A0 Photoinjector Program Extension to NML

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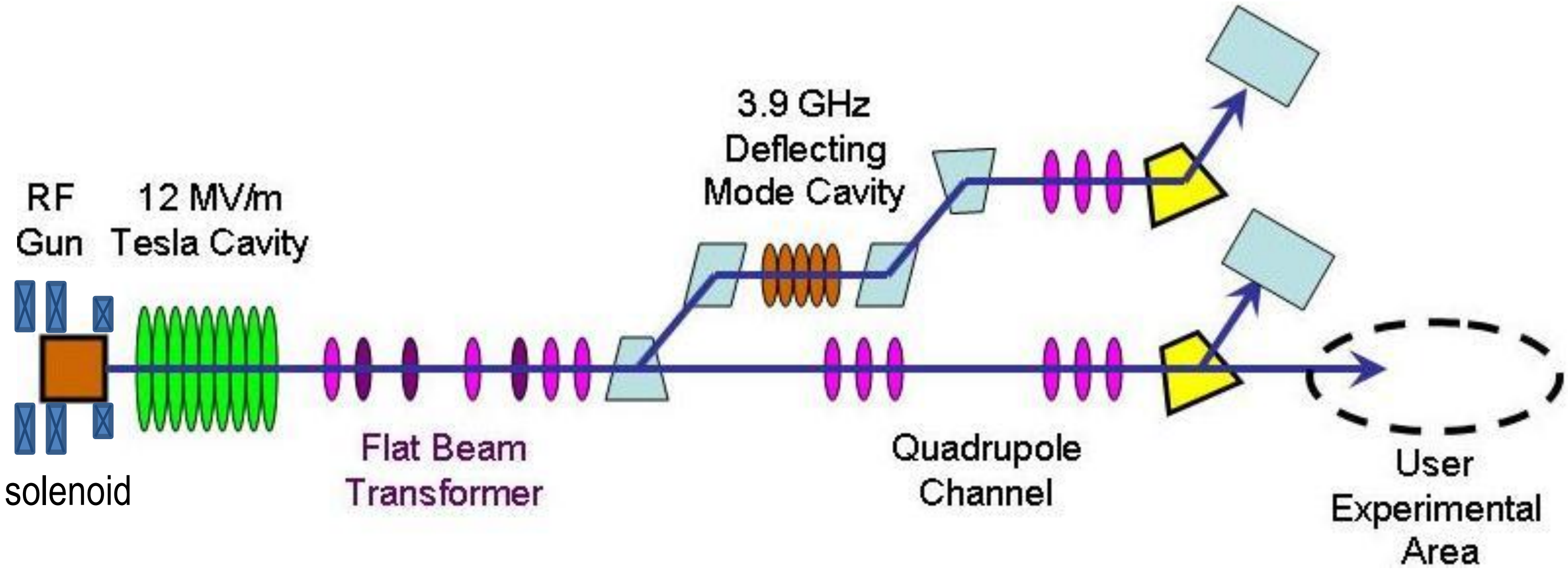
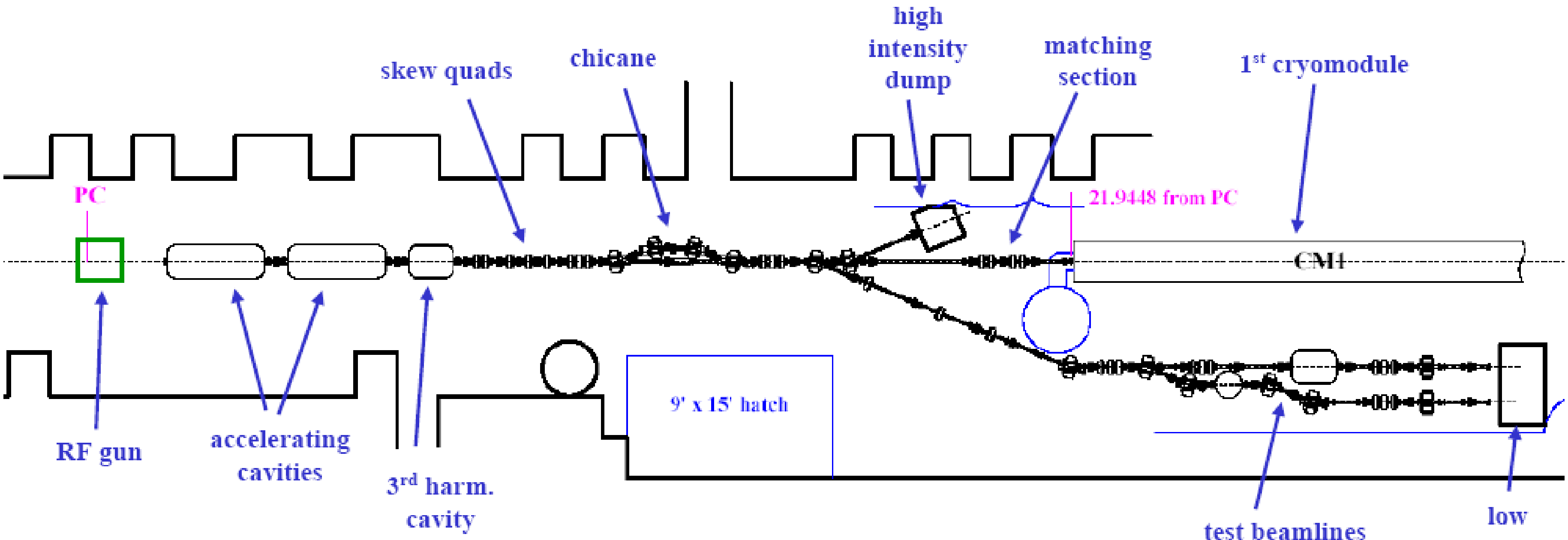
A0 Photoinjector



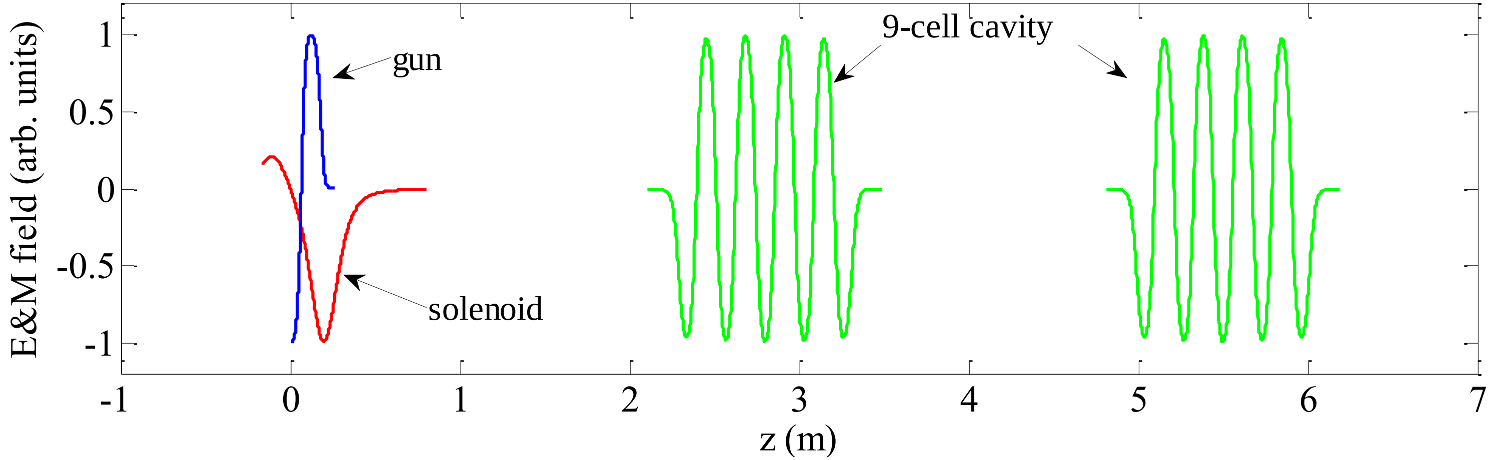
- Cs_2Te photocathode
- Nd:YLF drive-laser
- Typically the bunch charge is set to 1nC, it can be higher
- 1.5-cell 1.3 GHz NC rf-gun with three solenoids for emittance manipulation
- 9-cell TESLA type booster cavity
- Beam energy ~15 MeV
- Round-to-flat beam transformer
- Double dogleg + 3.9 GHz dipole mode cavity for long.-trans. emittance exchange
- Quadrupoles and steering magnets along the beamline for focusing and steering

NML injector (M. Church)

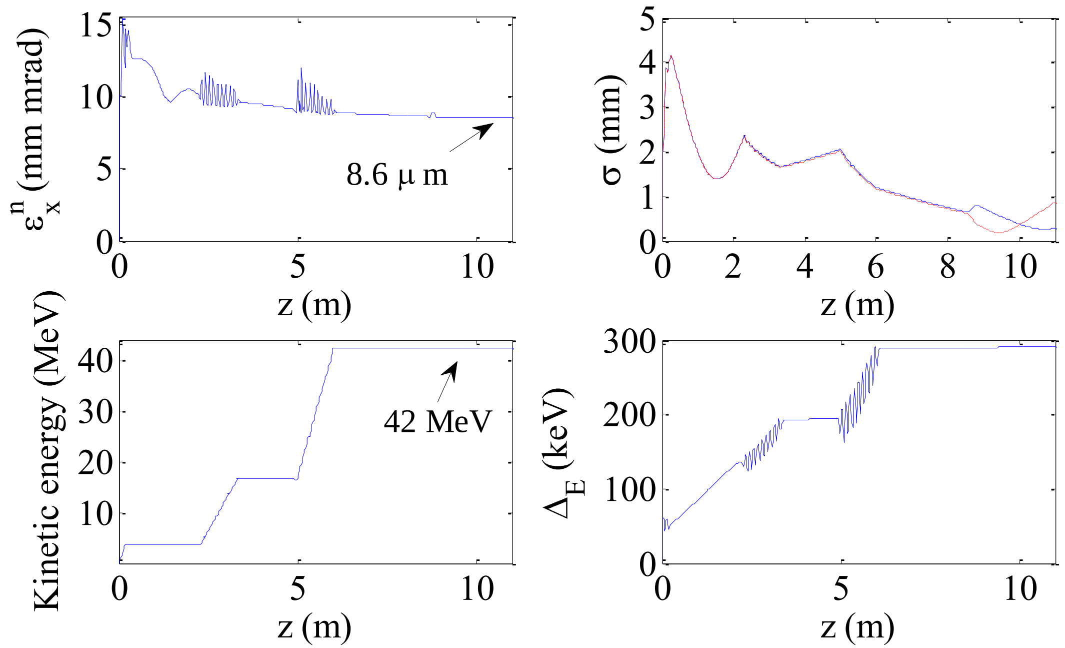


- normal conducting 1.3 GHz photocathode RF gun
- 2 superconducting 1.3 GHz accelerating cavities
- 1 superconducting 3.9 GHz cavity for bunch linearization
- 3 skew quads for flat beam generation
- 4-dipole chicane for bunch compression
- 2.5 KW dump
- area for two additional low energy test beamlines

NML injector optimization



- Bunch charge 3.2 nC
- Gun gradient 35 MV/m
- First cavity 24 MV/m, 2nd cavity 48 MV/m
- Drive laser rms length 3 ps, transverse rms 1.5 mm
- Beam energy ~40 MeV, emittance 6-8 μm.

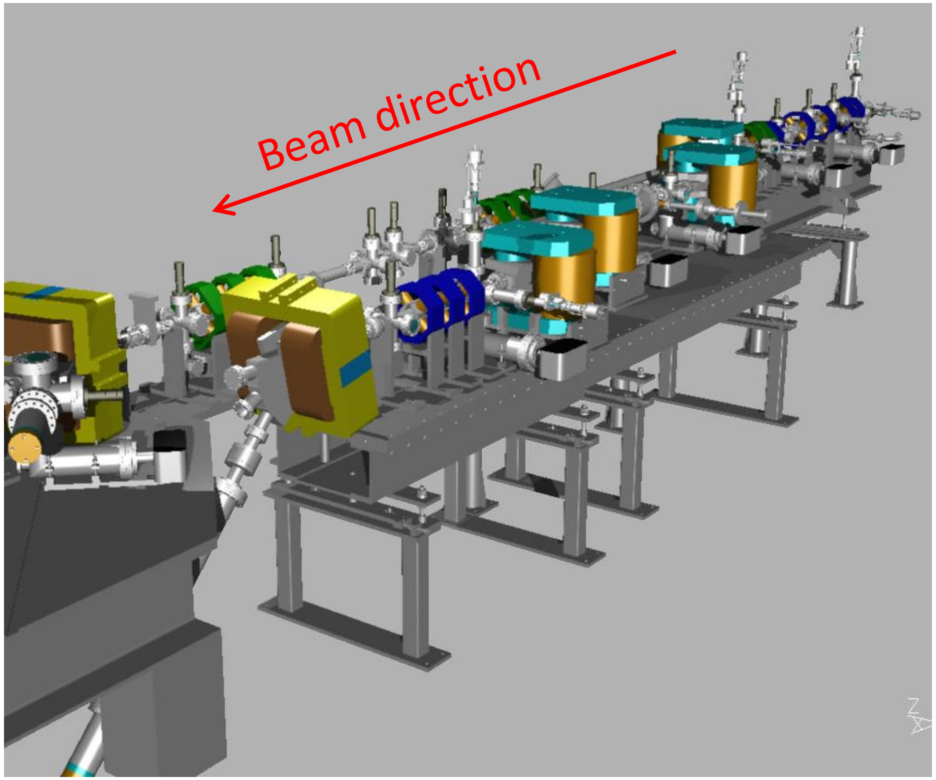


On-going and proposed experimental Program

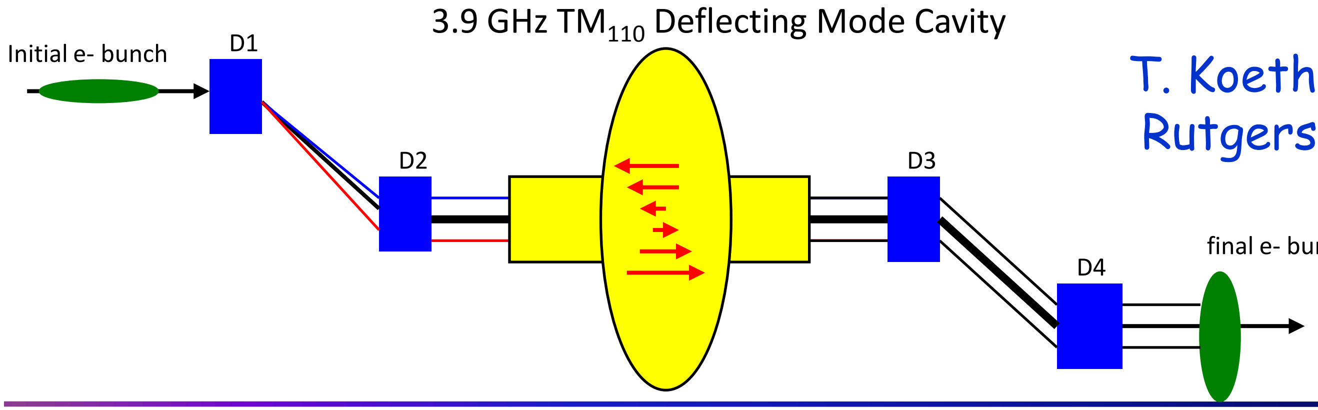
- Emittance Exchange (FNAL, ongoing)
- Slit microbunch generation (FNAL, ongoing)
- Flat beams and Image Charge Undulator (FNAL)
- Ellipsoidal Beam (NIU&FNAL)
- Microbunching investigations (FNAL, A. Lumpkin's talk on 5/12/09)
- Various instrumentation Projects (FNAL, M. Church's talk on 5/11/09)

Emittance Exchange

$$\begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_{out} = \begin{pmatrix} 0 & 0 & B_{11} & B_{12} \\ 0 & 0 & B_{21} & B_{22} \\ C_{11} & C_{12} & 0 & 0 \\ C_{21} & C_{22} & 0 & 0 \end{pmatrix} \begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_{in}$$



- Cornacchia & Emma (2002): a deflecting mode cavity in the center of a chicane
- Kim (2005): a deflecting mode cavity between two doglegs



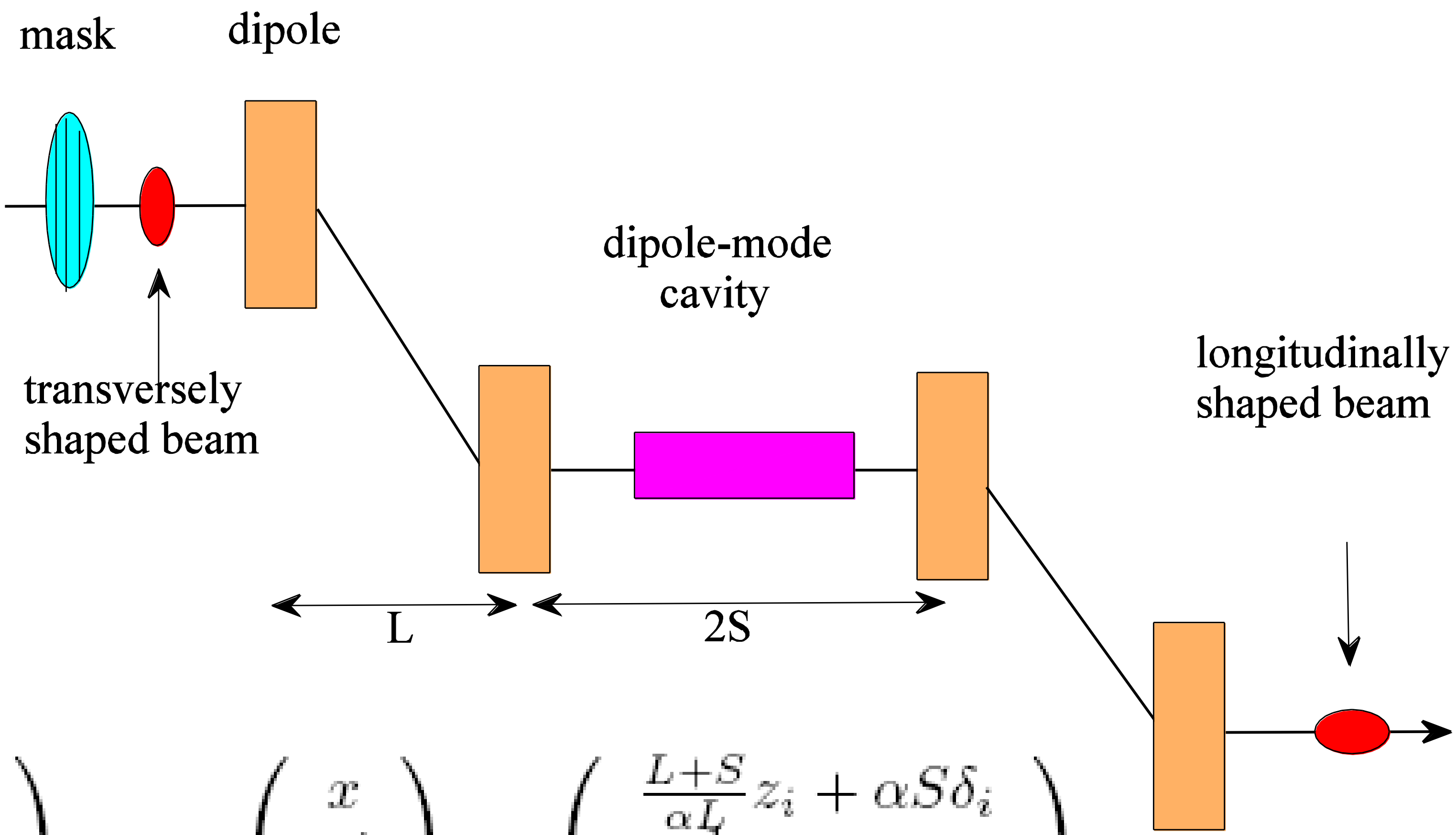
T. Koeth, Ph.D. dissertation, Rutgers

Feb. 11, 2009: EEX measurements

	Before EEX	After EEX
$\varepsilon^n{}_x =$	$3 \sim 5$ mm mrad	$\rightarrow$ 18 mm mrad
$\varepsilon^n{}_z =$	21 mm mrad	$\rightarrow$ 7 mm mrad
$\varepsilon^n{}_y =$	$4 \sim 5$ mm mrad	$\rightarrow$ 6 mm mrad

The numbers are obtained directly from the images, they did **not** include any contribution from YAG screen resolution, nor measurement system resolution, nor betatron function contribution for the energy spread measurement.

multi-pulses generation via the EEX

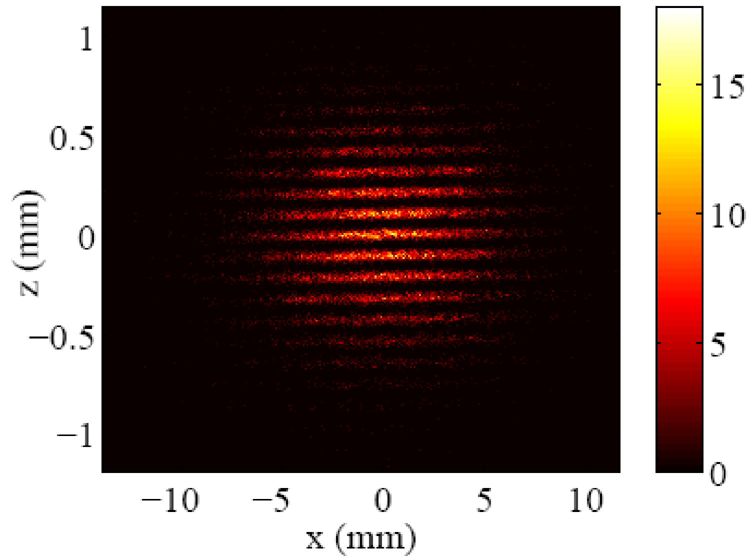


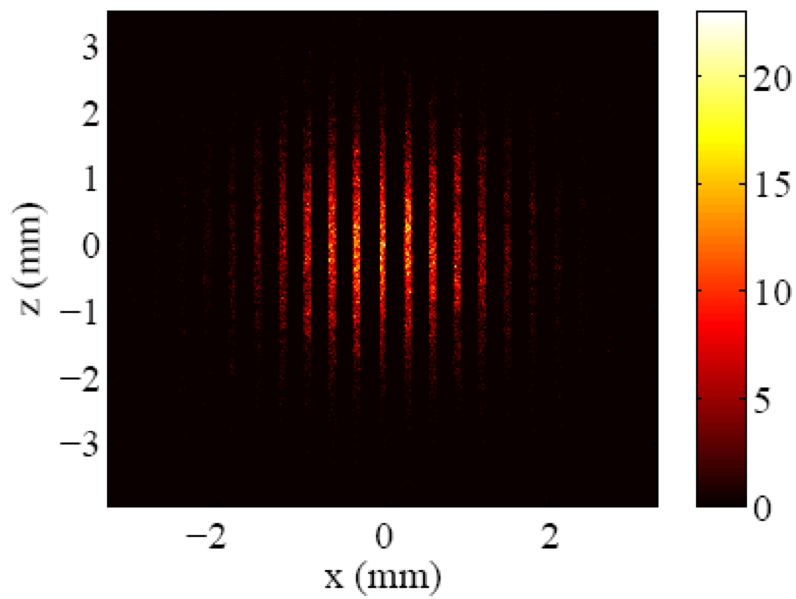
$$\begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_f = \mathrm{M} \begin{pmatrix} x \\ x' \\ z \\ \delta \end{pmatrix}_i = \begin{pmatrix} \frac{L+S}{\alpha L} z_i + \alpha S \delta_i \\ \frac{1}{\alpha L} z_i + \alpha \delta_i \\ \alpha x_i + \alpha S x'_i \\ \frac{1}{\alpha L} x_i + \frac{L+S}{\alpha L} x'_i \end{pmatrix}$$

An optimized case

Table 1: Parameters prior to the emittance exchange

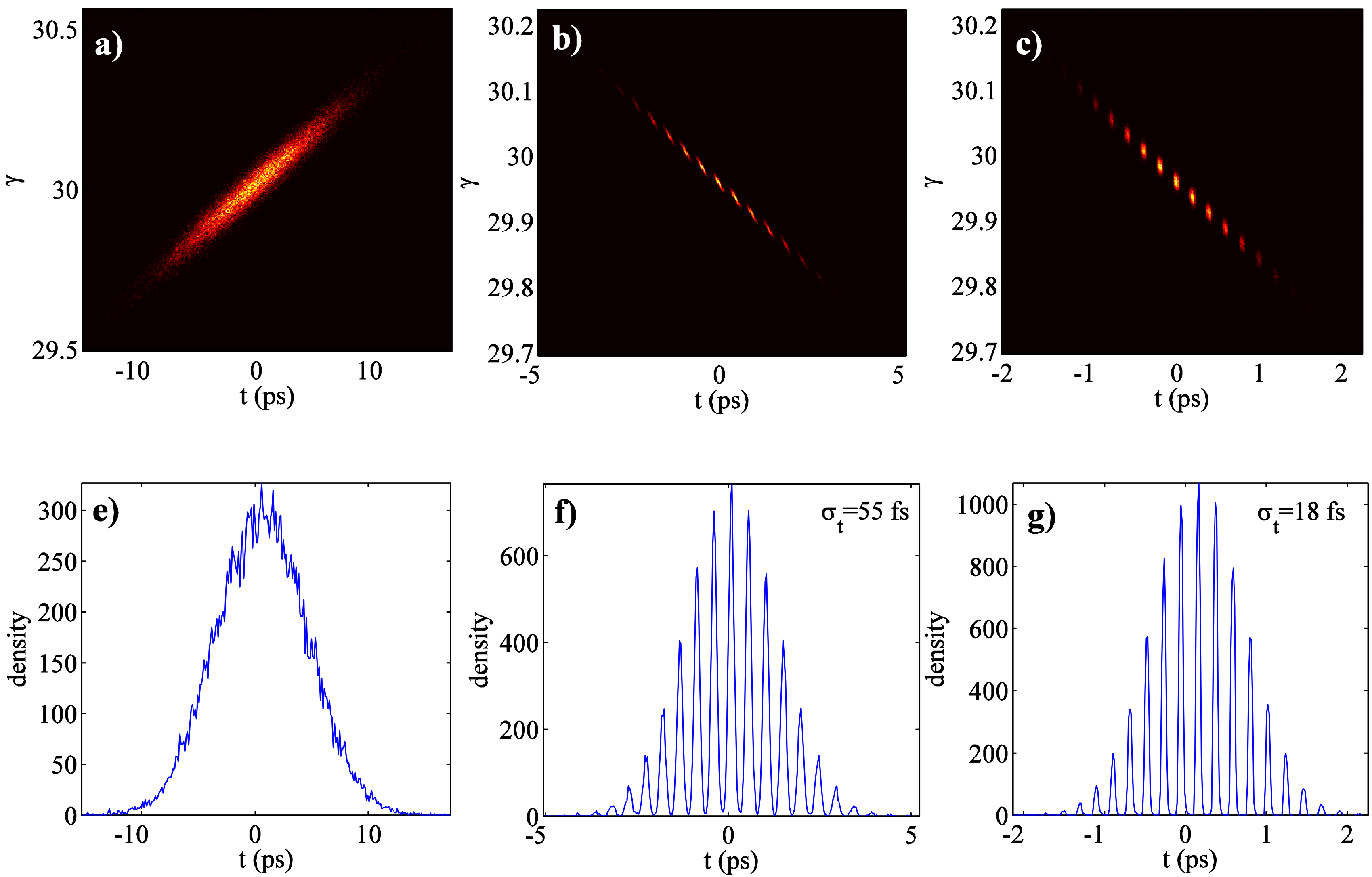
beam energy (MeV)	15
bunch charge (pC)	100
normalized horizontal emittance (μm)	1
normalized longitudinal emittance(μm)	27
horizontal beta function (m)	20
longitudinal chirp $\partial\delta/\partial z$ (m^{-1})	-4.5
rms bunch length (mm)	0.9
slit width (μm)	80
slit separation (μm)	300



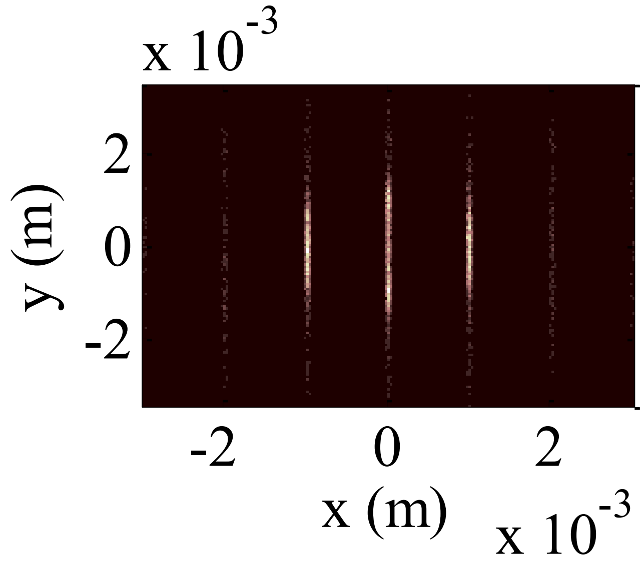


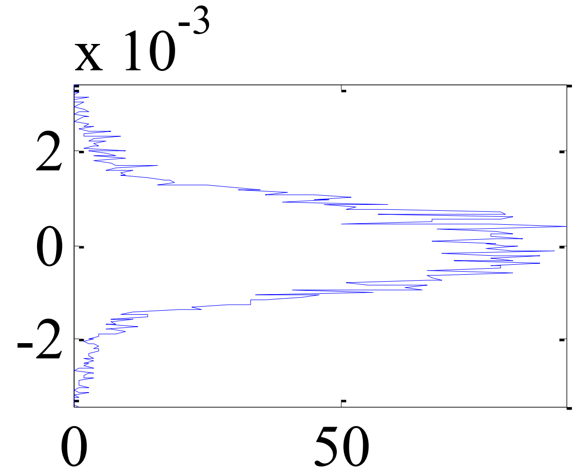
The beam at the end of the emittance exchanger has a train of micro pulses with rms length around 55~fs. The individual beamlets have a slope (correlation between energy and position) that is different from the slope of the whole bunch train. A two-dipole achromatic single dogleg compressor can be used to remove the correlation, and pulses with rms lengths of 18 fs and 120 fs separations can be achieved.

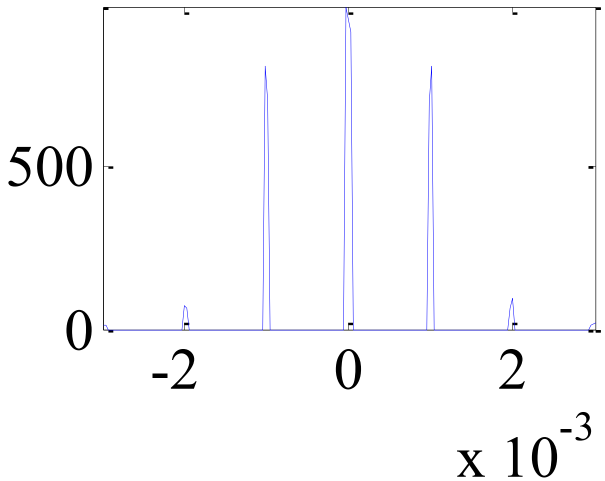
Longitudinal phase space of the optimized case



EEX Beam Line Elements Modelled

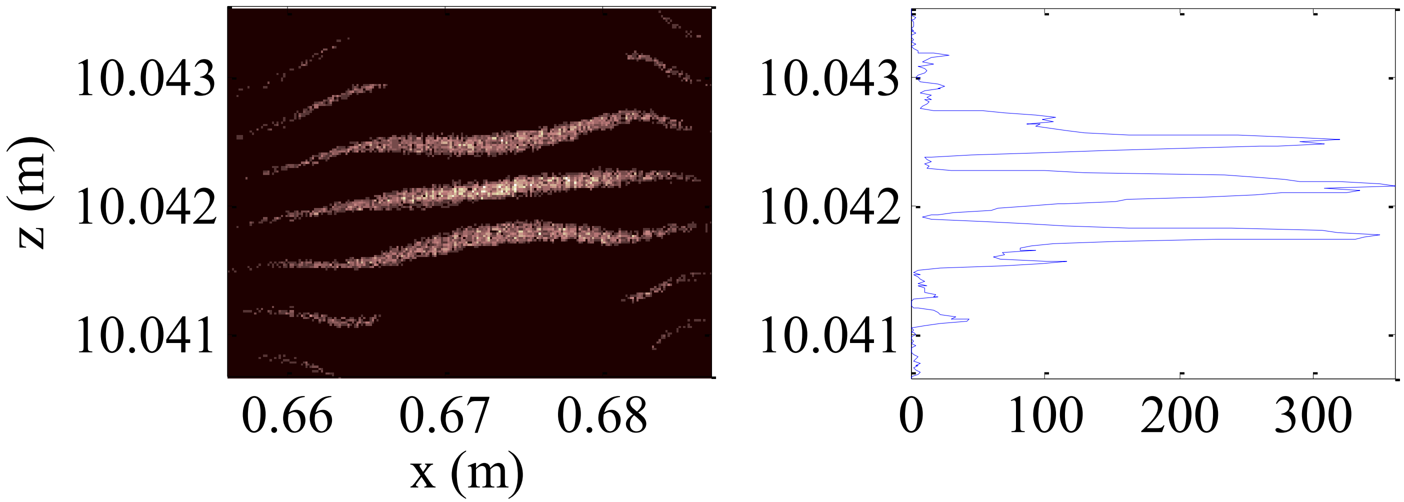


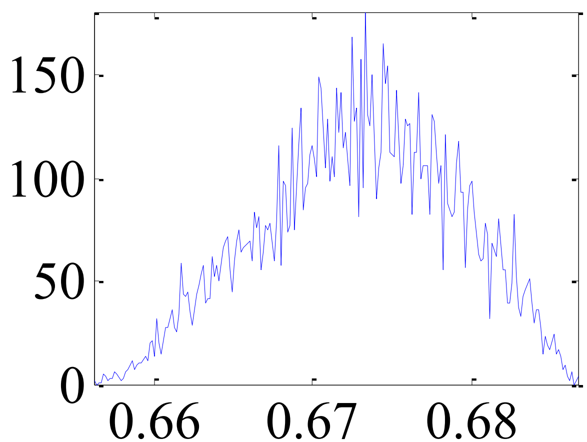




- beam after slits before EEX
- using existing vertical slits right after the booster cavity (50 um wide, 1 mm apart);

Beam after EEX



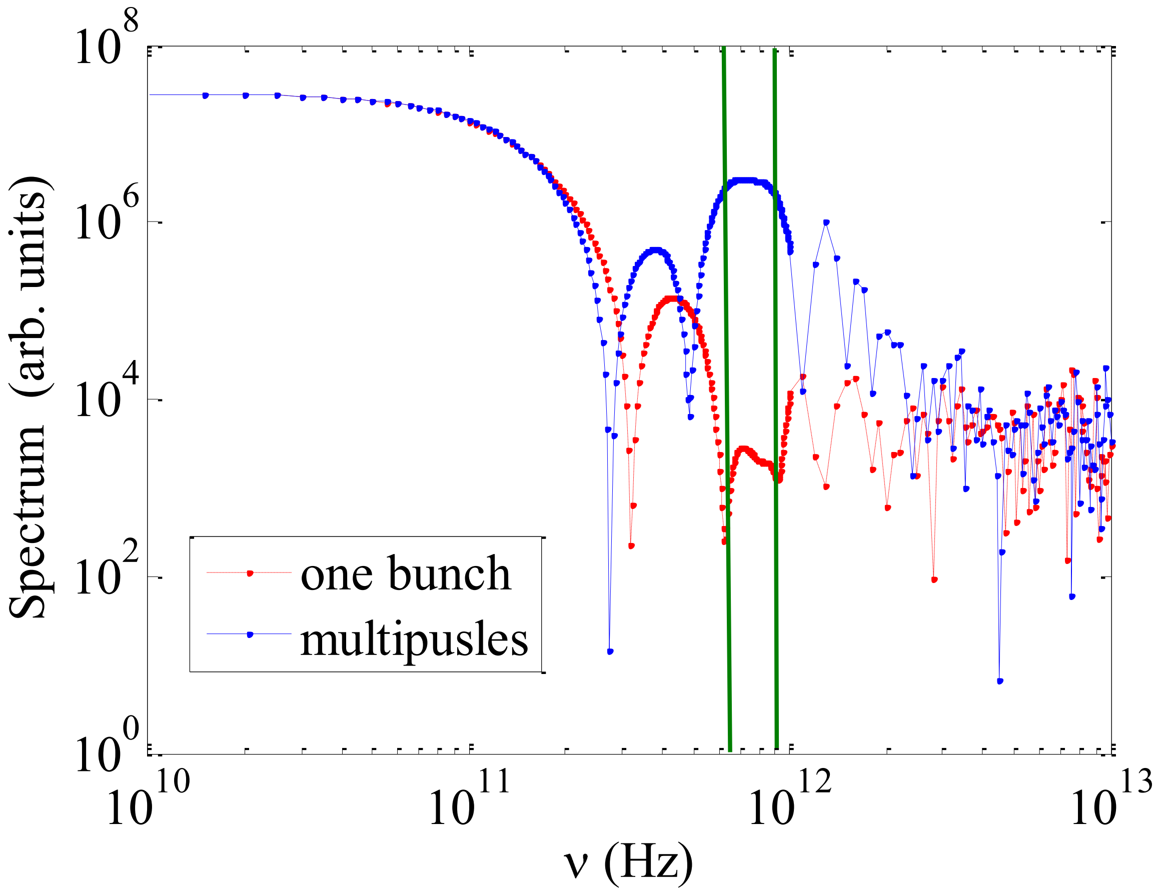


No. of e^- before the slits: 250k@250 pC
No. of e^- after the slits: 13522@14 pC
Transmission: 5.4%

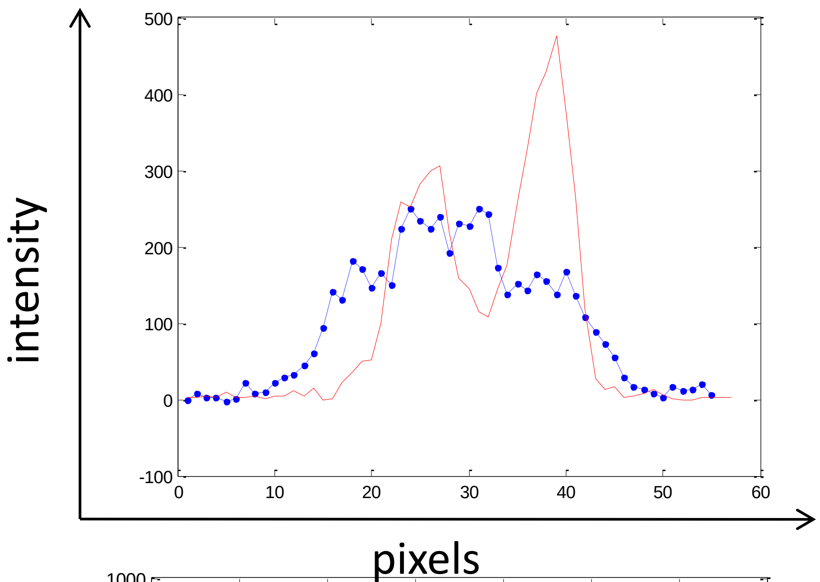
One could also put a multislits-mask directly on the drive-laser; image the slits directly at the entrance of the emittance exchanger.

Spectrum with and without slits

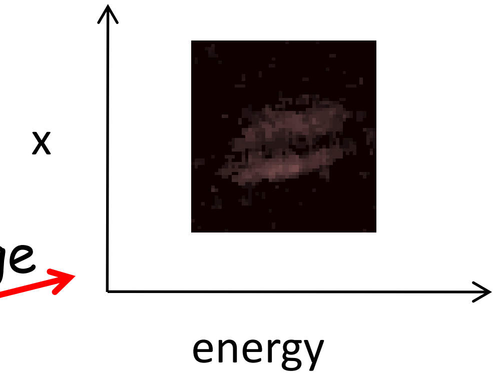
- We see that in the frequency range between the two green lines (0.5-0.9 THz), the intensity of the radiation spectrum increases by several orders of magnitude



Data on 3/18/2009: transverse to energy modulation



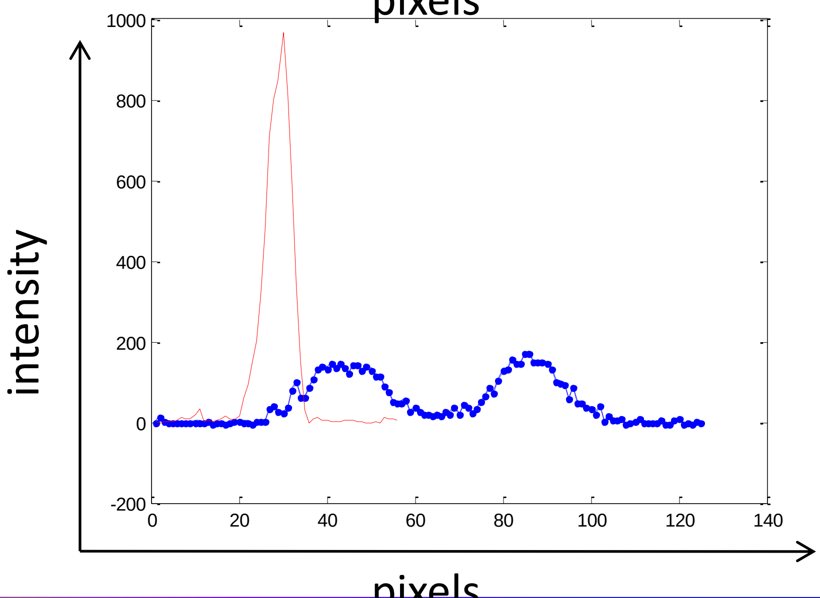
beam on the viewer downstream of the spectrometer:



two vertical slit image dipole cav. Off

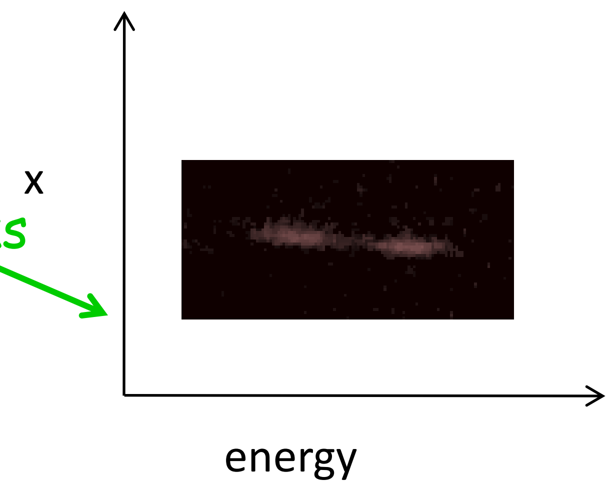
Red (vertical projection): x

blue (horizontal projection): energy

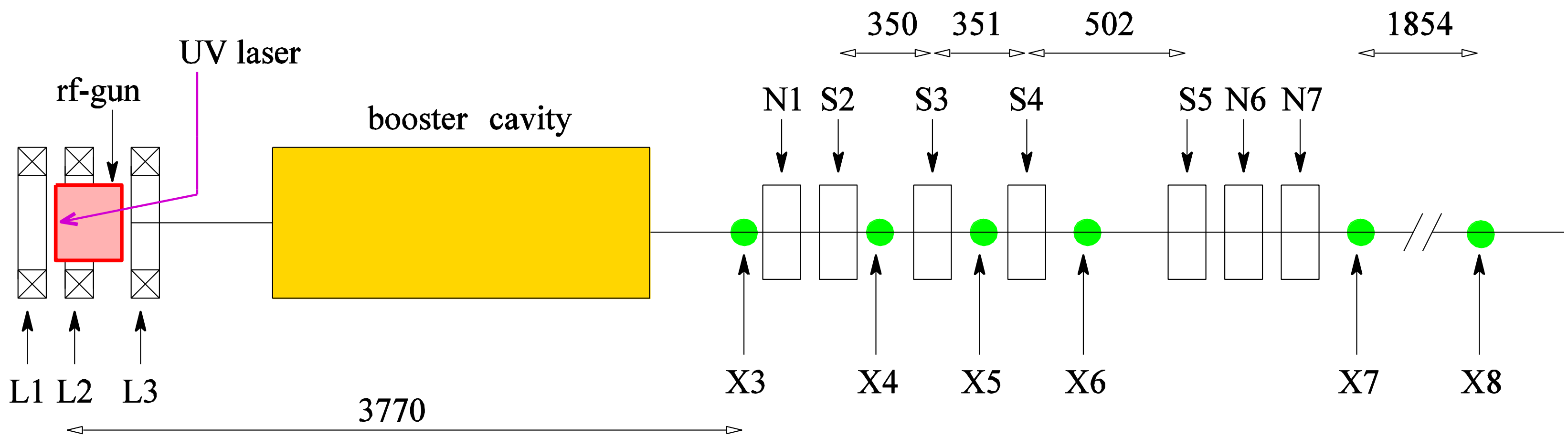


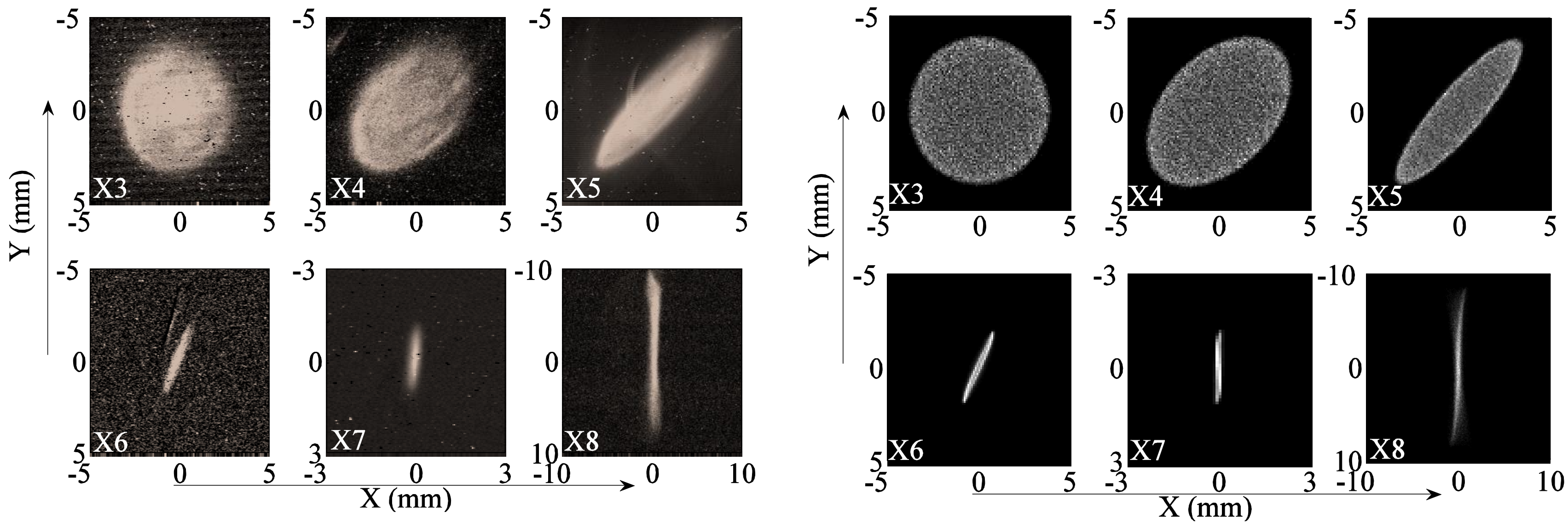
dipole cav. On

two energy peaks



Flat beam experiment at A0





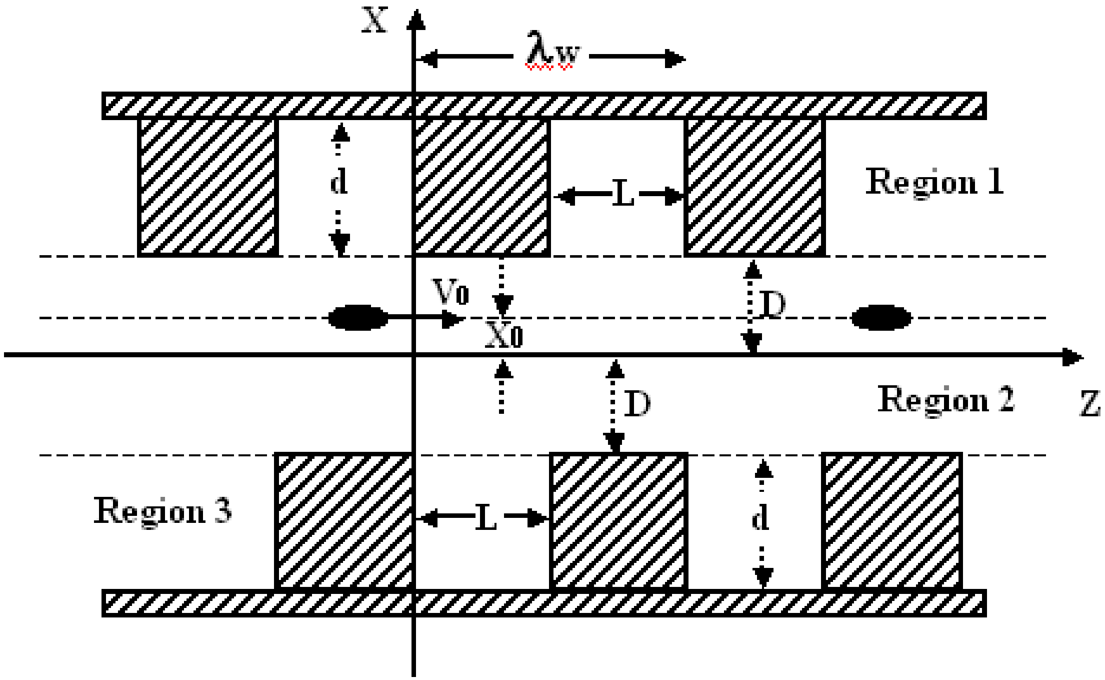
experiment simulation

Achieved flat beam parameters

Bunch charge (nC)	0.50 0.05
Laser trans. rms size (mm)	0.76
Laser long. rms size (ps)	3
Beam energy (MeV)	15.8
Q = nC	
rms_X7y (mm)	0.63 0.01
rms_X7x (mm)	0.088 0.001
rms_X8_hslit (mm)	1.68 0.01
rms_X8_vslit (mm)	0.11 0.01
ε_x (mm mrad)	**0.41±0.02**
ε_y (mm mrad)	**41.0 0.5**
$\varepsilon_y/\varepsilon_x$	100 5

P. Piot, Y. –E Sun and K.-J. Kim,
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **9, 031001 (2006)**
Y.-E Sun, Ph.D. thesis, University of Chicago [Report No. Fermilab-thesis-2005-17, 2005], available at http://fnalpubs. fnal .gov/ archive/ thesis /fermilab-thesis-2005-17.shtml

Image Charge Undulator (ICU)



Y. Zhang et al, NIM A, 507 (2003) 459 – 463; PAC 2003 Proceedings, Page 941.

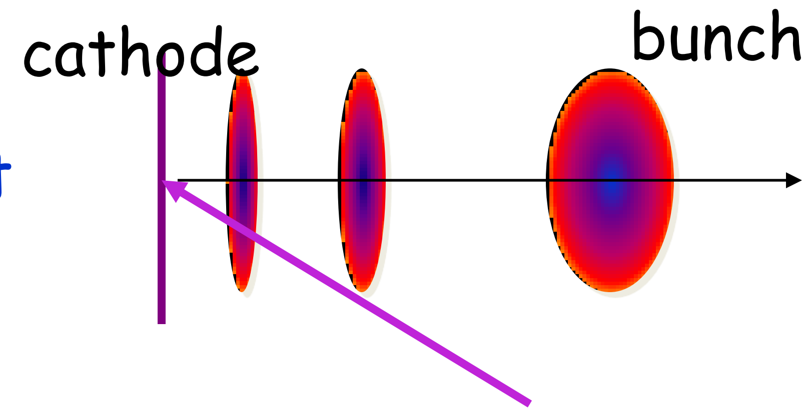
1. Two pieces of identical periodic metal grating;
2. Asymmetric arrangement;
3. A flat electron beam passes in between the gratings.

Flat beam and image charge undulator

- A challenging experiment due to the extremely small beam size required in the image charge undulator; simulations need to be performed to check the feasibility with A0 flat beam parameters.
- First experimental step will be passing a flat beam between two pieces of flat metal surfaces.
- Next step: spontaneous ICU radiation
  - Observe spontaneous radiation
  - Characterize energy spread generated on the beam due to the wake
  - Do this scanning various key parameters
    - Beam energy
    - Undulator gap
    - Bunch charge

Ellipsoidal bunches (P. Piot)

- In uniform ellipsoid distributions, space charge force are linear with respect to position
  ⇒ ideally no emittance growth!



•A “self generating” scheme to produce ellipsoidal bunch via photoemission was proposed by L. serafini [AIP413 (1997)] and J. Luiten et al. [PRL93 (2004)]

•Recently demonstrated with metallic cathodes and out of an rf-gun:
   –P. Musumeci, et al., PRL 100, 244801 (2008) and,
   –J. Luiten et al., presented at *AAC'08* (2008).

Goals & Originalities (P. Piot)

- Goals:
  - Generation and phase spaces characterization of a low emittance ellipsoidal bunch for a wide variety of operating conditions (e.g. charge, laser parameters, etc…).
  - Acceleration of an ellipsoidal bunch to ~ 15 MeV
  - Compression at low energy of an ellipsoidal bunch.
- Originalities:
  - 1st generation of such beam from Cs_2Te cathode
  - 1st generation in an L-band gun (with significantly lower E-field compared to S-band)
  - A downstream accelerating cavity (and possibly bunch compressor) would provide means to tune the (z,δ) correlation and possibly compress the beam
  - Eventually could revisit some of A0's favorites i.e. magnetized and flat beam generation and emittance exchange using ellipsoid bunches etc…

Summary

- Current beam physics space manipulation experiments and their applications can be continued at the NML at double the beam energy of A0:
  - Longitudinal-to-transverse emittance exchange longitudinal → beam profile manipulation such as bunch train, or ramped beam current profile et al as desired.
  - Round-to-flat beam → transformation image charge undulator et al
  - Combined ellipsoidal beam → flat beam → compressed → EEX …