Discussion on possible experiments in the ASTA Injector and high-energy beamline*

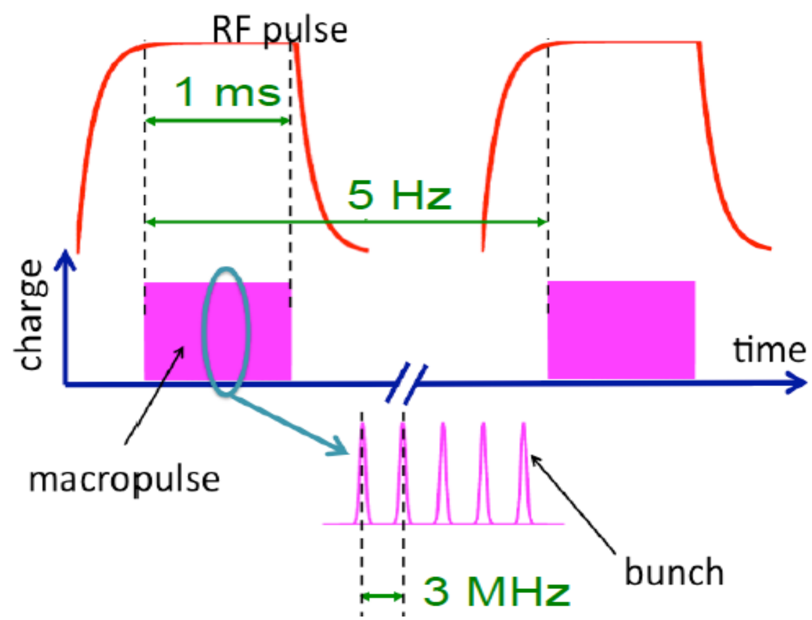
P. Piot for the ASTA team

Focused Workshop on Scientific Opportunities in IOTA,
April 28-29, 2015 Fermilab

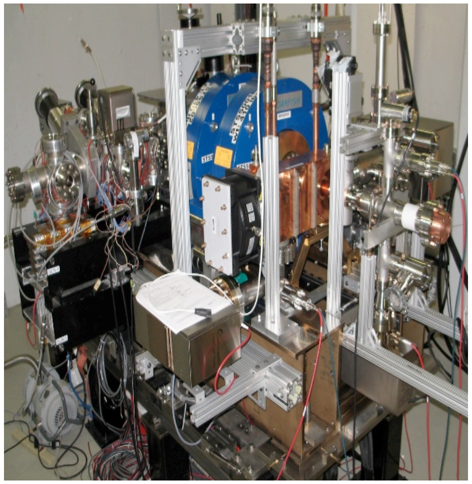
*sponsored by DOE contract #DE-AC02-07CH11359 to the Fermi Research Alliance LLC.

Outline & Motivations

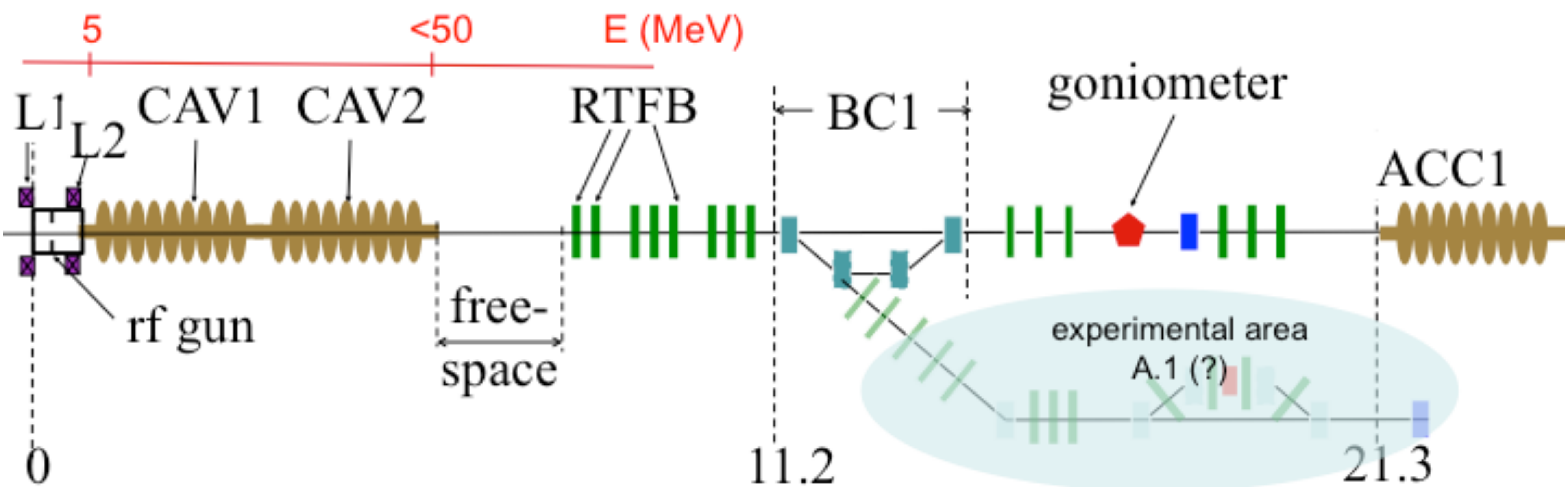
- **Current setup:** injector and laser capability, "high-energy" beamline(s).
- **Discussions on possible beamline additions (for WG3 to discuss)**
- **Classes of Possible Experiments (discussed at various venues):**
  - general beam dynamics
  - radiation sources
  - phase-space control & applications
  - advanced acceleration techniques



Beamline Configuration

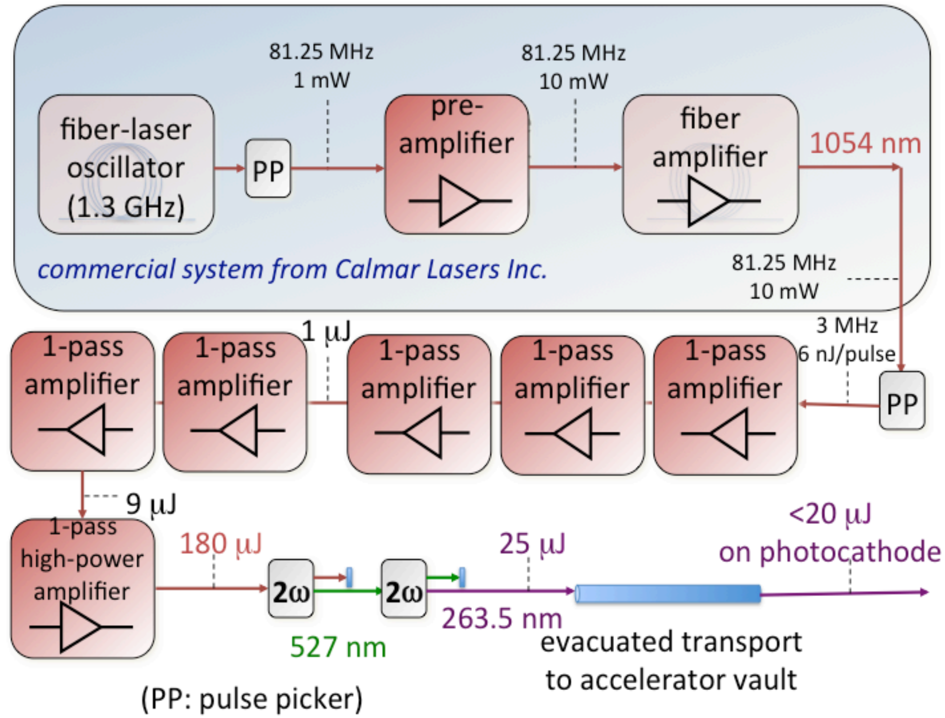


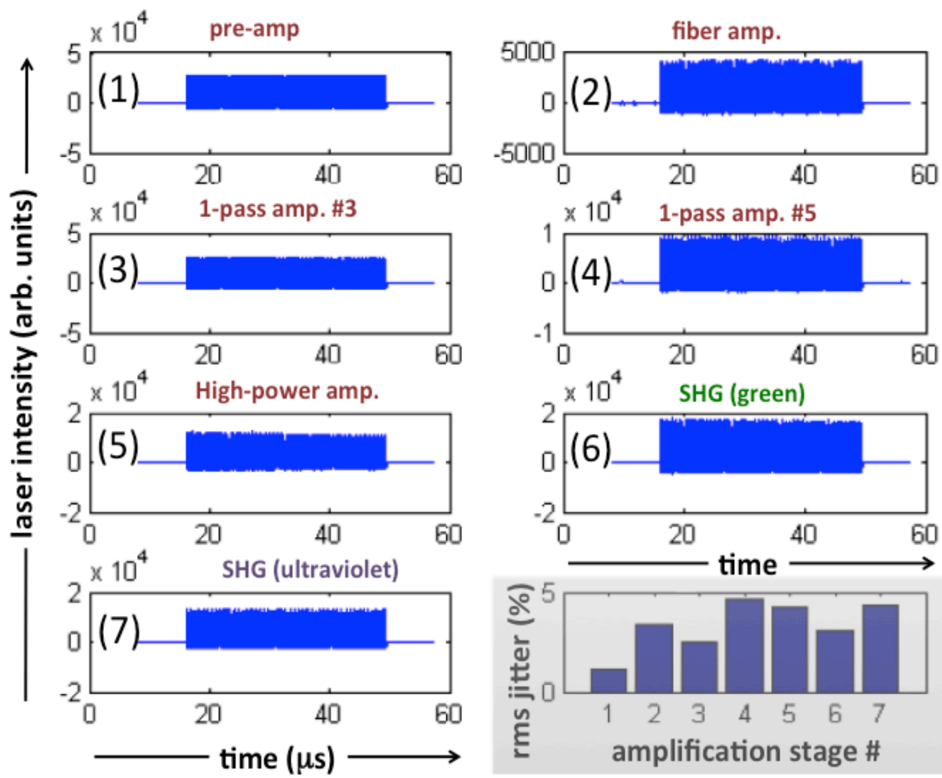
- 1+½ -cell DESY (axisymmetric coupler) gun,
- two SCRF booster **ca**vities (CAV1, 2),
- **R**ound-**to**-**f**lat **b**eam **t**ransformer (RFTB),
- **B**unch **c**ompressor (BC1) + diagnostic section,
- later stage: active or passive linearizer (?)
- low energy user area (A.1 ?).



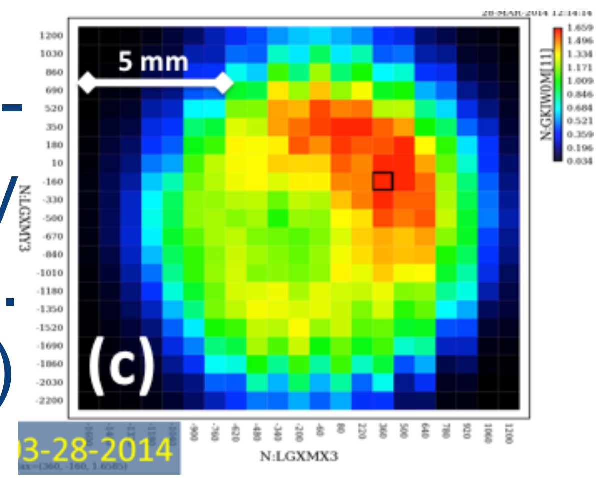
Cathode + Laser System

- Cs_2Te cathode,
- Yb-fiber/Nd:YLF laser,
- Q>5 nC possible.



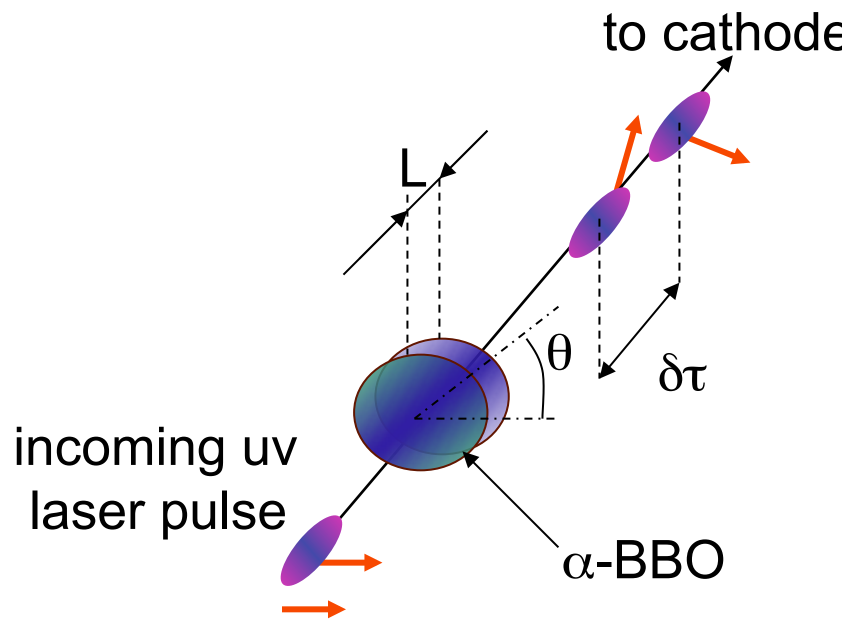


- quantum-efficiency map (typ. ~1% QE)

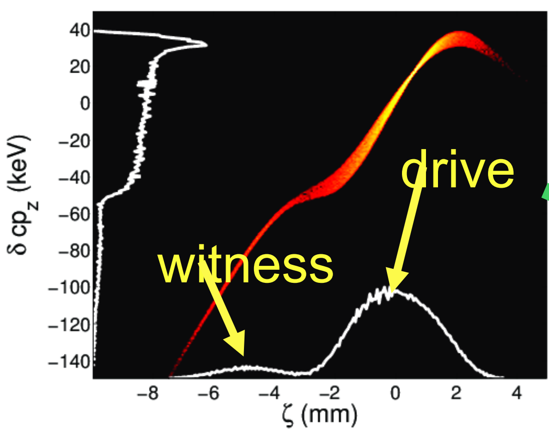


Laser temporal shaping

- Laser pulse transform-limited to ~3 ps (rms)
- Coarse shaping possible using α-BBO crystals

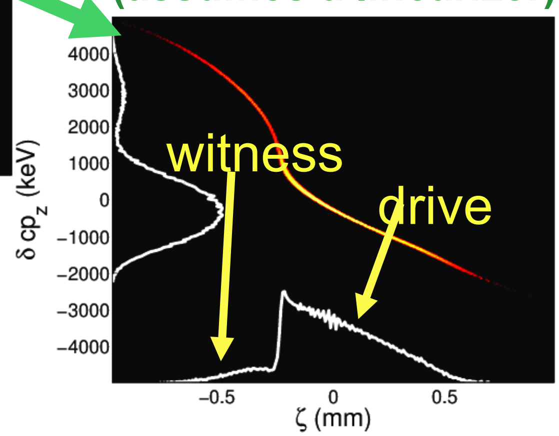


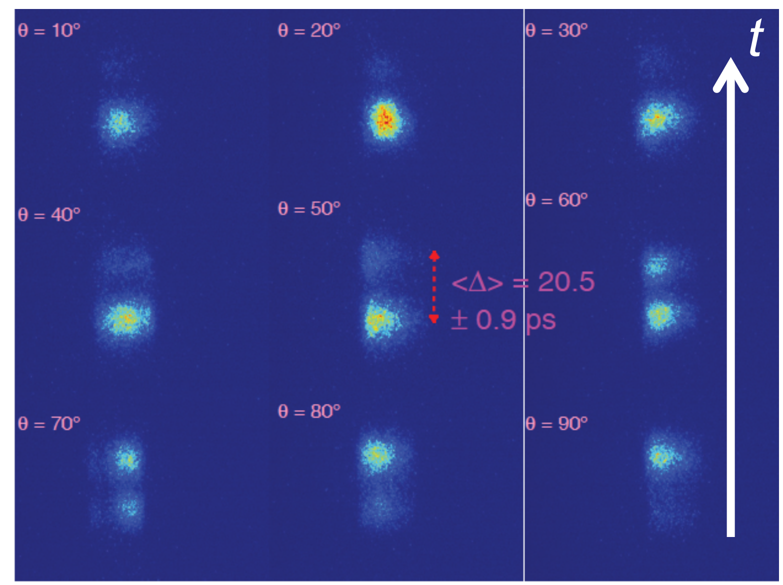
GUN EXIT



[simulations
P. Piot, AAC12 (2012)]

AFTER BC2
(assumes a linearizer)

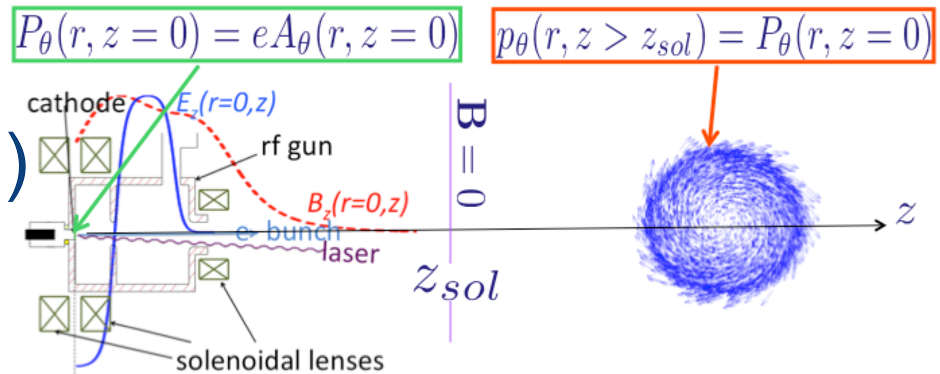




[UV laser measurements
J. C. T Thangaraj et al, LINAC14 (2014)]

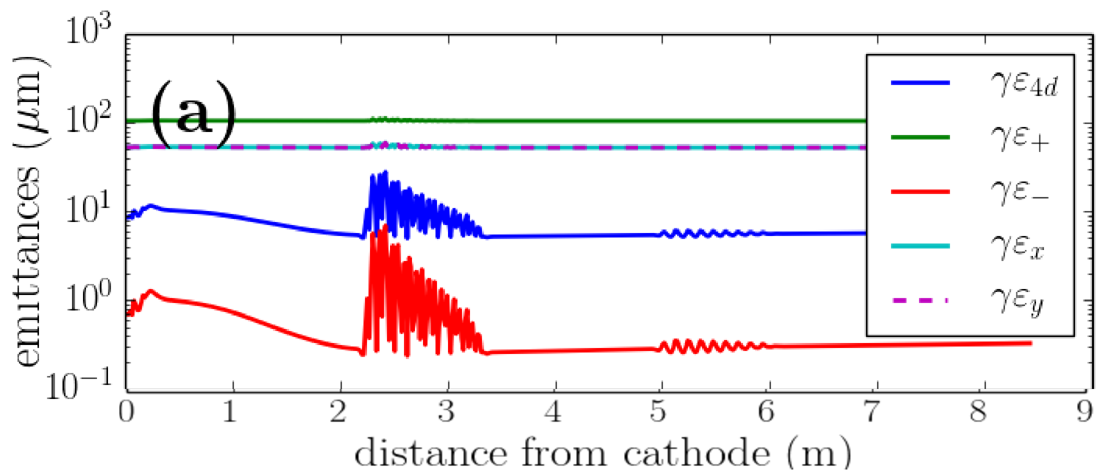
Asymmetric-emittance ("flat") beams

- Injector includes RTFB transformer (skew quad) ➔"flat beam" from a CAM-dominated beam.



- Flat beams w. similar 4D emit. as round beams.
- Compression of flat beam is possible.

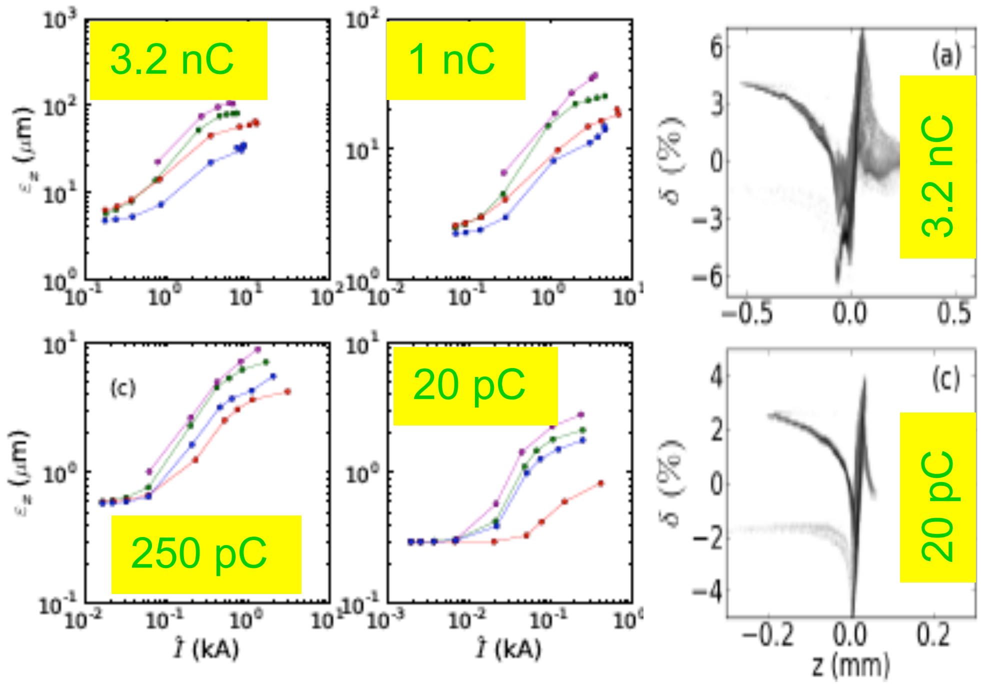
parameter	flat-beam configuration	round-beam configuration	units
Q	3.2	3.2	nC
E	47.18	48.77	MeV
ε_x	105.04	5.43	μm
ε_y	0.31	5.44	μm
ε_{4D}	5.53	5.44	μm
ρ	$\simeq 334$	$\simeq 1$	–



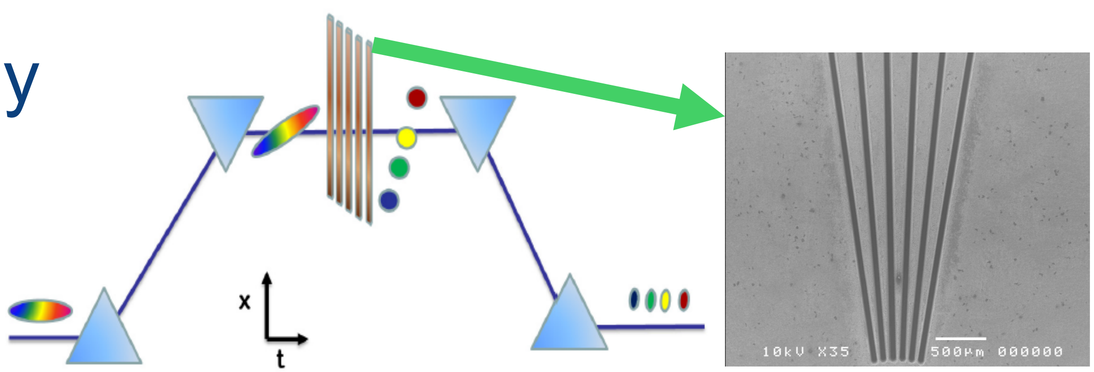
[P. Piot, et al., NAPAC13 (2013)
J. Zhu, et al., PRSTAB (2014)]

Bunch-compressor chicane

- Compression at low energy can be accomplished
  ➔ tradeoff btw emit. & peak current
- Dispersive selection using mask located in compressor
  ➔ shaping, energy bands, microbun-ches



[C. R. Prokop et al, NIM A (2013)]



[J. C. T Thangaraj et al, LINAC14 (2014), Y.-M Shin, et al. IPAC14 (2014)]

Compressed flat beams

- generation of compres-sed flat beams
  - various charge,
  - flexible emittance ratios

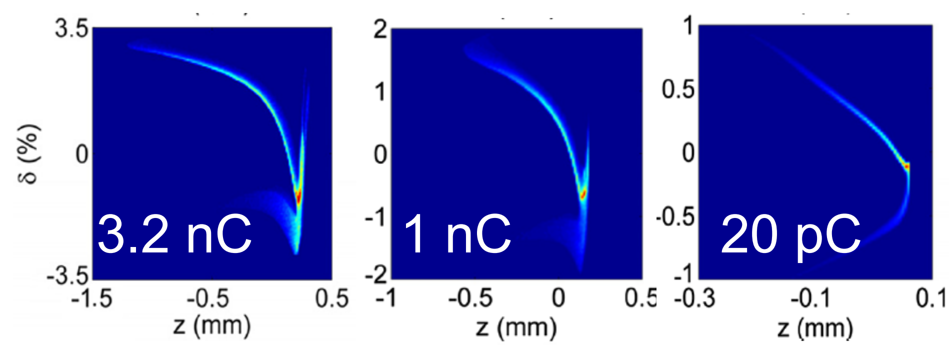
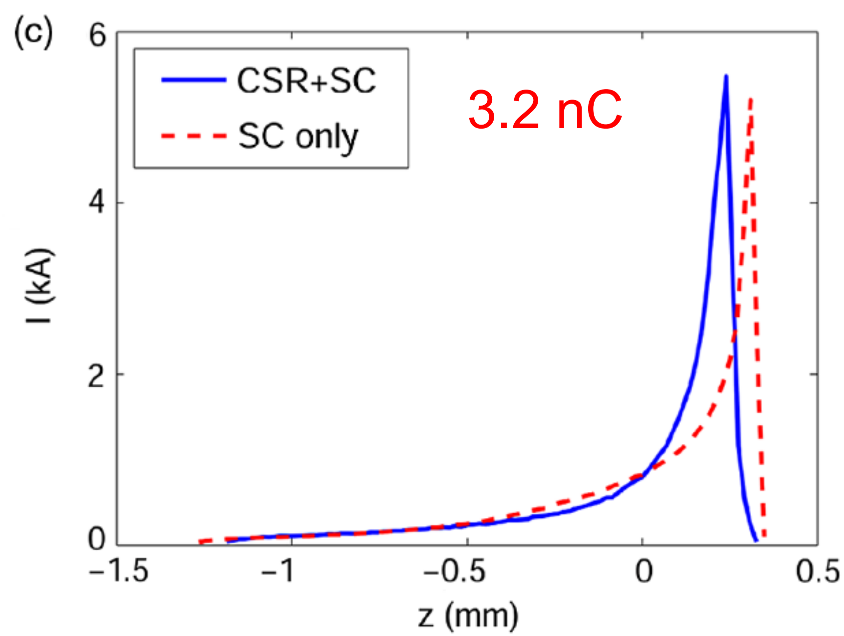


TABLE II. Properties of the optimized flat beams under full compression.

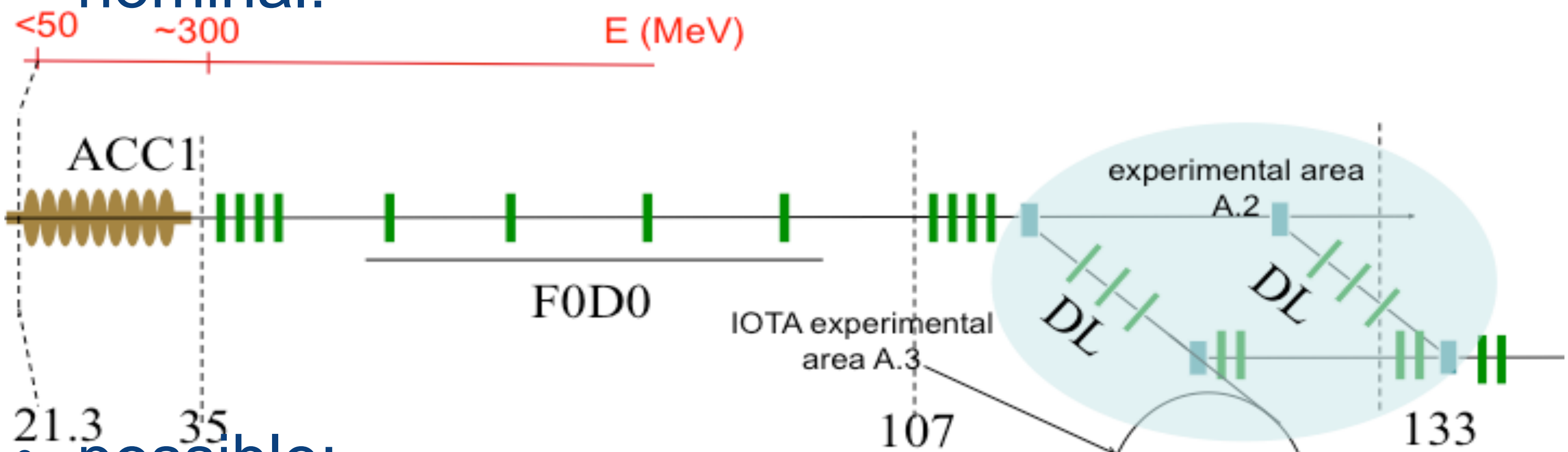
Bunch charge (nC)	3.2	1.0	0.02
Energy (MeV)	36.1	35.6	36.9
$\varepsilon_{n,x}$ (μm)	107.5	50.3	4.36
$\varepsilon_{n,y}$ (μm)	0.41	0.20	0.016
Slice emittance at current peak (μm)	0.54	0.28	0.015
Peak current (kA)	5.5	1.9	0.13
rms bunch length (mm)	0.32	0.19	0.066
Compression ratio	6.5	7.6	11.3
Peak current ratio	36.2	28.0	42.9

[J. Zhu, et al., PRSTAB (2014)]

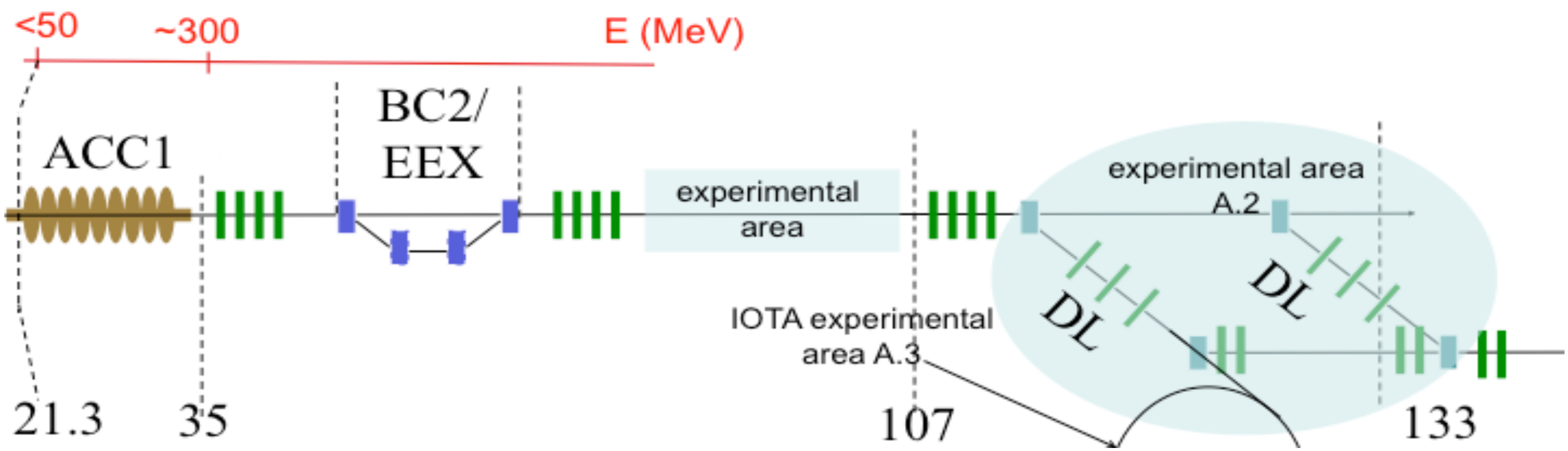


Cryomodule-to-dump transfer line

- nominal:

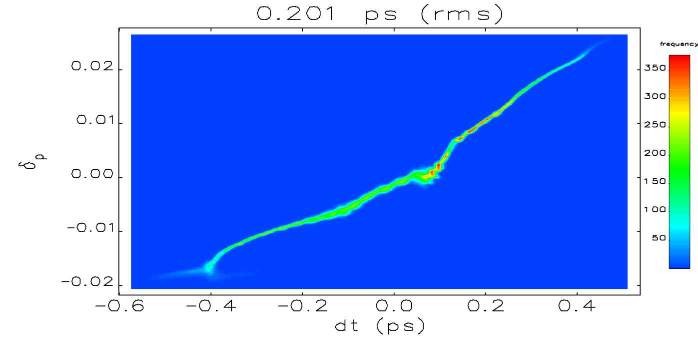


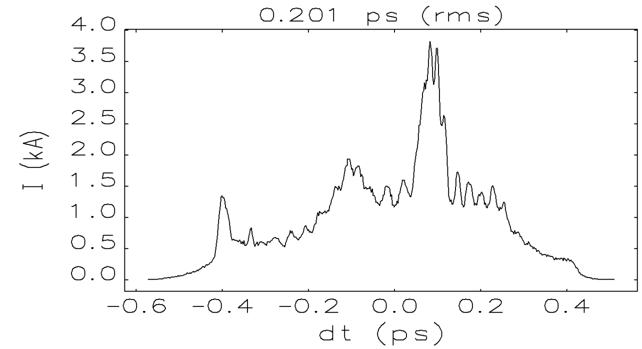
- possible:



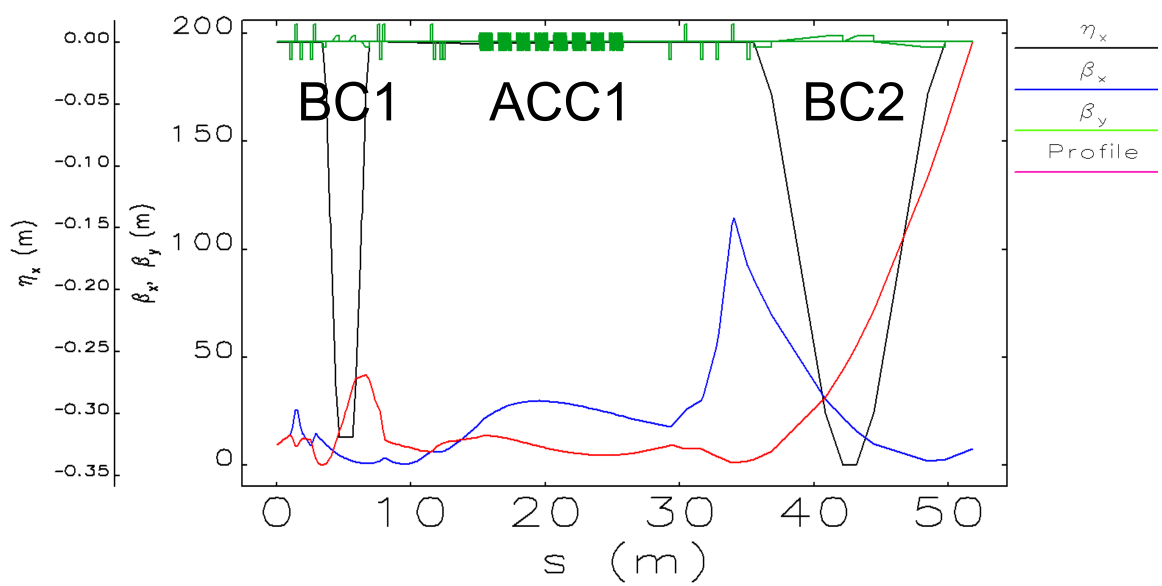
2^{nd} compressor (post ACC1)?

- challenging without a linea-rizer prior to the bunch compressor in injector
- spare parts identified
- Could some experiments benefit from it?





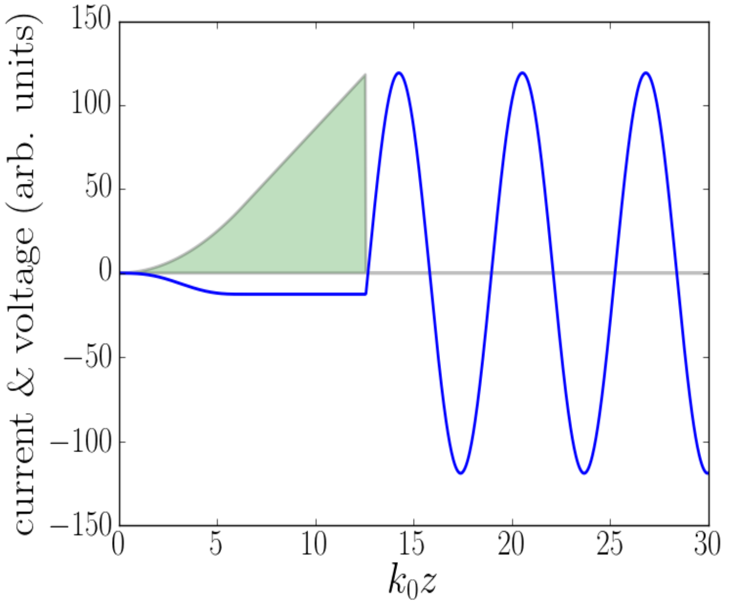
[J. Zhu, et al. summer 2014]



Application of temporal laser shaping

- control of collective effects
  - control of CSR
  - wakefield
- optimal shapes for beam-driven acceleration concepts
  - coarse shaping can lead to shape that support enhanced transformer ratio
  - twin (and more) bunches with variable spacing
    - excitation of single mode in accelerating structures,…
    - coherent-radiation
  - …

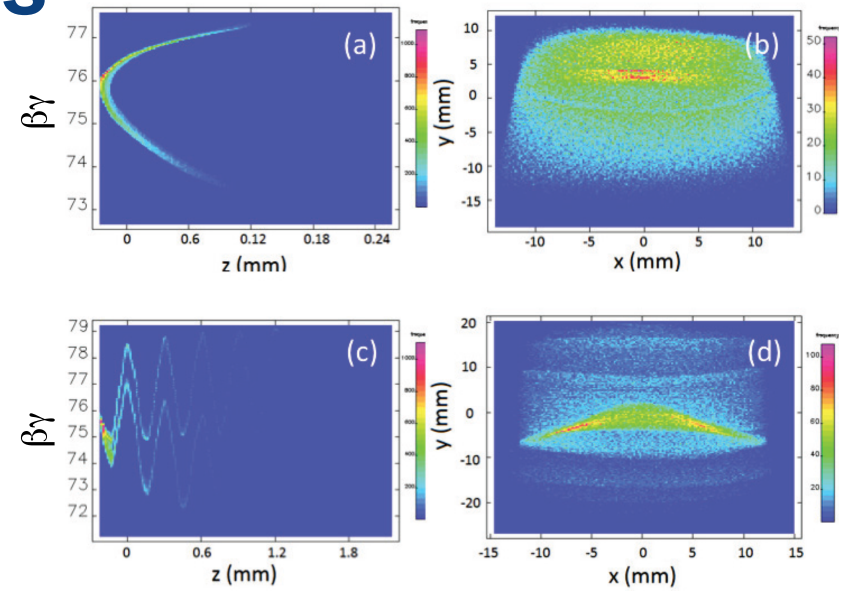
[F. Lemery to be published (2015)]



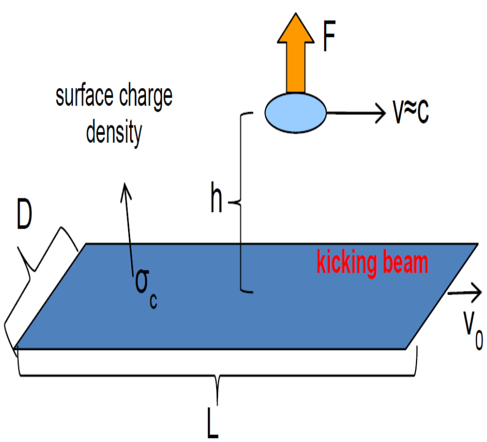
Application of flat beams

- acceleration in asymmetric structures
- test of micro-undulators
- mitigation of CSR in bunch compressors
- beam-beam kickers

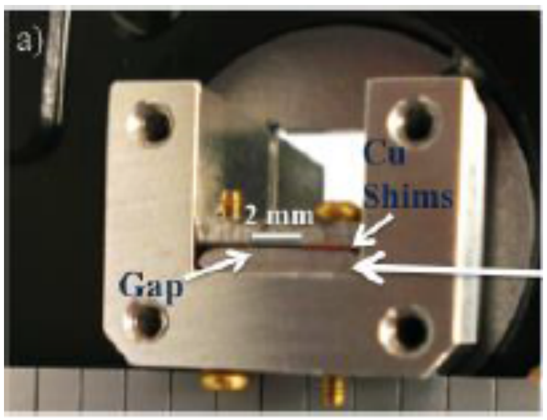
acceleration in a slab DLW



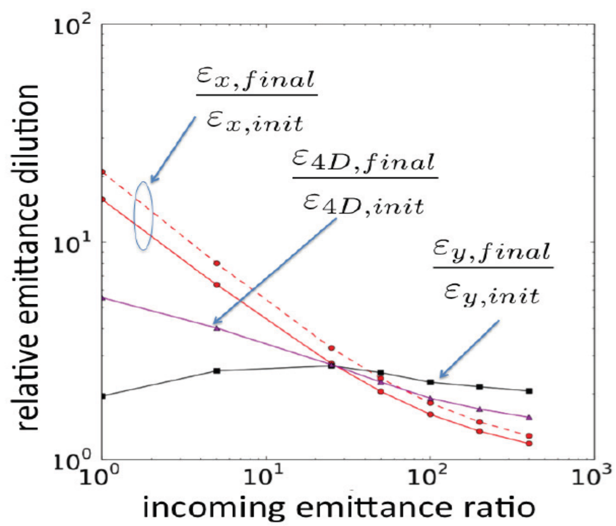
[F. Lemery, et al. in Proc. IPAC14 (2014)]



[adapted from Y. Zhang, et al., Jefferson Lab.]



[adapted from A. Garraud et al., U. Florida]

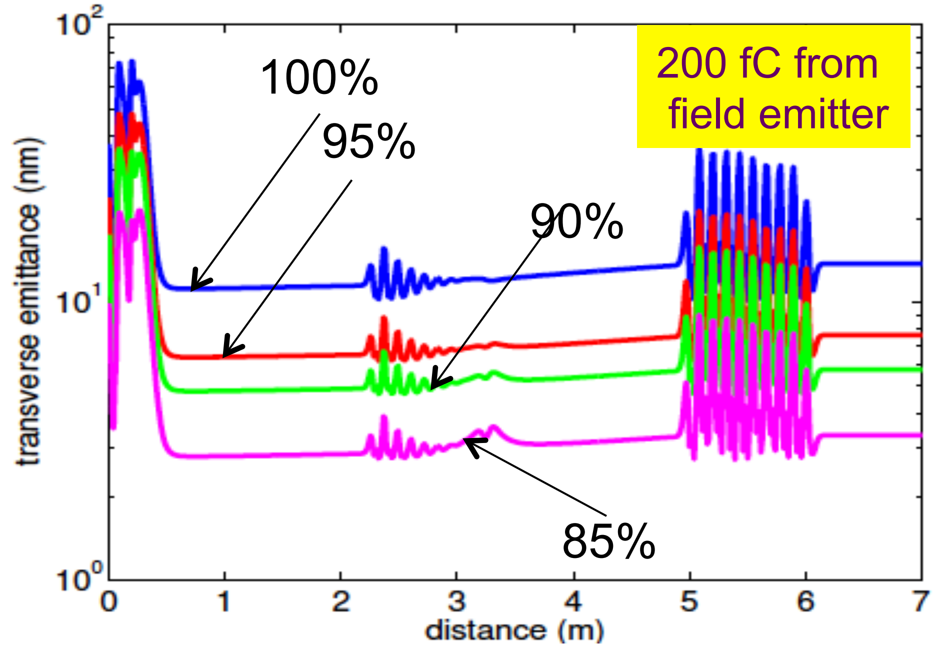


[C. R. Prokop NIMA (2013)]

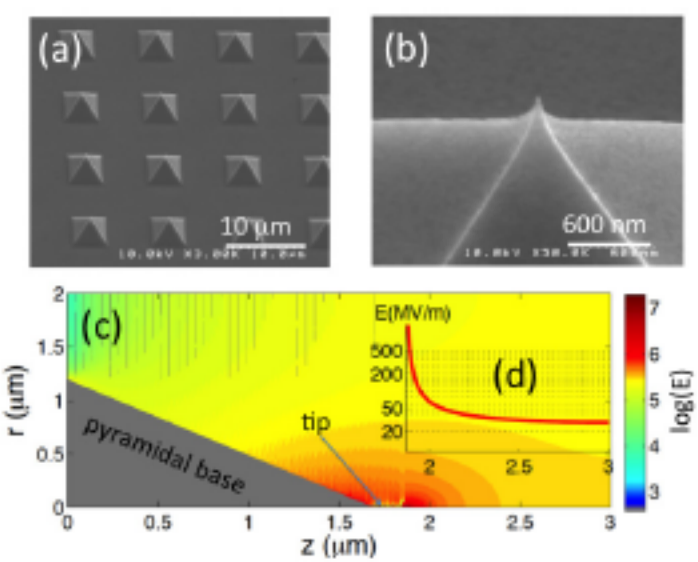
Low-emittance bunches

(See recent experiment
P. Musumecci, PRSTAB 2012)

- small laser spot on photocathode lead to extremely small emit-tances (sub-10-nm)
- Field-emission with gated cathodes could enable the production of low-charge bunches repeated at 1.3 GHz within 1 ms,
- Alternatively laser-triggered emission could produce low (a few electrons) short bunch (IOTA e- wave function measurement?)

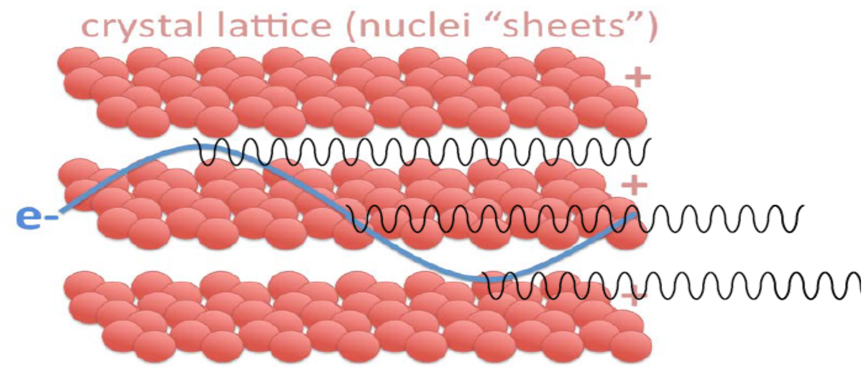


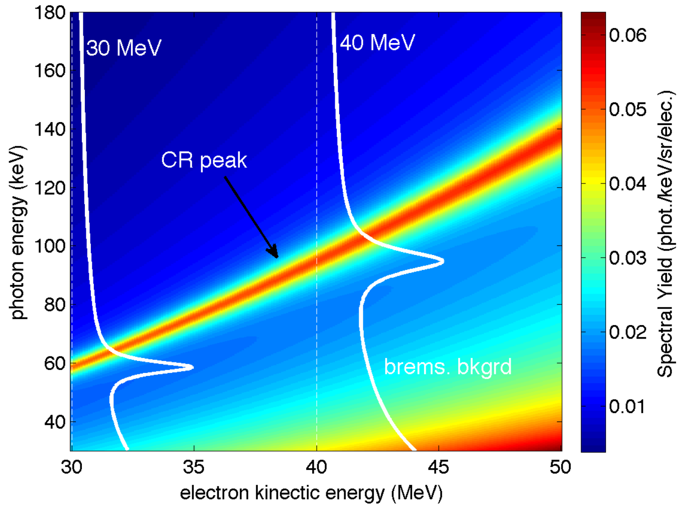
[P. Piot et al., APL 2014]

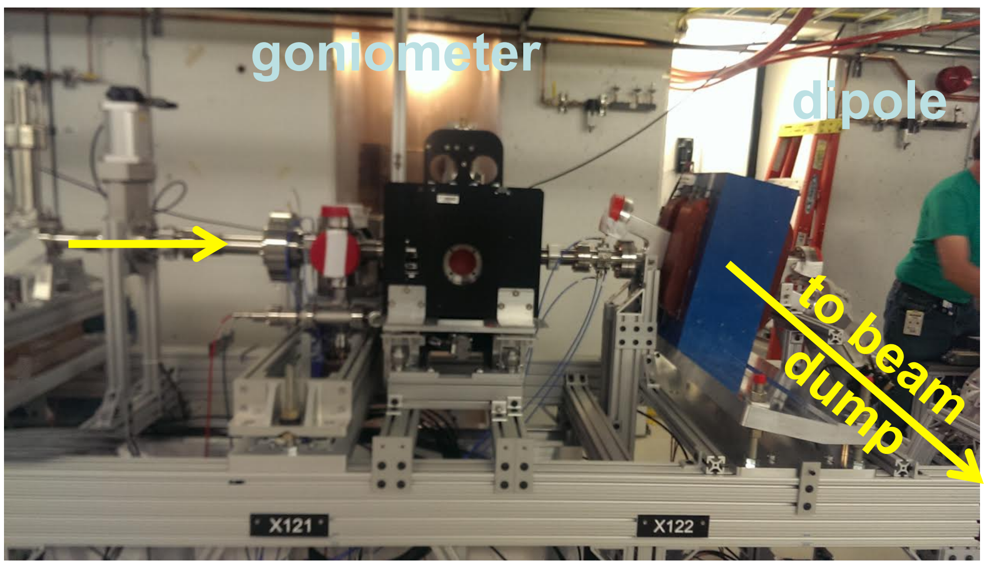


Application of low-emittance beam to X-ray sources (planned)

- channeling radiation
  - low charge beam focused on a ~160 μm diamond Xtal
- novelty:
  - high brilliance (~10^{10}),
  - combined with SCRF







[adapted from C. Brau et al. (2014), B. Blomberg FEL13 (2013)]

Summary

- Over the last two “user” workshops many experiments were discussed:
  - general beam dynamics, beam manipulations,
  - radiation source R&D,
  - advanced acceleration concept R&D
- Since then ASTA injector set to ~300 MeV

high-impact acivities - main thrusts	ASTA Stage:	I.1	I.2	I.3	II	III	IV									
		50 MeV	CM1 300 MeV	IOTA electrons	CM1-3 800 MeV	IOTA protons/H-	3.9 GHz Linearizer	Intensity Frontier	Energy Frontier	Future SCRF Accelerators	Novel Radiation Sources	Stewardship & Technology	benefits from 3 MHz microbunches	benefits from long pulses	High Energy Physics	Stewardship and Applications
*	Demonstration of High Power High Gradient SRF Cryomodules with Intense Beams	√	√		√			√	√	√		√		√		
*	Experimental Demonstration of Integrable Optics Lattices at IOTA	√	√	√				√				√				
*	Space Charge Compensation in High Intensity Circular Accelerators					√		√								
	Multi-Pickup Beam Profile Monitor for IOTA					√		√								
*	Optical Stochastic Cooling Experiment	√	√	√					√							
	Echo and Conservative Relaxation Studies with IOTA	√	√	√		√		√	√							
	Investigation of Acceleration & Cooling of Carbon-Based Crystal Structures for Muon Accelerators	√	√						√							
	Electron Wave Function Size Measurements in IOTA Ring	√	√	√				√								
	LBNE Targetry Experiements at ASTA		√			√		√								
	A Tagged Photon Beam at ASTA for Detector R&D	√	√					√			√					
*	Flat-Beam-Driven Dielectric-Wakefield Acceleration in Slab Structures	√	√				√		√			√		√		
	Artificial Intelligence-based LLLRF Control	√	√		√			√	√	√		√	√			
*	Long-Range Wakefield Measurements		√		√			√	√	√		√	√			
	A Magnetron Transmitter Test at the ASTA SRF Linac		√					√	√	√		√	√			
	Electron Beam Shaping and High Gradient Transformer Ratio Acceleration in a Dielectric Tube	√	√		√				√			√	√			
	Measuring Coherent Synchrotron Radiation (CRS) Effects in High Brightness Electron Beams	√							√		√	√				
*	Inverse Compton Scattering Gamma-Ray Source at ASTA and Its Applications	√	√		√			√			√		√	√		
	Coherent Diffraction Radiation Measurements of Bunch Length	√	√		√				√			√	√			
	Experiemntal Studies of CW Mode Operation of Pulsed SCRF Cryomodule		√					√	√	√		√	√	√		
*	Advanced Phase-Space Manipulations	√	√		√		√					√				
*	Ultra-Stable Operation of SRF Linacs with Beam-Based Feedback	√	√		√			√	√	√		√	√	√		
	Beam-Beam Kicker for Electron-Ion Collider	√								√		√	√	√		
*	High-Brightness X-ray Channeling Radiation Source	√					√				√	√	√	√		
	Generation of Parametric X-rays at ASTA	√					√				√	√	√	√		
*	Ultra-Low Emittance Techniques for Future Hard X-Ray Free Electron Lasers	√	√		√		√					√	√			
	Miniaturized Magnetic Undulators for X-Ray Generation	√	√		√							√	√	√		
*	Beam Dechirper for Free Electron Lasers	√	√		√					√		√	√	√		
	Critical Laser-Induced Microbunching Studies w High Micropulse-Repetition Rate Electron Beams	√	√		√		√					√	√			
	Feasibility of an XUV FEL Oscillator		√		√							√	√	√		
	Production of Narrow-Band Gamma-Rays	√	√								√	√				

Open questions for WG3

- Focus should be on deploying capability unique to ASTA in support to high-quality experiments:
  - flat beams can support advanced acceleration (e.g. SBIR proposal by Radiabeam, DOE funding to NIU, …),
  - longitudinal shaping (laser and mask methods). But what applications can they support?
  - BC2 possibility:
    - what are the benefits,
    - If so what would be the necessary auxiliary subsystems required (linearizer + dechirper?),
  - experimental area immediately downstream of BC2?
  - laser systems need?