GENERATION OF BUNCH TRAINS AND IT'S APPLICATIONS

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May 7, 2009

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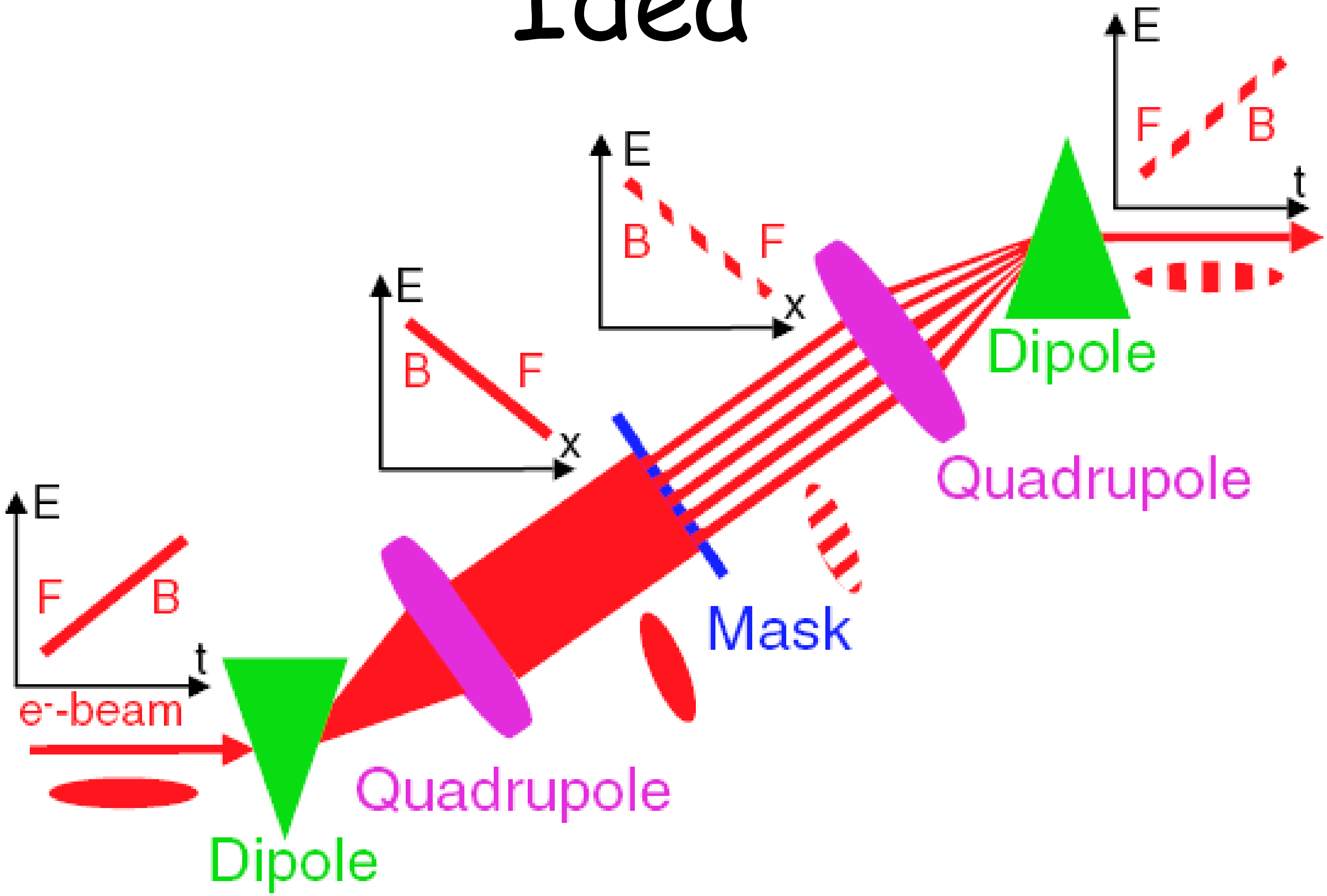
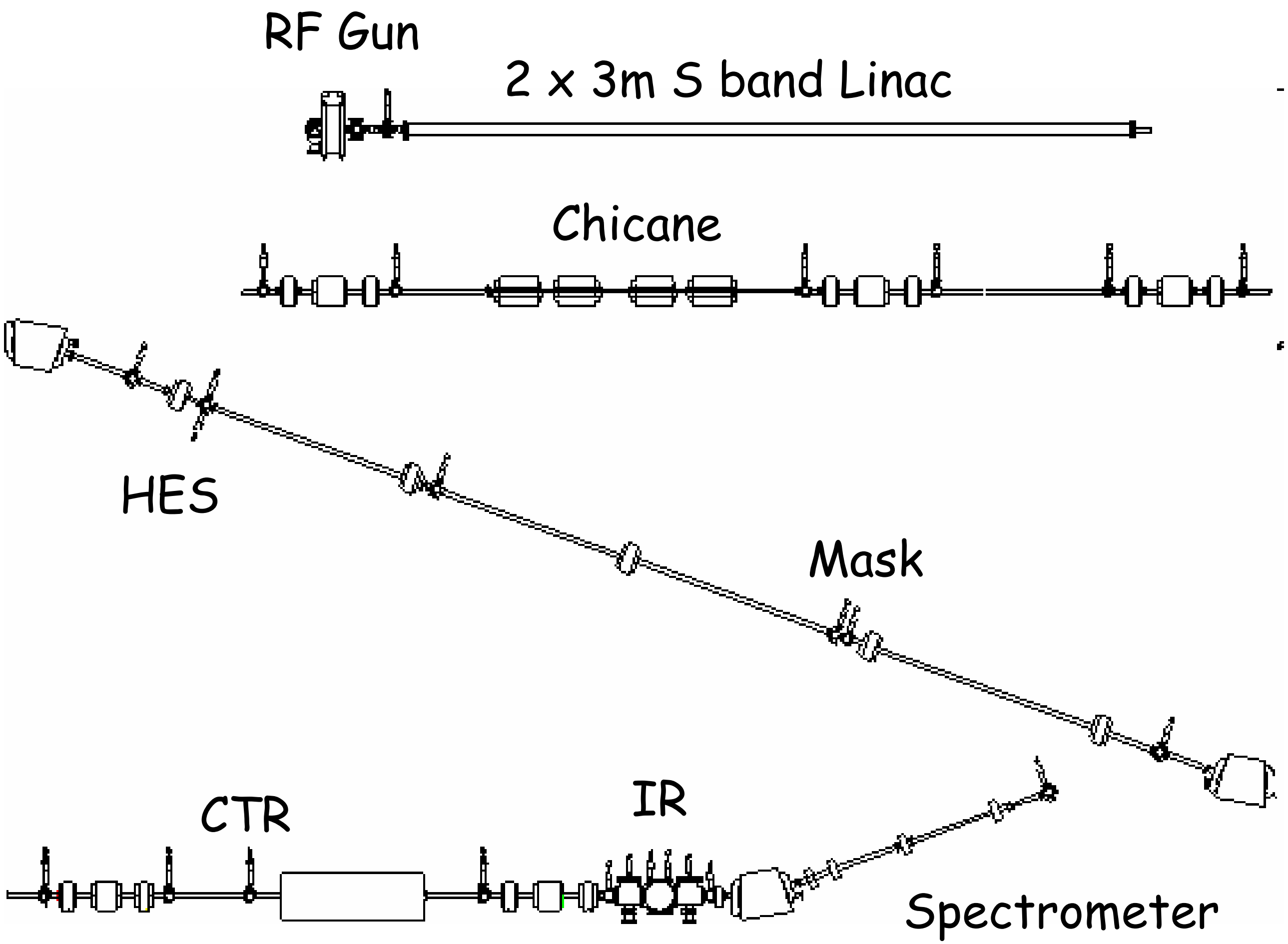
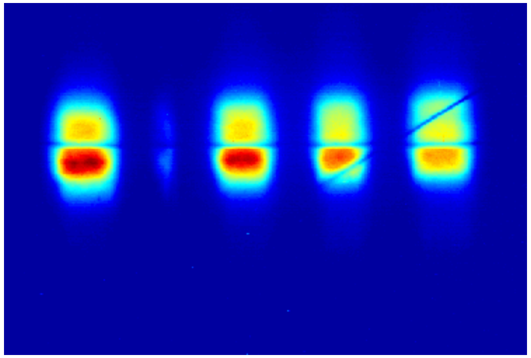
Idea



Simplified schematic of the mask principle. Only the dogleg section of the beam line is depicted (not to scale), and three quadrupole magnets are omitted. The side graphs represent the beam energy correlation with the beam front labelled by "F" and the back by "B."

Experimental Layout





Measured microbunches

Mask

Wire mesh mask and frame. The wires are d=800 μm in diameter with a period of D=1650 μm. The red arrow indicated the two consecutive wires.

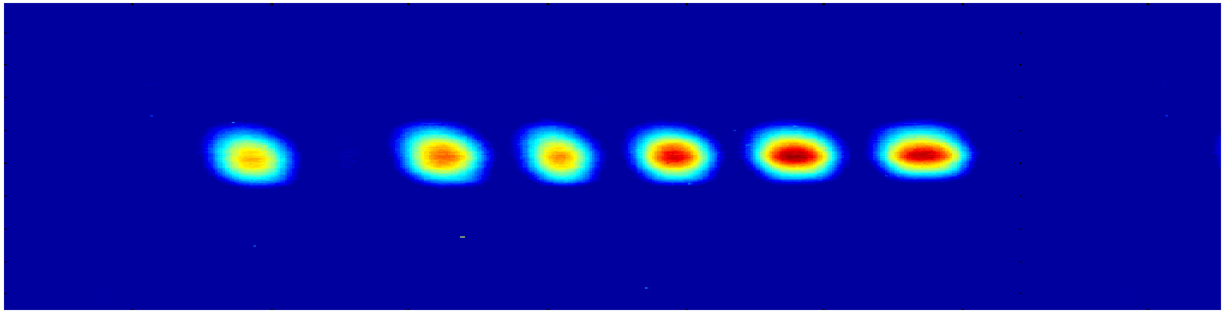
Beam optics for mask

Transverse size of the beam at the mask due to its emittance only must be smaller than the wire size.

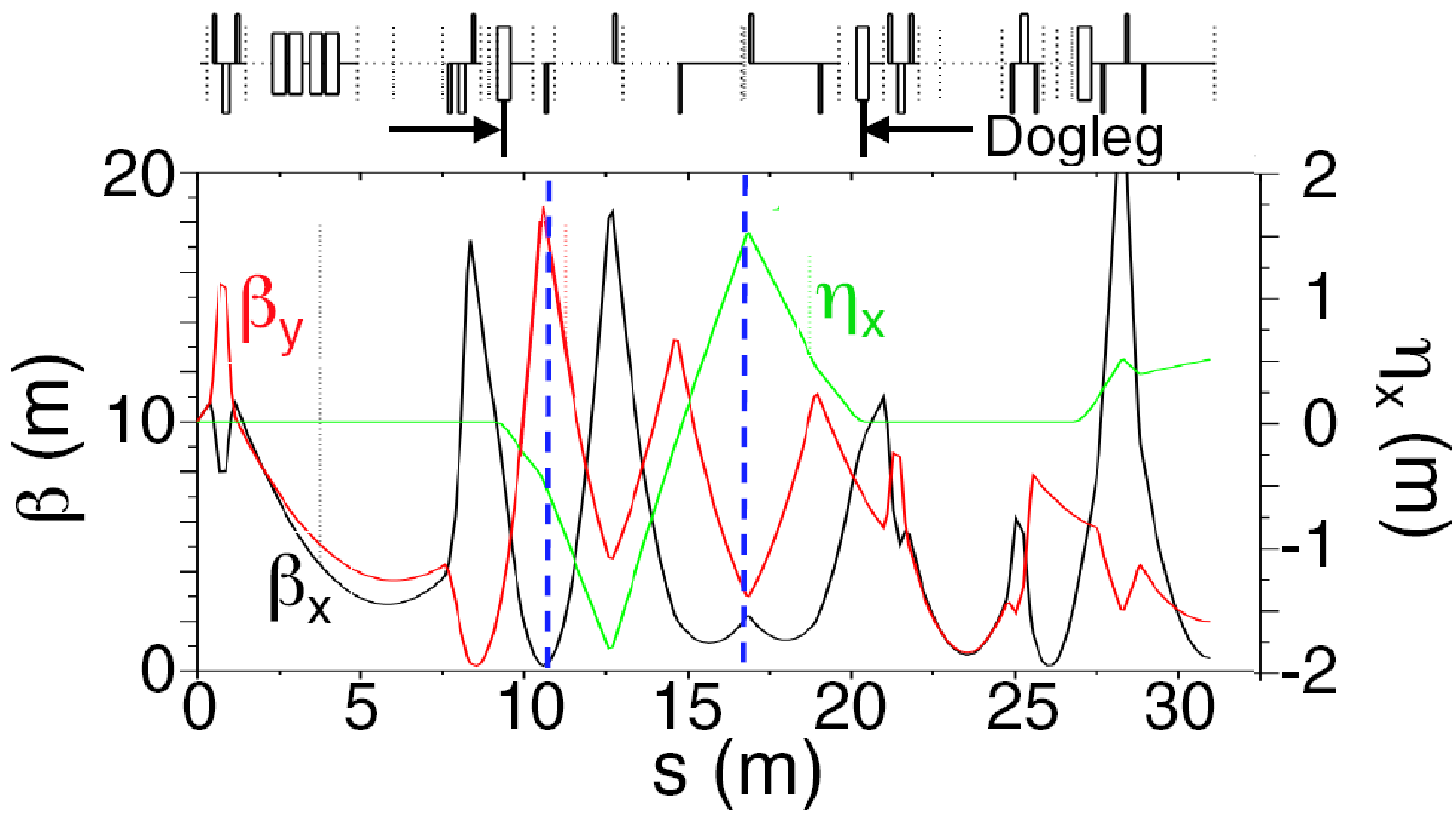
$$\sigma_x = (\beta_x \epsilon_N / \gamma)^{1/2} \ll d$$

beam size due to its correlated energy spread is much larger than that due to its emittance

$$\sigma_\eta = \eta_x |\Delta E / E_0| \gg \sigma_x = (\beta_x \epsilon_N / \gamma)^{1/2}$$



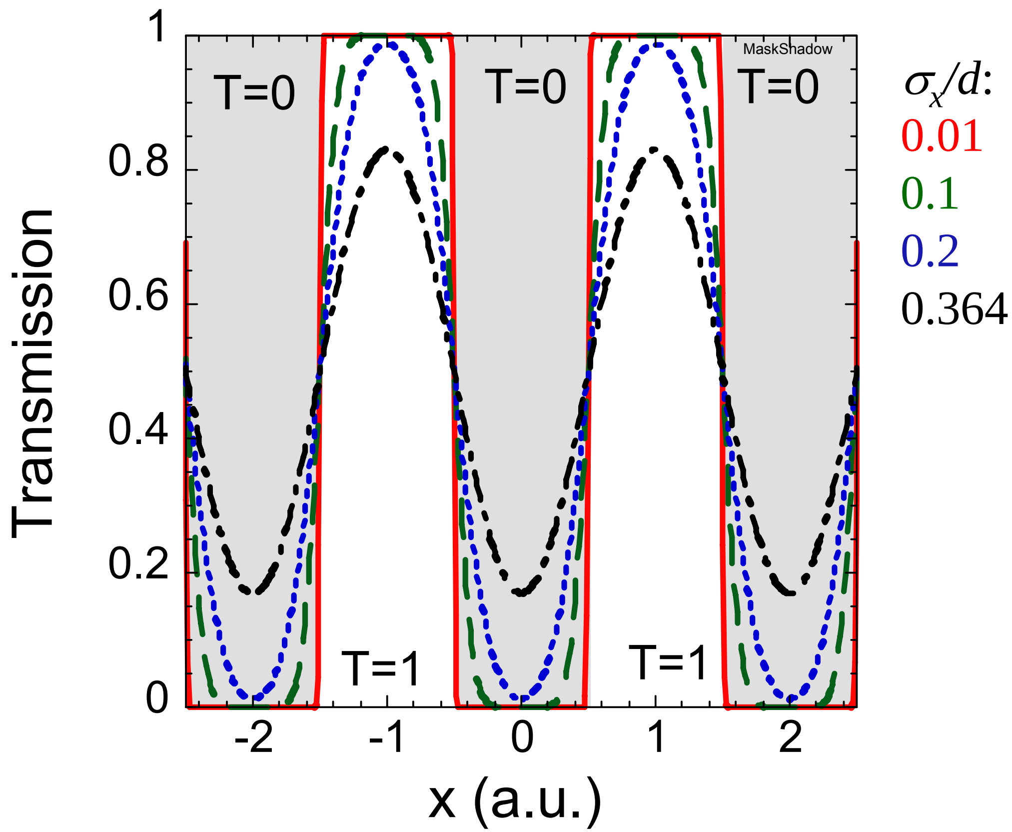
Beam optical functions



Contrast

$$T(x_0;x_{w,i},d,\sigma_x) = 1 - \frac{1}{2}\sum_i \left[erf\left(\frac{(x_{w.i} + d/2 - x_0)}{\sqrt{2}\sigma_x} \right) - erf\left(\frac{(x_{w.i} - d/2 - x_0)}{\sqrt{2}\sigma_x} \right) \right]$$

Convolution function mask and beam betatron size



Beam betatron size:

$$\sigma_x = \sqrt{\frac{\beta_x \varepsilon_N}{\gamma_0}}$$

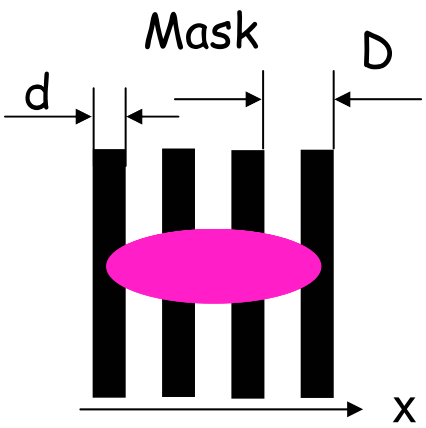
Wire positions:

$$D = x_{i+1} - x_i$$

Contrast decreases as σ_x/d increases

Present experiments: $\sigma_x/d \approx 0.1\text{-}0.2$

Bunch Train Parameters



β_x=1.9 m
ε_N=1 mm-mrad
η_{mask}=1.372 m
γ_0=117
$\Delta E/E_0$=1%

Beam size at the mask: $\sigma_x = \sqrt{\frac{\beta_x \varepsilon_N}{\gamma_0} + \left(\eta_{mask}\left|\frac{\Delta E}{E_0}\right|\right)^2}$ =1.372 cm

127 μm <<< 1.372 cm

D=1270 μm

Number of μbunches: $N_b = \frac{\sigma_x}{D} \cong \frac{\eta_{mask}}{D}\left|\frac{\Delta E}{E_0}\right|$ =10 to 11

L_z=1650 μm
R_{56}=4 cm

Mask transparency

$$T = \frac{(D-d)}{D}$$

μbunches spacing: $\Delta z = \frac{L_z'}{N} \cong D\frac{L_z + R_{56}\Delta E/E_0}{\eta_{mask}|\Delta E/E_0|}$ =400 μm

Q_0=500 pC
d=500 μm

Bunch chirp:

$$\Delta E/E_0$$

μbunches charge: $Q_{mb} = T\frac{Q_0}{N_b} \cong \frac{Q_0(D-d)}{\eta_{mask}|\Delta E/E_0|}$ =30 pC

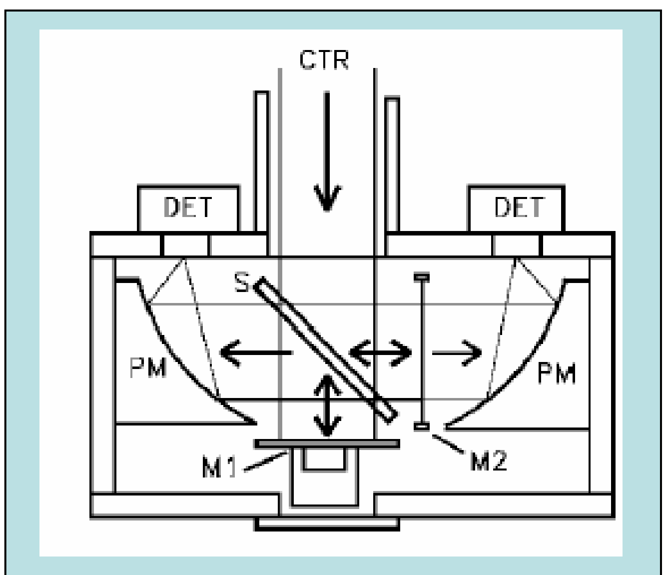
Bunch compression:

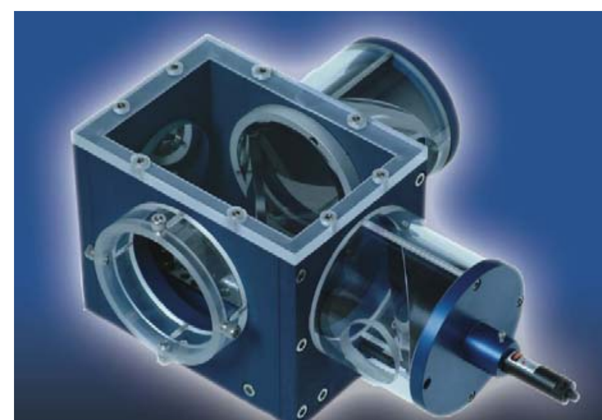
$$L_z' = L_z + R_{56}\Delta E/E_0$$

μbunches current: $I_{mb} = \frac{Q_0 c}{L_z'} = \frac{Q_0 c}{L_z + R_{56}\Delta E/E_0}$ =73 A

Pulse length measurement

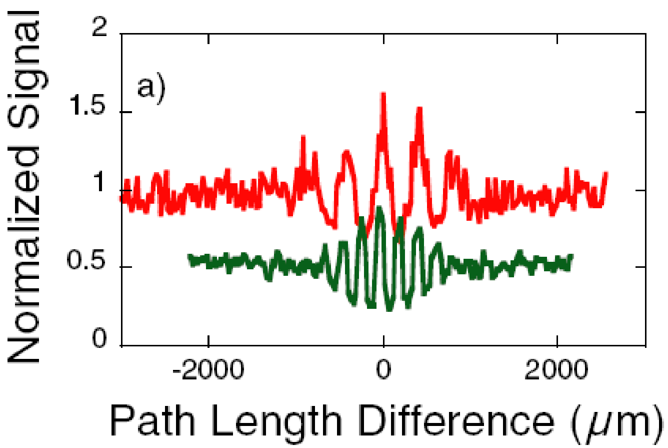
- Michelson Interferometer
  - Commercial Product (Radia beams)
  - Compact Footprint
  - Convenient Alignment
  - Resolution : 10 μm – 1.5 mm (rms)
- CTR is detected from retractable mirror
  - Two channel liquid He cooled Bolometer
  - Autocorrelation

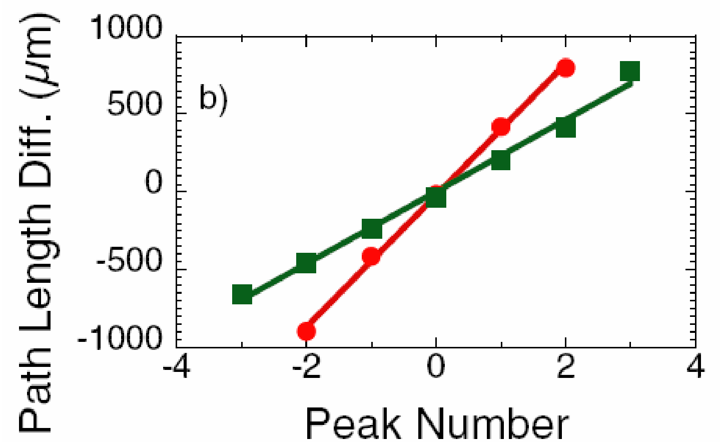




Tunable spacing

$$\Delta z = D \frac{\sigma_z \pm R_{56} \Delta E / E_0}{\eta_{x,\mathrm{mask}} |\Delta E / E_0|}$$

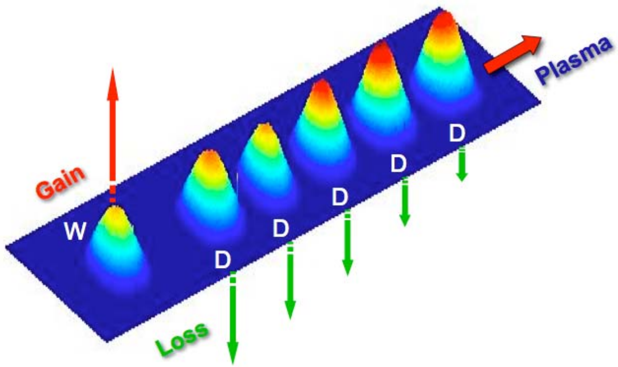




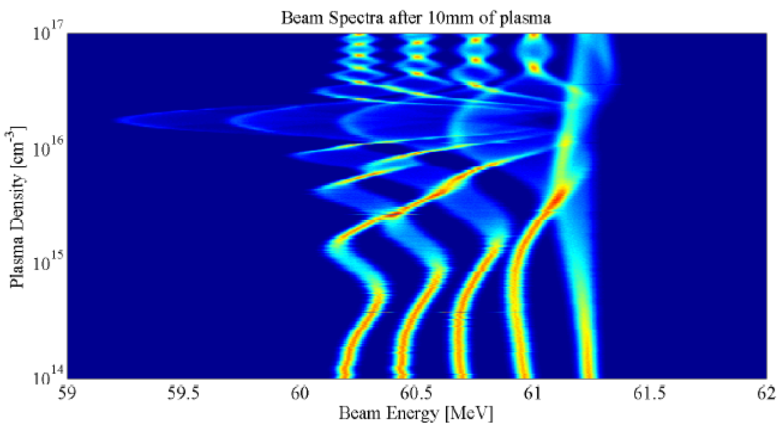
Normalized CTR traces obtained with two different incoming full energy spectra: $\Delta E/E0$~1.5% (red line, shifted up by 0.5 a.u. after normalization) and 3.4% (green line) and with different energy slit width, leading to trains with 3 and 4 microbunches, respectively.

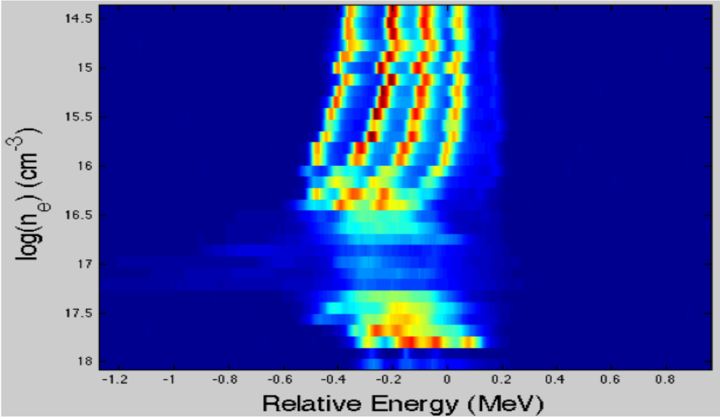
The distance between the peaks is determined from the slope of a linear fit of the measured path length difference versus peak number shown in. The two traces clearly show the dependency of *z* on the incoming correlated energy spread.

Multi-bunch Plasma Wake Field Experiment



Measured train of drive bunches excites high amplitude wake field





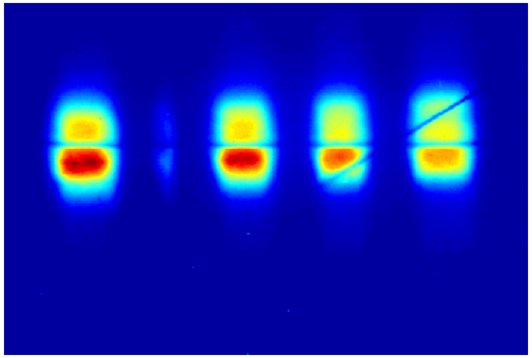
Complex interaction was studied in simulations

Characteristics of resonant interaction observed in first results

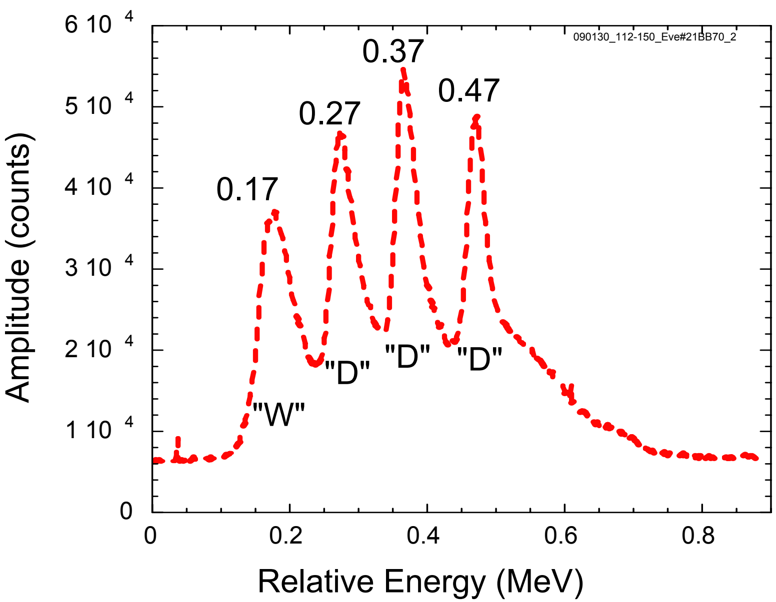
IEEE NPSS Particle Accelerator Science and Technology Doctoral Student Award in 2009

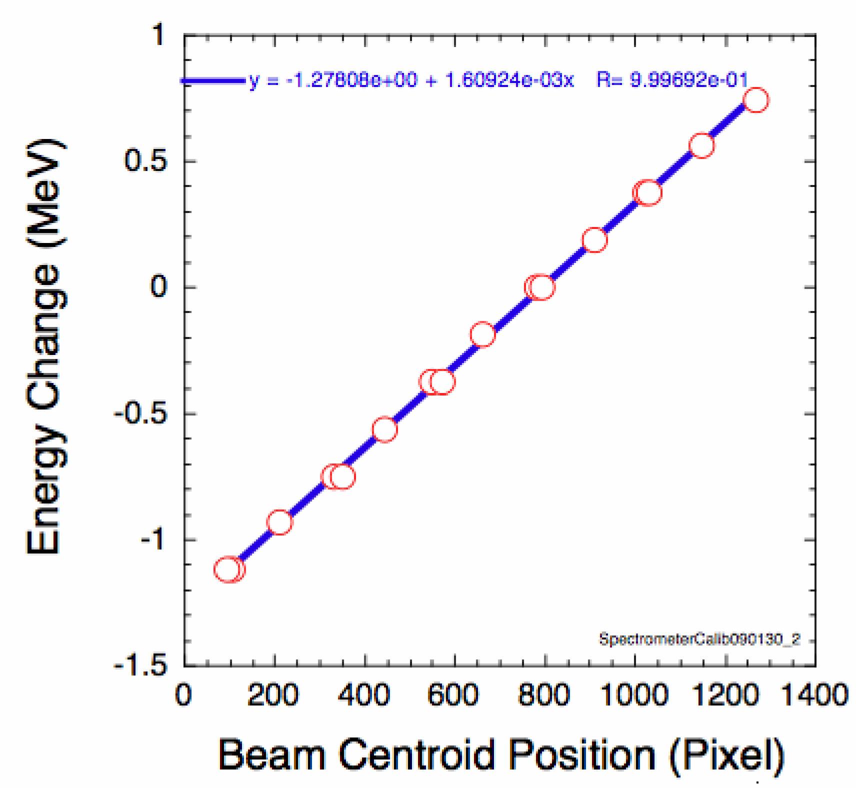
"CSR" challenge

Image after mask



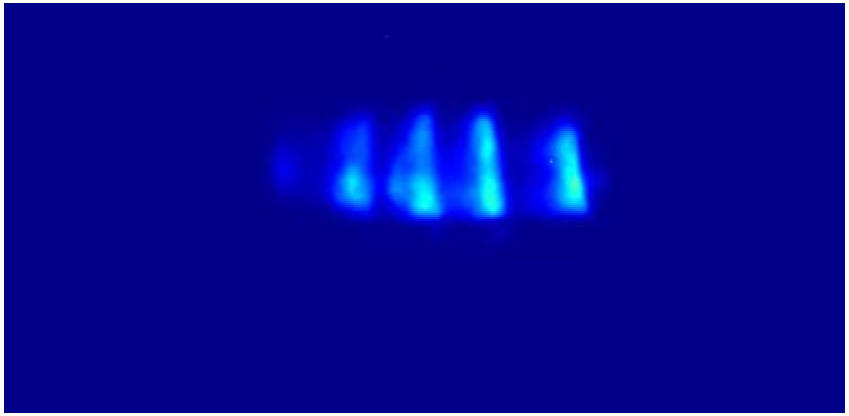
Projection at spectrometer





Energy is redistributed among bunches due to CSR

High contrast after mask leads to low contrast at spectrometer

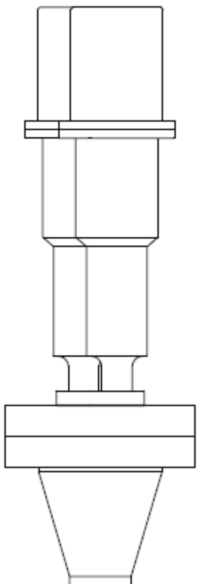
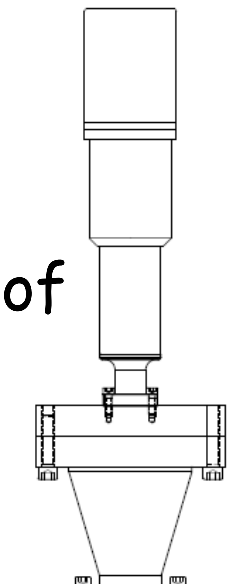
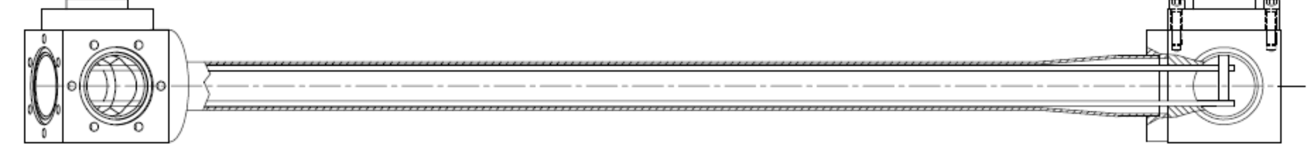
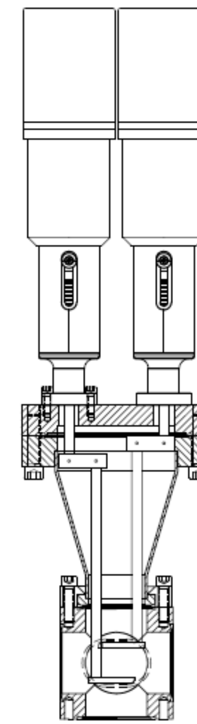
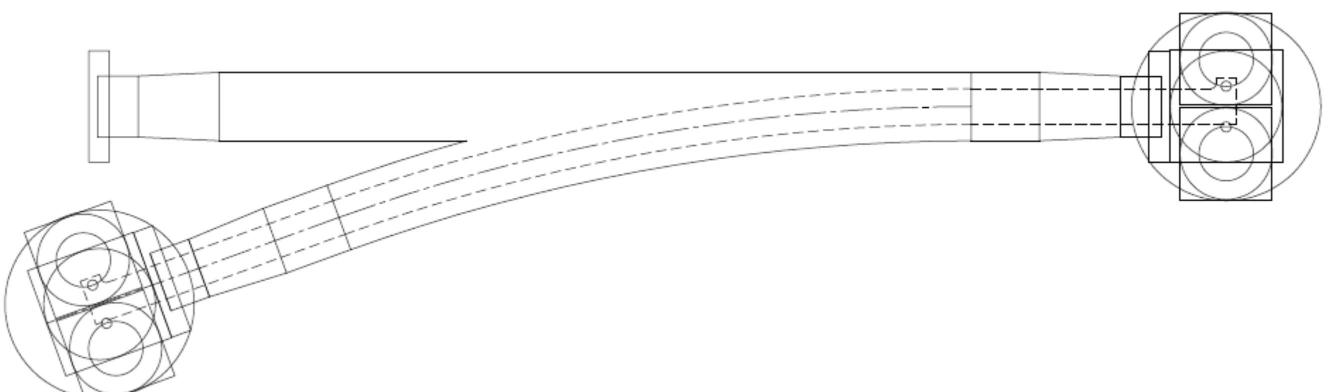


- Adjusting betatron size at the mask allows to generate Gaussian or “square” bunches.
- Energy spread from CSR changes ~3 times.

CSR shielding test

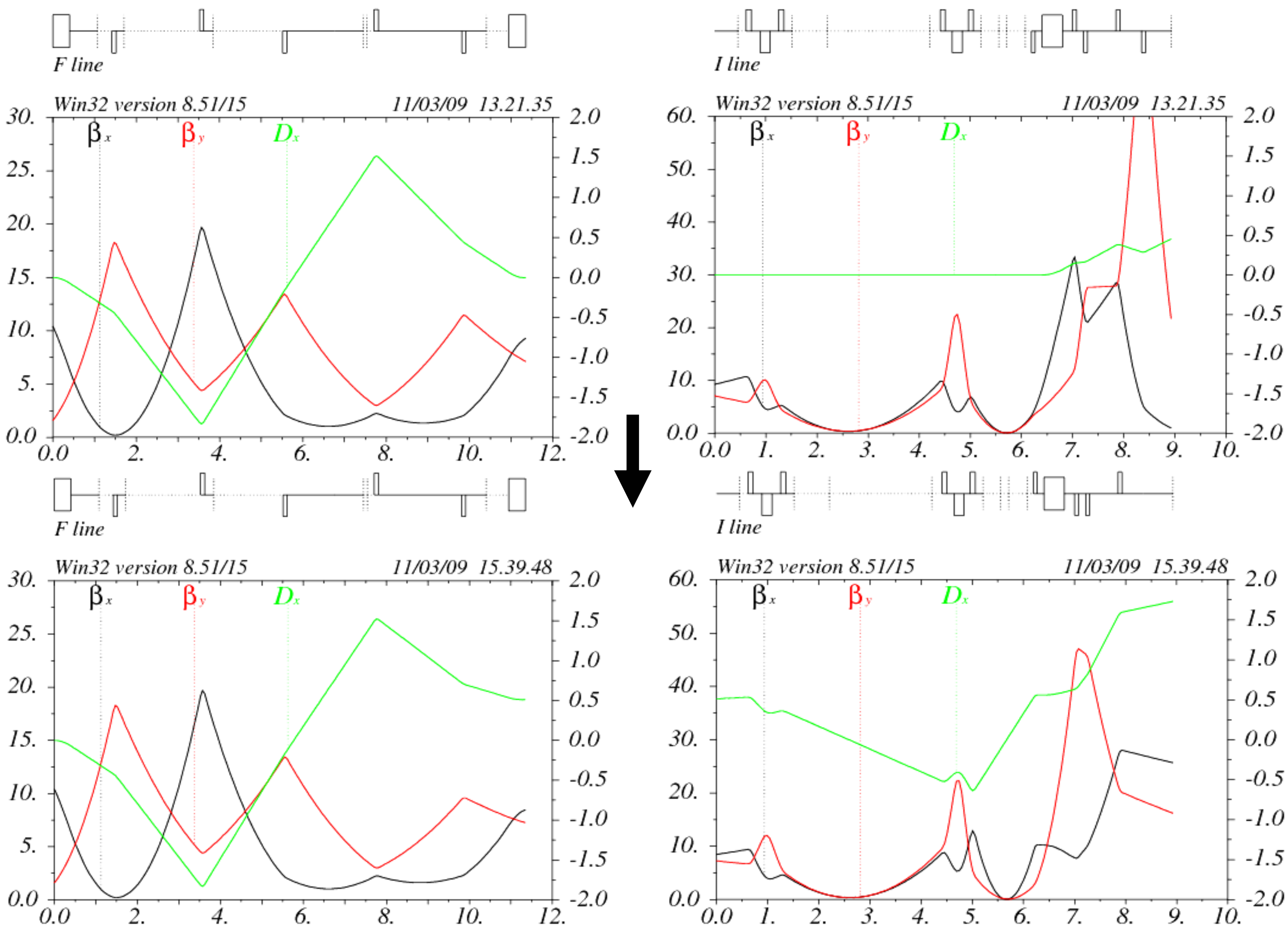
- Two parallel plates with adjustable gap will be installed into dipoles

- Studies of the suppression of the energy spread increase and energy loss due to CSR will be conducted

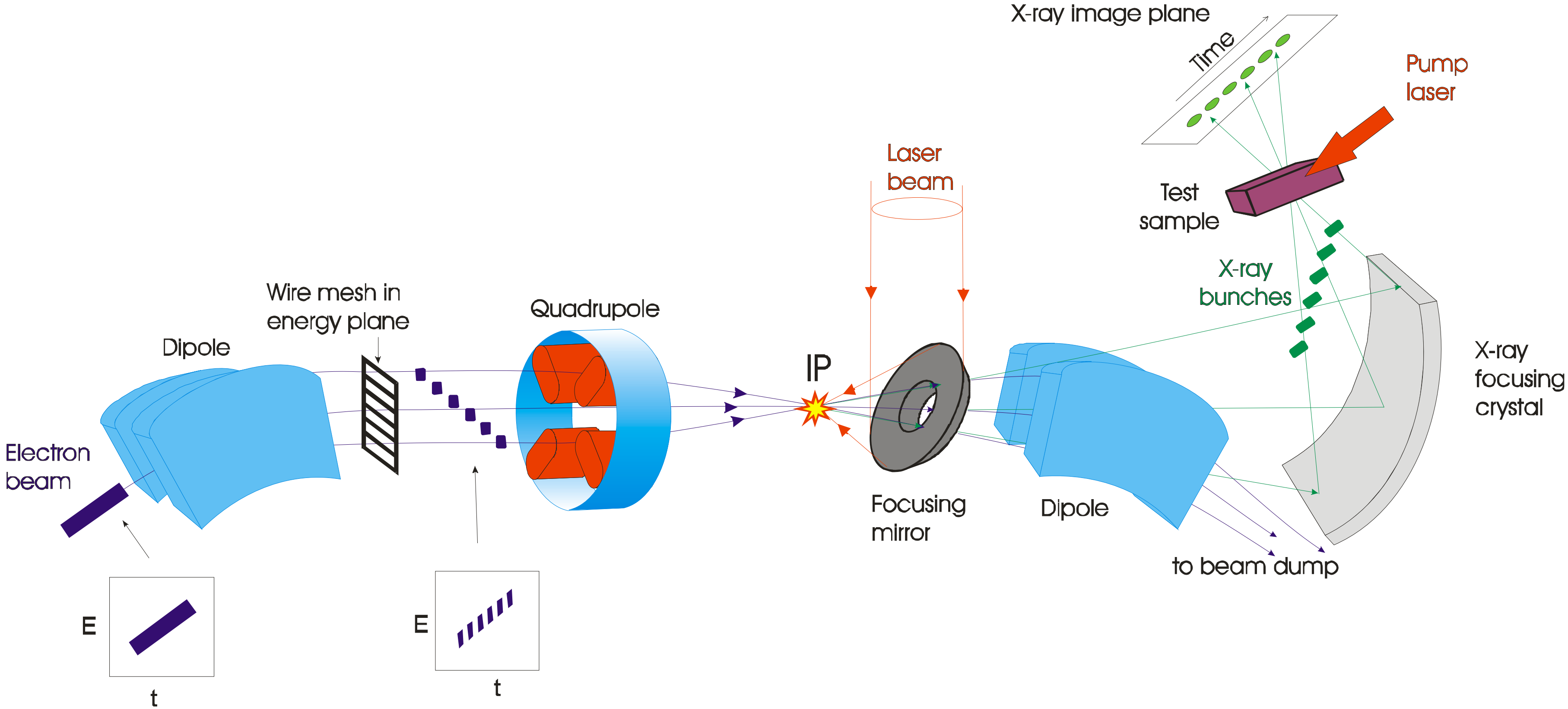






Challenges: Beam line tuning

Quad currents are adjusted to have zero dispersion with large derivative at IR. Angular distribution at IR is dominated by the energy chirp.



Idea of X ray camera



10^7 X-rays per beamlet are expected with 1% energy spread with 0.3 mrad divergence, 35μm source size and 100fs RMS duration. This correspond to peak brightness of 10^{23} ph/sec/mm^2/mrad^2/0.1%

Conclusion

- Simple method to produce tunable picosecond bunch train
- Stability in time and energy is set by mask
- Number of µbunches and their spacing can be selected
- Bunch train pattern can be tailored for specific applications
- Train length can be further varied trough bunch compression
- Applications:
  - Multi bunch PWFA
  - Study of CSR effects, suppression with shielding
  - 100fs frame rate x ray camera
- Many other applications…