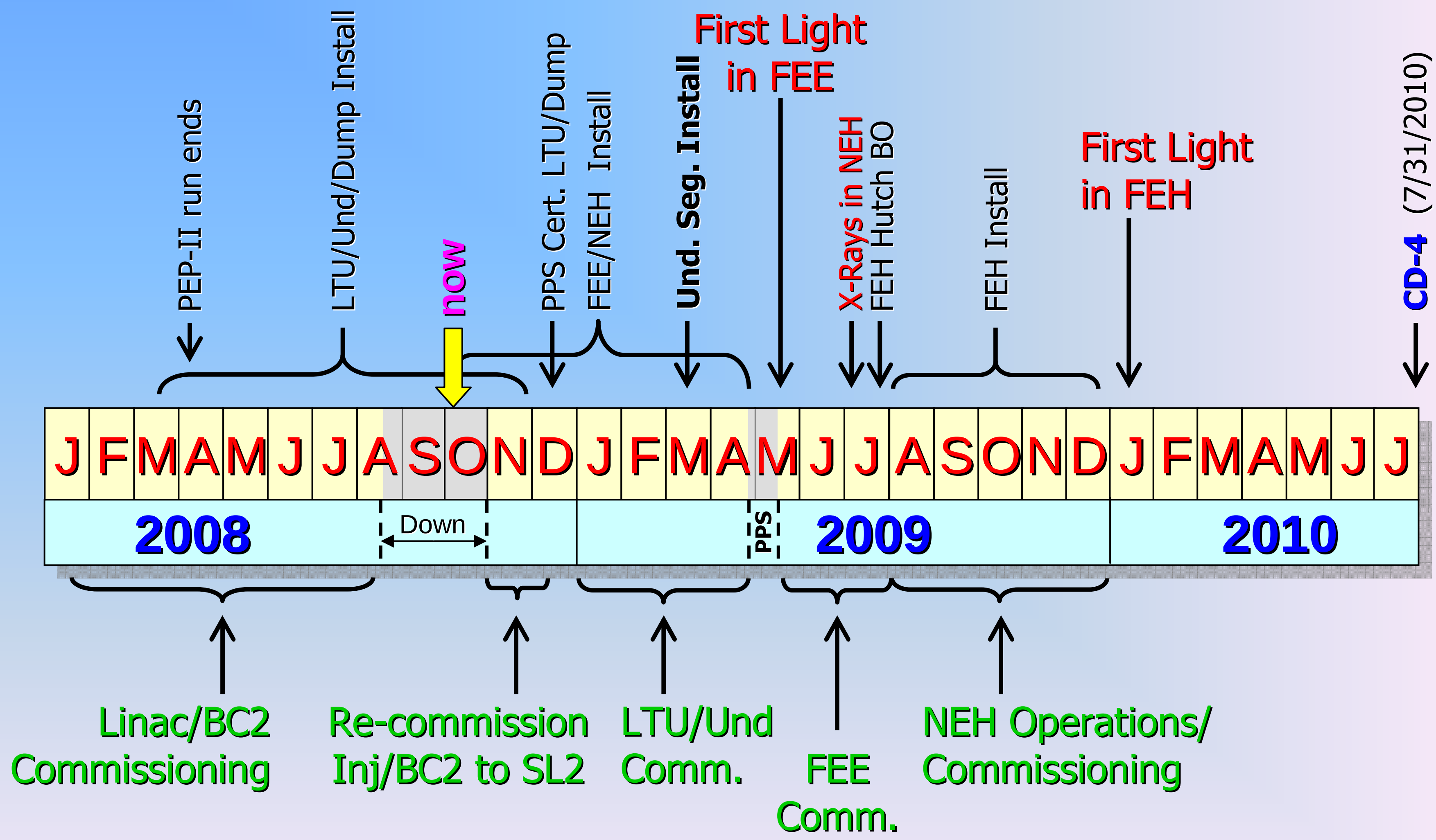
Microbunching Instability Workshop II

Oct. 6, 2008 (LBNL, USA)

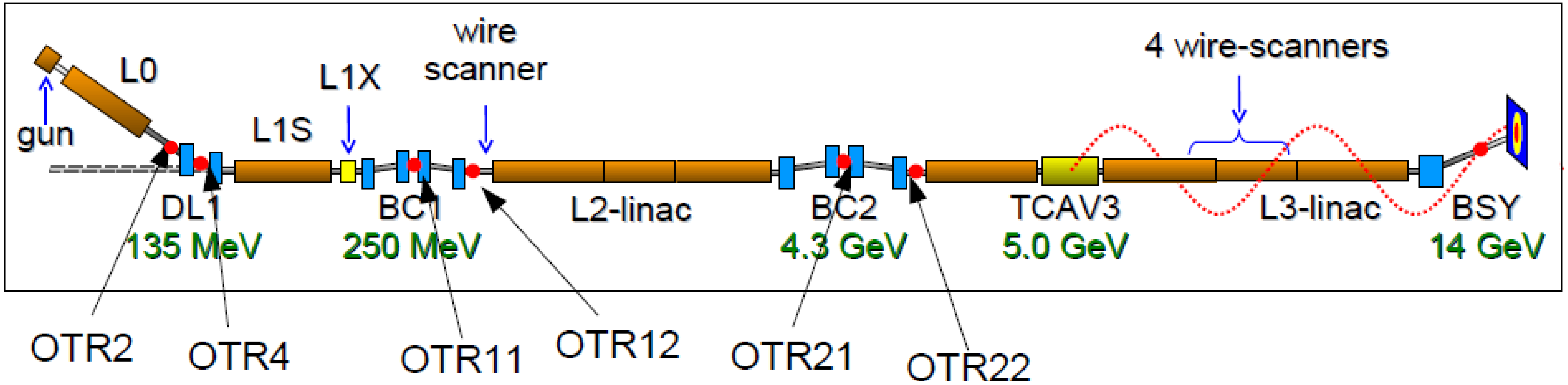
Outline

- *LCLS commissioning highlight*
- *DL1 & BC1 observations*
- *BC2 observations*
- *Summary*

LCLS Installation and Commissioning Time-Line

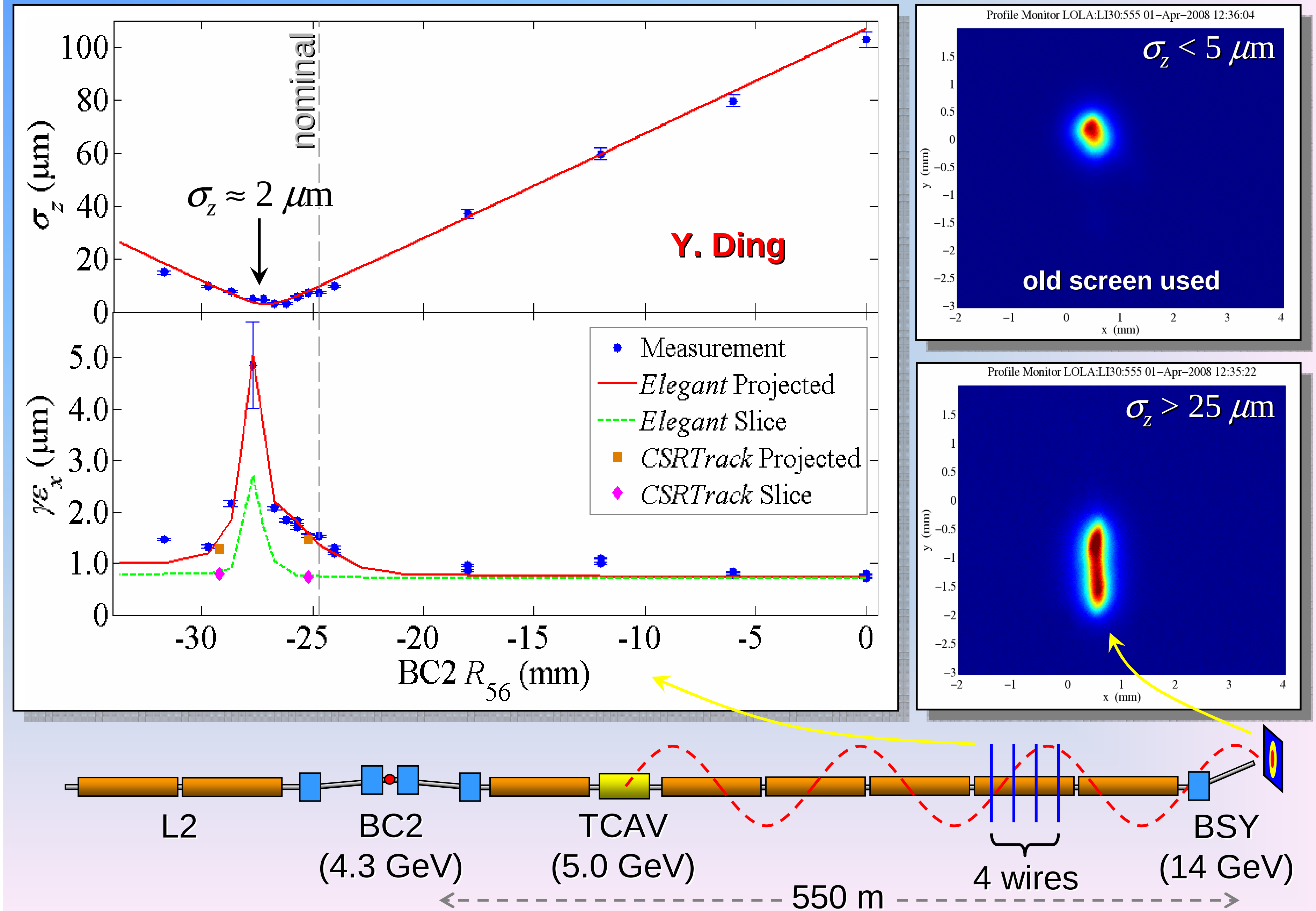


The *LCLS* Accelerator



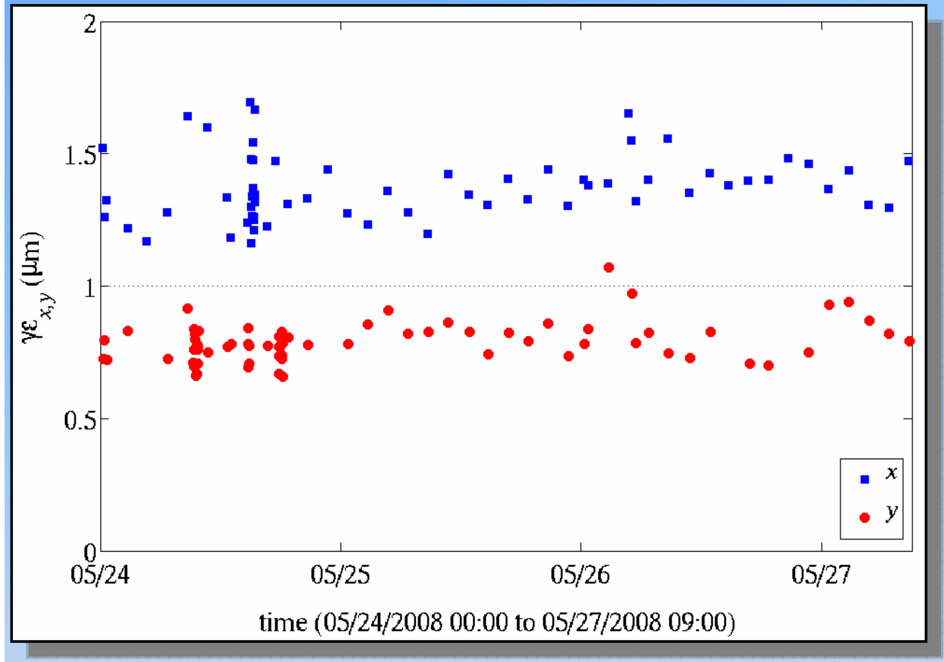
- Energy: 4.3 to 14 GeV
- Charge: 20pC to 1nC. Typical operation is 250 pC
- Typical peak Current
  - Gun to 250 MeV: 30~40 A
  - After BC1: ~300 A
  - After BC2: ~2500 A
- Most OTR screens after DL1 are compromised by strong coherent effects due to beam structures at optical wavelengths
- Emittances after bends are measured with wire scanners

Bunch Compression & CSR Measured after BC2 (0.25 nC)

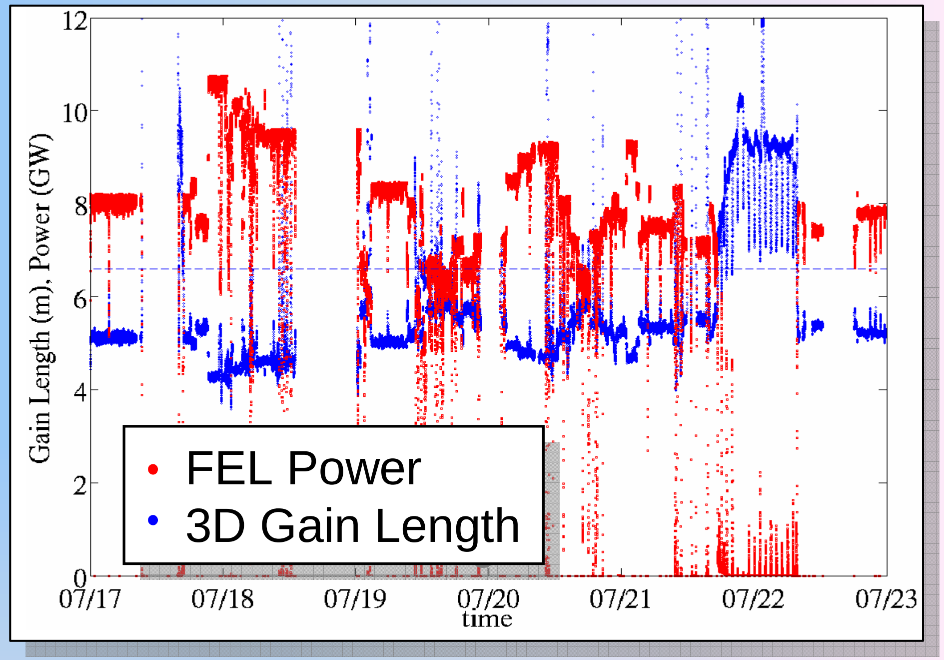


Beam Appears Bright Enough for FEL Saturation at 0.15 nm

End-of-Linac Emittance



Pseudo-FEL "Power/Gain length"



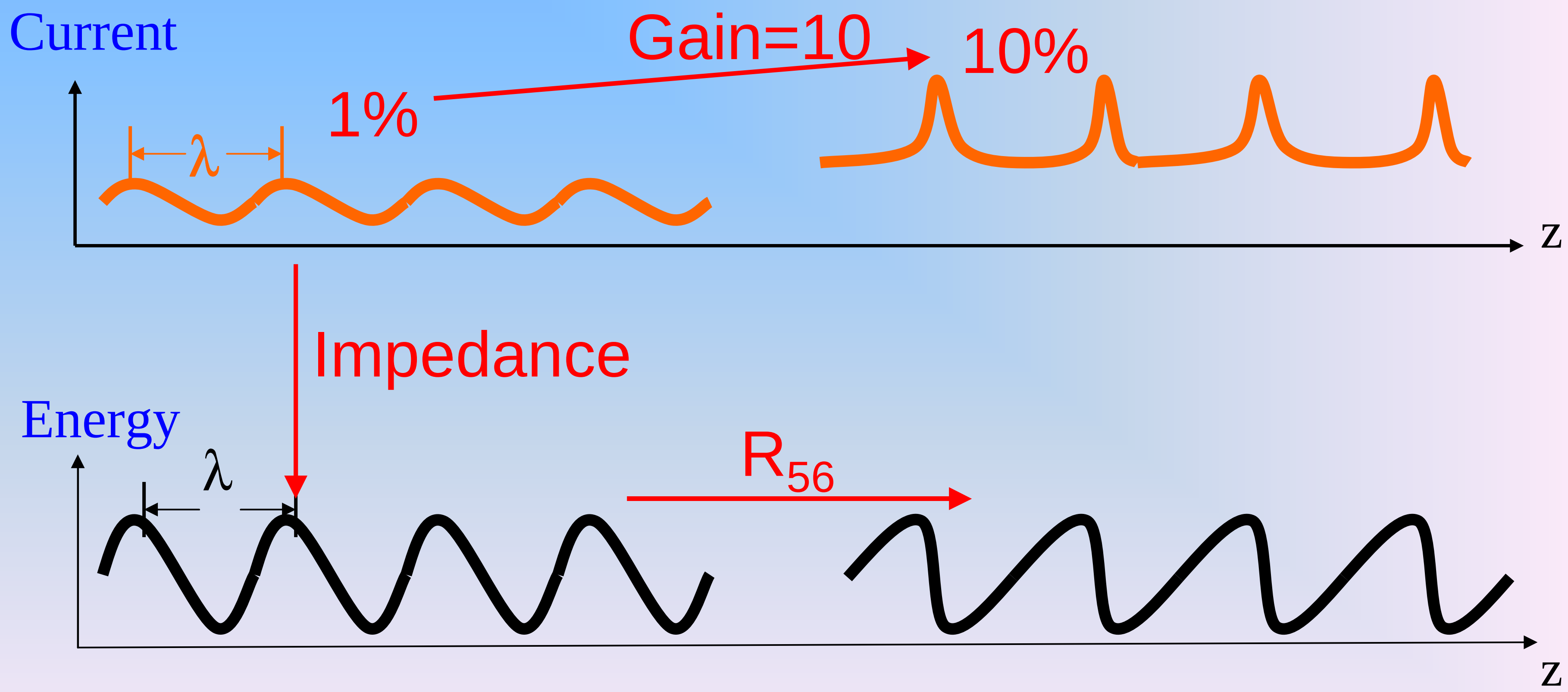
Measured over long weekend with no tuning, 0.25 nC charge

$$\gamma(\varepsilon_x \varepsilon_y)^{1/2} = 1.04\ \mu\text{m}$$

Calculation (using M. Xie's formulas) is based on measured end-of-linac *projected* emittance values, measured peak current, and design undulator parameters (assuming und. alignment and ≤0.01% rms slice energy spread – not yet measurable)

Microbunching Instability

• Initial density modulation induces energy modulation through longitudinal impedance Z(k), converted to more density modulation by chicane. Space charge impedance is typically more at fault here than CSR (Borland *et. al*. 2001; Saldin *et. al*., 2002;…)

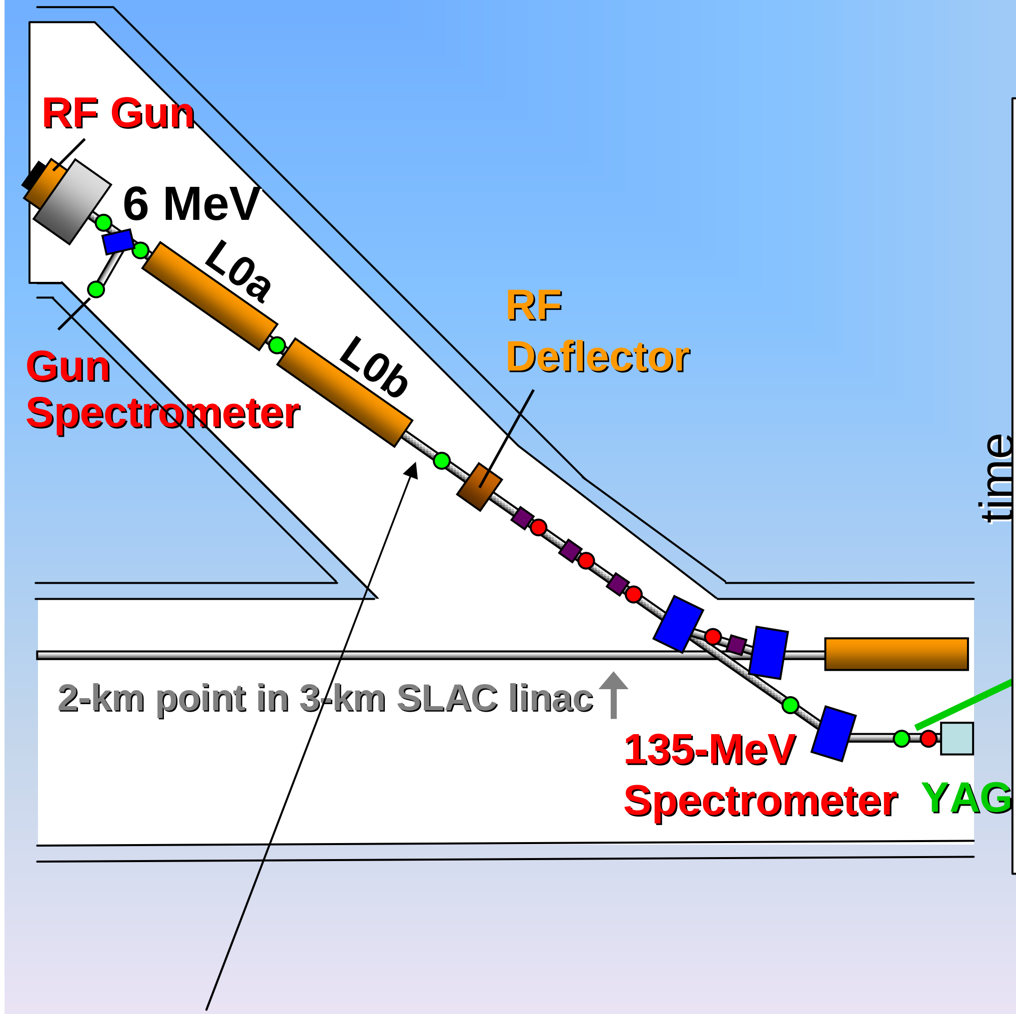


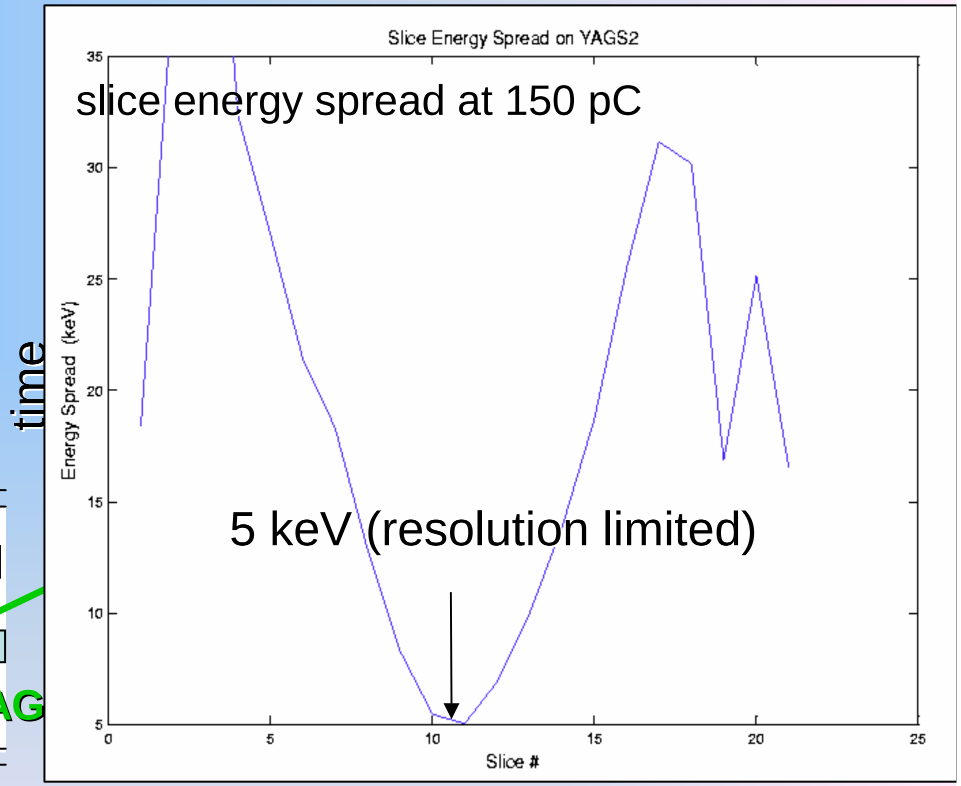
➔ growth of slice energy spread (and possibly emittance)

Slice energy spread

- Longitudinal phase space at 135 MeV spectrometer

H. Loos, C. Limborg

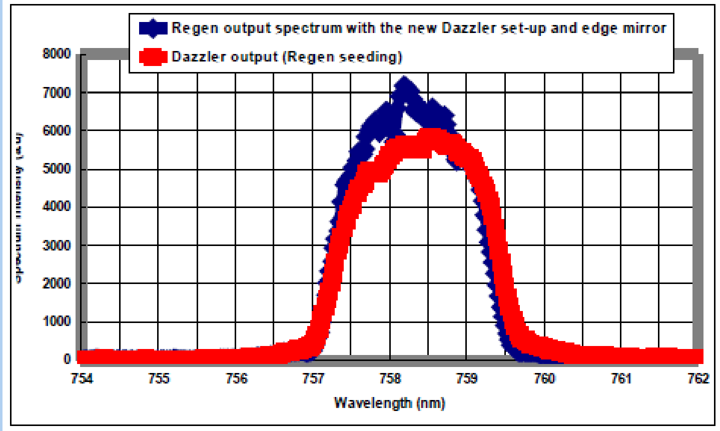




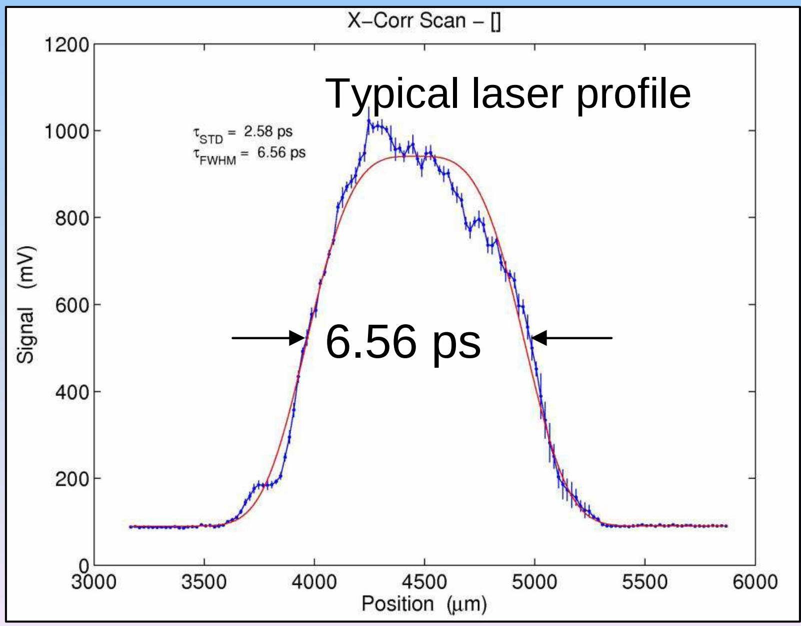
- Laser heater (under installation) will be used to control slice energy spread (P. Emma's talk)

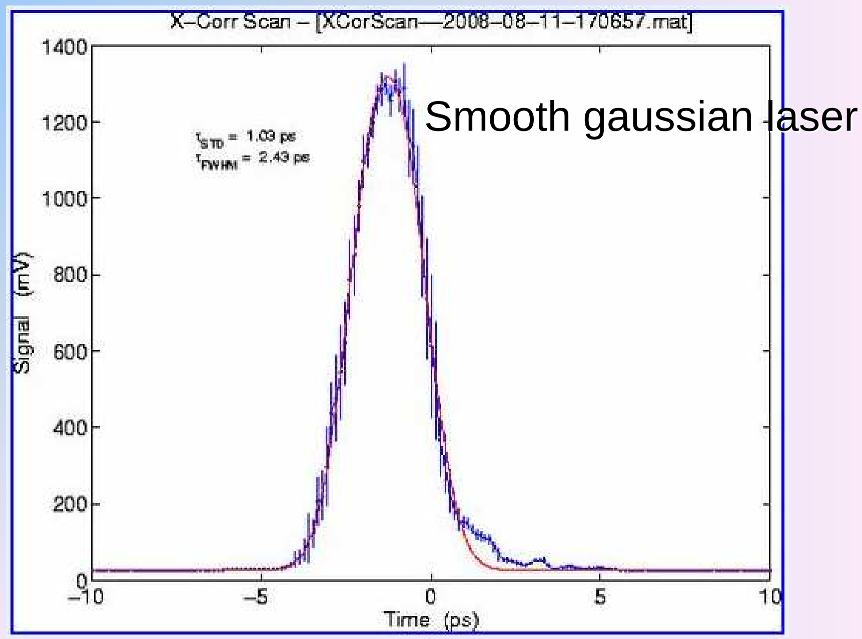
Drive Laser Profile

- Bandwidth of Ti:Sapphire laser (760 nm) is 3 nm, After frequency tripling, UV BW 1 nm ➔ laser-induced beam modulation wavelength >~ 50 μm



- Smoothing the laser profile did not change microbunching observations qualitatively

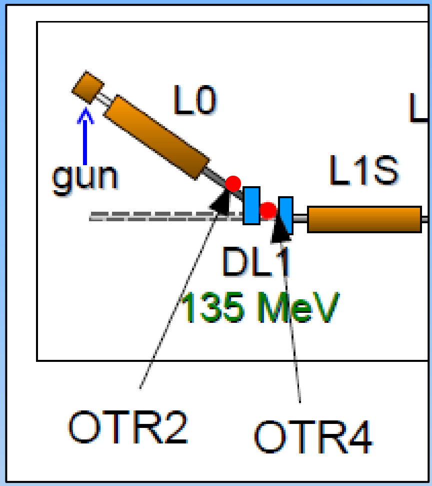




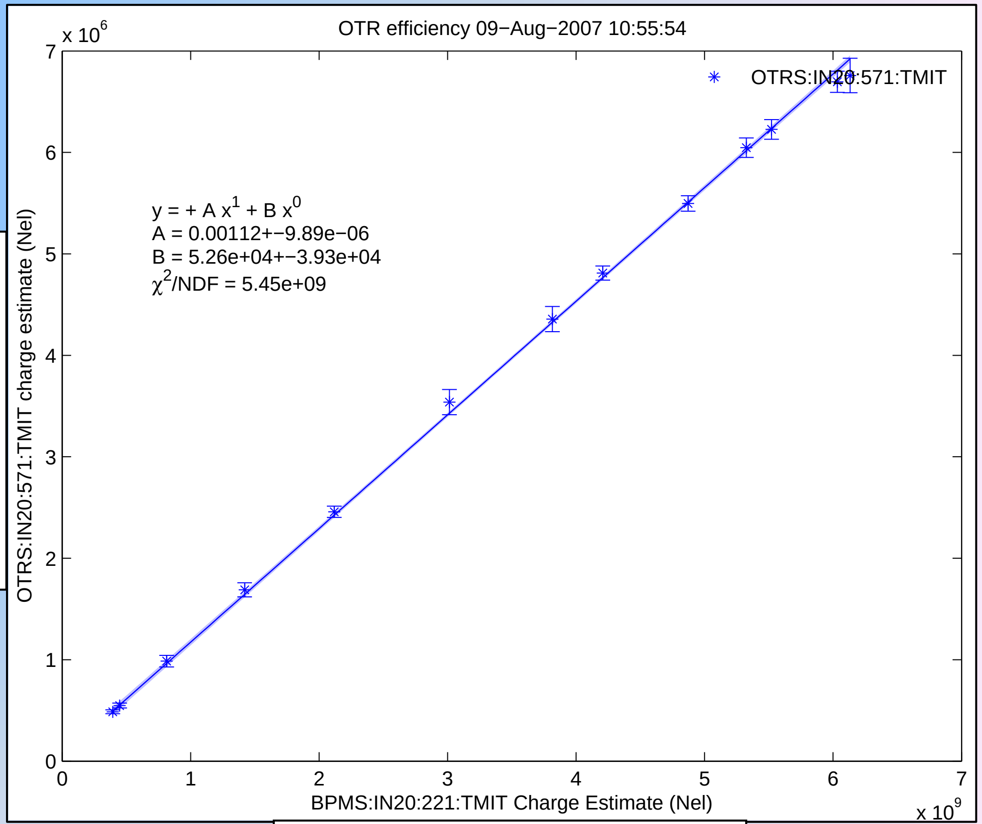
W. White *et. al.*,

No COTR observed before DL1

- OTR2 intensity vs. charge is linear



OTR2 intensity

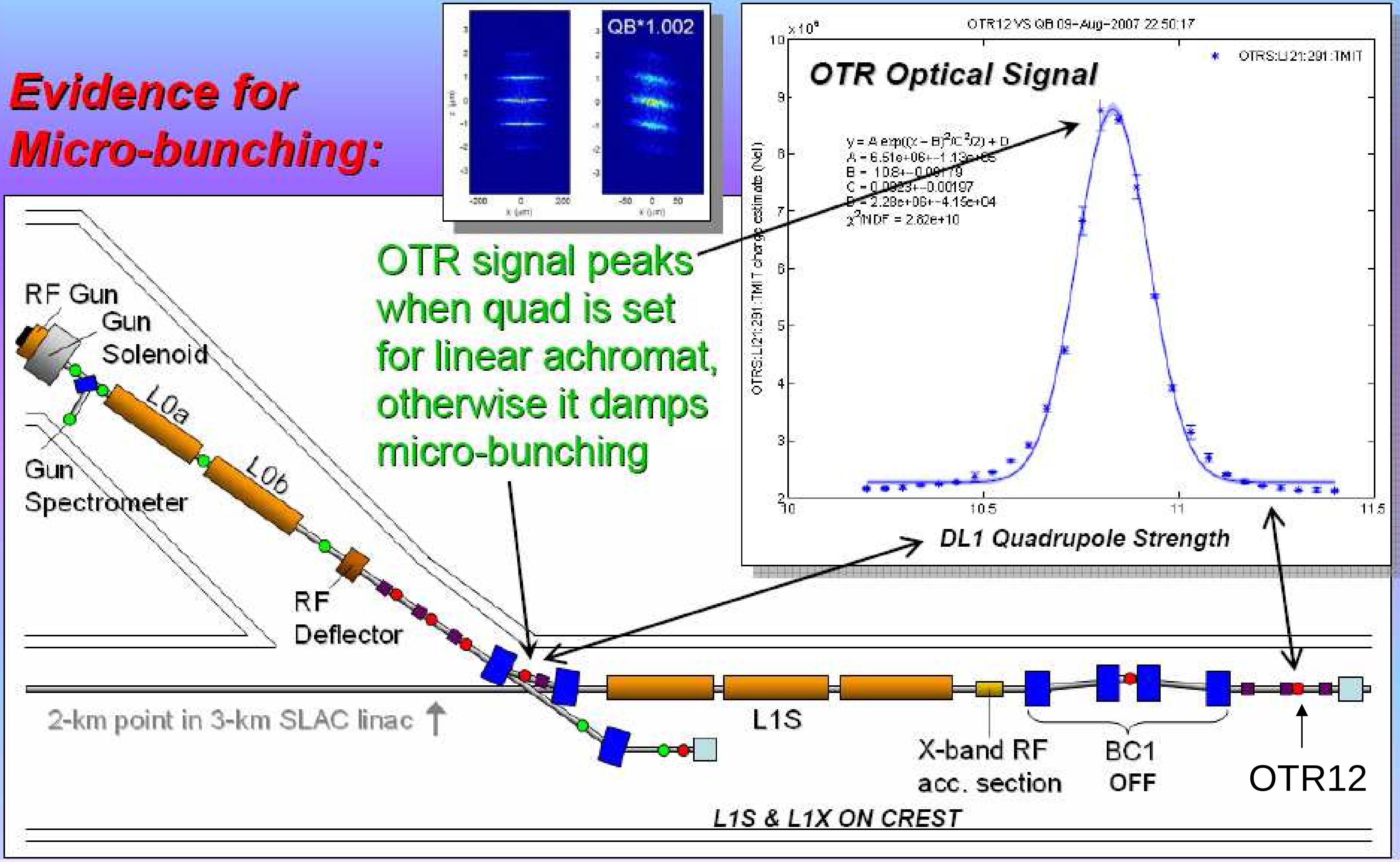


Number of electrons

- Incoherent radiation level ➔ initial density modulation at optical wavelengths come from shot noise fluctuations

Unexpected Physics! *Coherent OTR after 35-degree Bend, Even With No BC1*

Evidence for Micro-bunching:

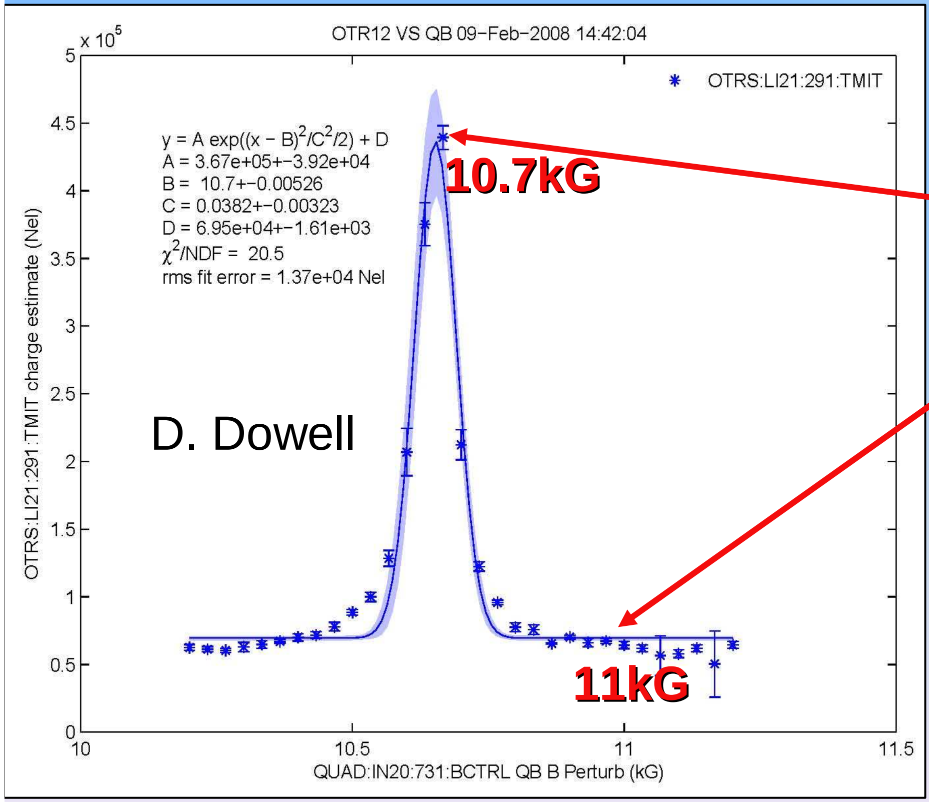


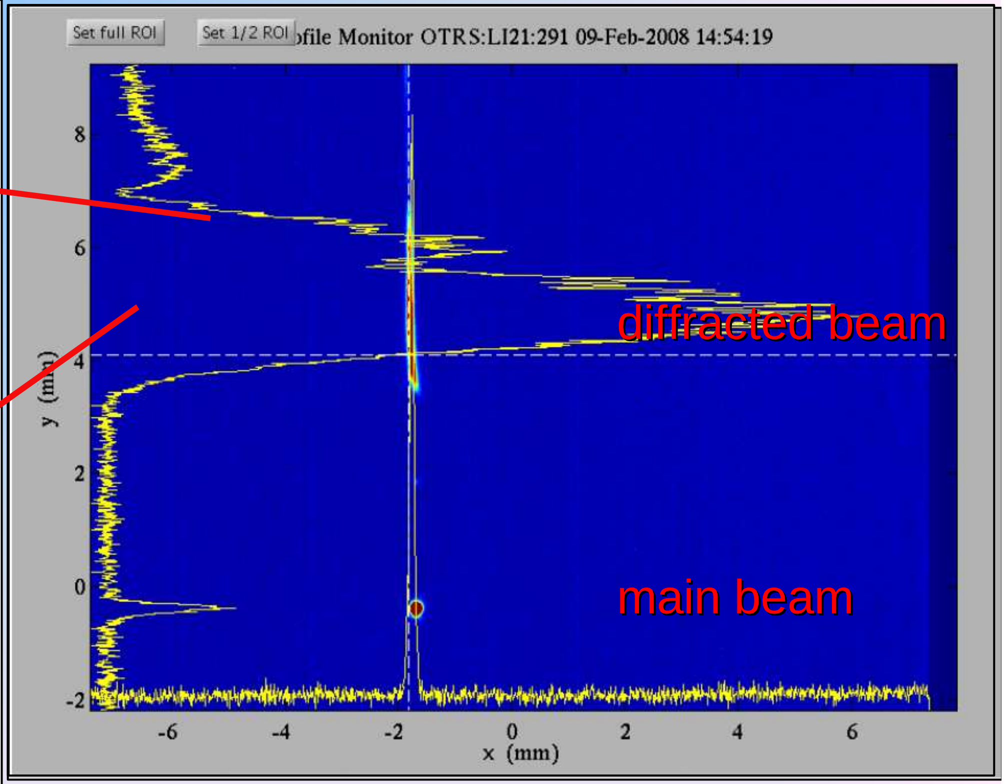
R. Akre, et al., PRST-AB 11, 030703 (2008)

OTR12 Spectrum

- Diffraction grating installed in OTR12
- Gives low resolution spectrum from ~400nm to ~800nm

No COTR (QB = 11 kG, nonzero R51&R52 after DL1 suppress μ-bunching)
COTR (QB = 10.7 kG, DL1 is linear achromat and enhances μ-bunching)

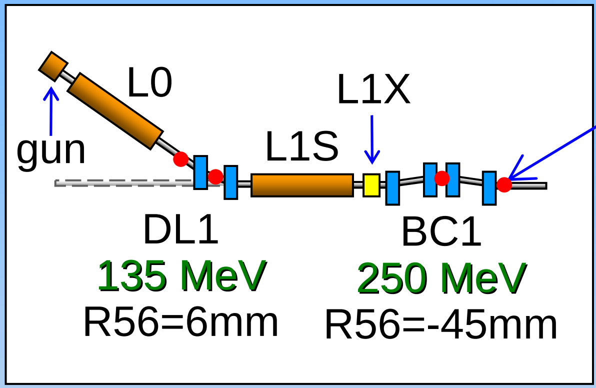


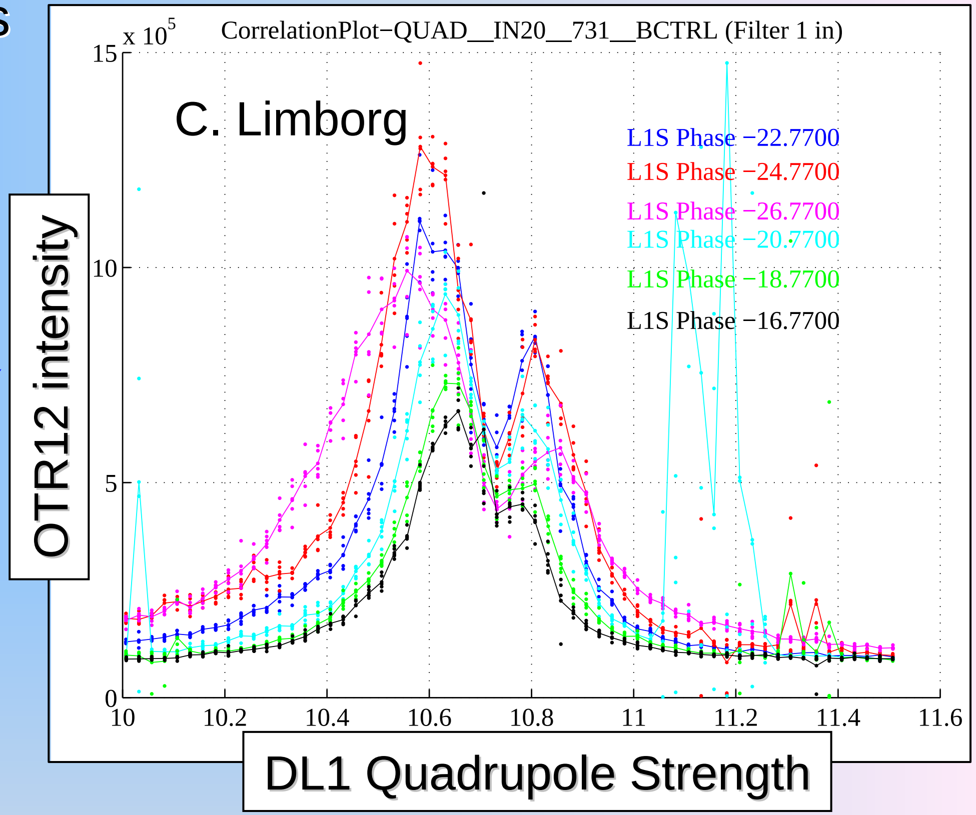


- Gain analysis and comparison with theory (D. Ratner's talk)

BC1 on

- L1S off-crest to chirp and compress the bunch, observed double peaks in OTR12 intensity vs. QB

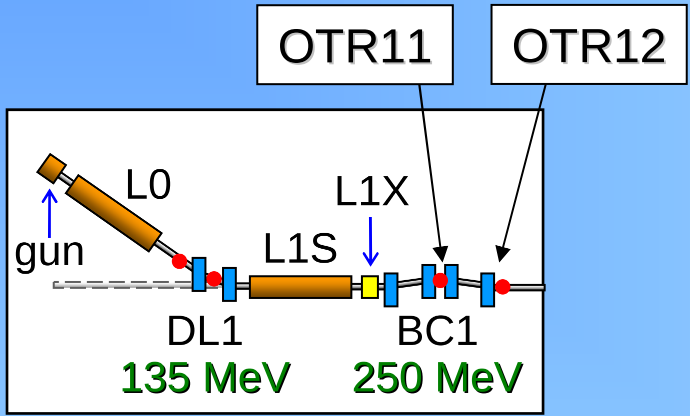


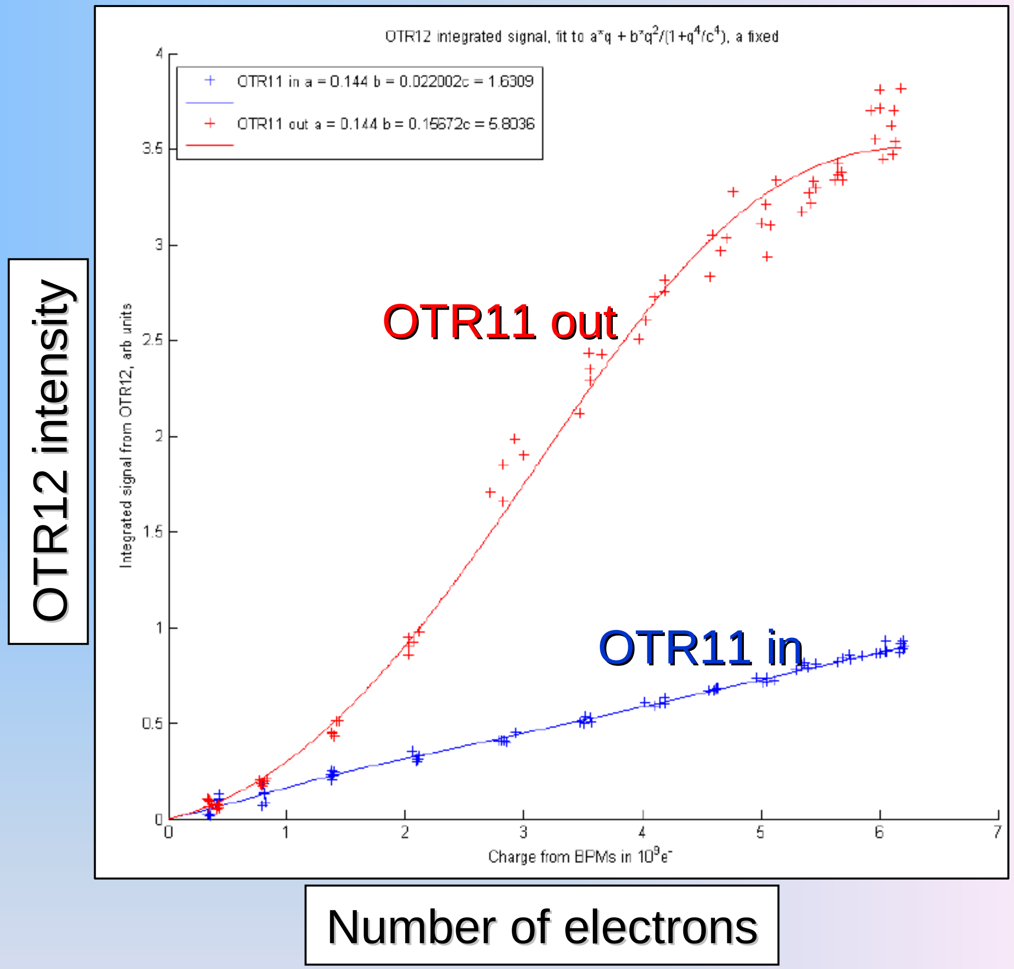


- Due to compression, OTR12 “sees” longer initial modulation wavelengths, which require larger QB range to suppress μ–bunching

- Coherence is reduced when DL1 is near achromat: High-frequency energy modulations are amplified after DL1 but dissipated in BC1 (due to its stronger R56). This may increase effective energy spread and reduce longer-wavelength gain

OTR11 suppresses COTR on OTR12



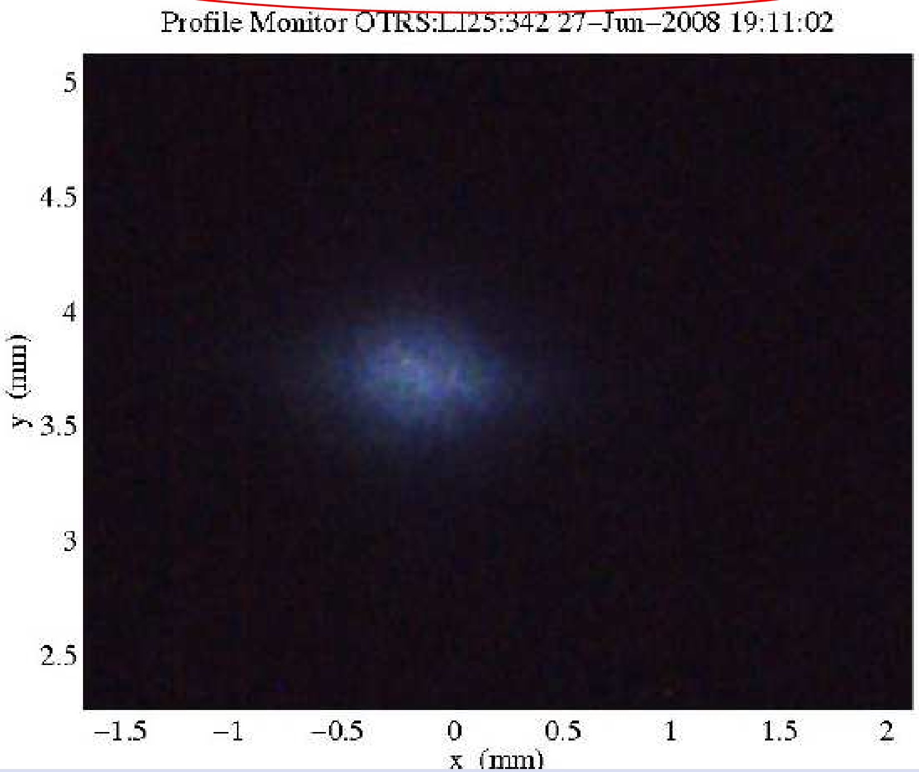


- OTR11 foil generates random angular scattering in middle of BC1, which creates time smearing of microbunching after transporting to OTR12 outside BC1.

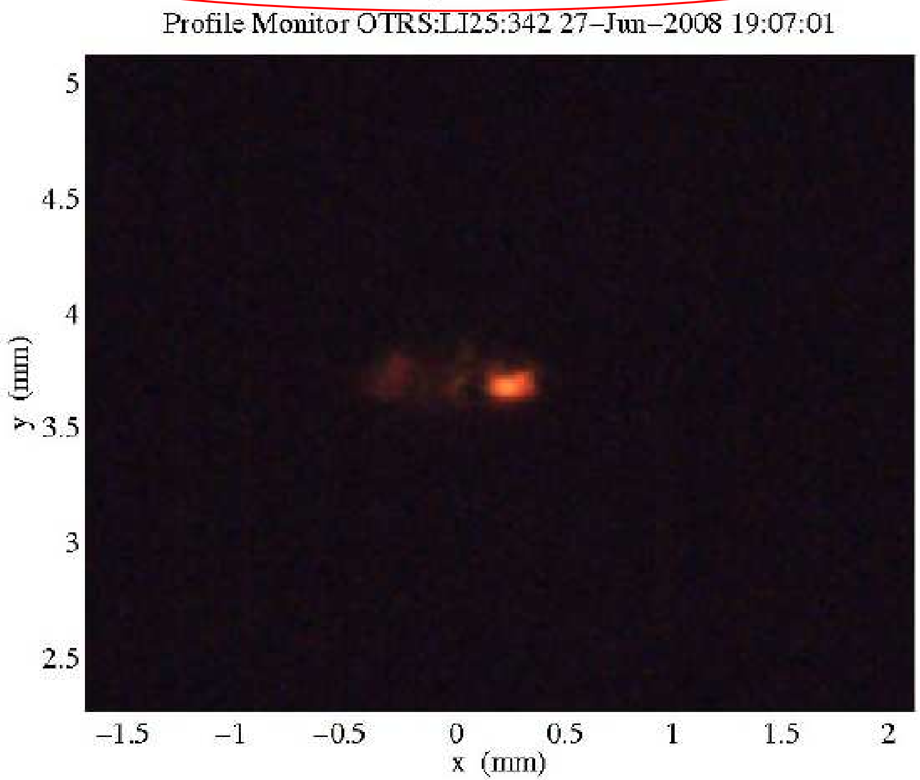
COTR after BC2 on OTR22

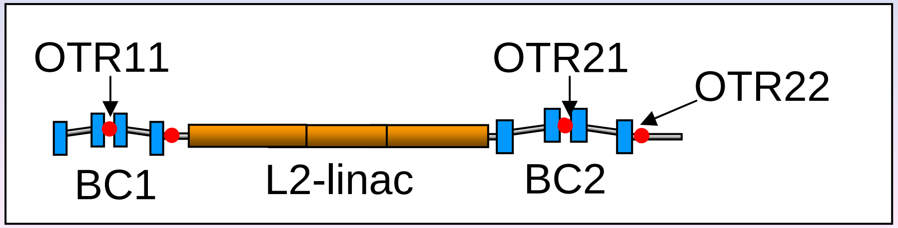
Approximately true color images. Note longer wavelength of coherent signal

OTR11, OTR21 inserted, no coherence



Normal operating conditions
X10,000 optical attenuation

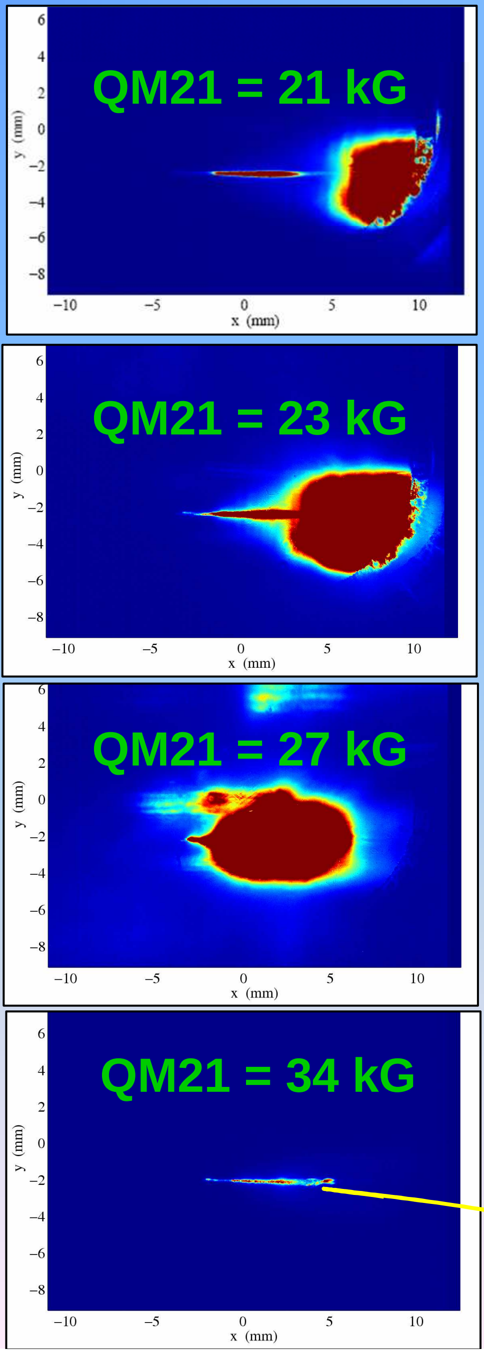




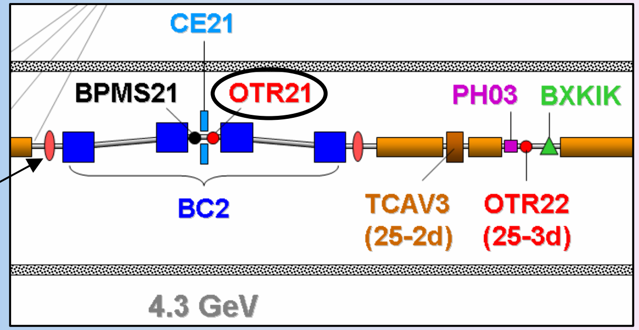
J. Frisch

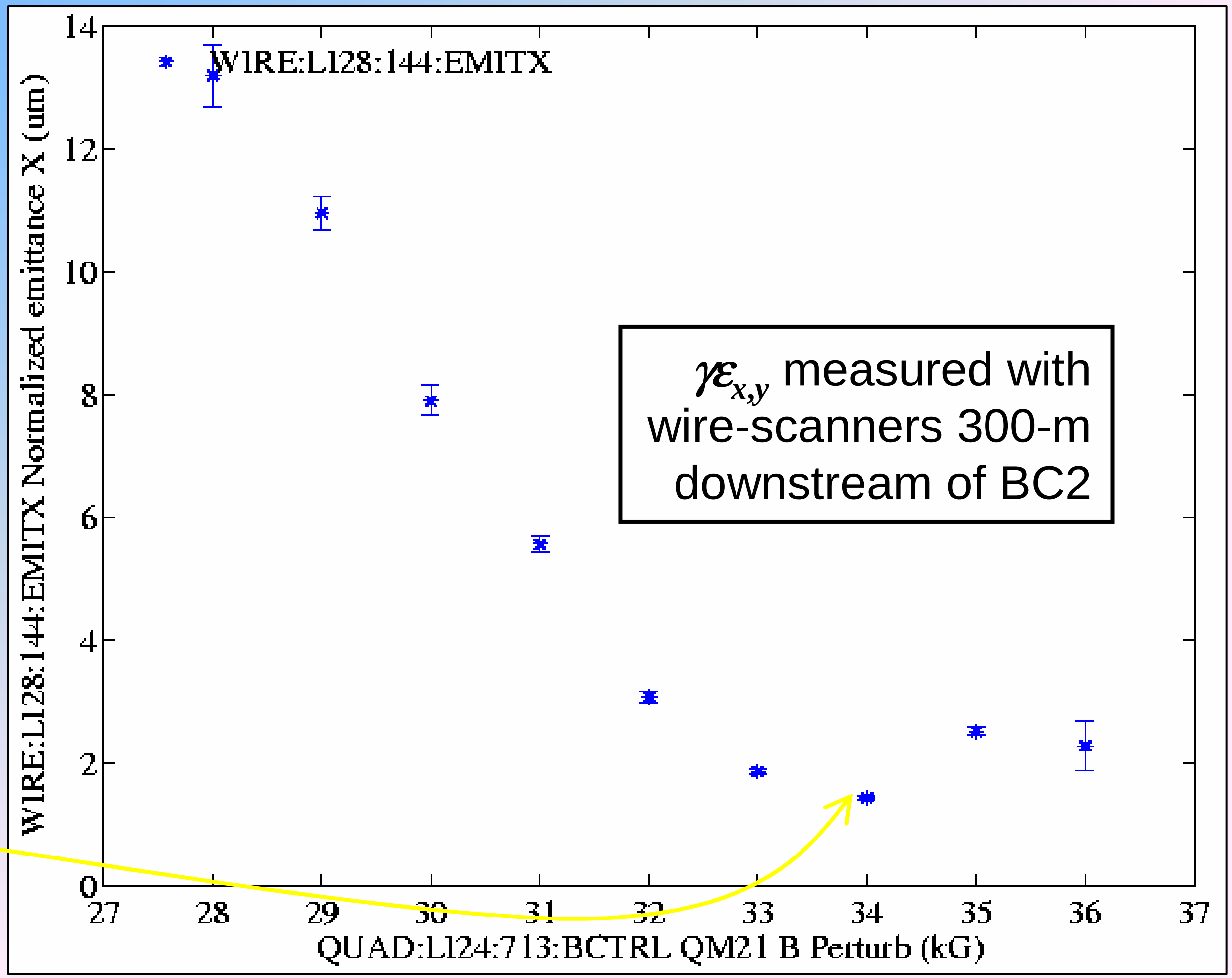
More COTR study (H. Loos talk)

OTR21 in BC2

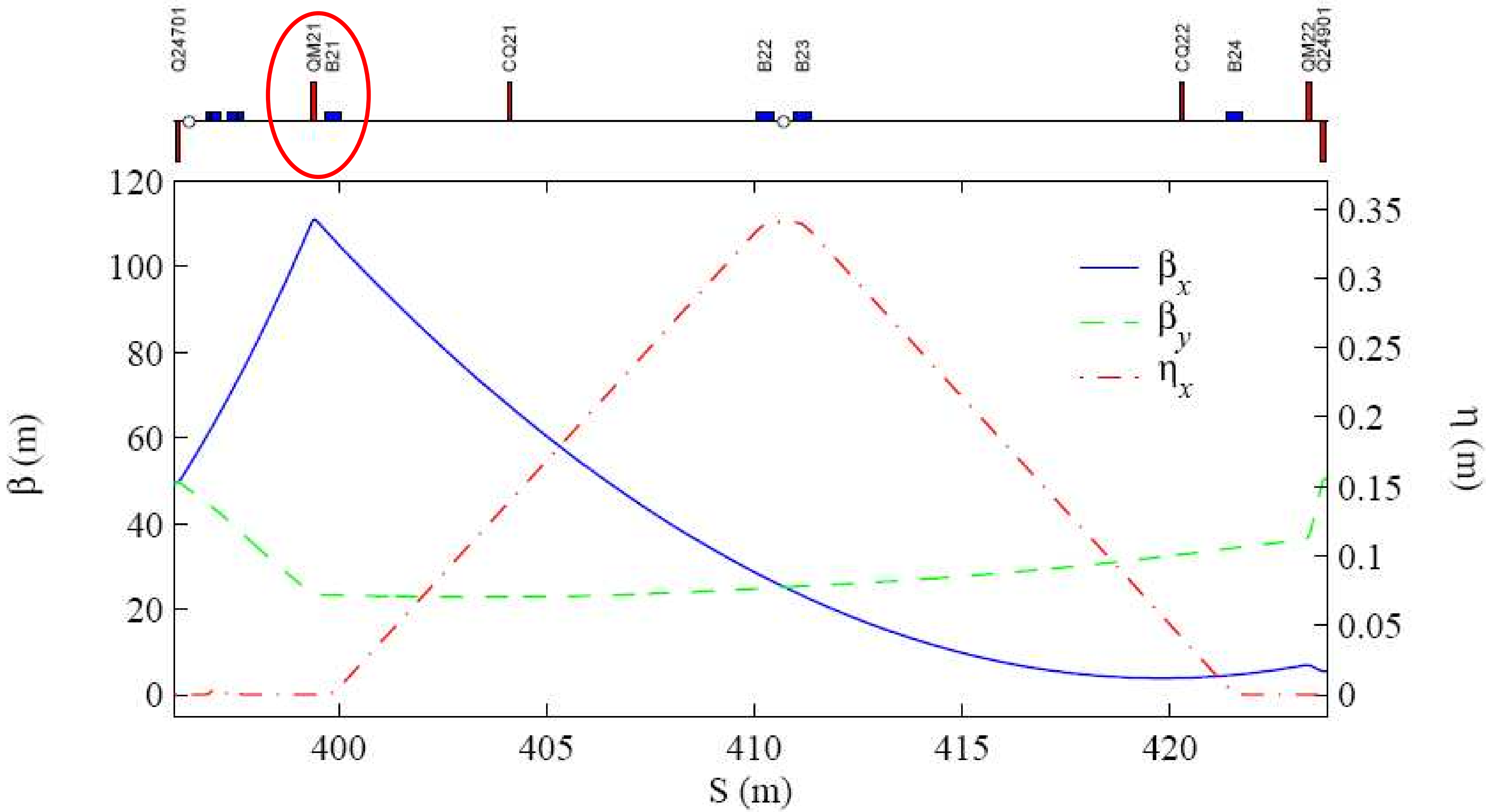


Scan QM21



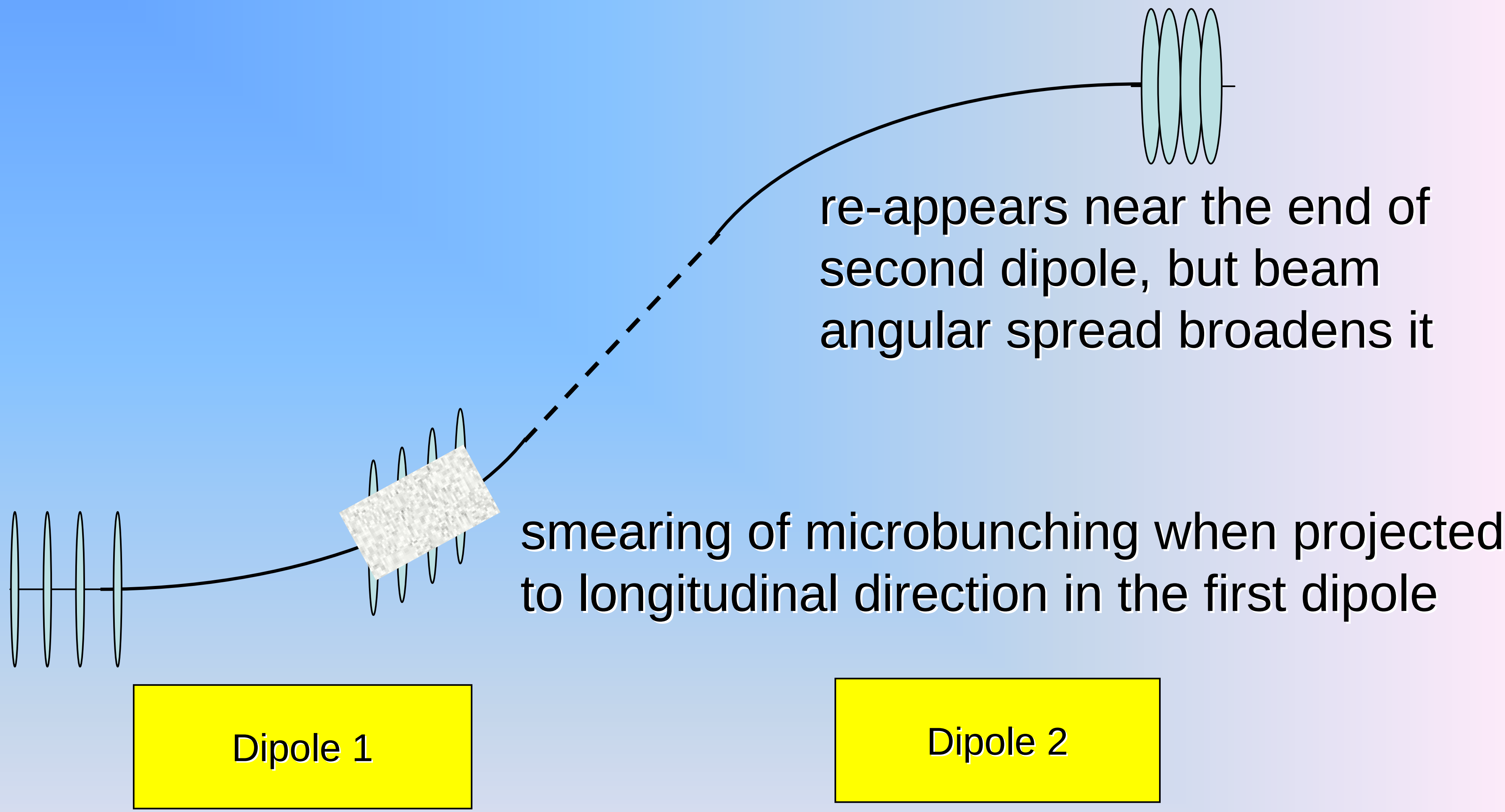


BC2 optics function



- QM21 changes beam divergence at BC2 entrance, not much effect on transverse size there

Microbunching evolution in a Chicane



- Varying pre-BC2 beam divergence (by QM21) changes sharpness of microbunching and sharpest location of microbunching in the second dipole

Analysis

- Ignore further CSR amplification of microbunching in BC2 (BC2 gain is low <3, see *Heifets/Stupakov/Krinsky, PRST 2002; also see Huang/Kim, PRST 2002*)

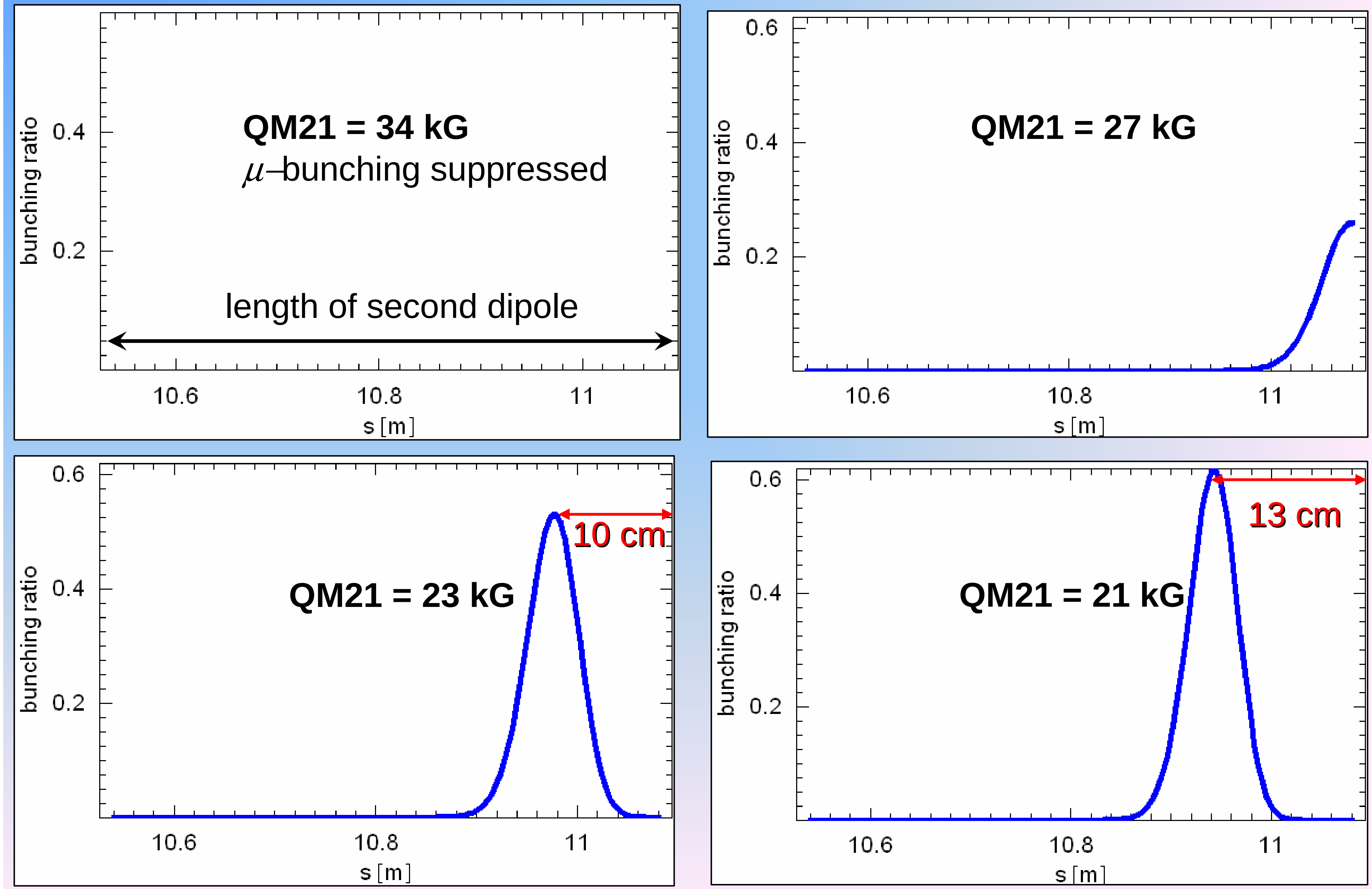
- Bunching evolution in a chicane is approximately

$$b_0[k(s);s] = b_0[k_0;0]e^{-k^2(s)R_{56}^2(s)\sigma_\delta^2/2} \times \exp\left[-\frac{k^2(s)\varepsilon_0\beta_0}{2}\left(R_{51}(s) - \frac{\alpha_0}{\beta_0}R_{52}(s)\right)^2 - \frac{k^2(s)\varepsilon_0}{2\beta_0}R_{52}^2(s)\right] \quad (26)$$

Initial bunching (+energy modulation) due to LSC instability in linac+DL1+BC1

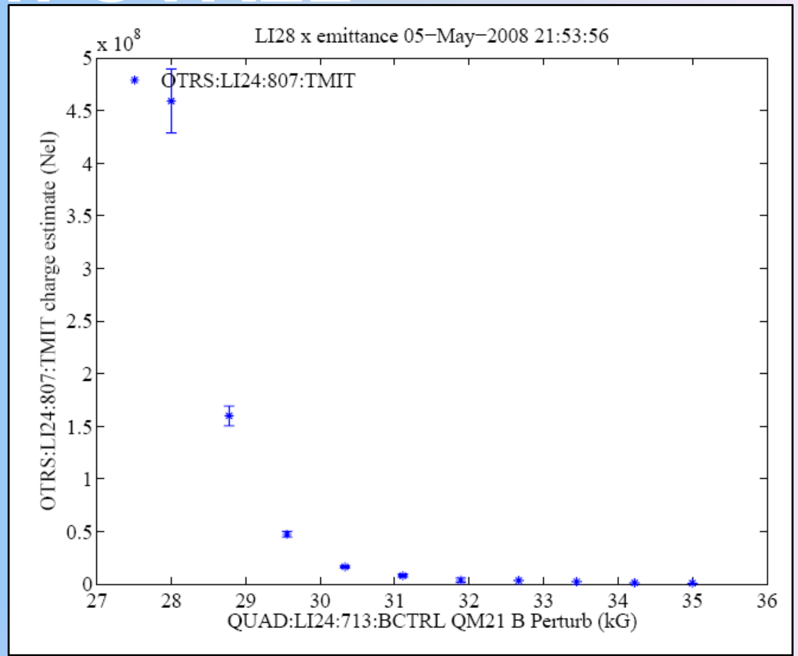
Controlled by QM21

Optical bunching in the second dipole



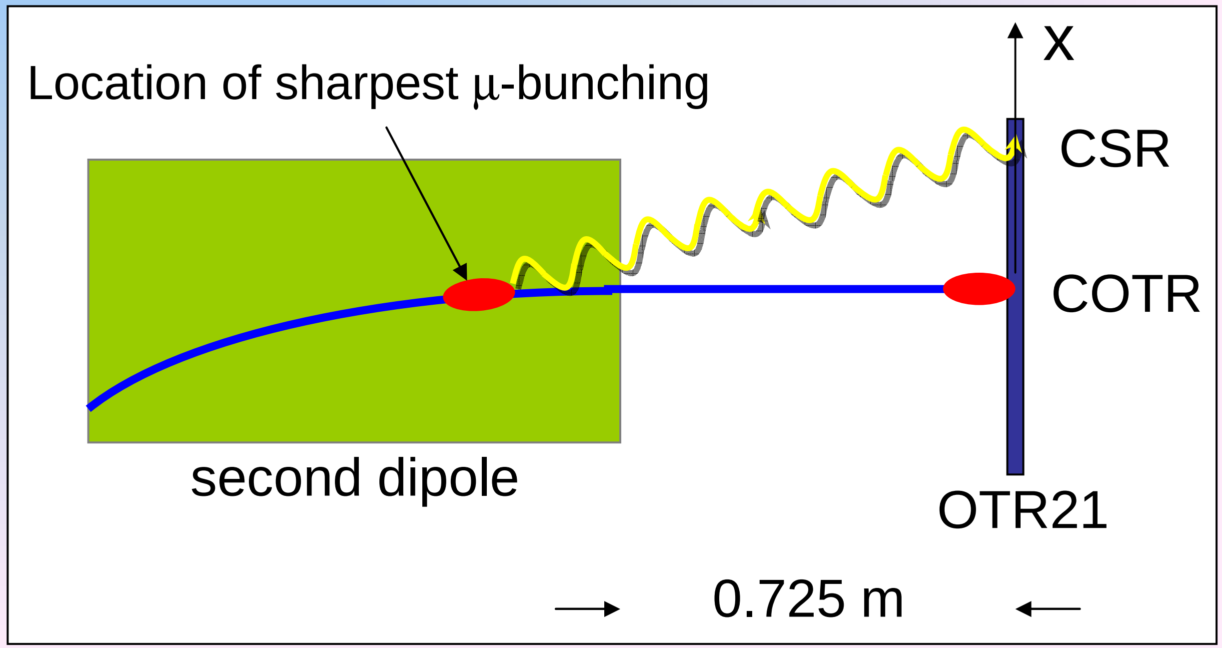
Effects on OTR21

• COTR+CSR intensity changes drastically with QM21 (QB-like effect)



• CSR is emitted near the bunching maximum in second dipole

➔ separation of COTR and CSR on OTR21

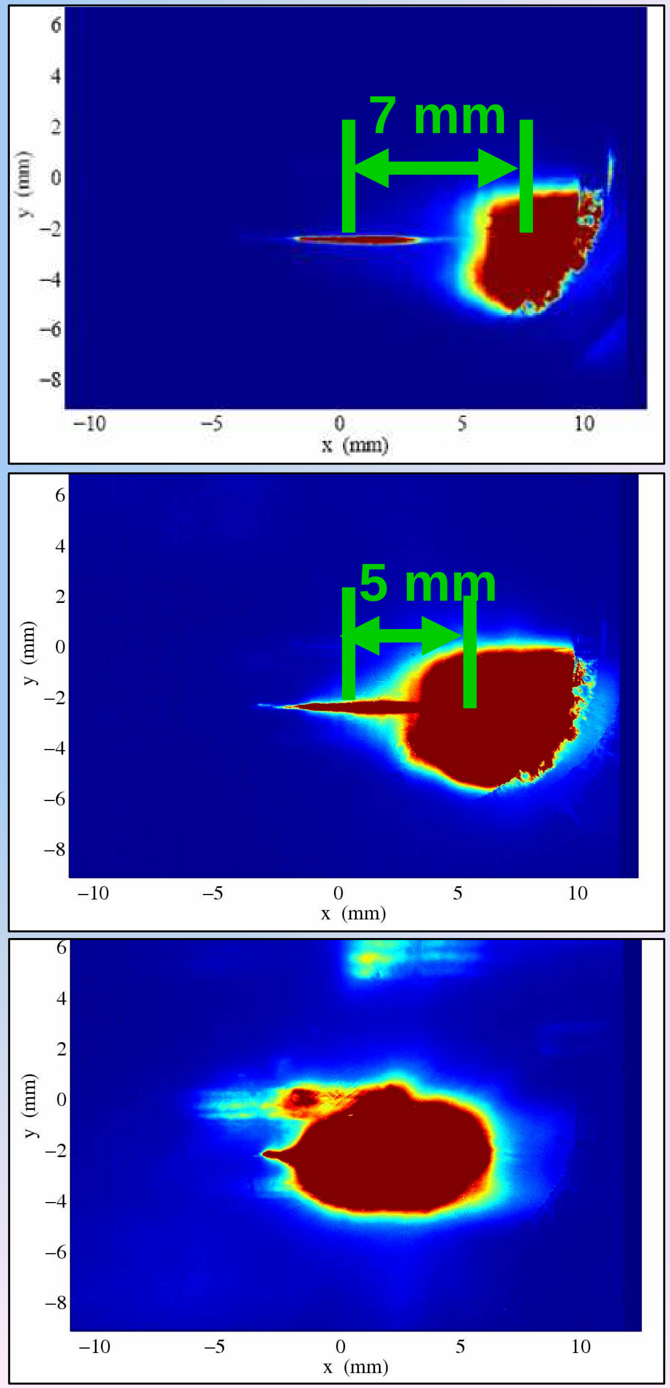


Shift of CSR from COTR

QM21 = 21 kG
Calculated shift ~ 7 mm

QM21 = 23 kG
Calculated shift ~ 5 mm

QM21 = 27 kG
Calculated shift ~ 0 mm



Summary

- A high-brightness beam such as generated by LCLS tends to microbunch itself in a bend system with nonzero R_{56}
  (Shot noise can naturally start the process).
- Strong COTR and CSR emissions at optical wavelengths are clear evidences of beam microbunching.
- Studies are ongoing: some effects are understood, some details are still missing.
- Laser heater (to be commissioned soon) will mitigate microbunching and (hopefully) get rid of lots of COTR/CSR.
  We look forward to how it works out.

Thank Bill Fawley for putting together this workshop!

Thank LCLS commissioning team for great team work and fun experience!