Characterization and Manipulation of Ellipsoidal Electron Bunches Generated from Cs$_2$Te Cathodes via “space-charge explosion”

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“Self-generating” ellipsoidal bunches

• 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 [AIP 413 (1997)] and J. Luiten et al. [PRL 93 (2004)]

\[ \frac{eE_0c\tau_l}{mc^2} \ll \frac{\sigma_0}{\varepsilon_0 E_0} \ll 1 \]

should work at A0

\begin{align*}
&= 0.001 \text{ for } \\
&\tau_l = 50 \text{ fs,} \\
&E = 50 \text{ MV/m} \\
&Q = 100 \text{ pC,} \\
&R = 1 \text{ mm}
\end{align*}

• 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).
"Self-generating" ellipsoidal bunches II

Figure 1: Domain of validity of the space charge expansion scheme. The nominal accelerating field of $A_0$ is $35\ \text{MV/m}$ [i.e. $\log(E_0)\sim 7.5$] and the charge density, $\sigma_0$, can be varied from 0.1 to 1000 pC/mm$^2$. The color-coding is such that blue corresponds to domains where the space charge expansion scheme is applicable [i.e. both inequalities in equations (1) are fulfilled] while red indicates domains where at least one of the inequalities is violated.
Motivation

- WiFEL seeded soft x-ray FEL proposed to NSF relies on ellipsoidal bunch generation from Cs$_2$Te cathode with gradient and charge similar to A0 parameters. Important proof of principle experiment with this cathode material and gradient.

- MIT compact x-ray source based on inverse Compton scattering also relies on similar experimental parameters. Demonstration of dogleg compressor with positive $R_{56}$ and low energy is also important.

- Operate A0 in a new regime will low transverse emittances (sub-$\mu$m) and possibly short electron pulse duration ($\sim$100 fs)

- This could foster a novel exciting Beam Physics program with the present configuration and possibly minor beamline reconfiguration.
Goals & Originalities

**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:**
- 1\textsuperscript{st} generation of such beam from Cs\textsubscript{2}Te cathode
- 1\textsuperscript{st} 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...
Experimental setup(s)

• The experiment does NOT requires any significant beamline upgrade: we plan on reusing/sharing all the hardware already installed in A0.

• Present gun (assumed to produce $E_{\text{peak}} = 35 \text{ MV/m}$).
• Current 9-cell cavity (assumed to provide $E_{\text{peak}} = 24 \text{ MV/m}$).

• Bunch compression would also bring exciting possibilities.
Anticipated results I

- **Preliminary** studies (no thorough optimization) are very encouraging

\[ X3: 50 \, \text{pC} \]

\[ X3: 200 \, \text{pC} \]
Anticipated results II

• Possibility to compress the bunch and reach multi-kA peak current

• Chirp imparted by linear space charge has the proper sign for compression in a dogleg type compressor

• Can also compress in a chicane but would have to operate the accelerating cavity far off-crest. ⇒ low energy

⇒ $Q \sim 200 \text{ pC}$
Laser

- NIU owns a Tsunami (tuned for 40th harmonic of 2.856 GHz) with SpitFire-Pro F-XP
  - output pulse energy > 3.5 mJ
  - rms pulse length < 50 fs at 800 nm
  - repetition rate 1 kHz
- New oscillator (operating at 1300/16= 81.25 MHz) was ordered and expected delivery in April/May.
- Frequency conversion to uv needs to be changed (3ω versus 4ω). Tripler designed, parts ordered. Assembly + test will be done at NIU with help from FNAL.
- New oscillator will be directly delivered and installed at A0. Amplifier would be temporally moved from NIU to A0 [late spring].
We need to investigate the best scheme for compression of ellipsoidal bunches at A0

- Dogleg is the natural choice (SC-induced energy chirp) but might complicate experiment.

- Compressor is easier but not “elegant” low energy due to needed chirp and would require a significant beamline reconfiguration (not compatible with $\varepsilon X$).

- Thorough beam dynamics studies still need to be performed.
Diagnostics

• Horizontally deflecting cavity (currently used in the exchanger) can provide the proper kick to resolve \(~100\) fs (taking \(k\sim3\ \text{m}^{-1}\) at \(15\ \text{MeV}\))

• Standard transverse view screens would be needed; probably most OTR screens would need to be changed to Cs:YaG to be sensitive to “low” charge operation (\(~100\ \text{pC}\)) in single bunch mode (but this is also needed for \(\varepsilon X\) experiment at some point)

\[Q=50\ \text{pC}, \ \gamma=33\]
Summary

• We proposed an experiment to produce, characterize and manipulate ellipsoidal bunches at A0.
• Preliminary simulations (beam dynamics and diagnostics) support the feasibility of such an experiment.

• The use of Cs₂Te photocathodes and the possibility to accelerate and manipulate (e.g. compress) such an ellipsoidal bunch present innovative and challenging Beam Physics problems.
• At least three external institutions have strong interest and are ready to collaborate.

• Installation could, in principle, happen in late spring (May, 2008)

• Eventually a new photocathode laser could foster exciting novel activities (e.g. shaped ellipsoidal laser pulse using a DAZZLER) see [Y. Li, S. Chemerisov, Opt. Lett. 33, 1996 (2008)].