FACET-II Diagnostics
TCAV & Spectrometer

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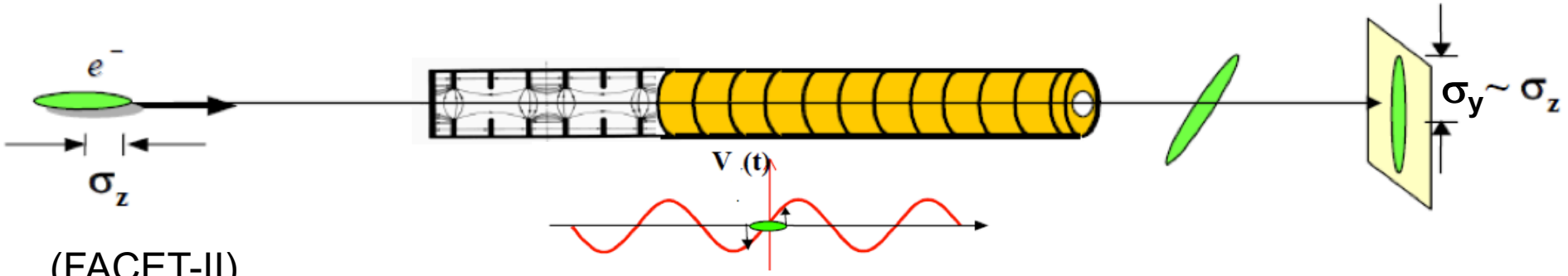
U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

TCAV Setup – Resolution Limits



(FACET-II)

Parameters:

σ_0=100μm
β_d~75m
β_s=6.25m
} R_{34}~20m
$\Delta\psi$=1.18
ϕ=0
eV_0=15 MeV
E_0=10000 MeV

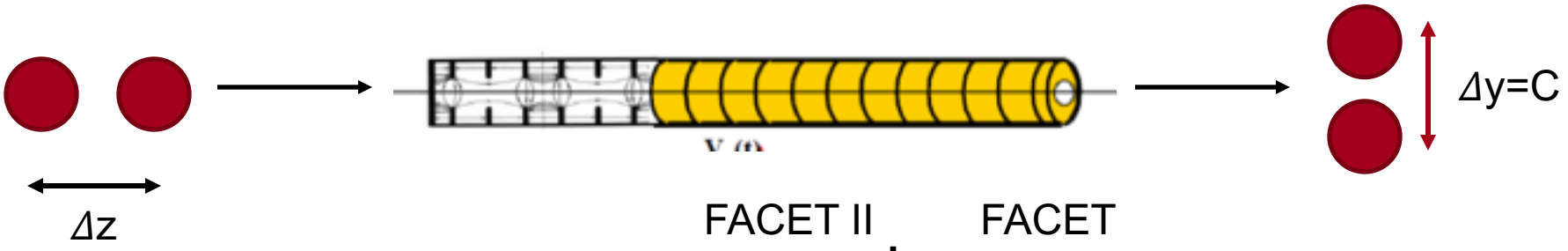
$$\Delta y \sim \frac{eV_0}{E_0}\sqrt{\beta_d\beta_s}\sin(\Delta\psi)\left(\frac{2\pi}{\lambda_{rf}}z\cos\phi + \sin\phi\right) \approx \mathrm{Sz}$$

$$\mathrm{S} \equiv \frac{2\pi eV_0}{\lambda_{rf}E_0}\sqrt{\beta_d\beta_s}\,\sin(\Delta\psi)\cos\phi \sim 8.5$$

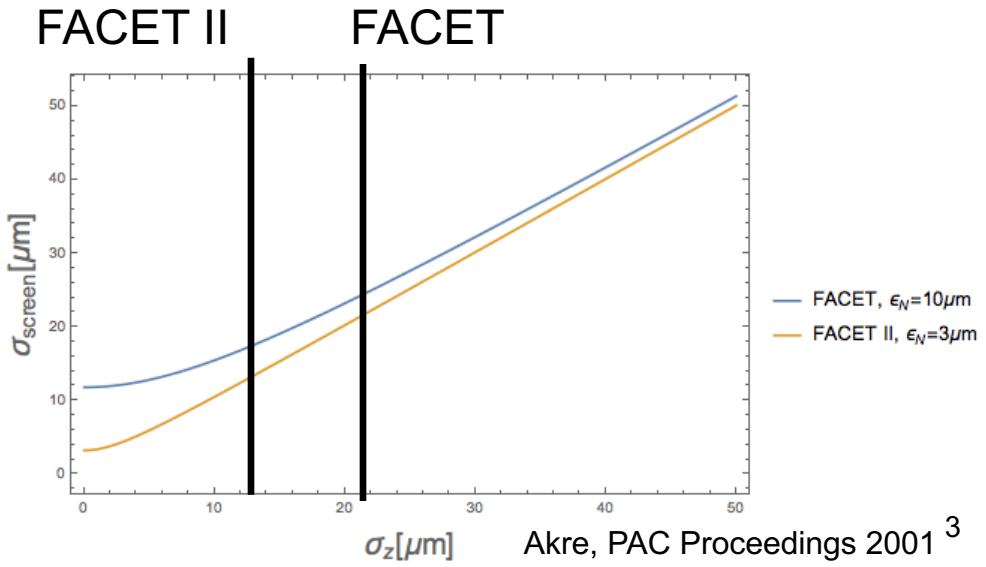
$$\sigma_y^2 = \sigma_0^2 + \sigma_z^2 S^2 = \varepsilon\beta + \sigma_z^2 S^2$$

TCAV

- How does emittance change measurement?
- “Single Particle”
- If measurement system resolves C=10 μm->Δz=C/S=1.2 μm (0.6 μm@ FACET II)

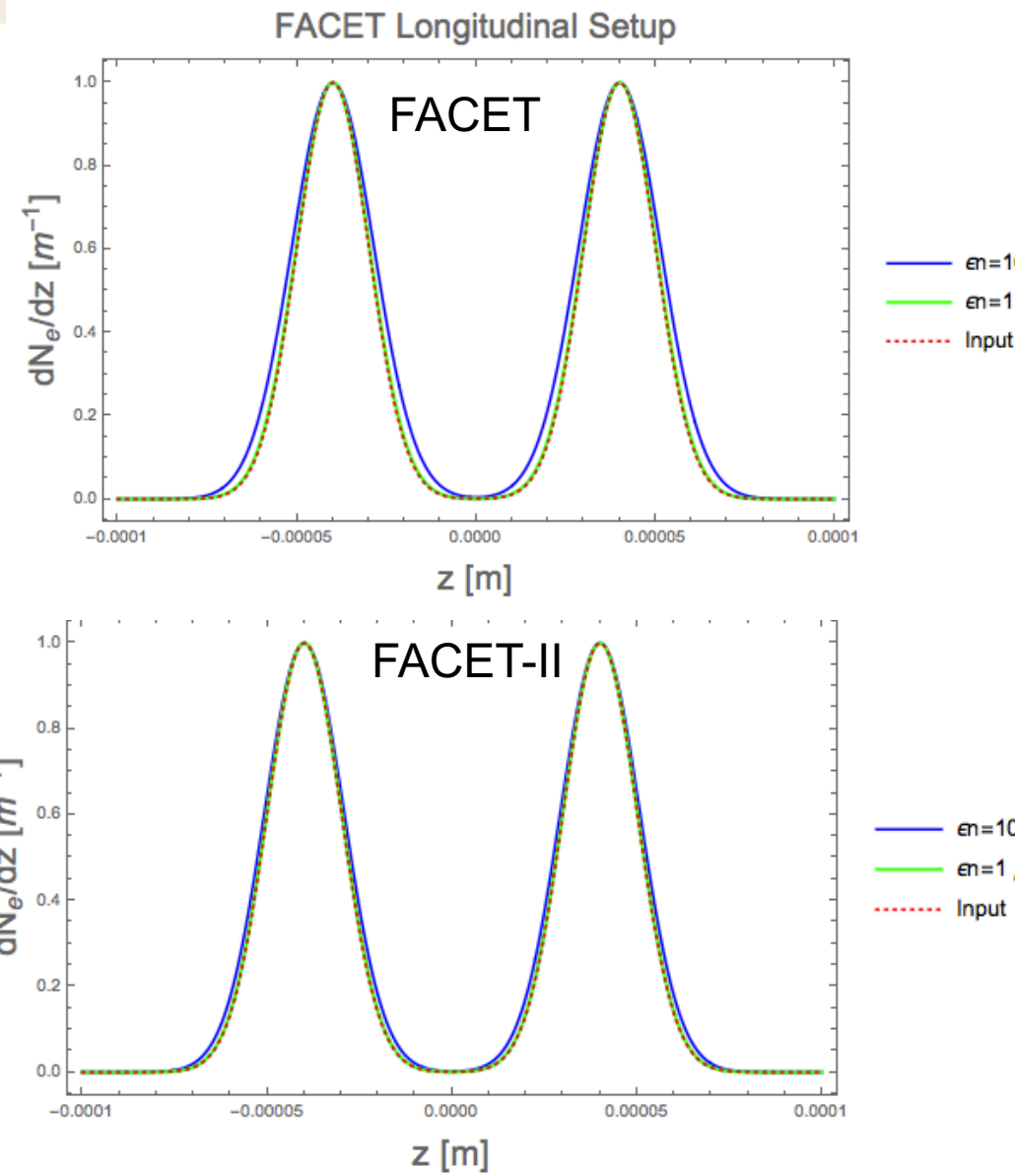


- Finite beam sizes, but only one image (Gaussian):



Example Multiple bunch

- Bunch separation: 267 fs
- Beam Optics: FACET for both
- Bunch lengths: σ_z=10 um



Parameters:
σ_0=100μm
β_d~75m
β_s=6.25m
} R_{34}~20m
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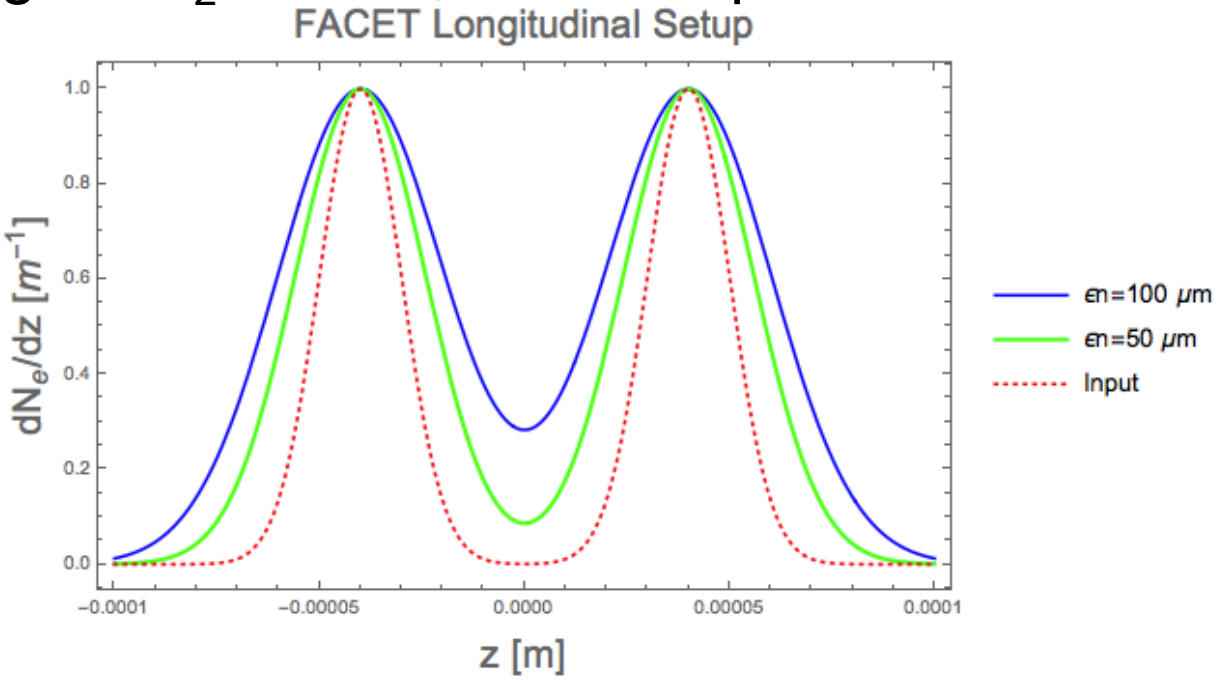
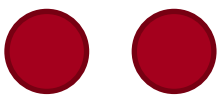
ϕ=0
eV_0=15 MeV
E_0=10000 MeV

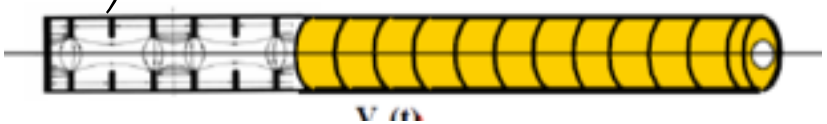
What about relatively large emittances?

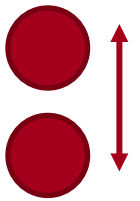
- Bunch lengths: σ_z=10 um, 75 um separation



$$\epsilon_N \leq \frac{\gamma S^2 \sigma_z^2}{\beta_s}\left(\left(\frac{N_z}{N_x}\right)^2 - 1\right) = 18\mu m$$ FACET-II, N_z=8, N_x=6





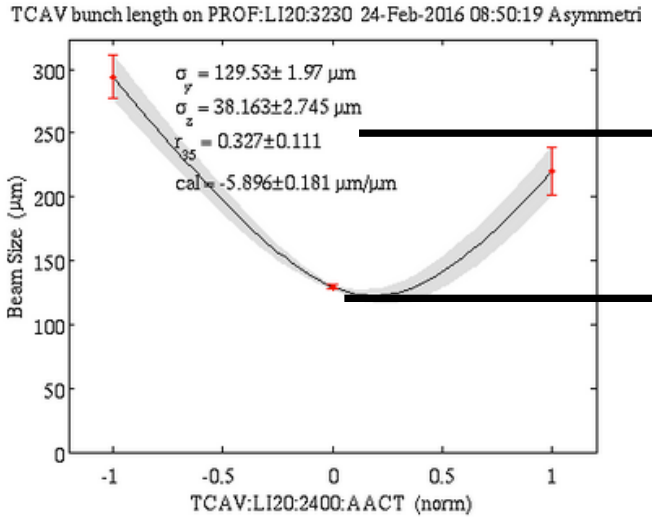


$\Delta y = N_x \sigma_x$

$\Delta z = N_z \sigma_z$

TCAV Multi Image (single bunch, FACET-II)

This measurement:



$\sigma_{x,max}$

$\sigma_0 \geq \frac{C}{2}$

$\Delta\sigma_x = \sigma_{x,m} - \sigma_0 \geq Res$

$Res = \frac{M_2 \Delta f^3}{24 n^2}$

$Res \rightarrow \frac{C^2}{4\sigma_x}$

$\Delta f = 6\sigma_x$

$M_2 = 6\sigma_x$

$n = \frac{\Delta f}{c}$

Gaussian

C = 10μm

$\epsilon_N \geq \frac{\gamma C^2}{4\beta} = 78\ nm$

Parameters:

σ_0=100μm
β_d~75m
β_s=6.25m
} R_{34}~20m

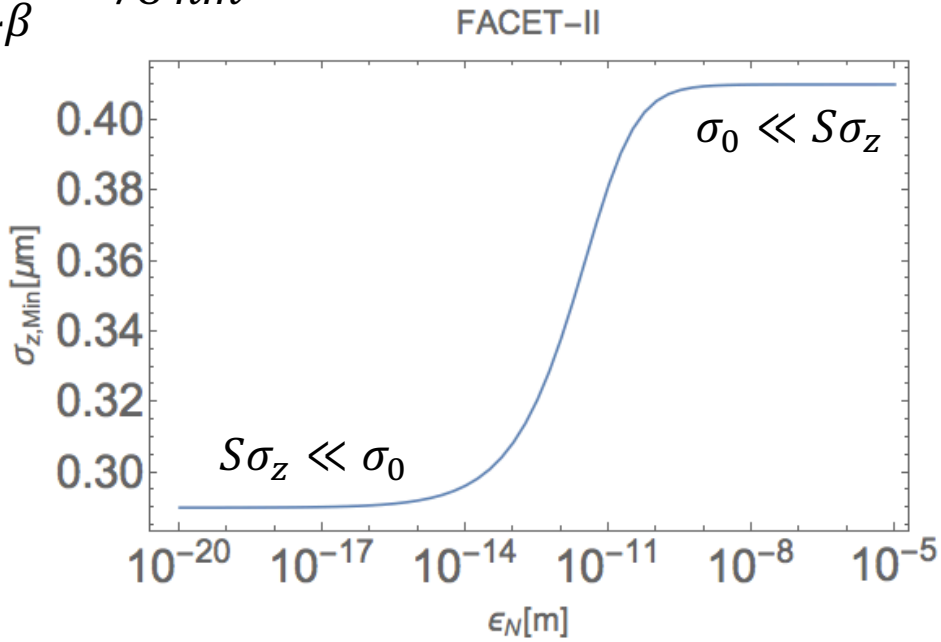
$\Delta\psi$=1.18

ϕ=0

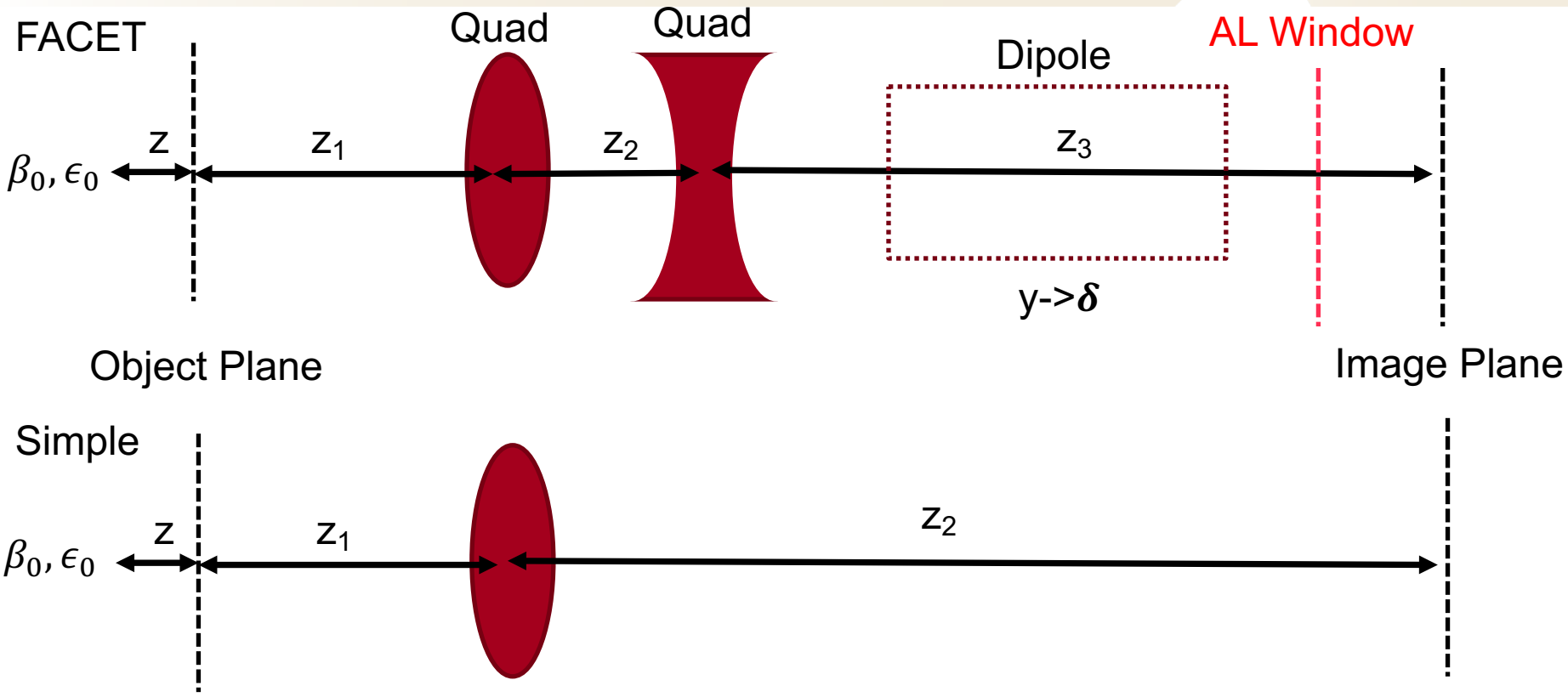
eV_0=15 MeV

E_0=10000 MeV

S = 8.5



Spectrometer Resolution



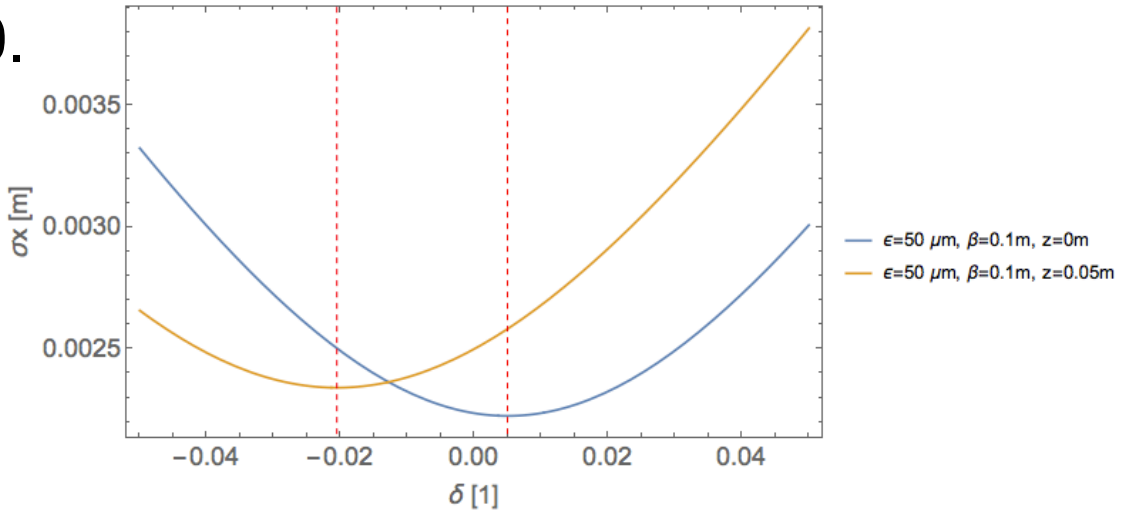
Simple:

$$\frac{1}{f} \rightarrow \frac{1-\delta}{f}$$

$$M = \begin{pmatrix} \delta + \frac{z2}{z1}(\delta - 1) & (z1 + z2)\delta + z\left[\delta + \frac{z2}{z1}(\delta - 1)\right] \\ \frac{(z1 + z2)}{z1z2}(\delta - 1) & Not\ Important \end{pmatrix}$$

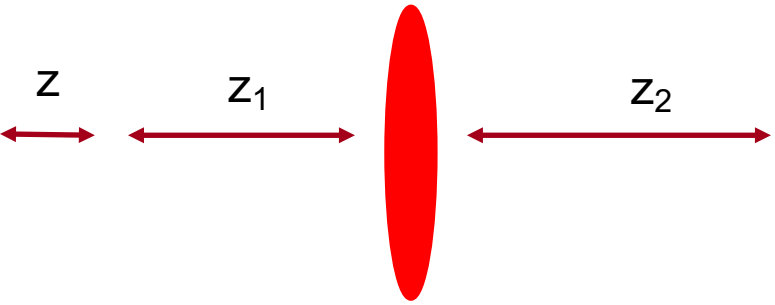
Chromaticity and the simple system

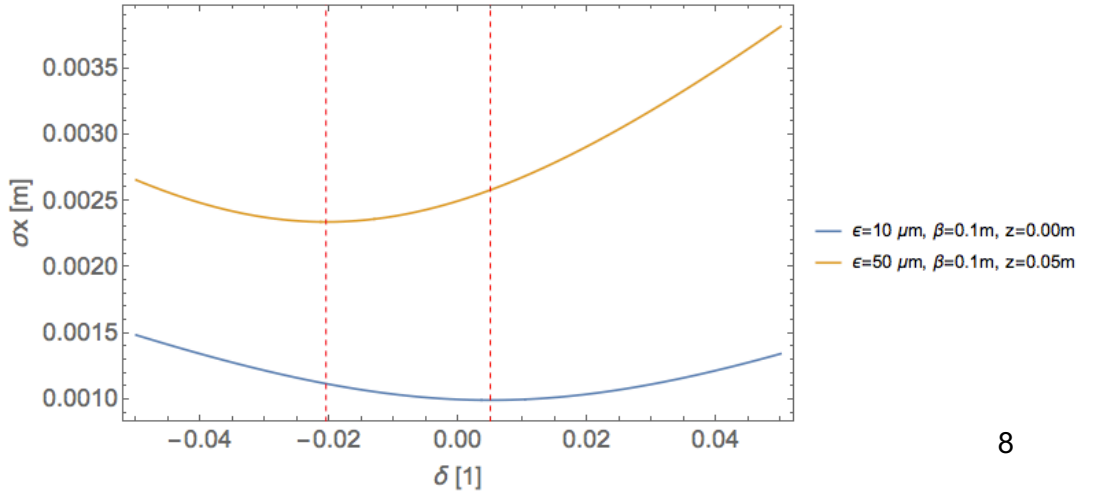
- Enforce $M_{12}=0$ for $\delta=0$.
- Assume the beam reaches a waist some distance z from the object plane.



$$Offset = \frac{1}{2}\frac{\beta^2 + z(z+1)}{(\beta^2 + (z-1)^2)}$$

$z_1=z_2=1$



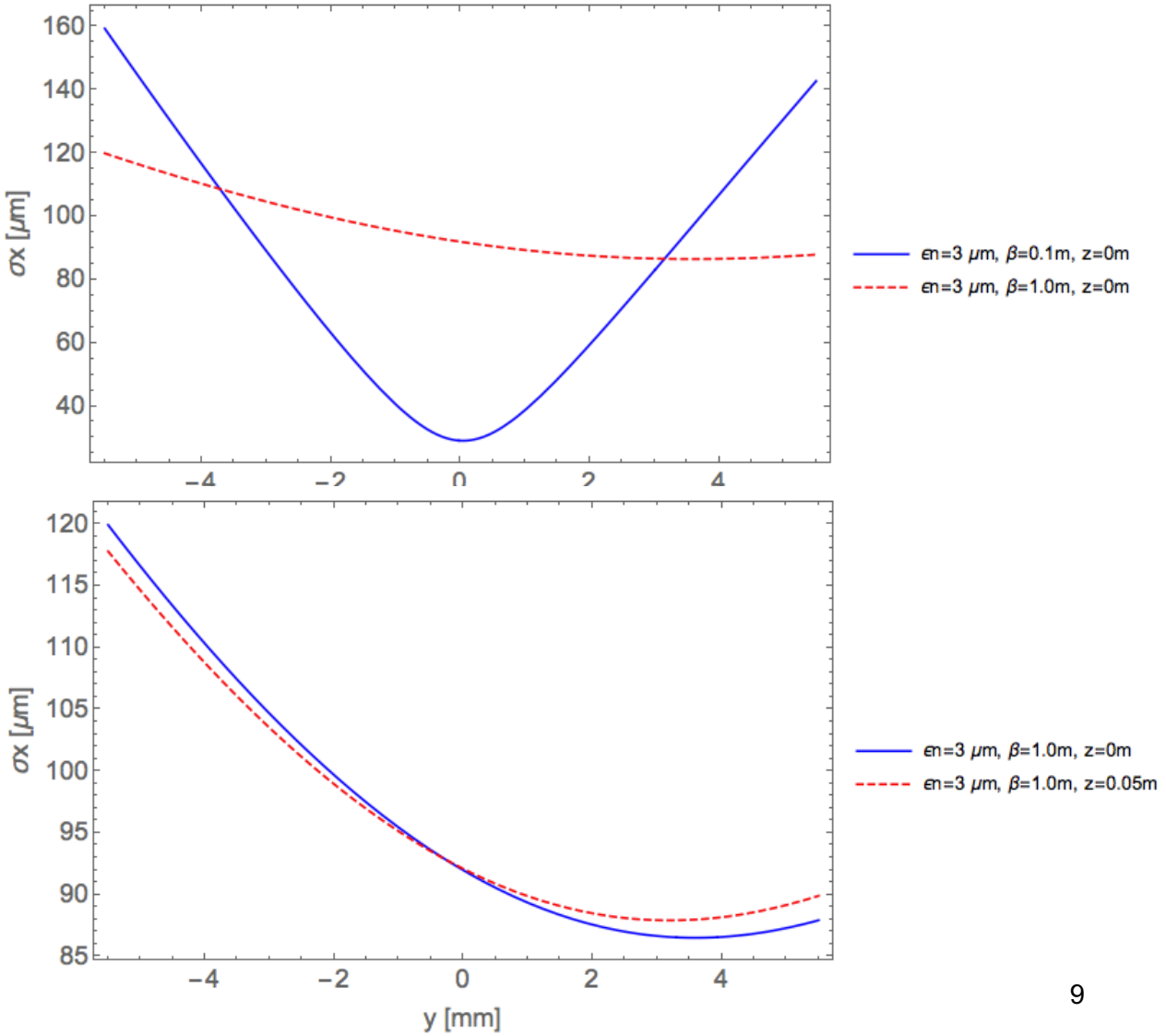


The FACET I/II Case

- Enforce M12 = M34=0.
- Assume that we do not know the beam's waist location.
- For small β the pinch dominated by z.

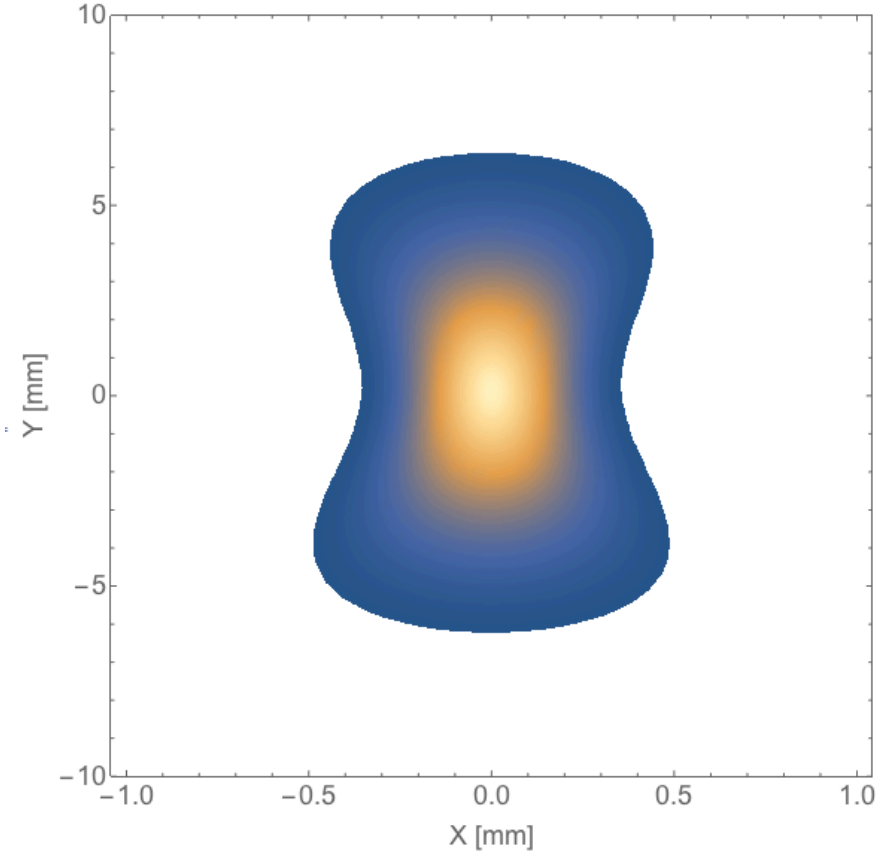
$$\frac{\sigma_x^2}{\epsilon} = M_{11}^2(\delta, z)\beta_0 + \frac{M_{12}^2(\delta, z)}{\beta_0}$$

FACET-II

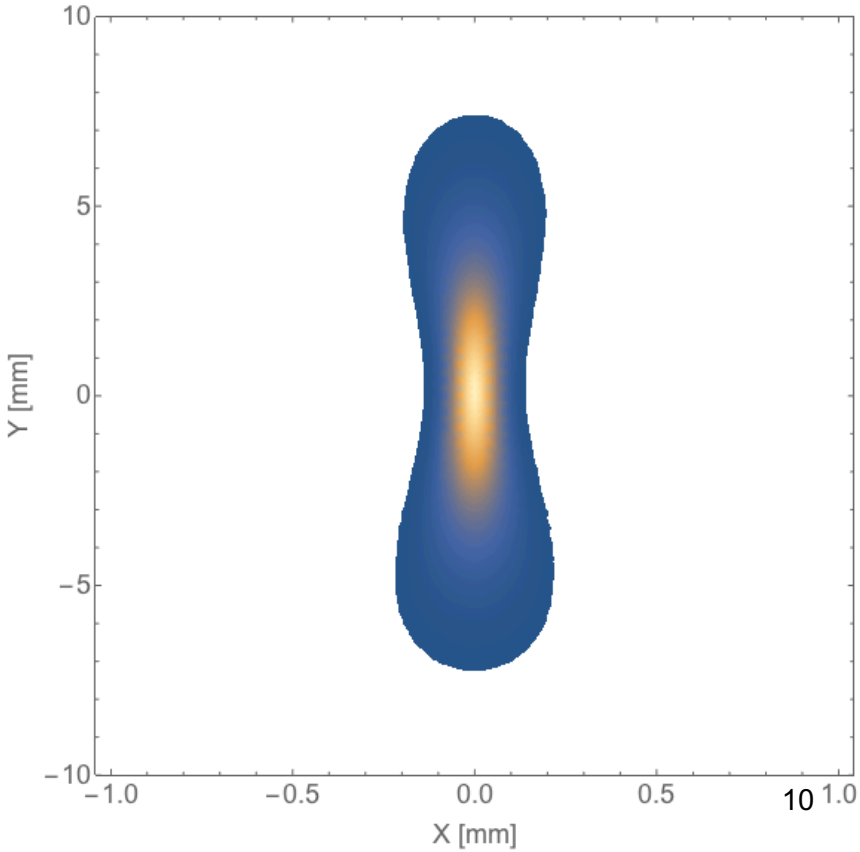


Examples @ FACET & FACET II

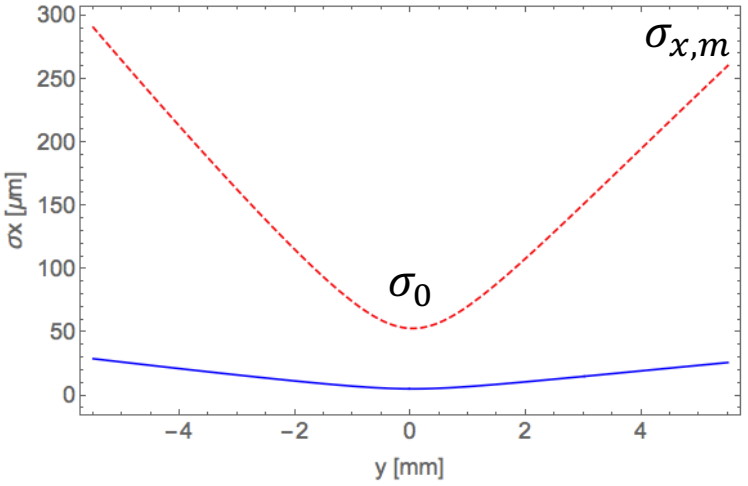
FACET
rms energy
spread 5%
50 um emittance
β=0.25m

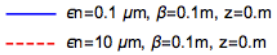


FACET-II
rms energy
spread 5%
3 um emittance
β=0.25m



What is the minimum emittance measurable?

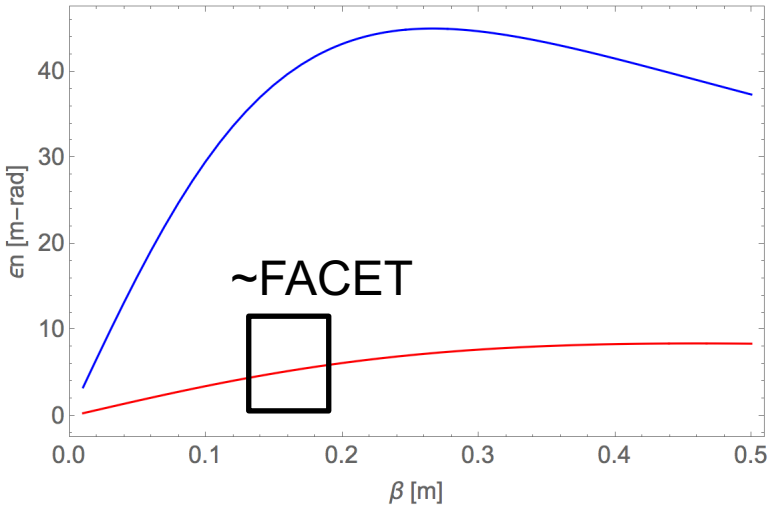


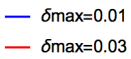


$$Res \rightarrow \frac{C^2}{4\sigma_x} \qquad \Delta\sigma_x = \sigma_{x,m} - \sigma_0 \geq Res$$

$$\sigma_{x,m} - \sigma_0 \geq \frac{C^2}{4\sigma_x}$$

$$\epsilon_N \geq \frac{\gamma C^2}{4} \frac{1}{[M_{11}^2(\delta) - M_{11}^2(0)]\beta_0 + [M_{12}^2(\delta) - M_{12}^2(0)]\frac{1}{\beta_0}}$$





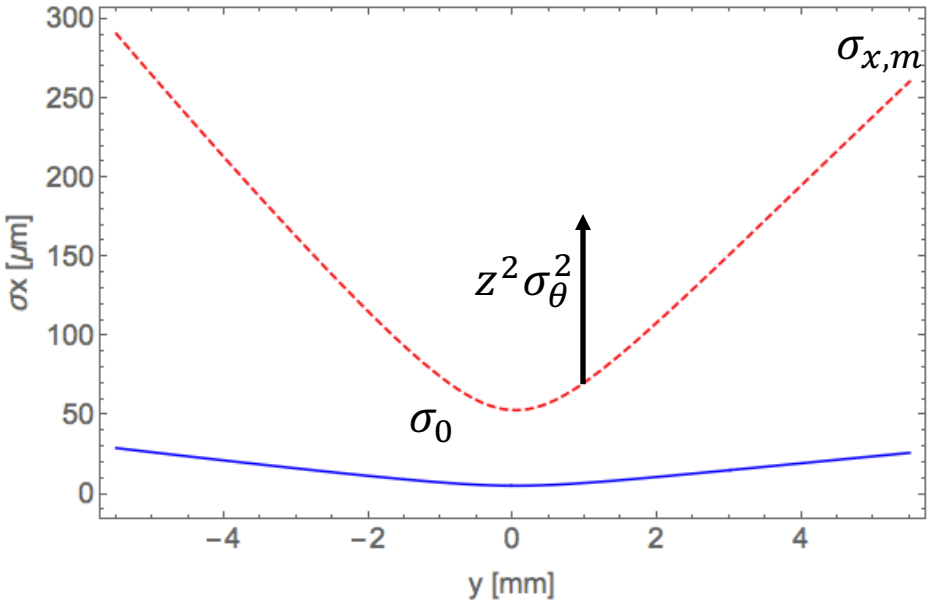
$$\sigma_{x,m}^2 - \sigma_0^2 \geq \frac{C^2}{4}$$

$$\sigma_{x,m}\sigma_0 - \sigma_0^2 \geq \frac{C^2}{4}$$

C = 100 um

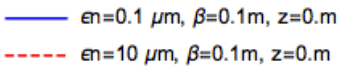
Effect of the AL Window?

$$\sigma_x^2 = a\delta^2 + b\delta + c \rightarrow a\delta^2 + b\delta + c + z^2\sigma_\theta^2$$

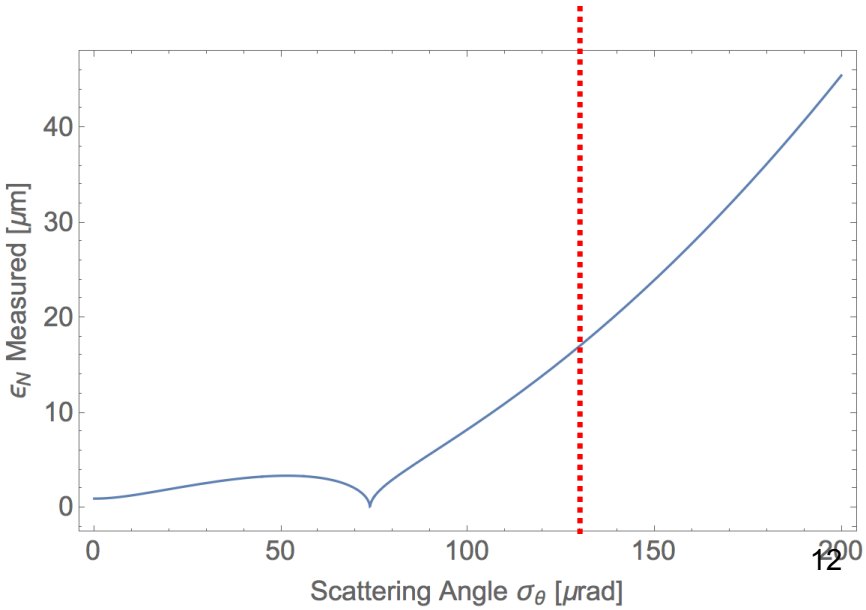


Input:

- β = 0.15m
- ε = 1μm
- Assume waist at object plane



Al Window



$$\beta_{meas} = \frac{2\sqrt{c}}{\sqrt{a-4c}}$$

$$\varepsilon_{meas} = \frac{1}{2}\frac{a\sqrt{c}}{\sqrt{a-4c}} - \frac{1}{2}\frac{4c^{3/2}}{\sqrt{a-4c}}$$

Conclusions

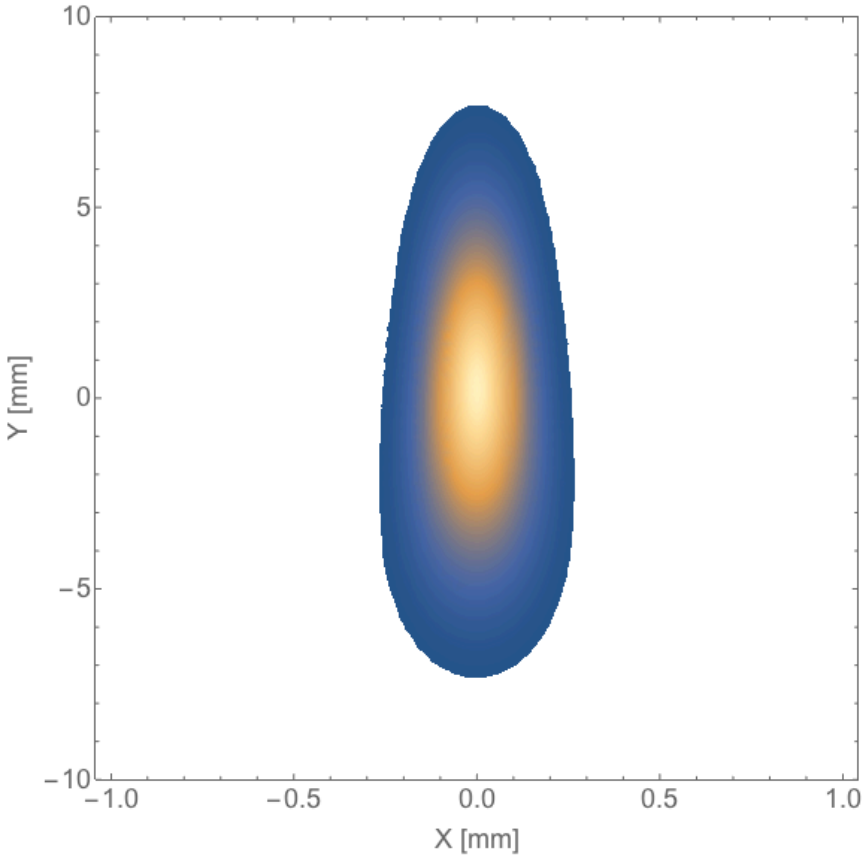
- TCAV
  - Generally can measure bunch length when: $S\sigma_z \geq \frac{C}{2}$
  - Single bunch length measurement resolution actually very weakly depends on emittance for FACET like parameters.
  - If detection resolution C = 10 μm, S=8.5 -> σ_z = 0.6 μm
  - Two bunch measurement: Want: $\epsilon_N \leq \frac{\gamma S^2 \sigma_z^2}{\beta_s}\left(\left(\frac{N_z}{N_x}\right)^2 - 1\right)$
- Spectrometer
  - FACET-II Limited to ~30 um (for FACET like beams)
  - Can improve things by improving calibration in the optical system.
  - Optics?
  - Better light collection
  - Get rid of AL window!

can only measure $\epsilon_N \geq \frac{\gamma C^2}{4}\frac{1}{\left[M_{11}^2(\delta)-M_{11}^2(0)\right]\beta_0+\left[M_{12}^2(\delta)-M_{12}^2(0)\right]\frac{1}{\beta_0}}$

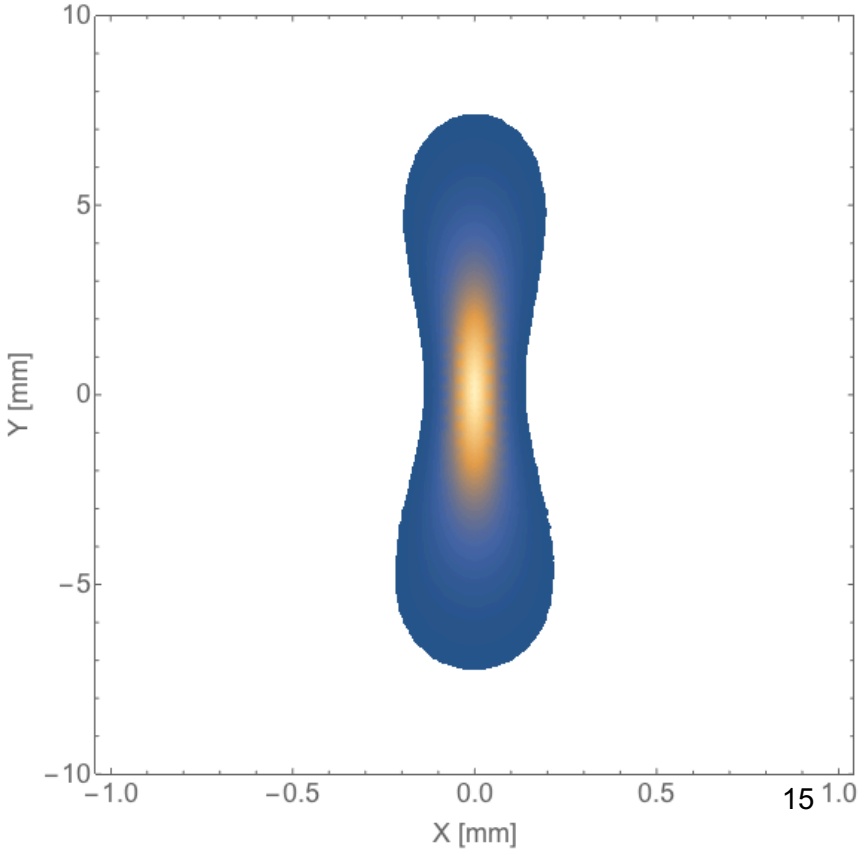
Other Stuff

A FACET-II Comparison

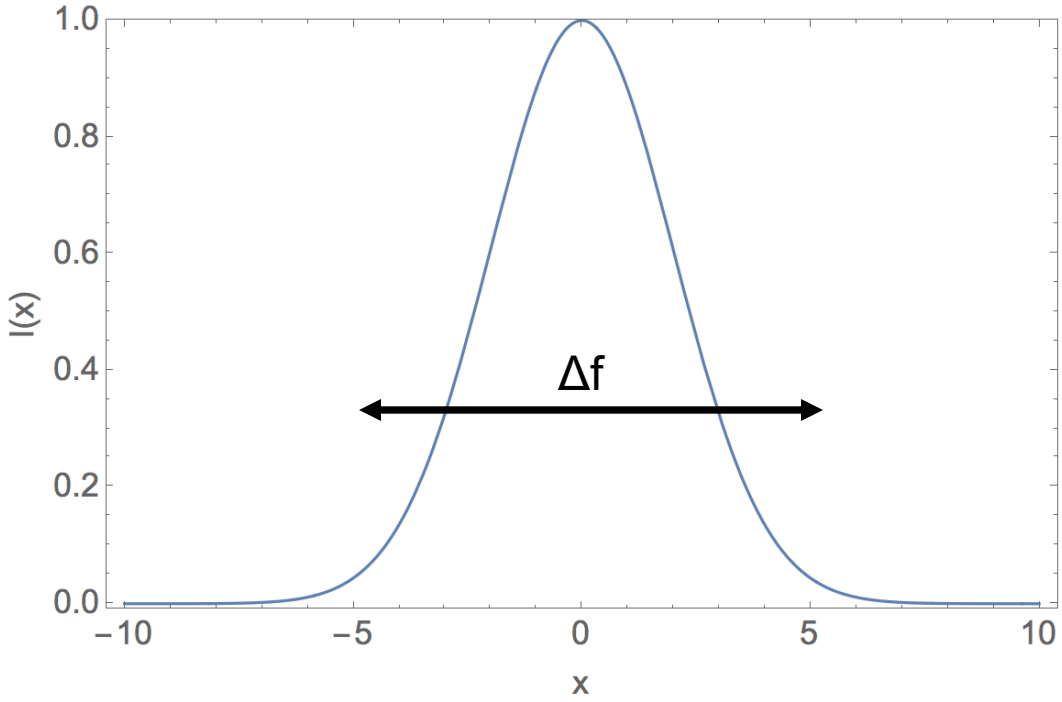
rms energy
spread 5%
3 um emittance
β=1.0m



rms energy
spread 5%
3 um emittance
β=0.25m



The resolution approximation



$$Error = \frac{M_2 \Delta f^3}{24 n^2}$$

$$n = \frac{\Delta f}{c}$$

M2 is shape dependent.

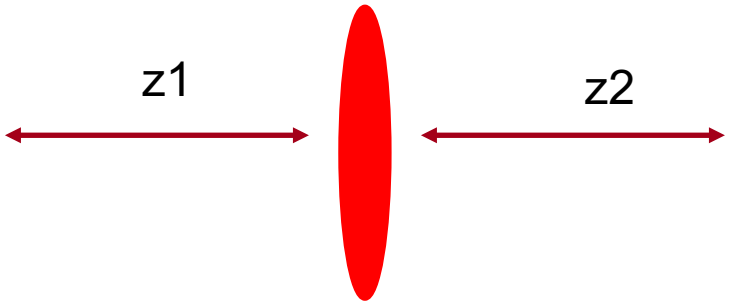
Chromaticity and a simple system

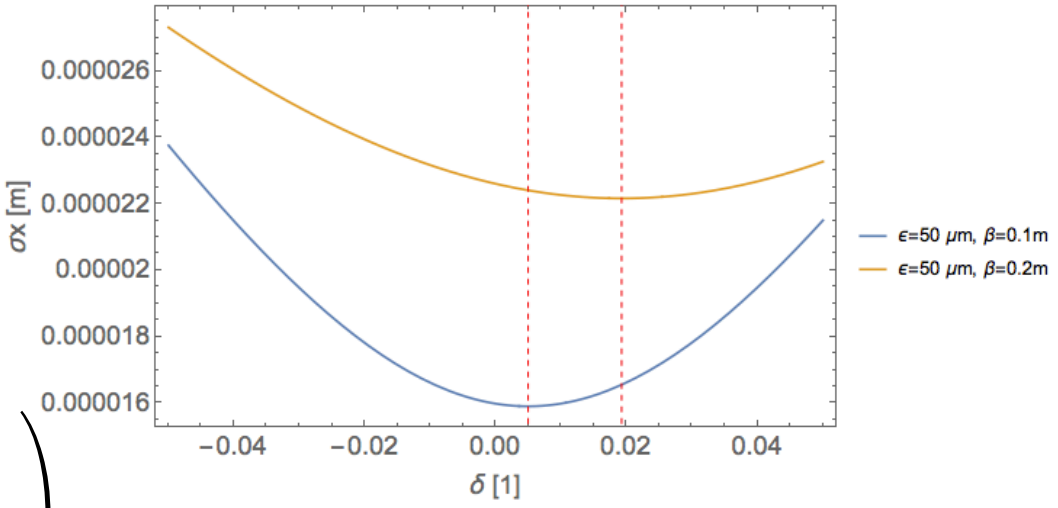
- Enforce M12=0 for δ=0.
- Assume the beam is always at a waist in the object plane (for now).

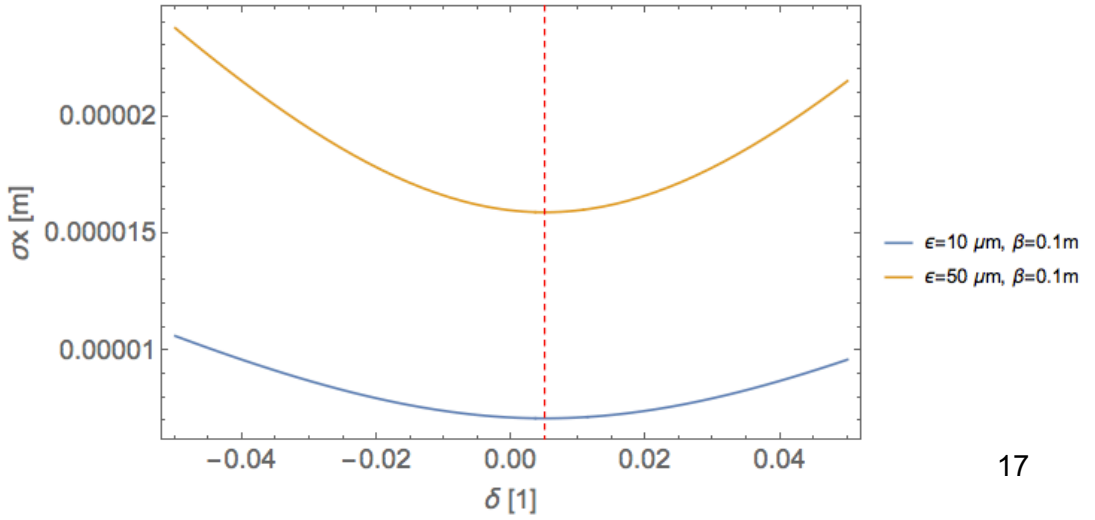
$$M = \begin{pmatrix} \delta + \frac{z2}{z1}(\delta - 1) & (z1 + z2)\delta \\ \frac{(z1 + z2)}{z1z2}(\delta - 1) & \delta + \frac{z1}{z2}(\delta - 1) \end{pmatrix}$$

z1=z2=1

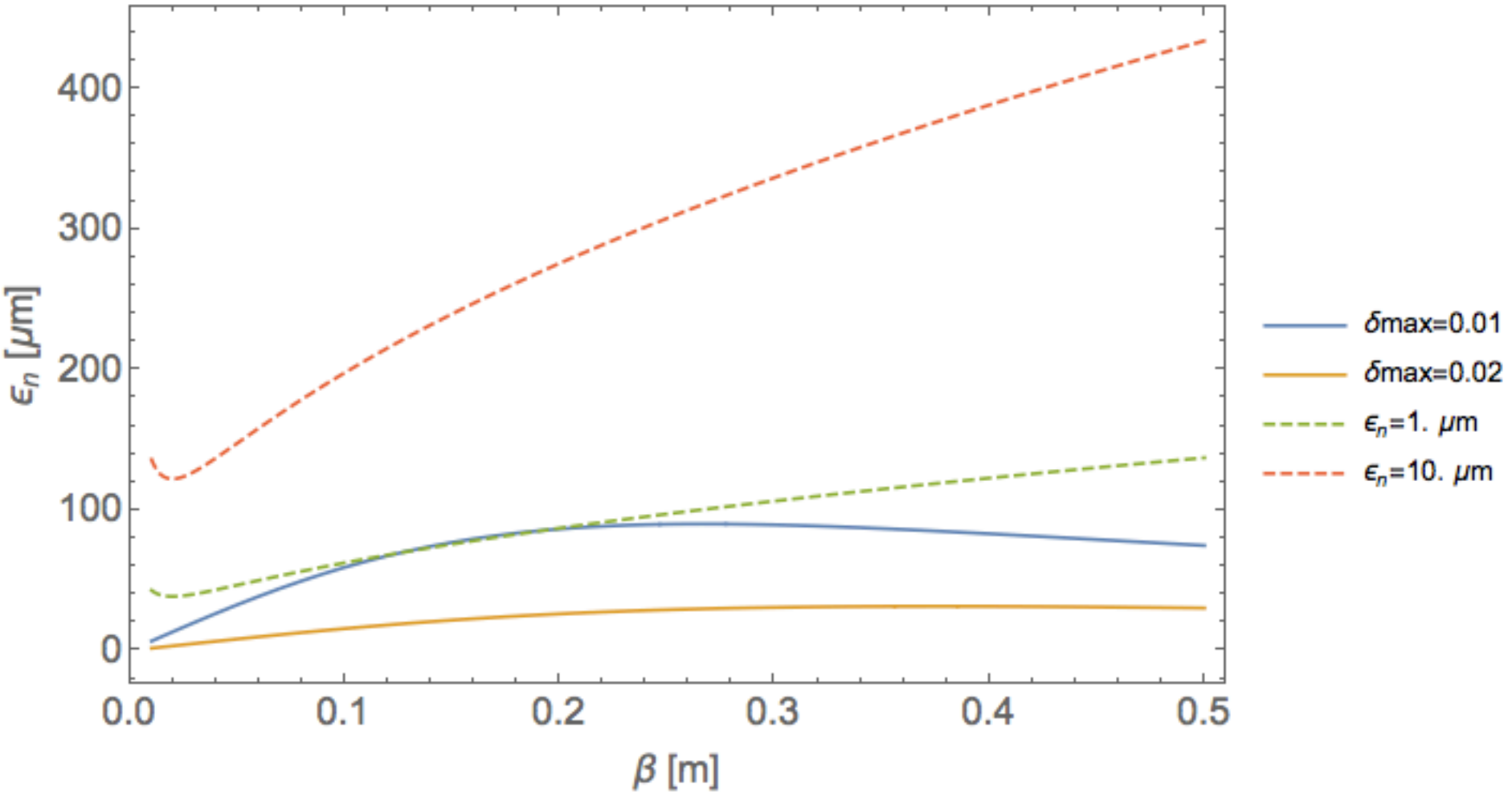
$$Offset = \frac{\beta^2}{2(1 + \beta^2)}$$







What about FACET?



For the single bunch TCAV, why does emittance not matter?

$$\Delta\sigma_x = \sigma_{x,m} - \sigma_0 \geq Res$$

$$+$$

$$Res \rightarrow \frac{C^2}{4\sigma_x}$$

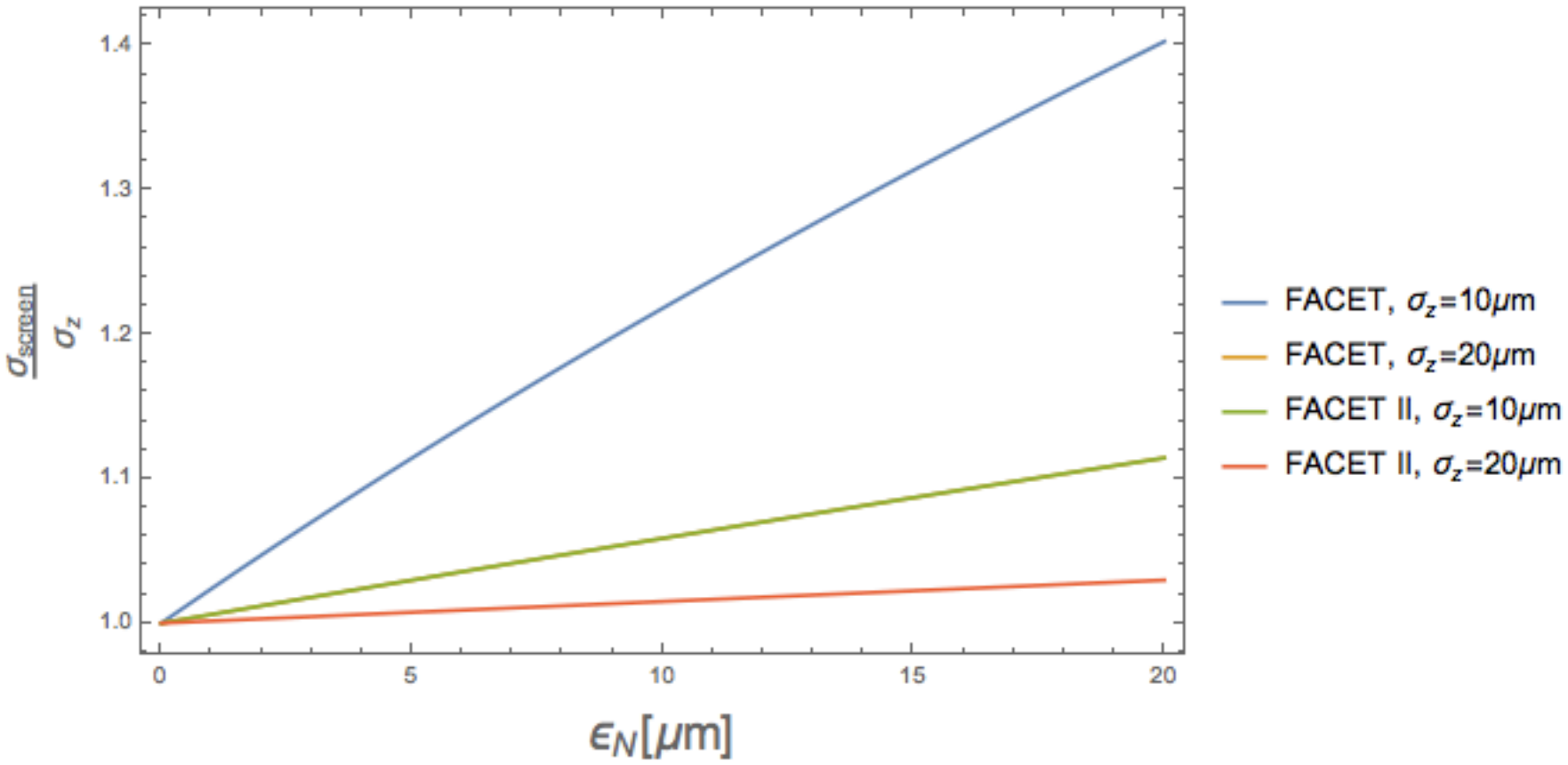
$$\downarrow$$

$$\sigma_{x,m}^2 - \sigma_0^2 \geq \frac{C^2}{4}$$

$$\downarrow$$

$$\sigma_0^2 + S^2\sigma_z^2 - \sigma_0^2 \geq \frac{C^2}{4}$$

TCAV pt. 2 (Once more single image)



SLAC National Accelerator Laboratory

SLAC

Our mission:

- Grow into a premier photon science laboratory
- Maintain our position as the premier accelerator laboratory
- Pursue strategic programs in particle physics, particle astrophysics and cosmology

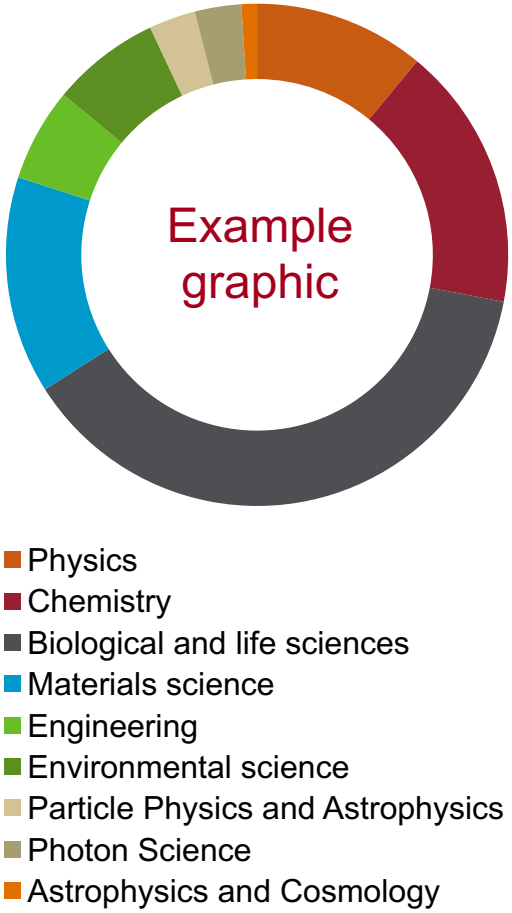
SLAC National Accelerator Laboratory
2 line headline option

- This PowerPoint template is one example of SLAC's new visual identity guidelines, which were introduced to:
- Ensure that the lab presents a unified look across all materials
- Create a strong, modern brand that distinguishes SLAC as a leader in scientific discovery

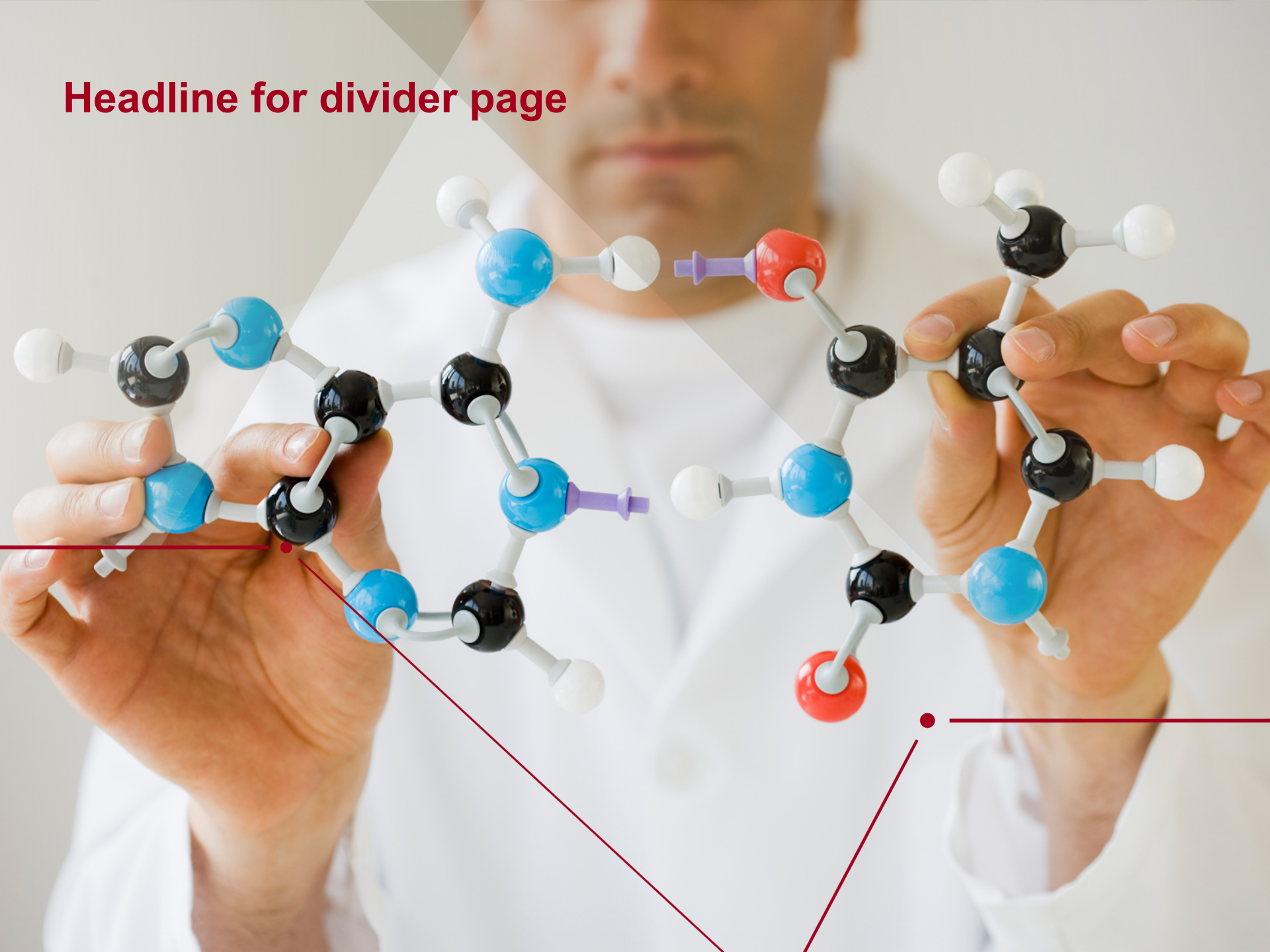
Sample images

Example graphic with secondary colors

- The complete visual identity guidelines are available on the Office of Communications website, as well as:
  - Letterhead template
  - Business card template
  - Logo files
- Please email communications@slac.stanford.edu with any questions or feedback.



Headline for divider page



Blank divider page

INSERT PREFERRED IMAGE AS BACKGROUND – INSTRUCTIONS:

1: Click “Insert” from menu and choose “Picture” to select image

2: Once image is inserted, right-click image and choose ‘Send to Back’