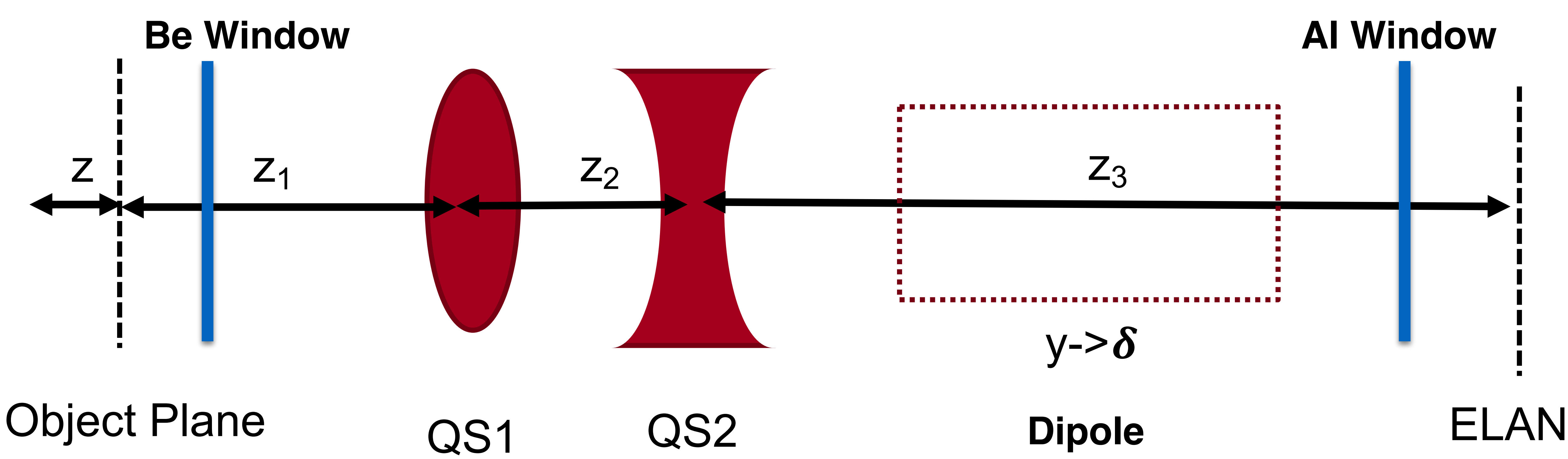
FACET-II Emittance Measurements

FACET-II SCIENCE WORKSHOP 2017
Kavli Auditorium, SLAC

Brendan O'Shea
October 17, 2017

FACET Spectrometer

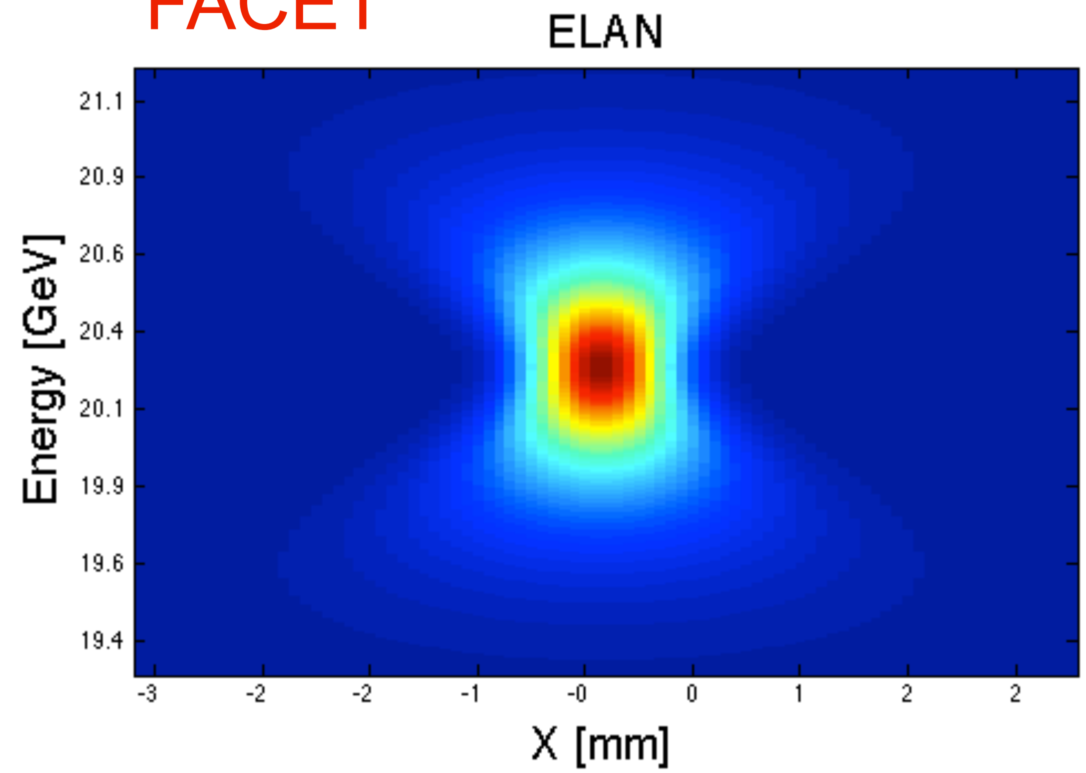
- Calibration of ~13 um/pixel
- Resolution dominated by pixel size
- Demand Imaging in x&y (energy) direction, $M_{12}=M_{34}=0$
- Two options a priori: change light optics or magnetic optics



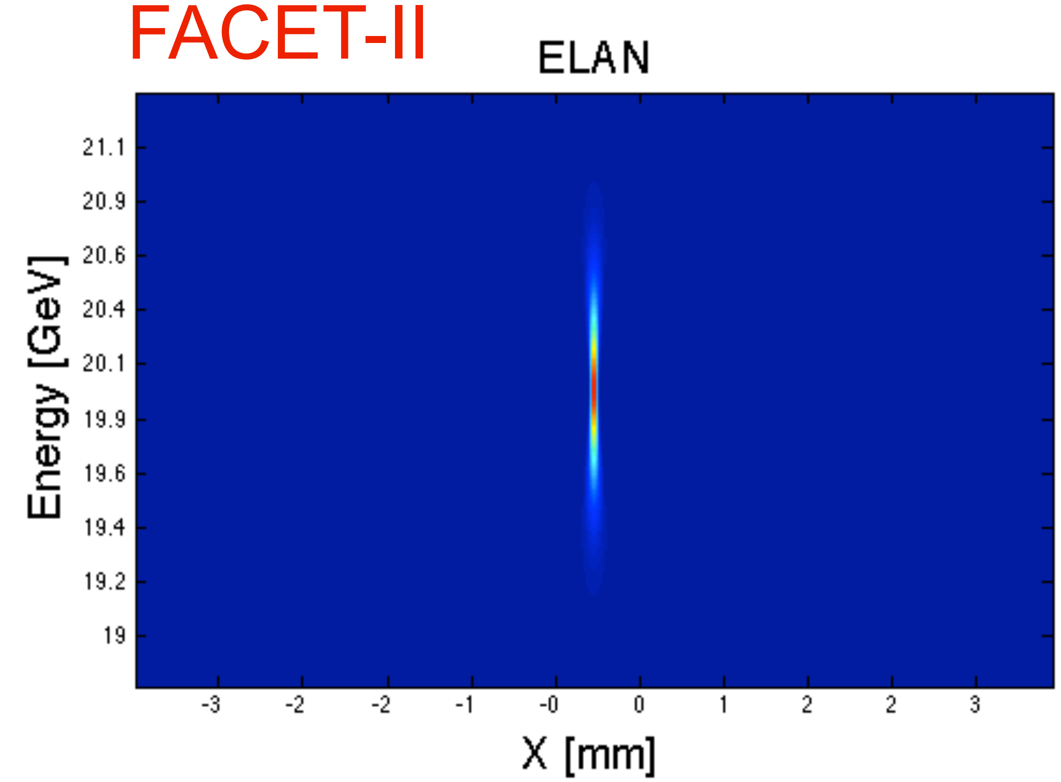
Measuring Emittance

- Butterfly technique for emittance measurement relies on imaging the beam waist, measuring contrast between waist and highest/lowest energy
- Emittance at FACET-II is ~10 times better than at FACET
  - FACET : σ_{x0}~91 μm (ϵ_{xn}=30 μm)
  - FACET II : σ_{x0}~14 μm (ϵ_{xn}=3 μm)
  - Injection Experiment : σ_{x0}~8.4 μm (ϵ_{xn}=0.1 μm)
    - Lower energy though…

FACET



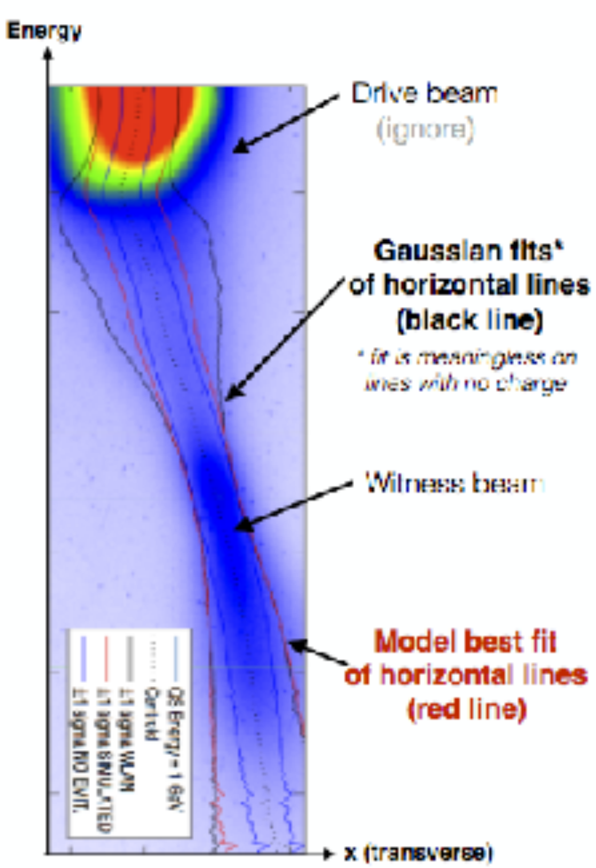
FACET-II



Measurement Experience at FACET

E210

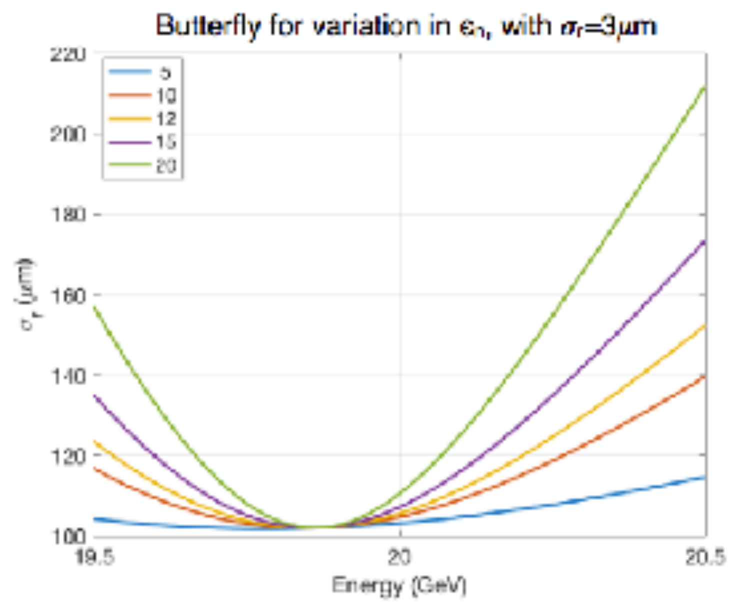
- Make assumptions about divergence before window
- Tune model to best fit data
- low-emittance, low-energy beams difficult due to increased scattering

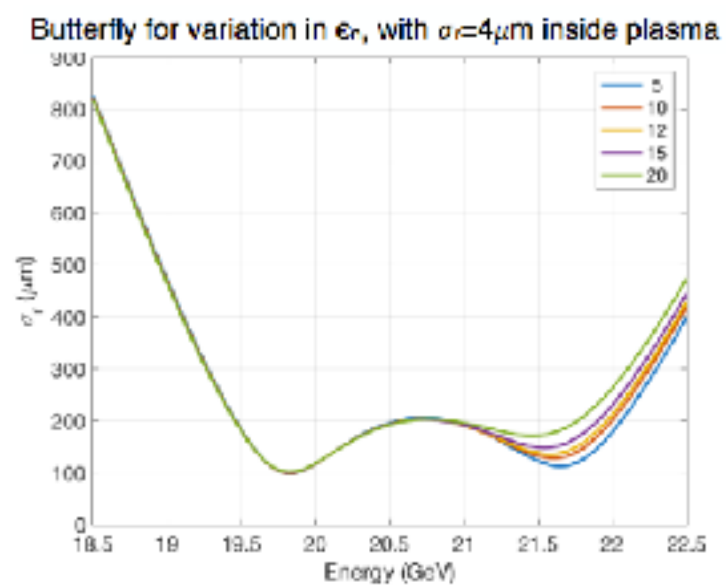


C. Lindstrom FACET-II Science Workshop 2016

E217

- Incorporate plasma ramps
- Small emittance challenging

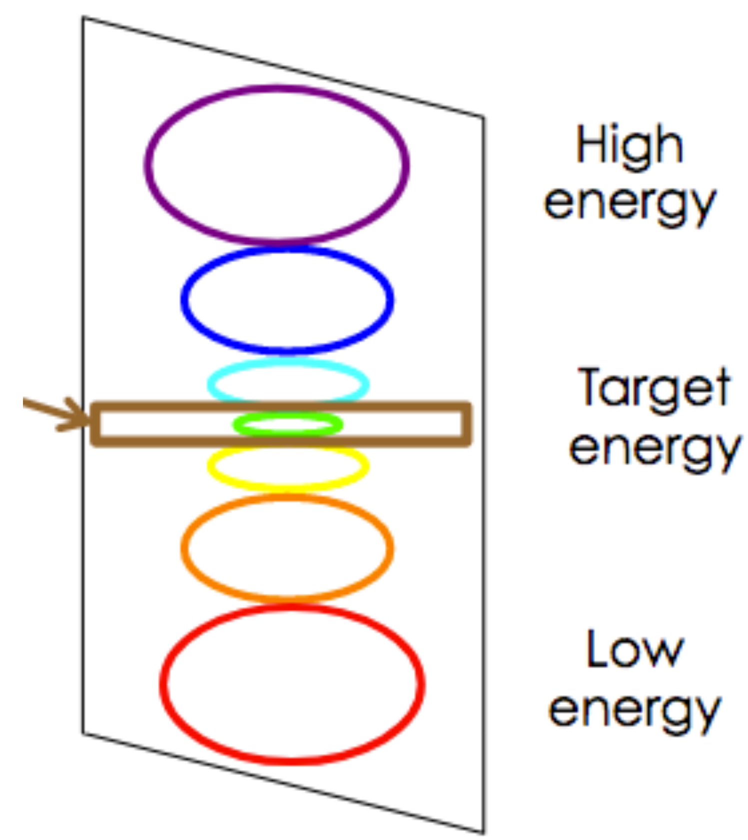




N. Vafaei-Najafabadi FACET-II Science Workshop 2016

E200

- Scan M12
- Reduce chromaticity effect on measurement
- Multi-shot complement to butterfly



S. Corde FACET-II Science Workshop 2016

Measuring Emittance at FACET-II

- Get rid of Be window
- Move diagnostic upstream of 5 mm AL window, inside vacuum

$\sigma_\delta[\%]=0.5$	$\epsilon[\mu m]$ 0.1	0.3	1	3
$\beta[cm]$ 1	$\sigma_{x,100}=28.3$	15.96	26.27	44.39
	$\sigma_x=1.21$	2.097	3.828	6.631
2.5	6.671	10.78	19.09	32.26
	1.914	3.315	6.053	10.48
5	5.152	8.892	15.75	27.79
	2.707	4.689	8.561	14.83
10	4.866	8.403	15.88	27.51
	3.828	6.631	12.11	20.97

Will work with off the shelf optics

Requires careful balance of photons vs resolution

All else require QS0

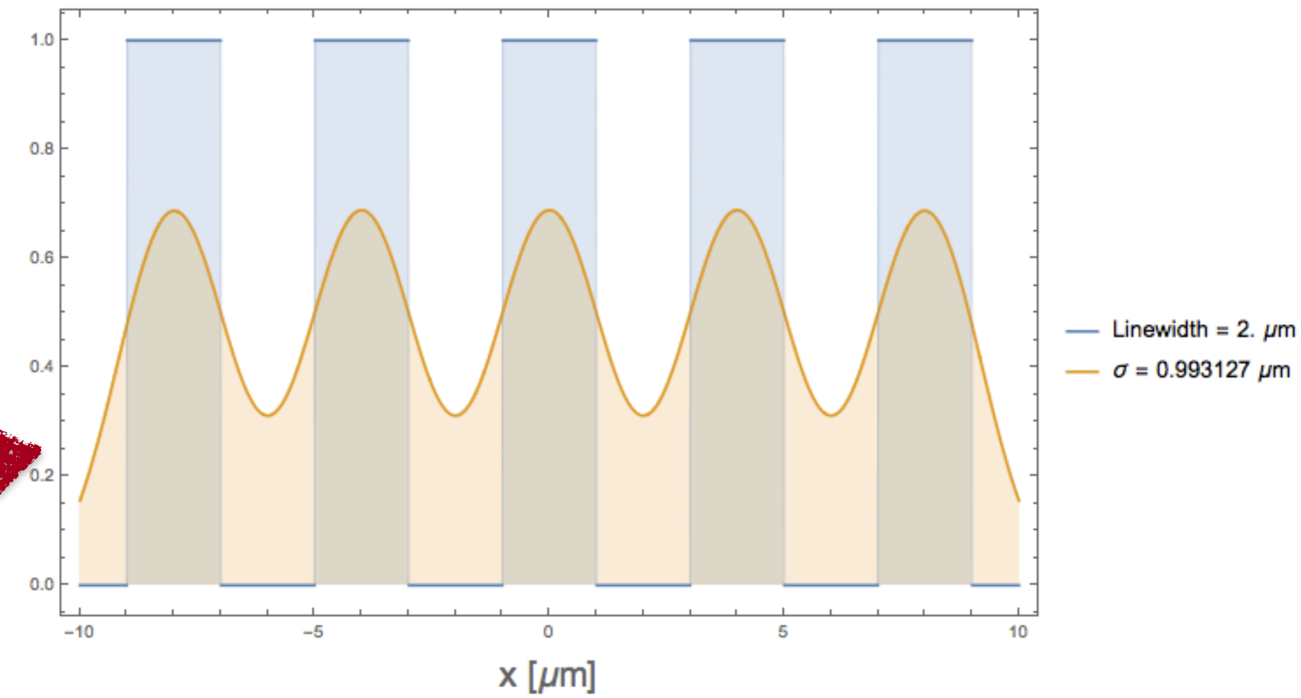
Define Resolution

- There are a few definitions of resolution, we define as:
  - The point spread function (PSF) of a lens

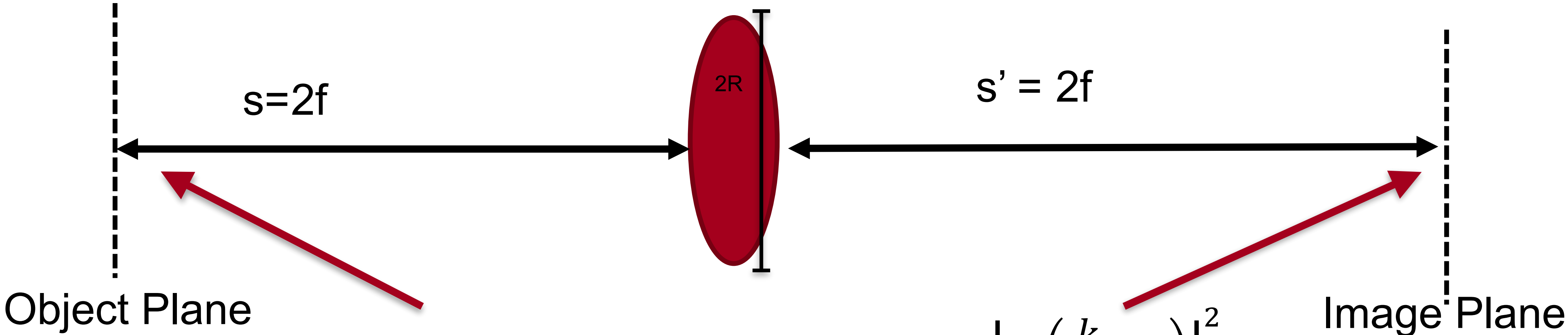
$$\frac{1}{\sqrt{2\pi(\sigma_b^2+\sigma_{psf}^2)}}e^{-\frac{x^2}{2(\sigma_b^2+\sigma_{psf}^2)}} = \frac{1}{2\pi\sigma_b\sigma_{psf}}\int_{-\infty}^{\infty} e^{-\frac{y^2}{2\sigma_b^2}} e^{-\frac{(x-y)^2}{2\sigma_{psf}^2}}\,dy$$

beam size   lens PSF

- Resolution measured using an Air Force 1951 Target
- σ_{psf} is half target line width when contrast is 50%
- In practice resolution limited by lens and pixel size



Diffraction Theory of a Simple Lens

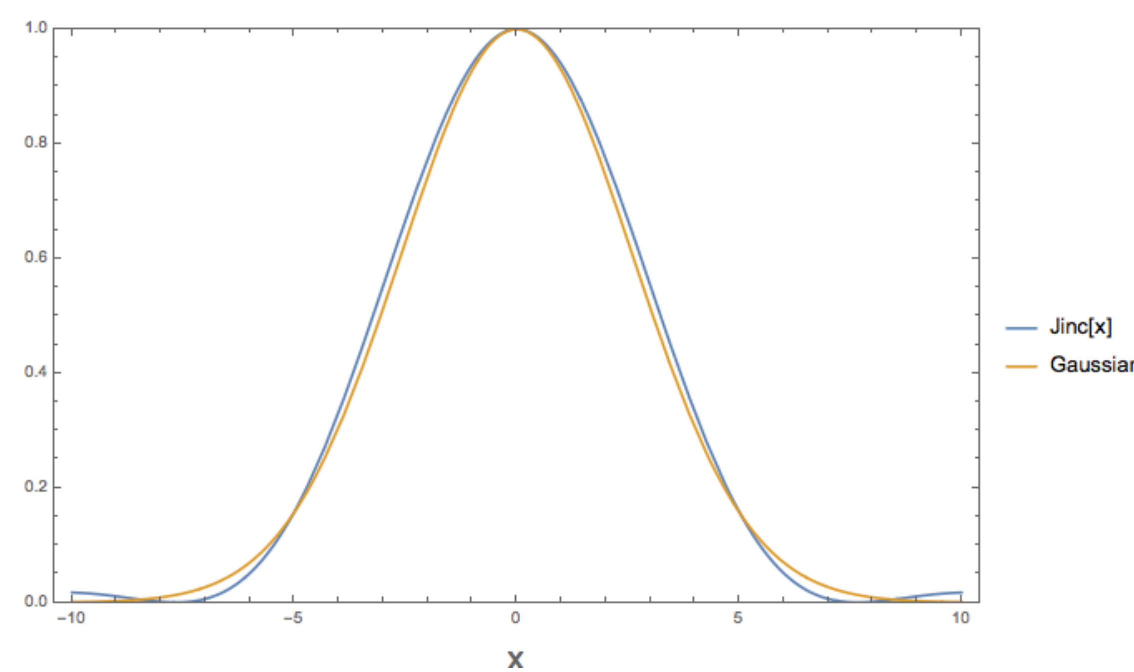


$$I(x) \sim \delta(x)^2$$

$$I(x) \sim 4\left|\frac{J_1\left(\frac{k}{2f}Rx\right)}{\frac{k}{2f}Rx}\right|^2$$

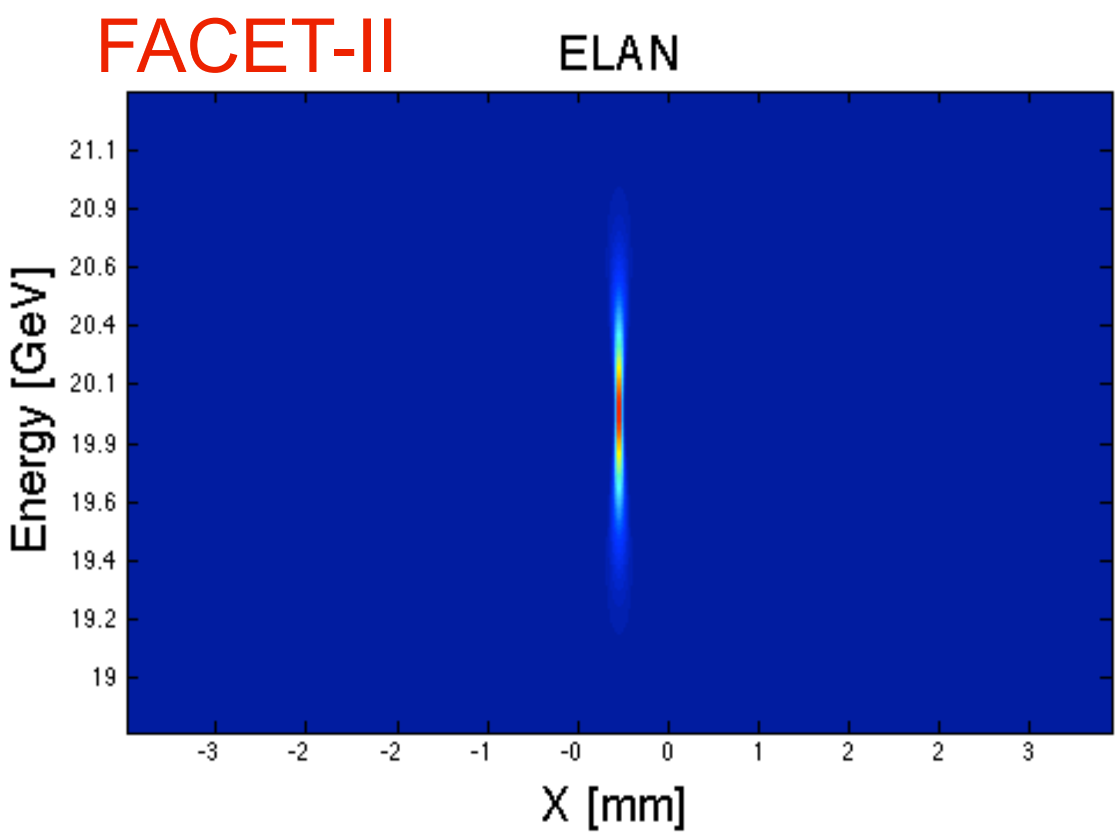
Approximate Intensity as Gaussian:

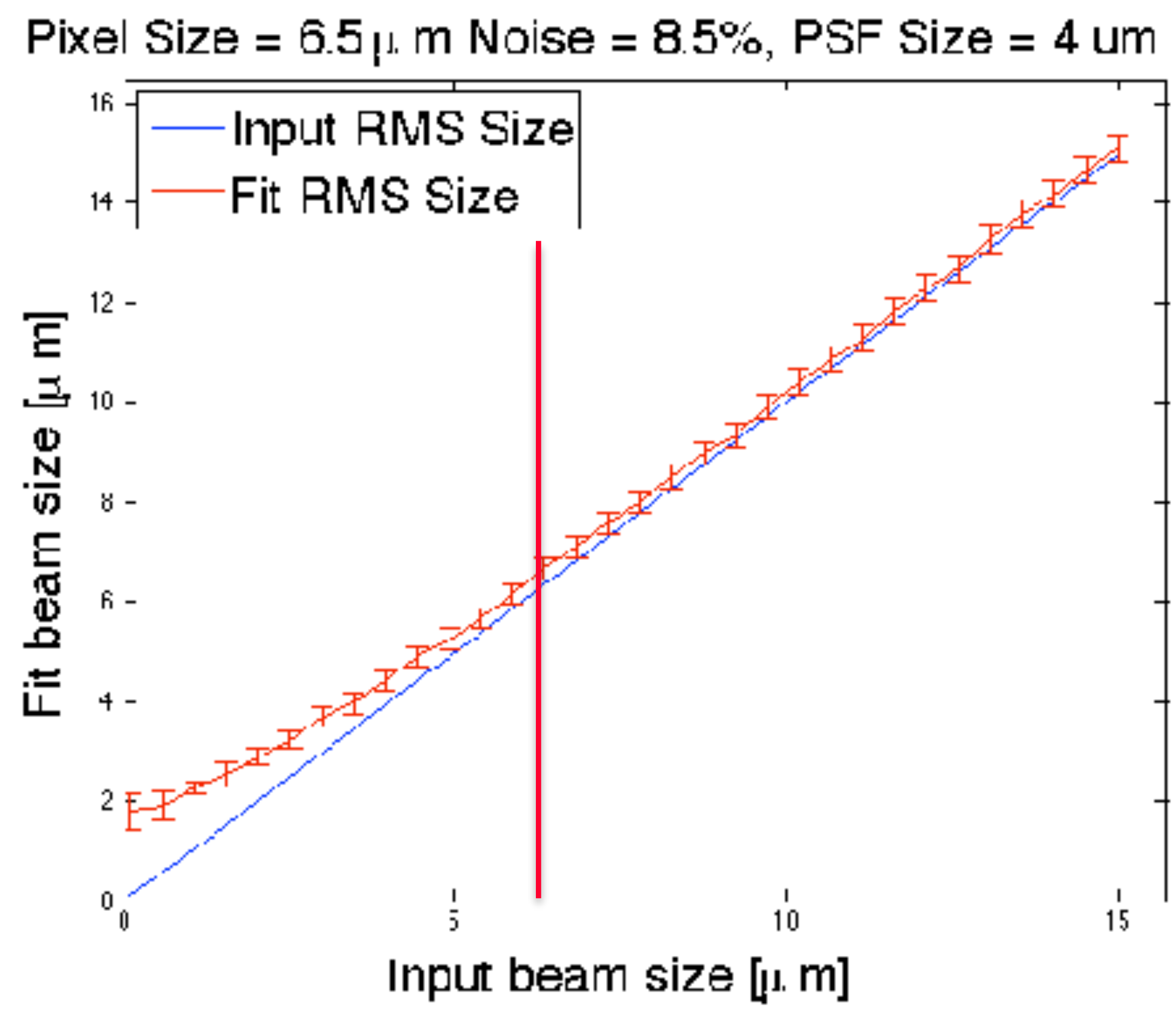
$$\sigma_{psf} \simeq \frac{1.3\lambda}{2\pi}(|M|+1)\frac{f}{R} = 0.41 * fNum$$



Measurement Limits due to Pixel Size

- σ_{PSF} can be removed, but errors add up
- Can't measure a beam size, σ_X, that is smaller than a pixel size, no matter how small σ_{PSF}





Measure to confirm Real Lens ~= Single Lens

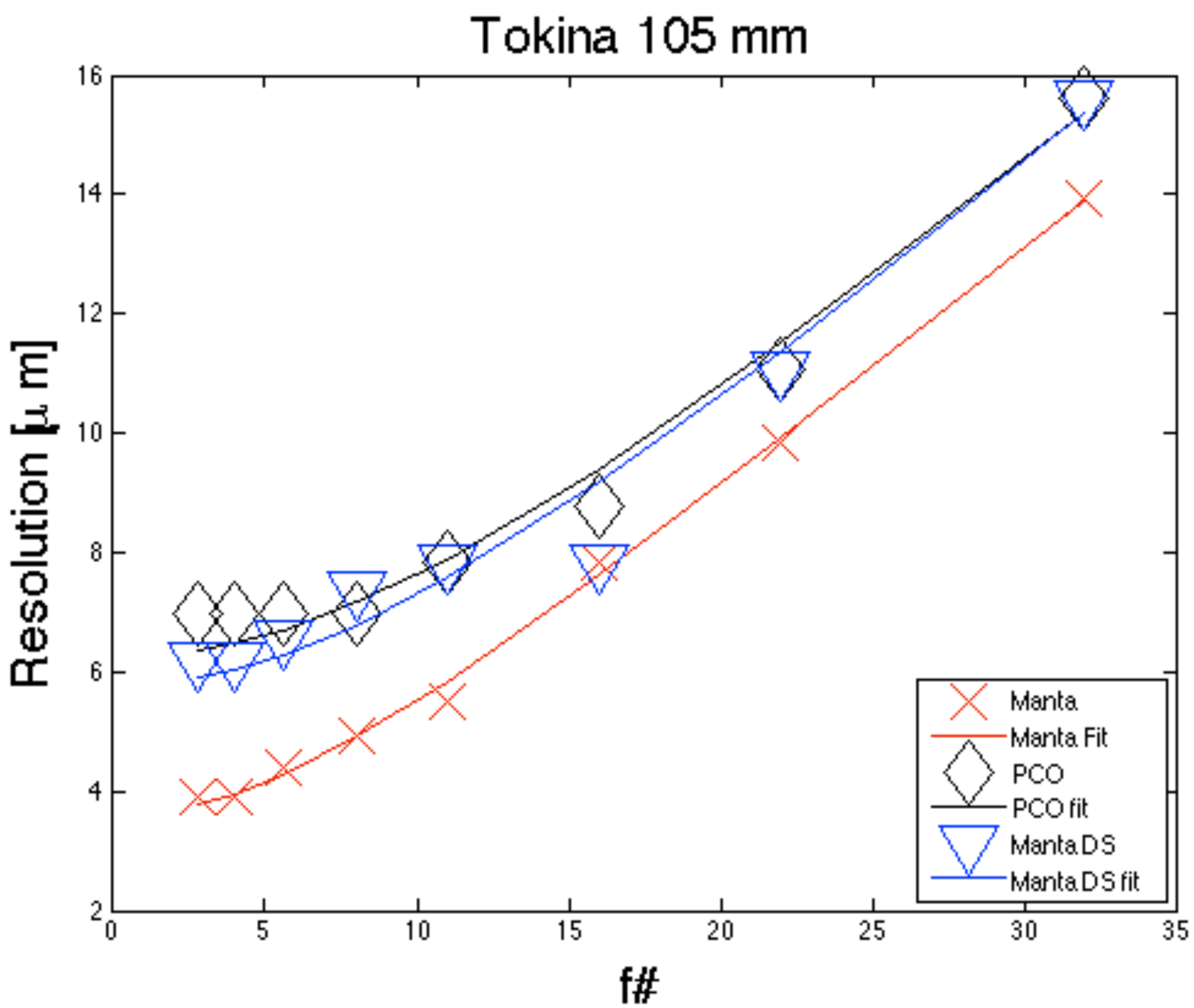
$$\sigma_{psf} \simeq \frac{1.3\lambda}{2\pi}(|M|+1)\frac{f}{R} = 0.41 * fNum$$

$$res = \sqrt{p^2 + (b * fNum)^2}$$

	p [μm]	b [μm]
Manta	3.6	0.42
PCO	6.22	0.42

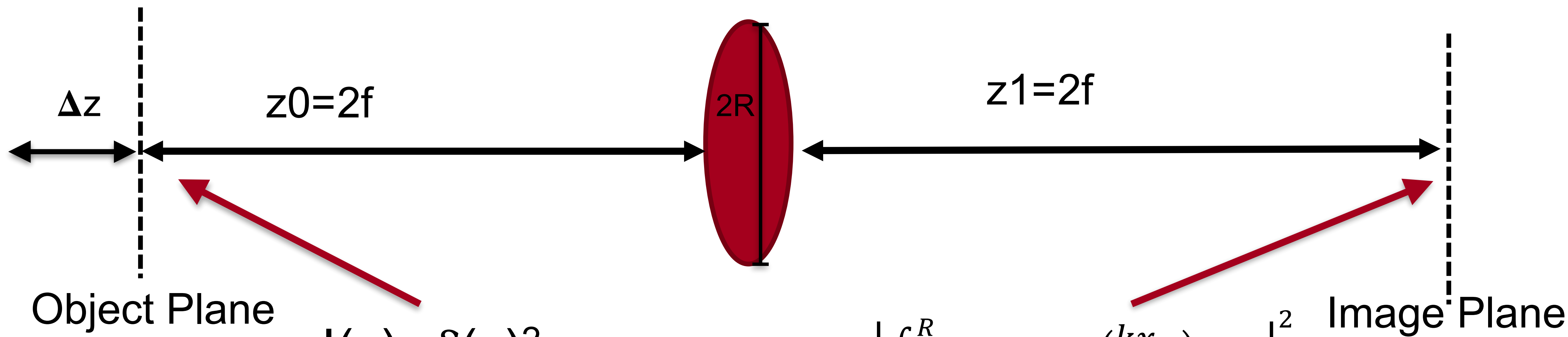
Manta Pixel Size: 3.75 μm

PCO Pixel Size: 6.5 μm



Measured:
Tokina 105mm, Nikon Nikkor 200mm, Nikon Nikkor 60mm
Canon 135 f/2, Nikon 50mm

Depth of Field



I(x)~δ(x)^2

$$I(x) \sim \left| \int_0^R e^{-ik\alpha r^2} J_0\left(\frac{kx}{z_1} r\right) r dr \right|^2$$

$$\alpha = \frac{1}{2}\frac{\Delta z}{z_0^2}(1 - \frac{\Delta z}{z_0})$$

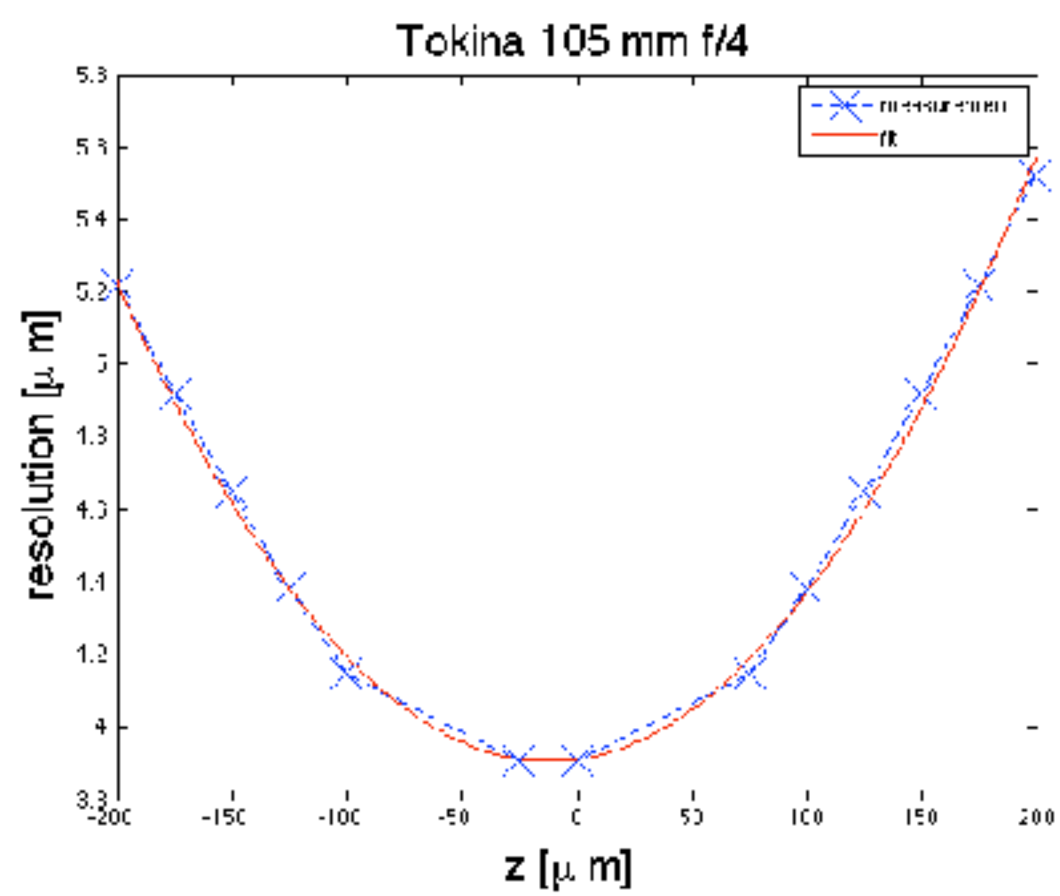
N=kαr^2

$$\Delta z = (\frac{M+1}{M})^2 \frac{4\lambda N}{\pi} f Num^2$$

e.x. N~1.5, λ=0.5 μm, M=1, f/4:

Δz = 61 μm

Measured **Δ**z = 64 μm



Camera Choice

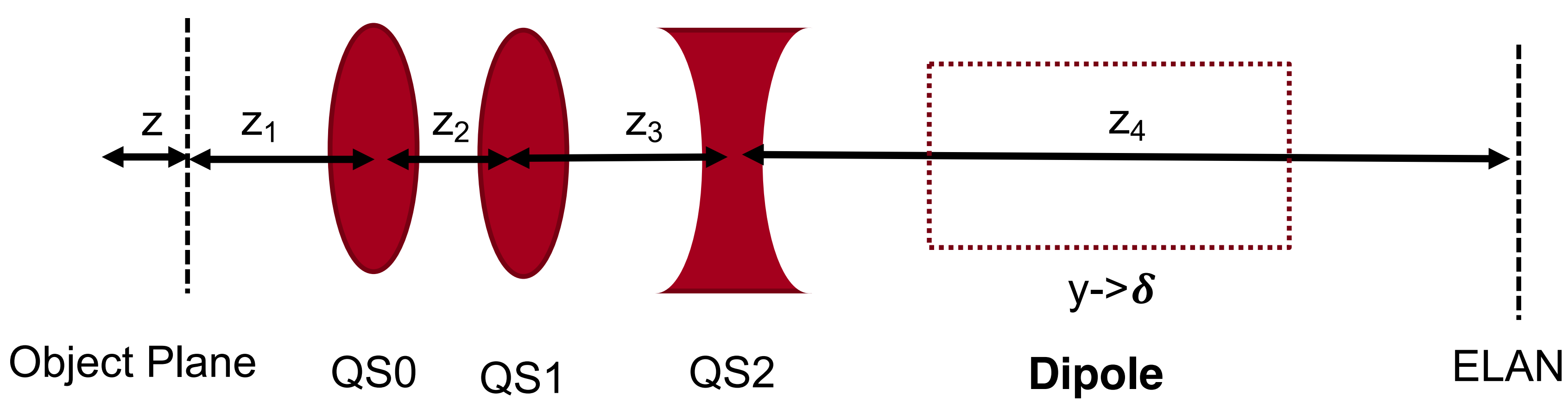
- Would like to use PCO/Hamamatsu

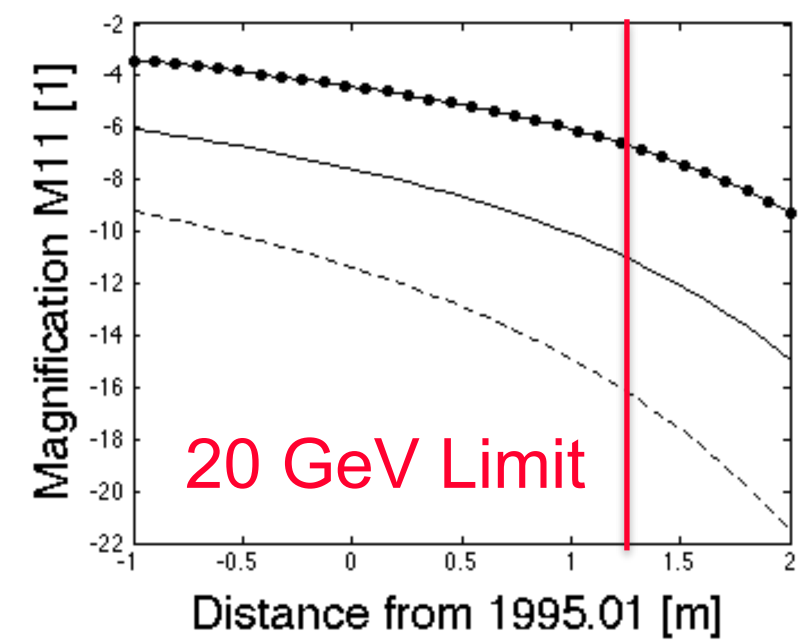
	Pixel Size [μm]	Resolution [μm]	Bit Depth	Detector Size [mm x mm]	Noise [counts]	Working f#	Counts/ Photon
PCO/ Hamamatsu (M=2)	6.5	4.1	16	8.3 x 7.0	0.4	12	0.87
Manta (M=1)	3.75	4.1	12	4.8 x 3.6	1.3	8	0.26

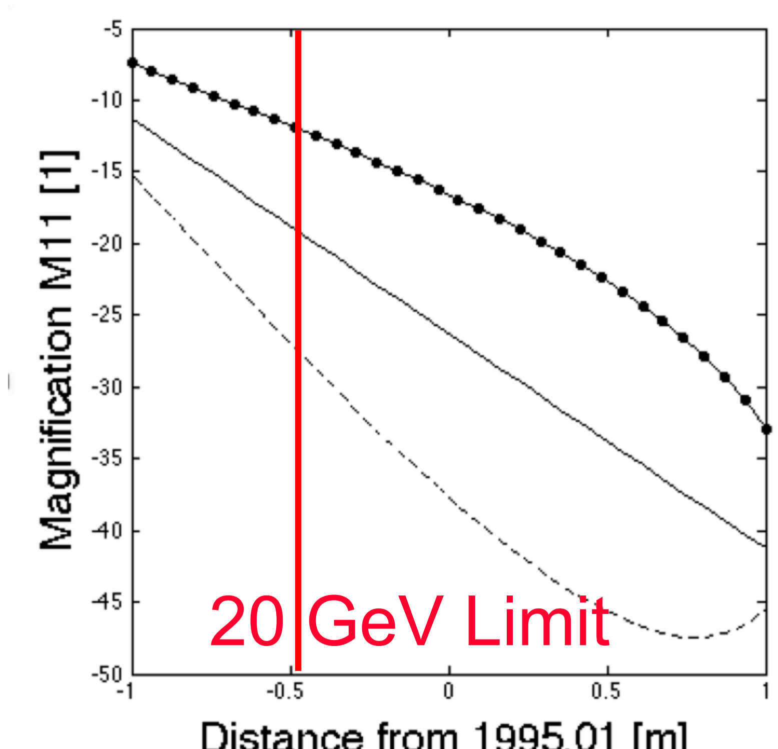
Table assumes Nikon Nikkor 200 mm f/4 lens

Options for Magnetic Optics

- Magnification M_{11} can be increased by moving the plasma output closer to QS1 (@ 20 GeV)
  - Nominal magnification M_{11}~7
  - Maximum magnification M_{11}~11
- We can bring back QS0
  - Magnification can be M_{11}~17







Summary

- 0.3 μm normalized emittance can be measured when the beta function is 5 cm, 0.5% energy spread by only changing light optics
  - Any or all of these parameters can be bigger
- Injected beams will have to be examined
  - lower energy does help when thinking about QS0
- 0.05-0.1 μm normalized emittance can be measured when the beta function is 5 cm, if QS0 is used (M_{11}=15)
- PCO/Hamamatsu sCMOS is the better camera for the measurement, because of sensitivity

Backups

Witness Bunch Emittance Table (M = 15)

SLAC

$\sigma_\delta[\%]$ =0.5	$\epsilon[\mu m]$ 0.05	0.1	0.5	1
$\beta[cm]$ 1	$\sigma_{x,100}$=5.56	7.294	15.31	21.49
	σ_x =1.7	2.398	5.361	7.582
2.5	4.182	5.775	12.93	18.29
	2.681	3.791	8.477	11.99
5	4.349	6.292	13.73	19.41
	3.791	5.361	11.99	16.95
10	5.675	8.025	17.94	25.38
	5.361	7.582	16.95	23.98