BC2 Beam Tilt Simulation
(Off-crest in ACC1)

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XY coupling+  
ZY coupling+  
wakes
XY coupling + ZY coupling
XY coupling + ZY coupling
### BC2 tilt measurements

Note: if coupler kicks are removed, tilt is -0.01 for zero bump and zero gun chirp

<table>
<thead>
<tr>
<th>Bump [mm]</th>
<th>Tilt (0.6nC)</th>
<th>Tilt (1.2nC)</th>
<th>Tilt (bad)</th>
<th>Tilt (no Gun chirp 1.2nC)</th>
<th>Tilt (no Gun chirp 0.6nC)</th>
</tr>
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<tbody>
<tr>
<td>3.1</td>
<td>1.79</td>
<td>3.2</td>
<td>-1.6</td>
<td>3.5</td>
<td>-2.05</td>
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<tr>
<td>2.6</td>
<td>-1.5</td>
<td>1.5</td>
<td>-0.8</td>
<td>1.7</td>
<td>-1.14</td>
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<td>-1.5</td>
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<td>-1.5</td>
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<td>1.7</td>
<td>-3.3</td>
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<tr>
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<td>0.05/-0.03/-0.2</td>
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<td>1.1</td>
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<td>-3.1</td>
<td>1.36</td>
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</tbody>
</table>

Really straight ahead
Straight ahead without coupler kicks
2nd corrector on a little bit
SR Camera BC2: Bunch tilt measurement; # of slices: 19, Fit range: 5 - 15

Plot courtesy of C. Gerth
SRS for a standing wave cavity

Rosensweig Serafini matches measurement

\[
\begin{bmatrix}
\cos \alpha - \sqrt{2} \cos \Phi \sin \alpha & \sqrt{8} \frac{E_i}{\Delta E} L \cos \Phi \sin \alpha \\
\Delta E & 1 \left( \frac{2 \cos \Phi + 1}{\cos \Phi \sqrt{8}} \right) \sin \alpha \\
\frac{\Delta E}{E_f L} \left( \frac{2 \cos \Phi + 1}{\cos \Phi \sqrt{8}} \right) \sin \alpha & \frac{E_i}{E_f} \cos \Phi \left( 1 + \sqrt{2} \sin \alpha \right)
\end{bmatrix}
\]

Predicts much larger tilt/bump slope

\[
\begin{bmatrix}
1 - \frac{1}{2} \frac{E_{acc}}{E_i} L & L \\
1 - \frac{1}{2} \left( \frac{E_{acc}}{E_i} \right)^2 L & 1 - \frac{1}{2} \frac{E_{acc}}{E_i} L
\end{bmatrix}
\]

\( E_i \gg \Delta E \)
Charge dependence of tilt

• High charge observation:
  – Tilt decreases for negative bump
  – Tilt increases for positive bump

• Possible explanations

  Same tilt can be generated for different ACC1 trajectories in which wakes are different

  The wakefields from the couplers are asymmetric
Tilted cavity or offset BPMs

- An orbit for which HOM signals were minimized
BC2 Fish Tail (Tale)

- head
- tail
Chasing the Red Herring

• coupler kicks
• wakefields
• dispersion in gun region
• laser-cathode interaction
- Go on crest and on axis with low charge

- Shift phase advance at screen to maximize C shape

- Look for differences in offset between tail and head for different gradients and charges
Minimum energy spread -> no dispersion after ACC1

Each pixel is \(~80\) um and there are \(~5\) pixels of separation between the head and tail.

Y emittance growth \(~1.8 \pm 0.2\)

Phenomenon consistent for different charges

M. Roehrs sees 30% X emittance growth from head tail separation (LOLA)
emittance growth 1.8136

emittance growth 2.0826

emittance growth 1.9565

emittance growth 1.6841

~1.8 ± 0.2

~400 um head tail separation
**Coupler Kick**

Take perfect phase advance from exaggerated kick and go back to expected kick. Divide $y'/100$ to make effect visible.

121 MeV

Too small to see with this simulation:
- effect of re-balancing ACC1 modules
- effect of changing gradient

17.5 μm
26.03.2006 04:51 schlarb, eislage

**Coupler kick changes orbit ACC1**

changed horizontal orbit into ACC1
data with ACC1 FB on:
2006-03-26T044831-meas-coupler-kick

We change the optics of the injector to achieve optimal condition for measuring the coupler kicker induced by the LLRF FB regulation.
FB on gain 30
2006-03-26T041609-meas-coupler-kick.mat
FB off
2006-03-26T042902-meas-coupler-kick.mat

**Naïve Simulation:**

20* coupler kick predicts
delta y = 4.5 mm
1* coupler kick predicts
delta y = 0.25 mm

Flaws:
not steady state (fw and bw pwr)
should only use field map from main coupler
Can you simulate something that looks similar with wakefields?

\[ y' / 100 \] at first corrector

Nominal quad setting -20%

Transverse wakefields from cavities

Wakefields "off"
3.5 mm bump
No coupler kicks

10nC charge
3.5 mm bump
No coupler kicks

2nC charge
3.5 mm bump
No coupler kicks

[Graphs showing particle trajectories with labels head and tail]
How much gun mis-alignment would be needed to cause 400 um head-tail separation in BC2?

• Exit of gun:
  – Offset: e.g. 1cm -> 100um separation

~1% energy chirp

Bending angle of correctors is energy dependent

Remove energy chirp
Lattice for space-charge dominated beam overfocuses

Mismatch Magnifies
ASTRA to end of ACC1

100 um offset in x becomes 140 um offset in y at end ACC1 and 40 um in x

RMS beam size

X (mm)

Y (mm)

Centroid position
Head-tail separation on the cathode

300 um head-tail separation on cathode -> ~1mm head-tail separation in BC2
600 um head-tail separation on cathode -> ~4 mm head-tail separation in BC2
300 um laser head-tail separation

Y emittance = 3.3 (ASTRA to 1st corrector) = 3.7 (ASTRA to end ACC1)

-1 deg ACC1

No cathode effects

Y emittance = 2.9 (ASTRA to 1st corrector) = 2.1 (ASTRA to end ACC1) = ~3.4 (recent measurements) = ~2 (past measurements)

+1 deg ACC1
Incidence angle onto cathode = 20.0°

<\frac{\partial X}{\partial z}> = 148 \, \mu m \cdot \frac{z}{\sigma_z}

<\frac{\partial Y}{\partial z}> = 0 \, \mu m \cdot \frac{z}{\sigma_z}

ASTRA to end of ACC1
350 mrad Z shearing
Y emittance growth 2.4/2.2 = 1.1

BUT

No X shearing allowed, just Z shearing

Z = 350 \times X + Z'
ASTRA to end of ACC1
700 mrad Z shearing
Y emittance growth 2.7/2.2=1.2

BUT
No X shearing allowed, just Z shearing

Z=700*X+Z'
Injector laser incidence on cathode

Incident angle? ~30 mrad
Tilted cathode? ~30 mrad
Pulse-front tilts? ~30 mrad
0 mrad angle of incidence on cathode

- BC2 with cathode tilt
- ACC1 -1 deg
- ACC1 +1 deg
- Solenoid on axis

Y emittance 2.85 (ASTRA up to 1st corrector)
2.2  (ASTRA up through ACC1)
200mrad angle of incidence on cathode

Solenoid on axis

Y emittance 2.85 (ASTRA up to 1st corrector)
2.2   (ASTRA up through ACC1)
400mrad angle of incidence on cathode

Solenoid on axis

Y emittance 2.97 (ASTRA up to 1\textsuperscript{st} corrector)
2.4 (ASTRA up through ACC1)
Omrad angle of incidence on cathode

BC2 with cathode tilt

Solenoid 1 cm off axis

Y emittance 3.8
“Most ultrashort pulses have spatial chirp and pulse front tilt. Amplified pulses are especially distorted. But no one ever looks for these effects because no quantitative diagnostic has been available.”

-Swamp Optics .com

(they are selling such a diagnostic in IR)
Ingo Will (phone conversation) estimates the pulse front tilt from the injector laser as < 0.1 ps/mm (~ 30mrad) caused primarily by slightly wedged elements, but he thinks inducing a pulse front tilt to compensate for correlated electron beam effects is an interesting option.
Making a pulse-front tilt

In the UV
50% losses
Coarse adjustment
(several ps/mm)

Diagnosing:
Streak camera

Future pulse shaping schemes could provide a mechanism for tuning the laser pulse front tilt.
Two-channel mixing scheme: reduced energy requirements to the broadband laser amplifier

- 75% of the total laser energy delivered by the Nd:YLF long-pulse system
- only 25% need to be delivered by broadband channel

**Moderate power, large bandwidth Yb:KGW channel**

- Diode-pumped short-pulse oscillator
  - $\tau < 1$ ps, $f = 54$ MHz
  - pulse picker
  - pulse shaper (1% transmission)

- Broadband pulse from Yb:KGW laser
  - sharp edges
  - $E_{micro} = 20 \mu J$
  - $\lambda = 1038$ nm

- Amplifier chain (one regenerative and one linear amplifier)

- Diode-pumped short-pulse oscillator
  - $\tau = 50$ ps, $f = 27$ MHz
  - pulse picker

**Nd:YLF amplifier chain**

- Nd:YLF laser
  - slow edges
  - $E_{micro} = 100 \mu J$
  - $\lambda = 349$ nm

- Mixing stage
  - Diode-pumped short-pulse oscillator
    - $\tau = 50$ ps, $f = 27$ MHz
  - Nd:YLF amplifier chain
    - $\tau = 50$ ps, $f = 27$ MHz

- Diode-pumped short-pulse oscillator
  - $\tau < 1$ ps, $f = 54$ MHz

- Output: rectangularly shaped micropulses
  - $E = 50 \mu J$, $P = 50$ W
  - $\lambda = 1038$ nm

- Narrowband pulse from Nd:YLF laser
  - slow edges
  - $E_{micro} = 100 \mu J$
  - $\lambda = 349$ nm

- Rectangularly shaped micropulses
  - $E_{micro} > 20 \mu J$
  - $\lambda = 260$ nm

**Nd:YLF amplifier chain**

- Nd:YLF laser
  - slow edges
  - $E_{micro} = 100 \mu J$
  - $\lambda = 349$ nm

- BBO crystal

- UV output pulse
  - sharp edges
  - $E_{micro} > 20 \mu J$
  - $\lambda = 260$ nm

**Large power, small bandwidth Nd:YLF channel**

- Beam stop

Slide by: Ingo Will
Pre-shaping the beam of the photocathode laser may significantly reduce losses in the beamline.

**Present scheme**
- Photocathode laser
- Gaussian laser beam $D = 2$ mm
- Overfilled beam-shaping aperture $D = 1...4$ mm
- Transmission < 20%  
  Losses > 80%
- Beamline telescope or spatial filter with pinhole

**Pre-shaping by an aspherical Lens pair**
- Photocathode laser with flat-top pump profiles
- Gaussian laser beam $D = 2$ mm
- Overfilled beam-shaping aperture $D = 1...4$ mm
- "Pre-shaped" beam
- Transmission ~ 70%  
  Losses ~ 30%
- Beamline telescope or spatial filter with pinhole
- Three times more energy than without pre-shaping

Slide by: Ingo Will
To-do list:

• Compare C-shape before and after shutdown (new gun alignment)
• Study dependence of C-shape on gun phase
• Use diffraction grating to create pulse front tilt in injector laser pulse
Summary

• The C-shape seen in BC2 is not understood
  – Charge independent
  – Not dispersion
  – Misalignement insensitive
  – Time-dependent coupler kicks are too small

• Injector laser pulse front tilts might be useful as a tuning tool if they are made after the iris

• It is only a projected emittance growth, but if we could get the slices under better control, maybe we could get more of them to lase

• Off-crest tilts seen in BC2 are consistent with Matlab simulation (ASTRA up to 1st corrector and then transfer matrices)