Emittance and Momentum Diagnostics for Beams with Large Momentum Spread

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Outline

- Motivation: The Compact Linear Collider (CLIC) drive beam decelerator
- Beam profile diagnostics for large momentum spread
  - Spectrometry
  - Emittance: Quadrupole scan
- The Post-PETS Line
- Summary and conclusions

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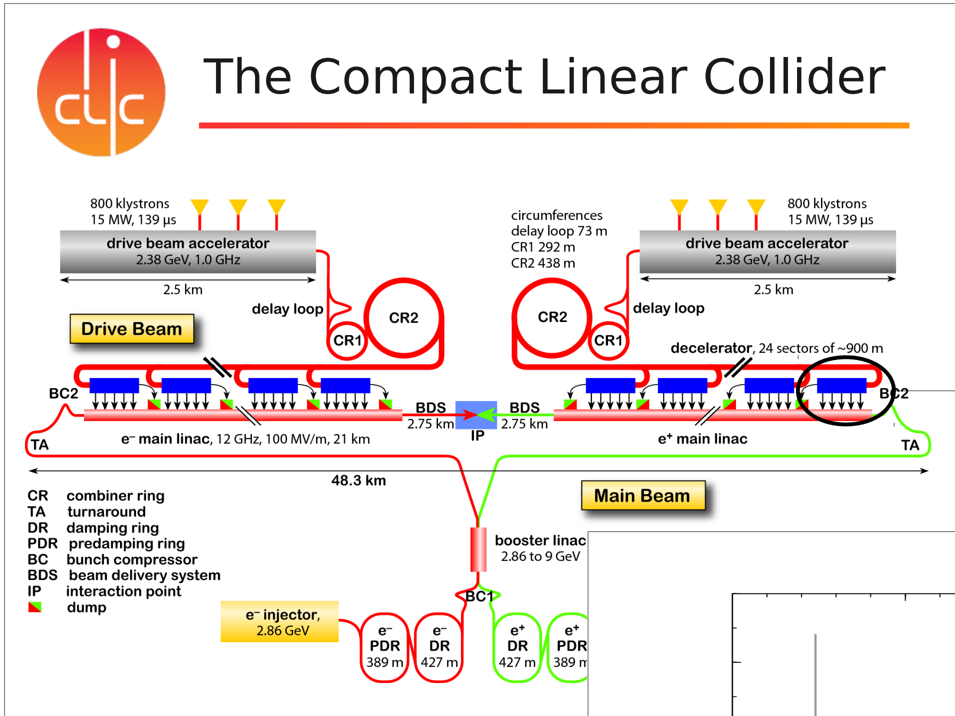
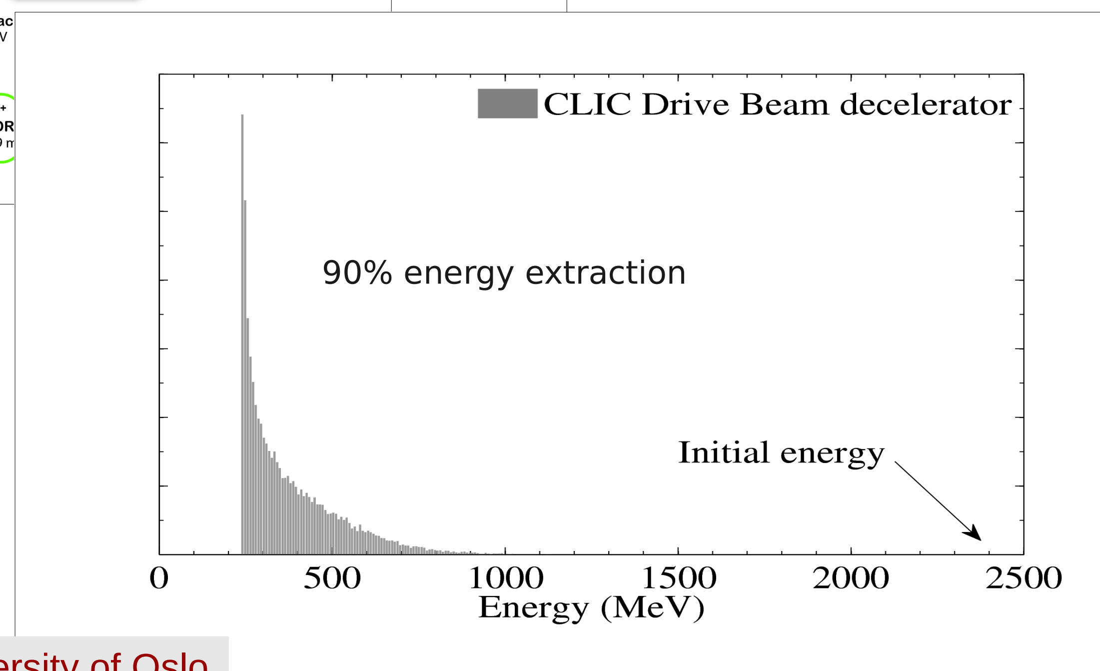
The CLIC Decelerator



Drive beam decelerator



PLACET simulation by E. Adli, University of Oslo

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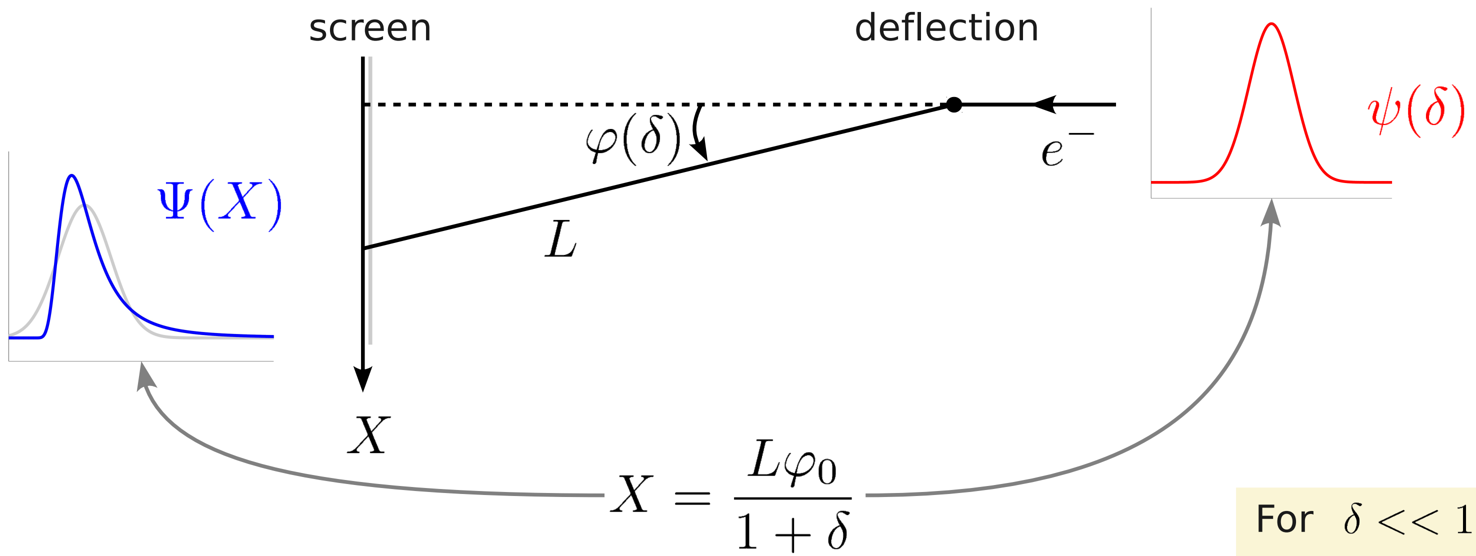
Spectrometry For Large Spreads



For $\delta << 1$:
$X \approx L\varphi_0(1-\delta)$

Spatial distribution

$$\Psi(X) = \int_\delta \psi(\delta)\delta_D\left(X - \frac{L\varphi_0}{1+\delta}\right)d\delta \; = \frac{L\varphi_0}{X^2}\,\psi\left(\frac{L\varphi_0 - X}{X}\right)$$

Momentum distribution

$$\int_X \Psi(X)\delta_D\left(\delta + 1 - \frac{L\varphi_0}{X}\right) = \frac{L\varphi_0}{(1+\delta)^2}\,\Psi\left(\frac{L\varphi_0}{1+\delta}\right) = \psi(\delta)$$

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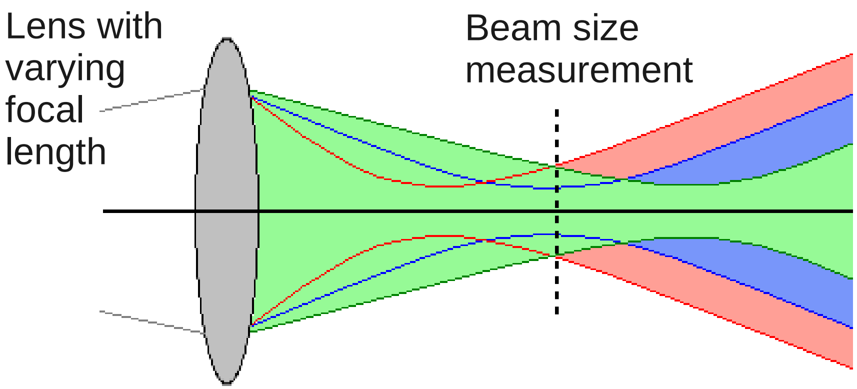
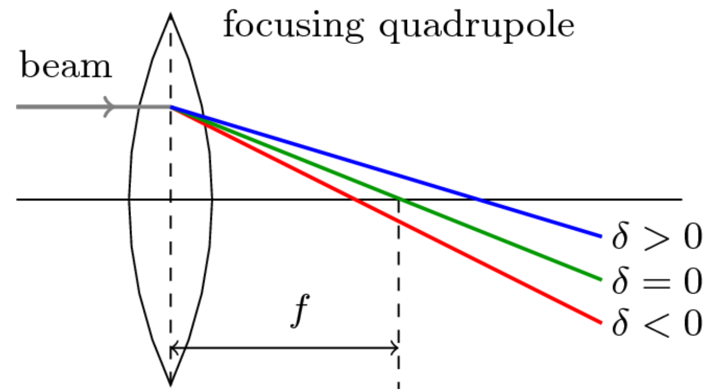
Emittance through Quadscan

Quadrupole scan

When $\delta = \frac{\Delta p}{p}$ is large





- Focal length depend on momentum → chromaticity
  - Beam size evolution varies with momentum and momentum distribution
- Analysis of quadrupole scan assumes monochromatic beam
  - New algorithm needed for large momentum spread

Chromatic Effects in Quadscans

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- Beam size with incoming Twiss in σ_{kl}

$$w^2(\delta) = R_{11}^2\left(\frac{k_0}{1+\delta}\right)\sigma_{11} + 2R_{11}\left(\frac{k_0}{1+\delta}\right)R_{12}\left(\frac{k_0}{1+\delta}\right)\sigma_{12} + R_{12}^2\left(\frac{k_0}{1+\delta}\right)\sigma_{22}$$

- Integrate numerically over momentum distribution $\psi(\delta)$

$$w^2 = \int_\delta w^2(\delta)\,\psi(\delta)\,d\delta = A\sigma_{11} + B\sigma_{12} + C\sigma_{22}$$

For **any** beamline and **any** momentum distribution $\psi(\delta)$.

- Illustrate for thin lenses: $f = \frac{1}{kl}$, $f = (1+\delta)f_0$
- We note that $R_{ij}(f) = a/f^2 + b/f + c$
- Integrating $w^2(\delta)$ over momentum distribution, the momentum dependence can be isolated as weighting factors ("chromatic integrals")

$$I_n = \int_\delta \frac{\psi(\delta)}{(1+\delta)^n}d\delta \quad n = 1, 2, 3, 4$$

- Can be calculated numerically for any distribution
  - Monochromatic beam: $I_n = 1$
  - CLIC decelerator: $I_1 = 0.71, \quad I_2 = 0.56, \quad I_3 = 0.46, \quad I_4 = 0.39$

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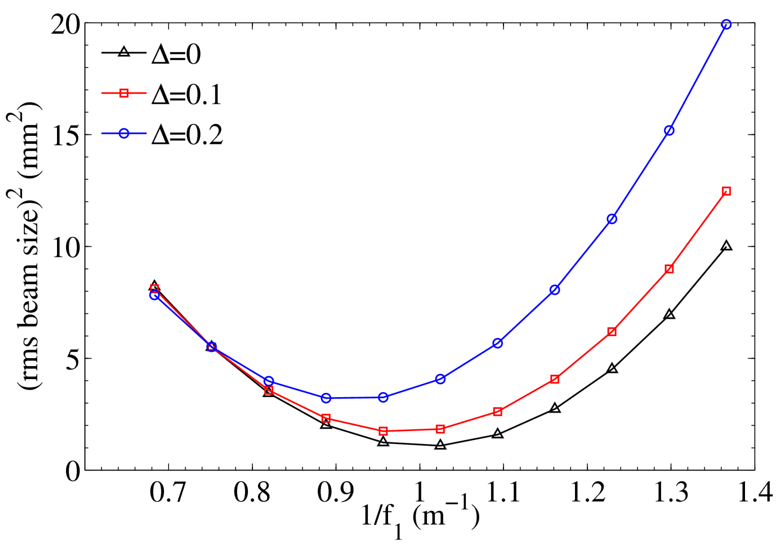
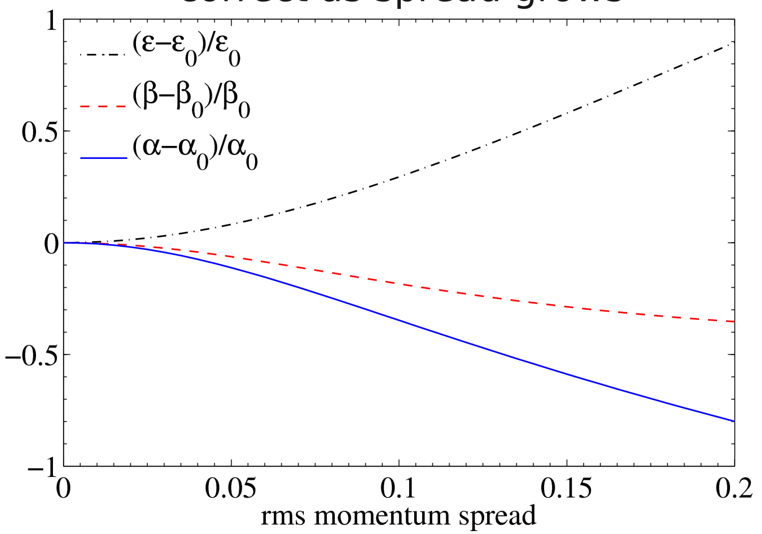
Example: Synthetic Quadscan

Beam size for varying focusing strength



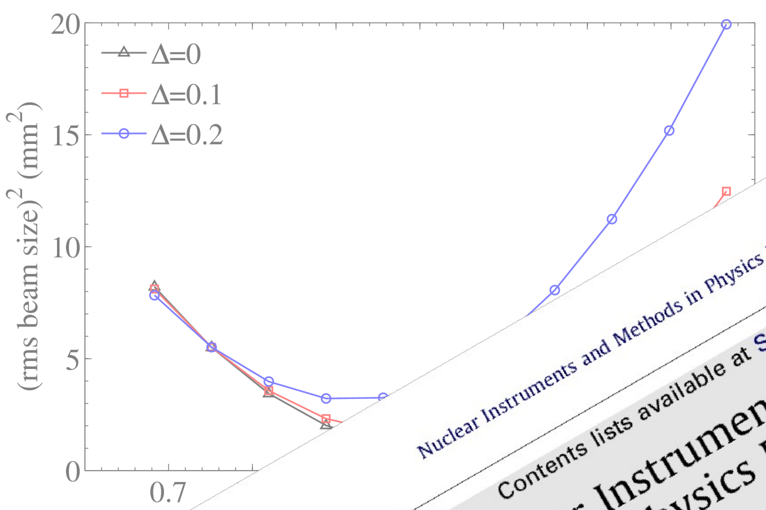
Extracted parameters diverge from correct as spread grows



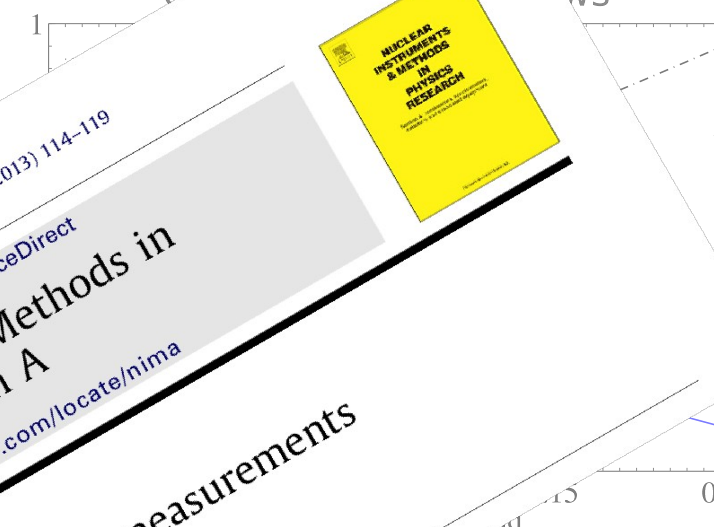
- Beam size on screen calculated with momentum distribution but analyzed without.
- Extracted parameters diverge from correct as spread grows.
- Effect can be accurately corrected.
- Chromatic effects also with multiple screen measurements. Similar algorithm to correct it.

Example: Synthetic Quadscan

Beam size for varying focusing strength



Extracted ... erge from ... ws



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Effect of large momentum spread on emittance measurements

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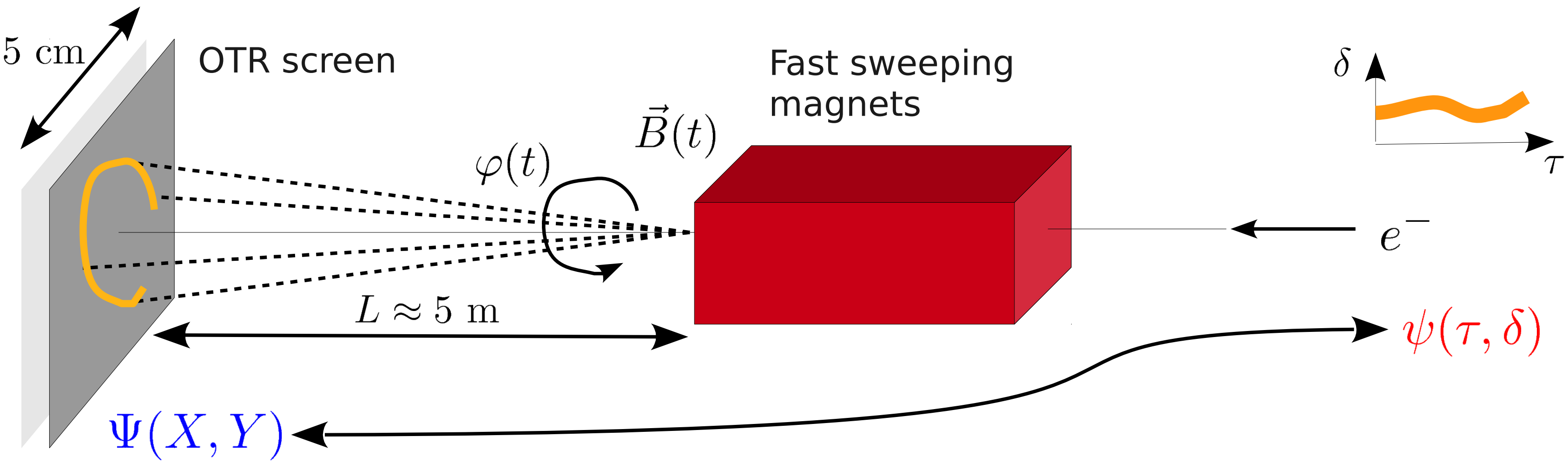
- Ef... corrected.
- Chro... also with multiple screen measurements. Simila... m to correct it.

The Post-PETS Line: Layout



- Two orthogonal magnets, excited with *sine/cosine* functions (Lissajous).
- Particle with momentum δ and arrival time τ hits screen at coordinates

$$\begin{cases} X = \dfrac{L\varphi_0}{1+\delta}\cos(2\pi\tau) \\ Y = \dfrac{L\varphi_0}{1+\delta}\sin(2\pi\tau) \end{cases}$$

with $0 < \tau < 1$ and $\tau = t/T$

Coordinate transformation from (τ, δ) to (X, Y) → Jacobi determinant

$$\Psi(X,Y) = \iint \psi(\tau,\delta)\delta_D\left(X - \frac{L\varphi_0\cos(2\pi\tau)}{1+\delta}\right)\delta_D\left(Y - \frac{L\varphi_0\sin(2\pi\tau)}{1+\delta}\right)d\tau d\delta$$

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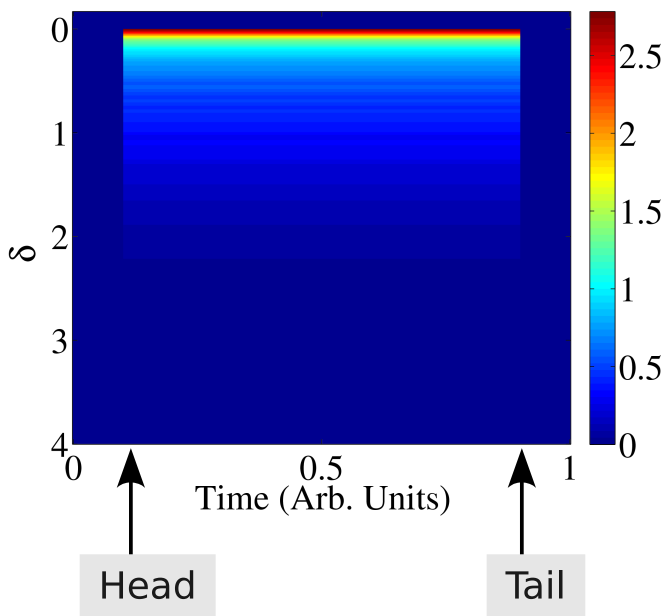
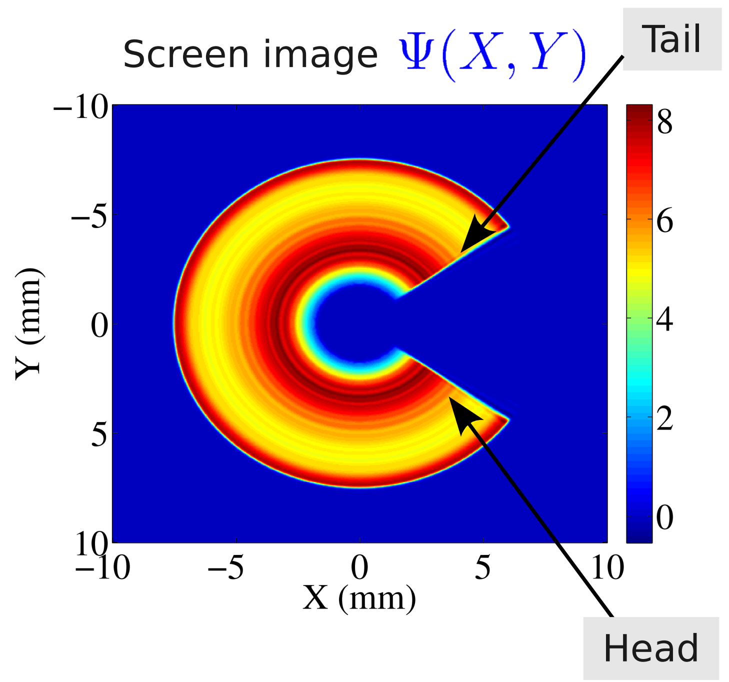
CLIC Distribution

$$\Psi(X,Y) = \frac{L\varphi_0}{2\pi}\frac{1}{(X^2+Y^2)^{3/2}}\psi(\tau,\delta) \quad \text{with} \quad \begin{cases} \tau = \frac{1}{2\pi}\arctan\left(\frac{Y}{X}\right) \\ \delta = \frac{L\varphi_0}{\sqrt{X^2+Y^2}} - 1 \end{cases}$$

Momentum distribution $\psi(\tau,\delta)$



Screen image $\Psi(X,Y)$



Inverse transformation: $\psi(\tau,\delta) = \frac{2\pi(L\varphi_0)^2}{(1+\delta)^3}\Psi(X,Y)$

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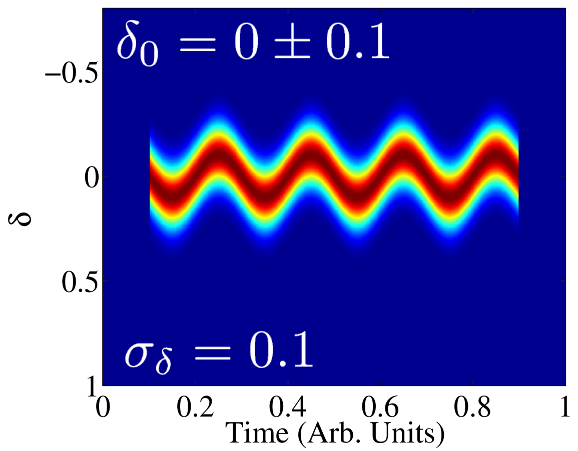
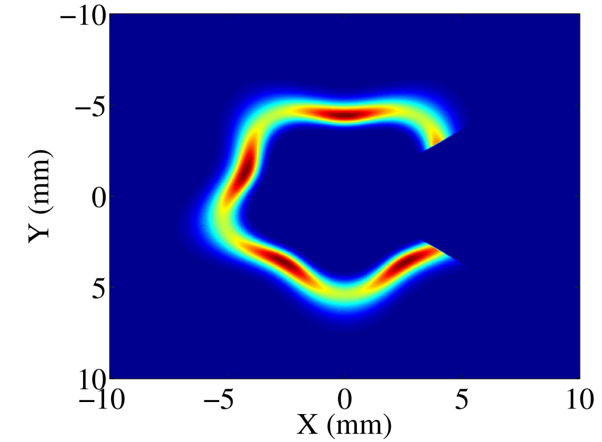
Gaussian Distribution

Initial distribution: $\psi(\tau, \delta)$

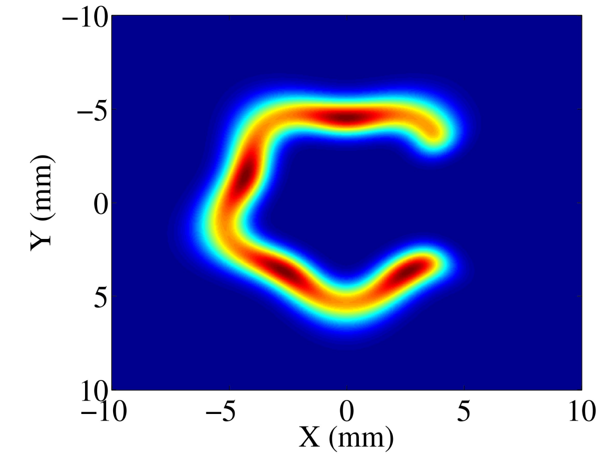


Project on screen

Screen image:

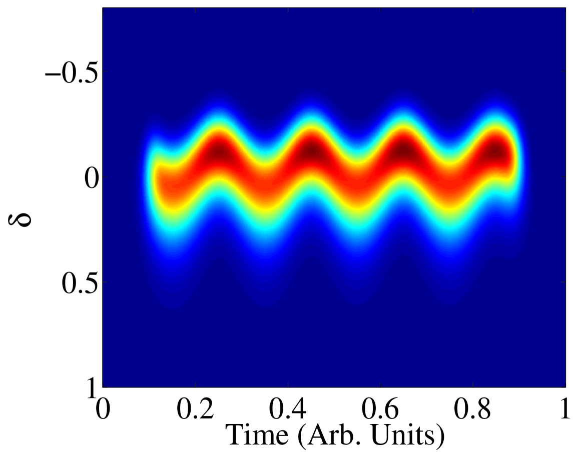


Add (large) emittance through convolution



Extract from screen image

Extracted distribution:



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Summary and Conclusions

- Standard diagnostic methods in the presence of large momentum spread
  - Systematic errors when analyzed conventionally
- Dispersion function fails
  - Non-perturbative spectrometry
- Excessive chromatic effects in quadrupole scans
  - Improved algorithm that correct for systematic effects.
- Time-resolved momentum measurements in the non-perturbative regime for the CLIC drive beam decelerator: the Post-PETS Line (POPEL)
  - Fast kicker magnet sweeping beam across OTR screen
  - Circular sweep for time-resolved spectrometry

Thank you

for your attention!