The Advanced Superconducting Test Accelerator (ASTA)

presented by P. Piot
on the behalf of the ASTA team

http://asta.fnal.gov/

Fermilab U.S. DEPARTMENT OF ENERGY | Office of Science

supported by DOE contract DE-AC02-07CH11359 to the Fermi Research Alliance LLC

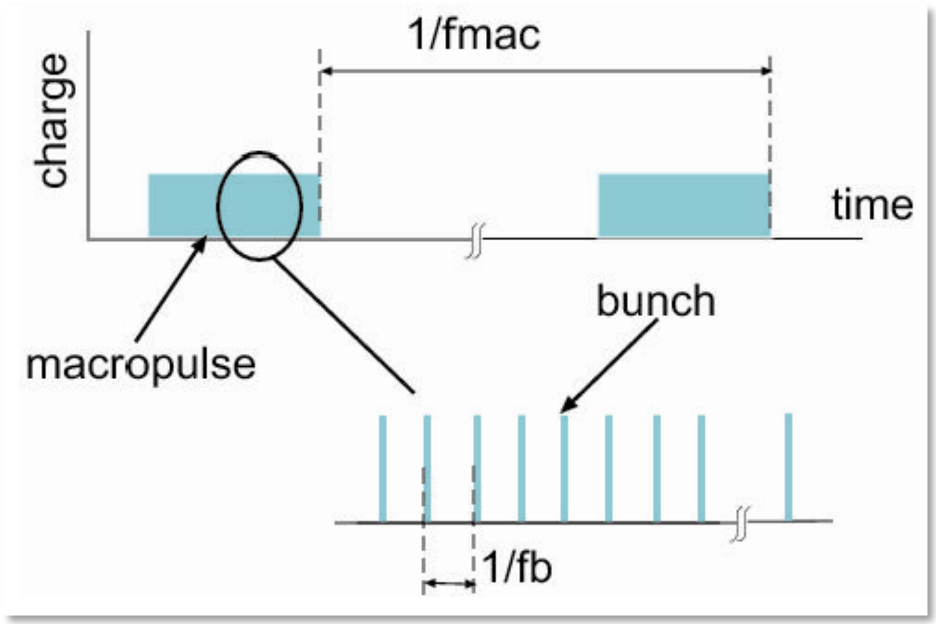
Background & history

- Construction of ASTA initiated in 2006 as part of ILC and SCRF R&D program later funded by ARRA program,
- Initial motivation: test of a complete ILC RF unit,
- It was recognized the facility could provide a valuable resource to the Advanced Accelerator R&D comunity,
- A proposal for an accelerator R&D user facility at ASTA has been submitted to DOE.

Introduction

- High-repetition rate: 1-ms rf macropulse, 3 MHz bunch rep rate (possibly up to 81.25 MHz),
- High-energy beam (eventually up to 800 MeV)
- Superconducting techno-logy combined with a high-quality electron beam,
- Extremely stable beams.

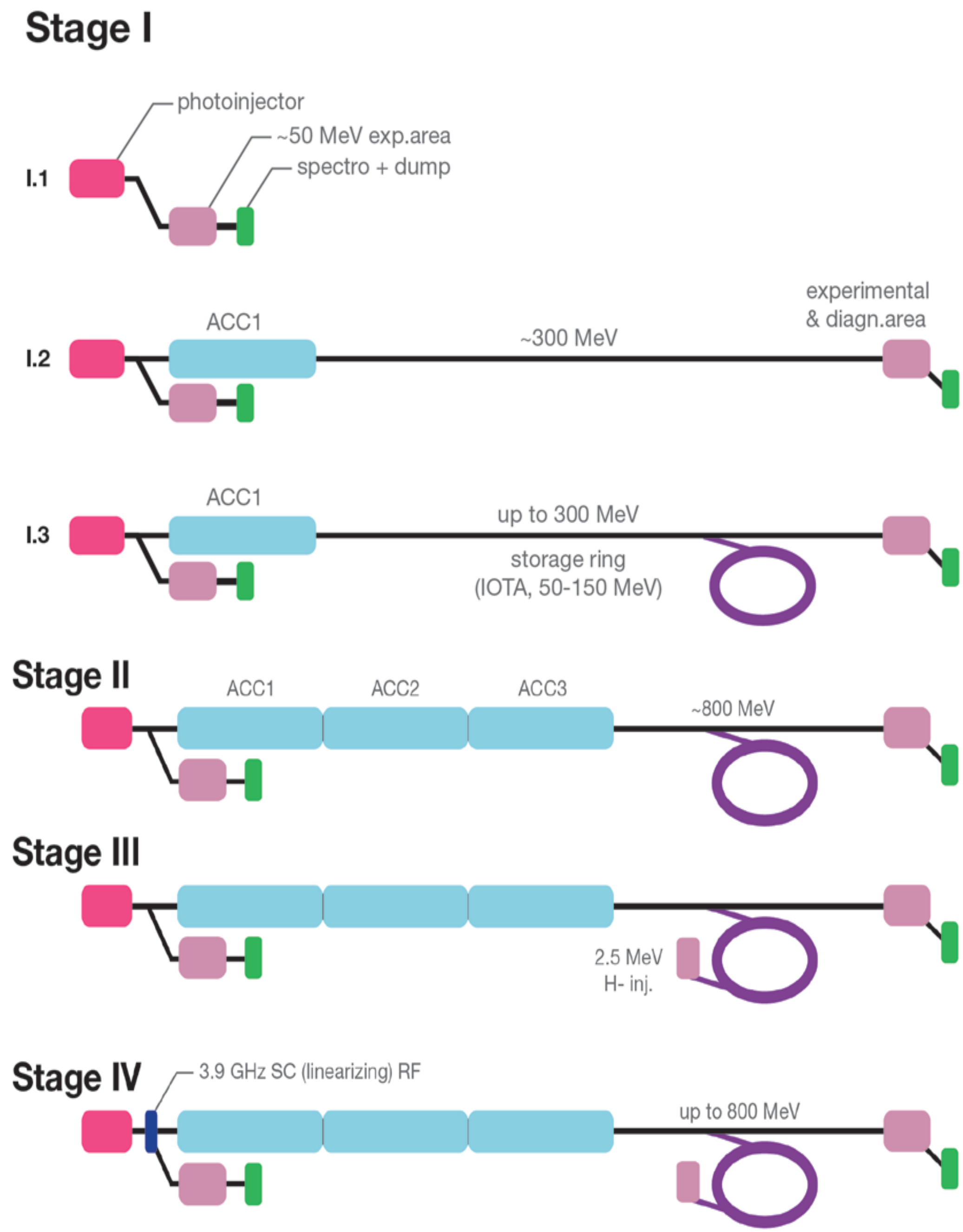
See WEPAC29 (Ristori)



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]	–

Overview

- Photoinjector electron source:
  - low emittances,
  - compressed bunches,
- Advanced phase space manipulations:
  - flat beams,
  - repartitioning of emittances,
  - Tailored current profiles,
- Compact storage ring
  - optical stochastic cooling,
  - integrable optics tests,
- **Accelerator construction is staged**

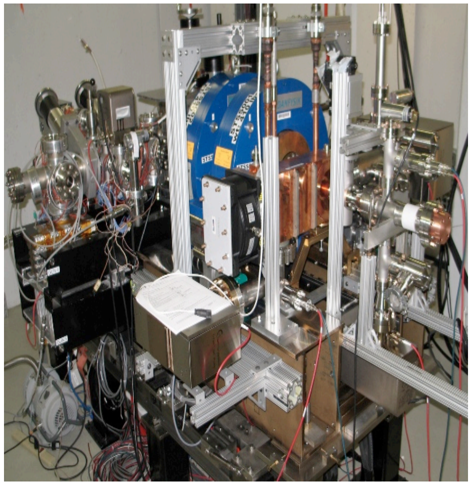


ASTA proposal

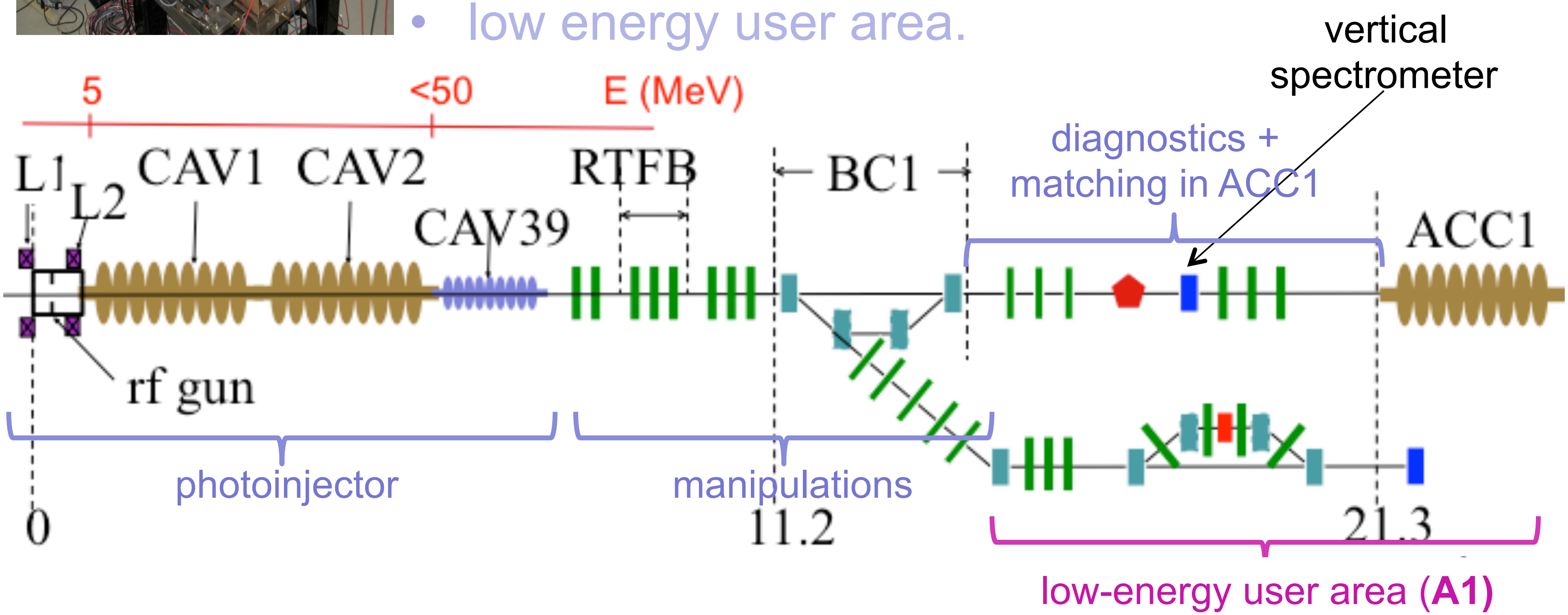
- ~100 coauthors from 18 institutions,
- proposed experiment includes:
  - advanced accelerator R&D,
  - SCRF R&D,
  - light source developments,
  - HEP detector R&D,…
- broad spectrum of proponents:
  - University groups,
  - SBIR companies,
  - National laboratories.
- Proposals for the 3 user areas:
  - A1: 50-MeV/photoinjector,
  - A2: 250-800 MeV,
  - A3: IOTA

See MOPAC15 (Shiltsev)

ASTA Photoinjector overview



- Cs_2Te cathode + Yb-fiber/Nd:YLF laser,
- two SCRF booster **ca**vities (CAV1, 2),
- **R**ound-**to**-**fl**at **b**eam **t**ransformer (RFTB),
- **B**unch **c**ompressor (BC1) + diagnostic section,
- later stage: linearizer (CAV39),
- low energy user area.



Photoinjector anticipated performances

- nominal operating charge:

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

- energy $\mathcal{E} \leq 50 \quad \text{MeV}$
- typical expected bunch parameters scaling over the nominal charge range:
  - transverse emittance [μm]:

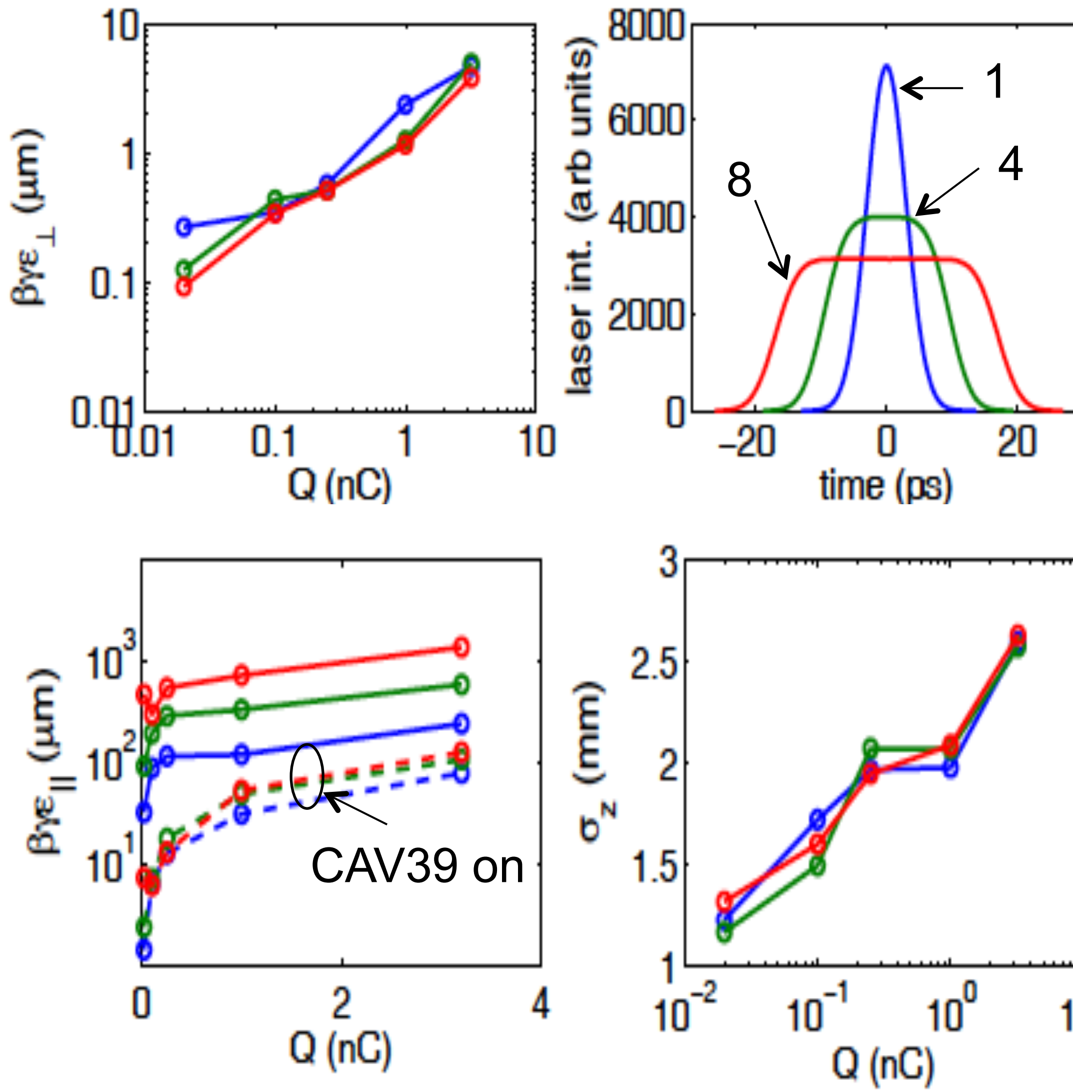
$$\varepsilon_{\perp} \simeq 2.11 Q^{0.69}$$

  - longitudinal emittance [μm]

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

  - uncompressed rms bunch length [mm]

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

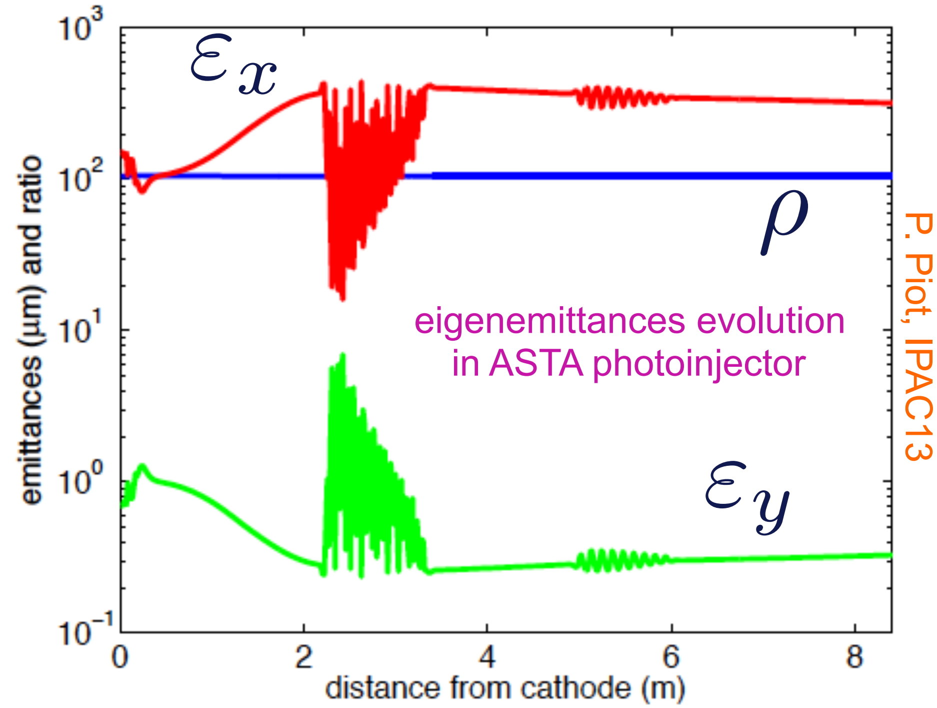


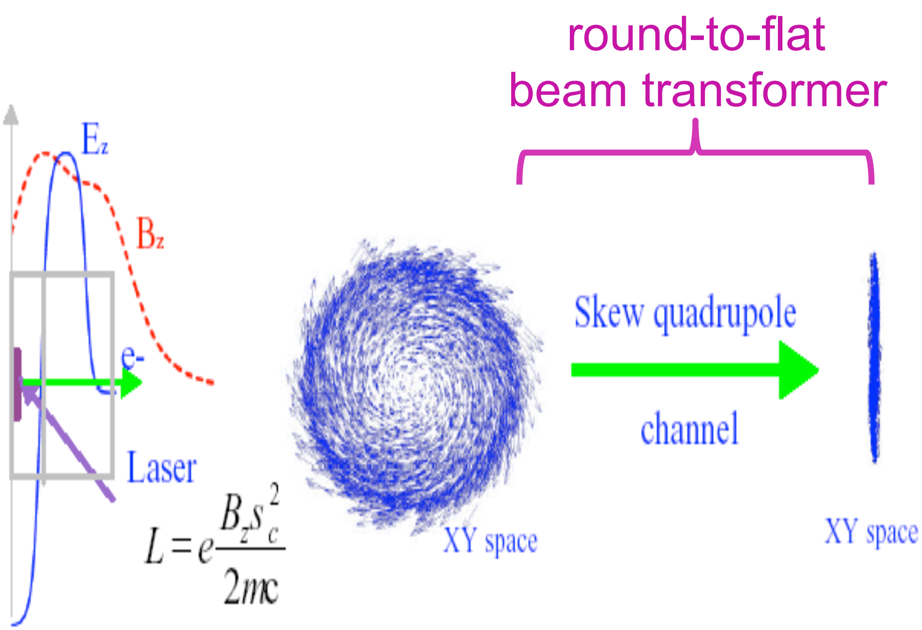
P. Piot, IPAC10

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

Flat-beam generation

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



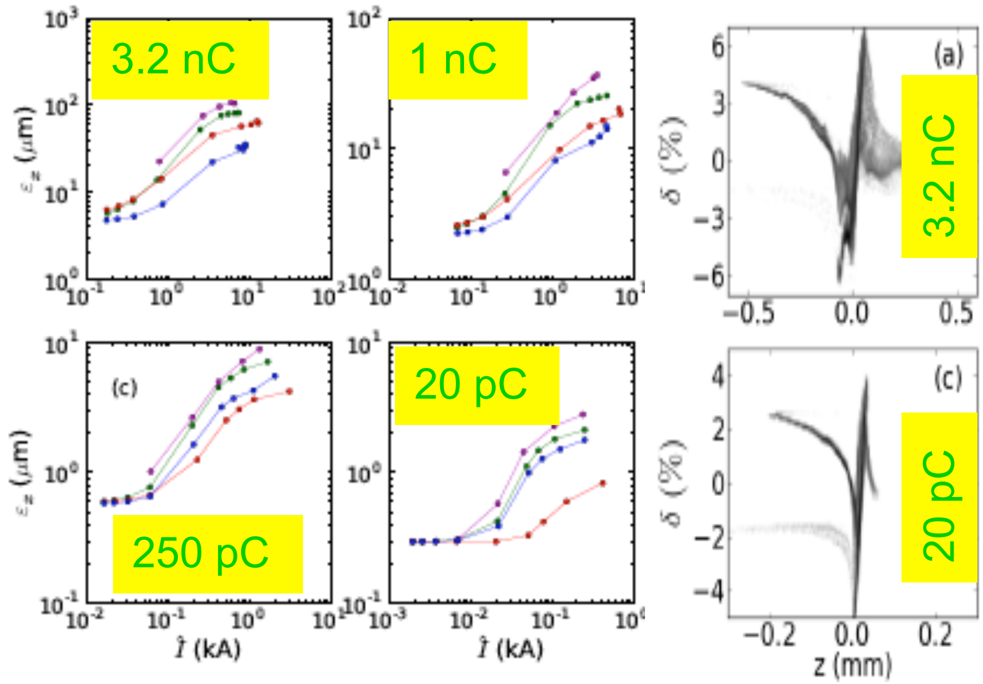


parameter	flat-beam configuration	round-beam configuration	units
Q	3.2	3.2	nC
E	47.18	48.77	MeV
ε_x	105.04	5.43	μm
ε_y	0.31	5.44	μm
ε_{4D}	5.53	5.44	μm
ρ	$\simeq 334$	$\simeq 1$	–

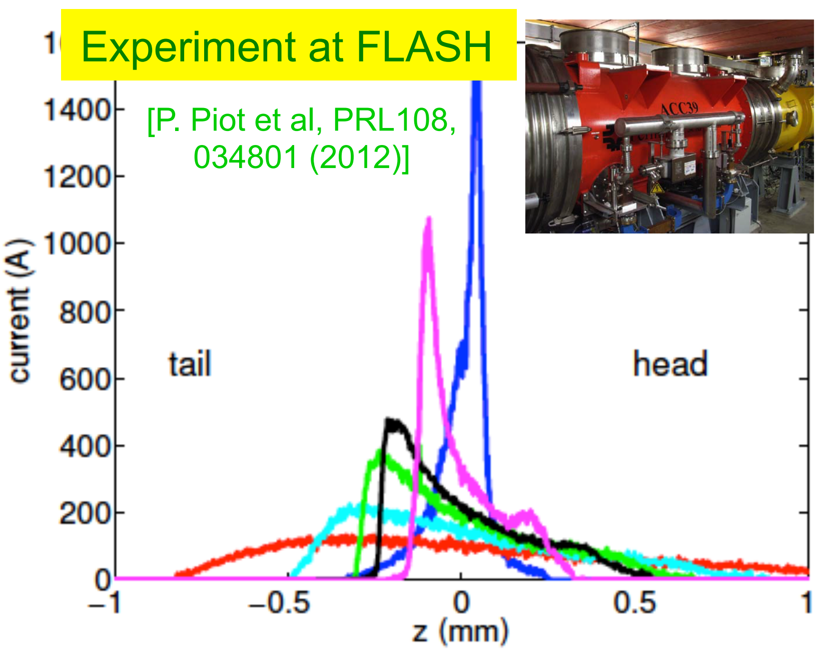
Bunch Compression

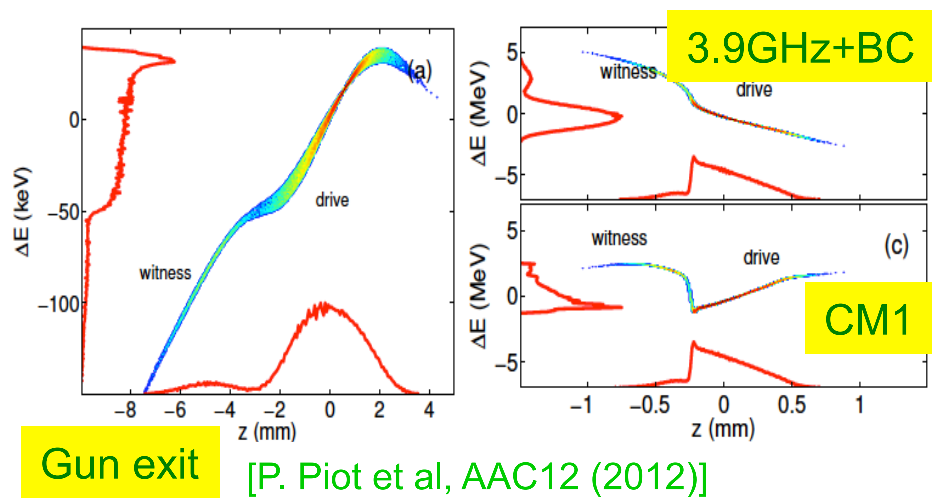
See WEPAC32 (Saini), TUPSM12 (Shin)

- high-peak-current beams,
- drive-witness bunch-generation
- tailored current profiles by controlled nonlinear distortion in the longitudin phase space.



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

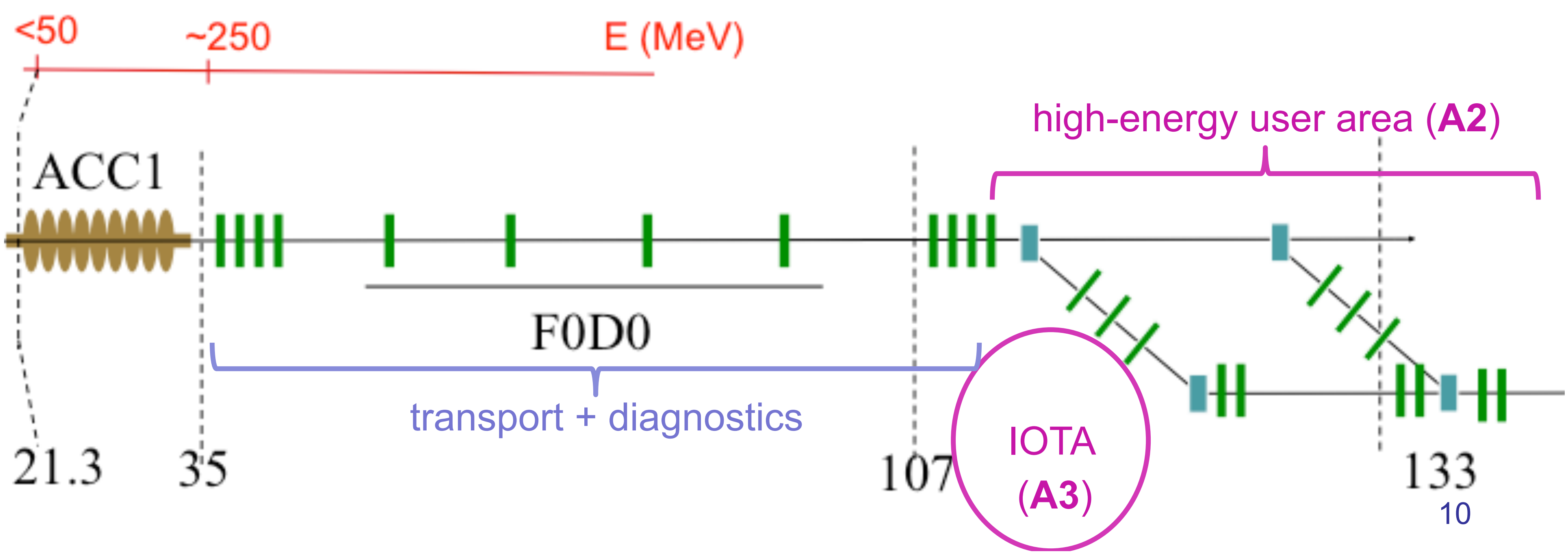




[P. Piot et al, AAC12 (2012)]

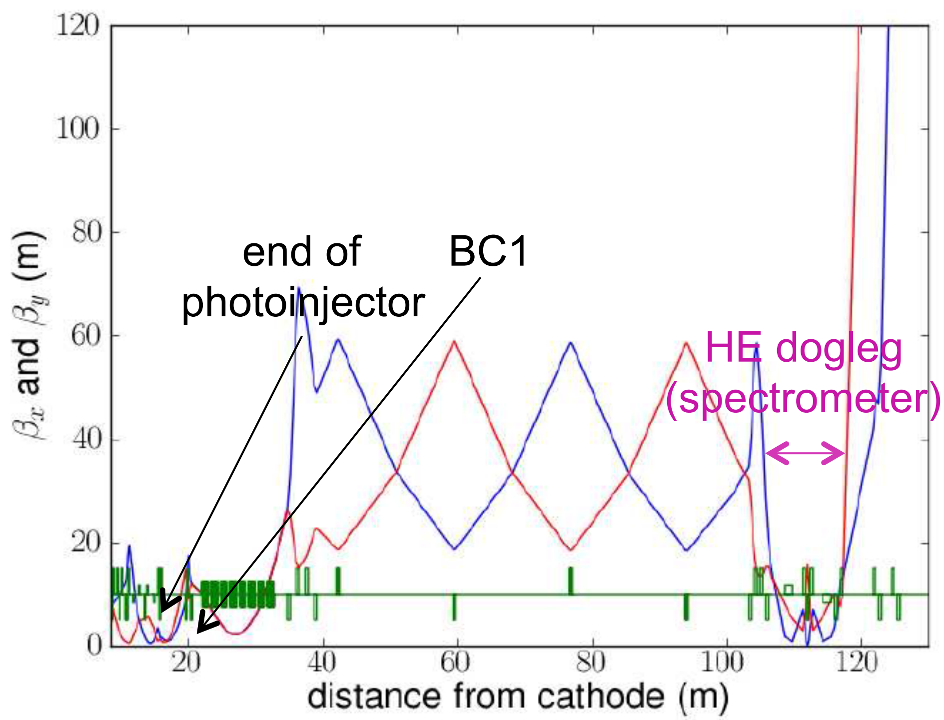
Post acceleration areas (1)

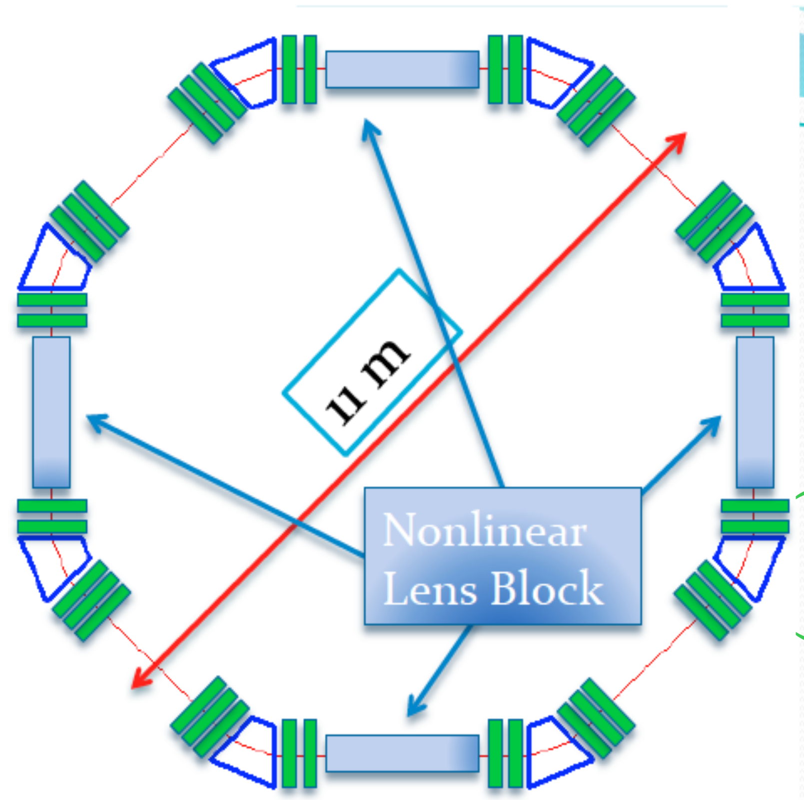
- Acceleration to ~250-300 MeV in one 8-cavity cryomodule
- post cryomodule beamline:
  - transport beam to high-energy user areas + high-power dumps
  - injection in IOTA
- high-energy user area include several parallel beamline
- Further acceleration to ~800 MeV ("stage II")



Post-acceleration areas (2)

- Nominally designed to transport beam to HE dumps,
- Integrable-optics test accelerator (IOTA),
- Possibility to include other experiment(s) in transport line under consideration,
- 2nd bunch compressor being designed.

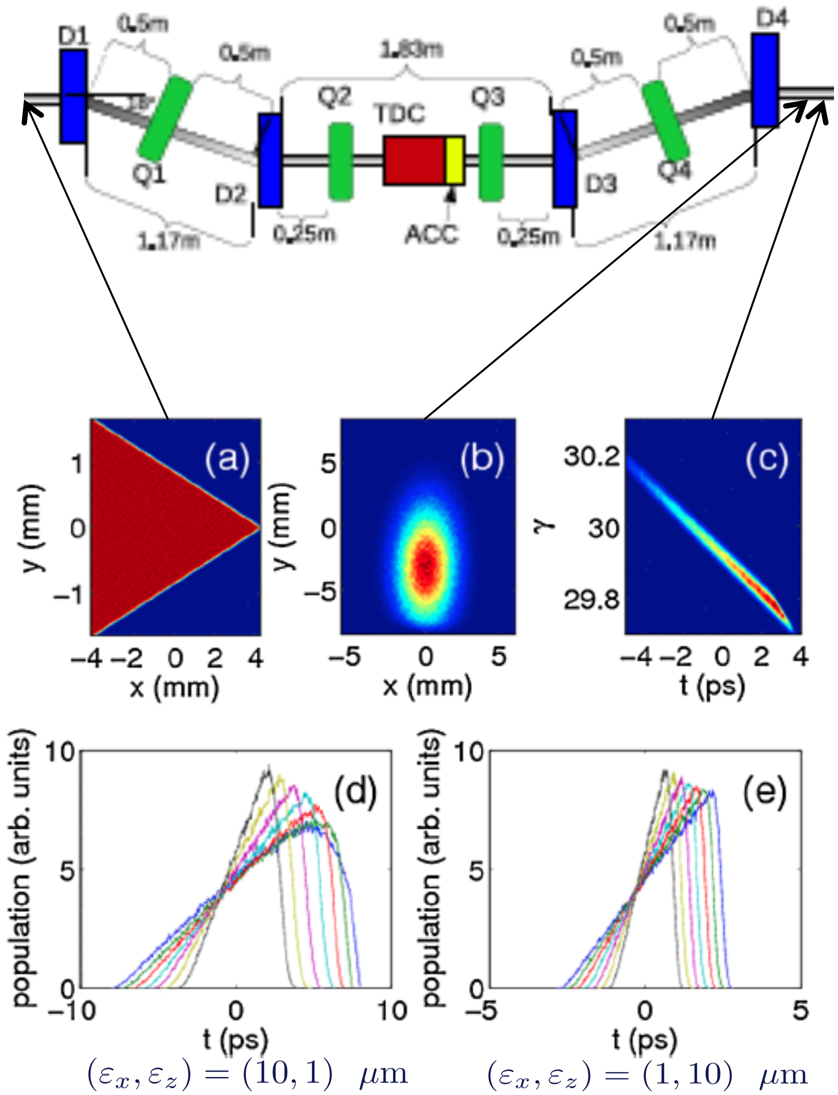


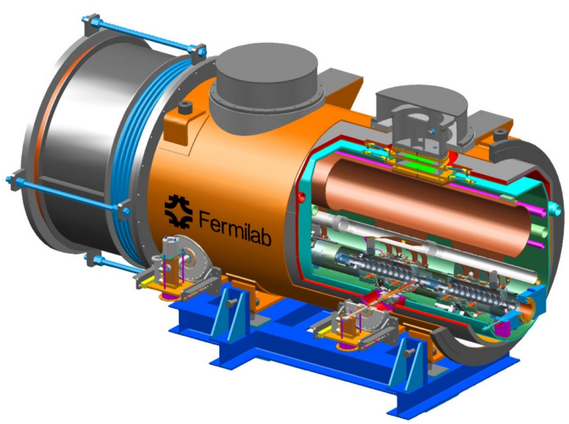


See MOODB2 (Zolkin)

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
- eventually need SC cavities to exploit multi-bunch capabilities



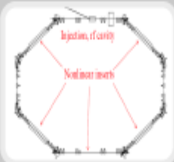


See TUPAC21 (Prokop), TUPMA13 (Simakov), MOPAC24 (Shchegolkov)

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

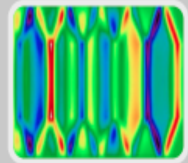
Enabled research thrusts

Intensity Frontier of Particle Physics



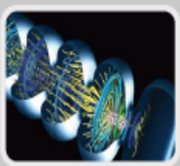
- Nonlinear, integrable optics
- Space-charge compensation

Energy Frontier of Particle Physics



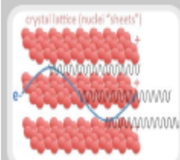
- Optical Stochastic Cooling
- Advanced phase-space manipulation
- Flat beam-driven DWFA in slabs

Superconducting Accelerators for Science



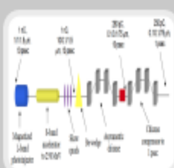
- Beam-based system tests with high-gradient cryomodules
- Long-range wakes
- Ultra-stable operation of SCLs

Novel Radiation Sources



- High-brightness x-ray channeling
- Inverse Compton Gamma Ray source

Stewardship and Applications



- Generation and Manipulation Ultra-Low Emittance Beams for Future Hard X-ray FELs
- XUV FEL Oscillator

First users' meeting (July 23-24, 2013)

Motivations:

- Give an opportunity to prospective users to
  - Present the work they intend to carry using ASTA beam
  - Discuss possible collaborations
  - Tour the facilities

- Organize the 1st program advisory committee meeting.

Meeting statistics:

- 84 participants
- majority (2/3) external users (non Fermilab)
- 36 talks in ~1.5 days

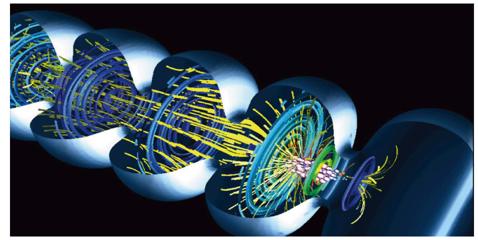
Outcome of 1st user's meeting

- 30 formal proposals,
- equal split between HEP and other applications (NP, radiation sources,…)

high-impact acivities - main thrusts	ASTA Stage:	I.1 50 MeV	I.2 CM1 300 MeV	I.3 IOTA electrons	II CM1-3 800 MeV	III IOTA protons/H-	IV 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 Experiments 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	√	√								√	√				

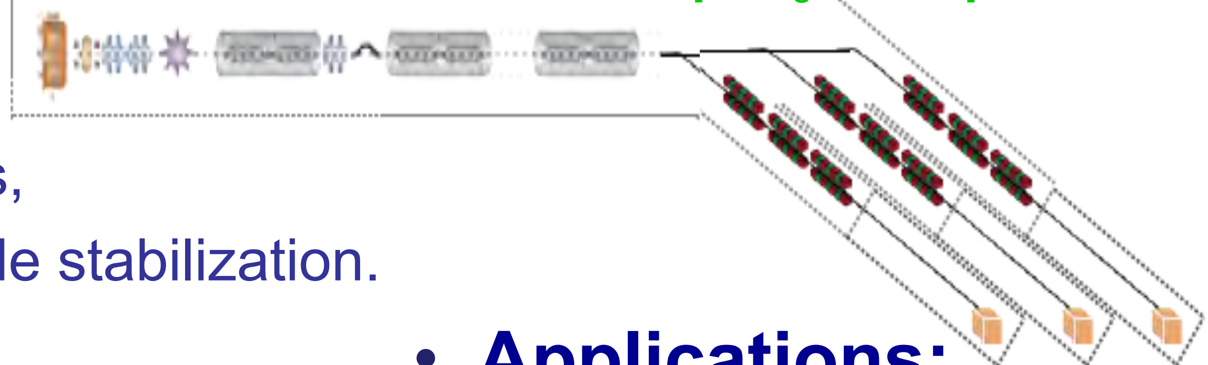
See TUZB1(Corlett), WEOAA1 (Venturini)

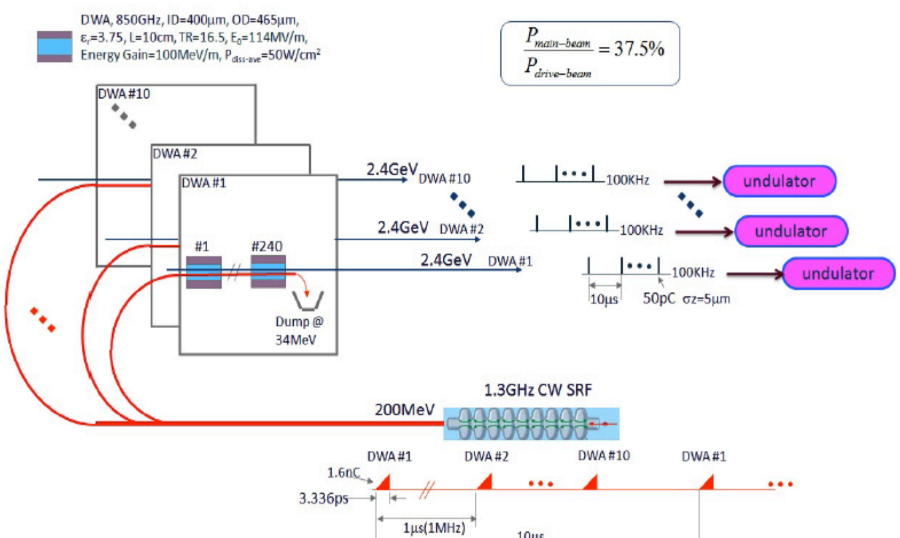
SCRF R&D



- **ASTA SCRF linac is an object of research by itself:**
  - LLRF system,
  - beam dynamics,
  - Phase/Amplitude stabilization.

[CW light source]



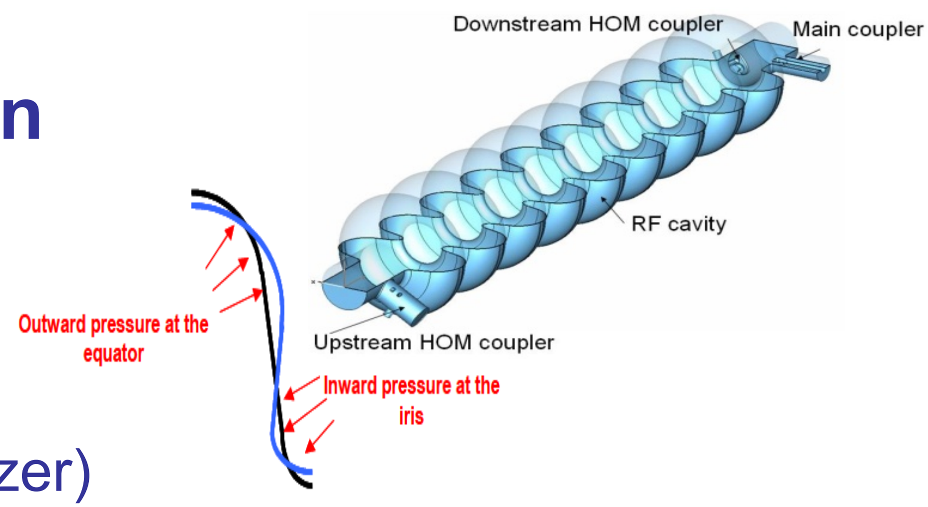


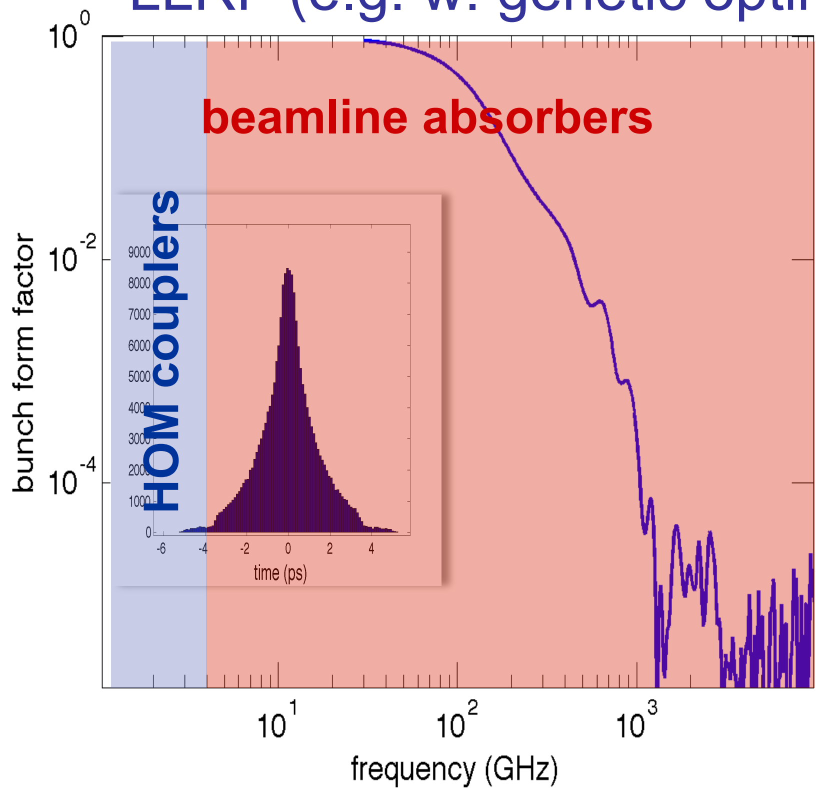
[C. Jing et al., FLS12, ANL/APS/LS223]

- **Applications:**
  - Multi-user FELs,
  - International linear collider,
  - Production of high-power H- beams.
  - some commonalities with ERL or CW-linac-based light sources.

SCRF R&D for high-intensity linacs

- **High-gradient operation**
  - Field emission,
  - microphonics,
  - Lorentz force detuning,
  - LLRF (e.g. w. genetic optimizer)

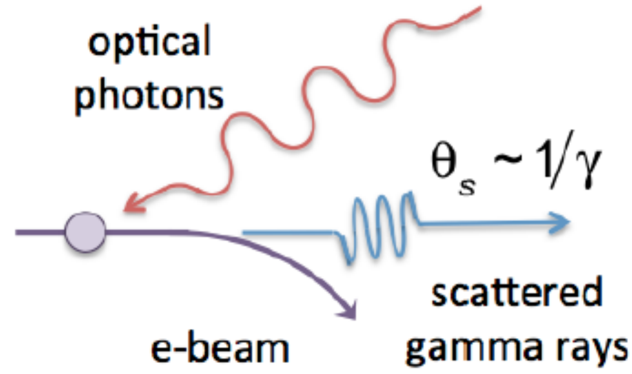


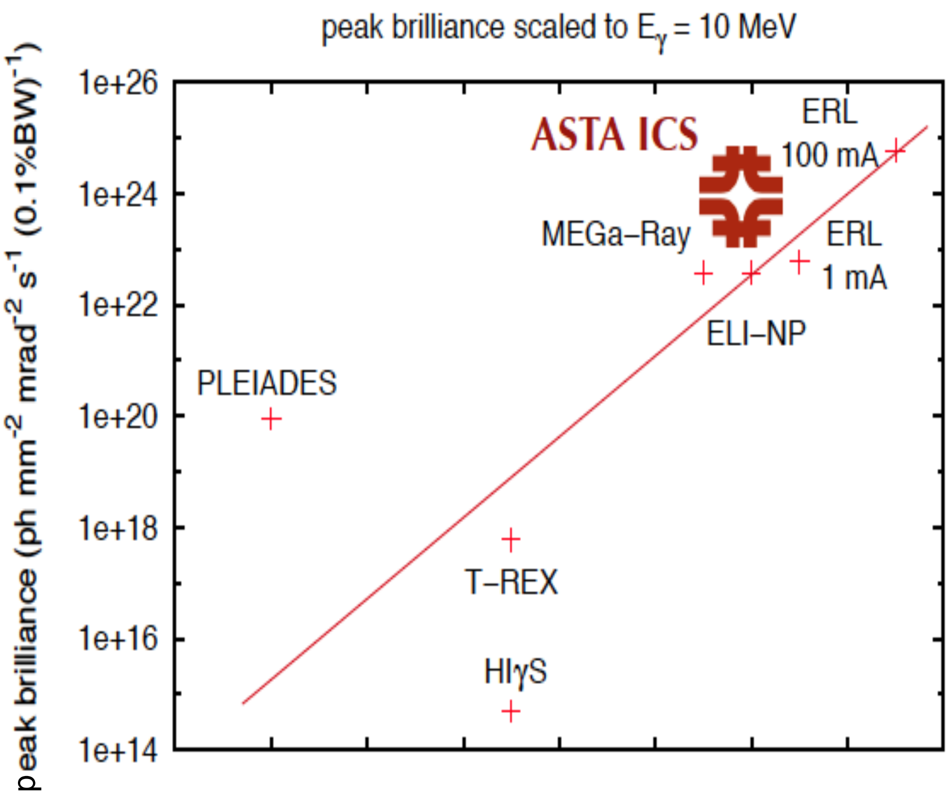


- **High-order modes**
  - spectrum, trapped modes
  - HOM-based BPMs
- **Beam dynamics**
  - Impact of HOM and input RF couplers
  - Multi-bunch effects

γ-ray source based on ICS

- ICS to produce γ ray with unprecedented flux is an appealing concept





[Habs, D.; Köster, U, Applied Physics B **103**, 2011]

[adapted from A. Murhok et al., Radiabeam]

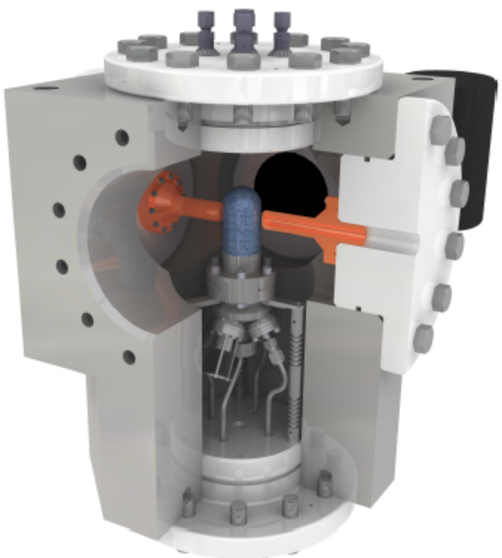
Gamma rays (single shot)	
Total single-shot flux	~ 10^9
Gamma-rays energy	5-20 MeV
Flux in 1 % bandwidth	~ 10^7

Pulse train mode	
Rep. rate	3 MHz
# of bunches in macropulse	~ 10,000
Average flux in 1% BW	~ 10^{12} cps
Average power of gamma flux	~ 1 W

possible only after stage II completion

High-flux γ-ray source: Application to Nuclear Astrophysics

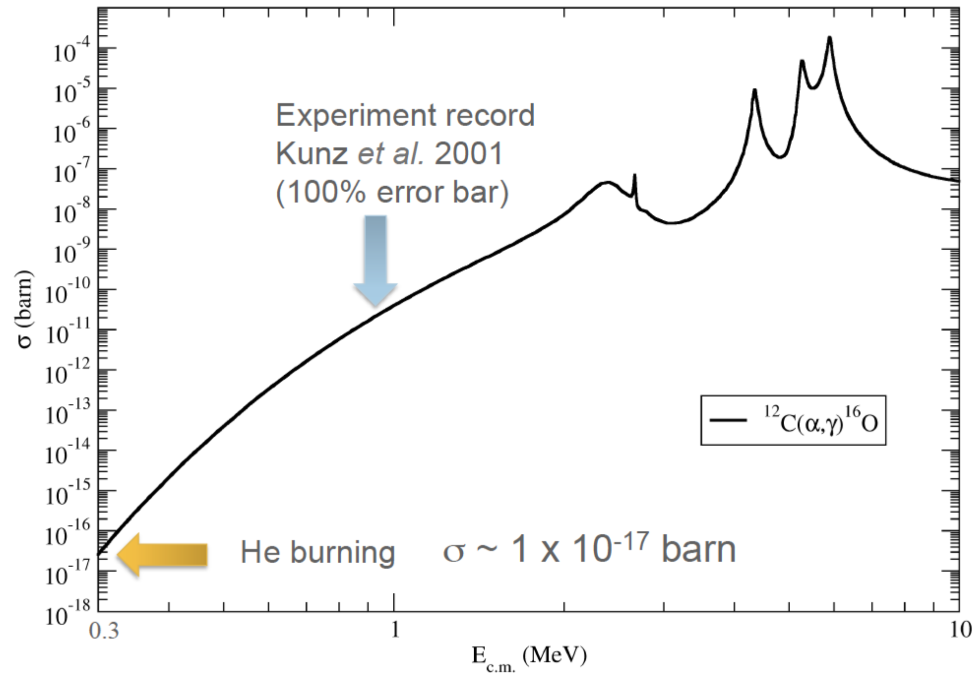
- $^{12}C(\alpha,\gamma)^{16}O$ is a crucial in Nuclear Astrophysics
- low cross section
  ➔ need high-flux γ-ray

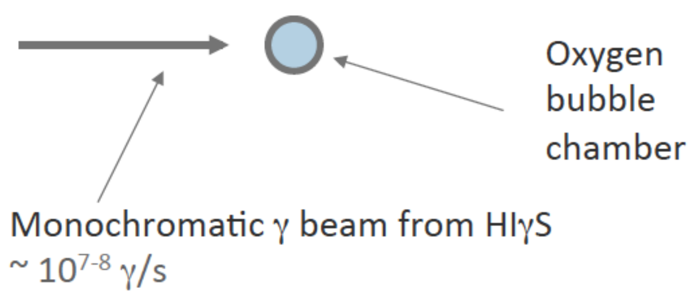


possible only after
stage II completion

[adapted from C. Ugalde et al., U. Chicago & Argonne]

STAR



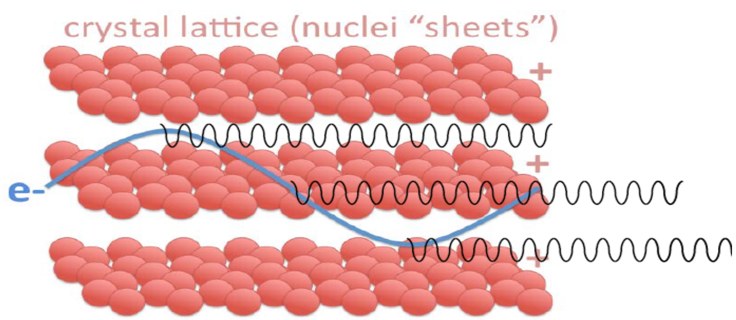


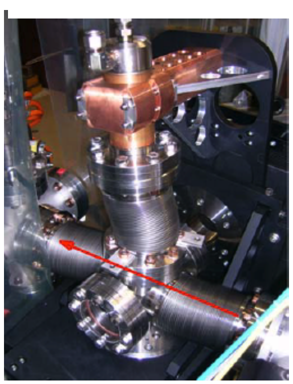
beam | target | signal

$\gamma + {}^{16}O \dashrightarrow {}^{12}C + \alpha$

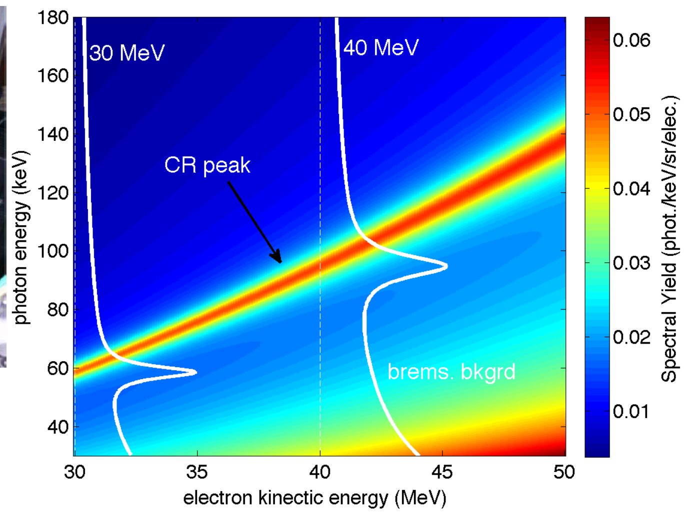
Other light-source concepts at ASTA

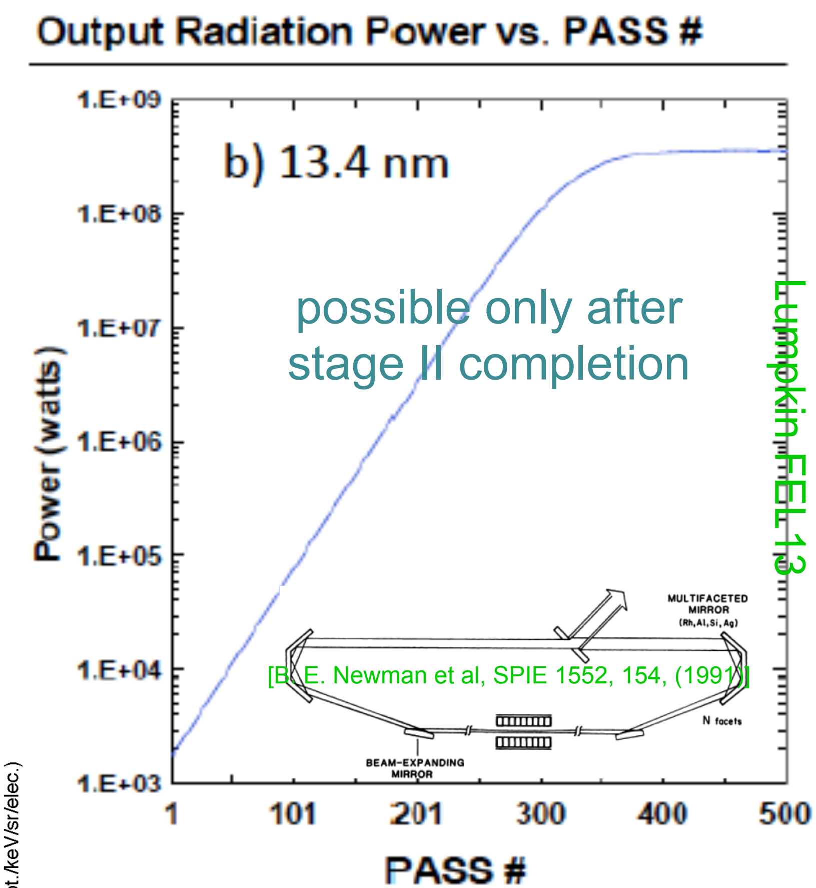
- high-brilliance X-ray from channeling though crystals in photoinjector area





[adapted from C. Brau et al., Vanderbilt U.]





possible only after stage II completion

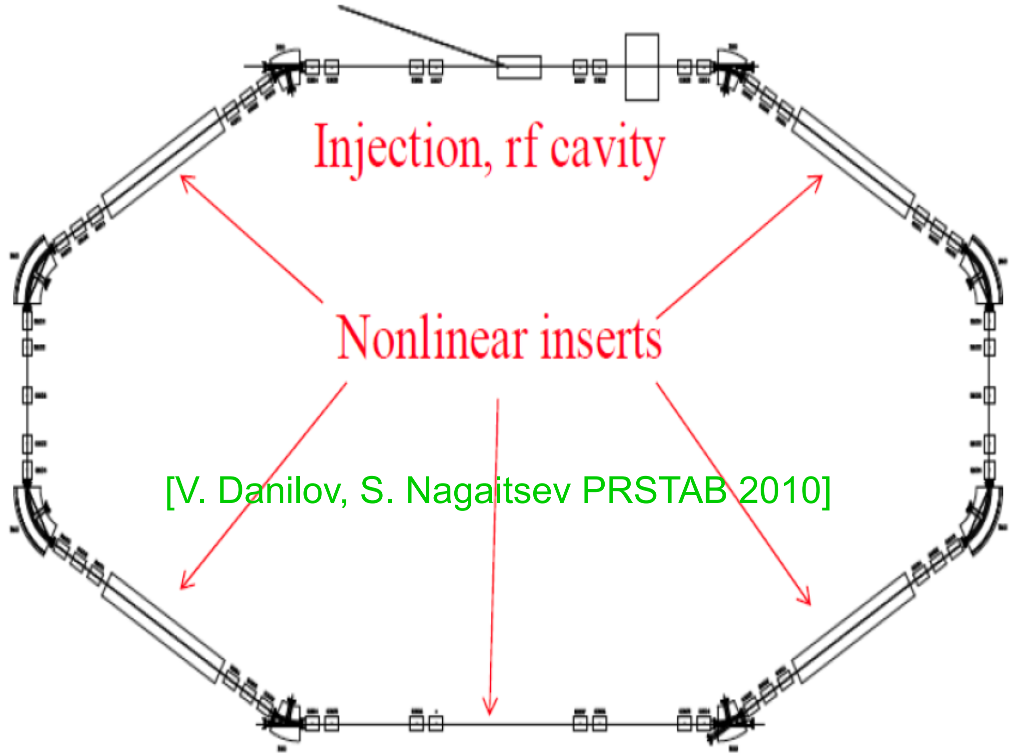
Lumpkin FEL13

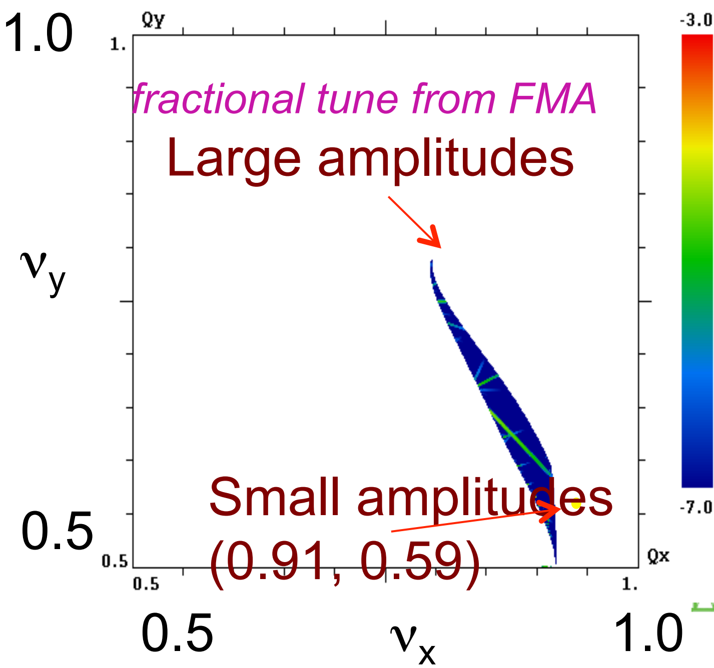
[courtesy of M. Reinsch, LBNL]

- Possible test of a EUV FEL oscillator down-stream of ACC1

Integrable-optics test accelerator (IOTA)

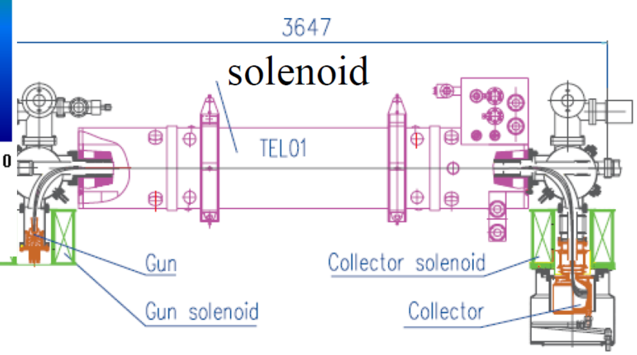
- demonstrate tune spread of 1 with no degradation of dynamic aperture,
- quantify effect of non-ideal nonlinear lens and optimize design.



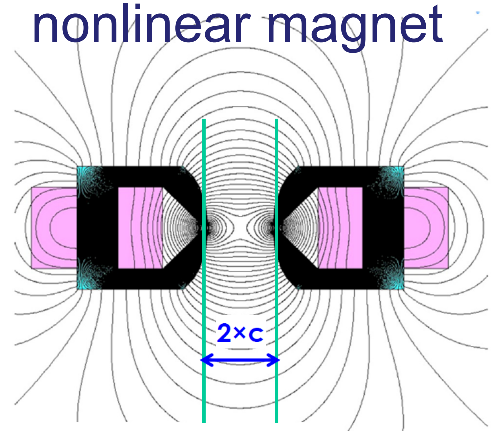


See MOODB2 (Zolkin)

electron (McMillian) lens

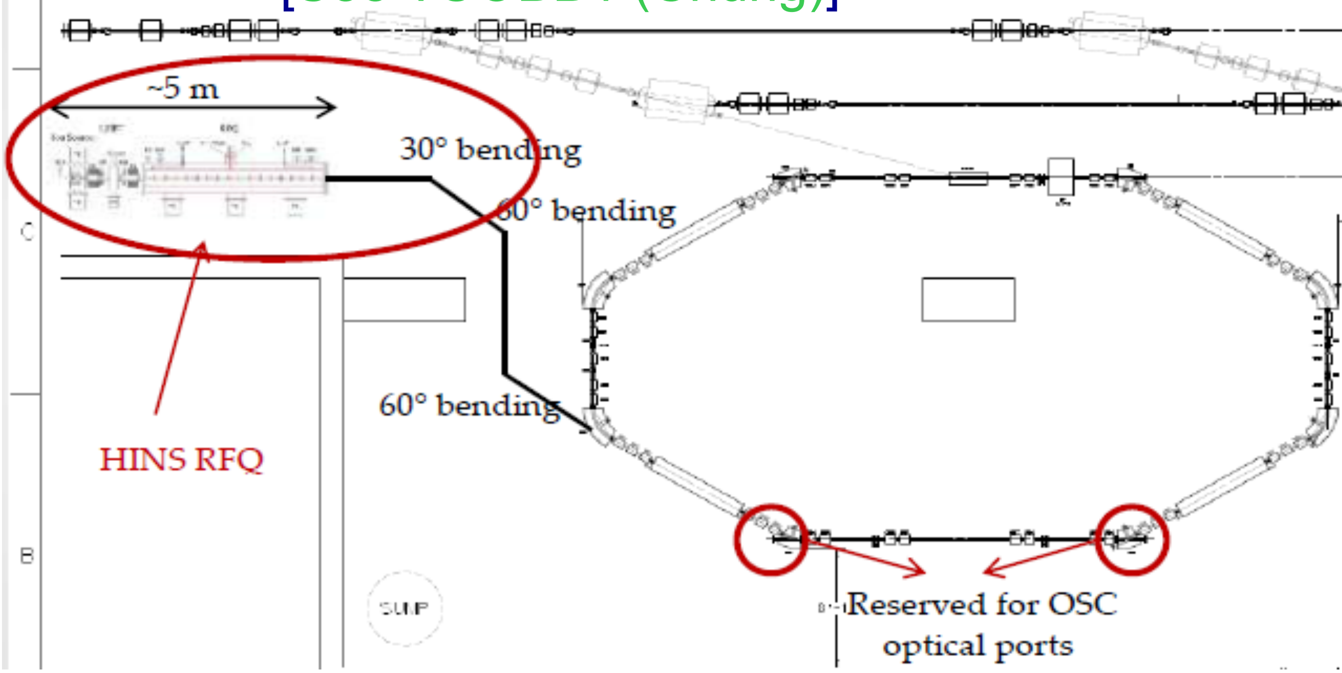


nonlinear magnet

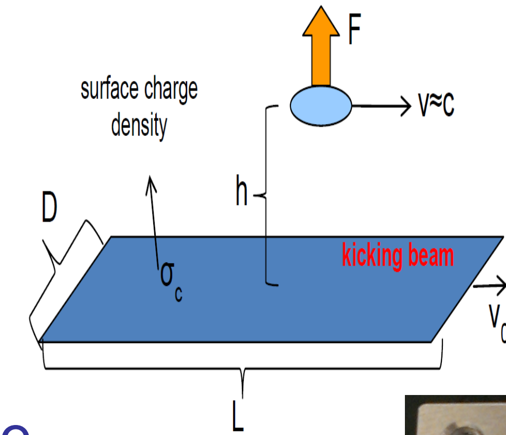


IOTA: other applications

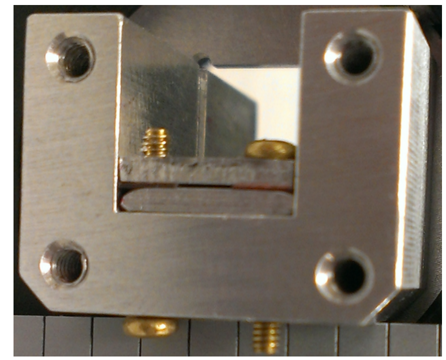
- Optical stochastic cooling [see TUODA2 (Lebedev)],
- Halo suppression [S. Webb, ArXiv:1205/7083]
- Proton source
  - tests of Integrable Optics with protons and realistic space-charge beam dynamics studies
  - Space-charge compensation experiments [See TUOBB1 (Chung)]



Applications of advanced phase space manipulations:

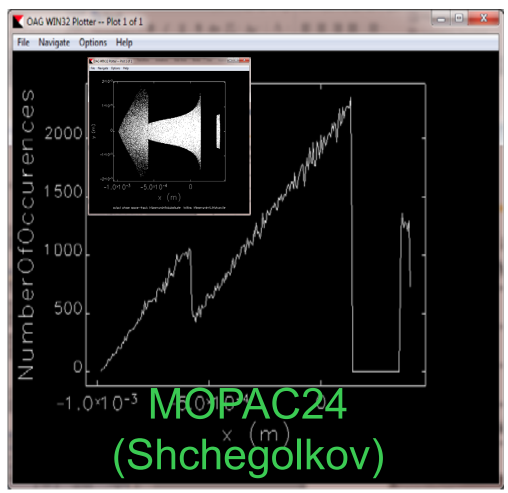


- **flat beams :**
  - beam-driven acceleration in asymmetric structures.
  - micro-undulators, image-charge undulators
  - beam-beam kickers [see TUPHO03 (Zhang)].

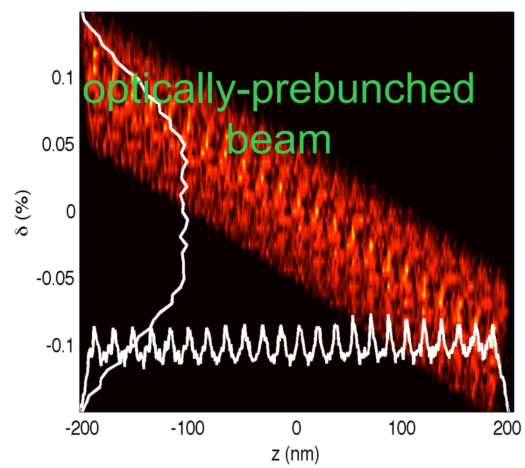


[adapted from A. Garraud et al., U. Florida]

- **transverse-to-longitudinal phase space exchanger:**
  - super-radiant source [W. Graves PRL2012],
  - bunch shaping for beam-driven acceleration technique



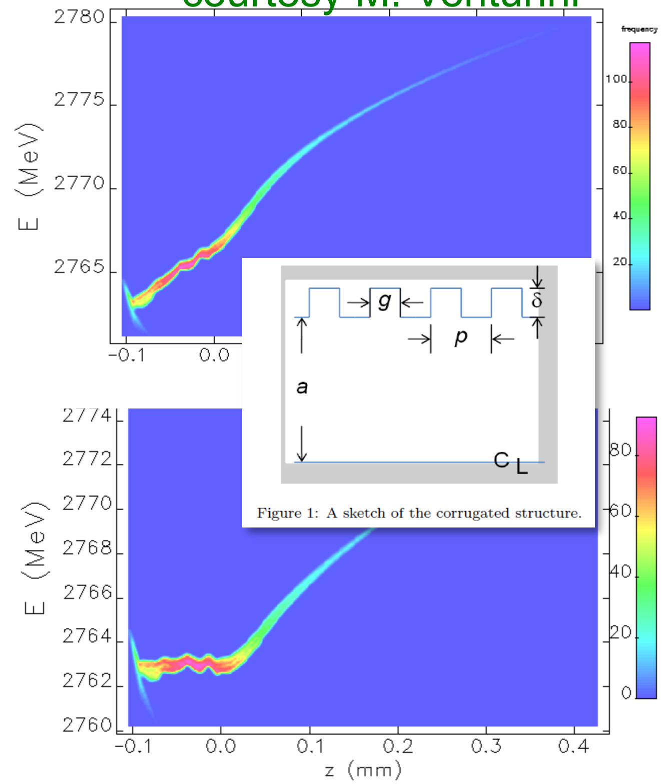
MOPAC24 (Shchegolkov)



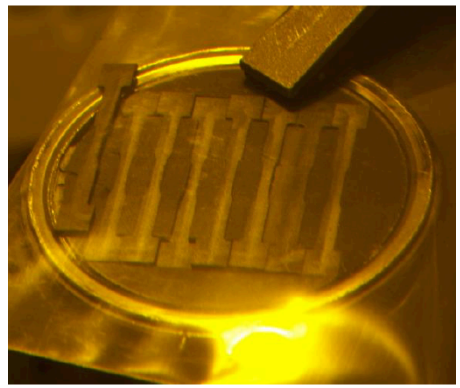
optically-prebunched beam

Glimpse at other proposals

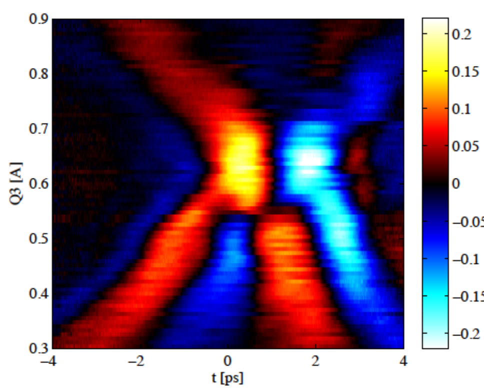
courtesy M. Venturini

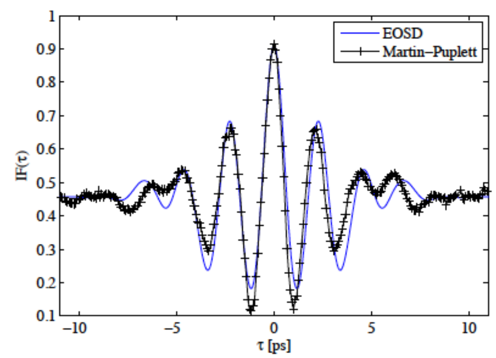


- energy-dechirper using
  - passive structures
    - corrugated, (G. Stupakov NIMA 2012),
    - dielectric (S. Antipov, PRL2012),
  - deflecting cavities [TUOBB3 Yampolsky]



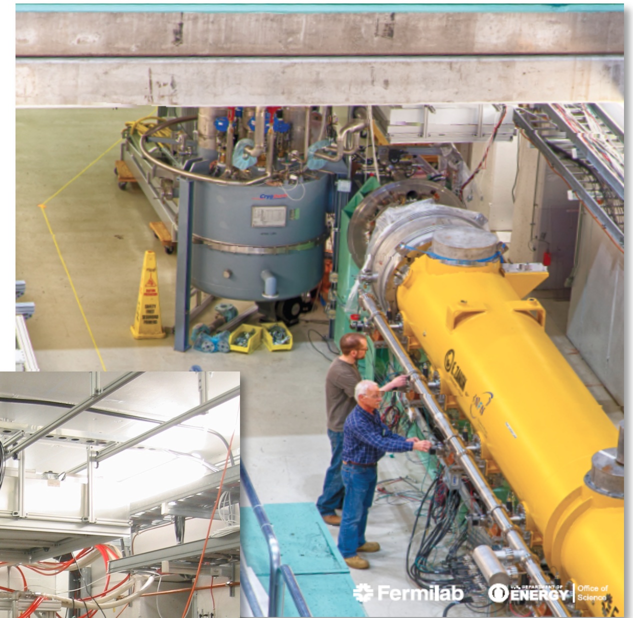
- LBNE Targetry experiments,
- Tagged bremsstrahlung photons for Project-X detector R&D
- Development of non-invasive diagnostics

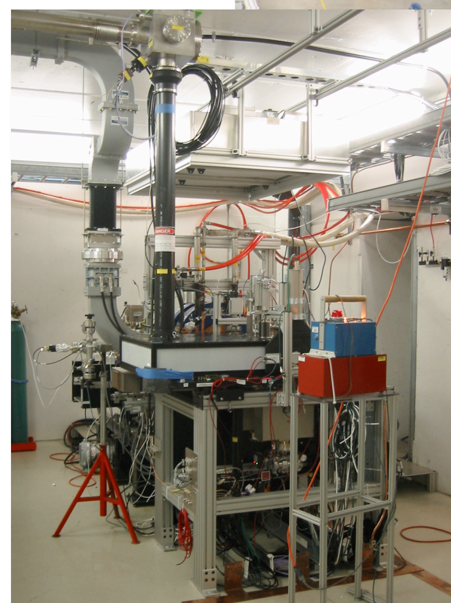


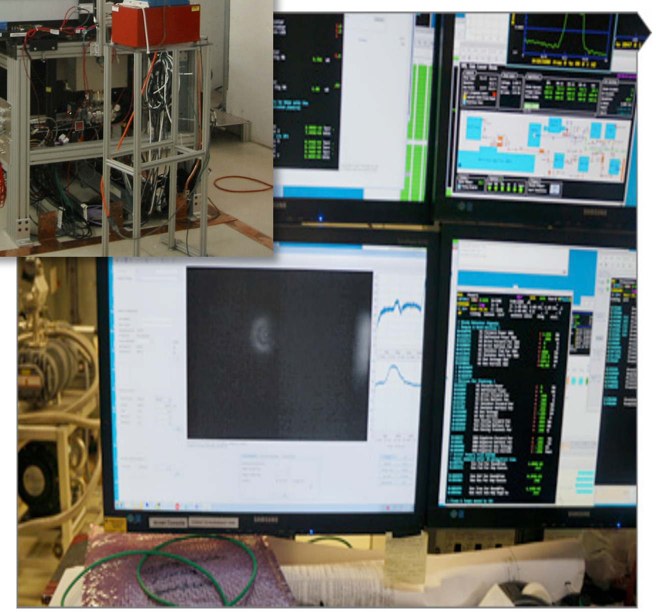


Status

- ASTA beamline is under construction
- Cryomodule ACC1 (“CM2”) was recently installed
- **Photoinjector produced 1st electrons in June 2013**
  - beam generated out of a Mo cathode,
  - operation currently limited (pending safety approval),
- 50-MeV beam expected early CY2014 with 1st-wave experiments,
- beamline from ACC1 to dumps will be assembled during FY14







Concluding remarks

- The ASTA facility will eventually combine:
  - a SCRF linac,
  - a high-brightness electron beam,
  - a small-footprint storage ring (with possible decoupled operation with H- beam)
  - and advanced phase space manipulations.
- This combination will provide unique beam parameters to the Accelerator Science community and beyond.

- 1st users' meeting encouraging strong potential user baseline (incl. Universities, Industry, Laboratories)
- Expressions of interest and collaborative opportunities to use ASTA are welcome; see http://asta.fnal.gov/

Thank you to all contributors to the ASTA proposal

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