Subradiant Undulator Emission at NLCTA

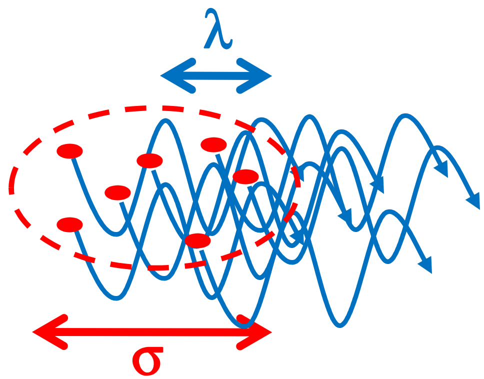
D. Ratner, E. Hemsing, A. Gover, A. Marinelli, A. Nause

August 26, 2015

Super- and Sub-radiance in Accelerators

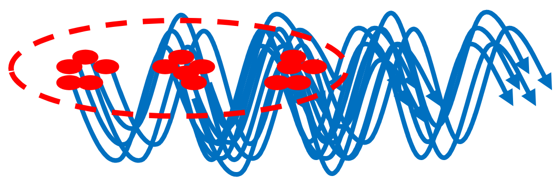
Number of electrons

Shot Noise



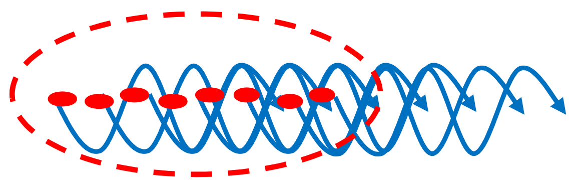
$$P_{rad}(\lambda) \propto N_e$$

Microbunching/ Superradiance



$$P_{rad}(\lambda) \propto N_e^2$$

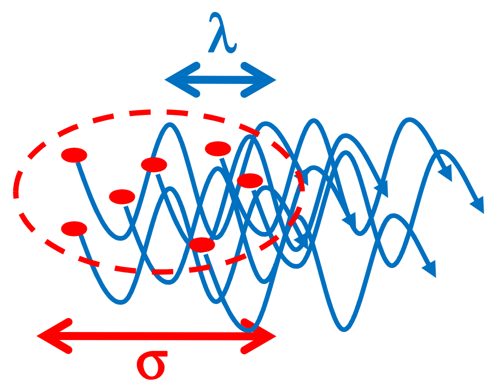
Noise Suppression/ Subradiance



$$P_{rad}(\lambda) \rightarrow 0$$

Super- and Sub-radiance in Accelerators

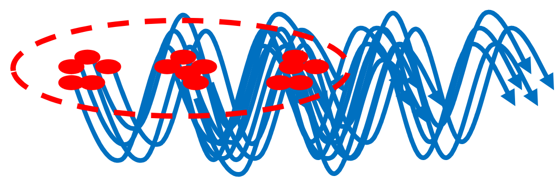
Shot Noise



Number of electrons

$$P_{rad}(\lambda) \propto N_e$$

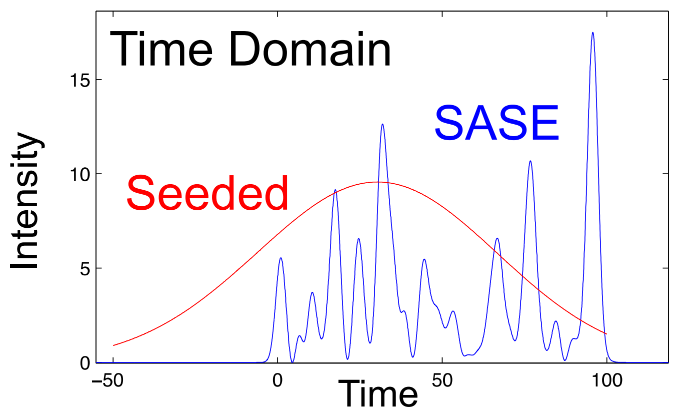
Microbunching/ Superradiance

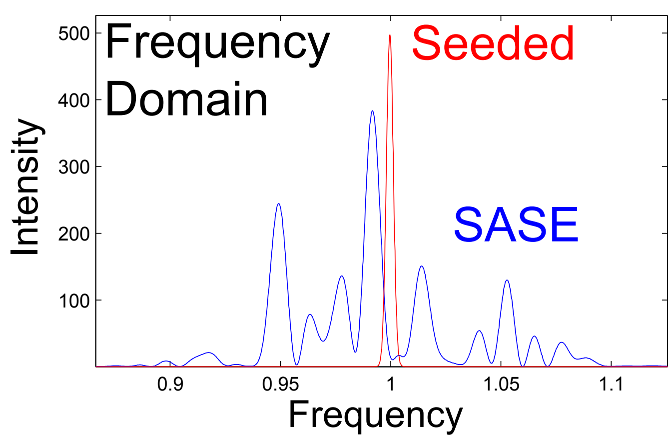


$$P_{rad}(\lambda) \propto N_e^2$$

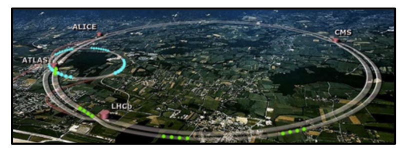
Applications

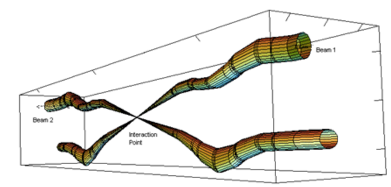
Reduce seed power requirements





Increase hadron cooling rates





Relative beam sizes around IP1 (Atlas) in collision

PRL **102,** 114801 (2009) PHYSICAL REVIEW LETTERS week ending 20 MARCH 2009

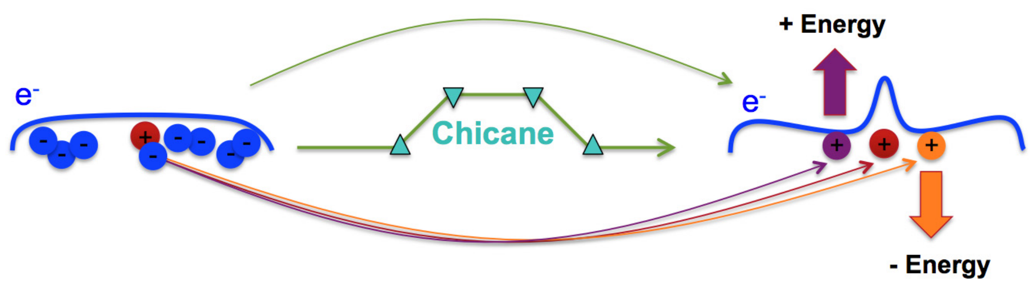
Coherent Electron Cooling

Vladimir N. Litvinenko[1,*] and Yaroslav S. Derbenev[2]

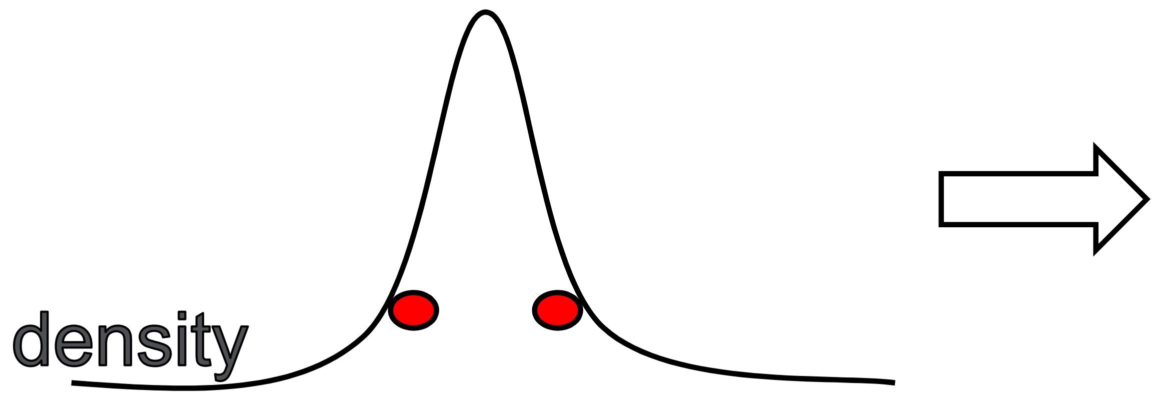
PRL **111,** 084802 (2013) PHYSICAL REVIEW LETTERS week ending 23 AUGUST 2013

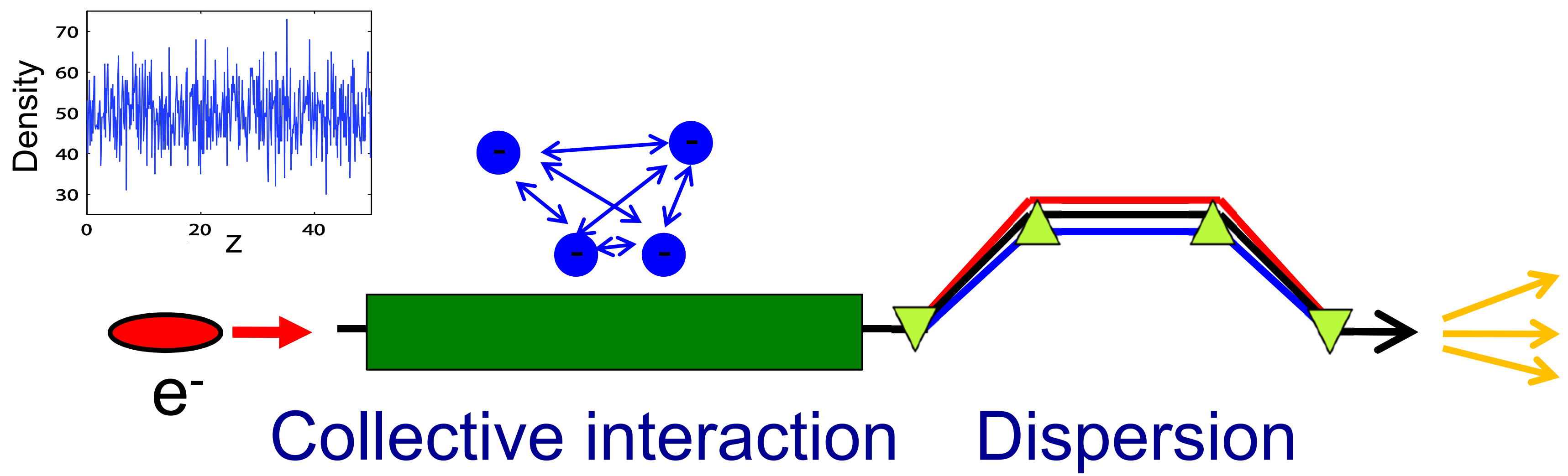
Microbunched Electron Cooling for High-Energy Hadron Beams

D. Ratner[*]

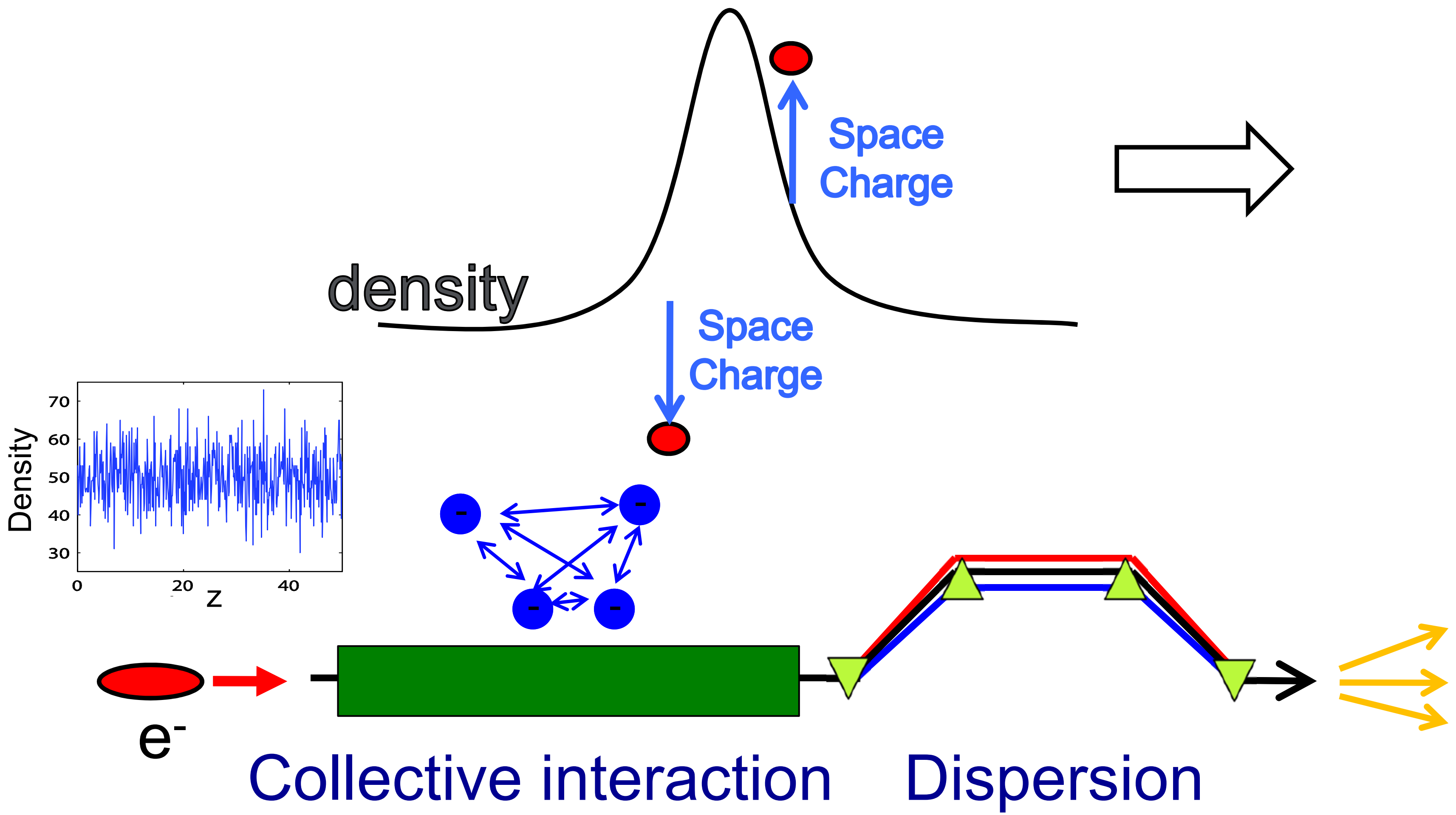


Physical Picture

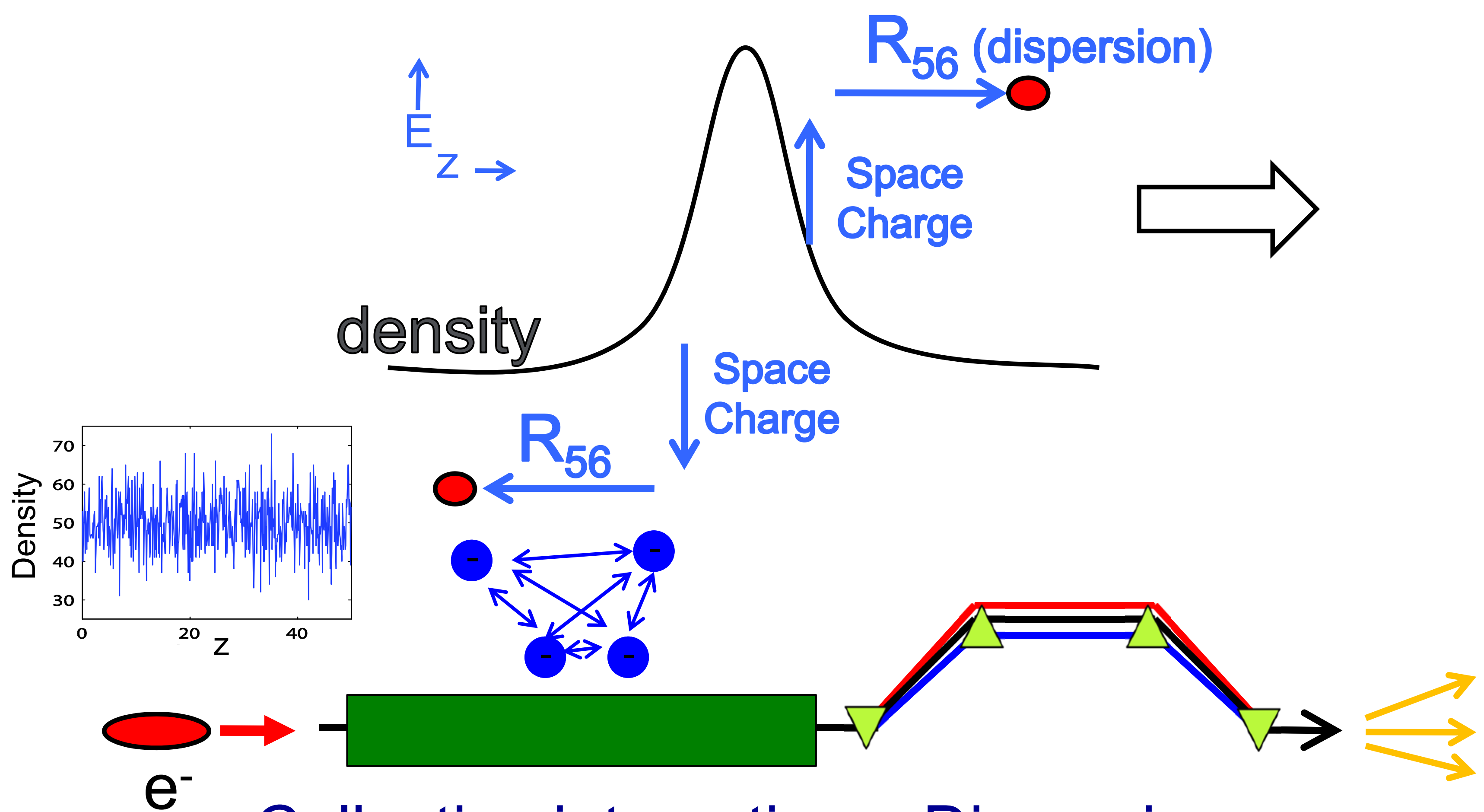




Physical Picture

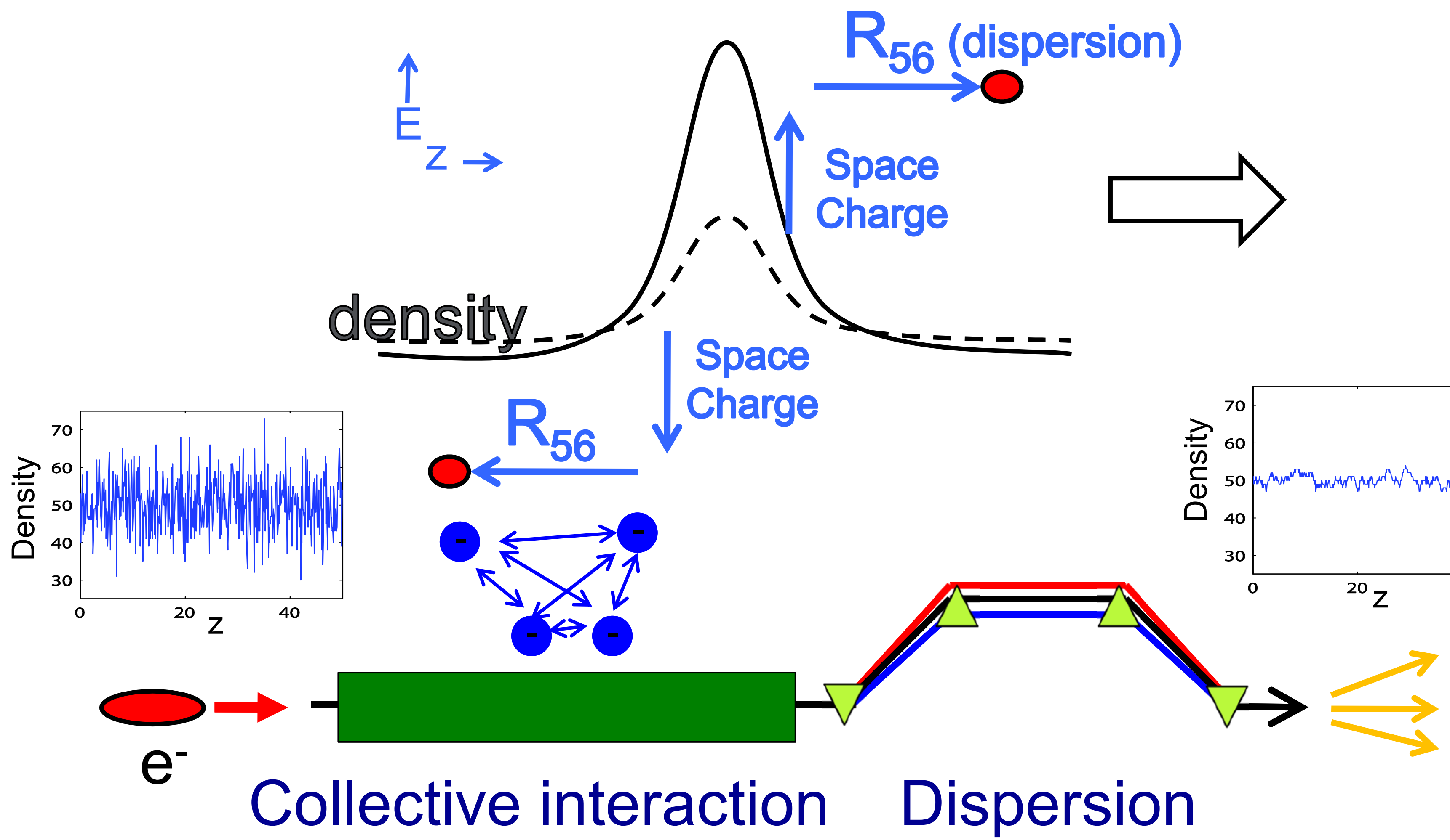


Physical Picture



Collective interaction Dispersion

Physical Picture



Suppressing radiation

Radiation: $P \propto NF(k)$ Bunching: $F(k) = \frac{1}{N}\left|\sum_j^N \exp[-ikz_j]\right|^2$

Number of particles N, wavenumber k

For dispersive suppression:

$$\langle F(k) \rangle \approx (1 - \Upsilon)^2 \qquad \Upsilon \equiv n_0 R_{56} A \qquad A = \frac{4 r_e L_a}{\beta \varepsilon}$$

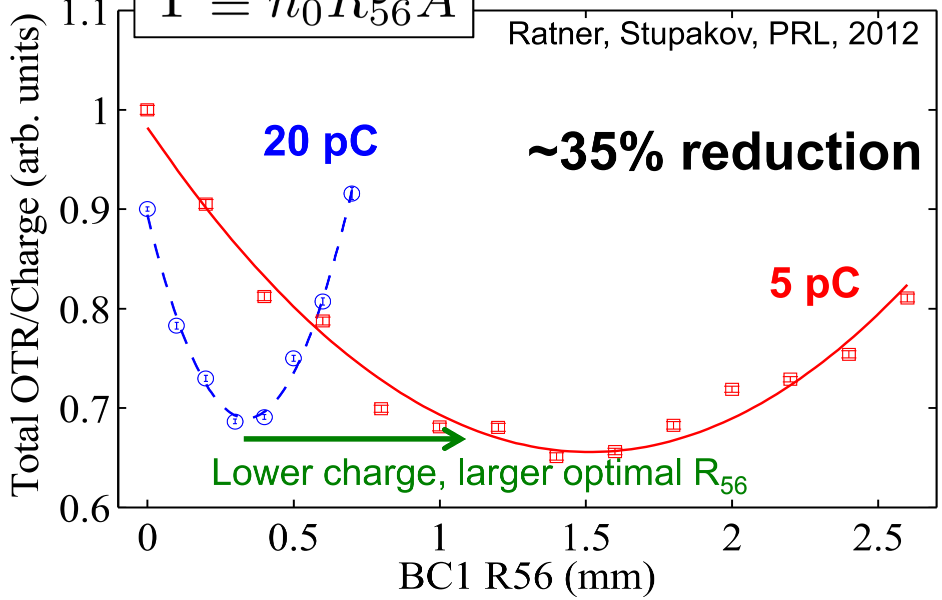
charge density n_0, dispersion R_{56}, interaction length L_a, emittance ε, beta function β, classical e- radius r_e

➔ Scan R56 and look for broad bandwidth reduction in radiative process

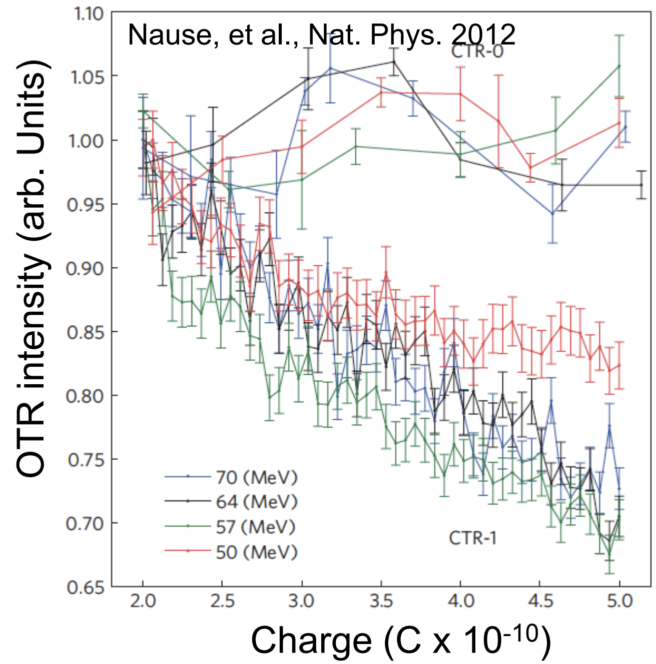
Proof of Principle

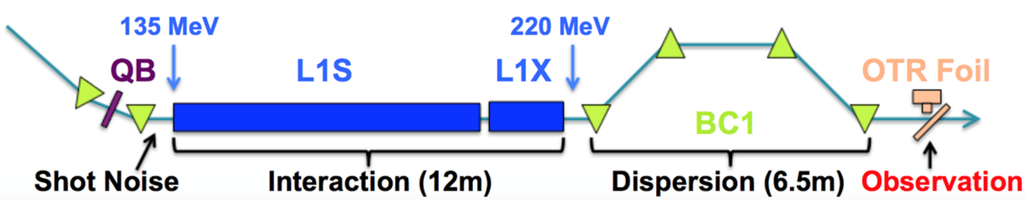
$$\langle F(k)\rangle \approx (1-\Upsilon)^2$$

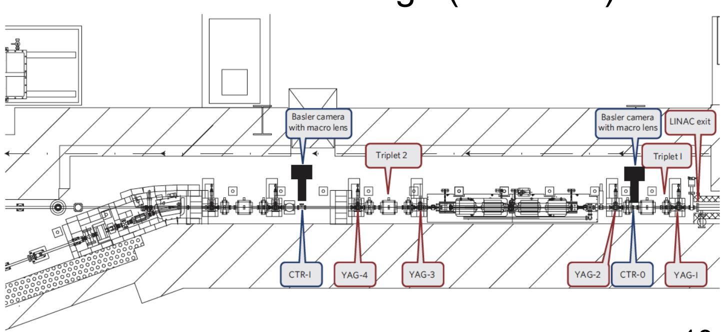
$$\Upsilon = n_0 R_{56} A$$



Plasma oscillations

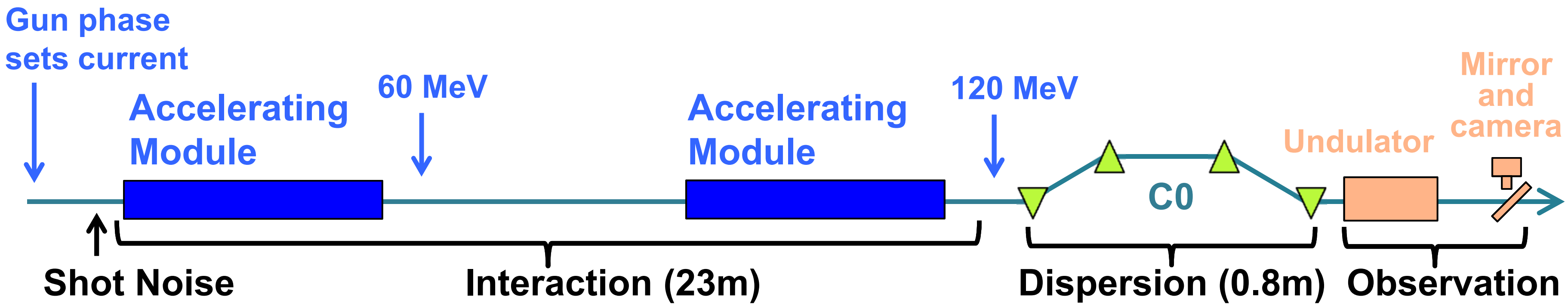






Undulator subradiance at NLCTA

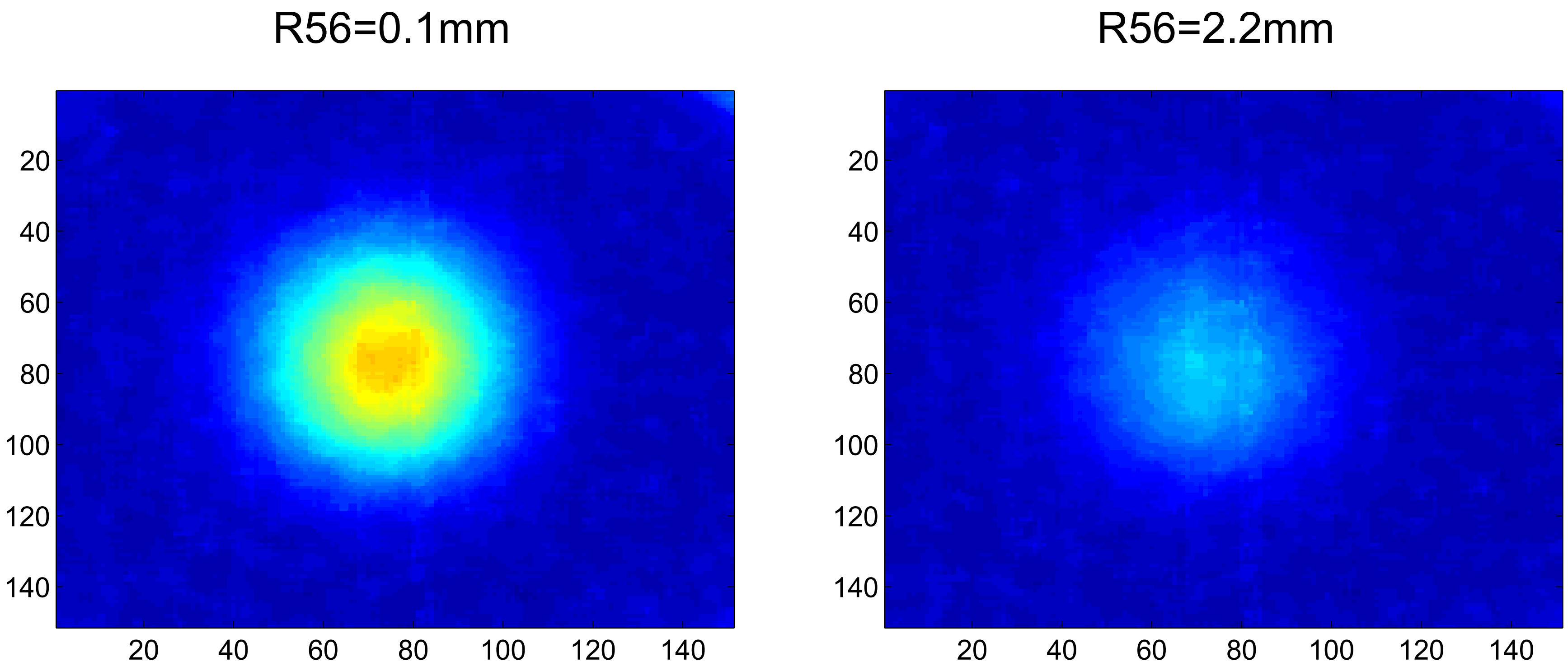
Experimental Parameters	
Charge	25 pC
Beam energy	120 MeV
Wavelength	800 nm
Peak current	5 to 20 A
Dispersion	0-8 mm
Gun Phase	-5 to -19.5 deg
Beam energy	120 MeV



Far field undulator radiation

Sample images with -14deg gun phase

Subradiance!

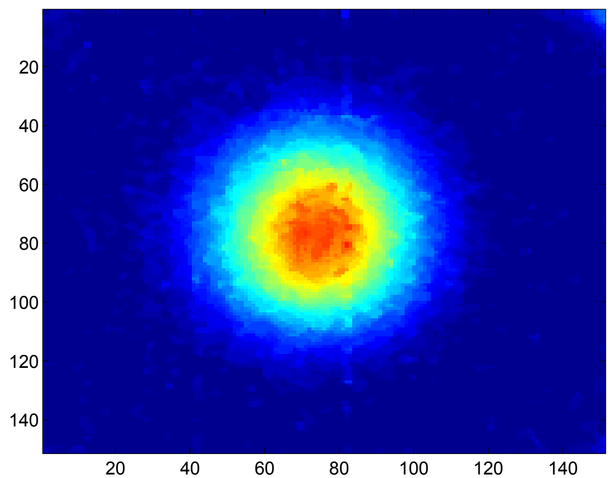


Undulator Radiation

Methodology

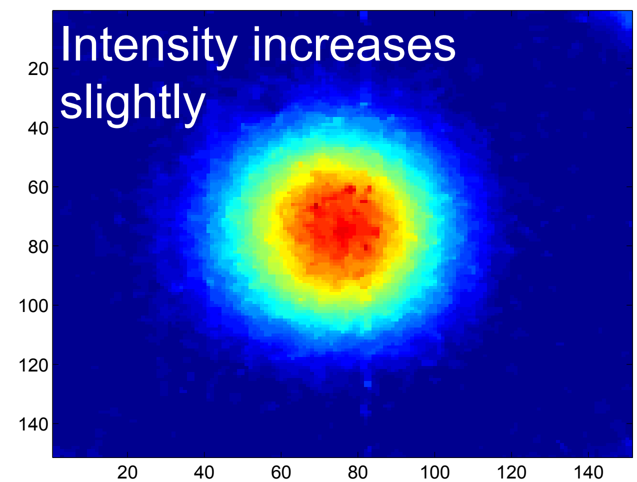
How to define 'shot noise level?

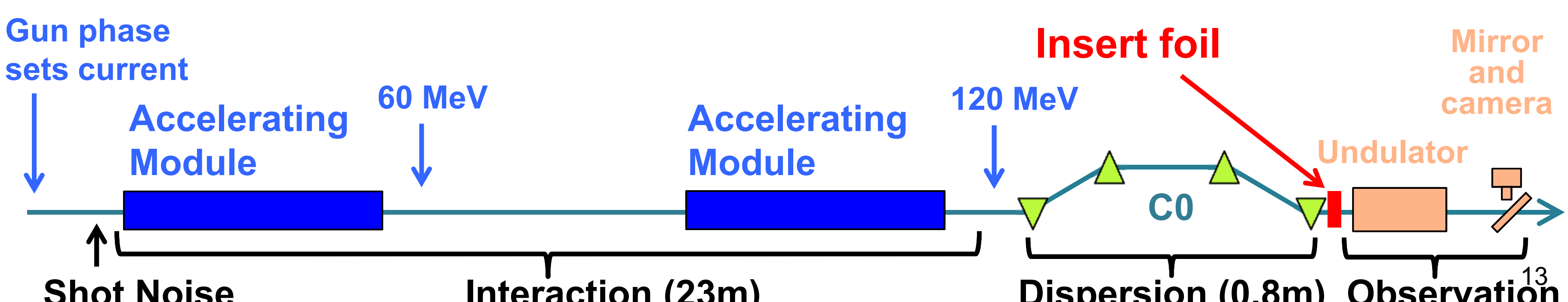
Foil OUT, R56=0.1mm



Define as shot noise

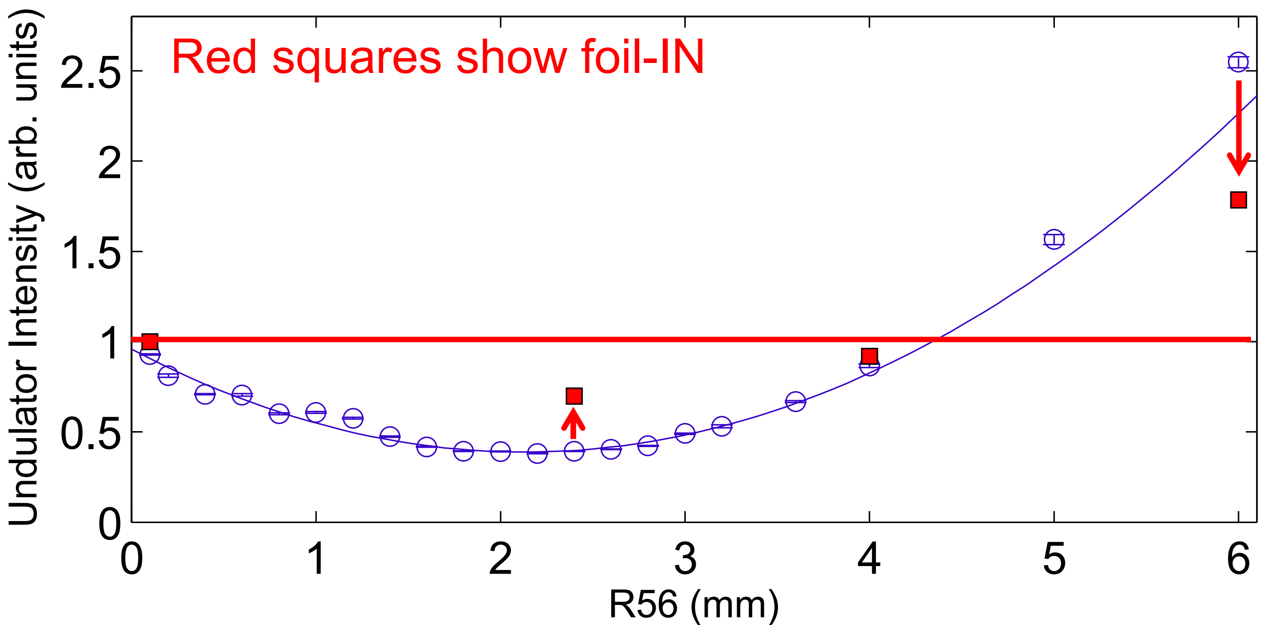
Foil IN, R56=0.1mm

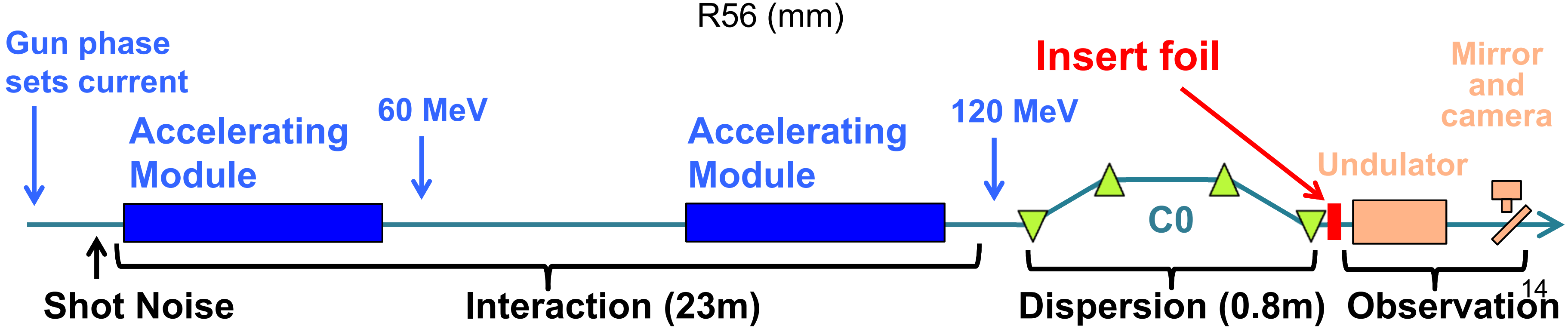




Methodology

Foil only partially effective

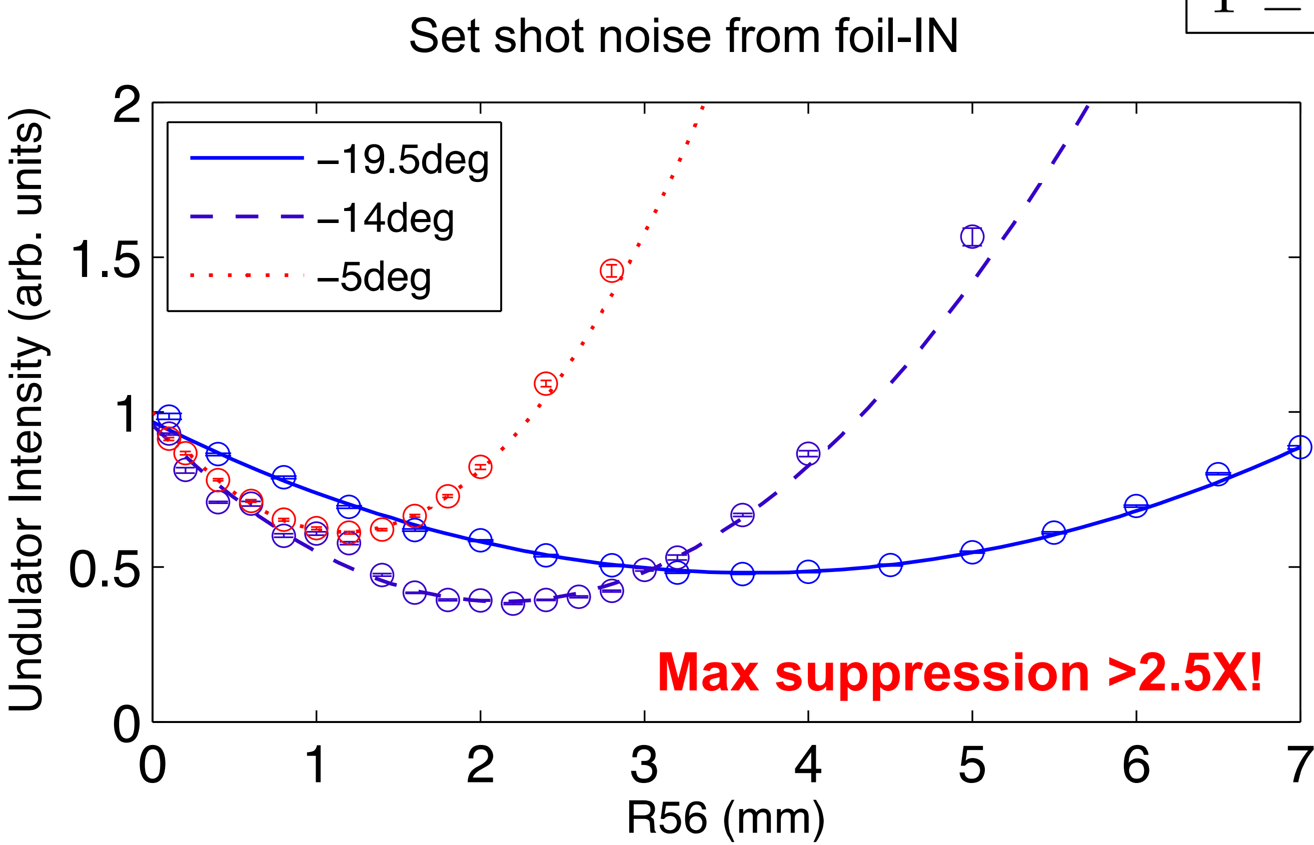




Scans vs. R56

More negative phase ➔ lower current ➔ weaker interaction ➔ stronger R56

$$\Upsilon \equiv n_0 R_{56} A$$



Angular dependence

Limited by camera

$$\theta_{\mathrm{cam}} < \frac{1}{\gamma}\sqrt{B\left(1+\frac{K^2}{2}\right)} = 2.2\mathrm{mrad}$$

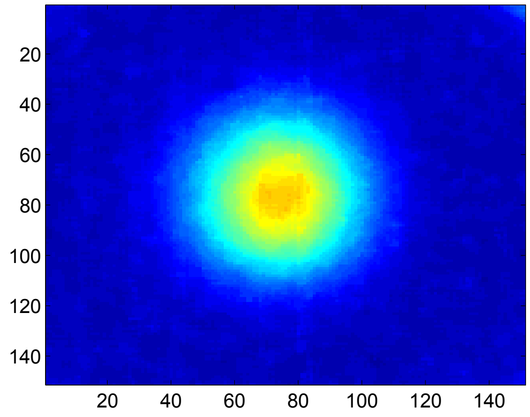
Und param. K=1.82
Rel. factor γ=240
camera bandwidth B=10%

Limit of suppression

$$\theta_{\mathrm{NS}} < \frac{1}{k\sigma} = 1.3\mathrm{mrad}$$

Frequency k=2π/800nm
Beam size σ=100um

Far-field image



Undulator Radiation

Angular dependence

Limited by camera

$$\theta_{cam} < \frac{1}{\gamma}\sqrt{B\left(1+\frac{K^2}{2}\right)} = 2.2\text{mrad}$$

Und param. K=1.82
Rel. factor γ=240
camera bandwidth B=10%

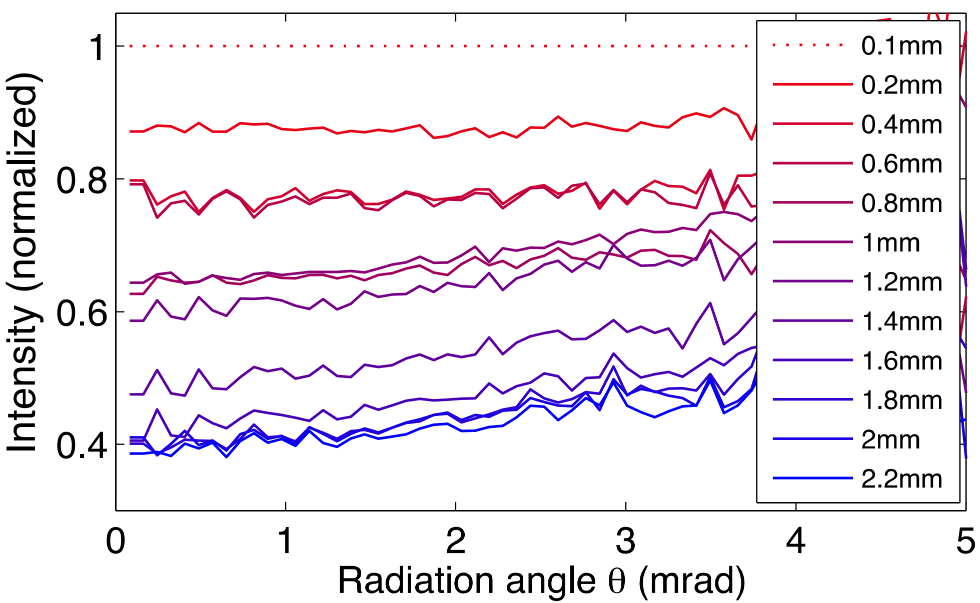
Limit of suppression

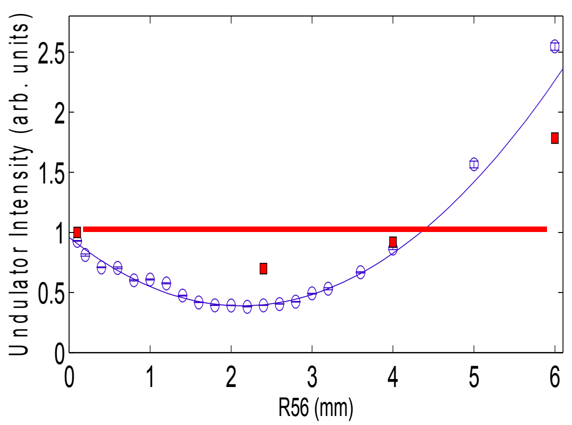
$$\theta_{NS} < \frac{1}{k\sigma} = 1.3\text{mrad}$$

Frequency k=2π/800nm
Beam size σ=100um

Beam size σ=100um
Coherence length σ ~ 25um?

OTR screen out, –14 deg phase





Suppression vs. angle

$$\theta_{\text{cam}} < \frac{1}{\gamma}\sqrt{B\left(1+\frac{K^2}{2}\right)} = 2.2\text{mrad}$$

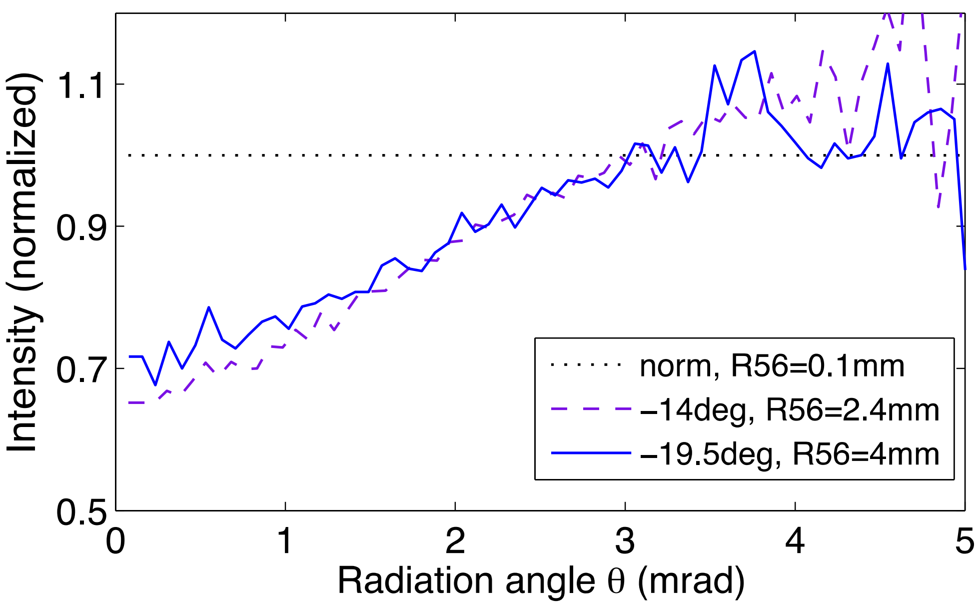
Und param. K=1.82
Rel. factor γ=240
camera bandwidth B=10%

$$\theta_{\text{NS}} < \frac{1}{k\sigma} = 1.3\text{mrad}$$

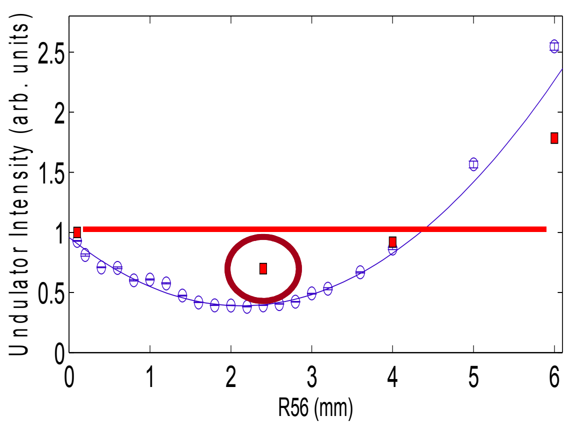
Frequency k=2π/800nm
Beam size σ=100um

OTR foil (2um Nitrocellulose, 50nm Al) scatters beam by ~50-100um

OTR screen inserted



Red squares show screen-IN



SLAC

Suppression vs. angle

$$\theta_{cam} < \frac{1}{\gamma}\sqrt{B\left(1+\frac{K^2}{2}\right)} = 2.2\text{mrad}$$

$$\theta_{NS} < \frac{1}{k\sigma} = 1.3\text{mrad}$$

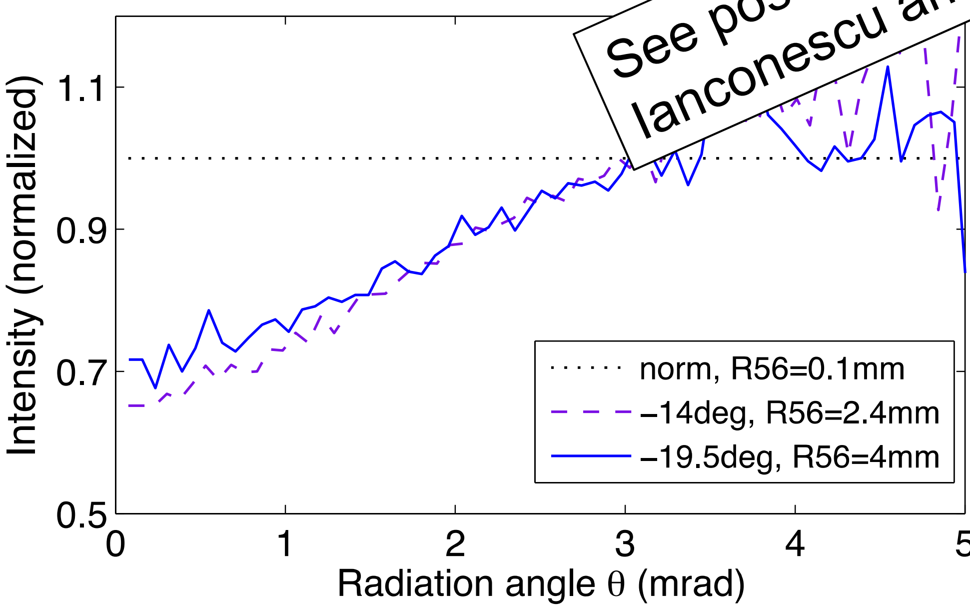
Und param. K=1.82
Rel. factor γ=240
camera bandwidth B=10%

Frequency k=2π/800nm
B m size σ=100um

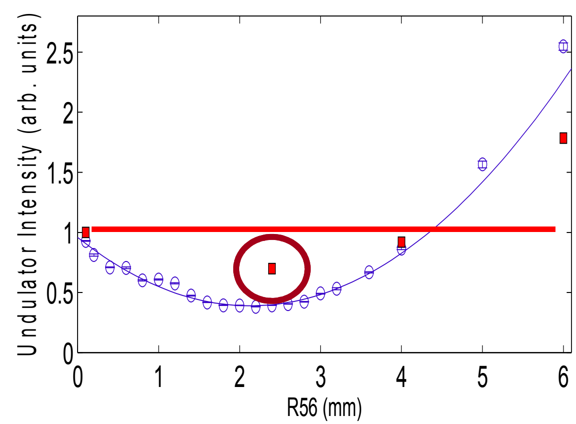
(2um Nitrocellulose, 50nm Al)
ters beam by ~50-100um

See poster MOP078, Ianconescu and Gover

OTR screen inserted



Red squares show screen-IN



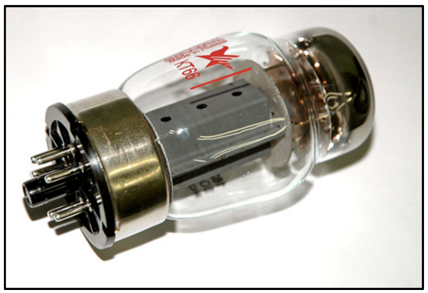
Next step: X-rays

Shorter wavelengths

Microwaves

Space-Charge and Transit-Time Effects on Signal and Noise in Microwave Tetrodes*

L. C. PETERSON†, ASSOCIATE, I.R.E.



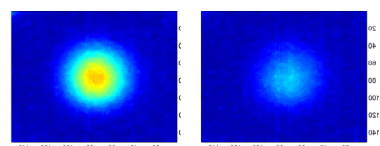
x 10^{-3}

Optical

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS 18, 050703 (2015)

Subradiant spontaneous undulator emission through collective suppression of shot noise

D. Ratner,[1,*] E. Hemsing,[1,†] A. Gover,[2] A. Marinelli,[1] and A. Nause[3]



x 10^{-3}

X-rays?

$$\langle F(k)\rangle \approx 1 - 2e^{-k^2 R_{56}^2 \sigma_\eta^2}\Upsilon + e^{-k^2 R_{56}^2 \sigma_\eta^2}\Upsilon^2$$

R_{56} = 1um, $\sigma_\eta = 2\times10^{-4}$ ➔ $\lambda > 2$nm   Borderline, but possible

(For plasma oscillation approach, see Nause et al, “Short wavelength limits of shot-noise suppression” Phys. Plasmas 21, 083114 (2014) ; Erratum: 21, 129904 (2014))

Wide bandwidth noise suppression

$$\langle F(k)\rangle \approx (1-\Upsilon)^2$$

$$\Upsilon \equiv n_0 R_{56} A$$

Only constraint on *h(z)*: Step function interaction!!!

Space charge: $A = \dfrac{4r_e L_a}{\beta\varepsilon}$

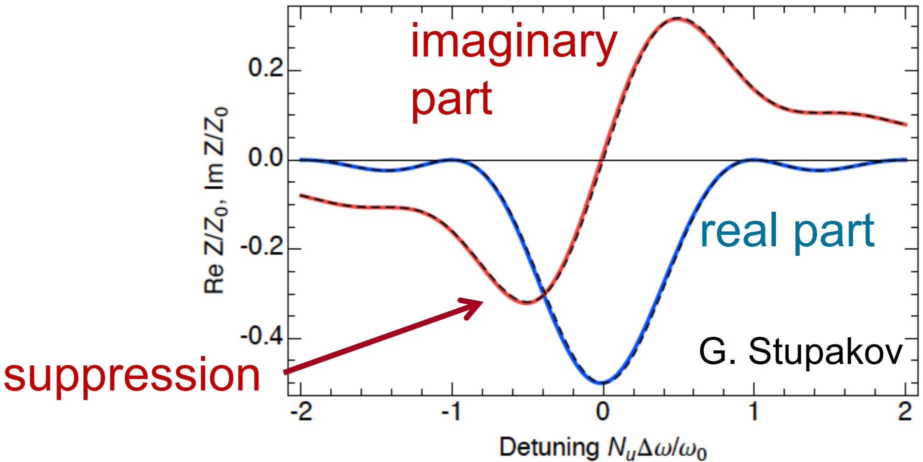
Undulator (high harmonic): $A_{\text{und}} = \dfrac{-4r_e L_u}{\beta\varepsilon}\dfrac{K^2}{1+K^2}$

Narrow bandwidth suppression:

$$\Upsilon \equiv n_0 k R_{56} \mathrm{Im}\left[\tilde{h}(k)\right]$$

$$\frac{A_{\text{und, res}}}{A_{\text{sc}}} \propto N_u$$

Undulator detuned:



Summary

1. Substantial suppression of undulator radiation possible
2. Measured factor of ~2.5, believe more in core of bunch
3. Next steps:
   a) Observe X-ray subradiance
   b) Demonstrate suppression from undulator interaction
   c) Control SASE FEL startup

Thanks for listening!