Proposal to the ATF

Experimental Study of Undulator Spontaneous Radiation Suppression by Current-Noise Control in High Energy e-beams

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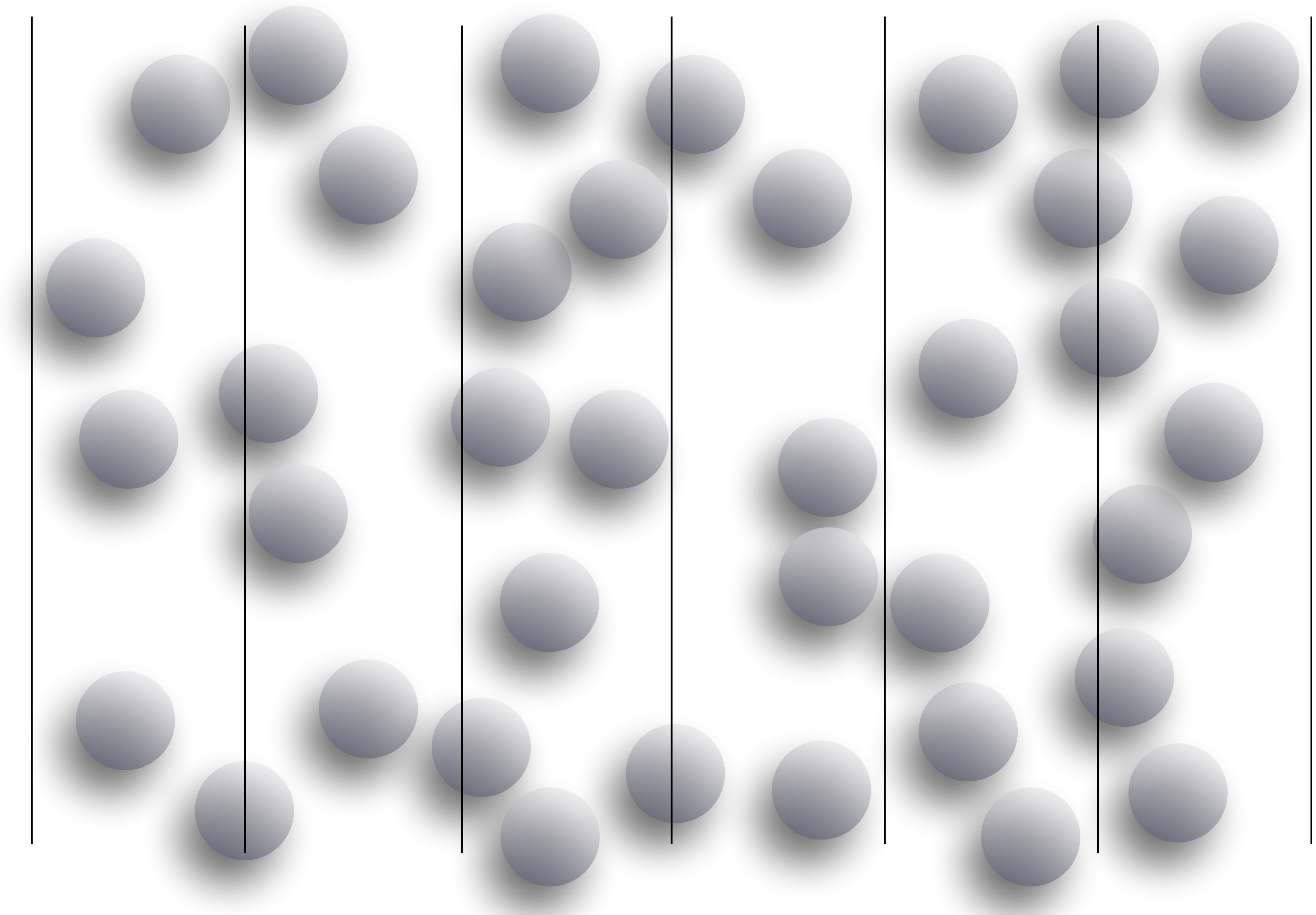
Motivation

- Take advantage of the new ATF facility to demonstrate suppressed noise e-beam in higher energies (and lower wavelengths).
- Continuation of previously conducted experiment in ATF.
- First time demonstration of Undulator spontaneous radiation suppression.
- Collective-micro-dynamics is the underlying mechanism in disruptive phenomena such as:
    - Micro-bunching instability
    - Coherent Optical Transition Radiation effects in beam diagnostics

  All appear in transport of modern-day bright high quality electron beams in the presence of dispersive elements.
- This also may be a problem in major new FEL projects like LCLS II, where high current, high quality beams are transported to great distances at high energies.

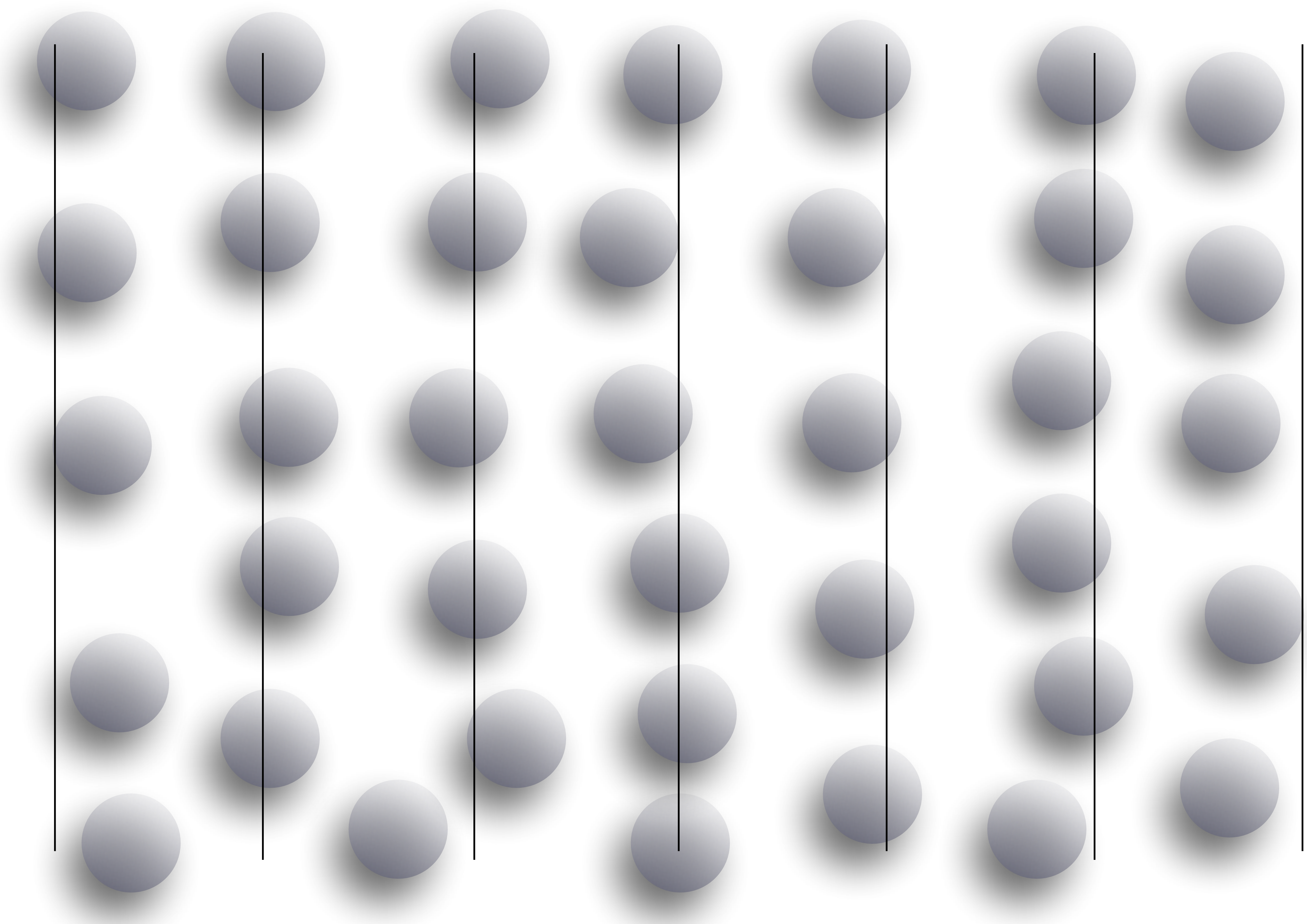
Shot Noise

$$\overline{|\breve{i}(0,\omega)|^2} = eI_b$$

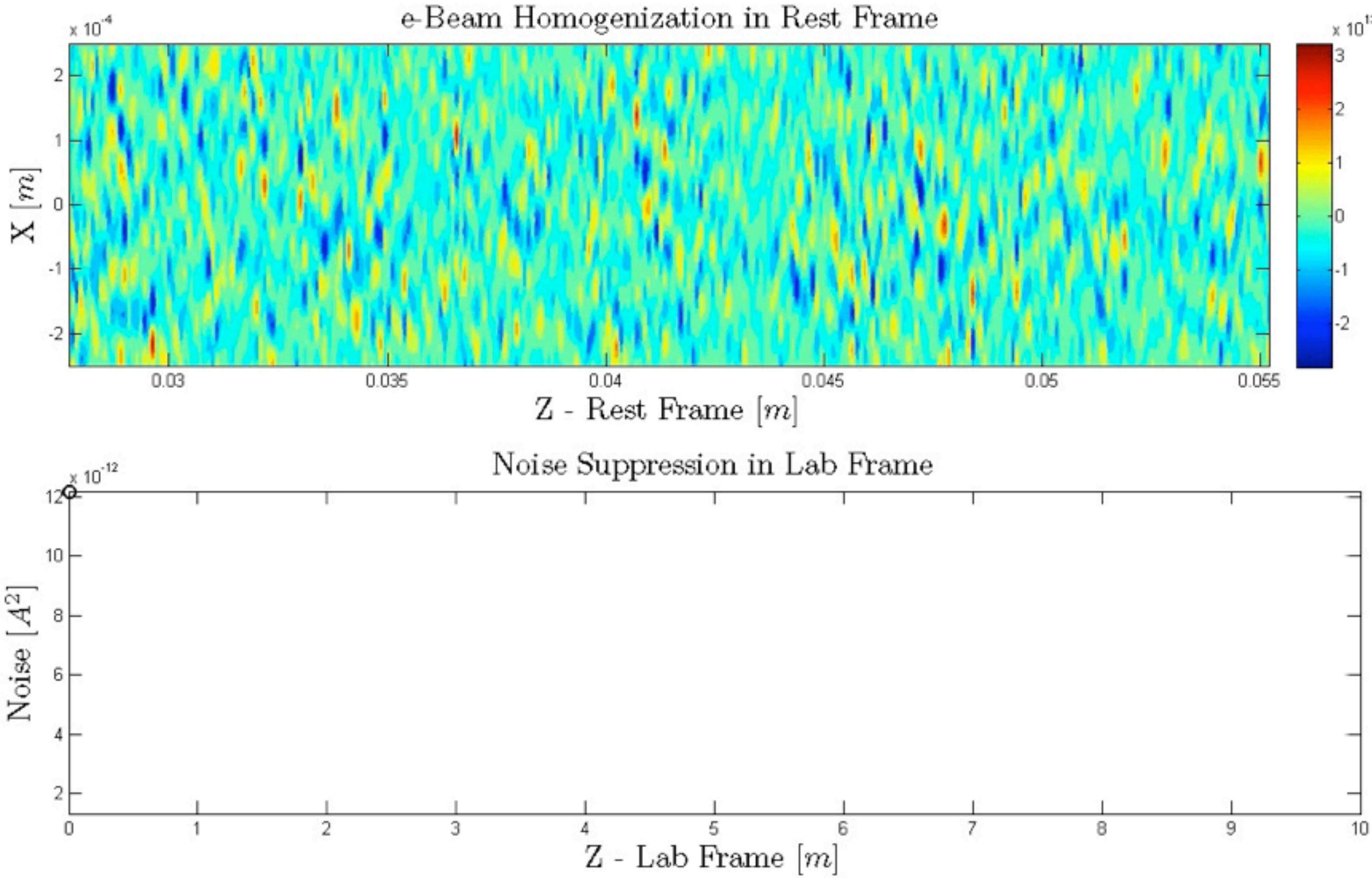


Shot Noise

$$\overline{|\breve{i}(L_d, \omega)|^2} << eI_b$$

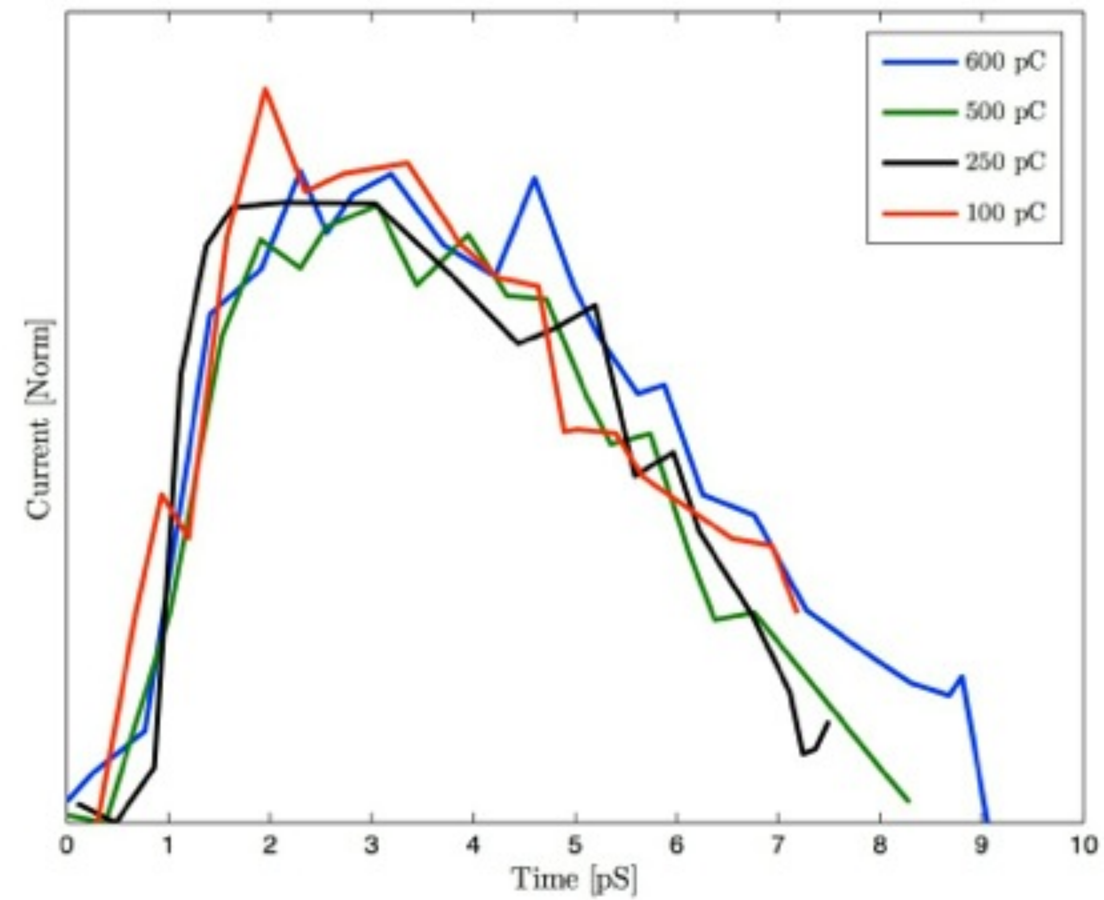


What does the noise suppression and homogenization process looks like?

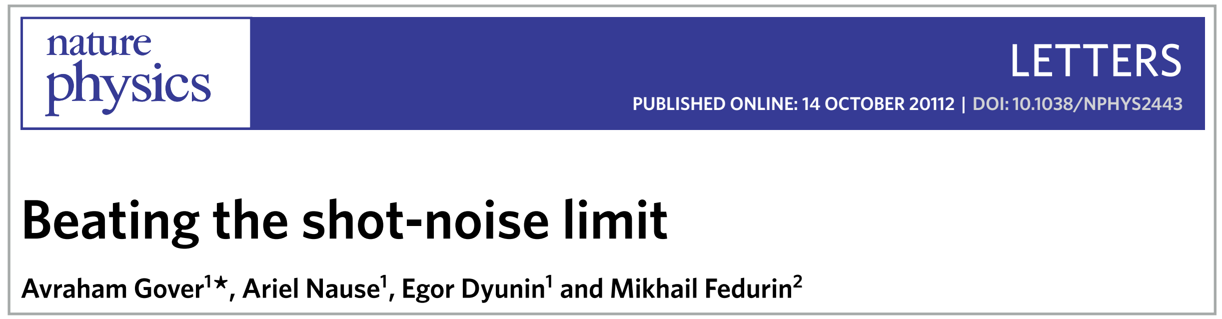


Operating Parameters

- Pulse Length: 5 pS
- Beam Energy: 50-70 MeV
- Beam Current: 40-100 A
- Normalized Emittance: ~3 mm-mrad
- Initial Beam Size: 400-500 um
- Acceleration Phase: On crest
- Copper OTR Screen
- Basler CCD camera equipped with a Nikkor Macro lens (100 mm)



Experimental Results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Beating the shot-noise limit

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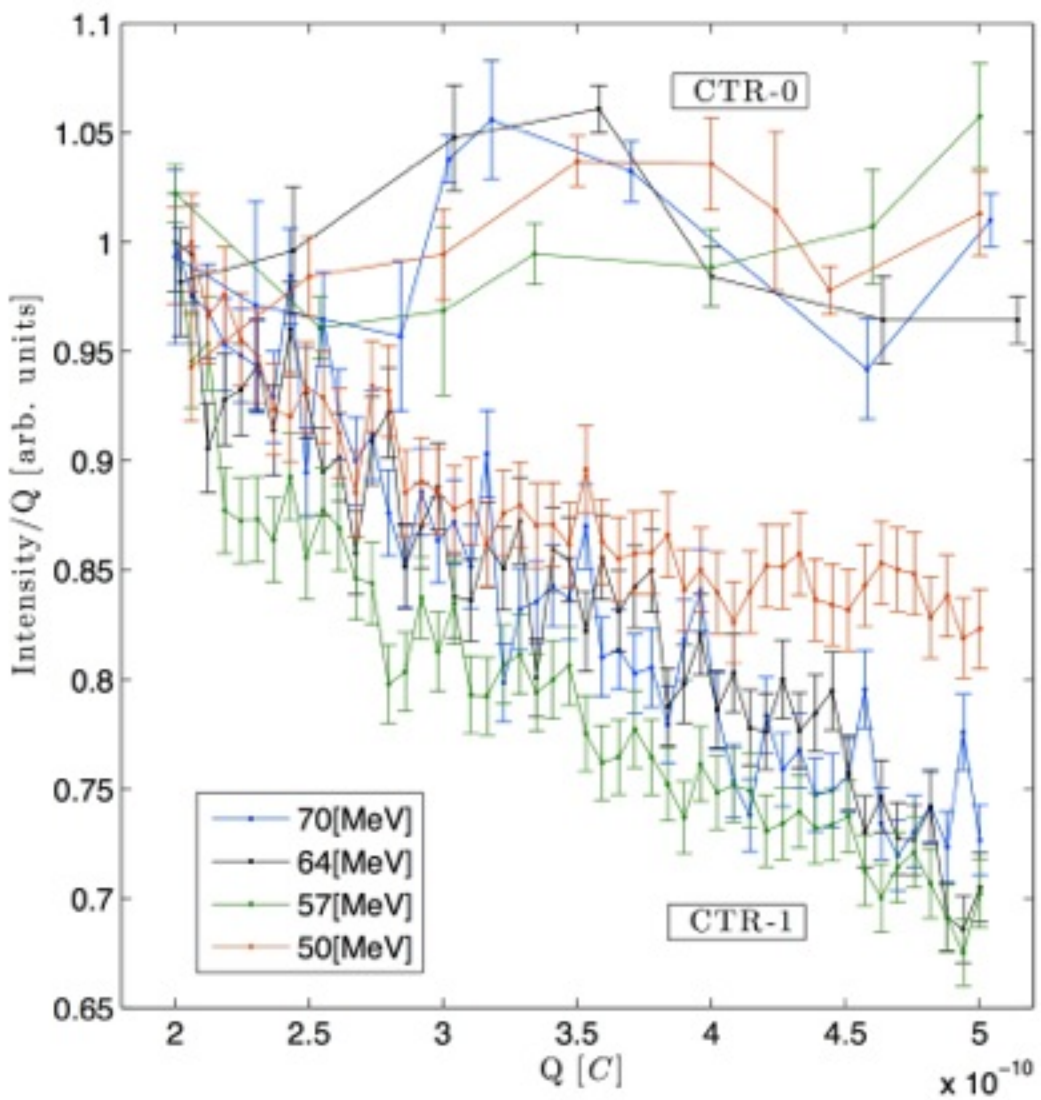
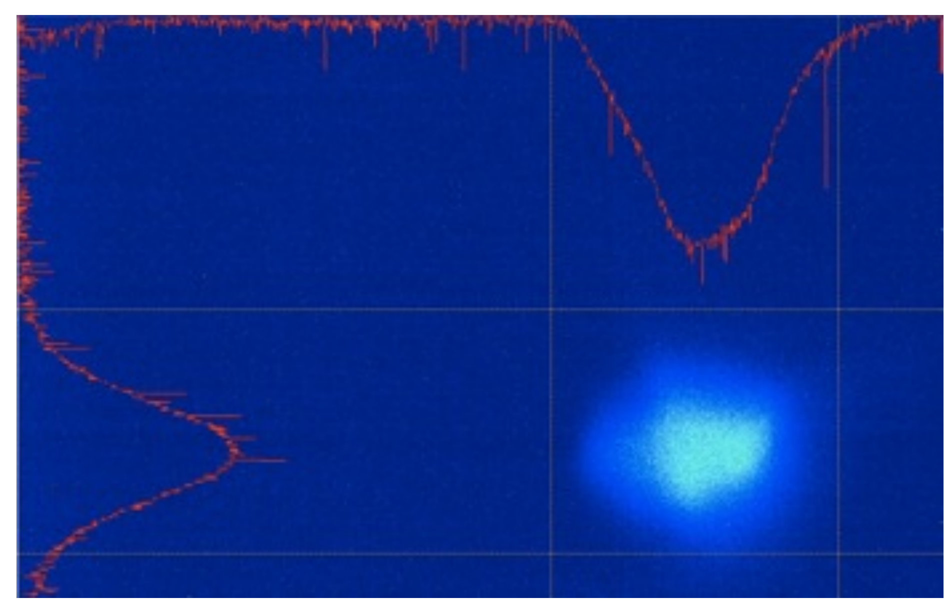


ATF/BNL – October 2011



Suggested Experiments in ATF2

Main Goals

Suppression of spontaneous (incoherent) radiation emission in electron beam radiation schemes (sub-radiance in the sense of Dicke).

In the context of FELs: demonstrating radiation noise suppression and coherence enhancement of seed radiation injected FEL.

Noise suppression in the UV range.

Experimental Plan

- Drift/dispersive scheme. Scan Chicane R_{56} to control and suppress Undulator spontaneous radiation (first stage).
- Drift/dispersive scheme. Scan Chicane R_{56} to control e-beam noise and demonstrate noise suppression measured with OTR screens along the beam line (second stage).
- Drift only scheme in later experiments. Noise will be evaluated by measuring TR power (second stage).

Experimental Concept

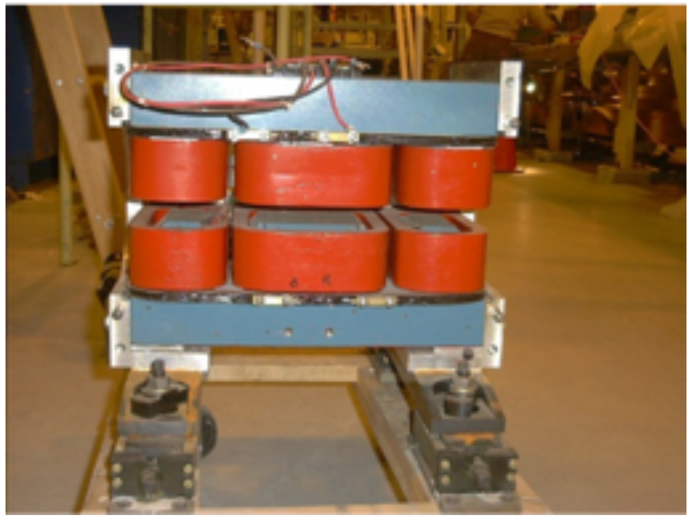
Suppression of spontaneous Undulator radiation.

- Measuring the spontaneous radiation from an Undulator and studying the radiation spectral intensity using a CCD or spectrometer.
- The undulator radiation will serve as a sensitive diagnostic means for evaluating the noise suppression and at the same time will also exhibit demonstration of spontaneous emission sub-radiance in an FEL undulator.
- Without suppression one would expect to measure on axis a substantial level of undulator radiation power in proportion to the un-suppressed current shot-noise input level. Detection of suppression can be made with good sensitivity by measuring the integrated optical power.

Experimental Method

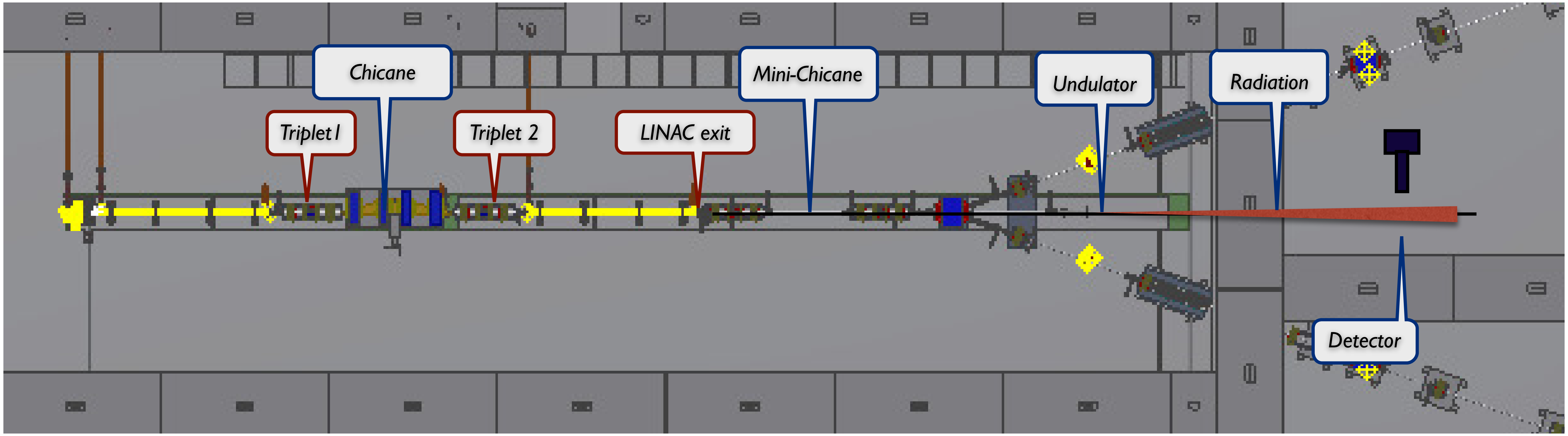
Scan Chicane R_{56} to control and suppress Undulator spontaneous radiation.

- Demonstrate Undulator spontaneous radiation suppression in a relativistic electron beam in a drift/dispersive scheme using two Chicanes as the dispersive sections: SDL Chicane installed after linac 1 (E=80MeV) and a small chicane (OK4) which we will install right after Linac2 triplet.
- Suppression rate will be measured using a CCD camera or a spectrometer recording emitted radiation from the Undulator.
- The R_{56} parameter of the chicane will be scanned in order to observe the effect.

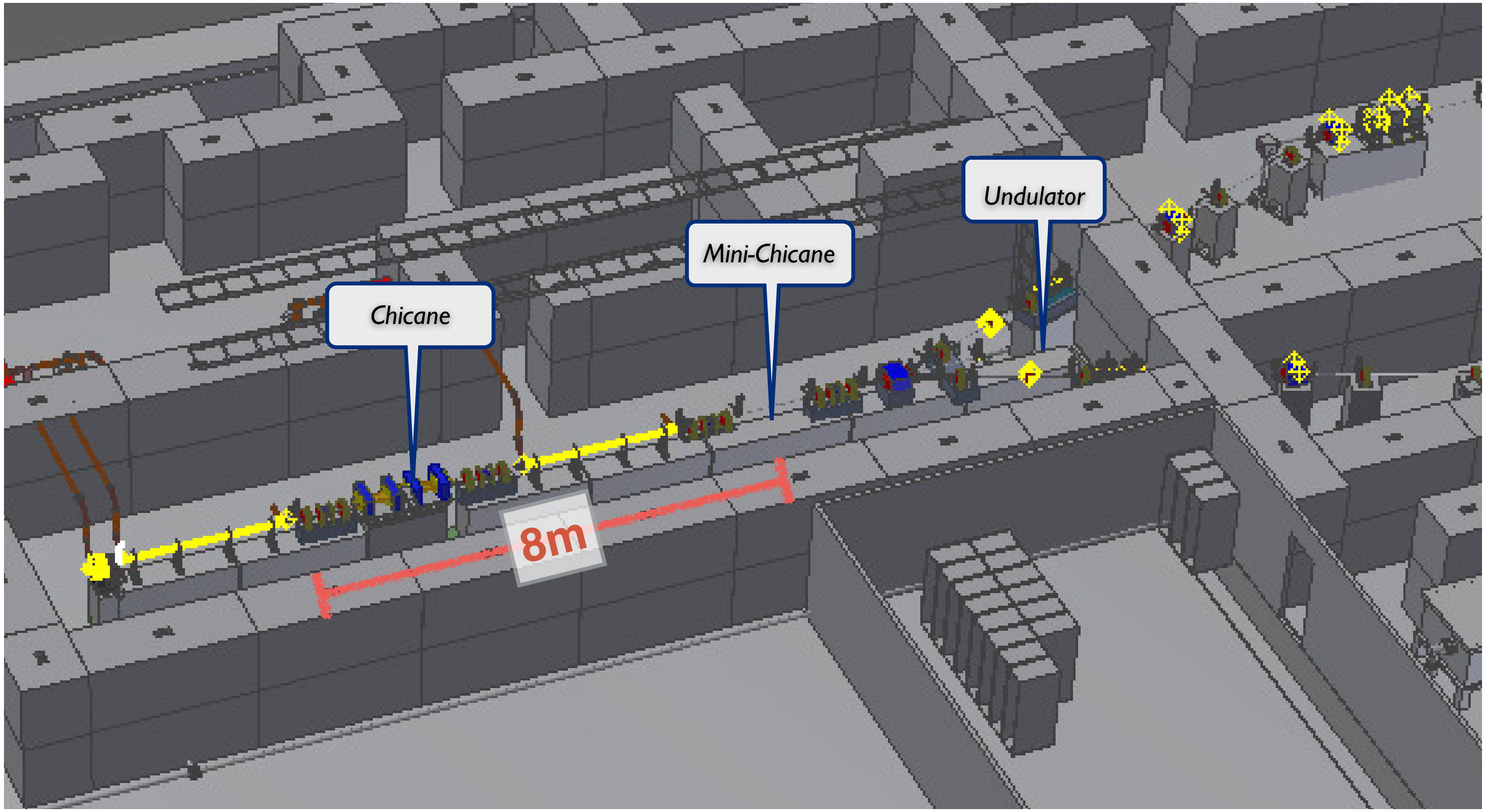


Experimental Method

- SDL chicane already installed between the two linac sections.
- OK4 mini Chicane will be installed after linac exit and before the bending dipole.
- UCLA 1.5cm Undulator will be installed right after the dipole.
- Beam will not be compressed (on crest acceleration) or bended.
- The R56 values can be achieved are up to 3mm for OK4 and a few cm for the SDL Chicane.



Experimental Method



Experimental Method

- The radiation pattern from an Undulator is proportional to the beam micro-bunching spatial spectrum.
- A better tool for studying the 3-D features of micro-bunching. Of most interest is the maximal emission on axis within a coherence cone.
- An expression for the spatially coherent Undulator spectral power (spatially filtered "single transverse mode") is:
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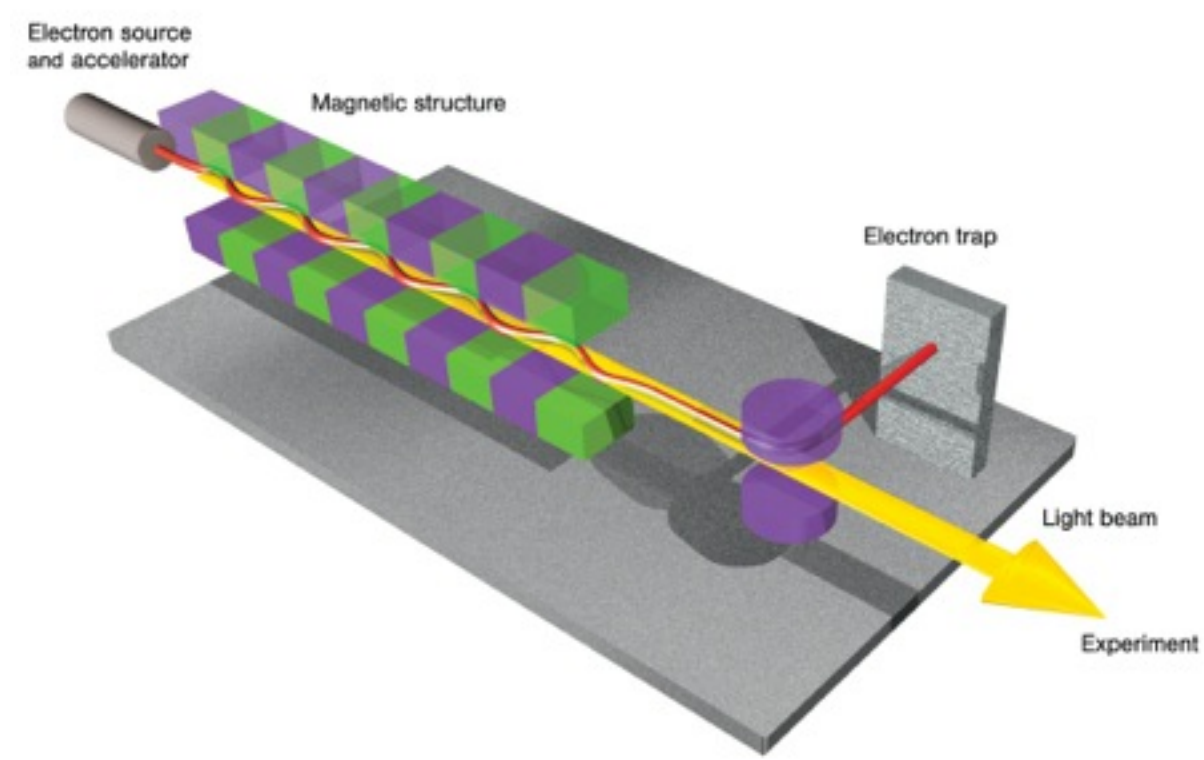


$$P = \frac{1}{4}\frac{a_w^2}{1+a_w^2/2}\sqrt{\frac{\mu_0}{\epsilon_0}}\frac{c}{\lambda}\overline{|\breve{i}(\omega)|^2}$$

Numerical Model

We construct the theoretical model example from three segments as follows:

1) Free drift of 8m from the exit of the first LINAC (the second is off) until the dipole magnet – M_{d0}.
2) Dispersive section, which in this example is OK4, length of 0.35m – M_{disp}.
3) Free drift of 3m, from the end of the chicane until the entrance to the Undulator – M_{d1}.

Matrices

Transfer matrices represent the transformation of density bunching and velocity bunching.

Free drift matrix:

$$M_{do}(Q,K) = \left\{ \begin{array}{ll} \cos(\theta_p(Q))L_{d0} & \frac{-i}{W_d(Q,K)}\sin(\theta_p(Q)L_{d0}) \\ -iW_d(Q,K)\sin(\theta_p(Q)L_{d0}) & \cos(\theta_p(Q))L_{d0} \end{array} \right\}$$

Dispersive section matrix:

$$M_{disp}(Q,K) = \left\{ \begin{array}{ll} 1 & -i\frac{Q}{t_p}\frac{m_e c^2 \gamma}{e}k(K)R_{56} \\ 0 & 1 \end{array} \right\}$$

Final result is multiplication of three matrices:

$$M_{final}(Q,K,R_{56}) = M_{d1}(Q,K)M_{disp}(Q,K,R_{56})M_{d0}(Q,K)$$

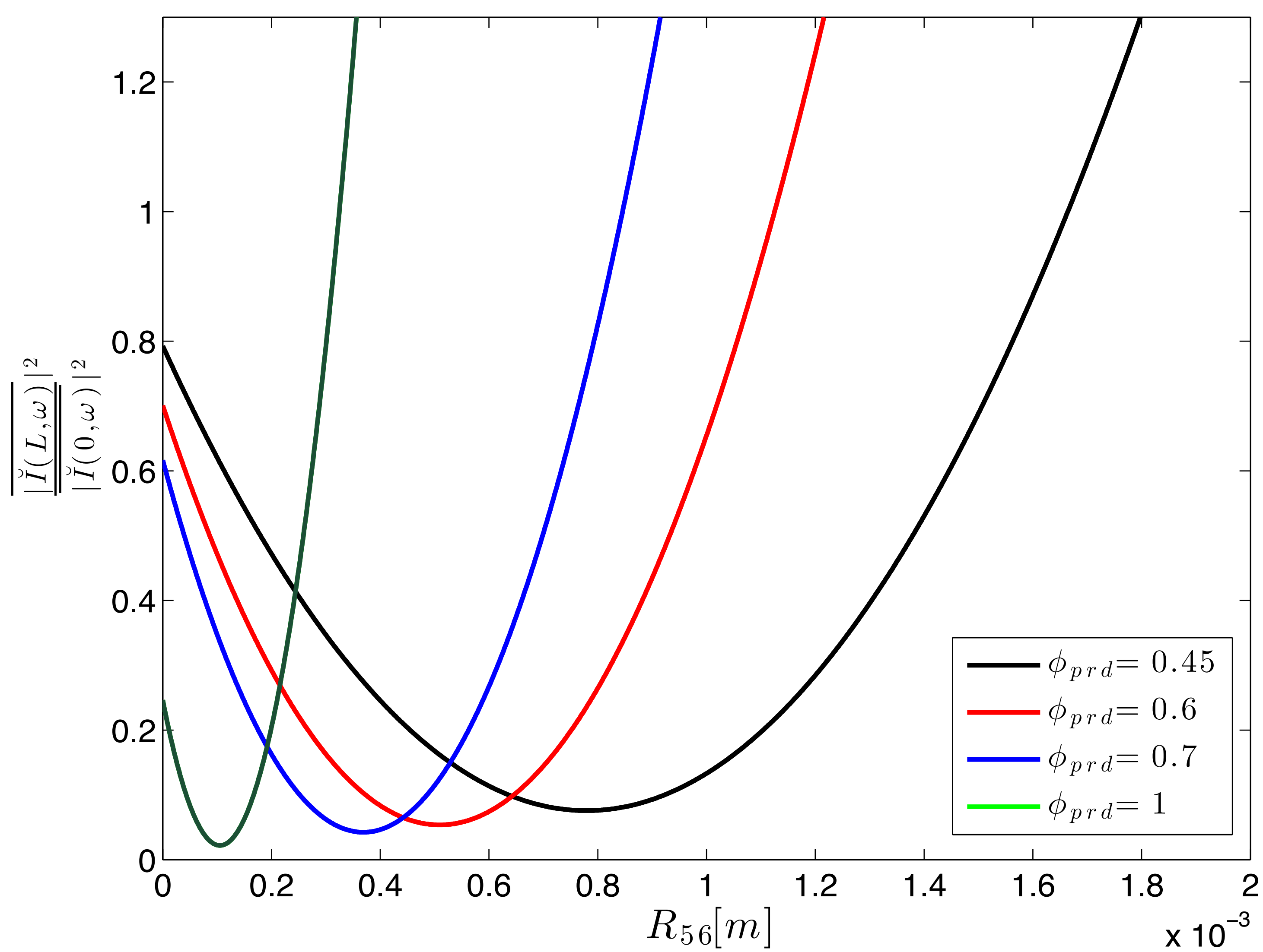
Beam Parameters

- E=100–300 MeV (turning the second acceleration section on/off and using the SLED cavities energy doubler option), sigma = 300–500 um, Q=100–1000 pC.
- Relatively large beam transverse profile was used in order to use as little focusing as possible in the drift.

Numerical Results

Scan Chicane R_{56} to control and suppress current noise.

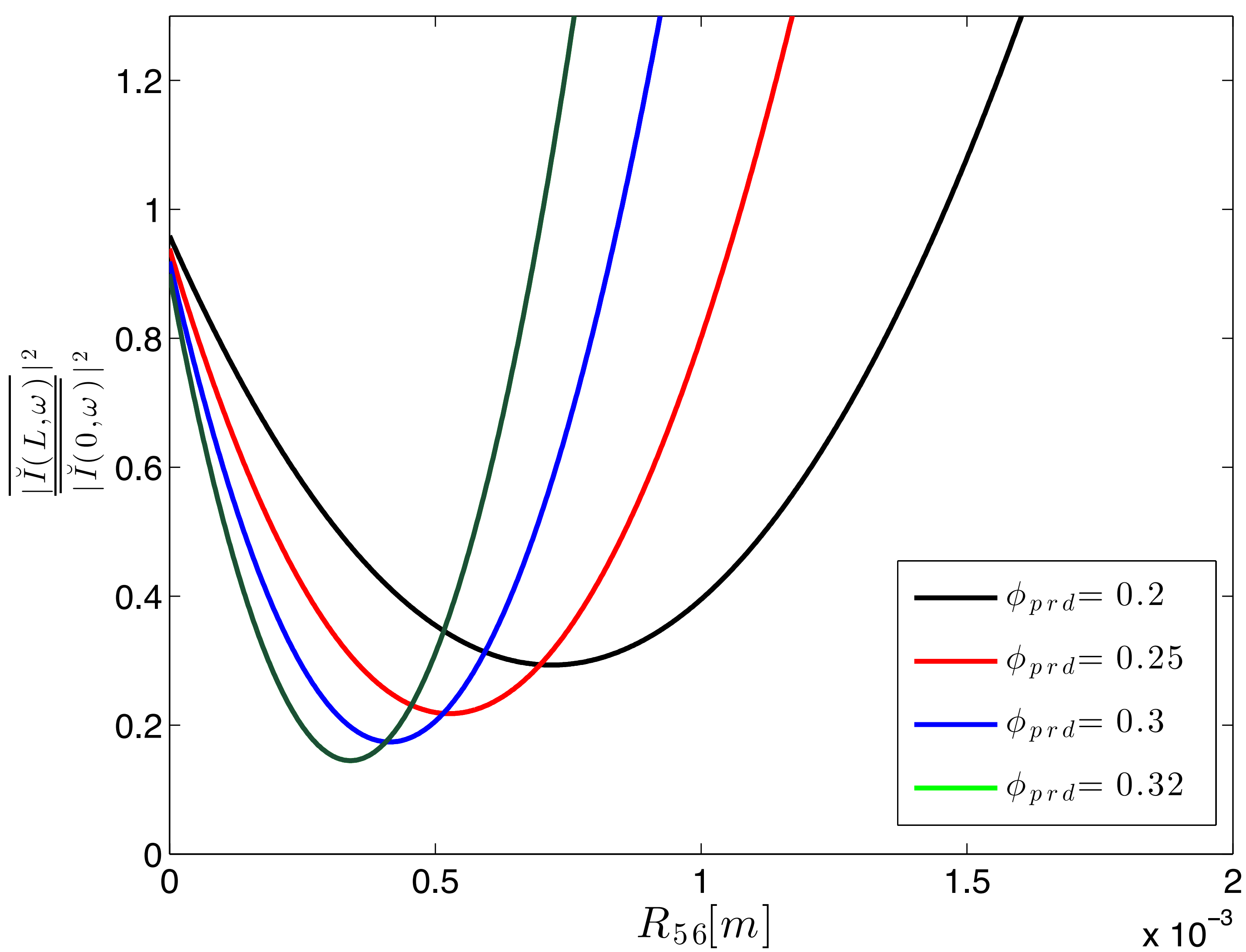
Energy	**100 [MeV]**
Pulse Charge	0.1–0.5[nC]
Beam Waist	0.3 [mm]
Normalized Emittance	1–2[μm]
$\Delta\gamma/\gamma$	0.05[%]
L_d	8[m]
λ	0.3[μm]



Numerical Results

Scan Chicane R_{56} to control and suppress current noise.

Energy	**300 [MeV]**
Pulse charge	0.1–0.25[nC]
Beam waist	0.25 [mm]
Normalized emittance	1–2[μm]
$\Delta\gamma/\gamma$	0.05[%]
L_d	15[m]
λ	0.1[μm]



How to Estimate the R_{56} Value?

We calculate the maximal R_{56} coefficient using the amplitude of the magnetic field in the chicane dipoles. We take SDL Chicane as an example:

We use:

$$R_{56} = -\frac{1}{\gamma^2}\int_0^{L_m}(1 + a_\perp^2(z))dz$$

Where:

$$a_\perp(z) = -\frac{e}{mc}\int_0^z B_\perp(z')dz'$$

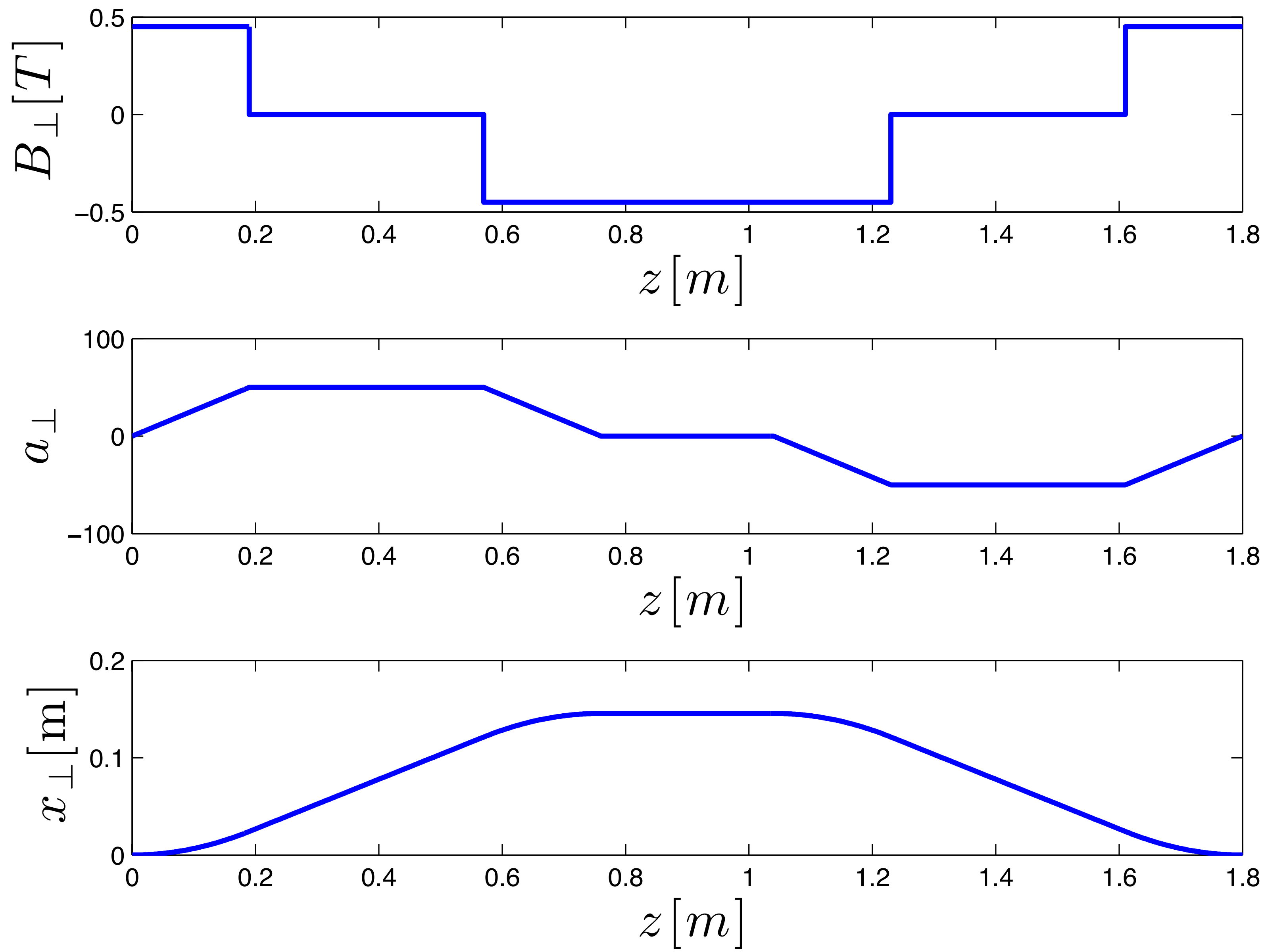
We assume constant magnetic field in the dipoles.

We use amplitude of 0.45T for the magnetic field in the dipoles.

We use lengths of 0.19m for the magnetic length of the dipoles, 0.38m drift between the outer dipoles and 0.28m drift between the inner dipoles.

This calculation gives a more accurate estimation of the R56. It's based on geometrical size and magnetic fields of the dispersive section. Allows using a non-symmetrical chicanes as well (SPARC).

How to Estimate the R_{56} Value?



$$R_{56} = -\frac{1}{\gamma^2}\int_0^{L_m}(1 + a_\perp^2(z))dz \longrightarrow 4.3 \text{ [cm]}$$

Thanks