



# Time-Resolved Images of Coherent Synchrotron Radiation Effects in the *LCLS* First Bunch Compressor

C. Behrens, *DESY*

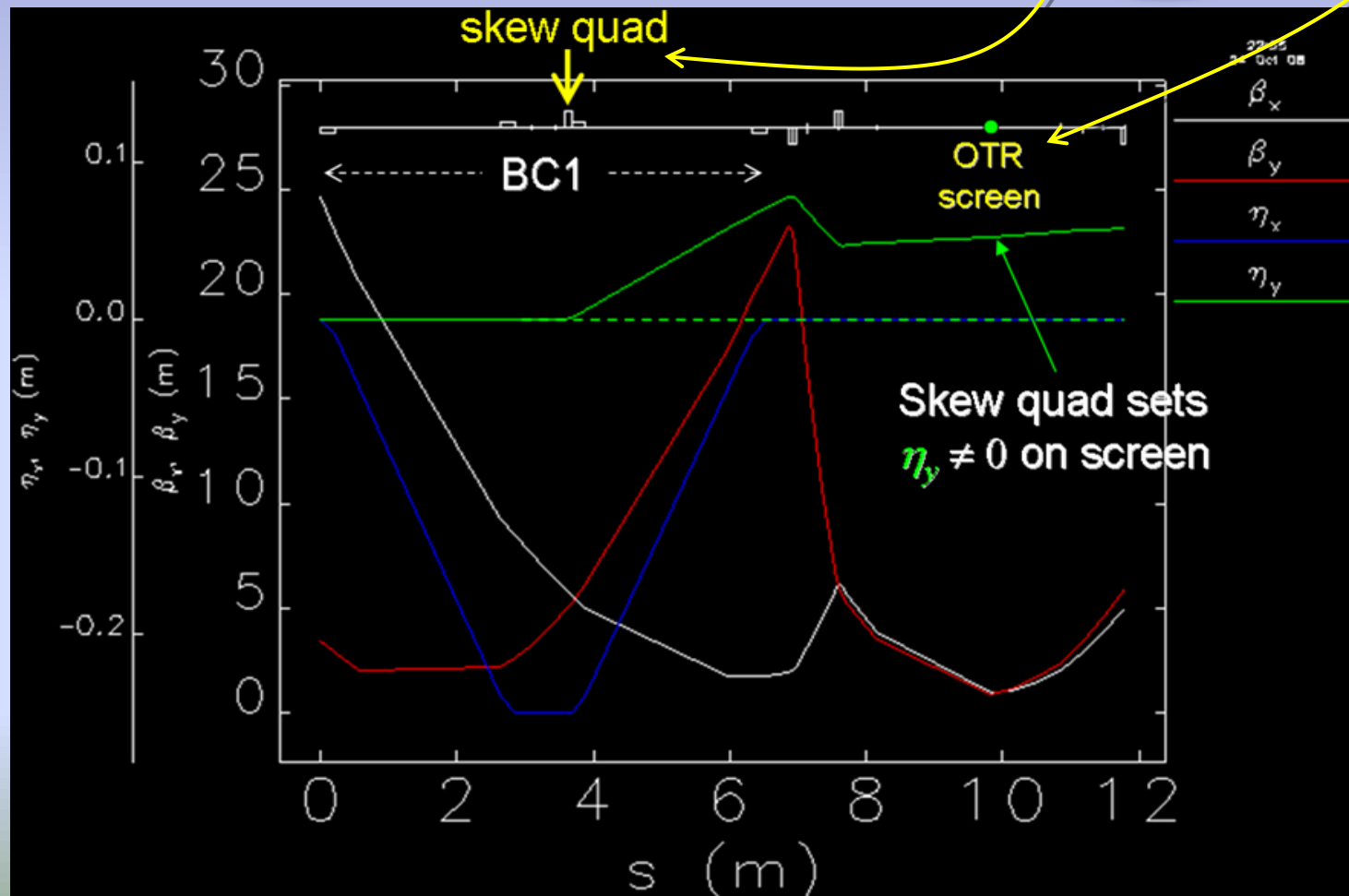
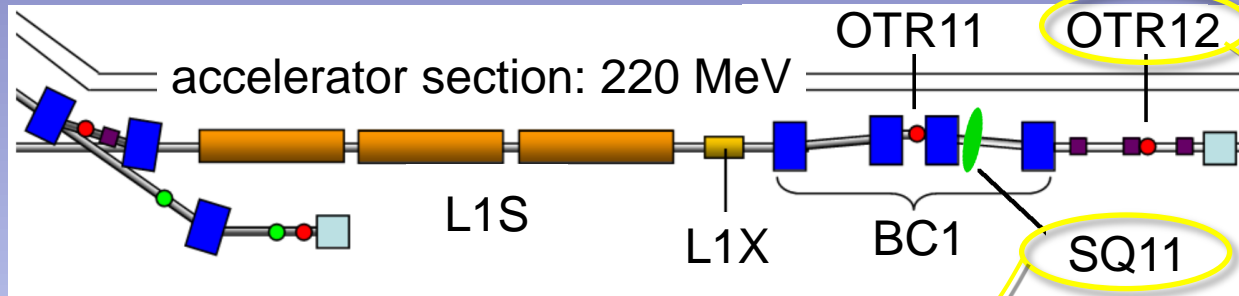
P. Emma, *LBNL*

F. Zhou, Z. Huang, *SLAC*

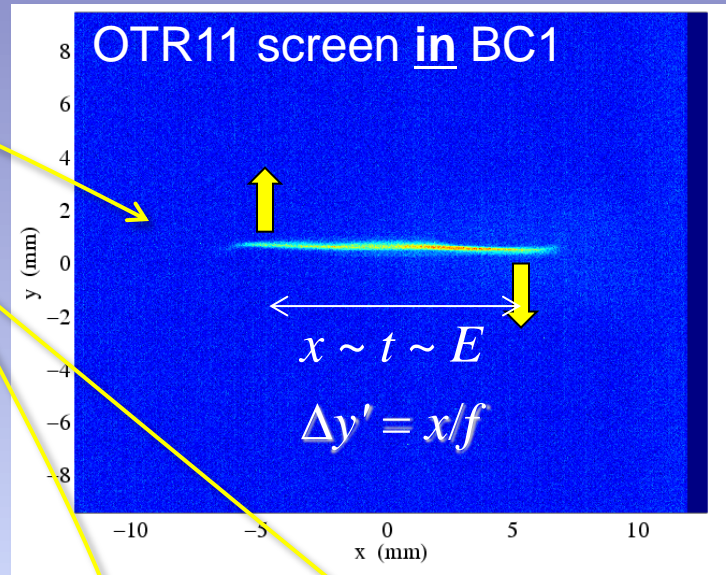
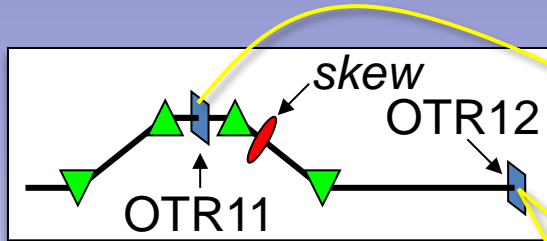
# Motivation & Idea

- “*...would like to see the time-resolved effects of CSR*”  
- Joe Bisognano (UW), **2008 LBNL FEL Workshop**
- “*Can we use a skew quad?*” - Oleg Shevchenko (BINP),  
**2008 LBNL FEL Workshop**
- Yes ... Skew quad is a poor man's transverse RF deflector, with a few differences
- Skew quad installed at *LCLS-BC1* in 2009 (PAC'09)
- Creates vertical dispersion after chicane, revealing  $x$  vs.  $t$  space (CSR effects)
- Measurements & simulations discussed here ...

# Add a CSR-Diagnostic Skew Quad in BC1

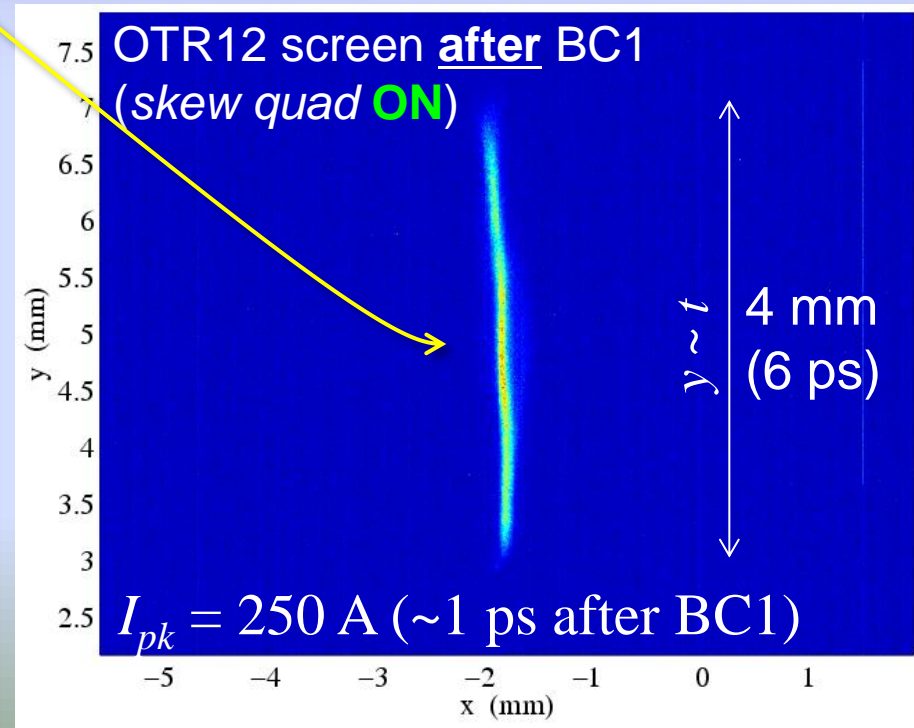
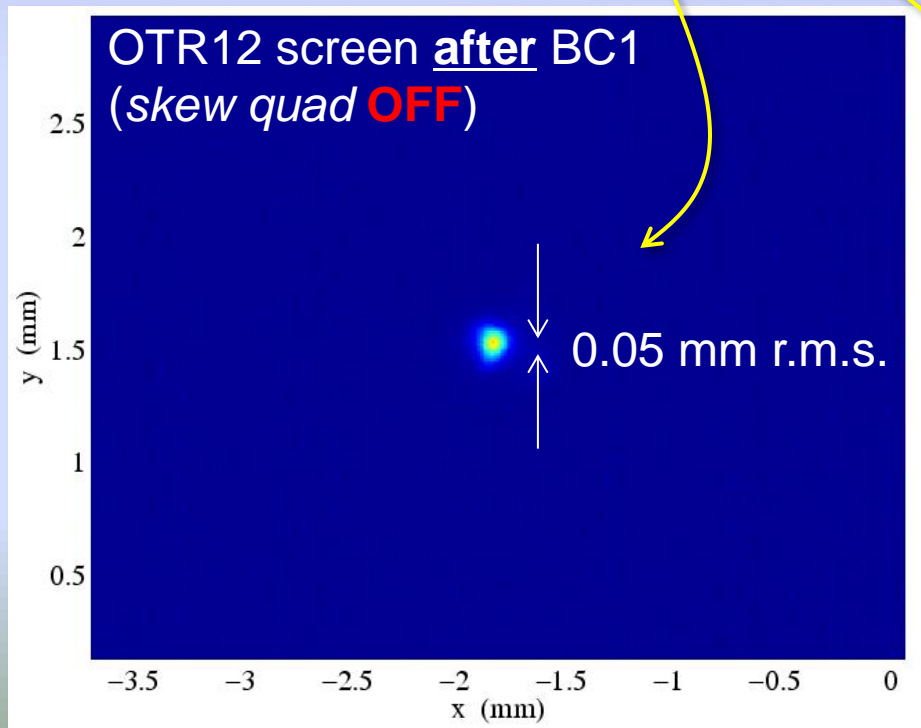


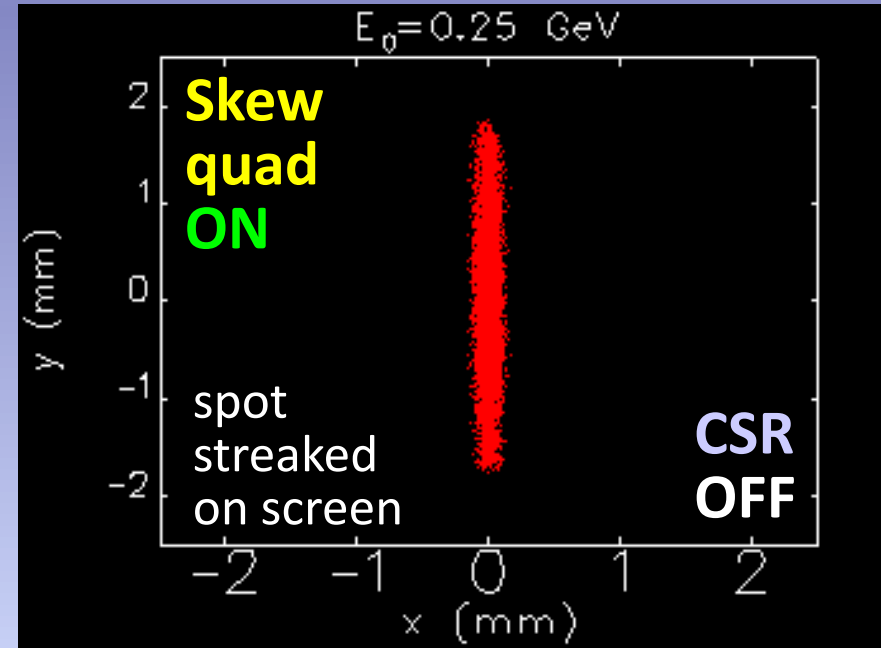
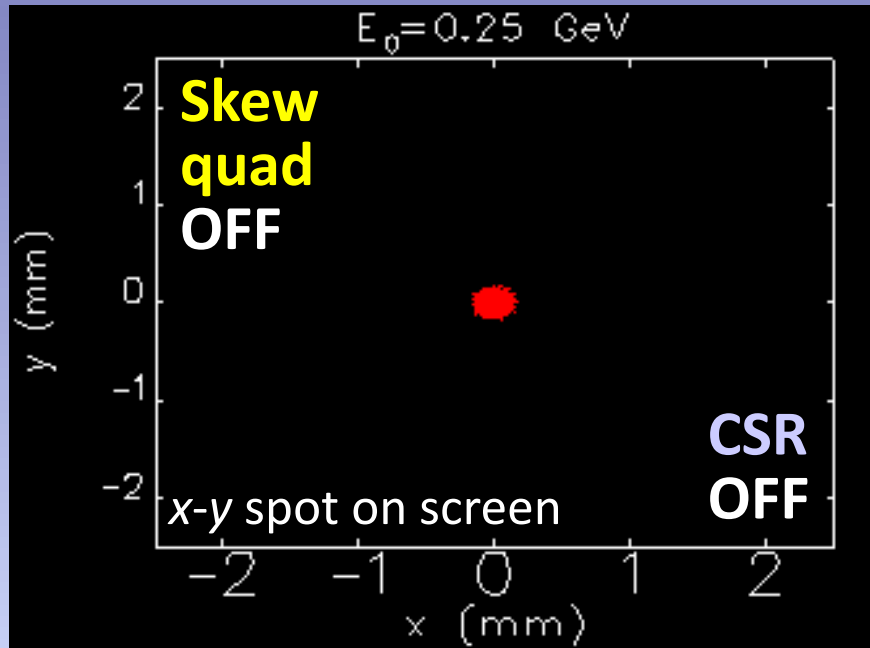
# How it Works (first measurements Dec. 15, 2009)



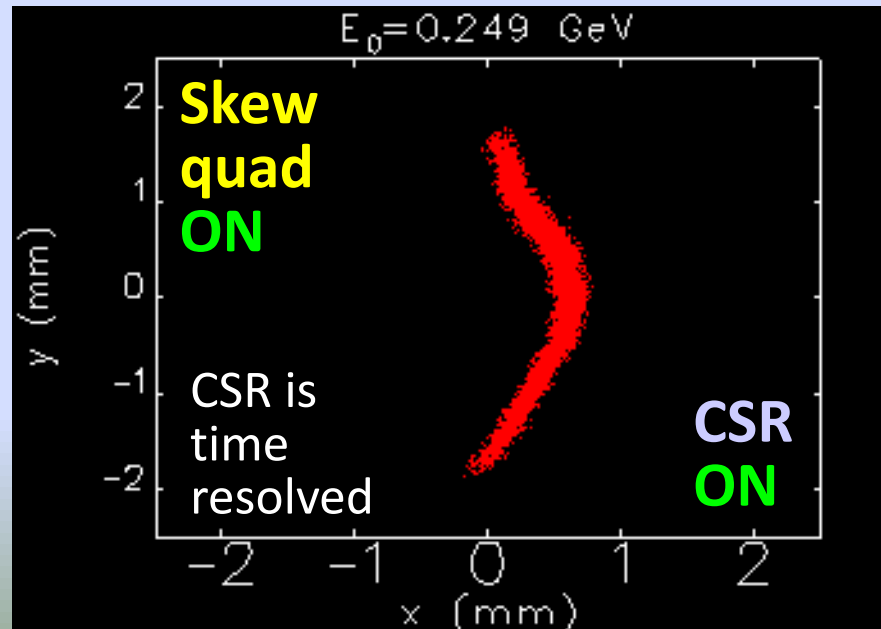
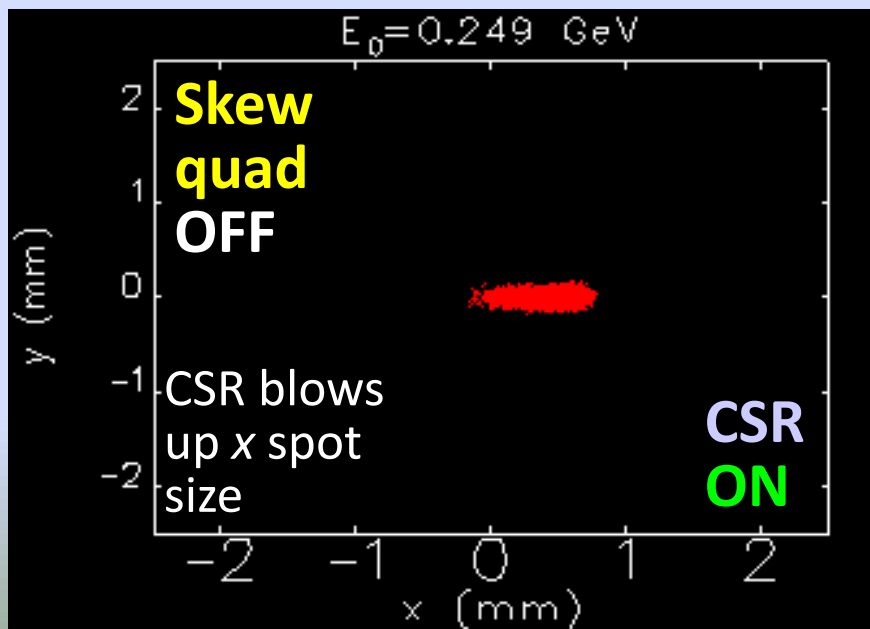
~1% chirped energy spread at 220 MeV and large dispersion at chicane center

*Skew quad* generates  $y'$  from  $x$ :  
 $\Delta y' = x/f$



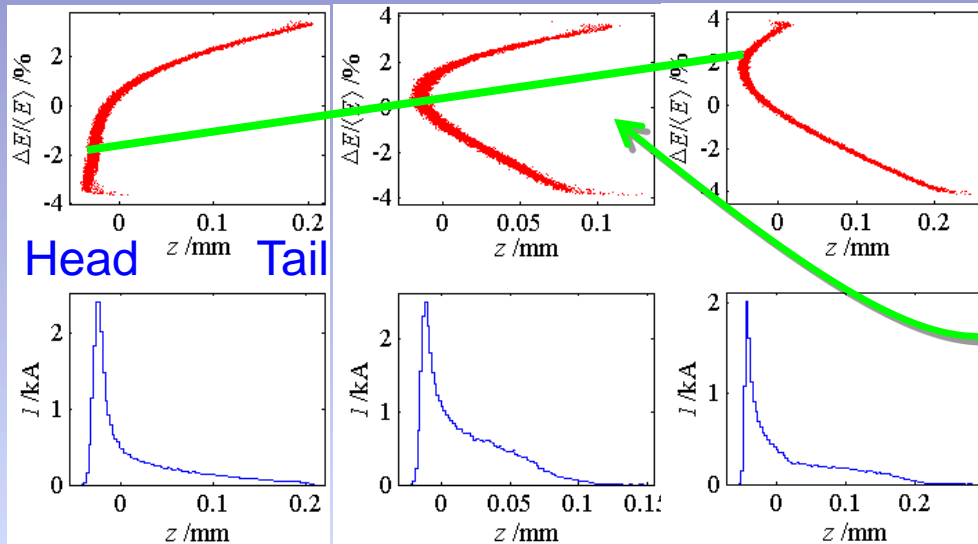


Simulation of skew quad effect at OTR12 for 1nC, with and without CSR



# X-band RF Linearizer (L1X) varied for different L1S phases:

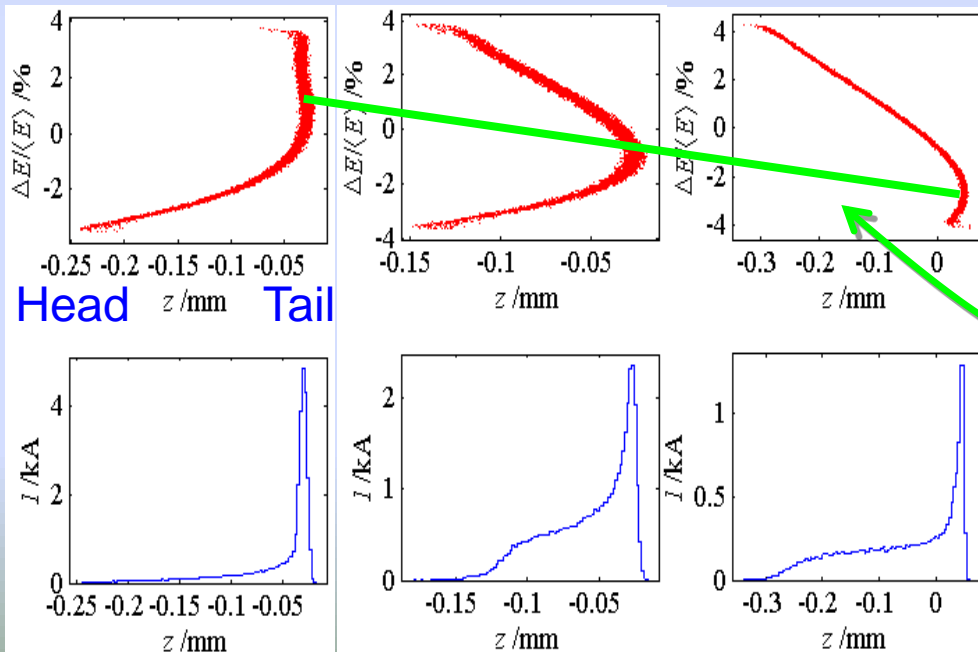
too weak (16 MV), too strong (22 MV), and just right (19 MV)



Head Tail

$L1X = 16$  MV (too weak)

Region of high peak current moves from head to tail (pre-BC1)



Head Tail

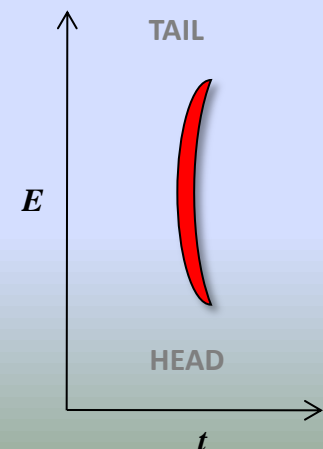
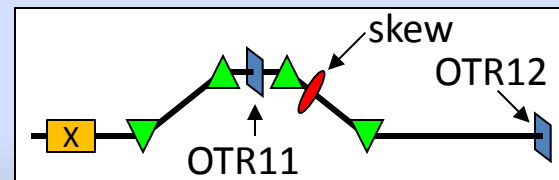
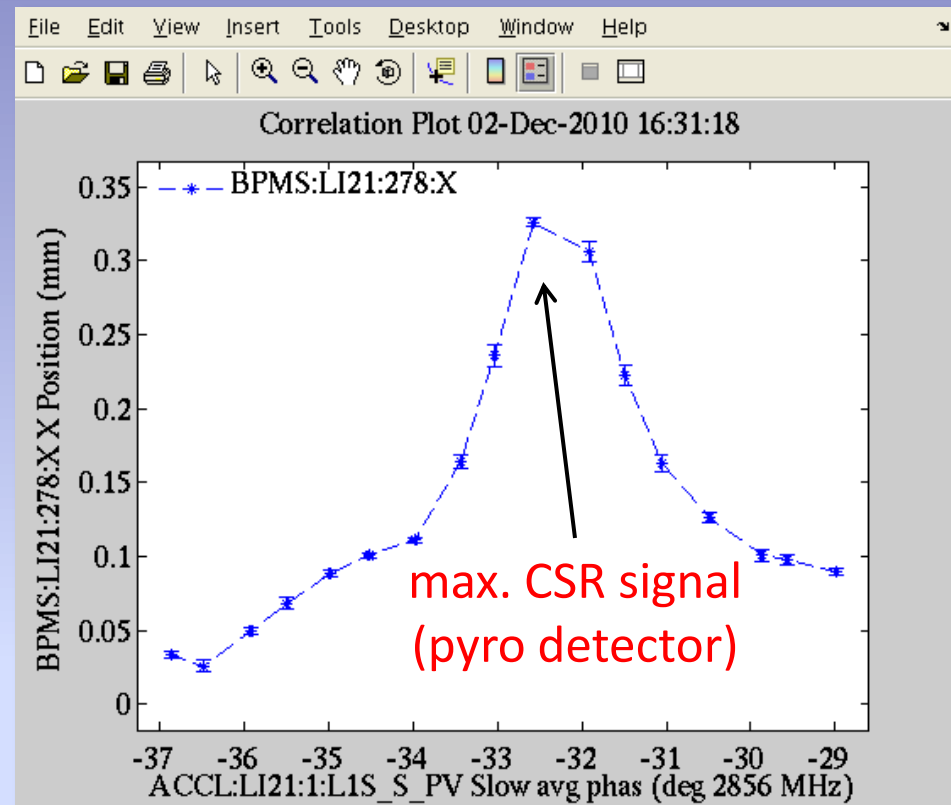
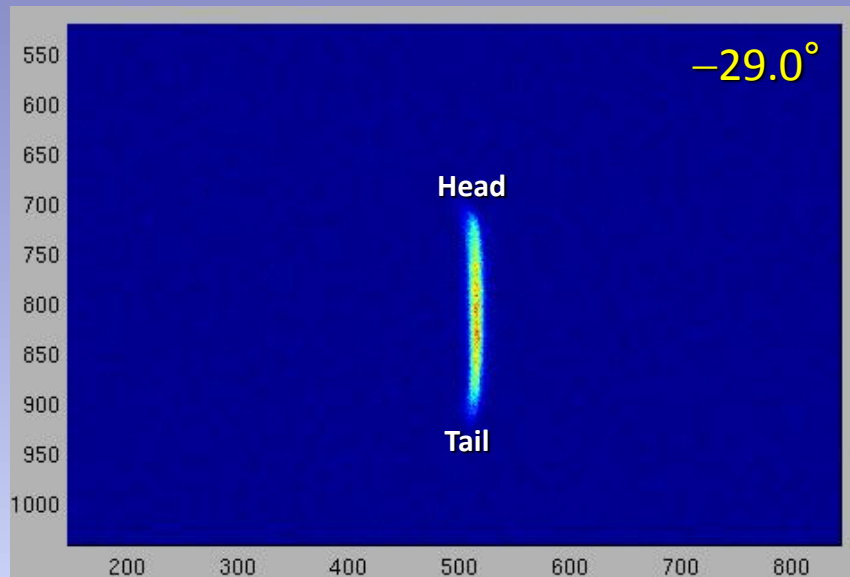
$L1X = 22$  MV (too strong)

Region of high peak current moves from tail to head (pre-BC1)

$L1X = 19$  MV (just right),  
linearizes phase space,  
not shown here

Scan L1S phase holding BC1 energy constant

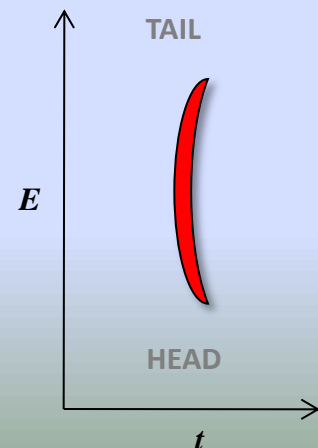
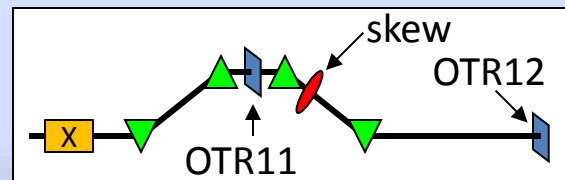
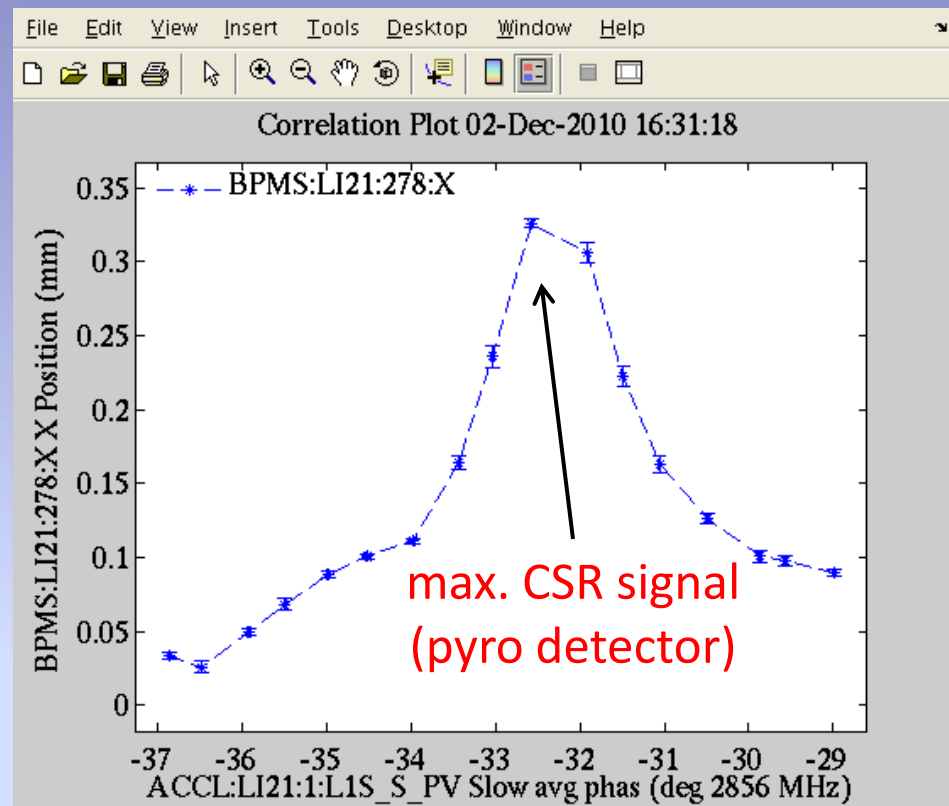
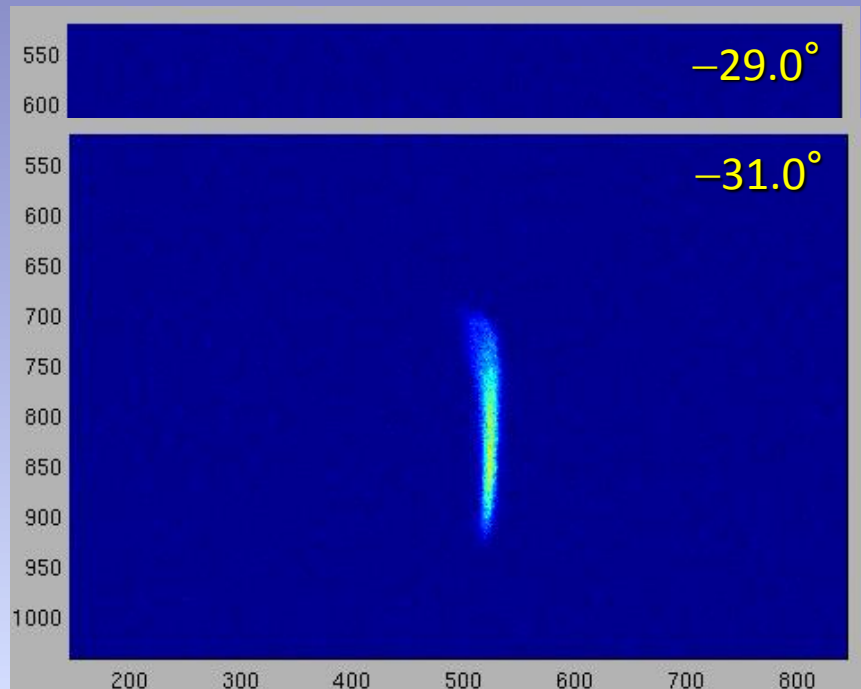
L1X Voltage = 16 MV (too weak)





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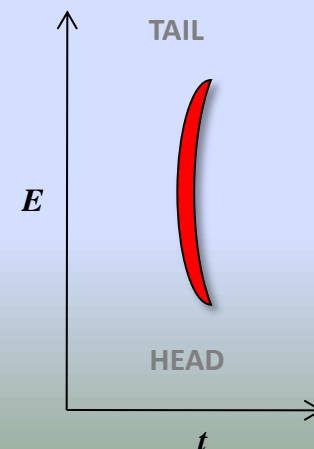
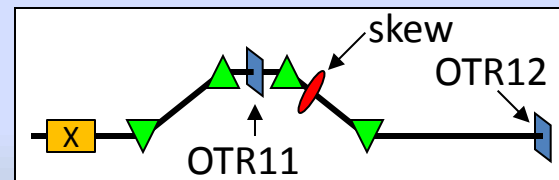
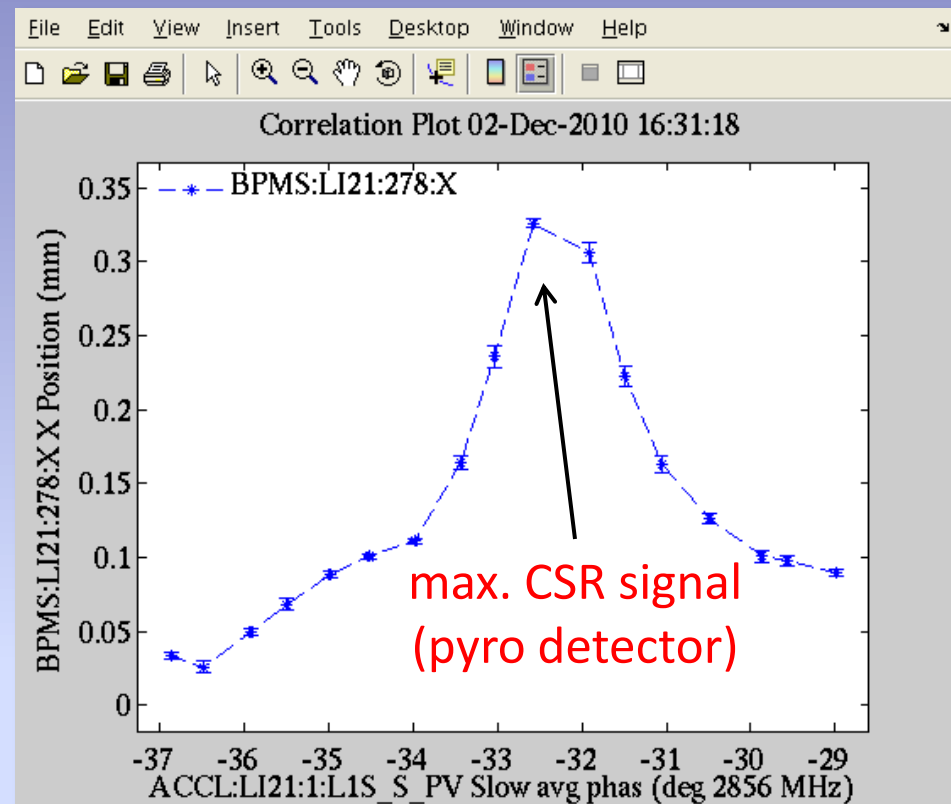
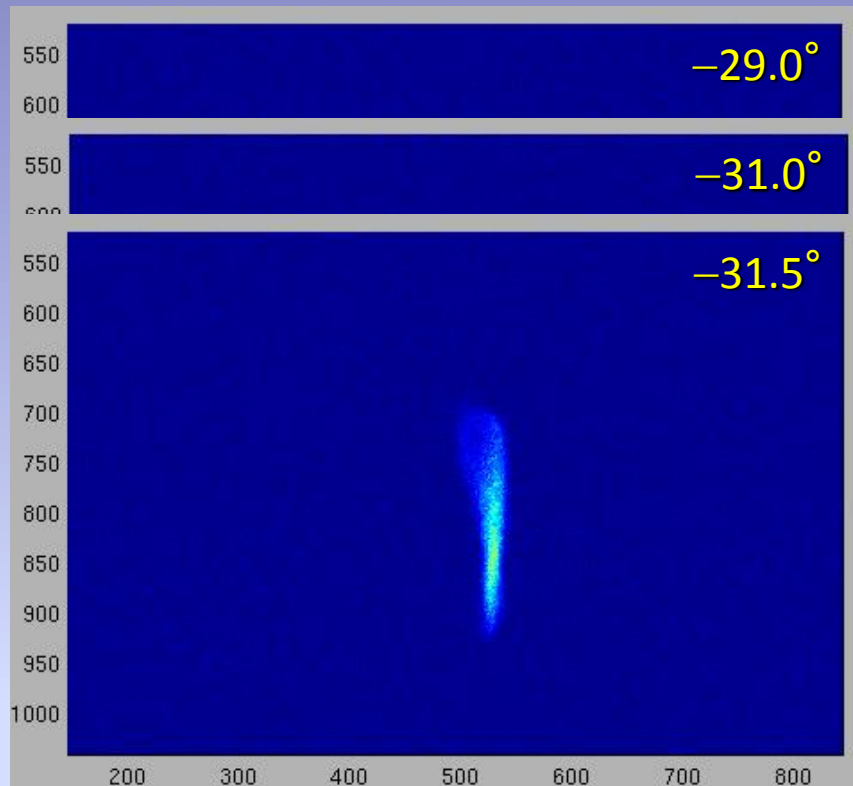
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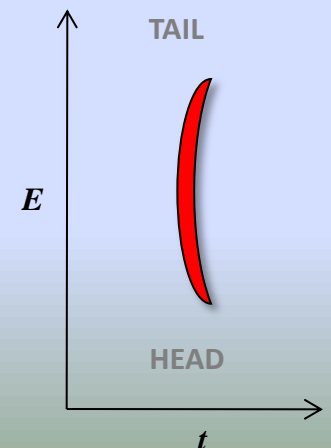
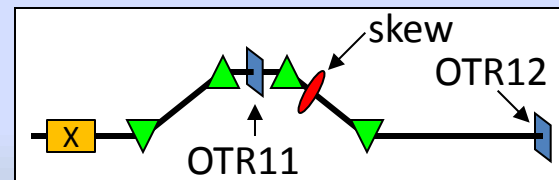
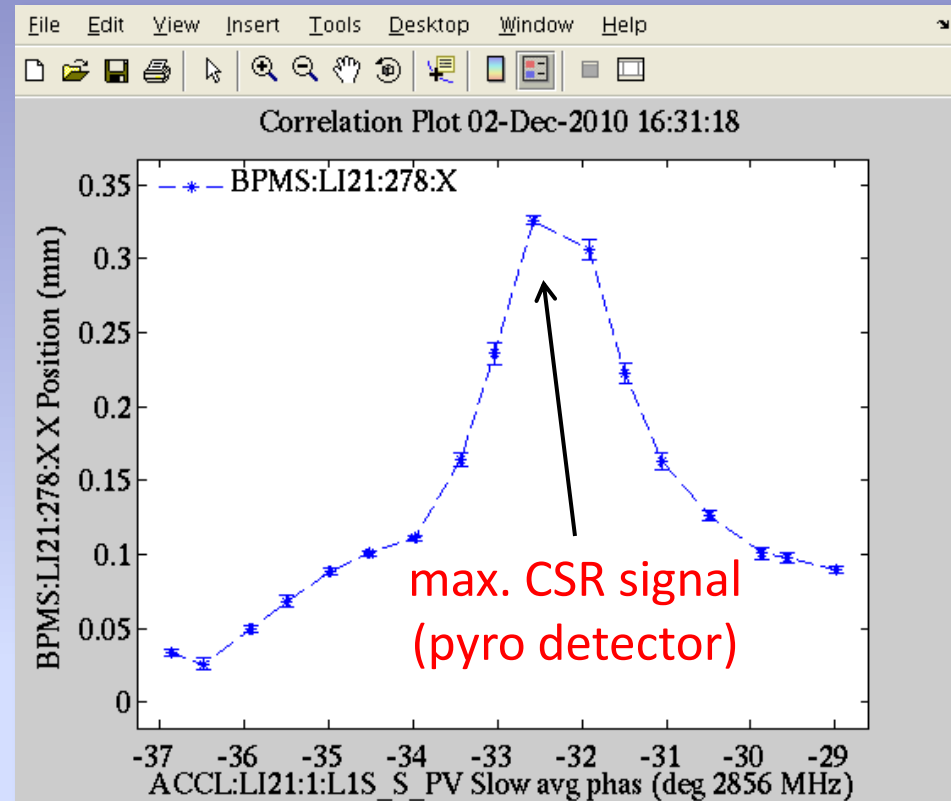
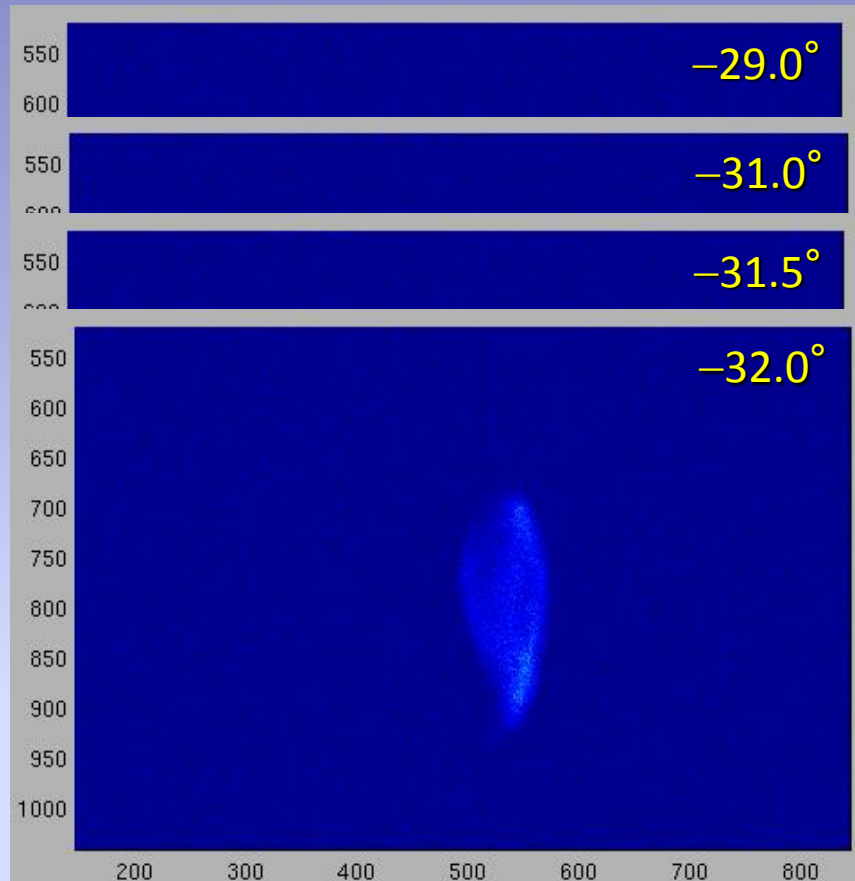
Scan L1S phase holding BC1 energy constant

L1X Voltage = 16 MV (too weak)



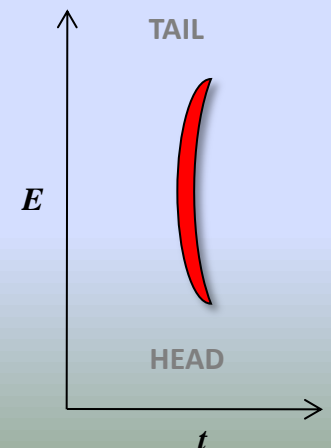
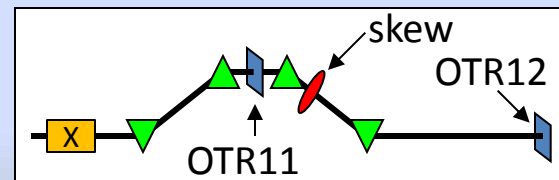
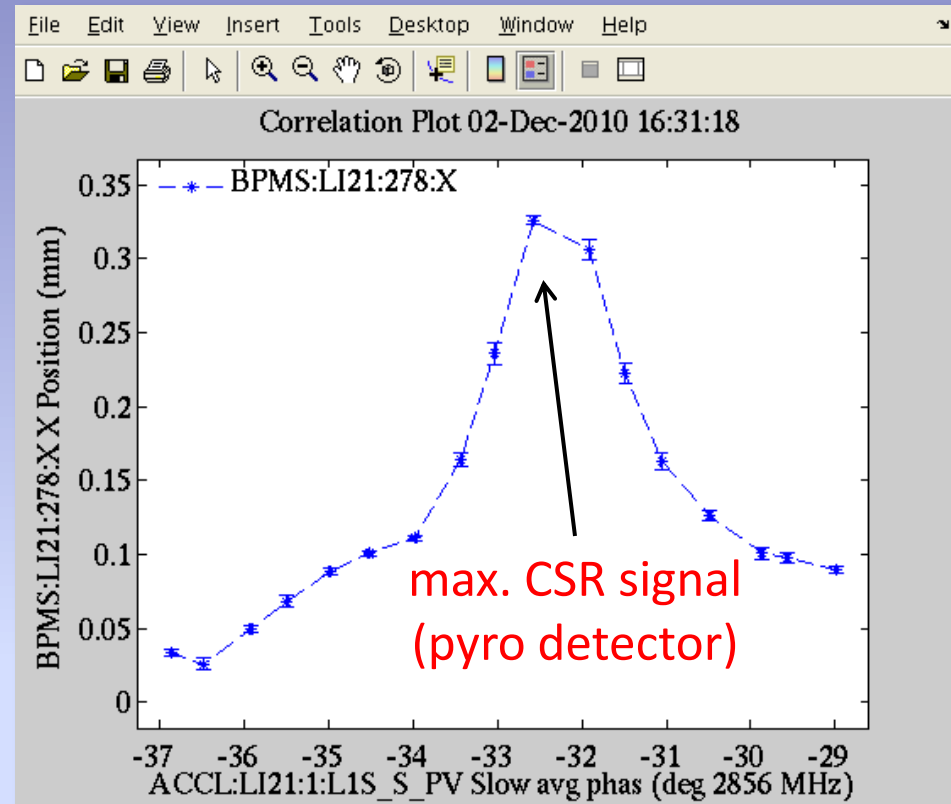
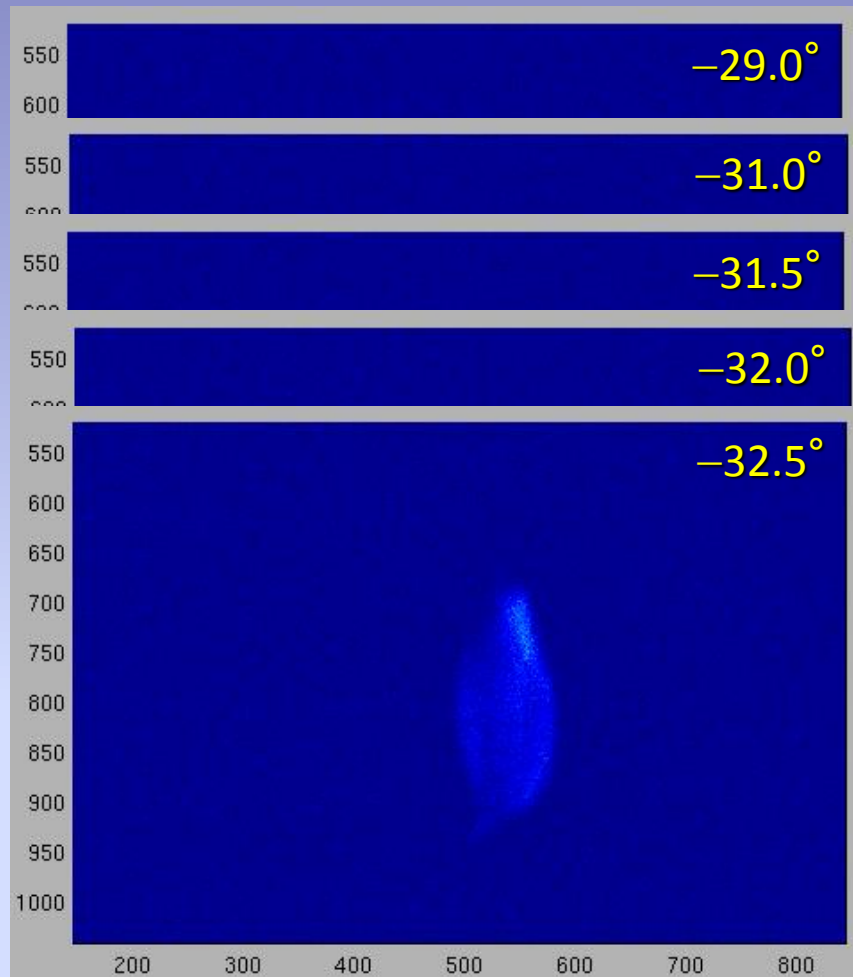
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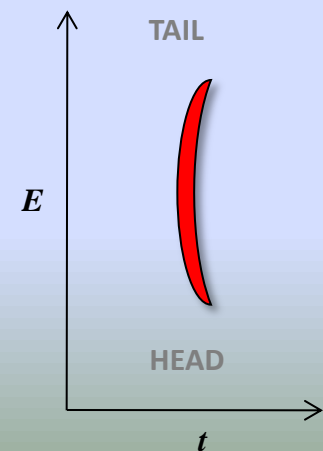
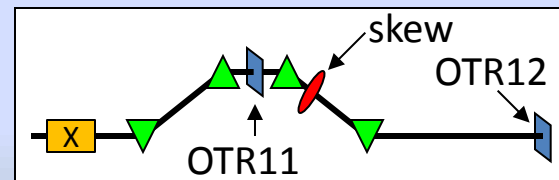
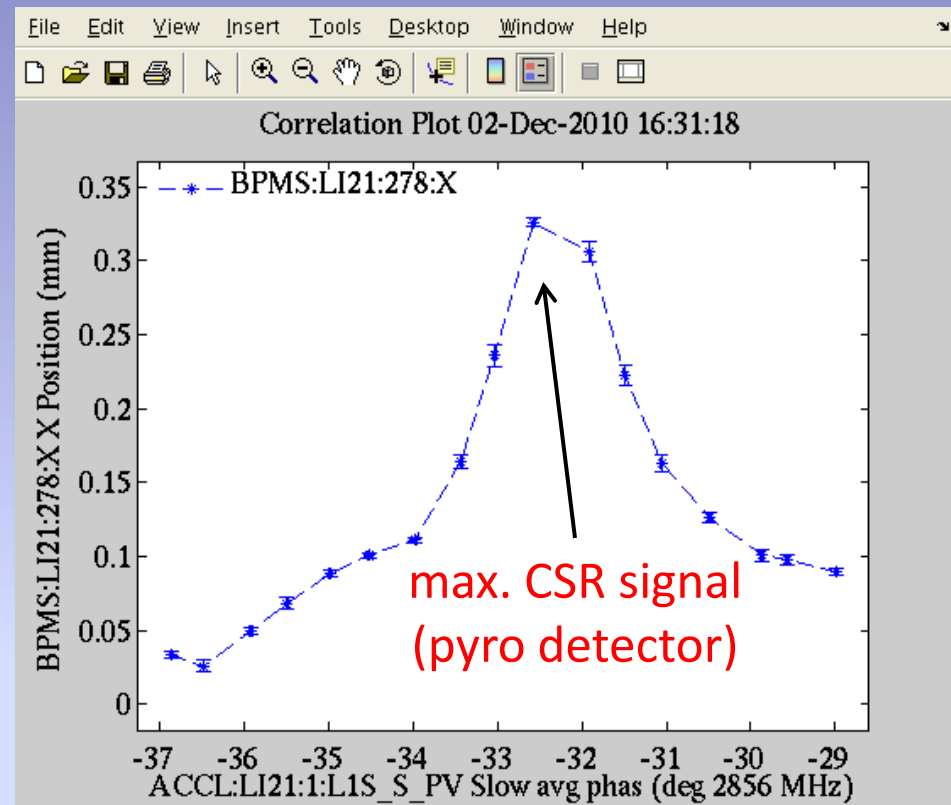
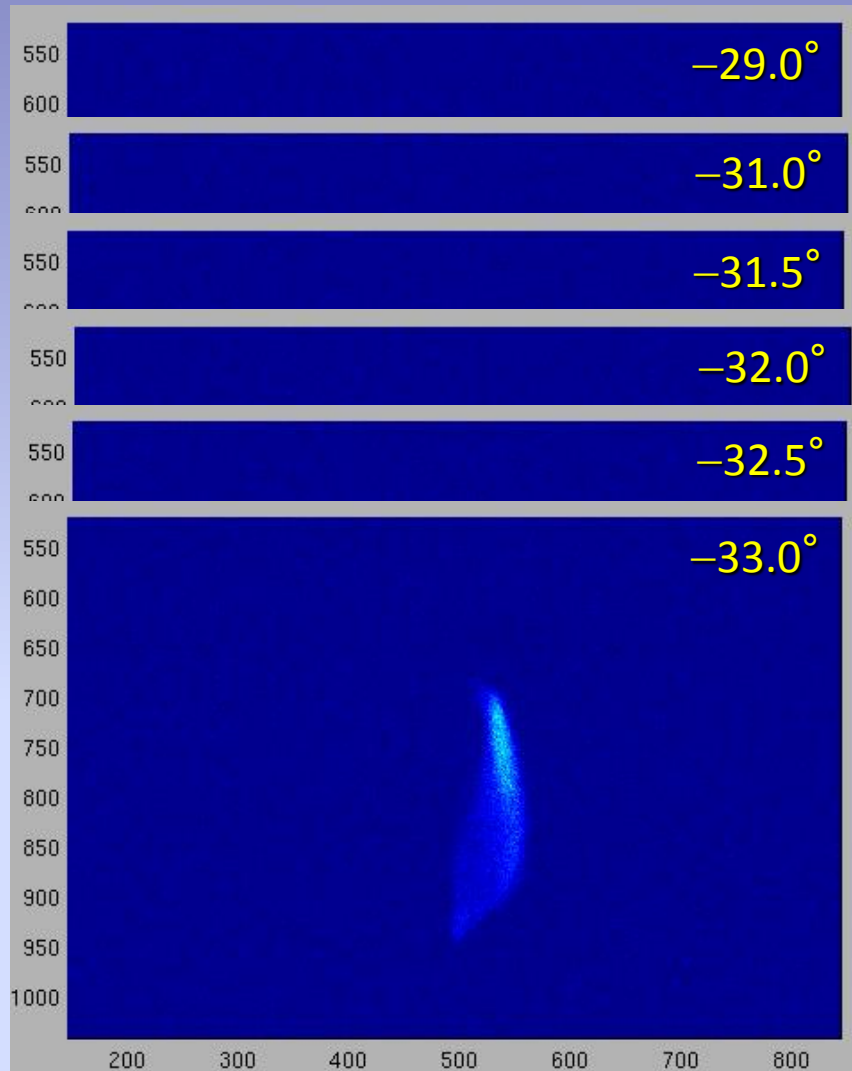
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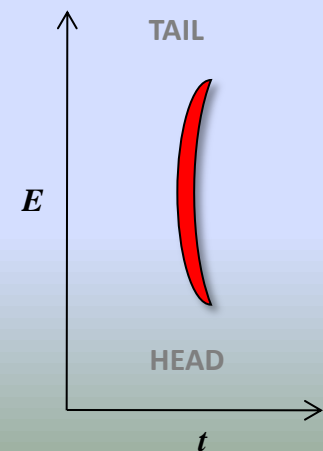
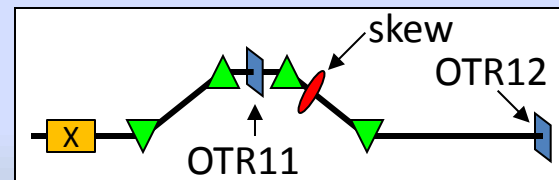
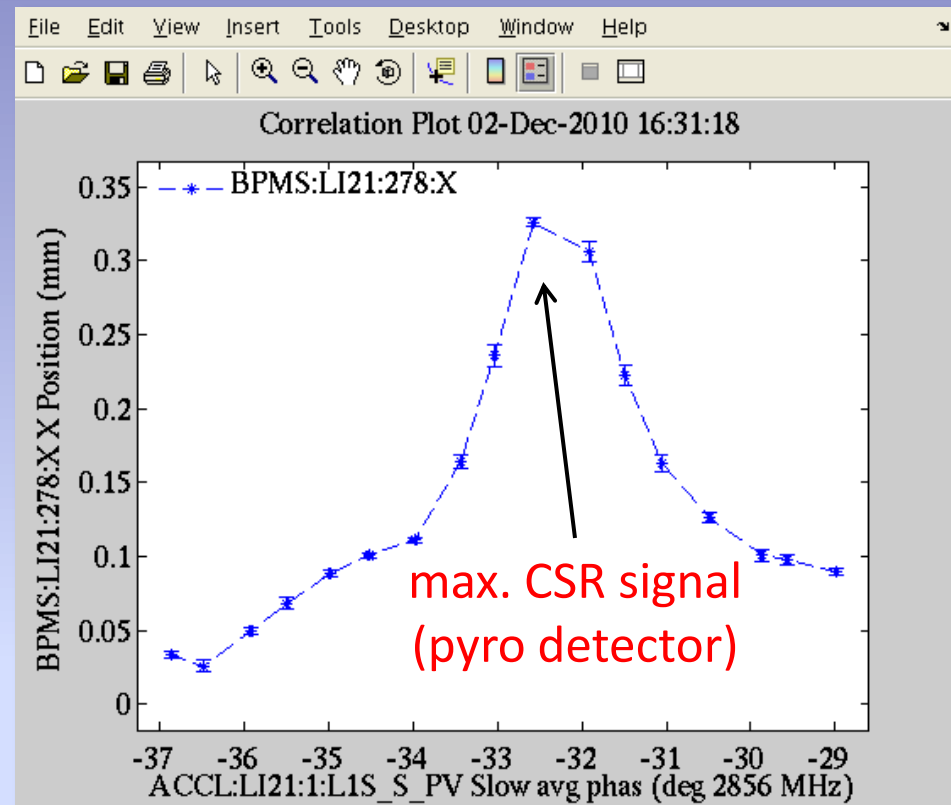
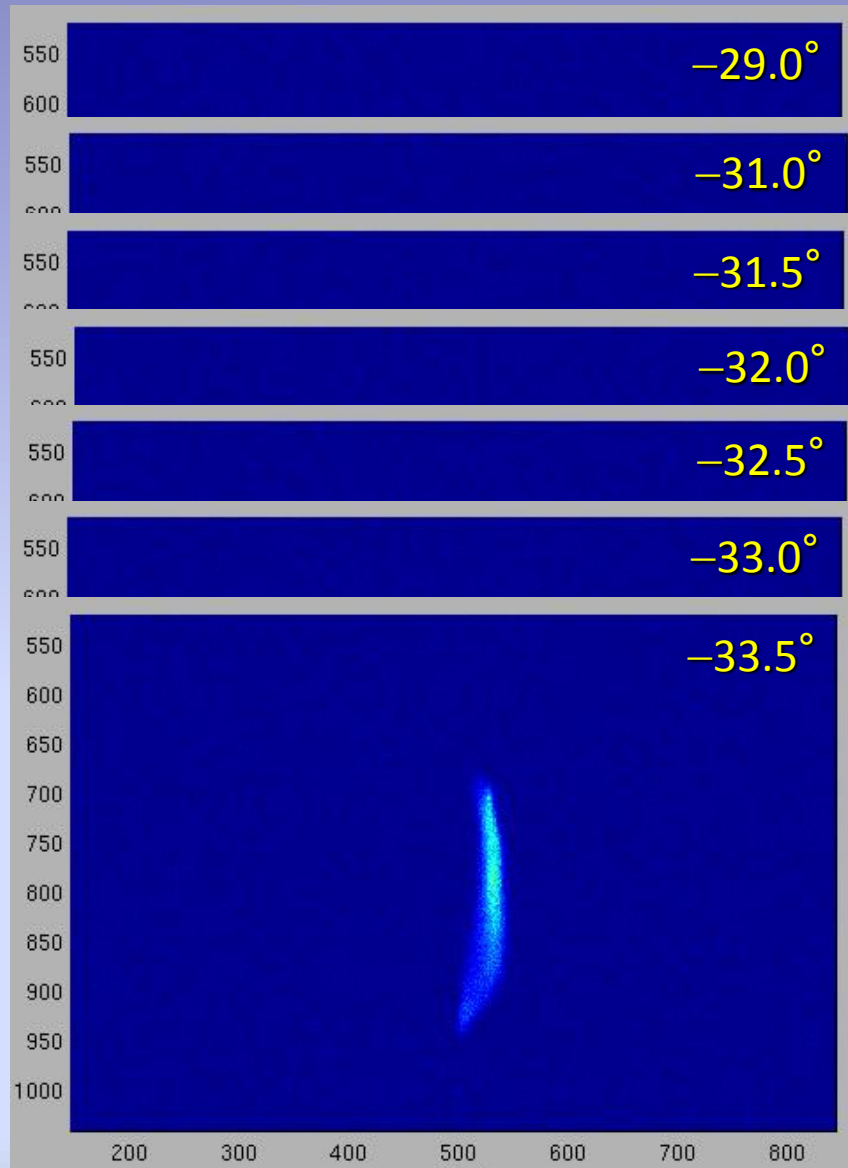
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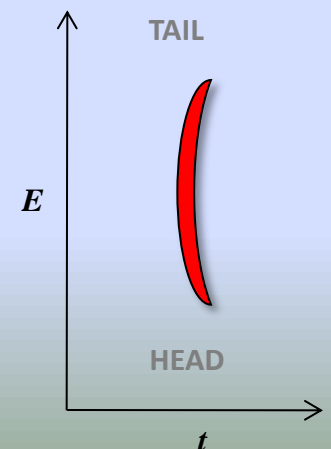
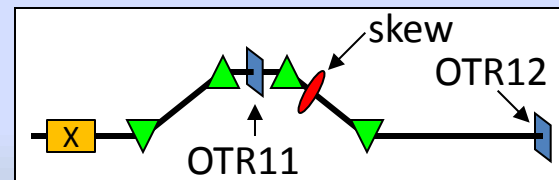
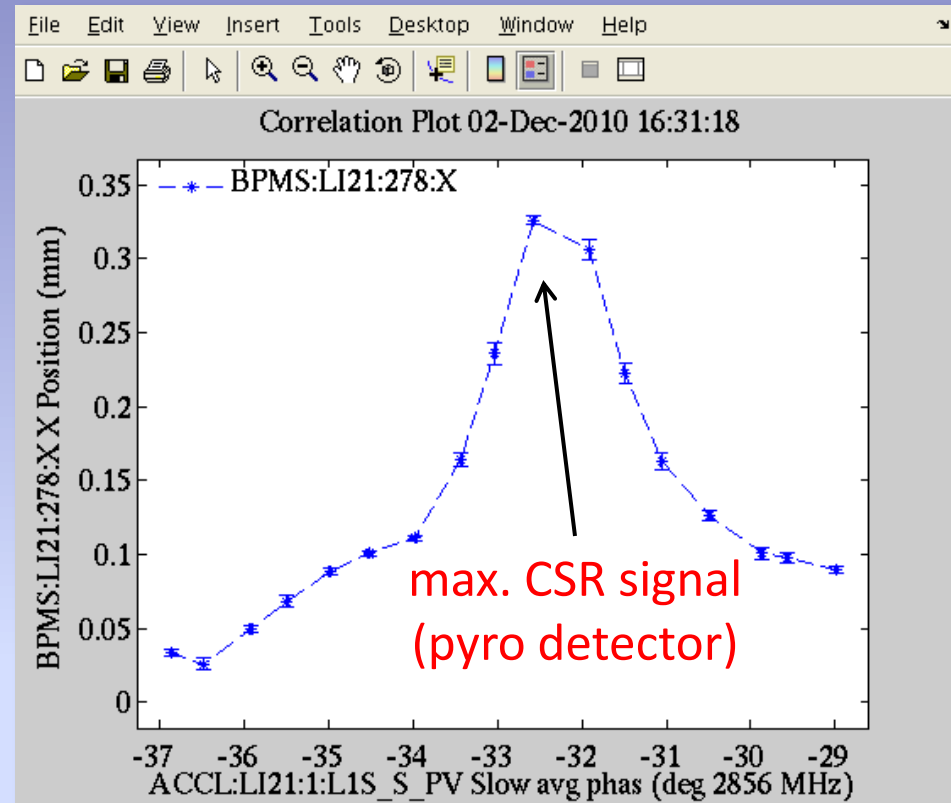
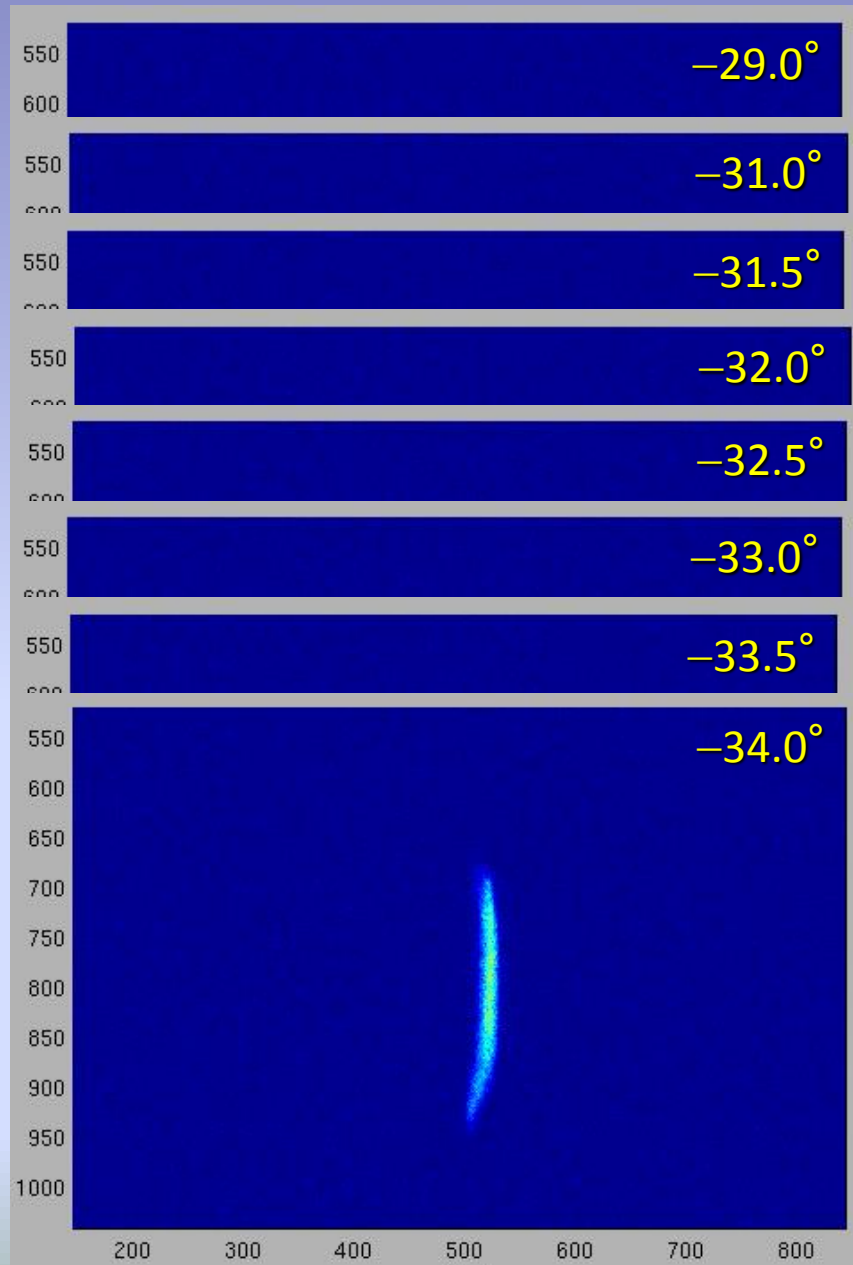
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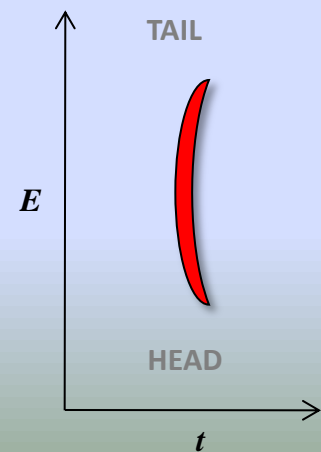
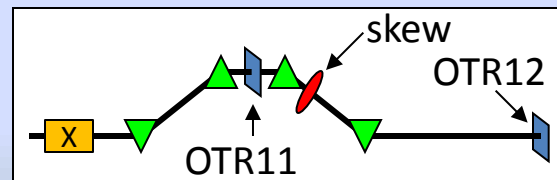
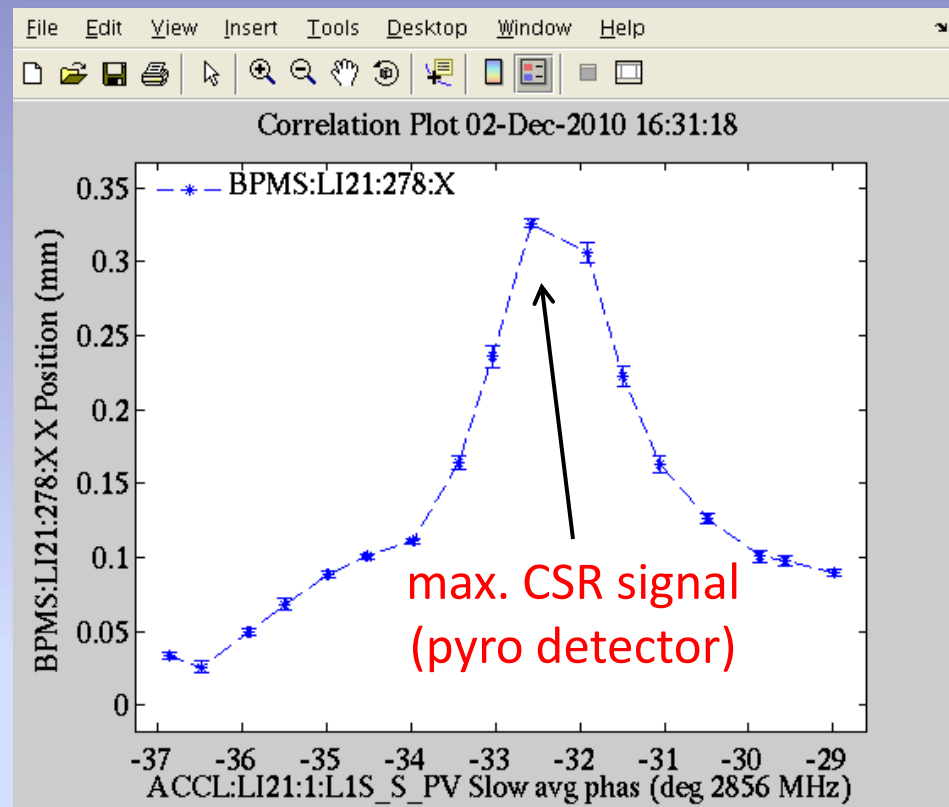
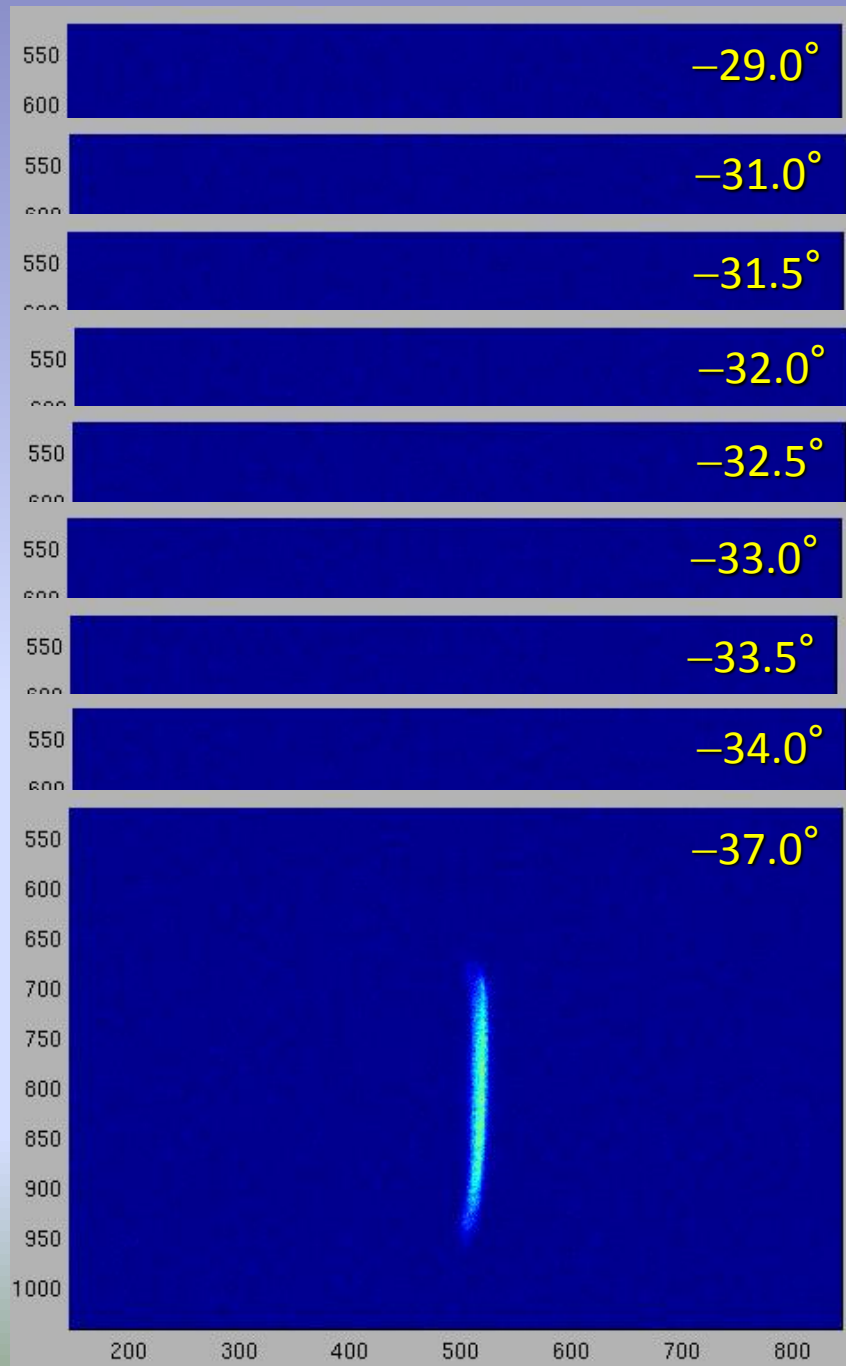
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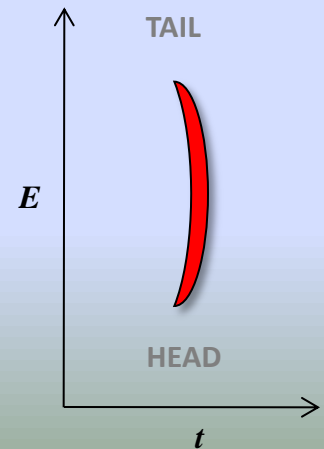
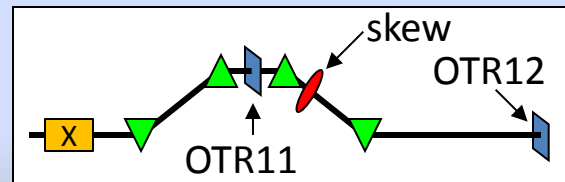
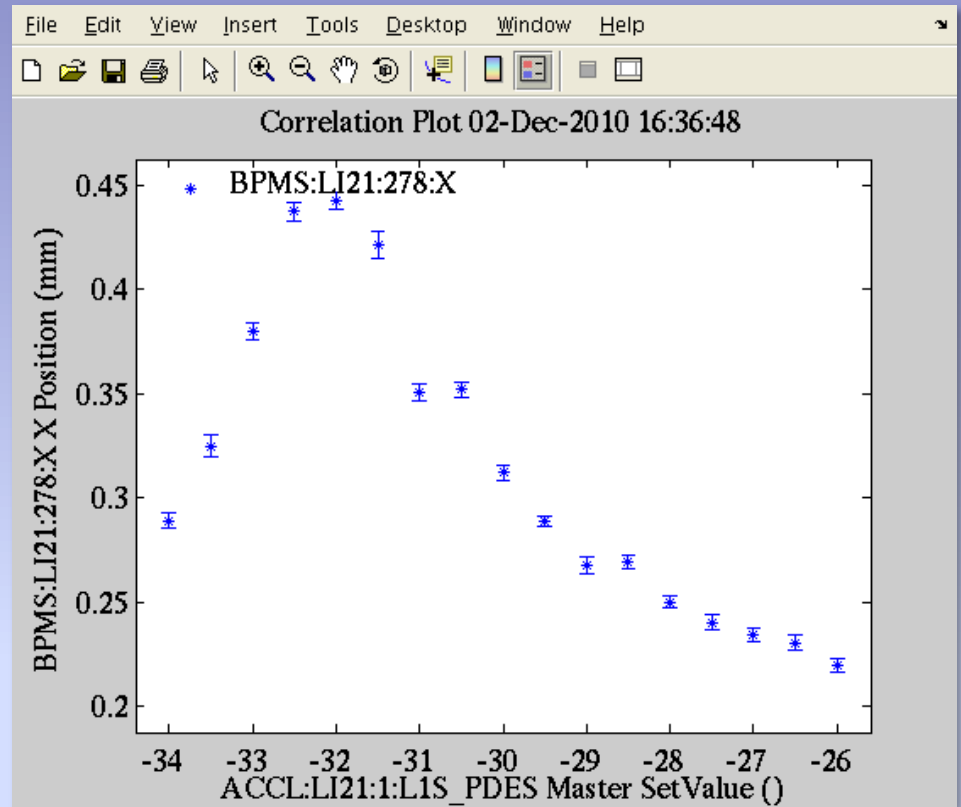
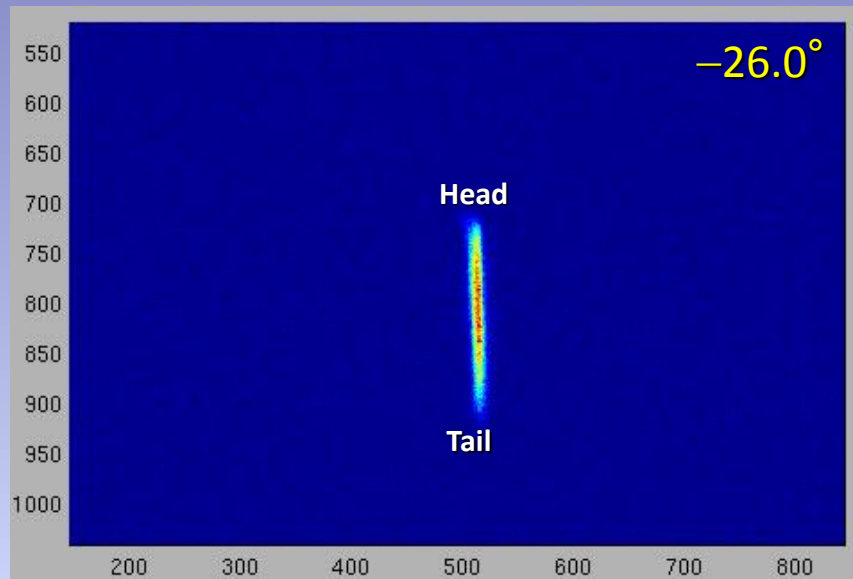
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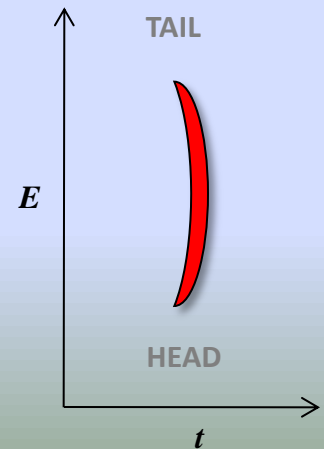
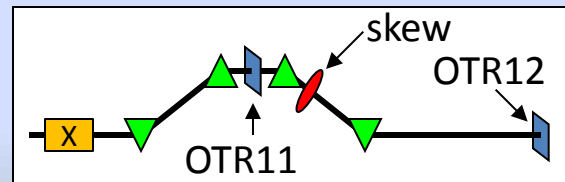
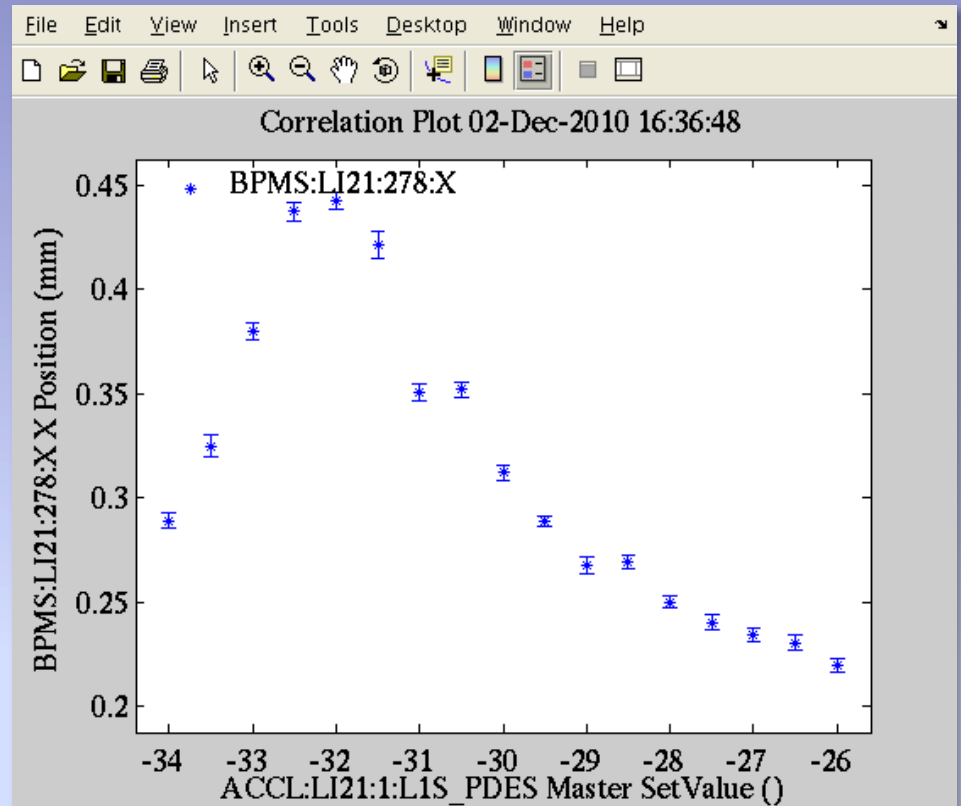
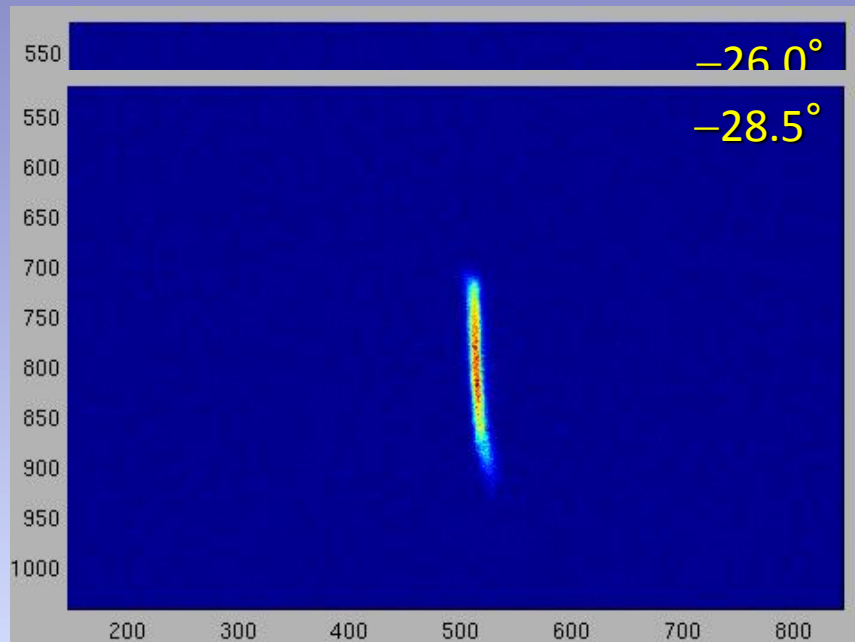




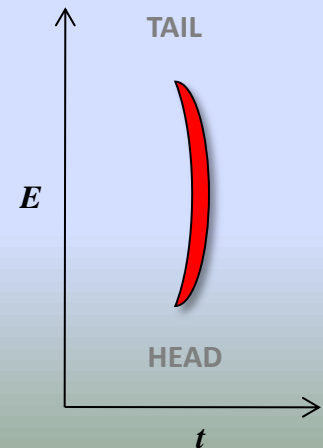
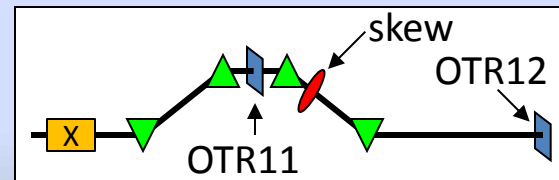
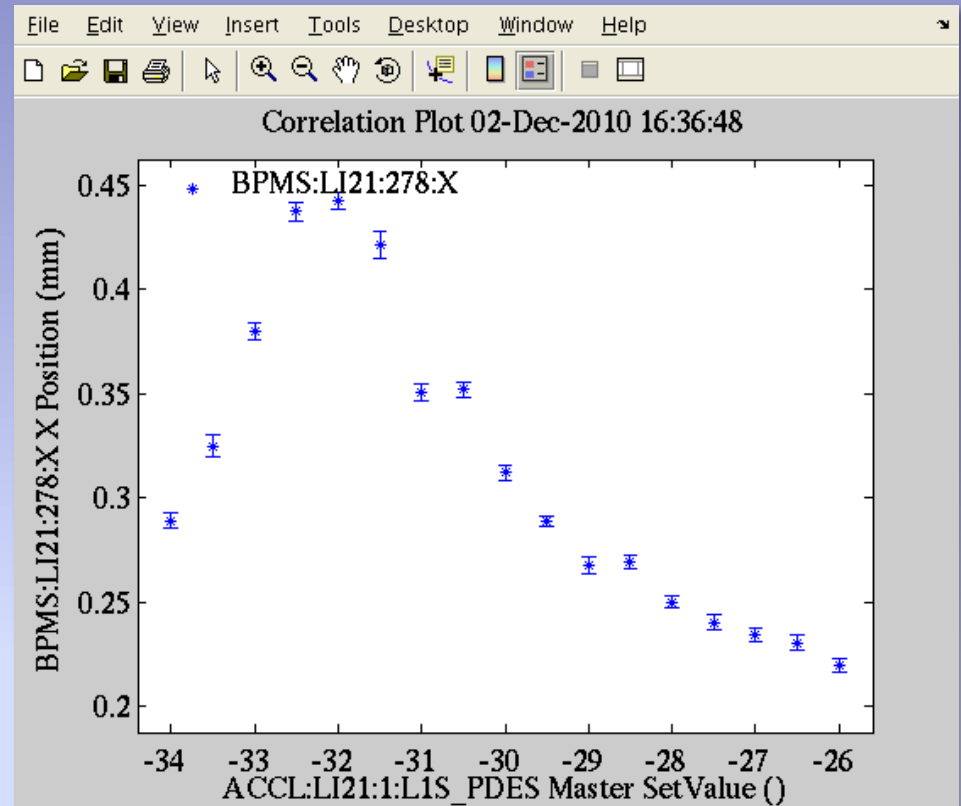
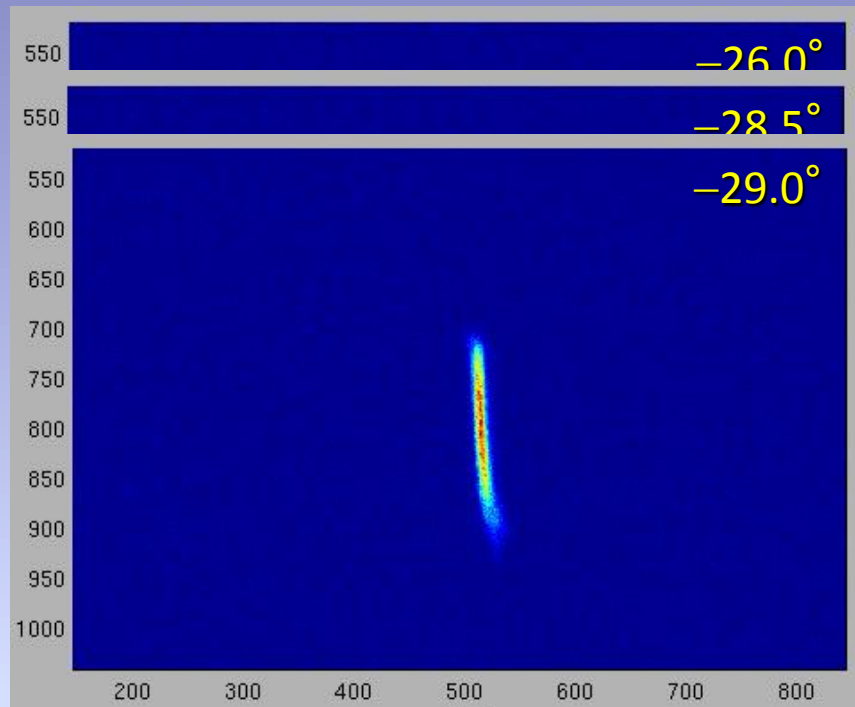
# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



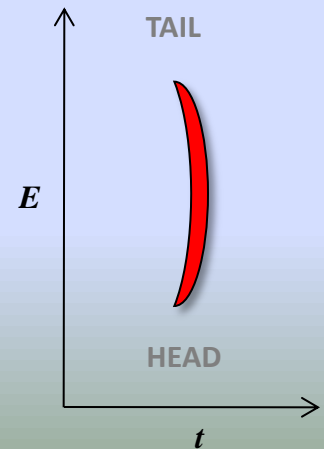
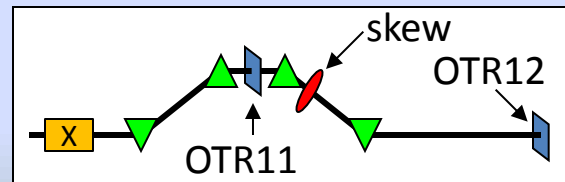
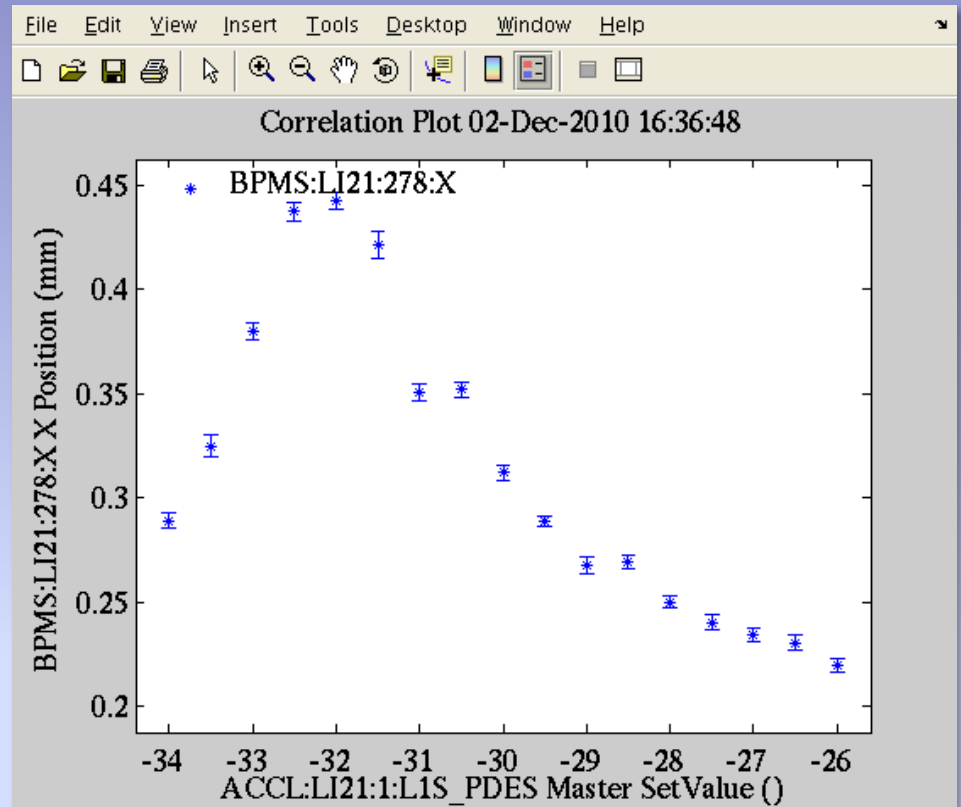
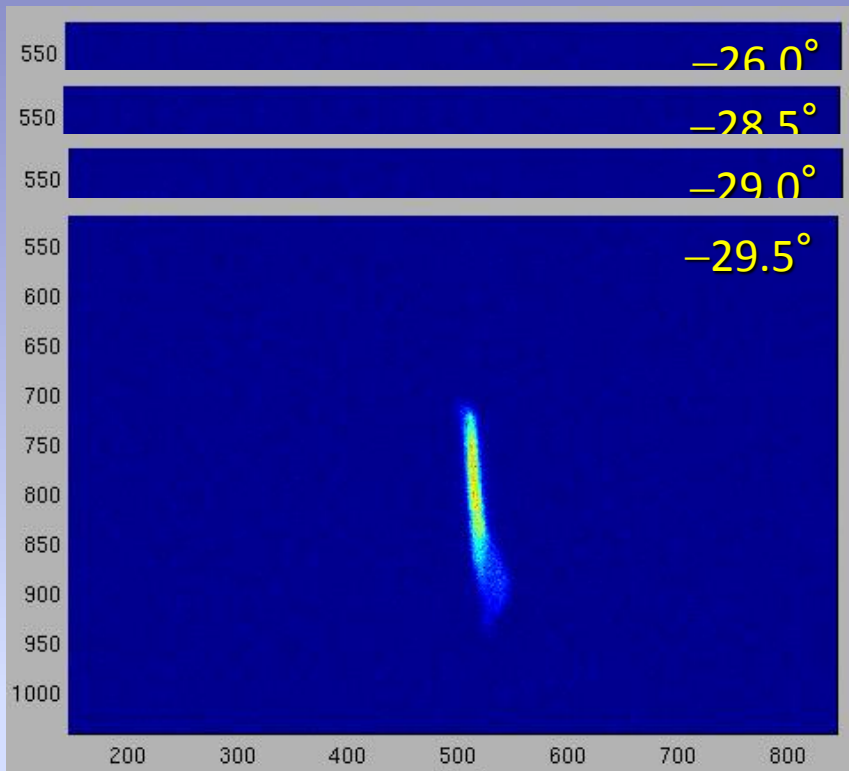
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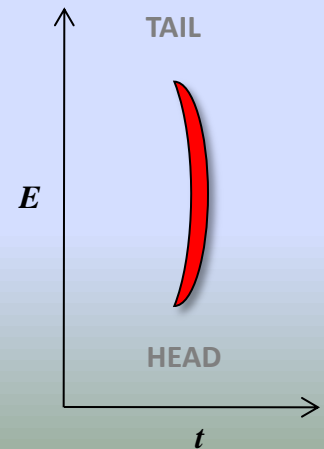
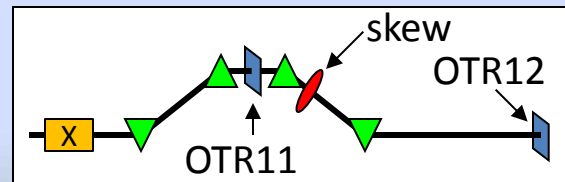
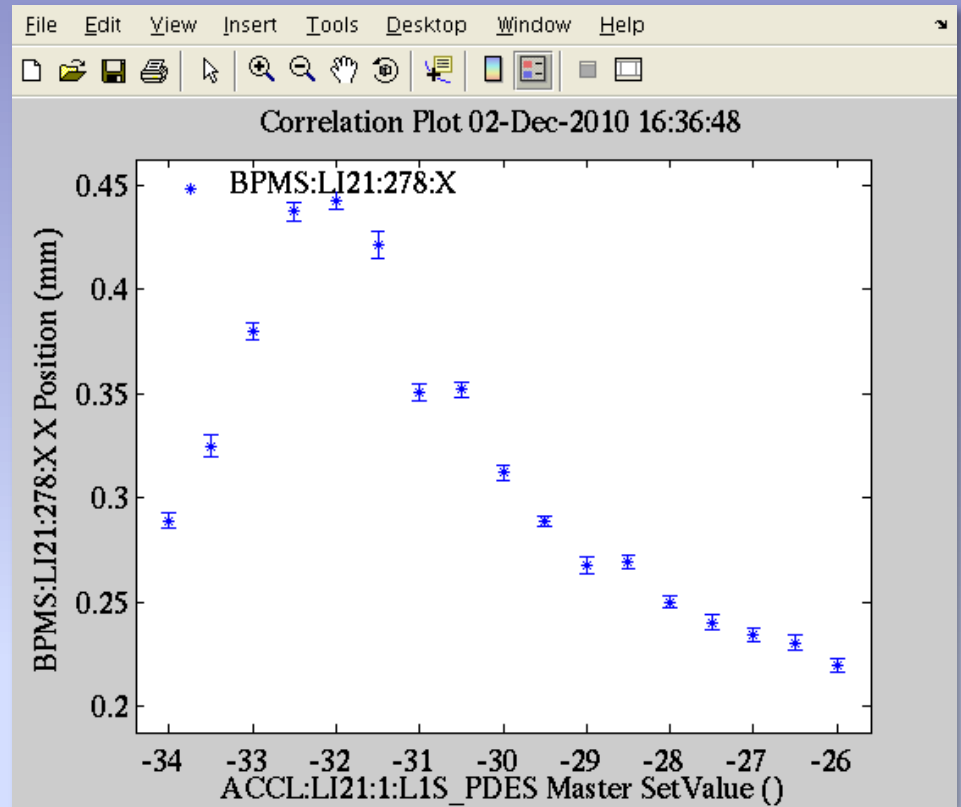
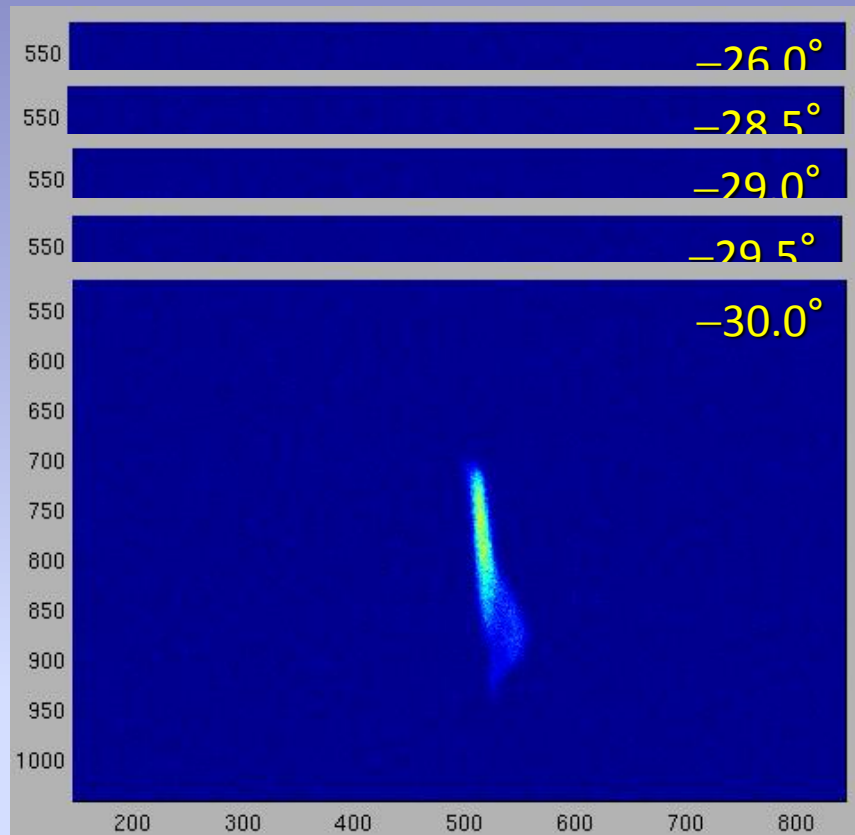
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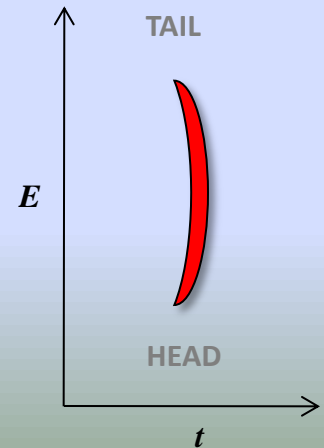
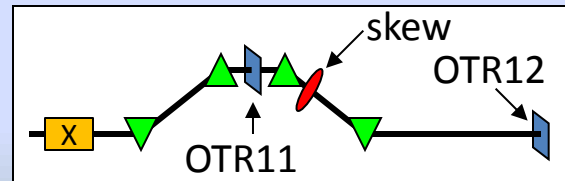
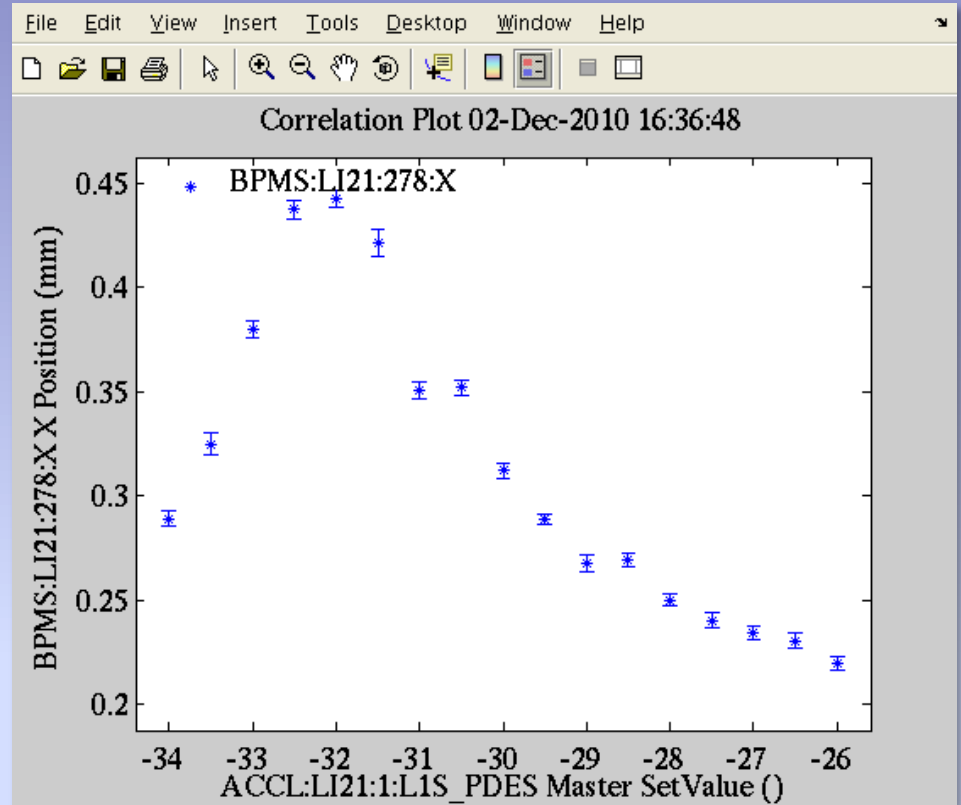
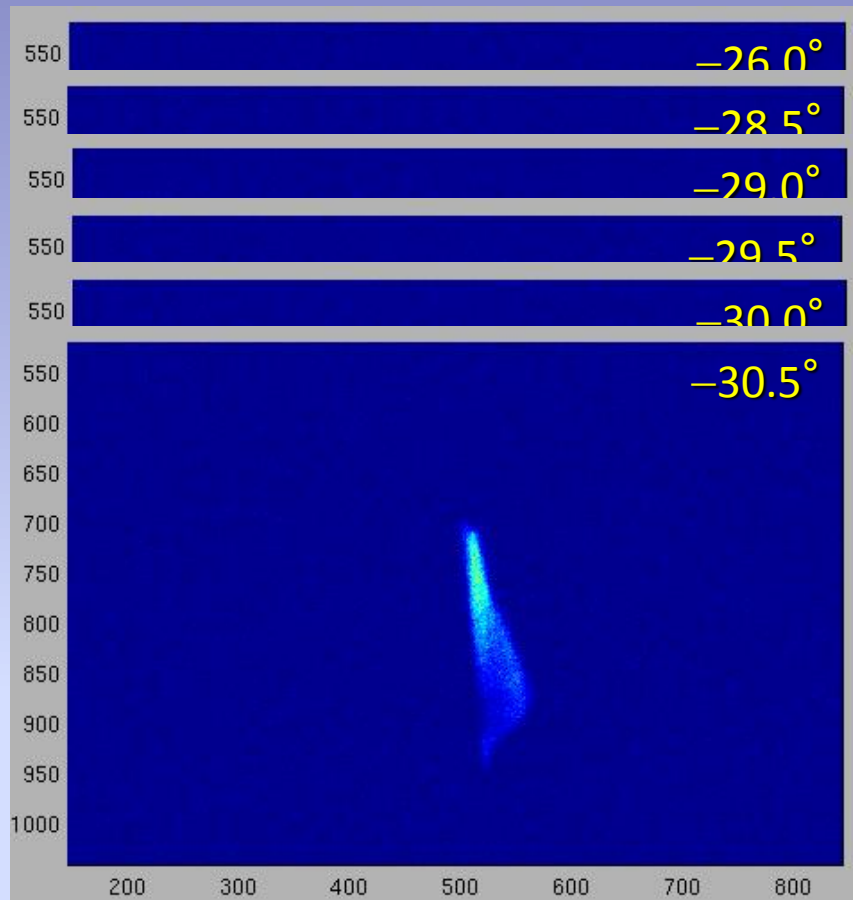
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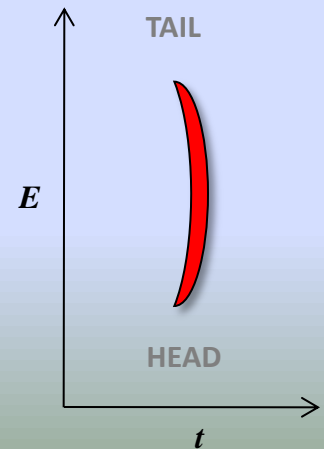
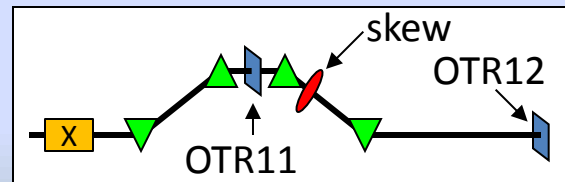
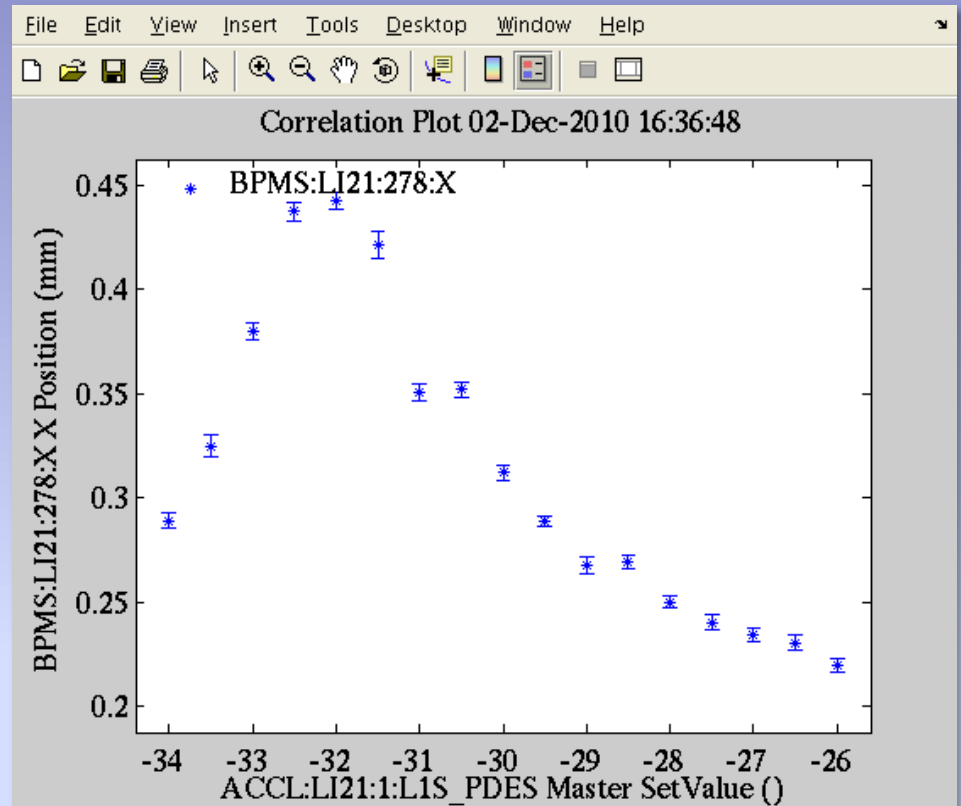
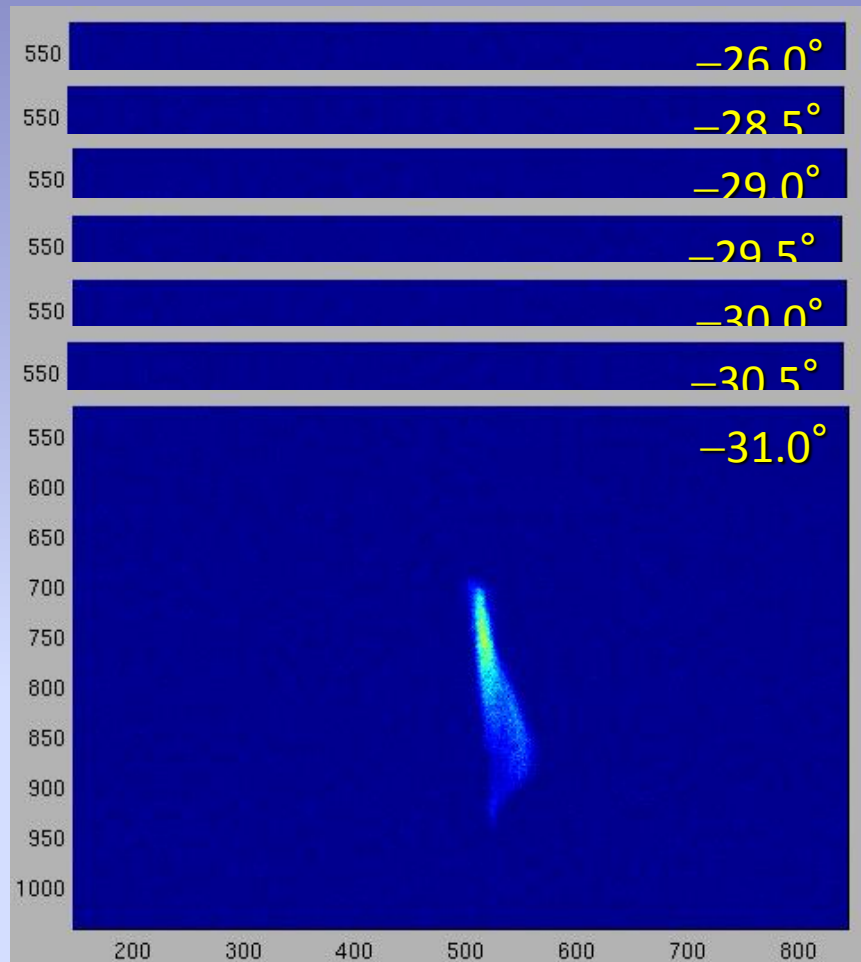
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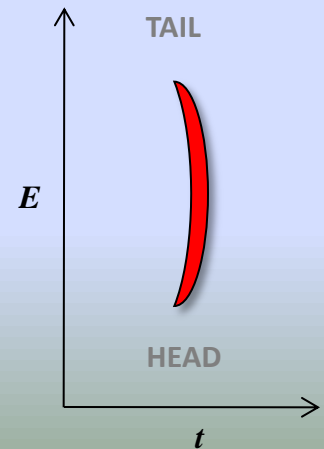
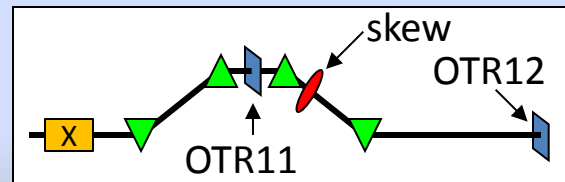
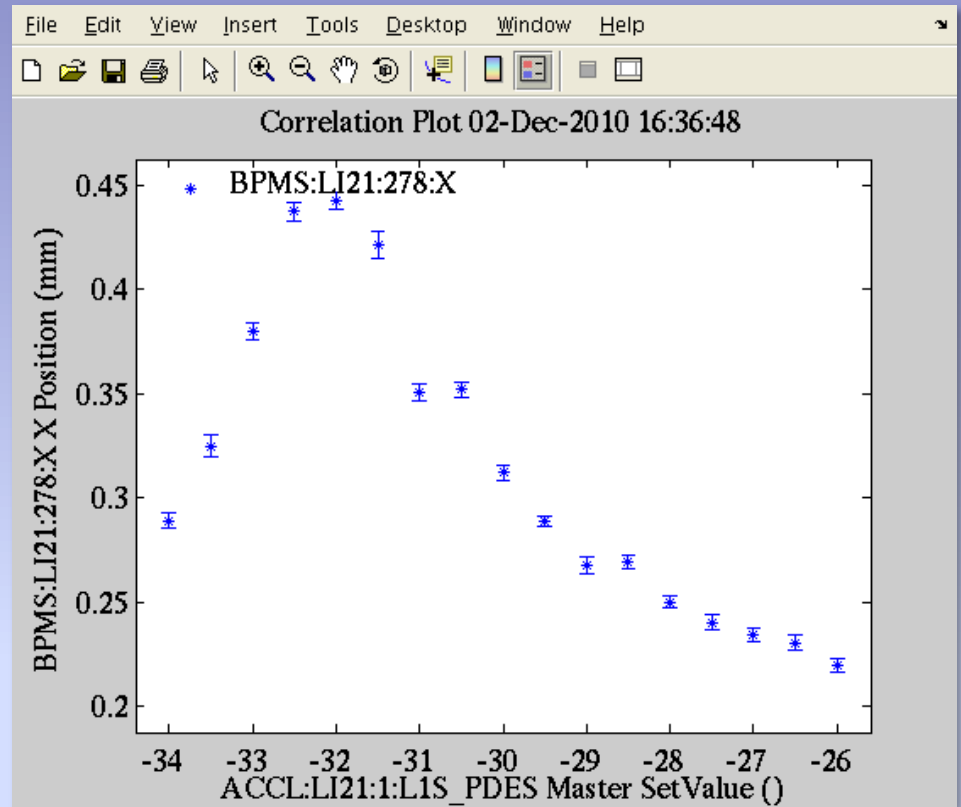
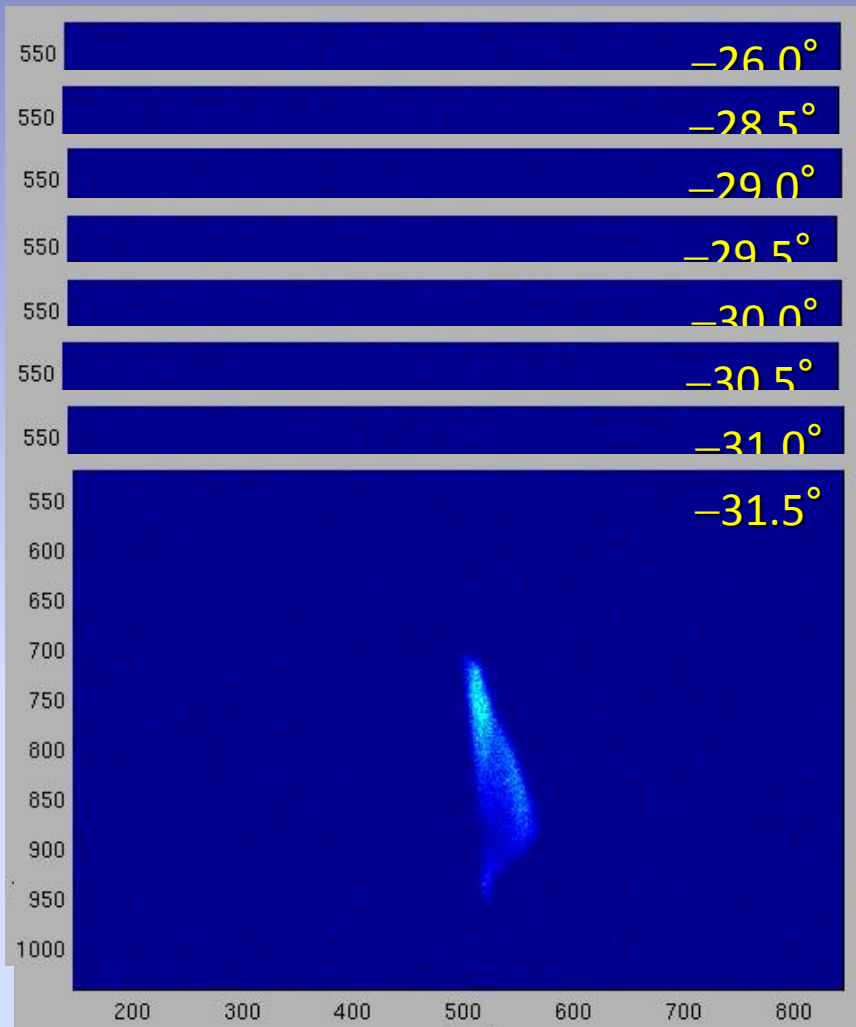


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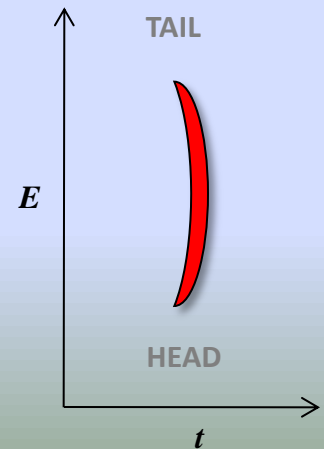
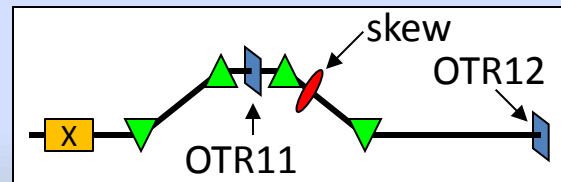
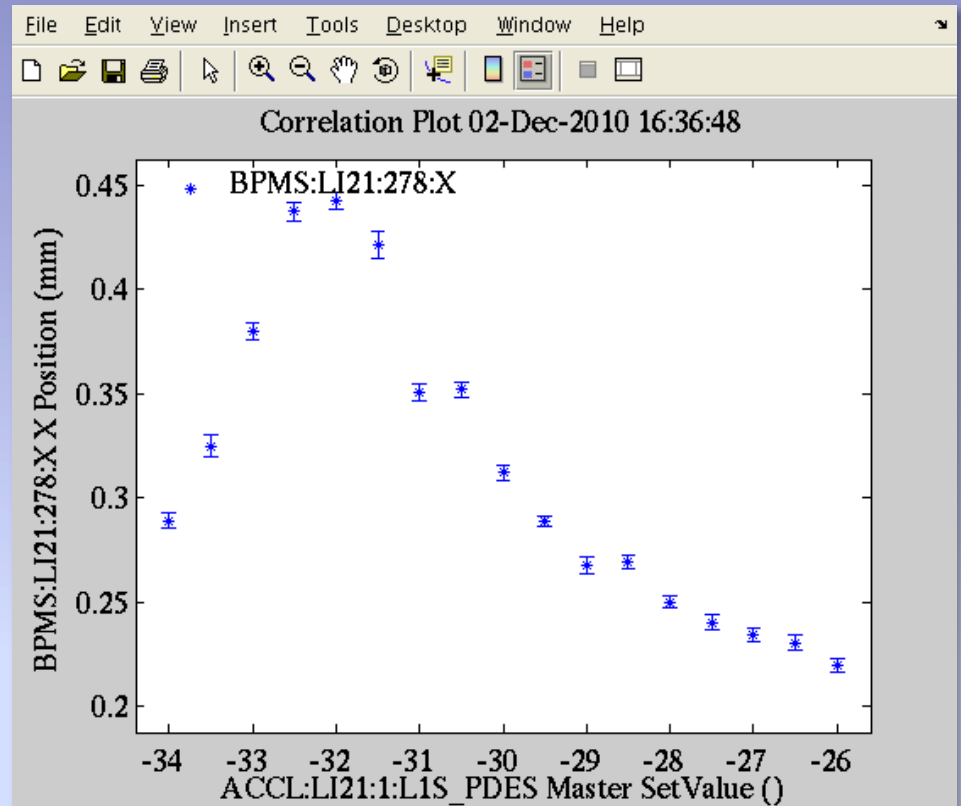
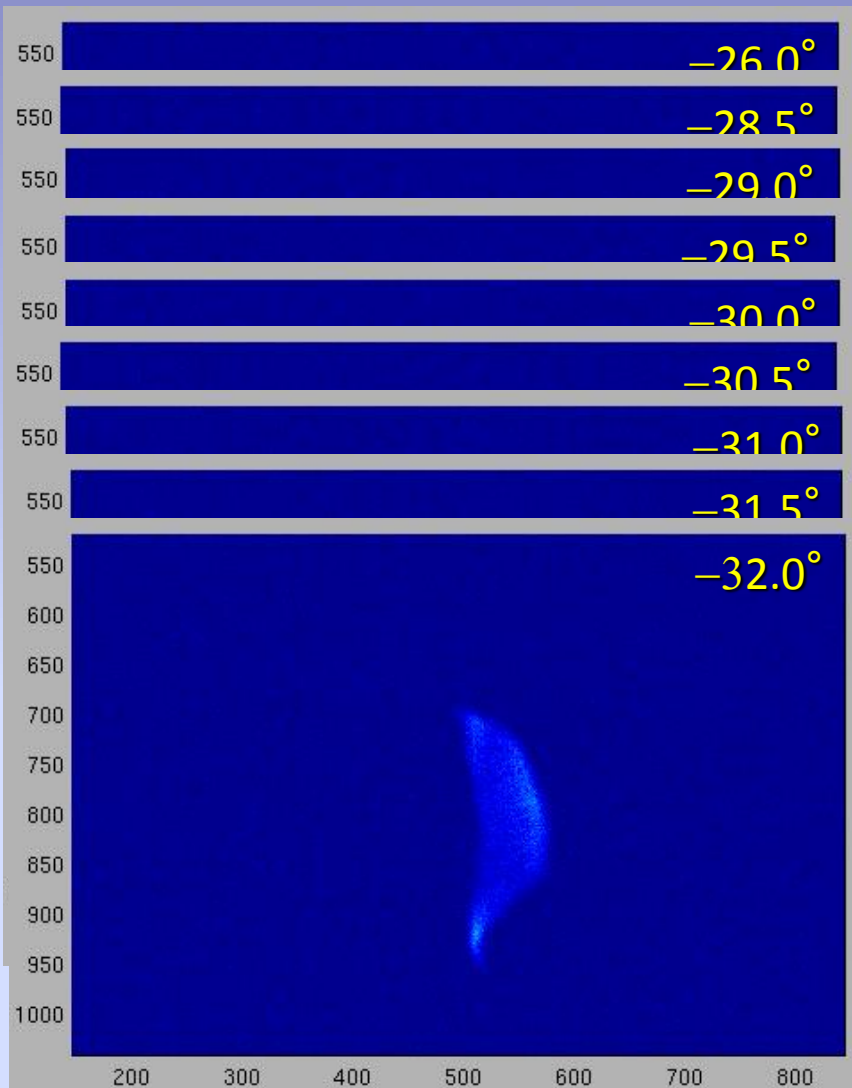




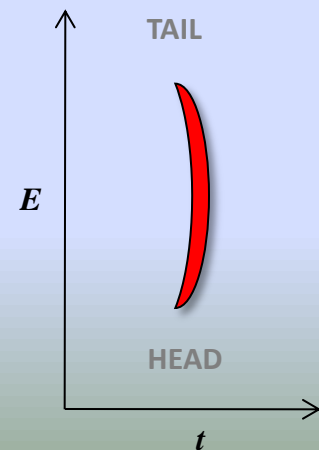
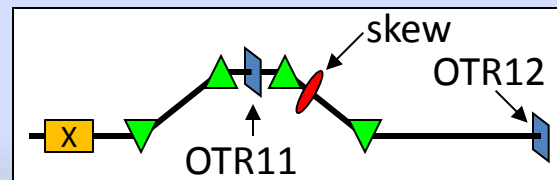
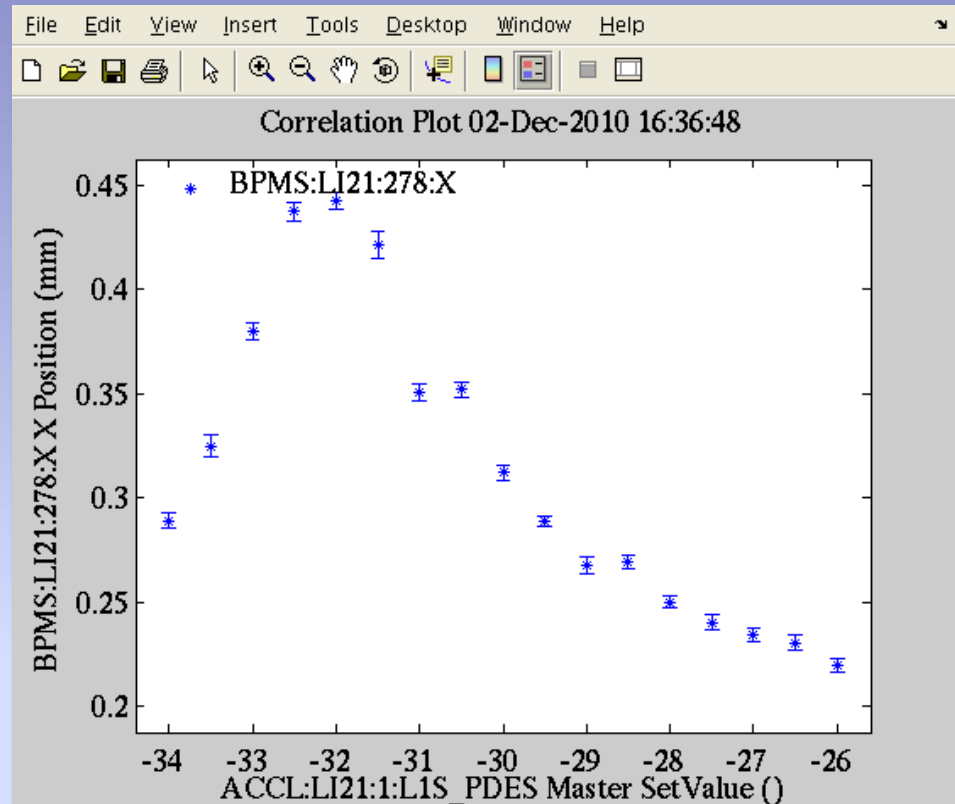
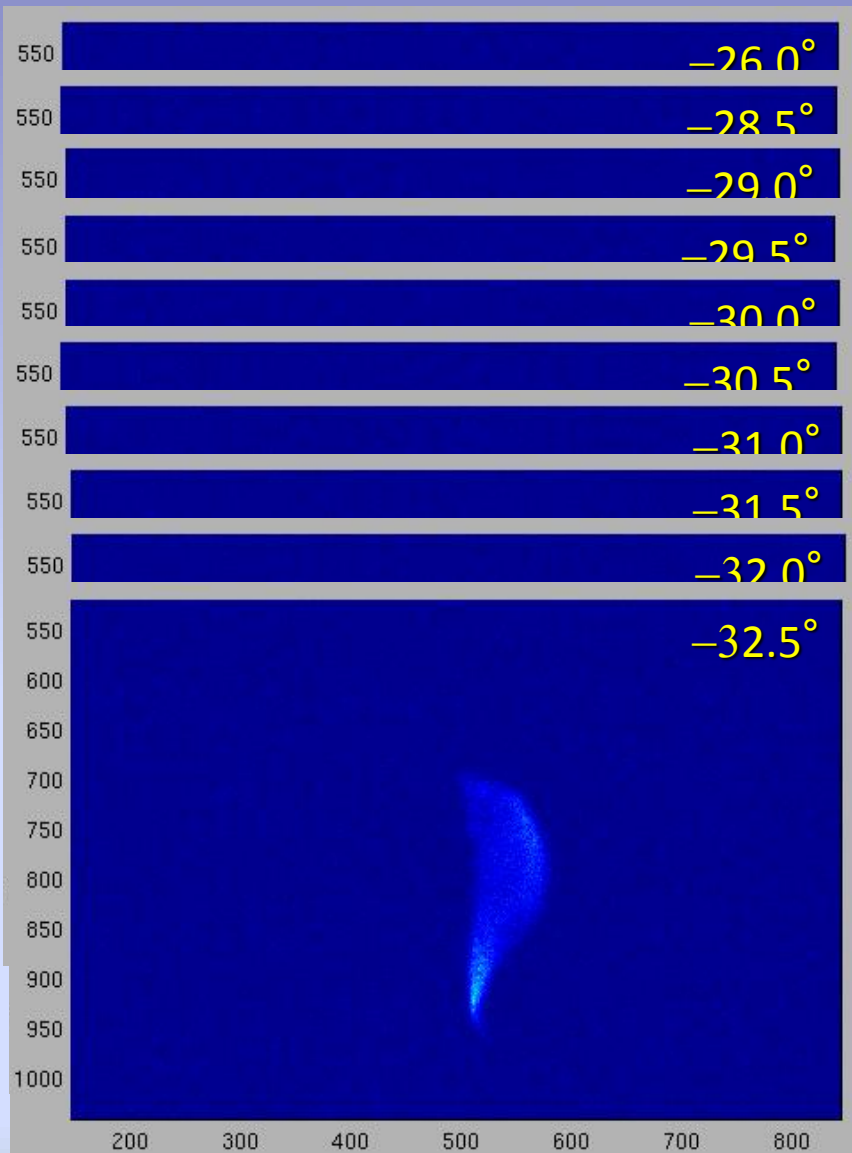
# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



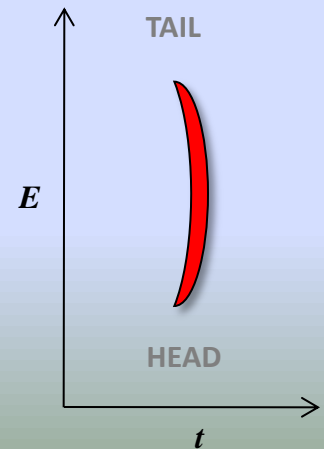
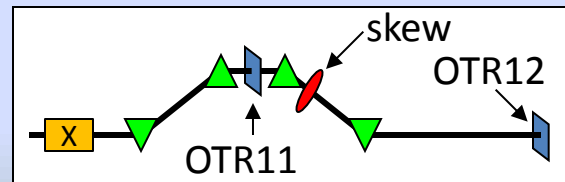
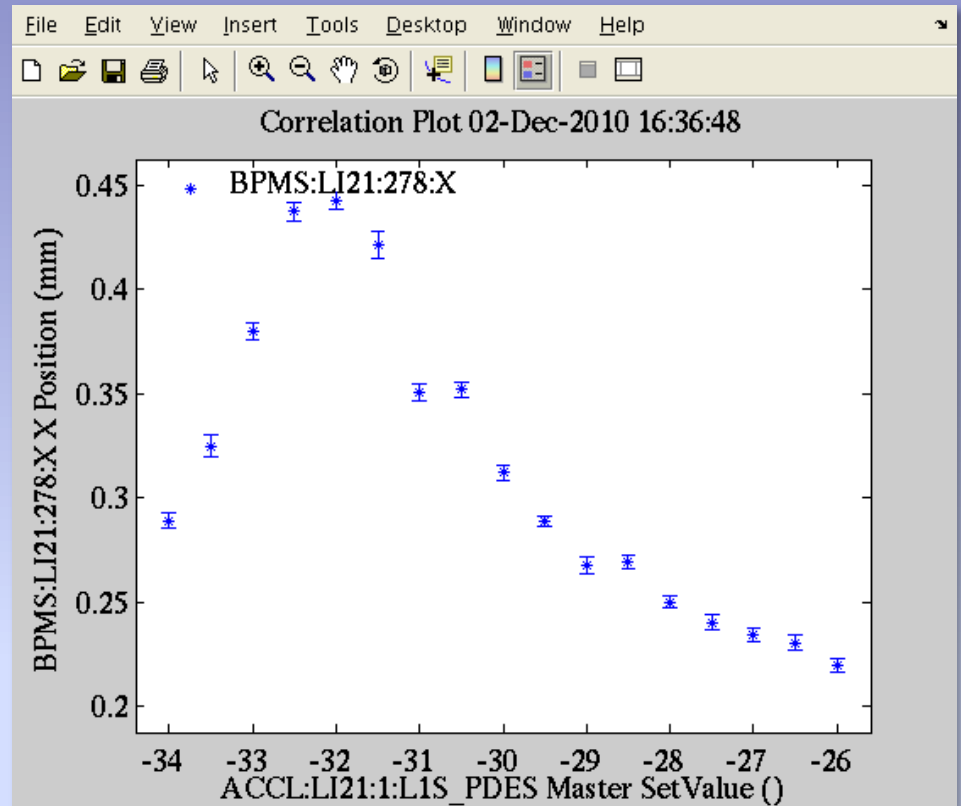
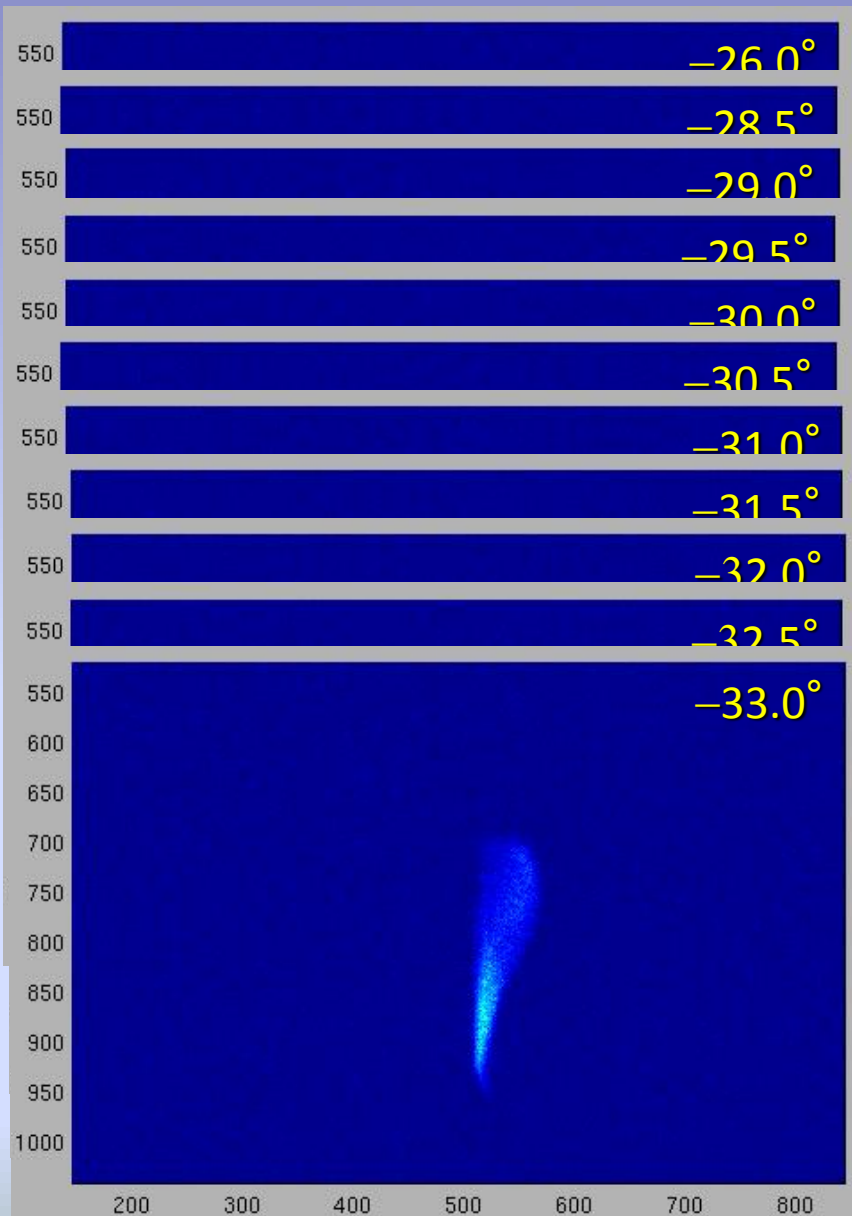
# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



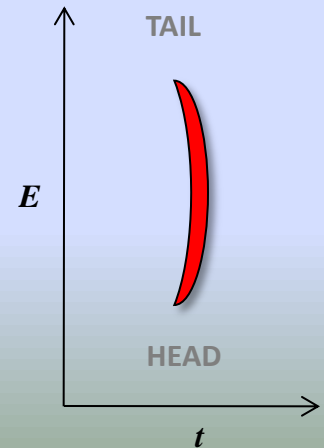
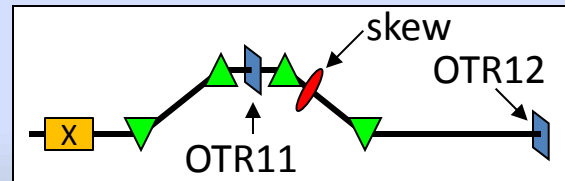
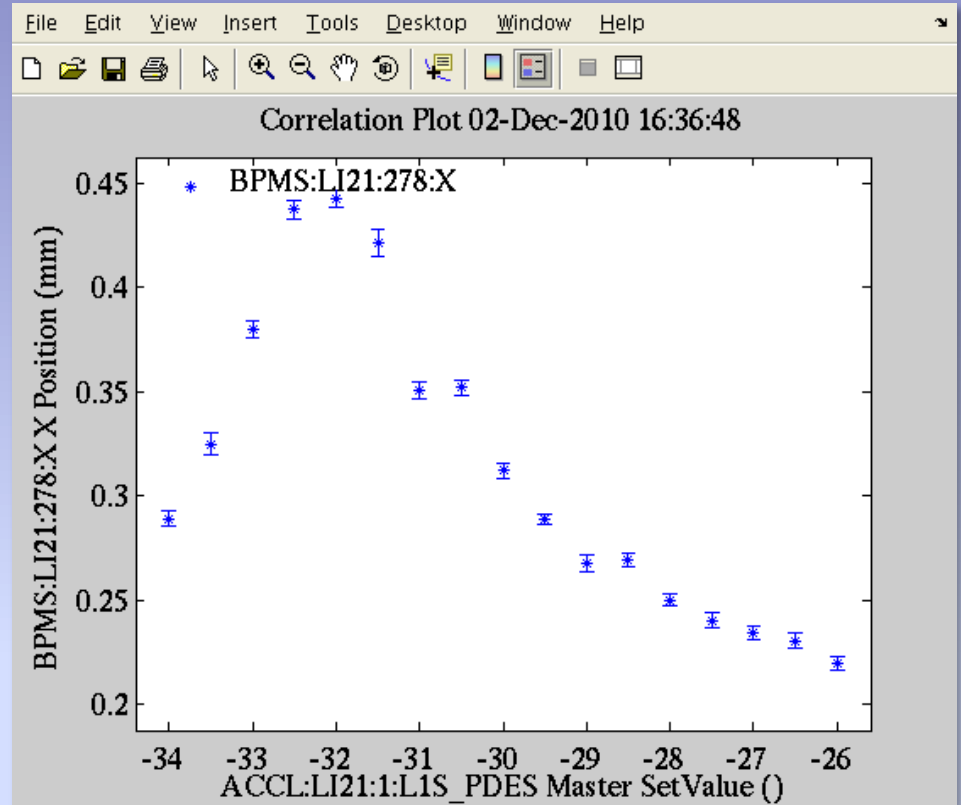
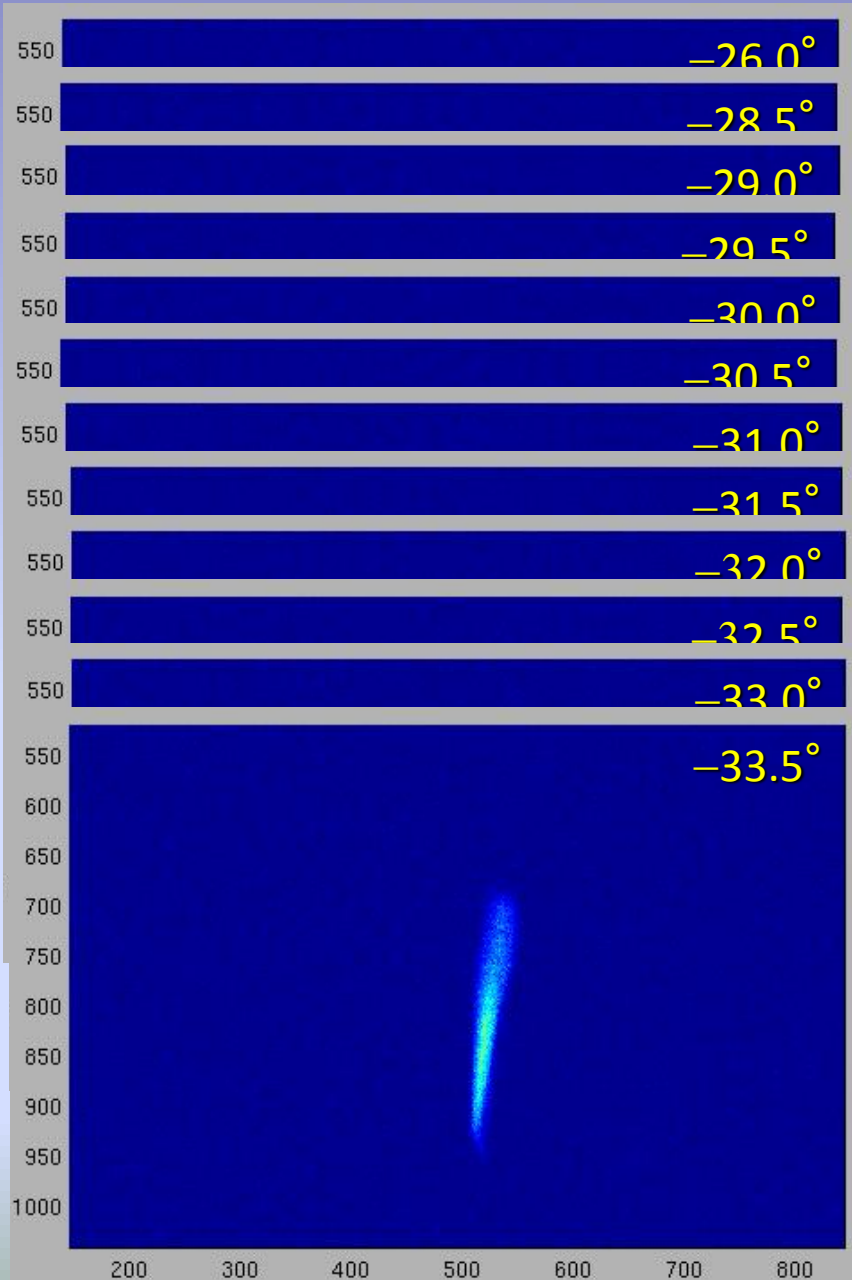
# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



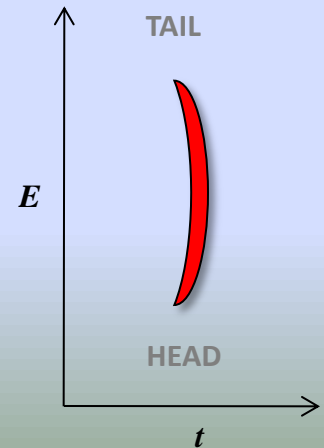
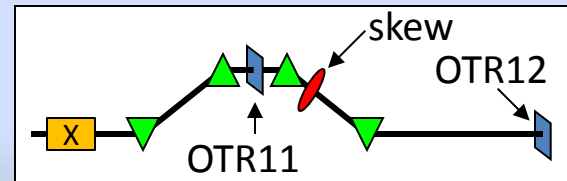
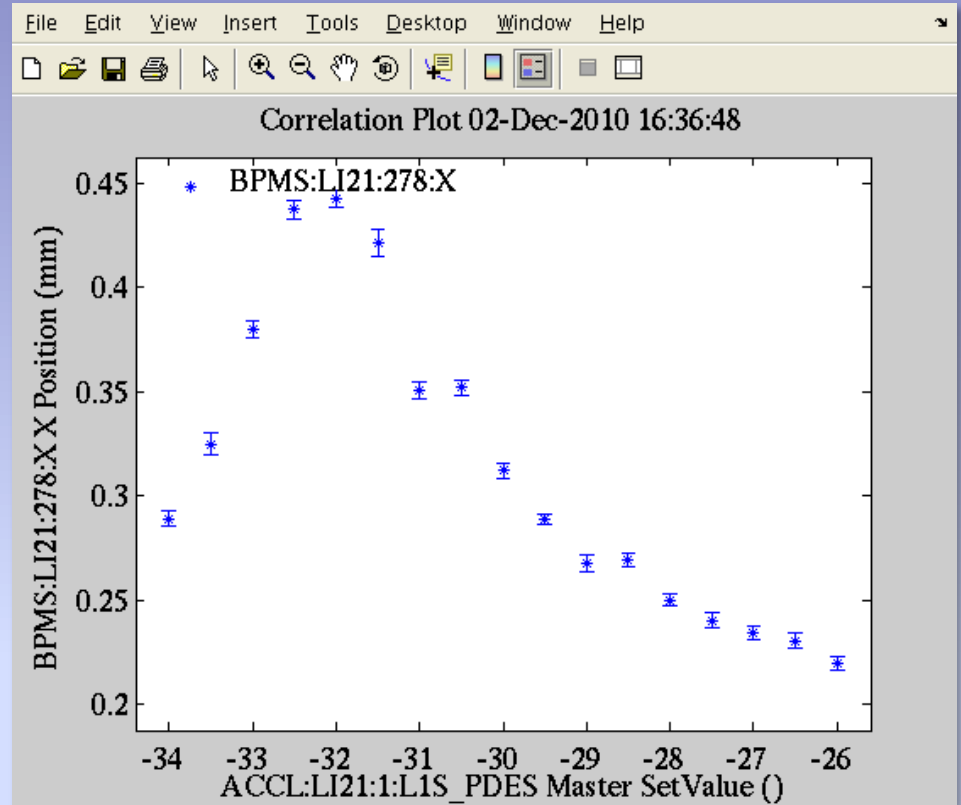
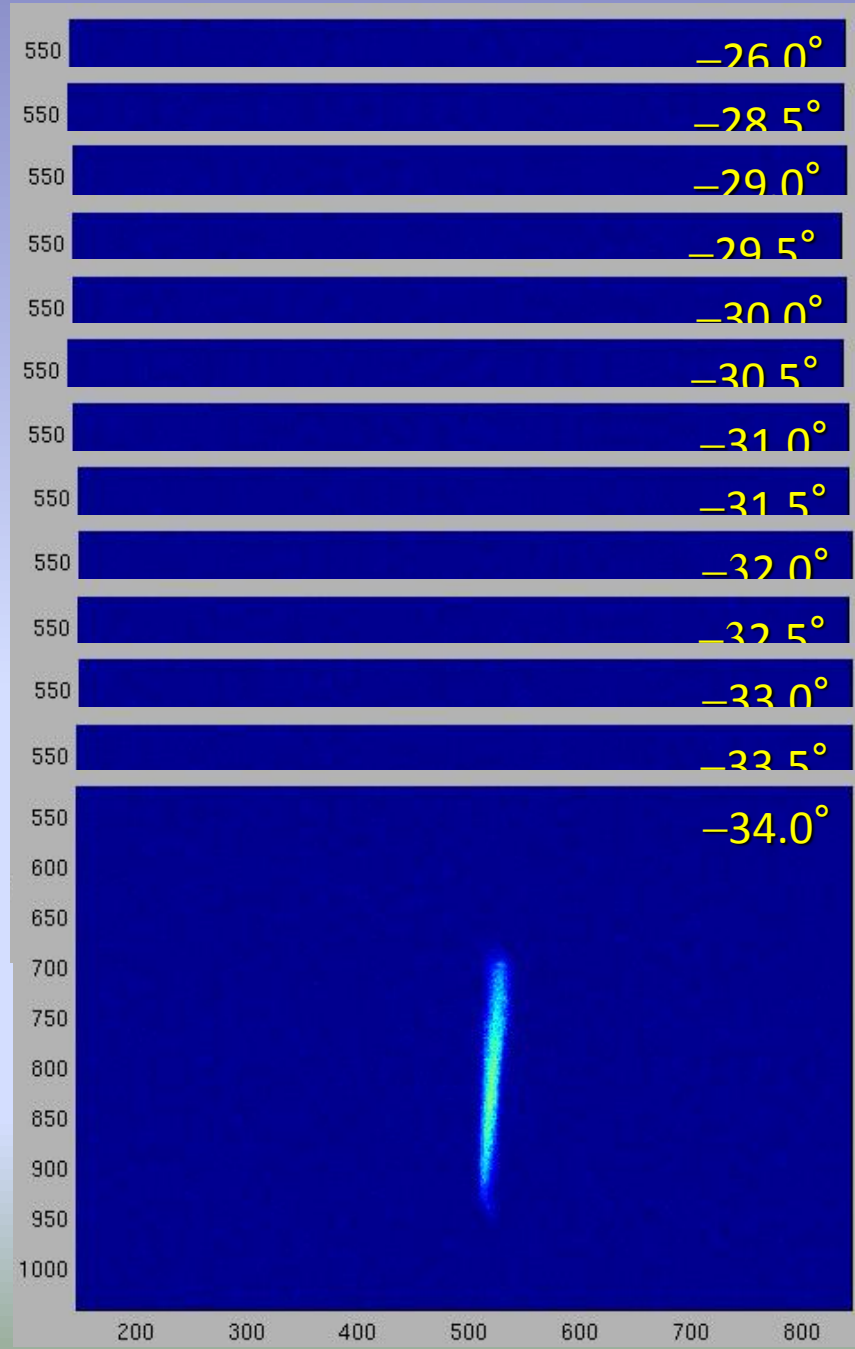
# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)

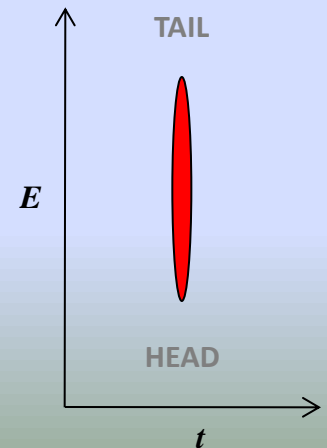
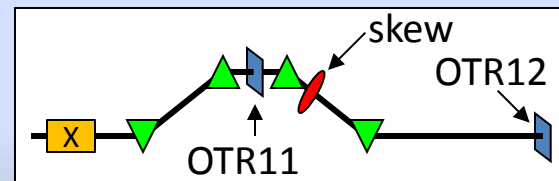
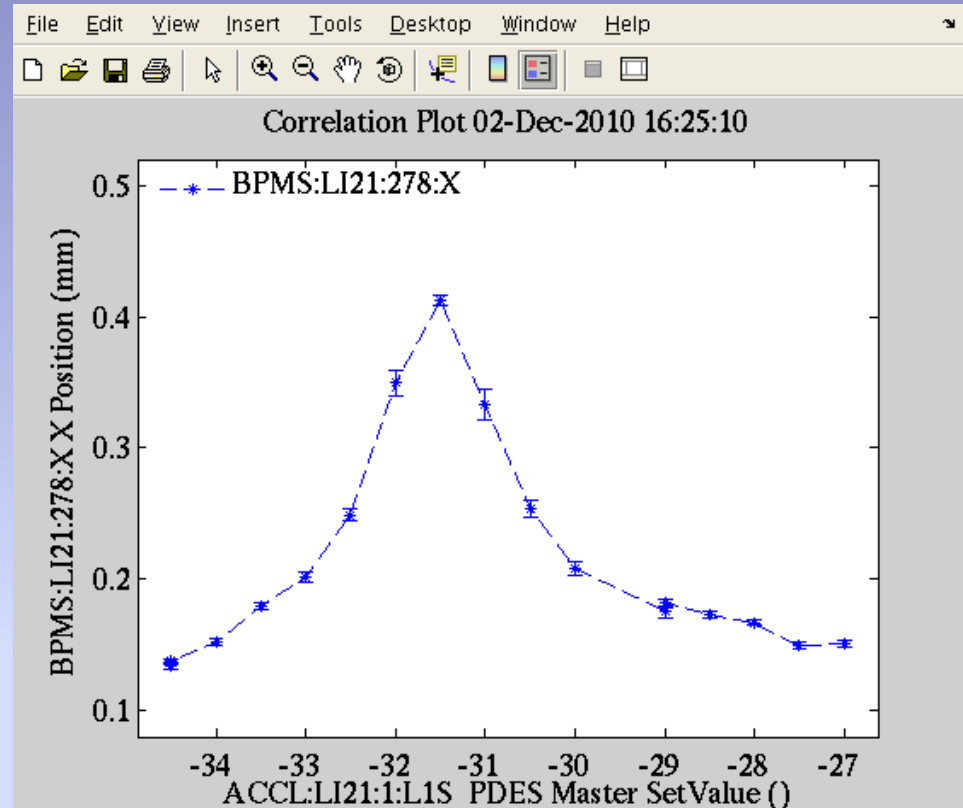
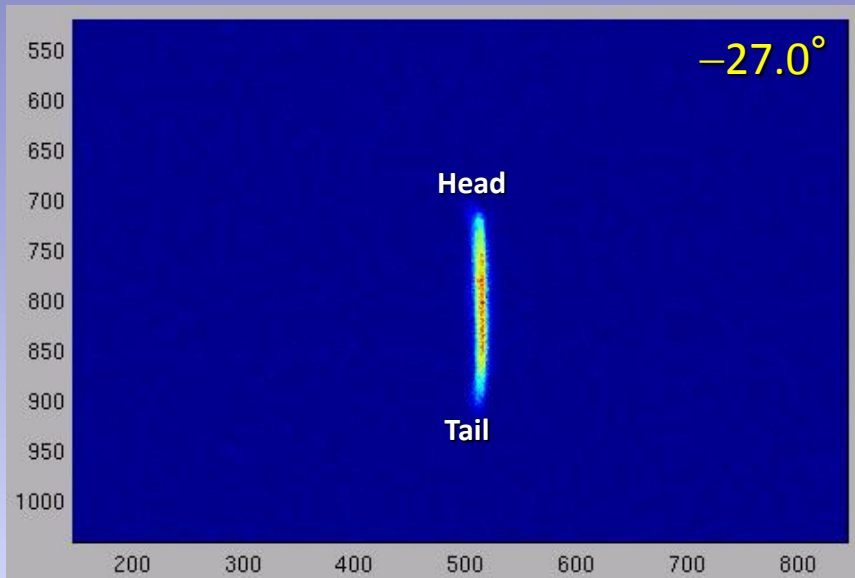


# Scan L1S phase holding BC1 energy constant L1X Voltage = 22 MV (too strong)



Scan L1S phase holding BC1 energy constant

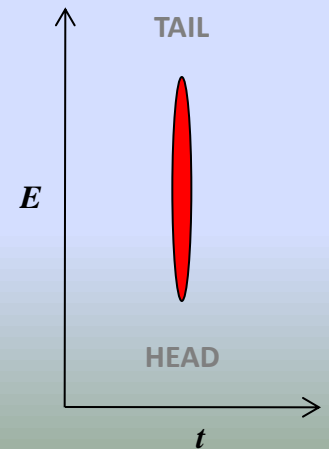
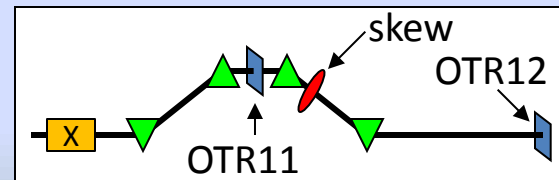
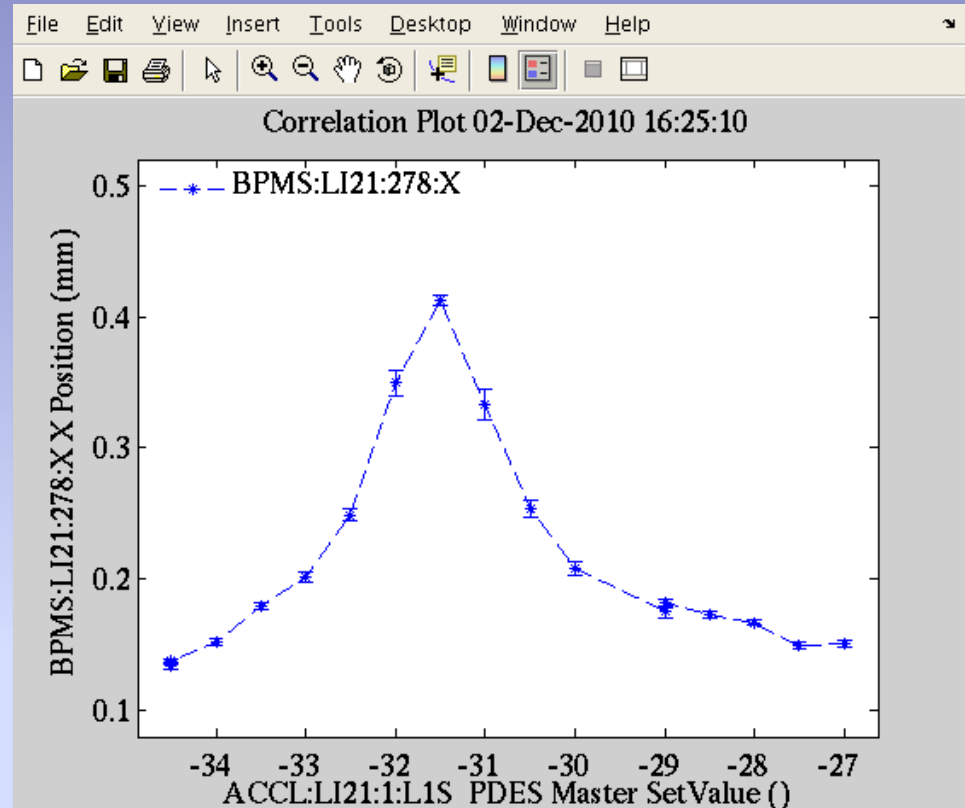
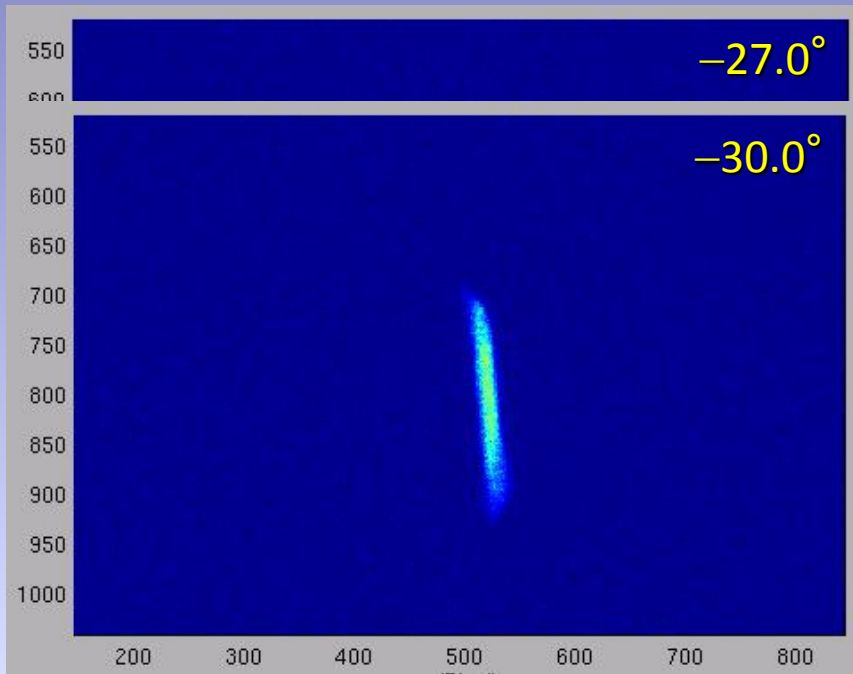
L1X Voltage = 19 MV (just right)





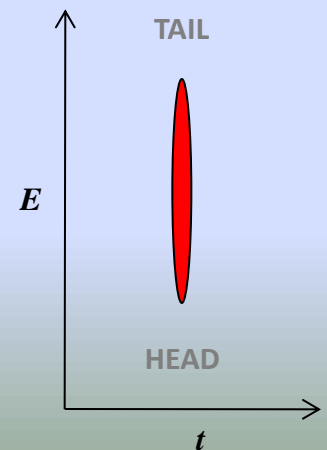
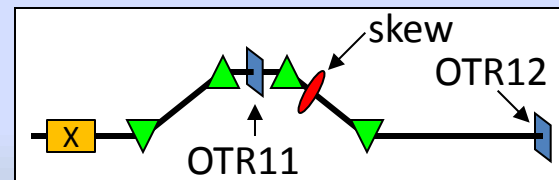
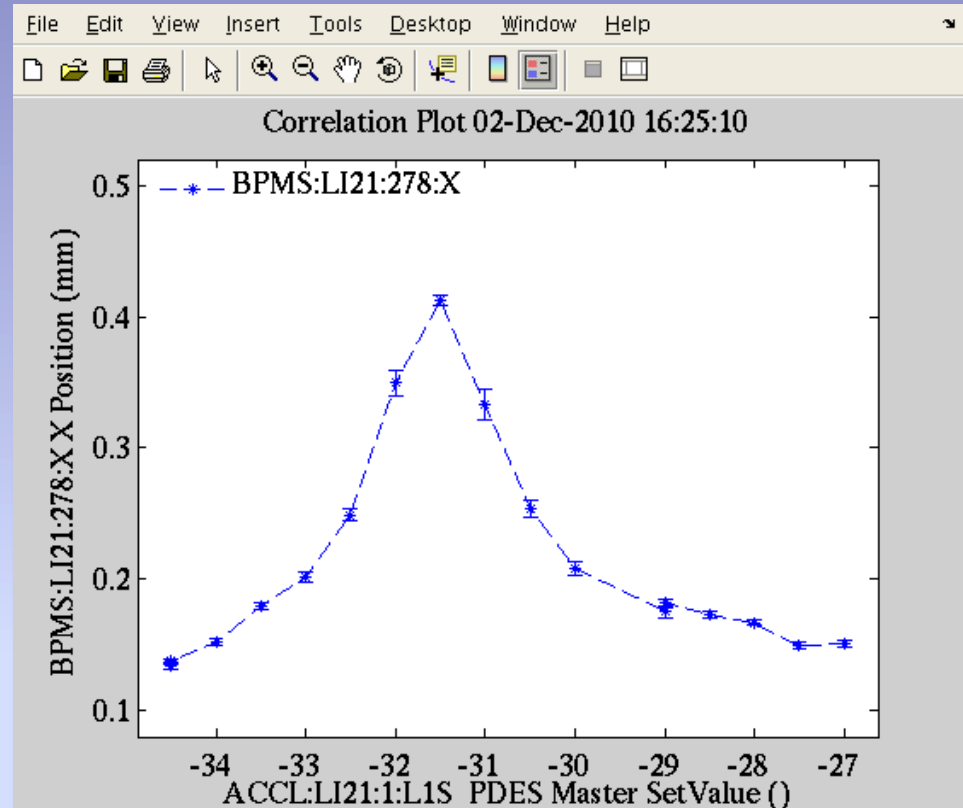
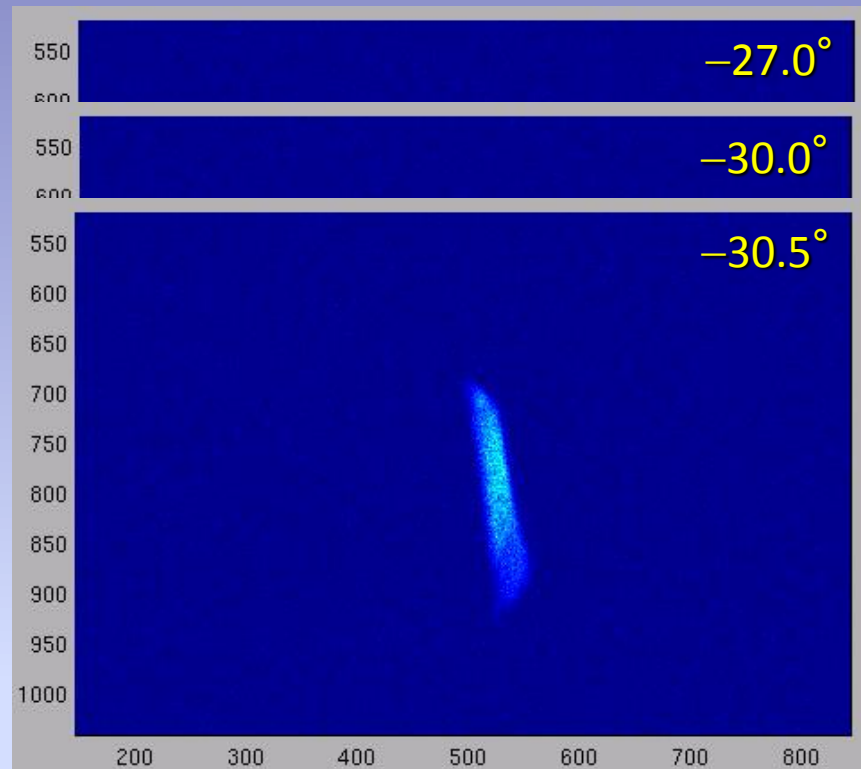
Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)



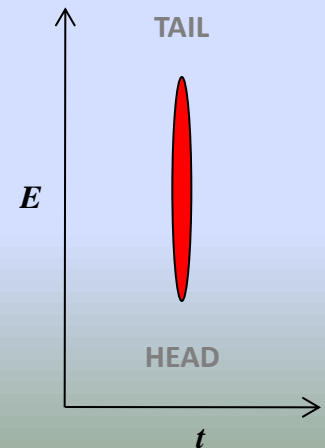
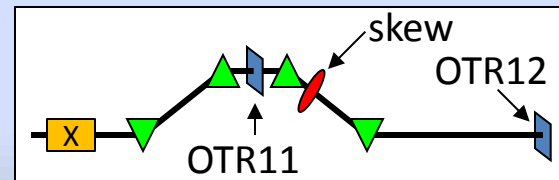
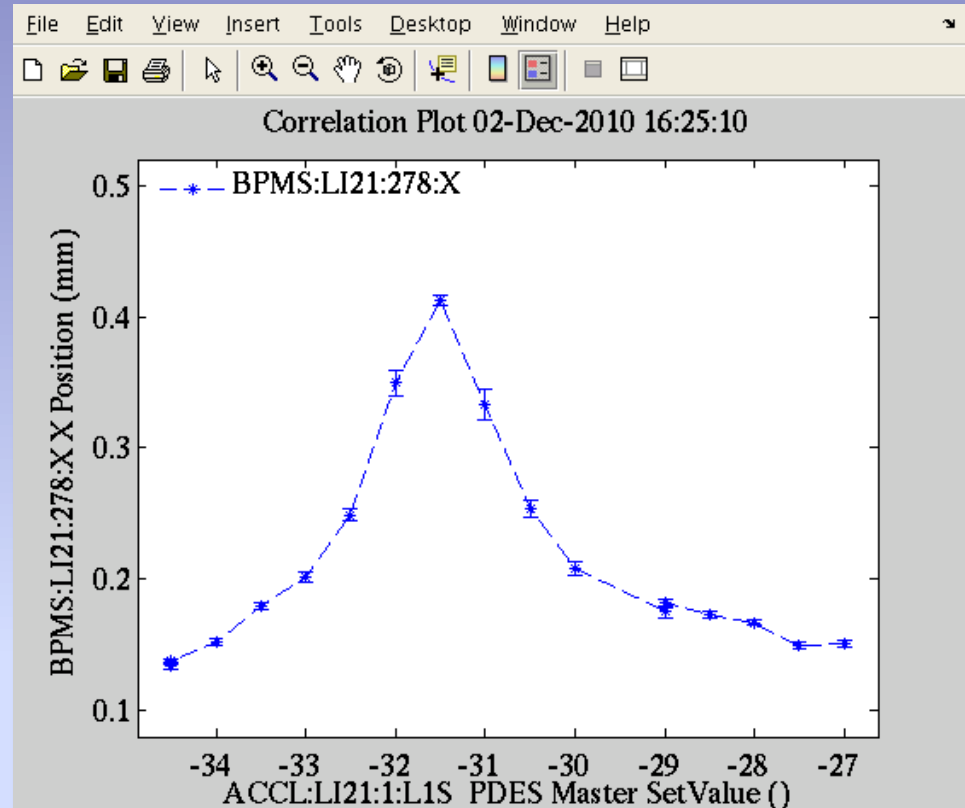
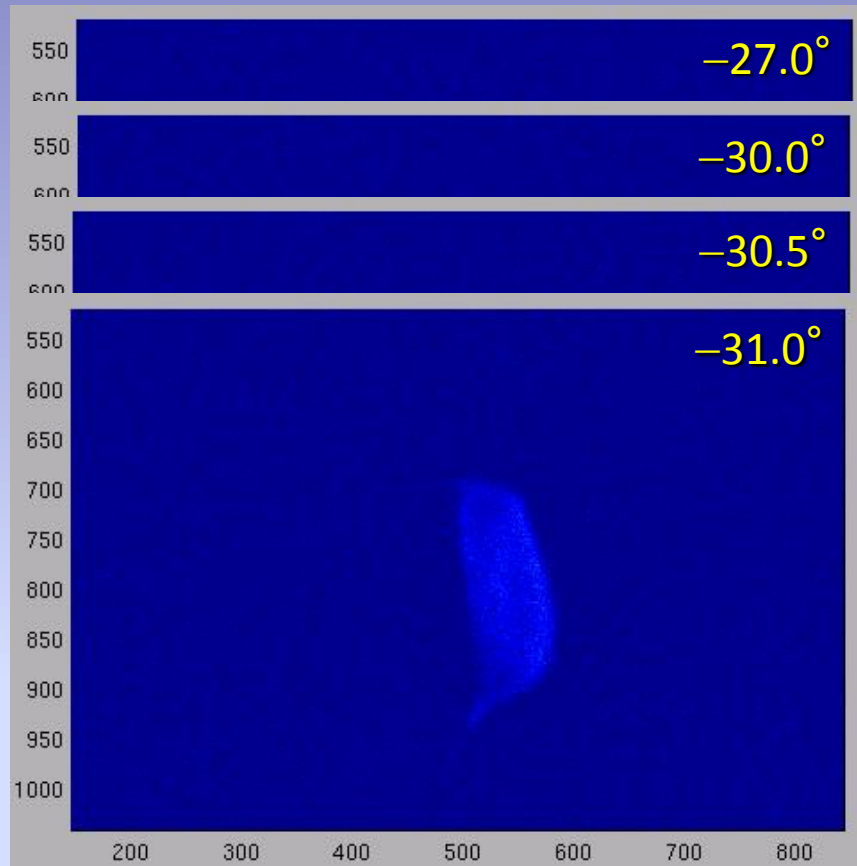
Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)



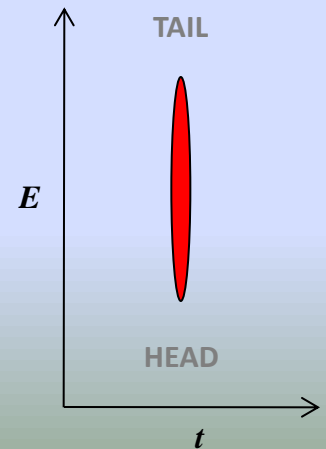
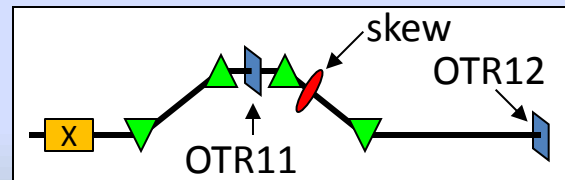
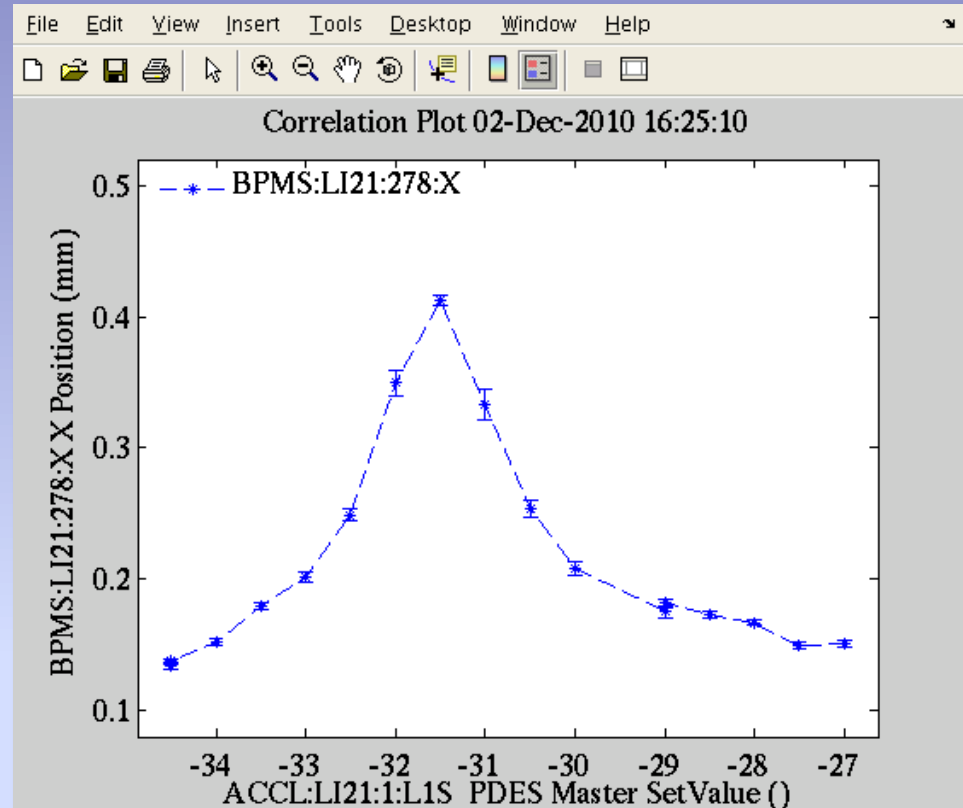
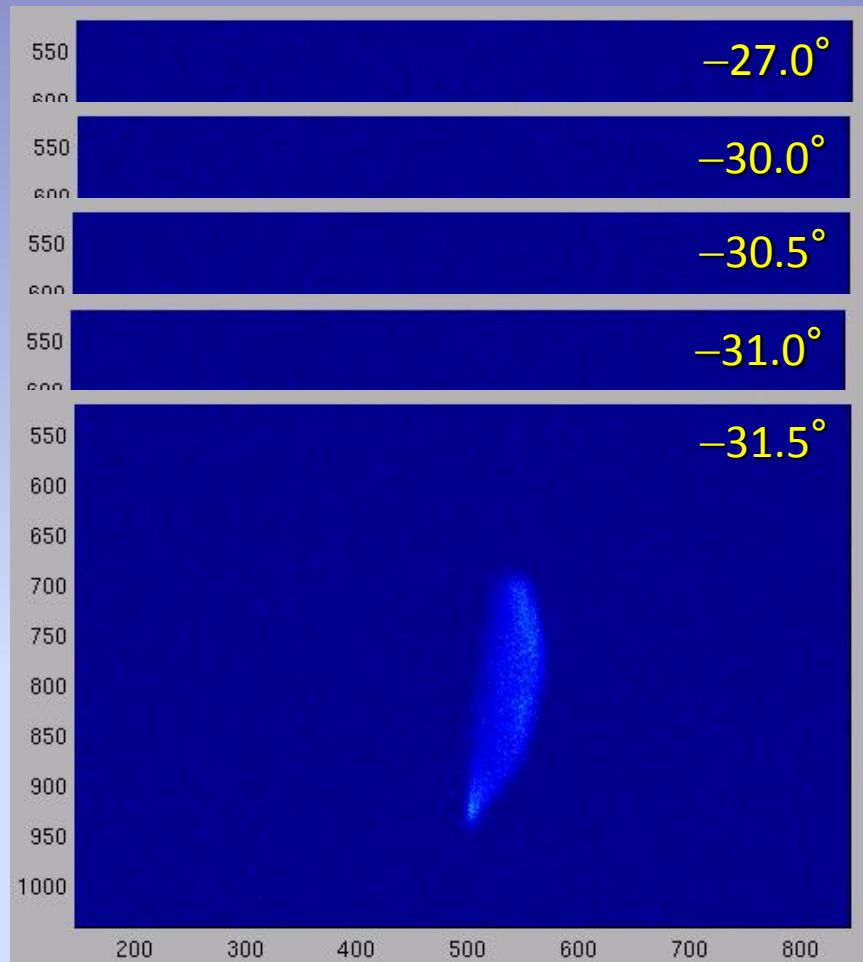
Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)



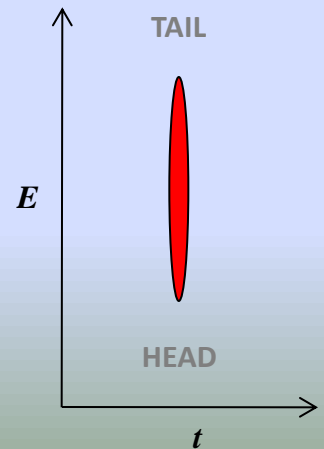
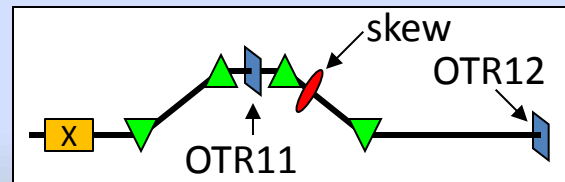
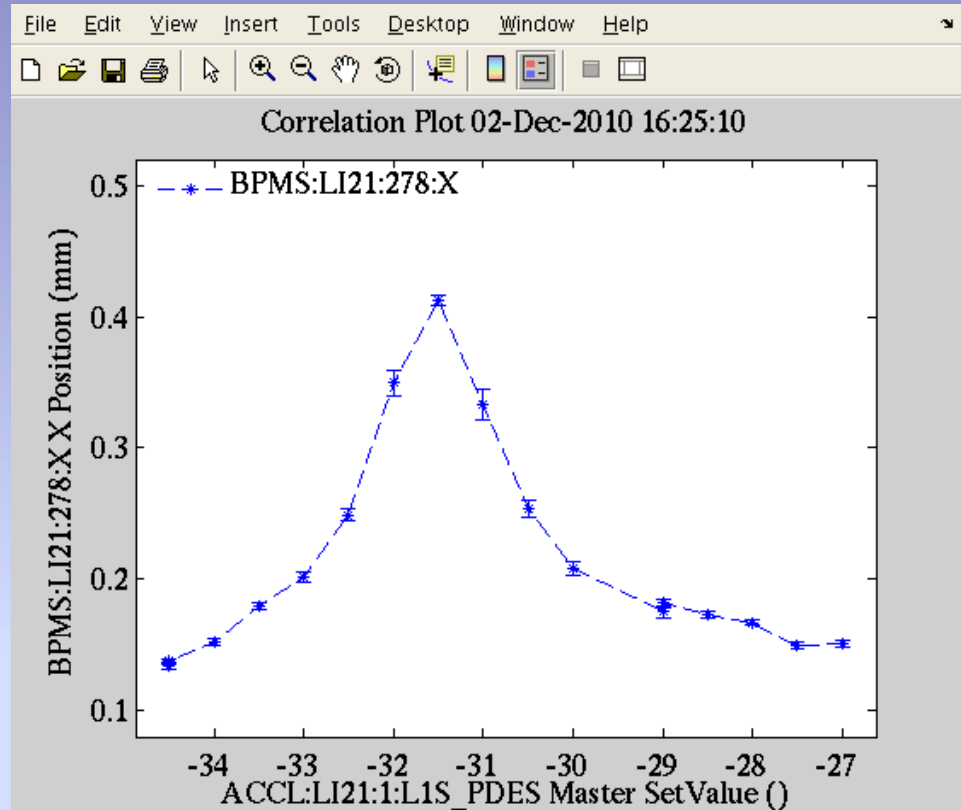
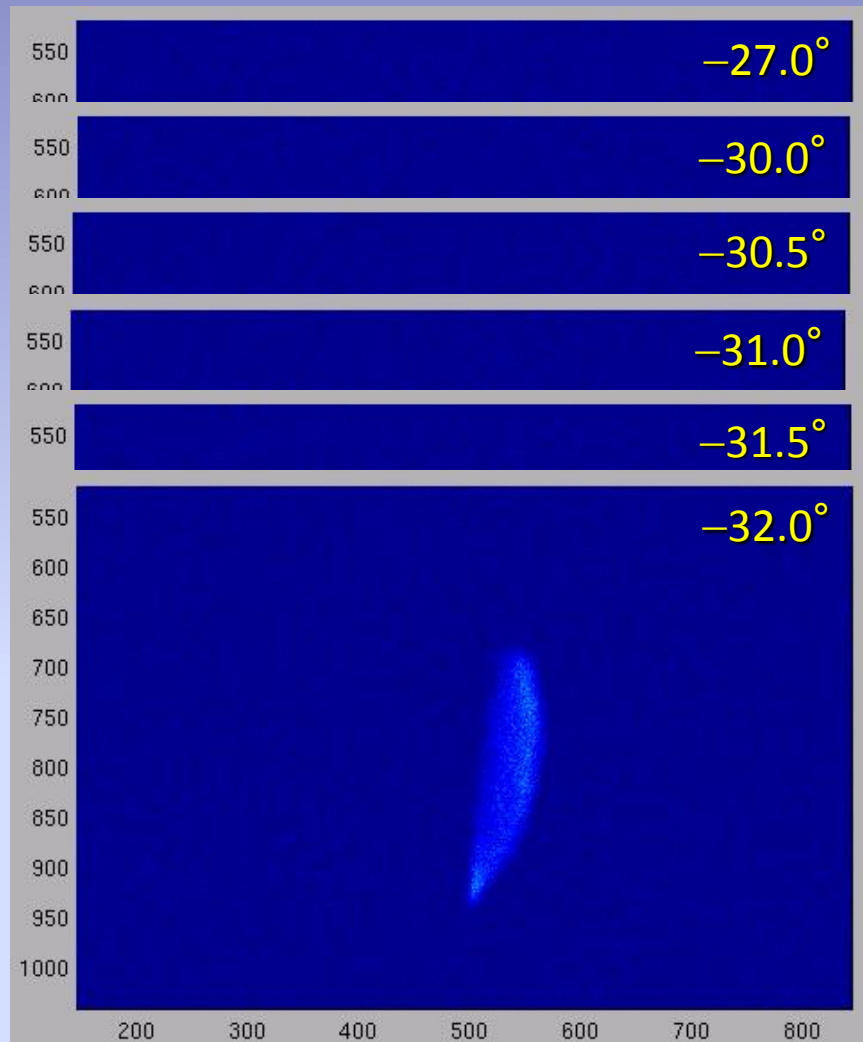
Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)



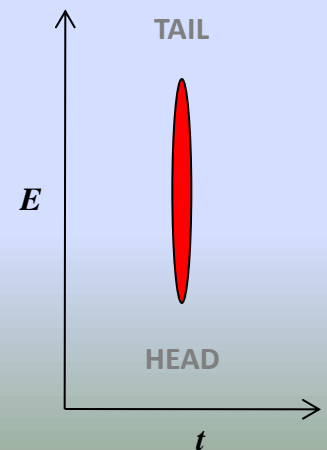
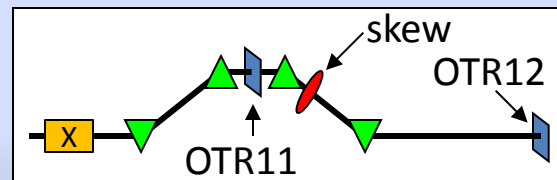
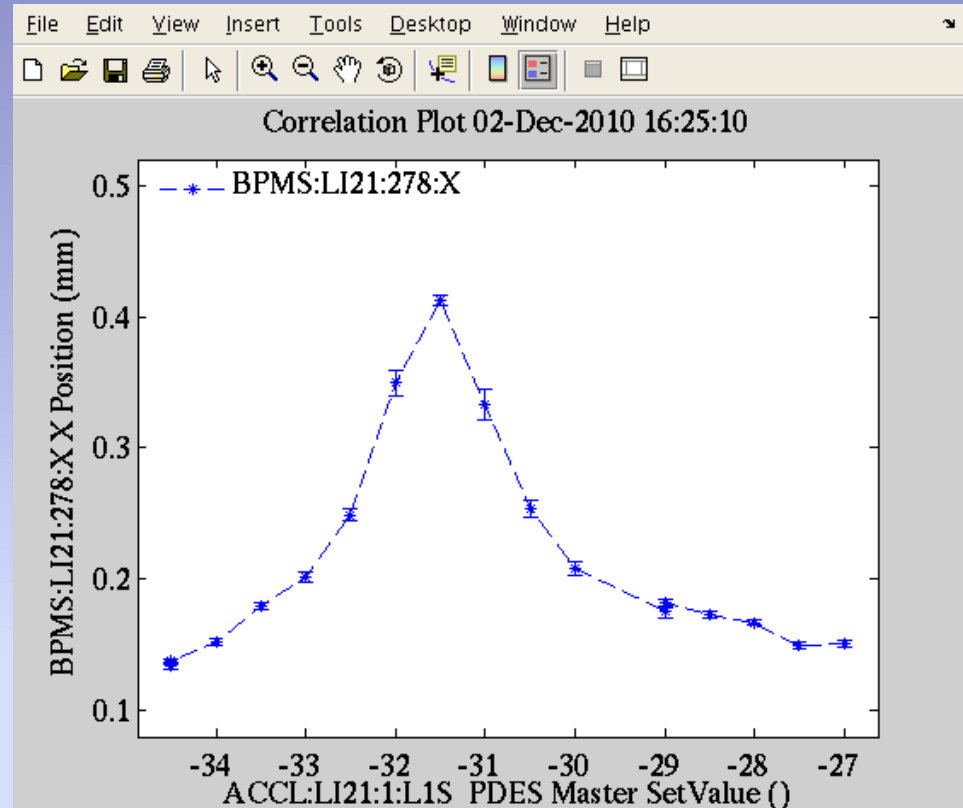
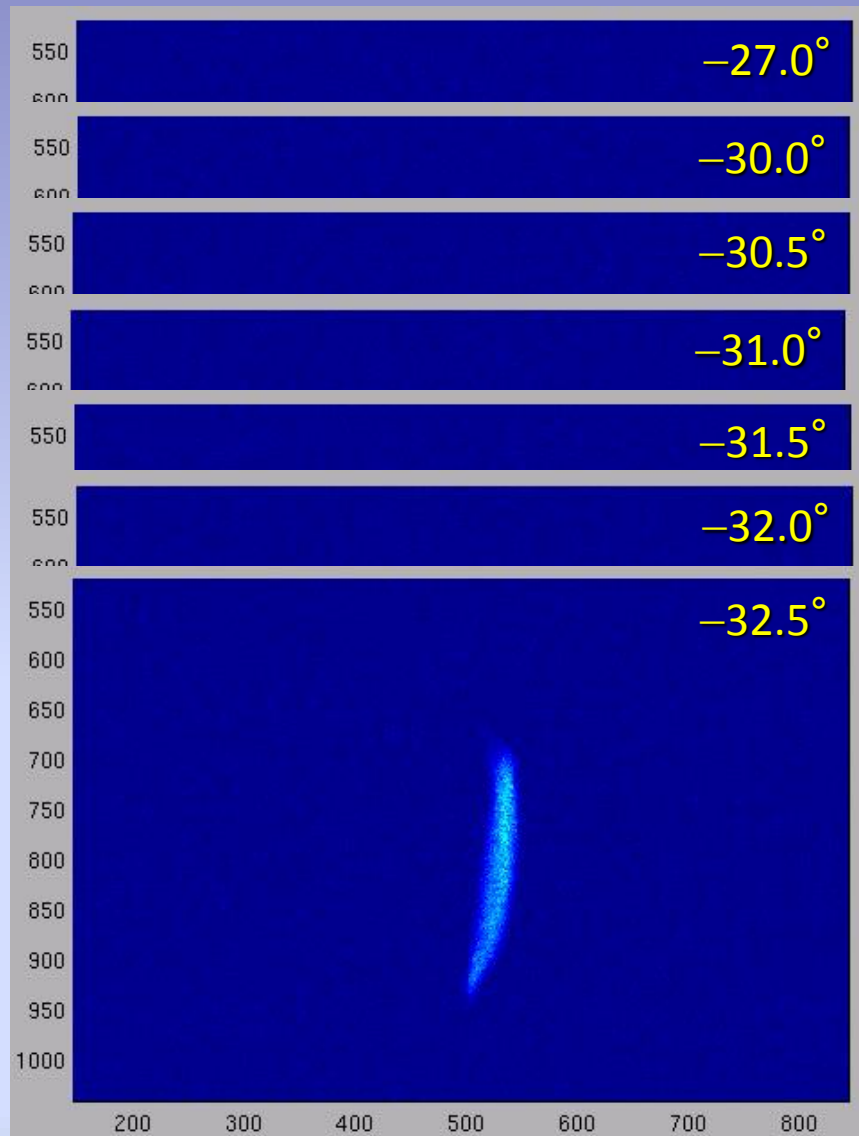
Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)

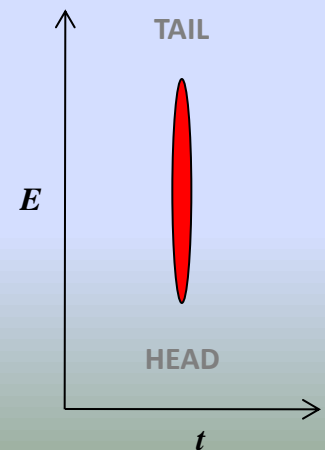
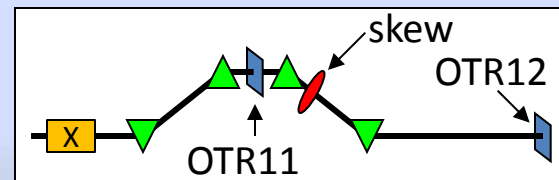
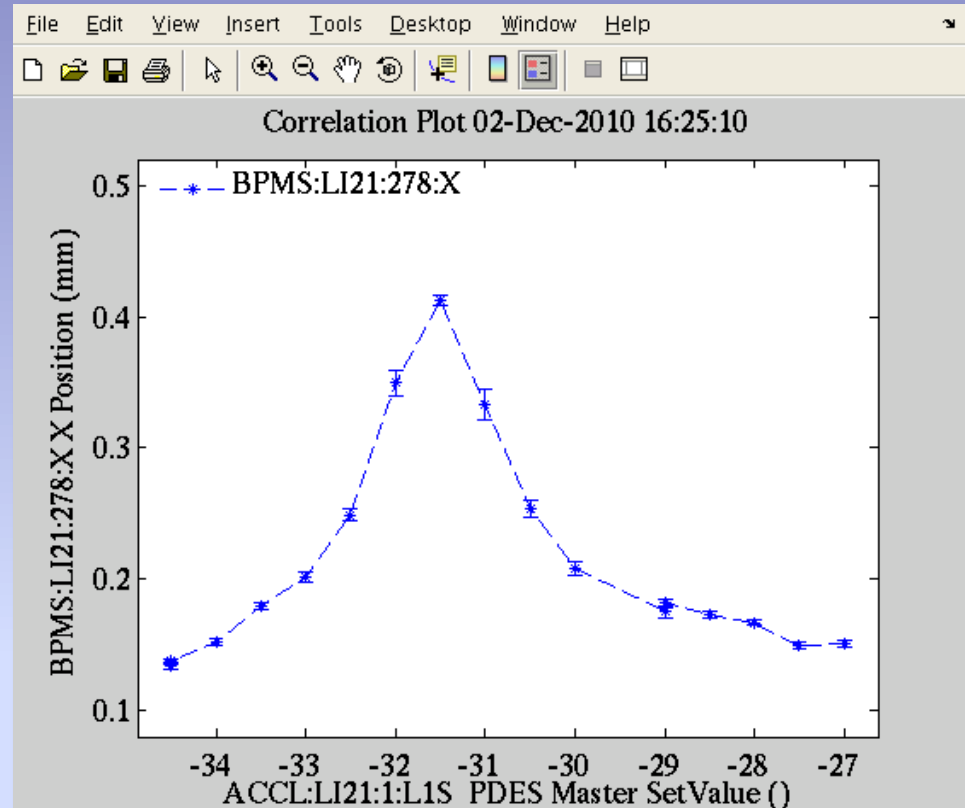


Scan L1S phase holding BC1 energy constant

L1X Voltage = 19 MV (just right)



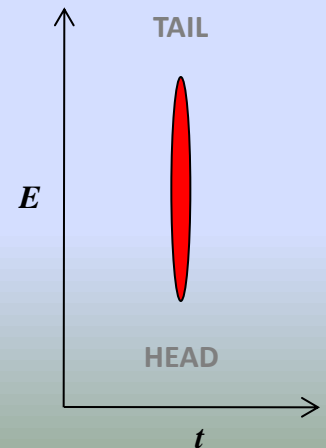
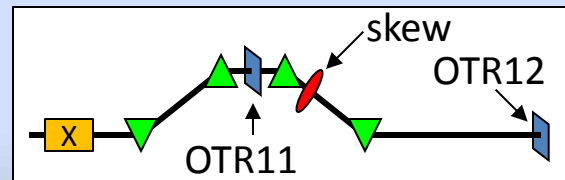
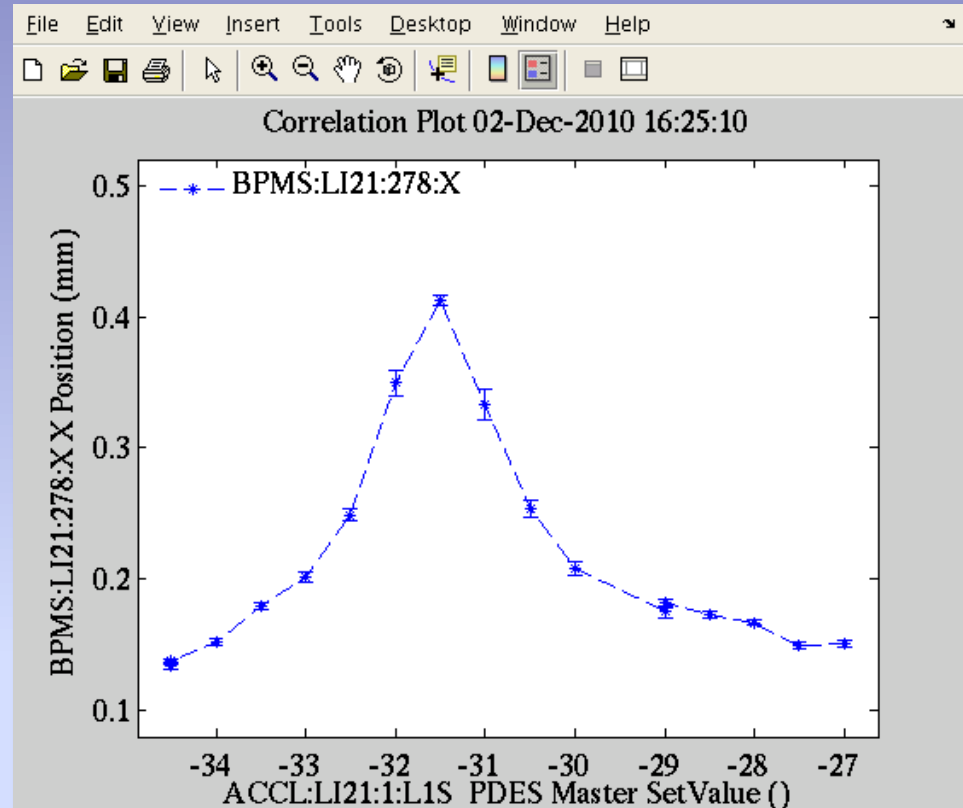
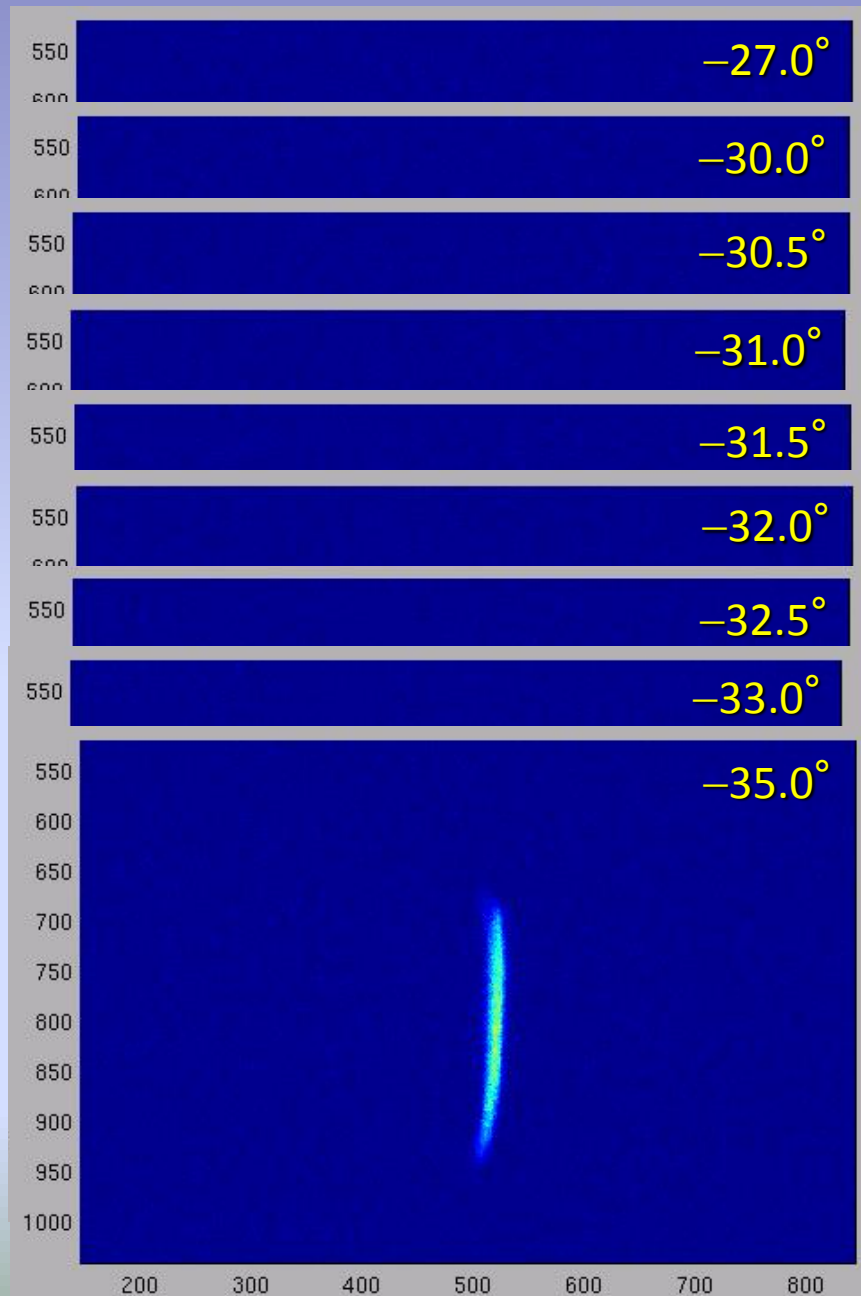
L1X Voltage = 19 MV (just right)





Scan L1S phase holding BC1 energy constant

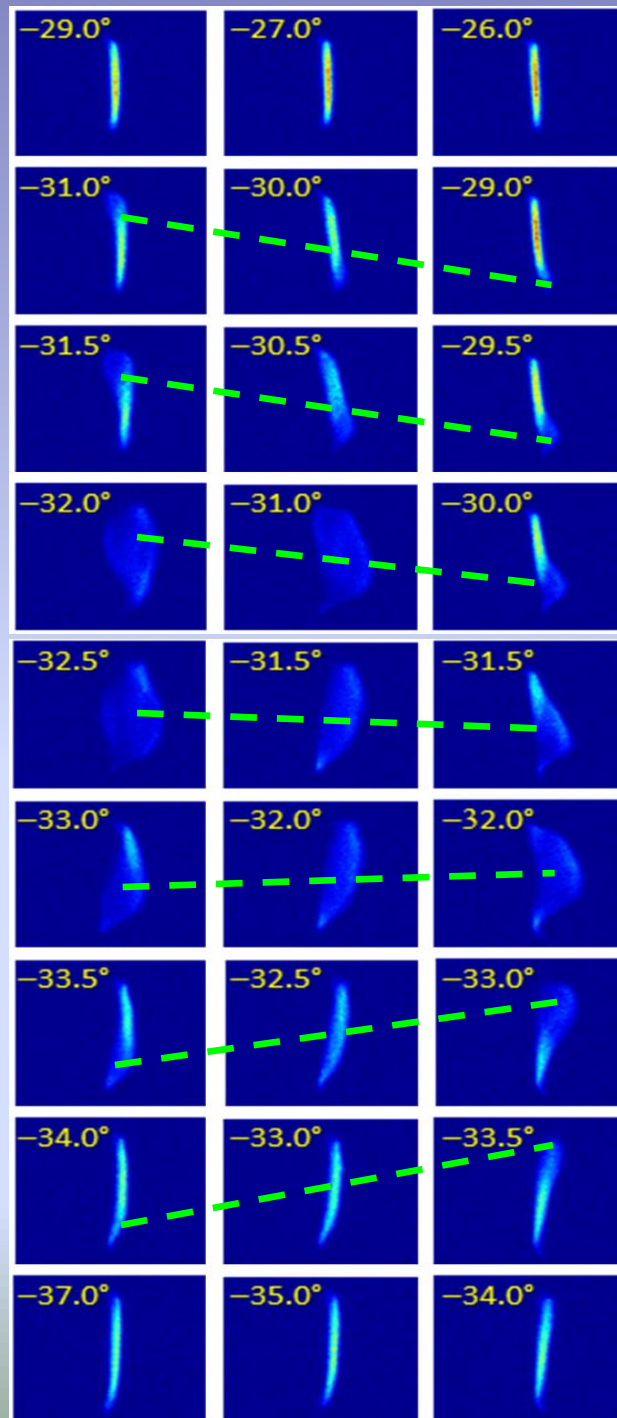
L1X Voltage = 19 MV (just right)



# Summary of previous 3 slides

Measured OTR  
screen images:

X-band RF set at:  
16 MV (*left*),  
19 MV (*center*), and  
22 MV (*right*)

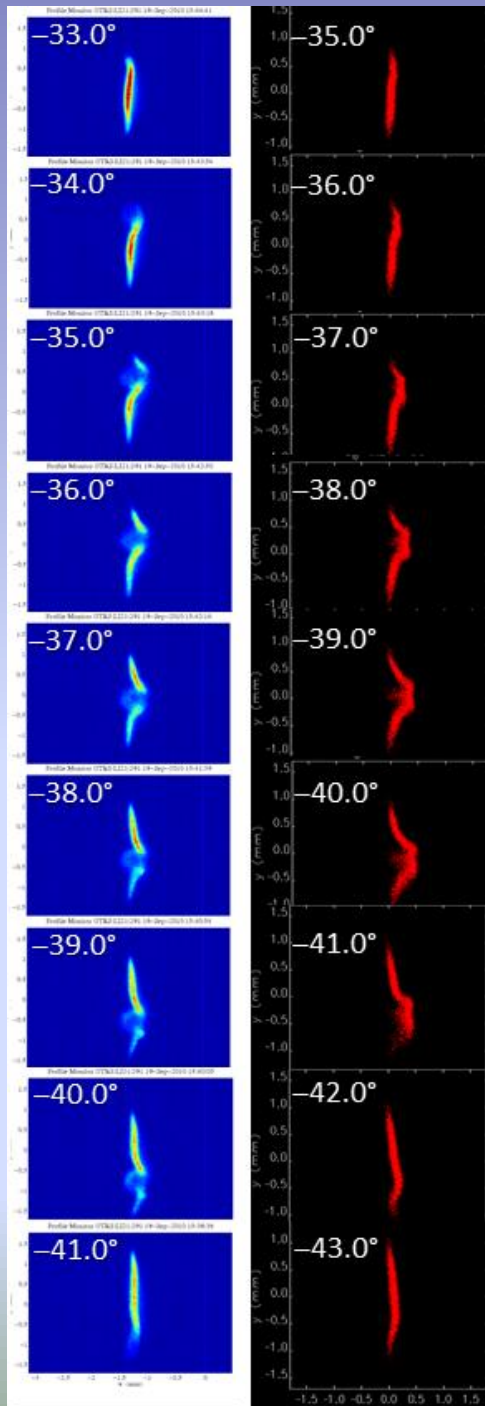
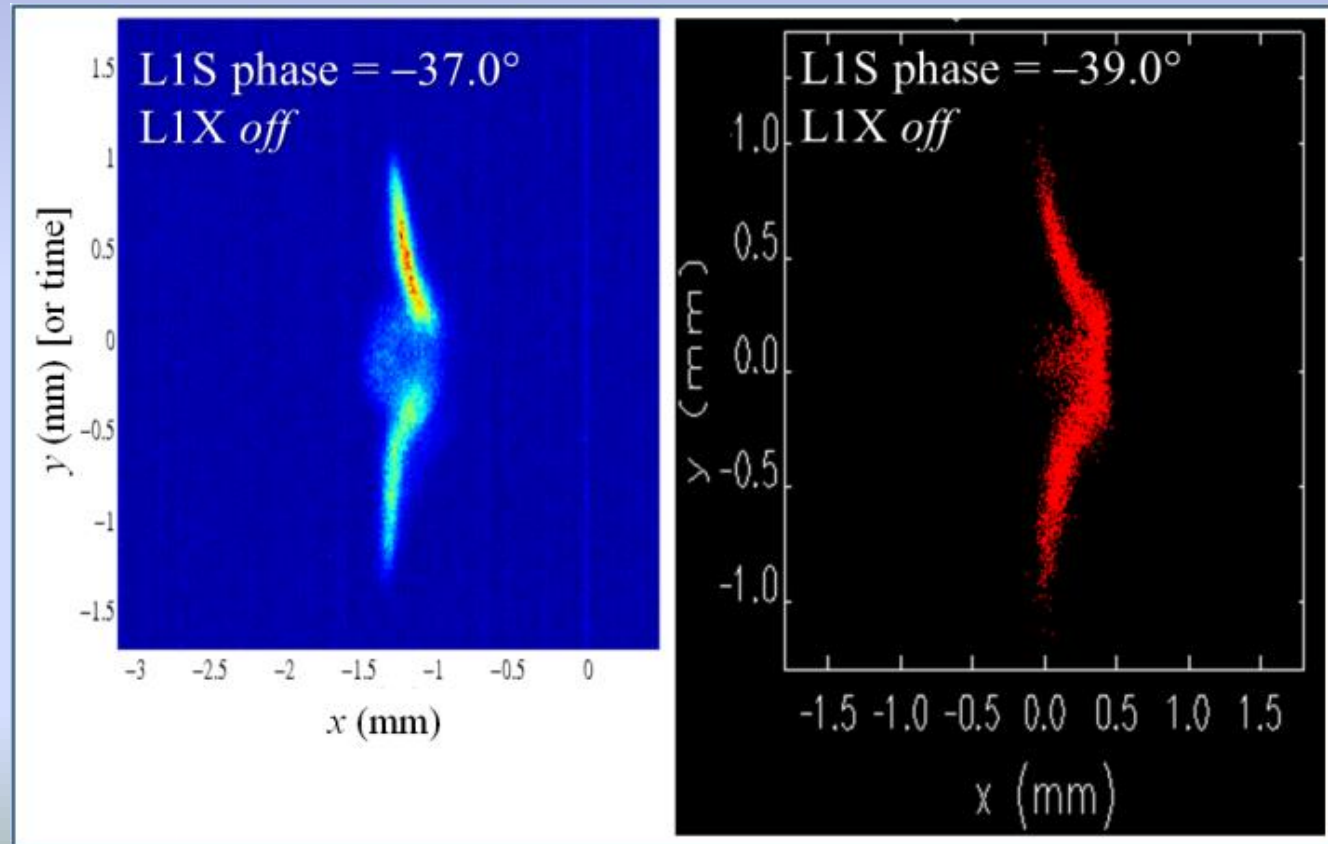


Bunch length (vertical  
streak) is  $\sim 6$  ps FWHM

pre-BC1 bunch head at  
the top of each image.

# Now Switch OFF L1X RF

Measurements (left) and simulations (right) with X-band RF switched off. The L1S phase settings differ between measurement and simulation by  $2^\circ$ .



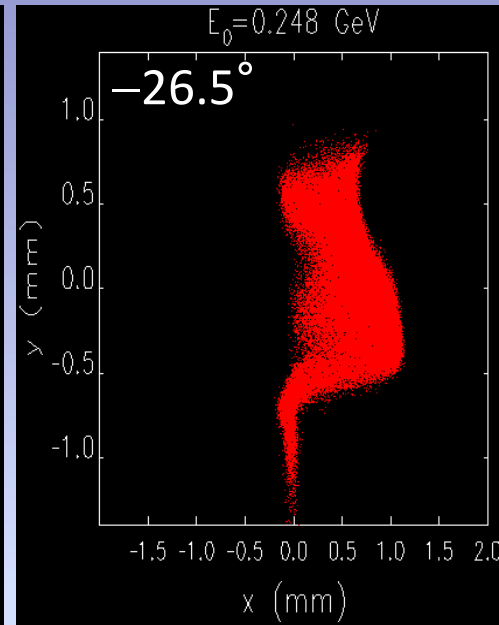
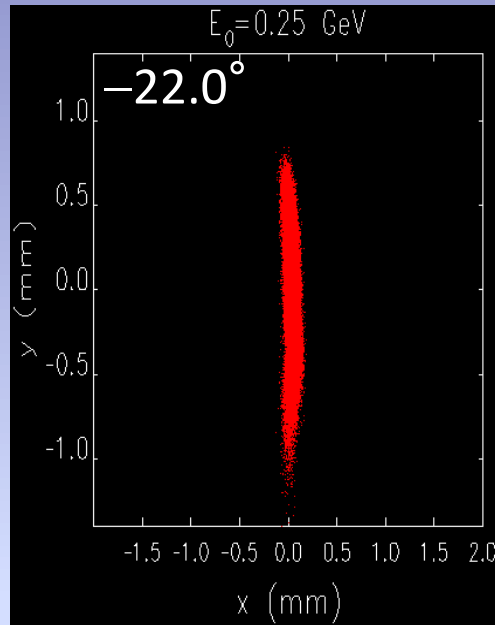
# Summary

- Skew quad is simple, inexpensive, and adds time-resolved electron beam measurements
- Reasonable agreement with simulations (1d-CSR model in elegant), but preliminary results
- Limited beam time has been available
- Should repeat and run more careful simulations as well
- Skew quad can also be used to correct vertical dispersion

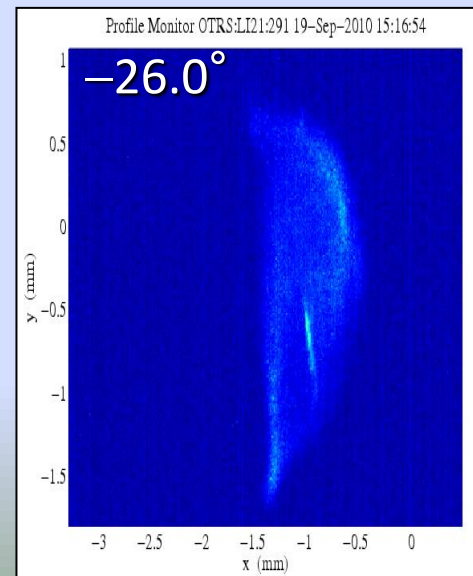
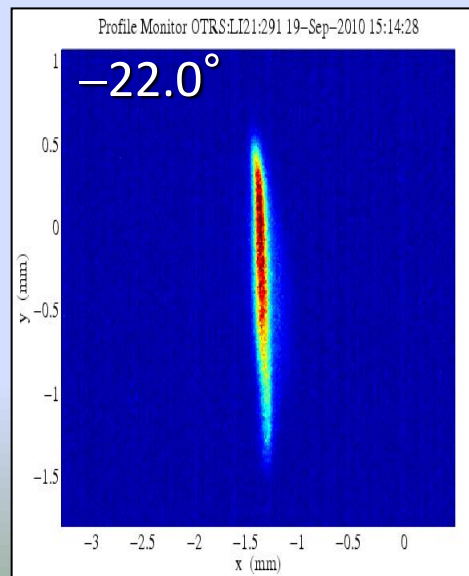
## Thanks for your Attention

# Blow-up reasonably well modeled at extreme compression

Vertical (time) is pre-BC1 bunch-length coordinate, not post-BC1, so blow-up is not so familiar w.r.t. usual simulations



*Elegant*



*Measurement*  
( $L1X = 19 \text{ MV}$ )