ASTA Linac Beamline configurations & capabilities

presented by P. Piot[1,2]
based on work by C. Prokop[1], D. Mihalcea[1],
F. Lemery[1], J. Zhu[2], and collaborations with
B. E. Carlsten[3].
[1] Northern Illinois University, [2] Fermilab,
[3] Los Alamos National Laboratory.

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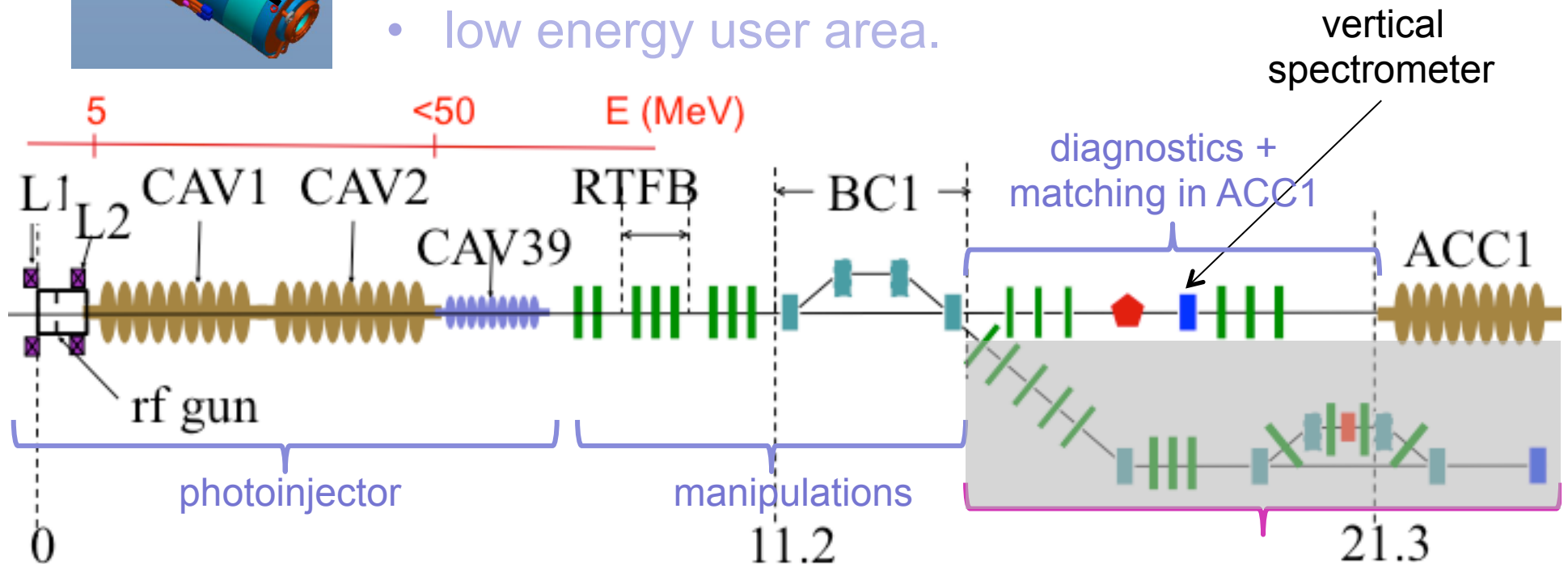 – Tailored current profiles.
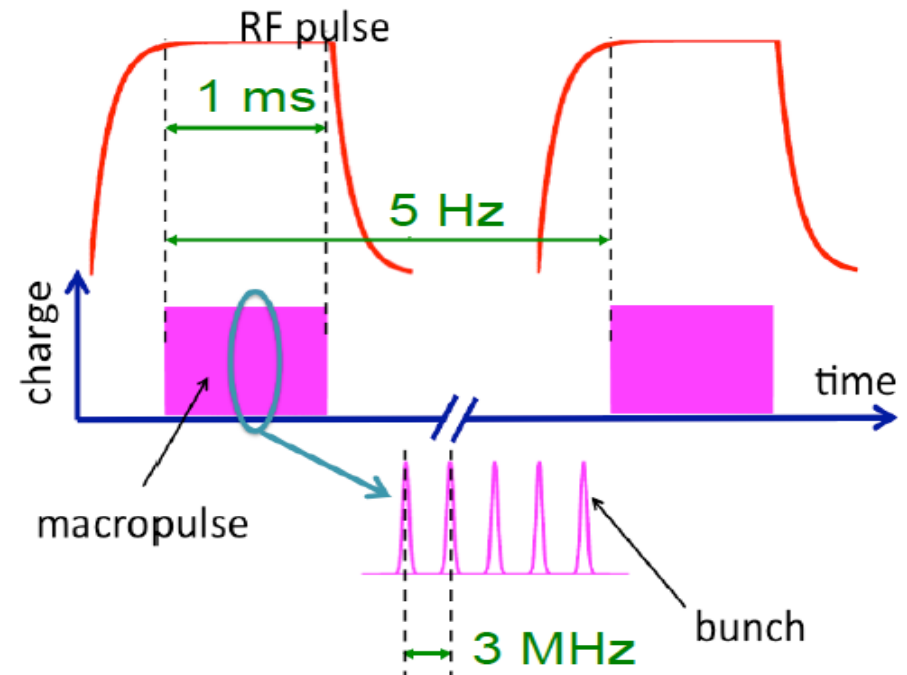
parameter	nominal value	range	units
energy exp. A1	50	[5,50]	MeV
energy exp. A2	~ 300 (stage 1)	[50,820]	MeV
bunch charge Q	3.2	[0.02,20]	nC
bunch frequency f_b	3	see [a]	MHz
macropulse duration τ	1	≤ 1	ms
macropulse frequency f_{mac}	5	[0.5, 1, 5]	Hz
num. bunch per macro. N_b	3000	[1,3000]	–

ASTA linac Overview (injector area)

DESY-type
L-band RF gun
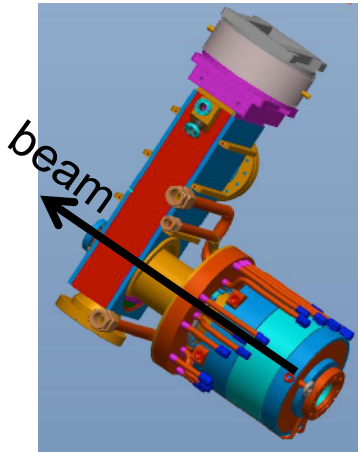
beam

- Cs$_2$Te 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.

vertical
spectrometer

diagnostics +
matching in ACC1

5   <50   E (MeV)

L1 L2   CAV1   CAV2   RTFB   ← BC1 →   ACC1
              CAV39

rf gun

photoinjector   manipulations

0   11.2   21.3

P. Piot, ASTA 2nd users' meeting

low-energy user area (**A1**)

Photoinjector capabilities (1)

- nominal operating charge:

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

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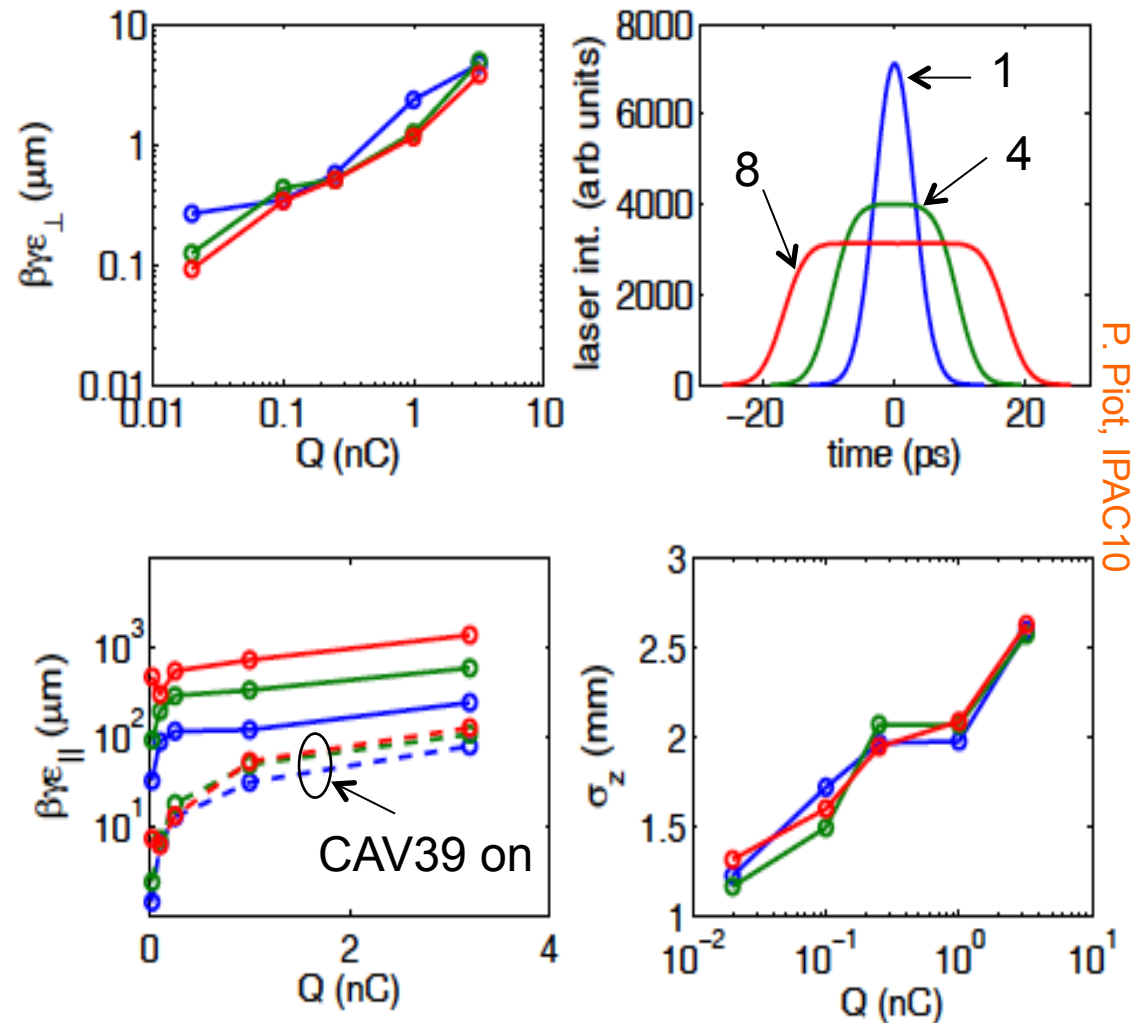 - transverse emittance [µm]:

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

  - longitudinal emittance [µm]

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

 - uncompressed rms bunch length [mm]

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

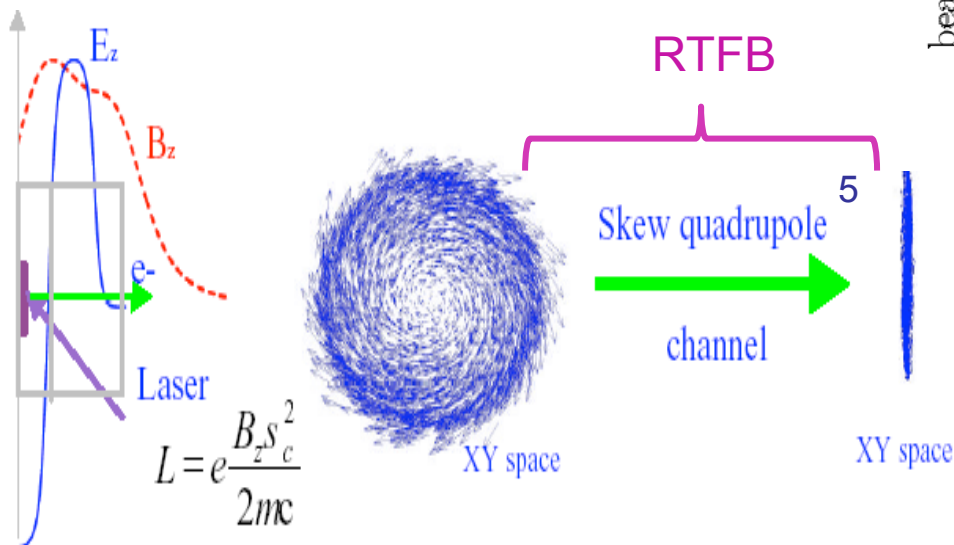CAV39 on

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

P. Piot, IPAC10

Flat-beam generation (on-going work)

- beams with asymmetric transverse-emittance partition can be produced

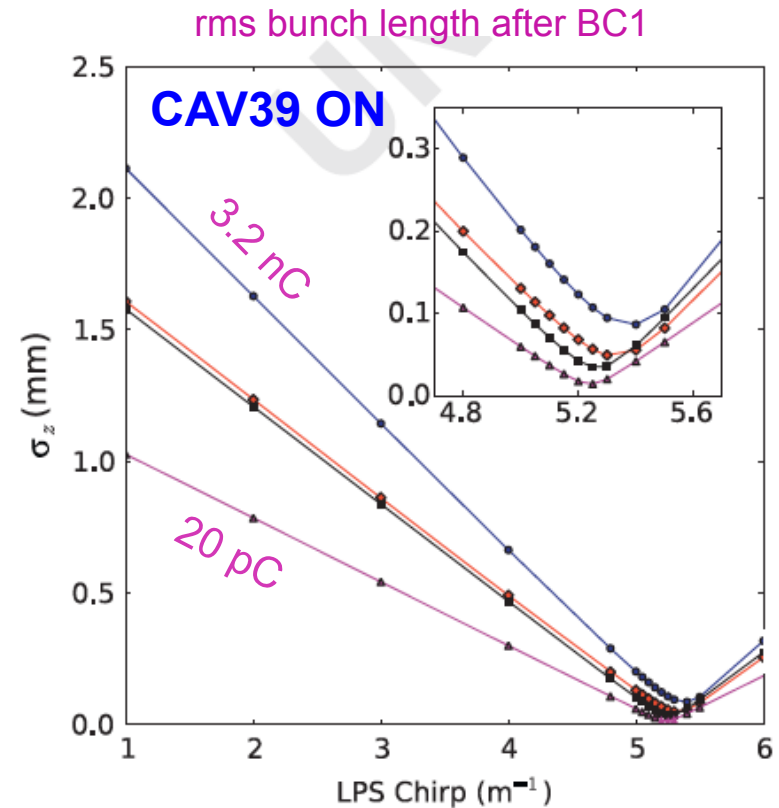- optimized flat beams have similar 4D emittance than round beams

$$L = e\frac{B_z s_c^2}{2mc}$$

RTFB

Skew quadrupole channel

XY space

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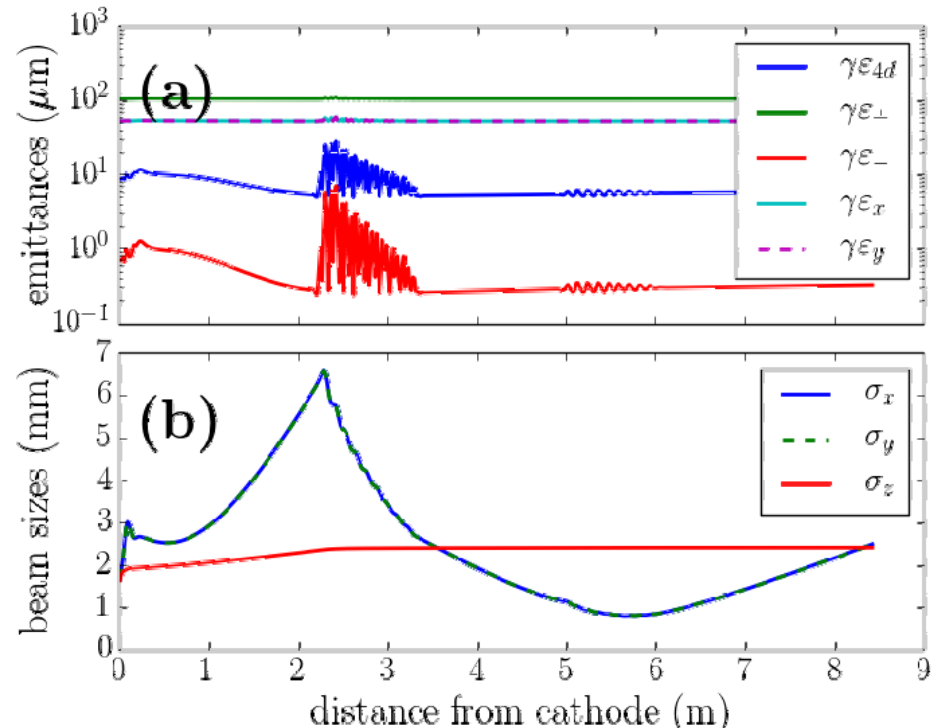
parameter	flat-beam configuration	round-beam configuration	units
Q	3.2	3.2	nC
E	47.18	48.77	MeV
ε_x	105.04	5.43	μm
ε_y	0.31	5.44	μm
ε_{4D}	5.53	5.44	μm
ρ	$\simeq 334$	$\simeq 1$	–

Low-energy bunch compression (1)

- Compression performed with a chicane-type bunch compressor (BC1)

- long. dispersion $R_{56} = -19$ cm

before BC1   after BC1

CAV39 ON
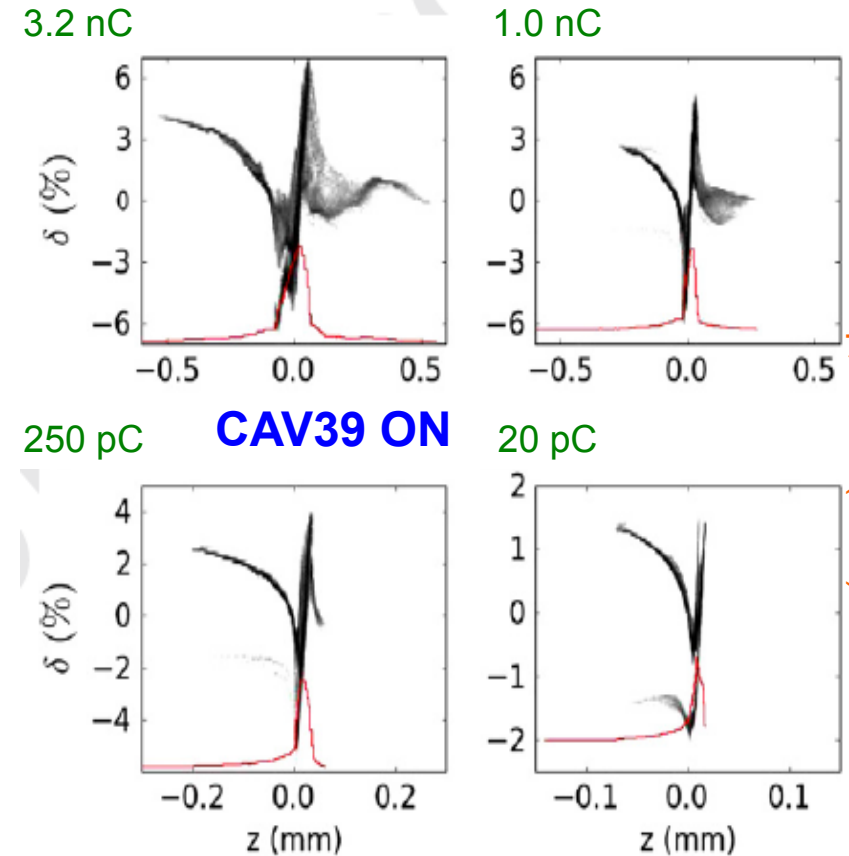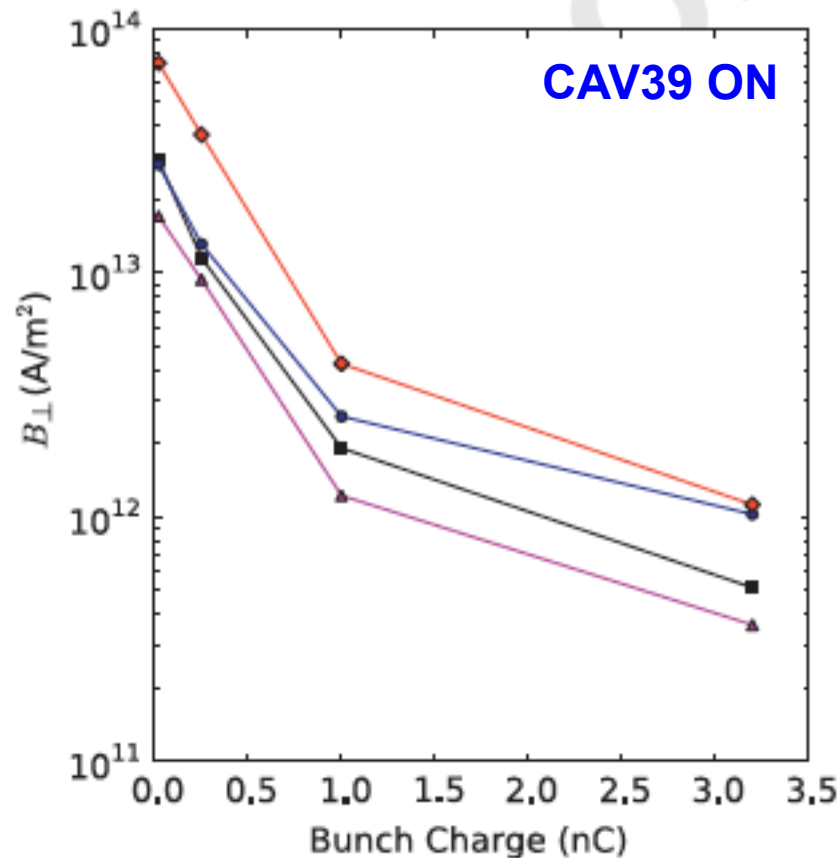CAV39 OFF
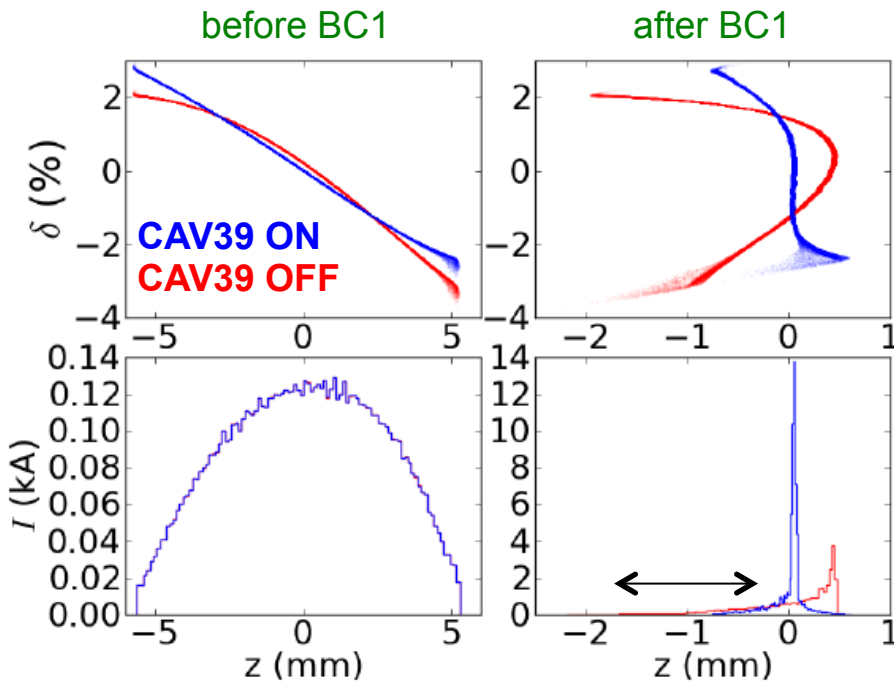
single-particle-dynamics simulation of BC1

rms bunch length after BC1

CAV39 ON

3.2 nC

20 pC

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

Low-energy bunch compression (2)

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

3.2 nC   1.0 nC
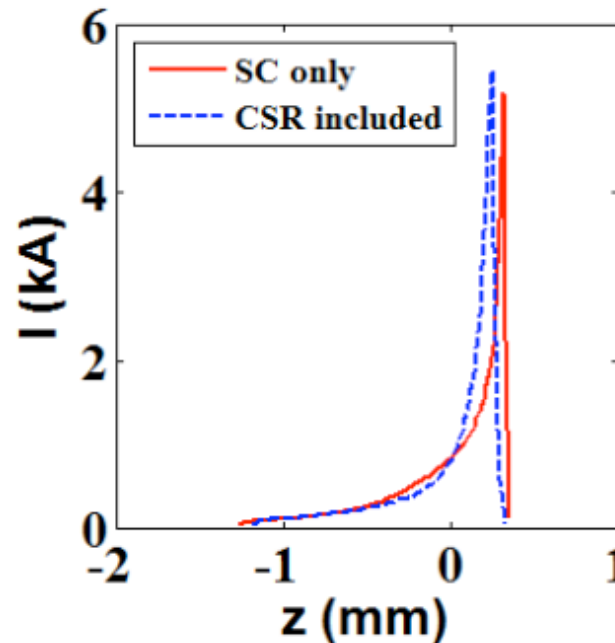

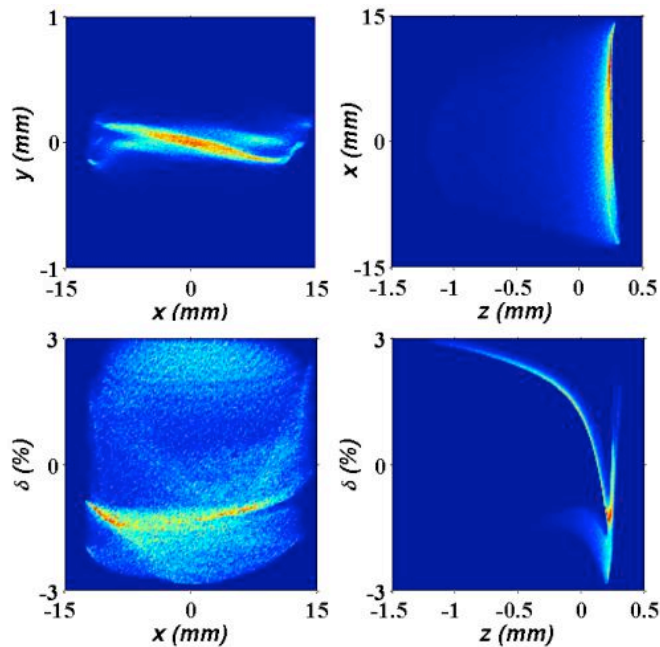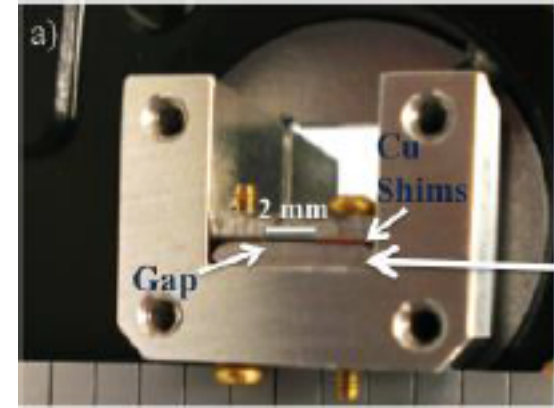**CAV39 ON**

250 pC   **CAV39 ON**   20 pC

C. Prokop, NIM A (2013)

- lower charges result in higher transverse brightness

Compression of flat beams

- Compressed flat beams have applications to test asymmetric structure (DWFA, μ-undulator),

- comprehensive beam dynamics study recently completed,

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")

P. Piot, ASTA 2nd users' meeting
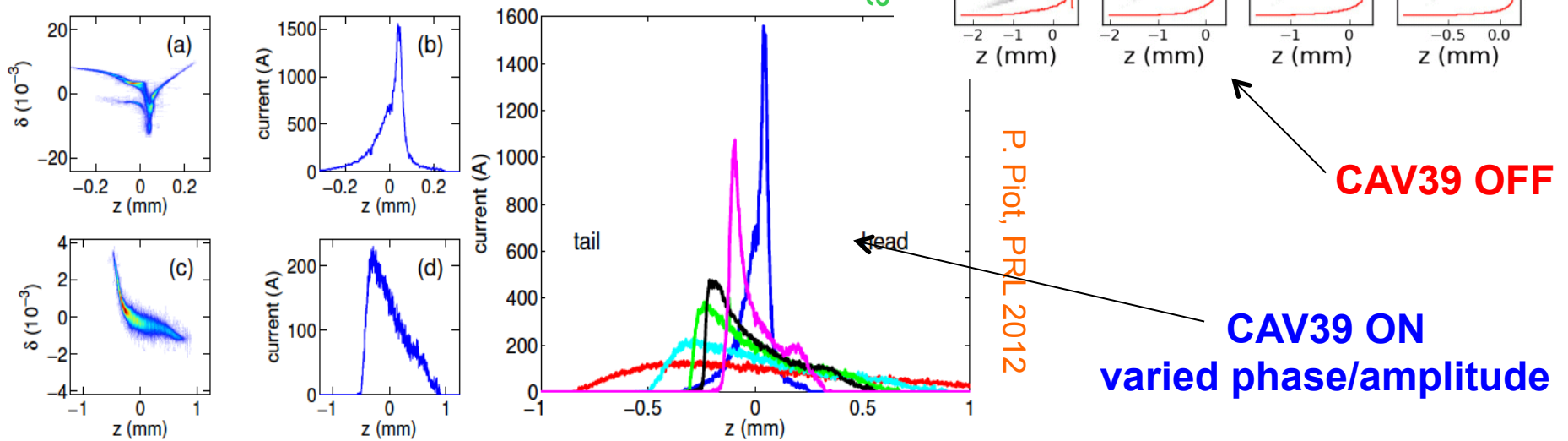
9
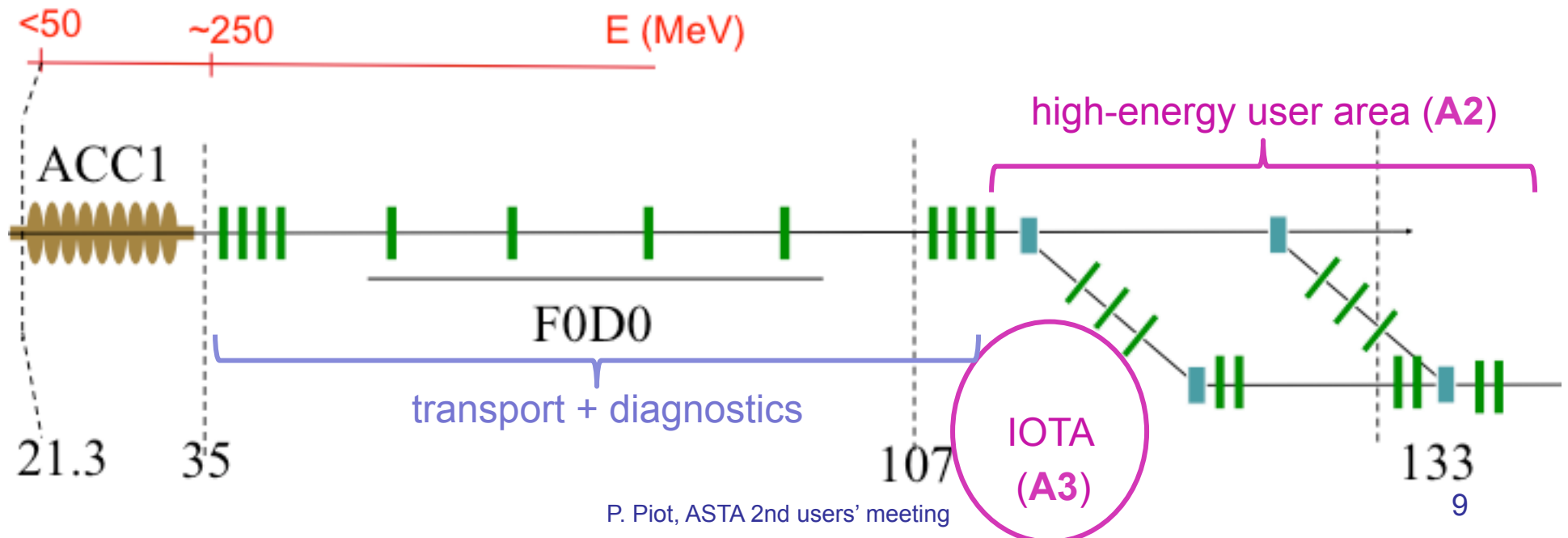
post ACC1 beam optics

- Nominally designed to transport beam to HE dumps,
- possibility to transport 50 MeV + have other low-energy "insertable" experiment(s) located in transport line.
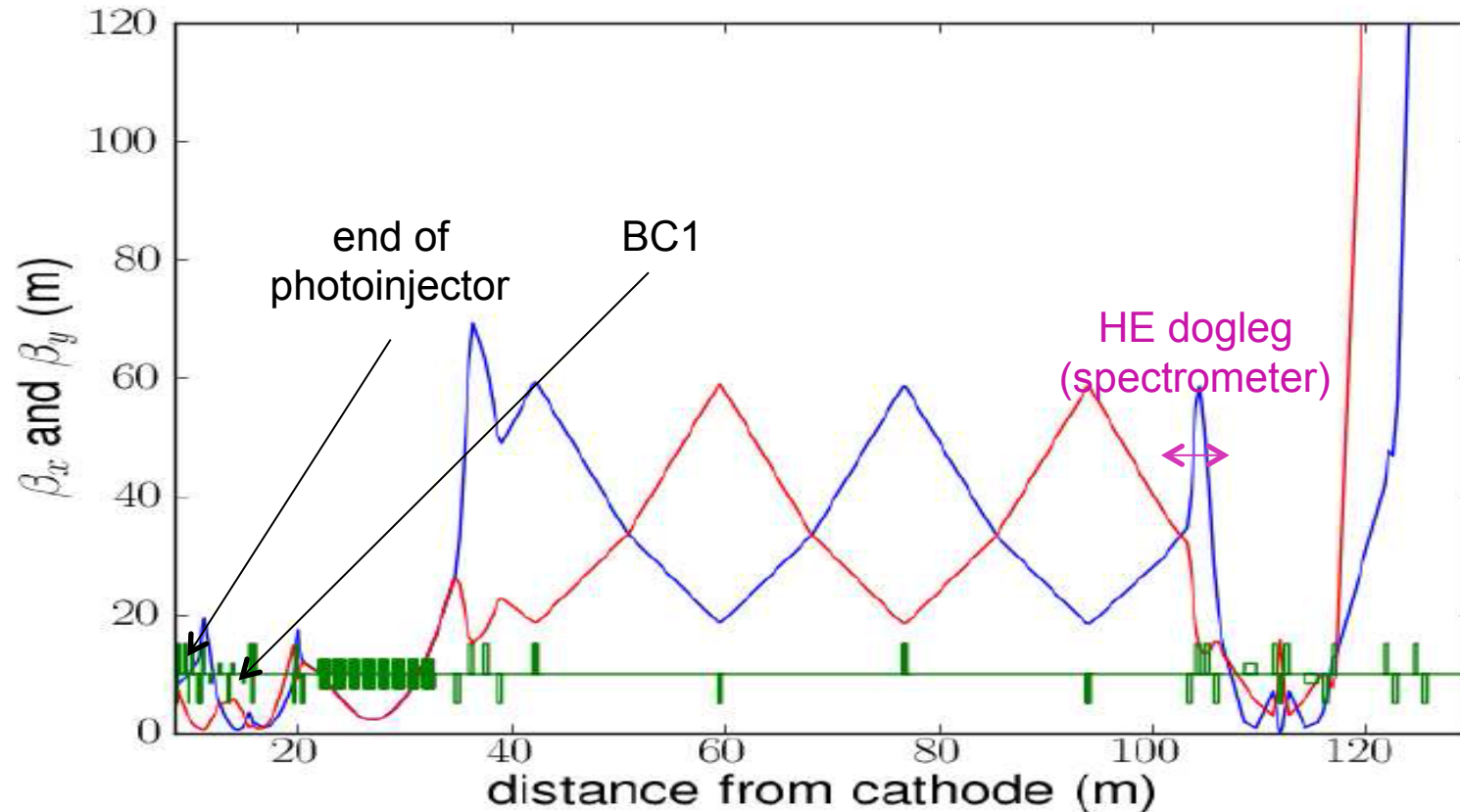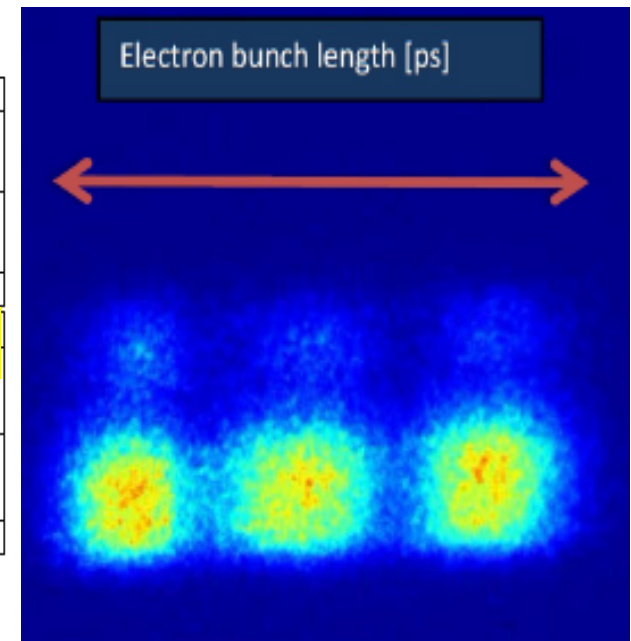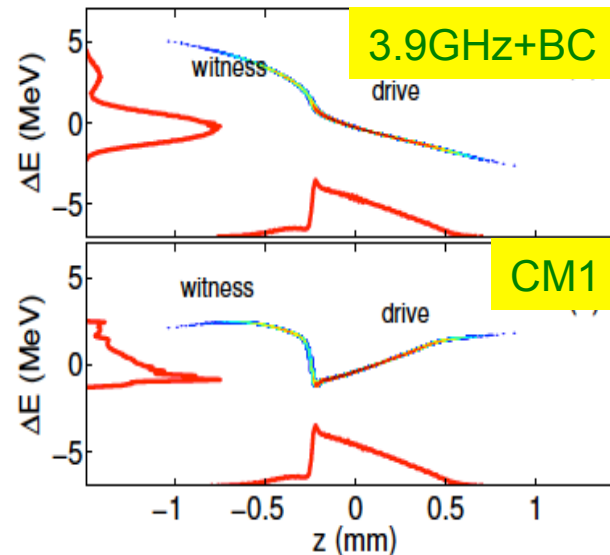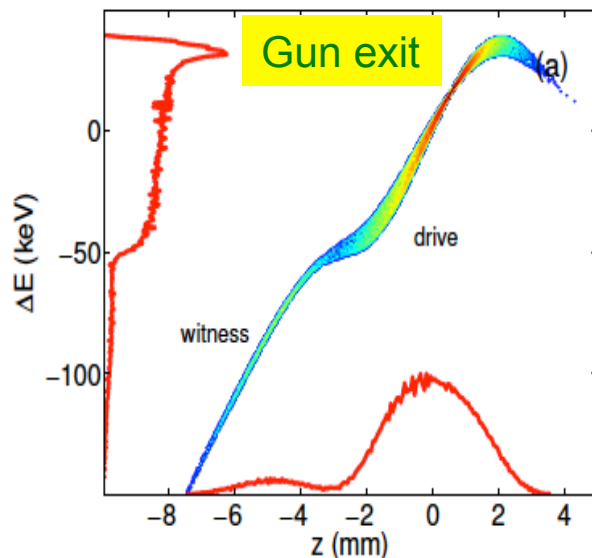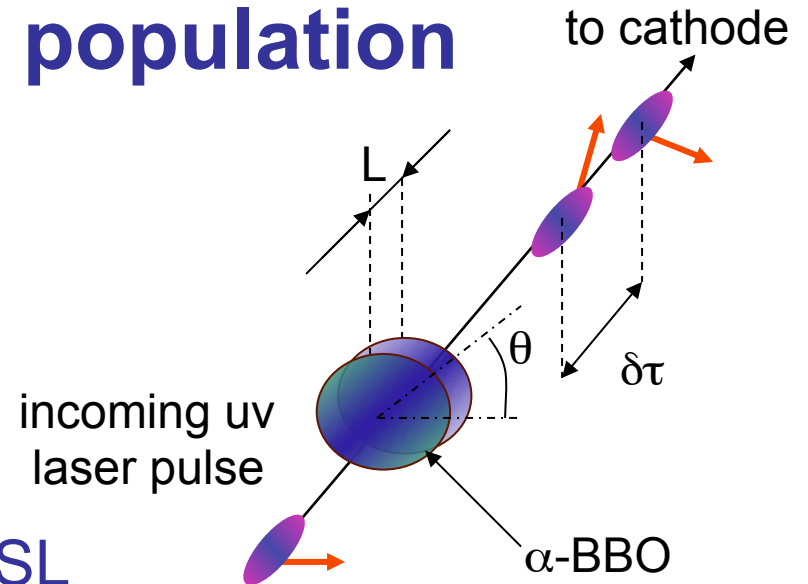
Conventional bunch-temporal shaping

- nominal bunch compression w.o. CAV39 leads to long tail (good for sampling wakes – see Lemery's talk),

- possibility to combine with disper-sive scarping,

- use of CAV39 to impart controlled nonlinearities (later stage).

Q= 3.2   1.0   0.2   0.02 nC

before BC1

after BC1

C. Prokop, IPAC11

CAV39 OFF

P. Piot, PRL 2012

tail   head

CAV39 ON
varied phase/amplitude

Generation of a witness population

- Witness bunch produced with a birefringent crystal
- Drive/witness hierarchy preserve downstream of BC1
- Shaping experiment on-going using ASTA laser and A0-HBESL beamline

to cathode

L

θ

$\delta\tau$

incoming uv laser pulse

α-BBO

Gun exit

(a)

ΔE (keV)

drive

witness

z (mm)

3.9GHz+BC

ΔE (MeV)

witness

drive

CM1

ΔE (MeV)

witness

drive

z (mm)

Electron bunch length [ps]

Experiment by J. C. Thangaraj et al. (2014)

[P. Piot et al, AAC12 (2012)]

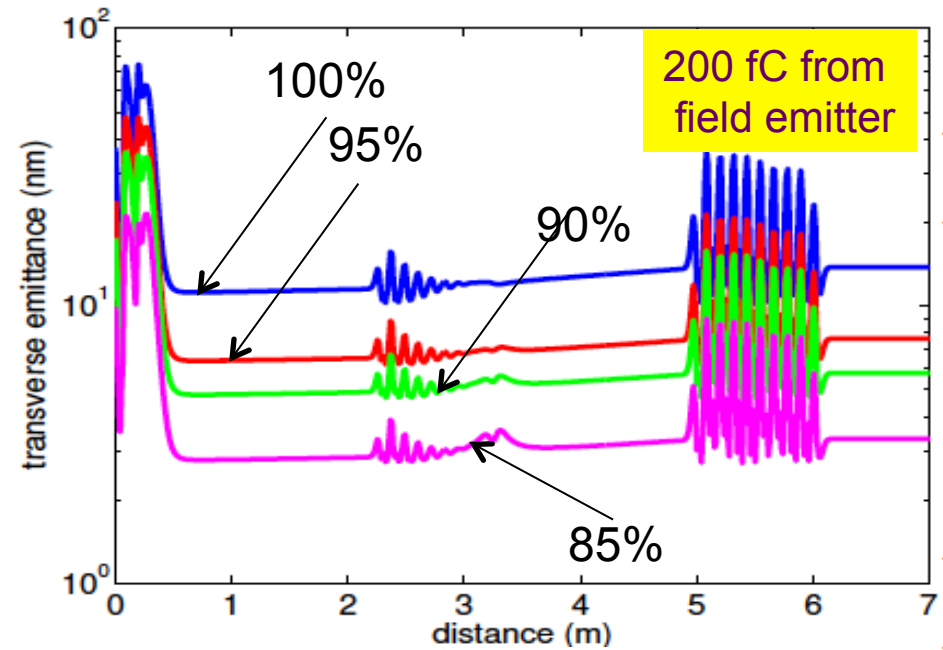P. Piot, ASTA 2nd users' meeting

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EEX-based bunch temporal shaping

- emittance exchanger (EEX) could be used to shape the bunch current profile (bunch train, ramped bunches, …)

- need SC cavities to exploit multi-bunch capabilities

$(\varepsilon_x, \varepsilon_z) = (10, 1)\ \mu m$

$(\varepsilon_x, \varepsilon_z) = (1, 10)\ \mu m$
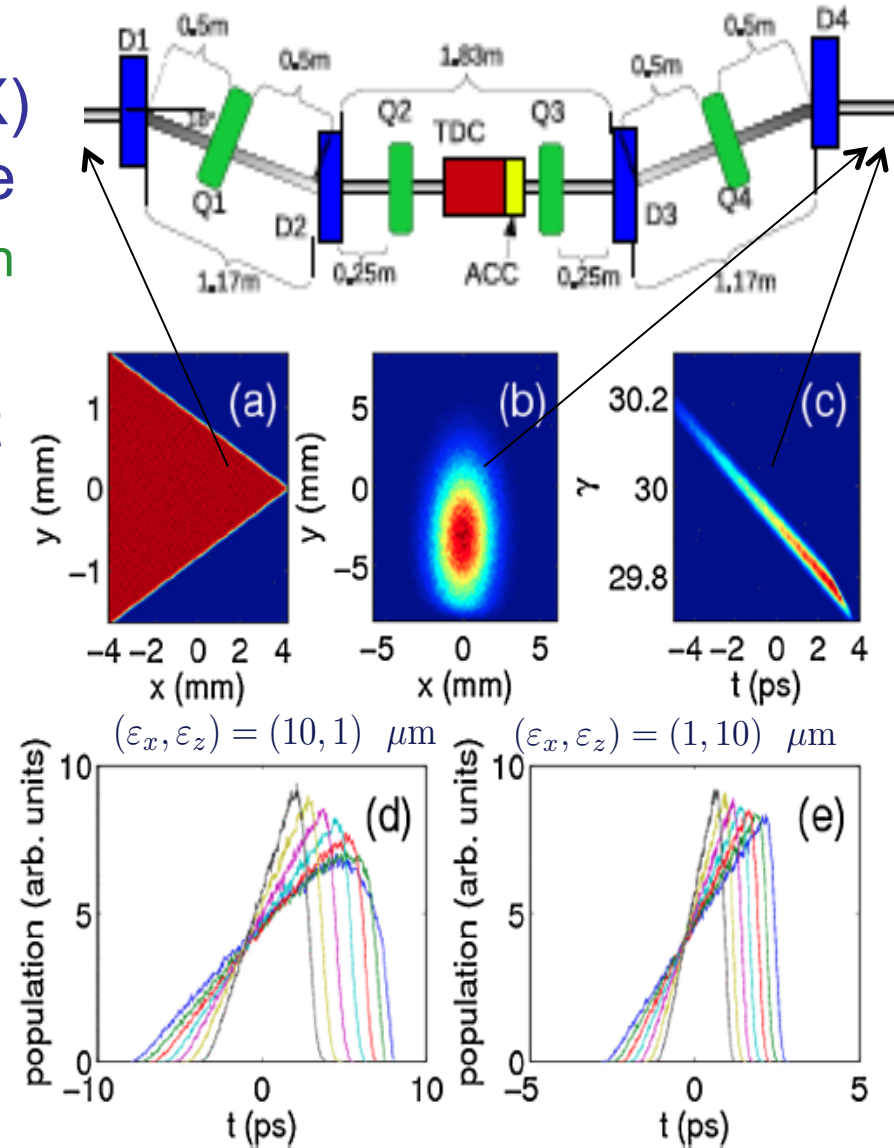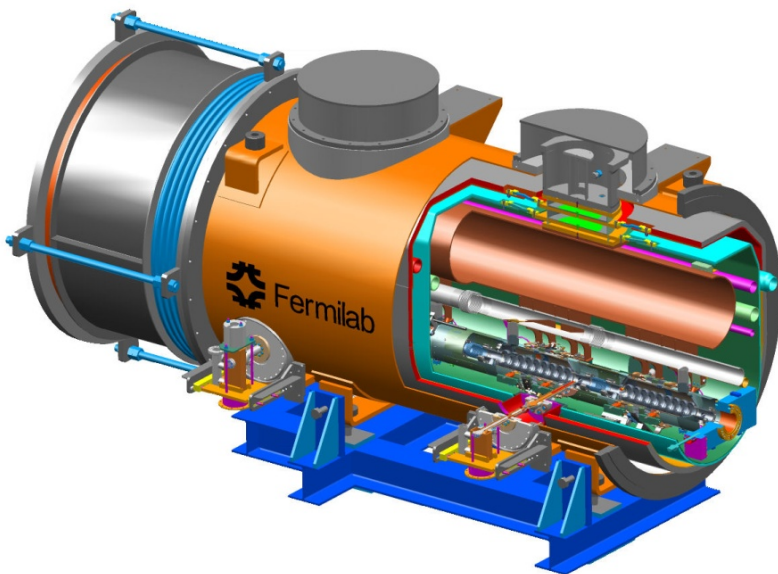
Ultra-low emittance low-charge beams

- small laser spot on photocathode or field-emitter cathodes lead to extremely small emit-tances (sub-10-nm)

- produced beam are chal-lenging 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!
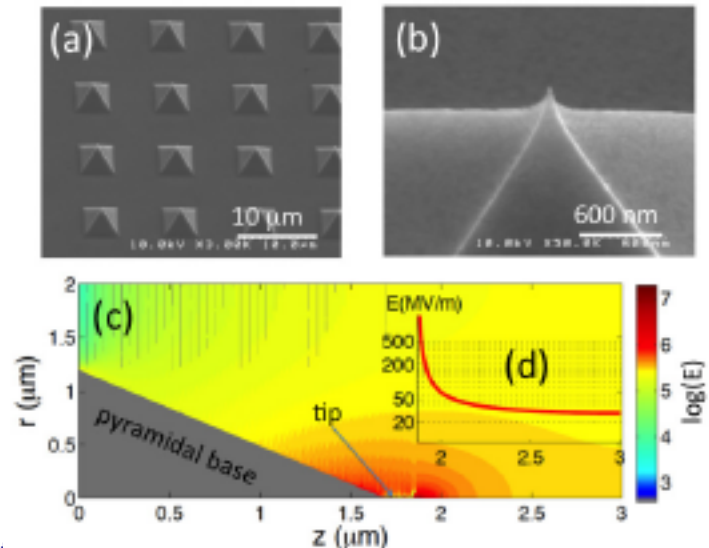
200 fC from field emitter

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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 might 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]