ASTA Linac Beamline configurations & capabilities

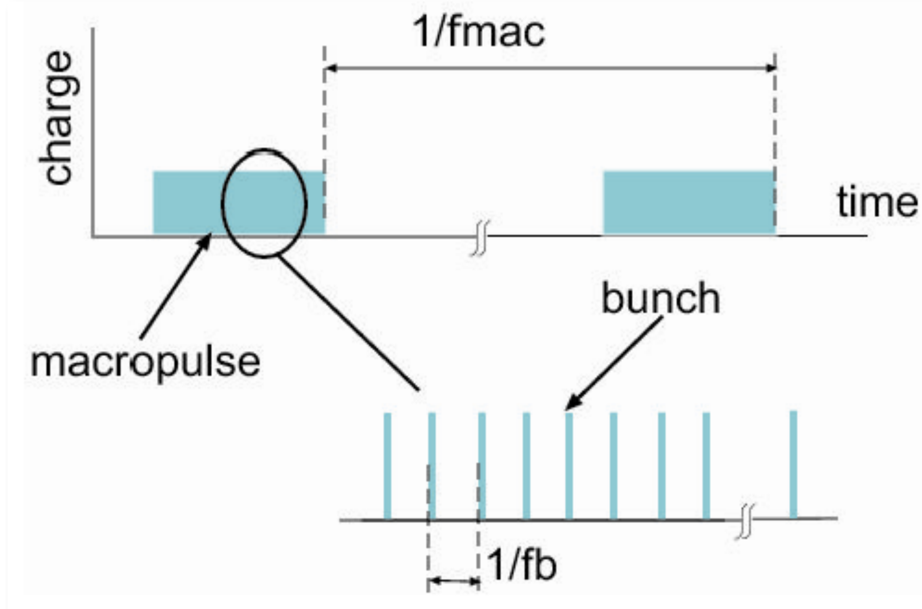
presented by P. Piot[1,2]
based on work by C. Prokop[1], D. Mihalcea[1],
F. Lemery[1], M. Church[2], and collaborations with
B. E. Carlsten[3], and P. Stoltz[4]

[1] Northern Illinois University, [2] Fermilab,
[3] Los Alamos National Laboratory, [4] Tech-X corp.

Credits: extensive use of beam-dynamics simulation codes provided by M. Borland (ANL), K. Flottmann, M Dohlus (DESY), J. Qiang and R. Ryne (LBNL)

Introduction

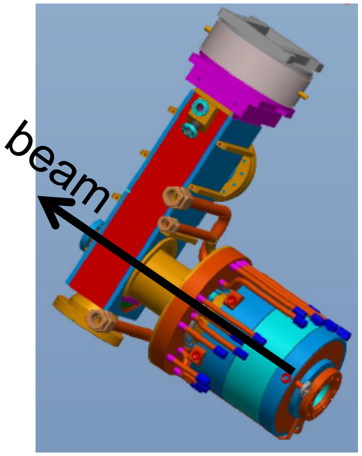
- Ultimately variable energy from ~50 (possibly lower) to ~800 MeV,
- High-repetition rate (1-ms rf pulse, 3 MHz rep rate):
  - Exploration of dynamical effects, e.g., in beam-driven acceleration methods.
- L-band (1.3-GHz) SCRF linac:
  - Well suited for mm/cm-wavelengths beam-driven acceleration,
- Photoinjector source:
  - Provides low-emittance beam,
- Arbitrary emittance partition:
  - repartition of phase spaces to match final applications,
  - Tailored current profiles.



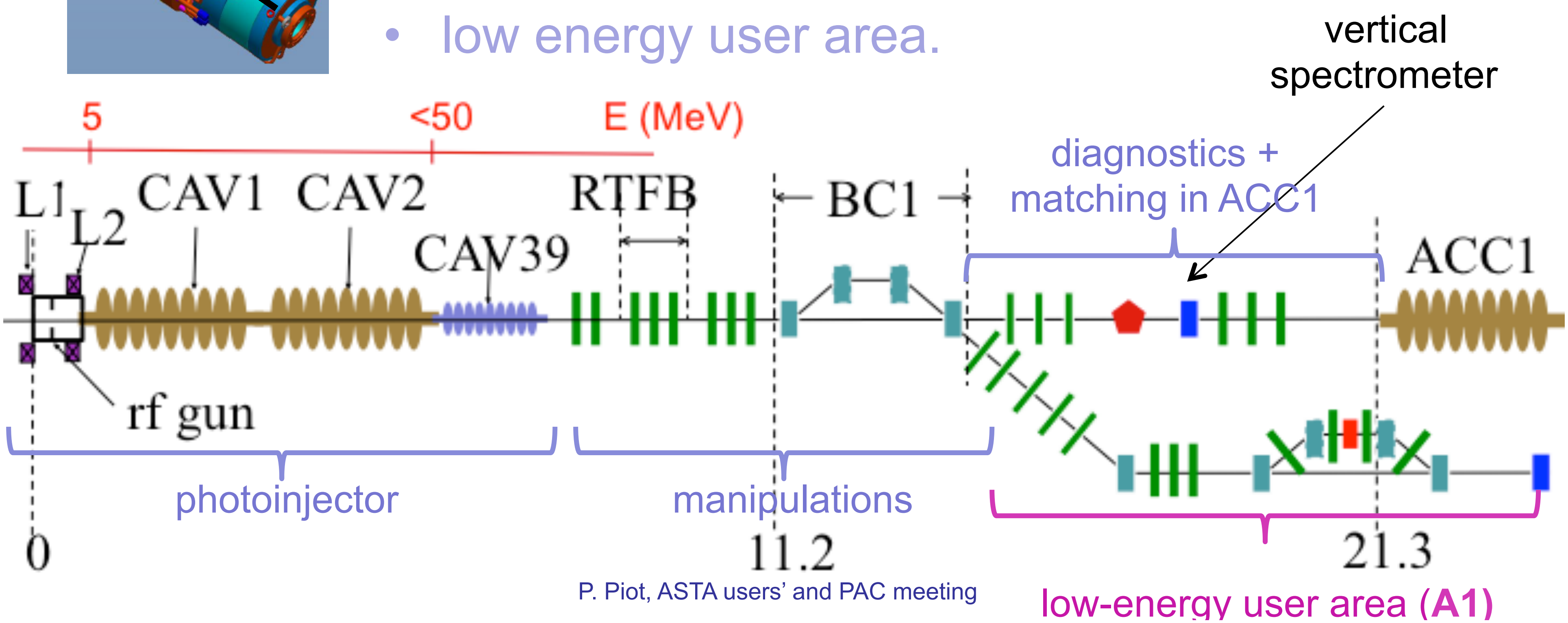
parameter	nominal value	range	units
energy exp. A1	50	[5,50]	MeV
energy exp. A2	~ 300 (stage 1)	[50,820]	MeV
bunch charge Q	3.2	[0.02,20]	nC
bunch frequency f_b	3	see [(a)]	MHz
macropulse duration τ	1	≤ 1	ms
macropulse frequency f_{mac}	5	[0.5, 1, 5]	Hz
num. bunch per macro. N_b	3000	[1,3000]	–

ASTA linac Overview (injector area)

DESY-type
L-band RF gun



- Cs_2Te cathode driven by a Yb-fiber + Nd:YLF,
- two SCRF booster **cav**ities (CAV1, 2),
- **R**ound-**t**o-**f**lat **b**eam **t**ransformer (RFTB),
- **B**unch **c**ompressor (BC1) + diagnostic section,
- later stage: linearizer (CAV39),
- low energy user area.



Photoinjector capabilities (1)

- nominal operating charge:

$$0.02 \le Q[\mathrm{nC}] \le 3.2$$

- energy $\mathcal{E} \le 50 \quad \mathrm{MeV}$
- typical expected bunch parameters scaling over the nominal charge range (for 1 laser uv pulse):
  - transverse emittance [μm]:

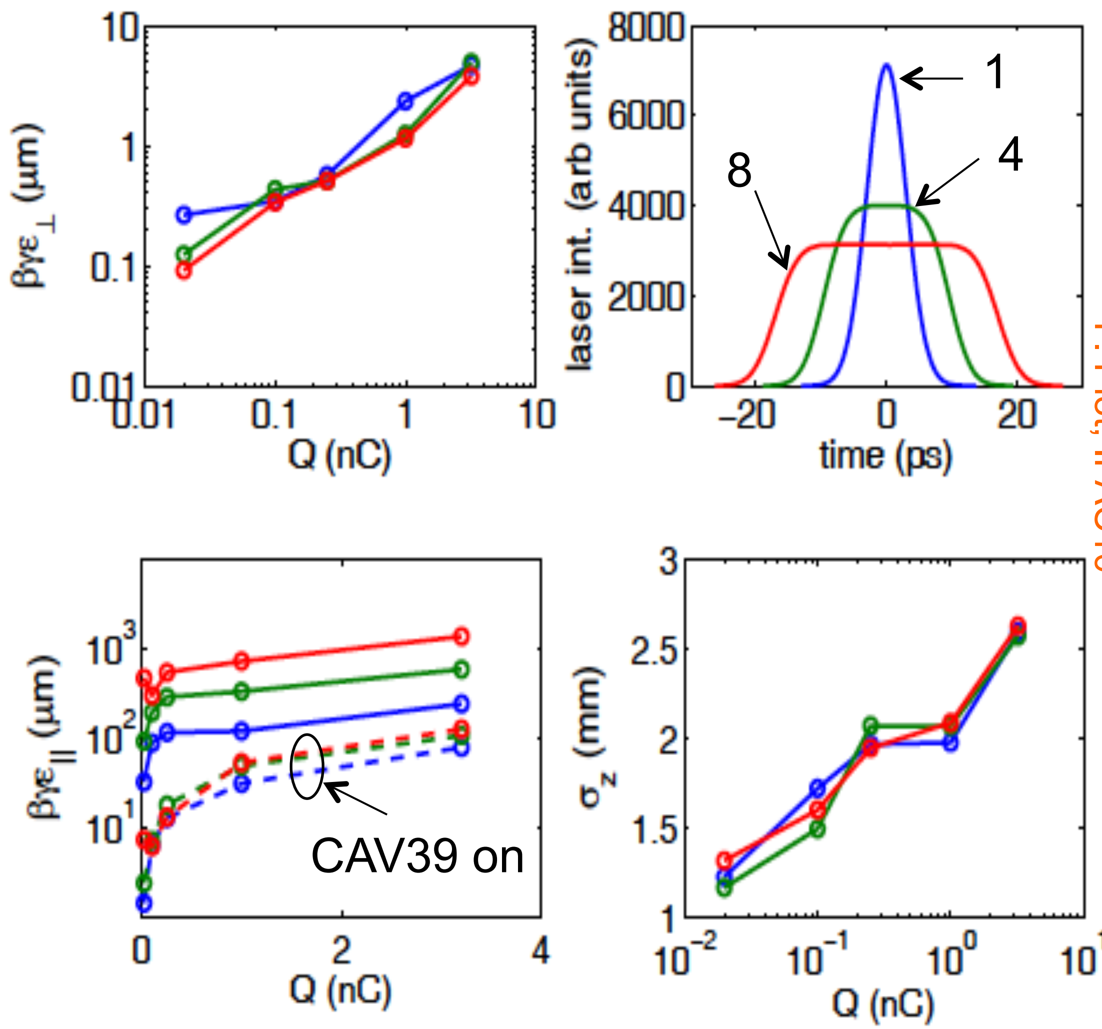
$$\varepsilon_{\perp} \simeq 2.11 Q^{0.69}$$

  - longitudinal emittance [μm]

$$\varepsilon_{||} \simeq 30.05 Q^{0.84}$$

  - uncompressed rms bunch length [mm]

$$\sigma_{||} \simeq 2.18 Q^{0.13}$$

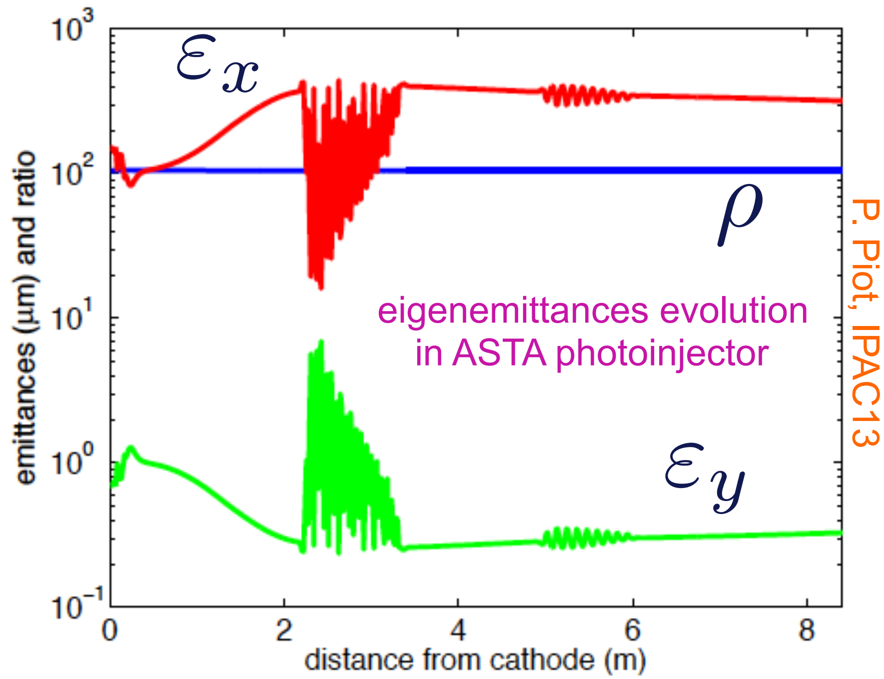


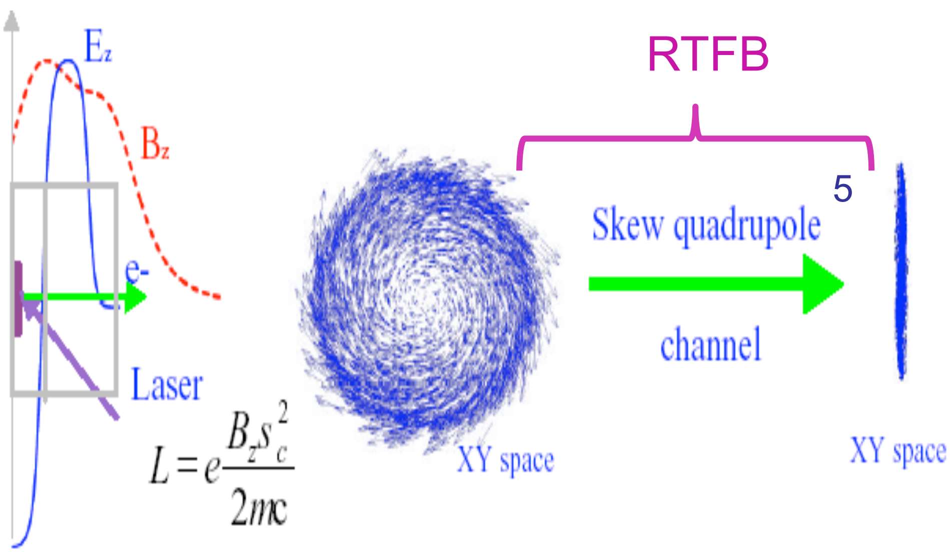
P. Piot, IPAC10

[optimized with `Astra` (DESY) + `GeneticOptimizer` by Borland/Shang APS/ANL]

Flat-beam generation (on-going work)

- beams with asymmetric transverse-emittance partition can be produced
- optimized flat beams have similar 4D emittance than round beams



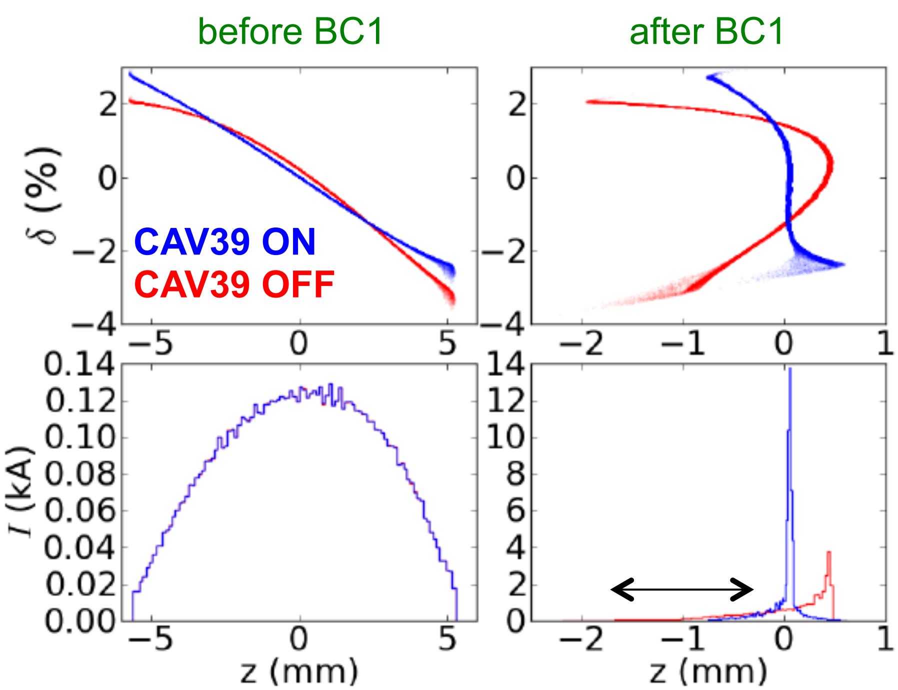


parameter	flat-beam configuration	round-beam configuration	units
Q	3.2	3.2	nC
E	47.18	48.77	MeV
ε_x	105.04	5.43	μm
ε_y	0.31	5.44	μm
ε_{4D}	5.53	5.44	μm
ρ	$\simeq 334$	$\simeq 1$	–

Low-energy bunch compression (1)

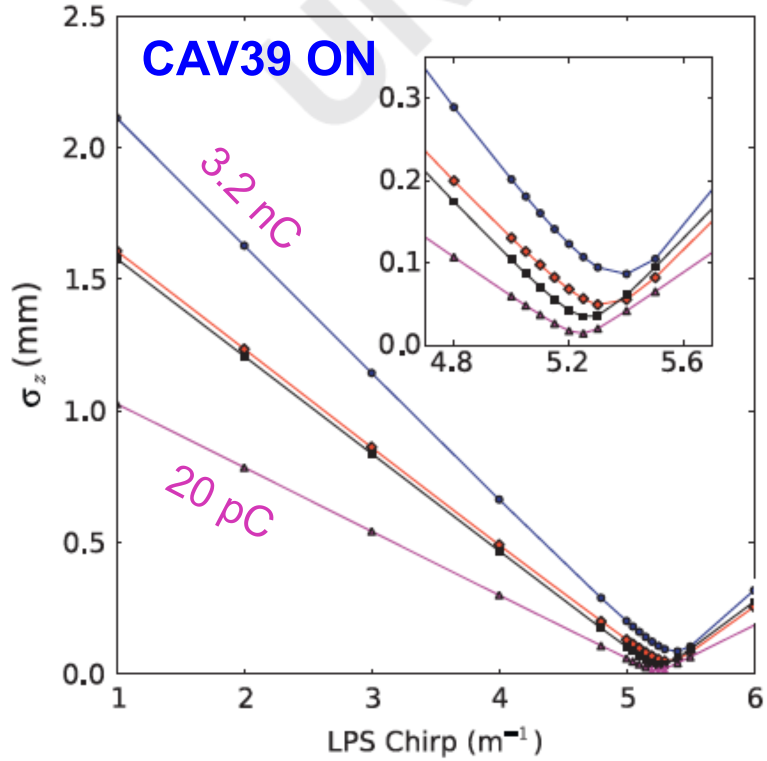
- Compression performed with a chicane-type bunch compressor (BC1)
- long. dispersion $R_{56} = -19\text{ cm}$

C. Prokop, NIM A (2013)



single-particle-dynamics simulation of BC1

rms bunch length after BC1

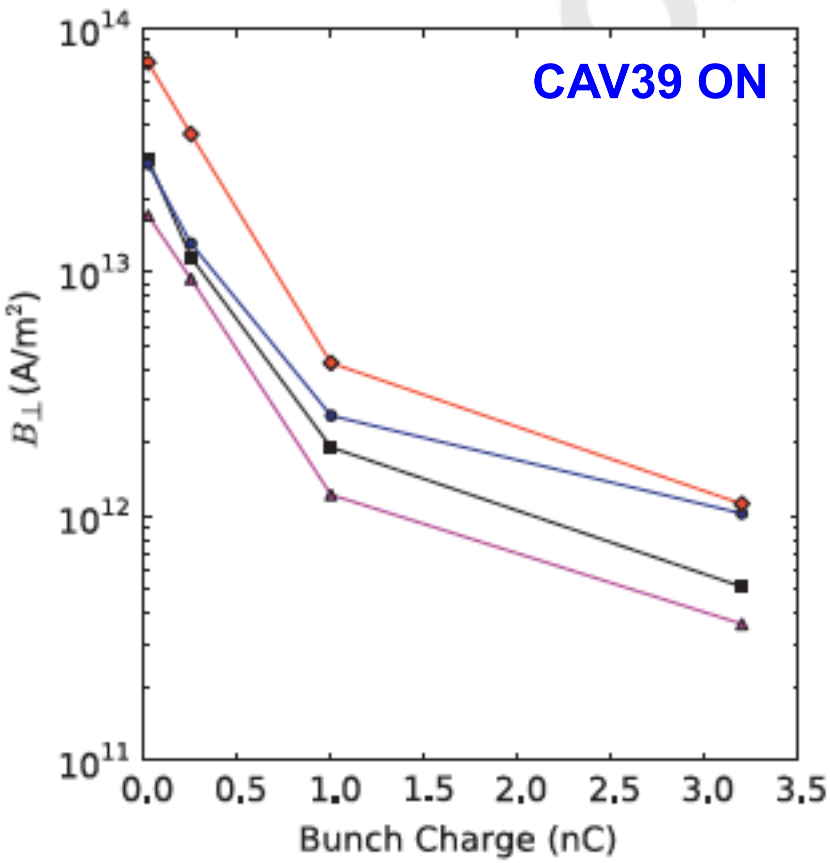


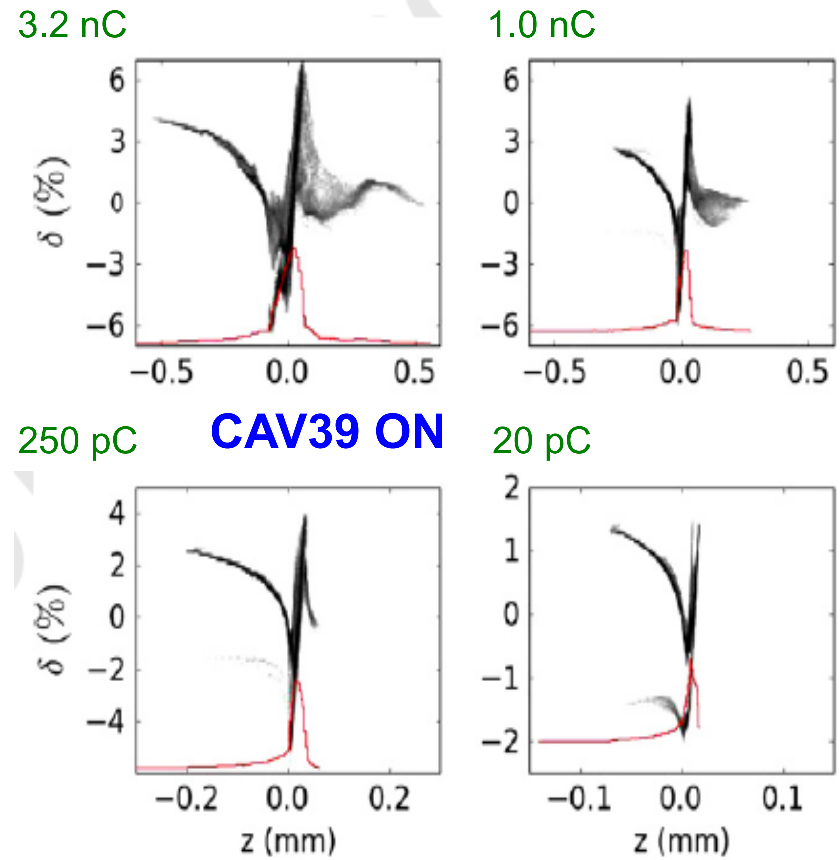
- BC1 comp. nominally limited by 2nd order nonlinearities
➔CAV39 eventually needed

[simulations with Impact-T/Z (LBNL) from J. Qiang & R. Ryne]

Low-energy bunch compression (2)

- overall performance of BC1 is be dominated by collective effects (LSC and CSR)



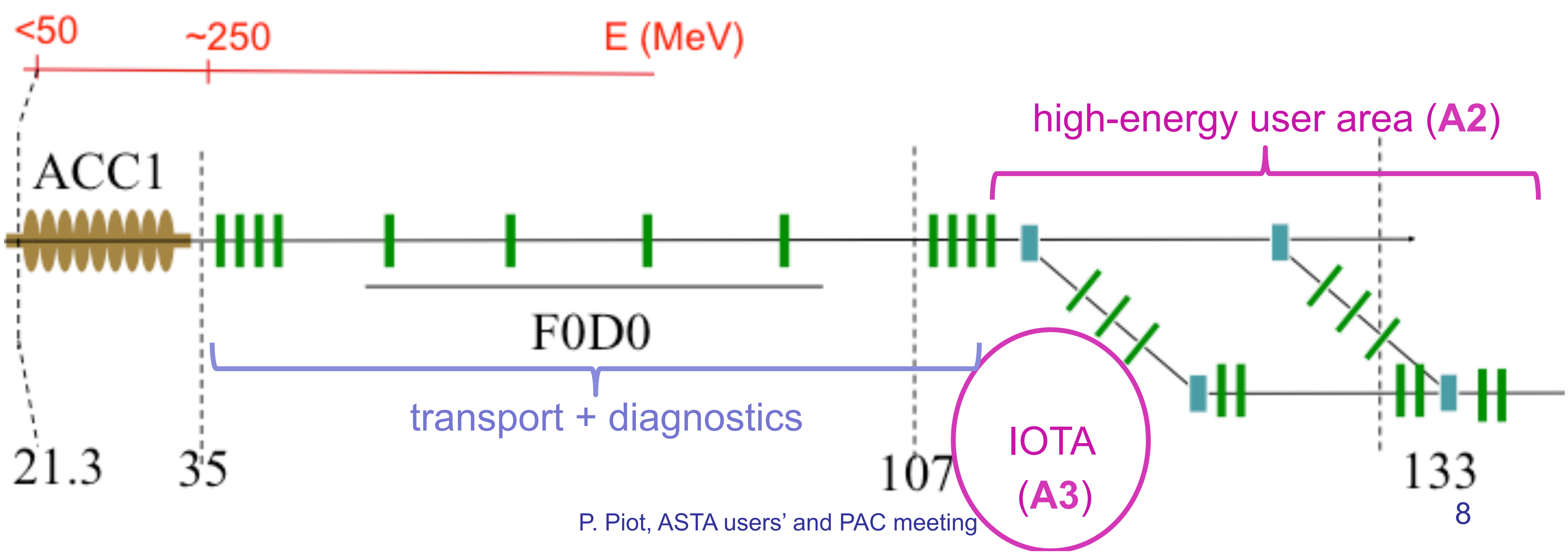


C. Prokop, NIM A (2013)

- lower charges result in higher transverse brightness

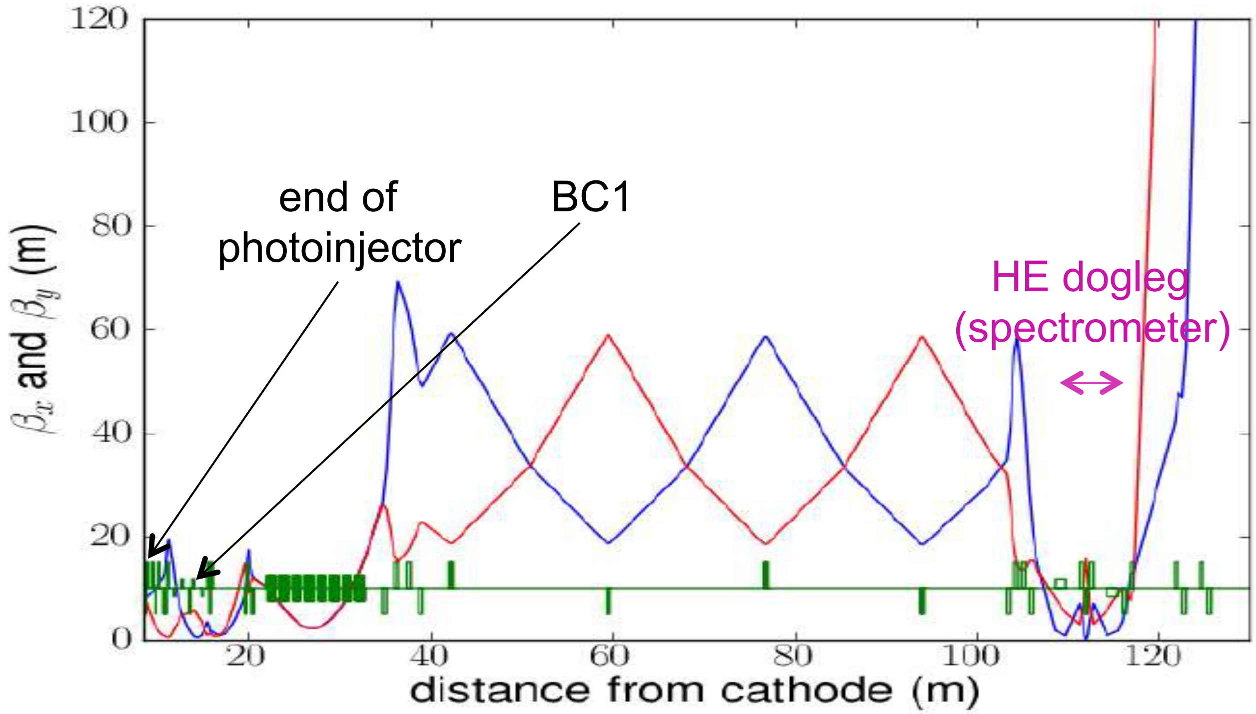
ASTA linac Overview (post ACC1 area)

- Acceleration to ~250-300 MeV in one 8-cavity cryomodule
- post cryomodule beamline:
  - transport beam to high-energy user areas + high-power dumps
  - injection in IOTA
- high-energy user area include several parallel beamline
- Further acceleration to ~800 MeV ("stage II")



post ACC1 beam optics

- Nominally designed to transport beam to HE dumps,
- possibility to transport 50 MeV + have other low-energy “insertable” experiment(s) located in transport line under consideration.

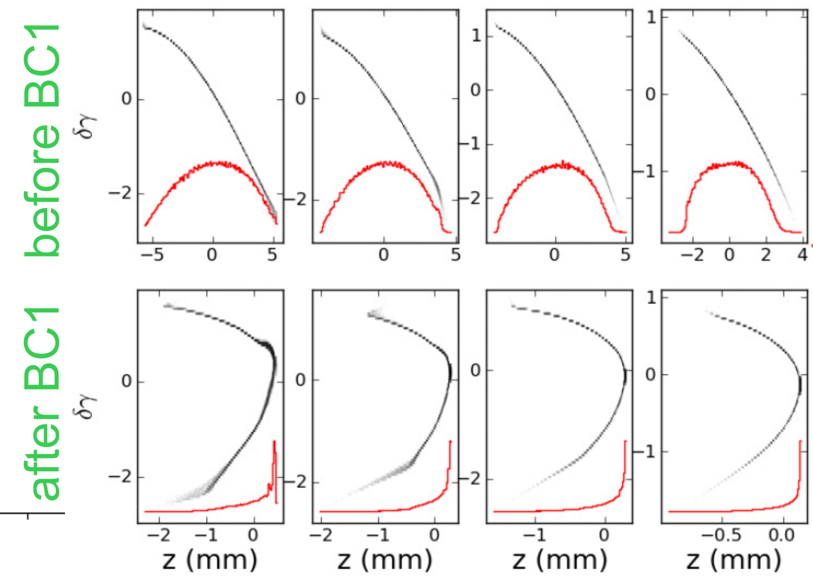


C. Prokop, FNAL TM -2516-APC

Conventional bunch-temporal shaping

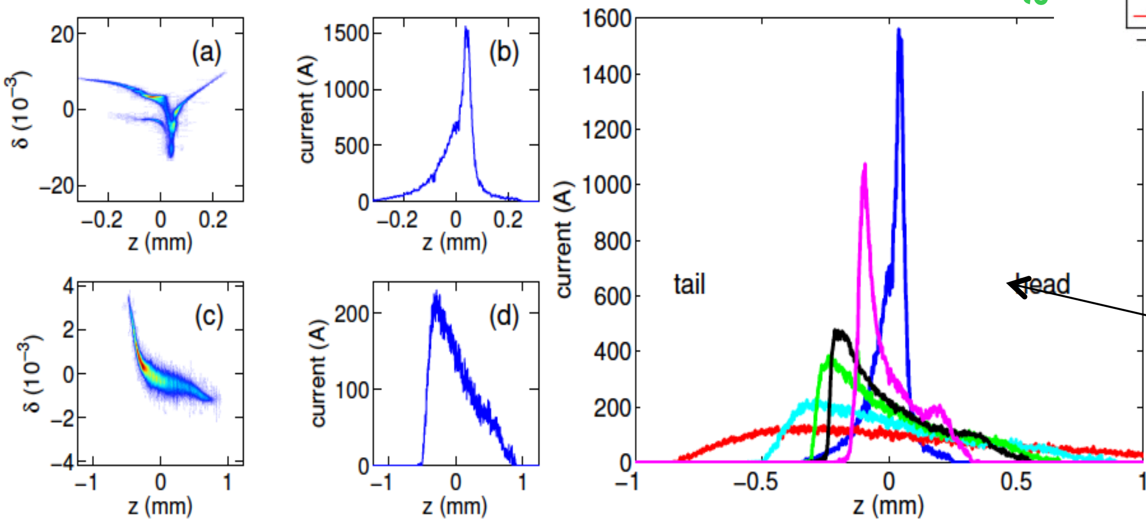
- nominal bunch compression w.o. CAV39 leads to long tail (good for sampling wakes – see Lemery's talk)
- possibility to combine with dispersive scarping (see Thangaraj's talk)
- use of CAV39 to impart controlled nonlinearities (later stage)

Q= 3.2 1.0 0.2 0.02 nC



C. Prokop, IPAC11

CAV39 OFF

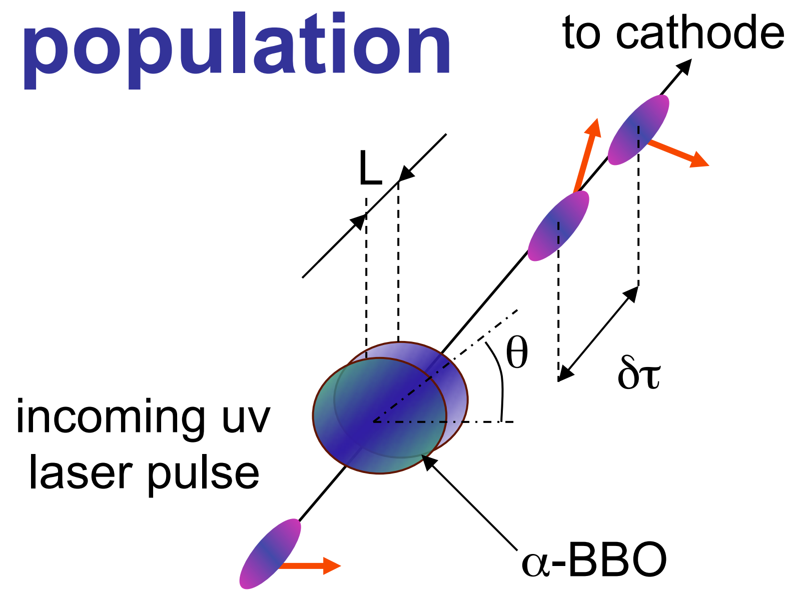


P. Piot, PRL 2012

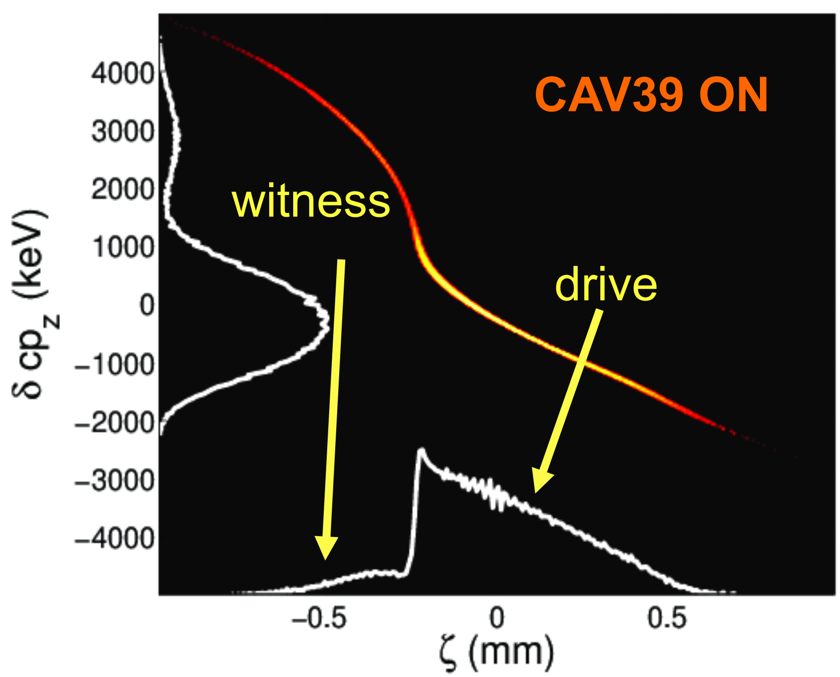
CAV39 ON
varied phase/amplitude

Generation of a witness population

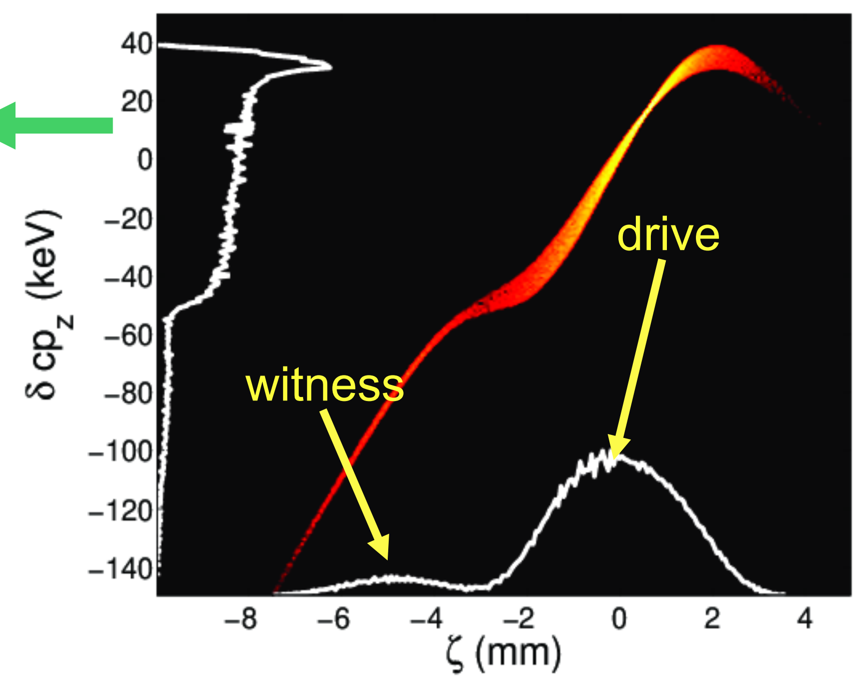
- Witness bunch produced with a birefringent crystal
- Drive/witness hierarchy preserve downstream of BC1
- Preliminary experiments plan-ned at A0/HBESL



AFTER BC1

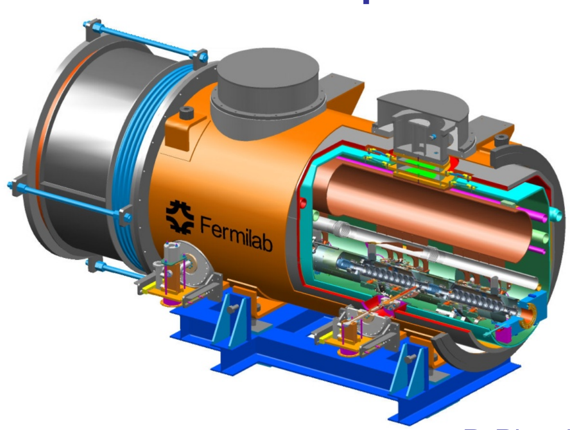


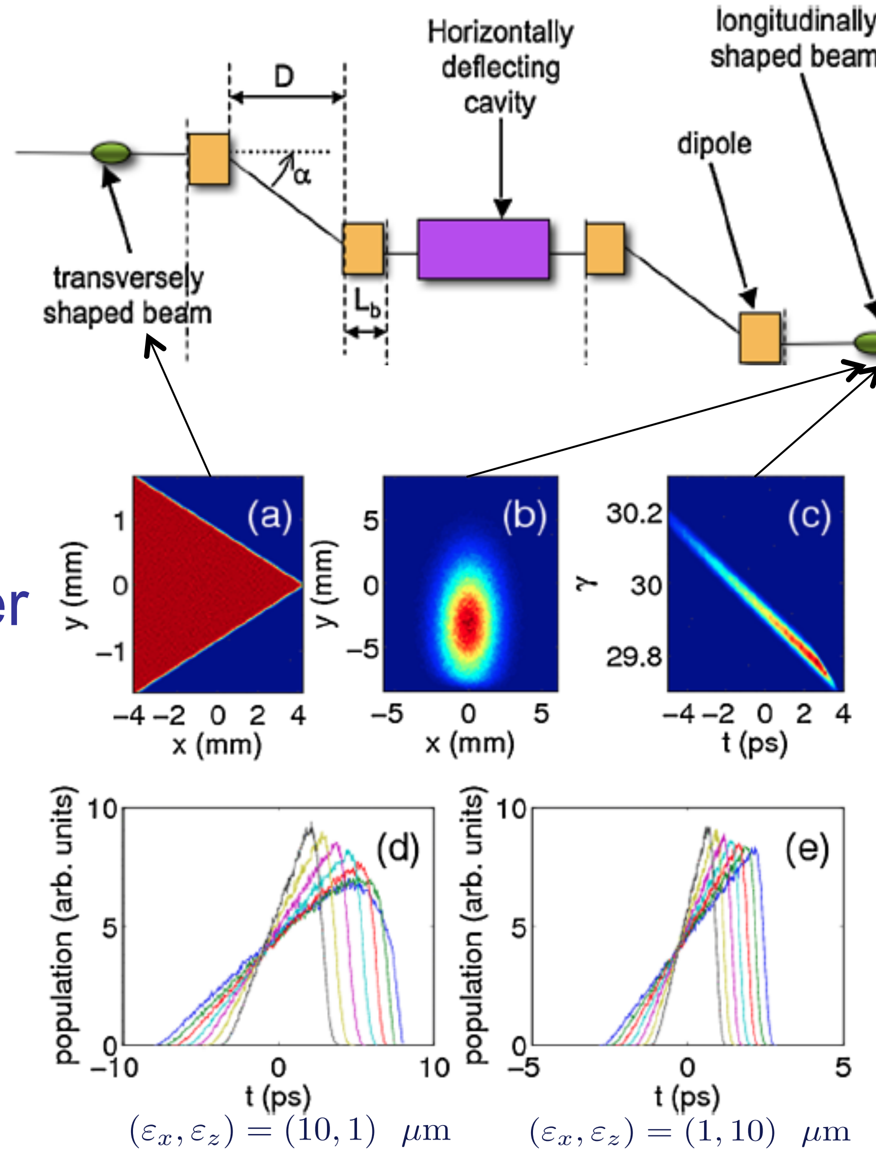
GUN EXIT



EEX-based bunch temporal shaping

- emittance exchanger (EEX) could be used to shape the bunch current profile (bunch train, ramped bunches, …)
- 1st experiment planned w. Los Alamos to explore performance of pulse shaper
- need SC cavities to exploit multi-bunch capabilities





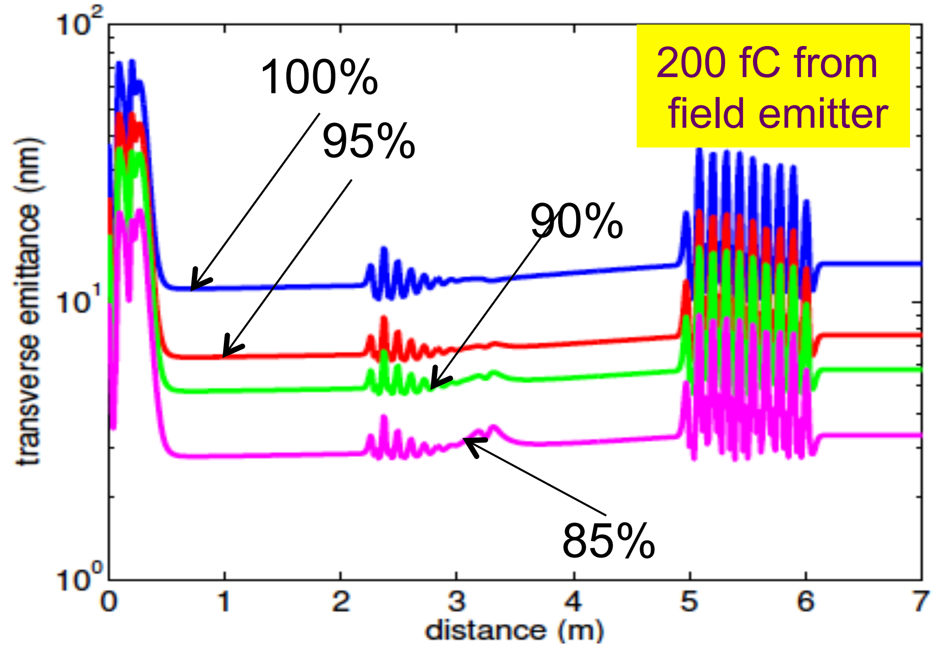
See also proposal/talk from E. Simakov

P. Piot, AAC08, P. Piot, PRSTAB 2011, Y.-E Sun PRL2010, C. Prokop, IPAC13]

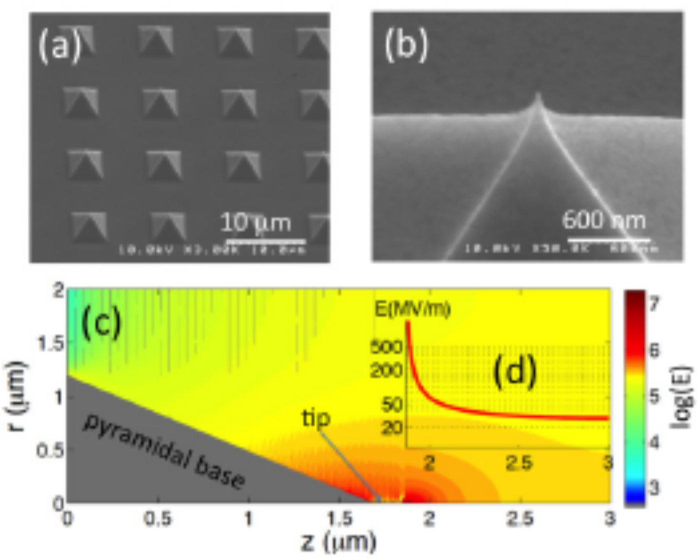
Ultra-low-emittance low-charge beams

See recent experiment
P. Musumecci, PRSTAB 2012)

- small laser spot on photocathode or field-emitter cathodes lead to extremely small emittances (sub-10-nm)
- produced beam are challenging to diagnose with ASTA nominal diagnostics
- Field-emission with gated cathodes could enable the production of low-charge bunches repeated at 1.3 GHz with 1 ms!



C. Brau, SRN (2012), W. Gabella NIMB (2013), D. Mihalcea, Phys. Script. (2013)



C. Brau, B. Choi Vanderbilt

Summary

- ASTA will provide beams within a vast parameter space,
- Some of the advanced phase-space manipulations pioneered at Fermilab's A0 photoinjector are integral part of the design (flat beam) or will be installed early (EEX),
- Low-energy chicane-based bunch compression is not optimal but viable, at a later stage (after ACC1 installed), a second stage compressor will be added,
- Beam-dynamics performances of ASTA should be able to support most of the proposed experiments,
- We will be glad to collaborate and/or provide detailed calculations in support of your experiment [eventually all simulations files will be posted on ASTA web page so user can freely carry these calculations]