The Advanced Superconducting Test Accelerator (ASTA) facility at Fermilab: plans and opportunities

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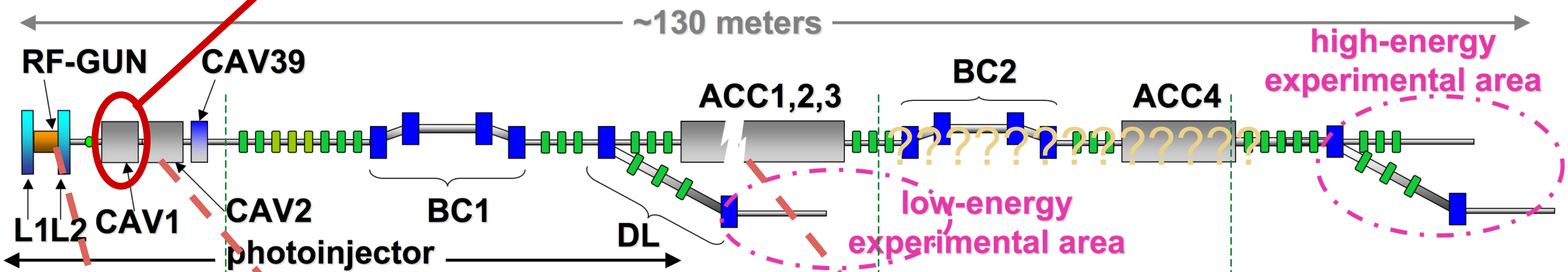
ASTA overview

This cavity is currently at A0



<40 MeV

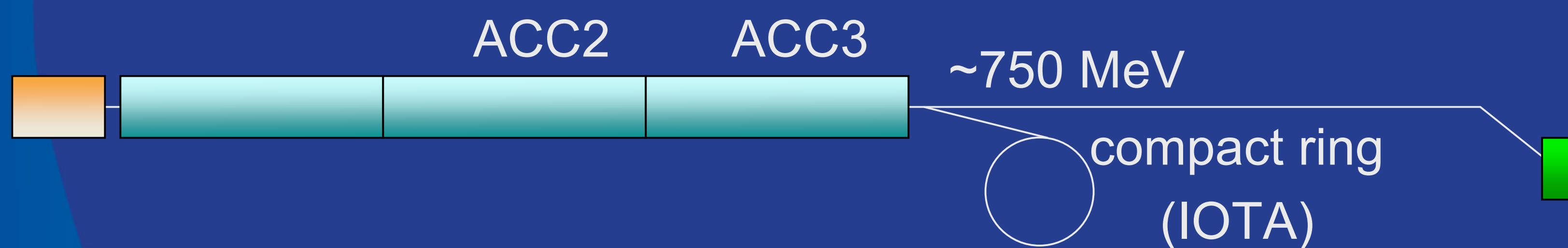
< 750 MeV

< 1 GeV

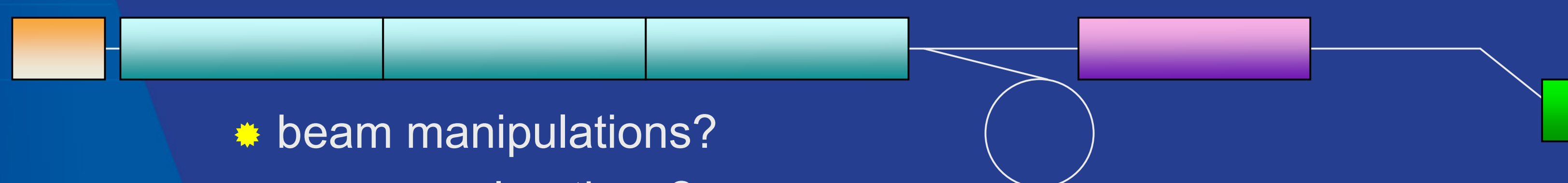
ASTA phases

- **FY12: photoinjector commissioning +250 MeV**

- **FY 13-14: install commission ACC2+3**

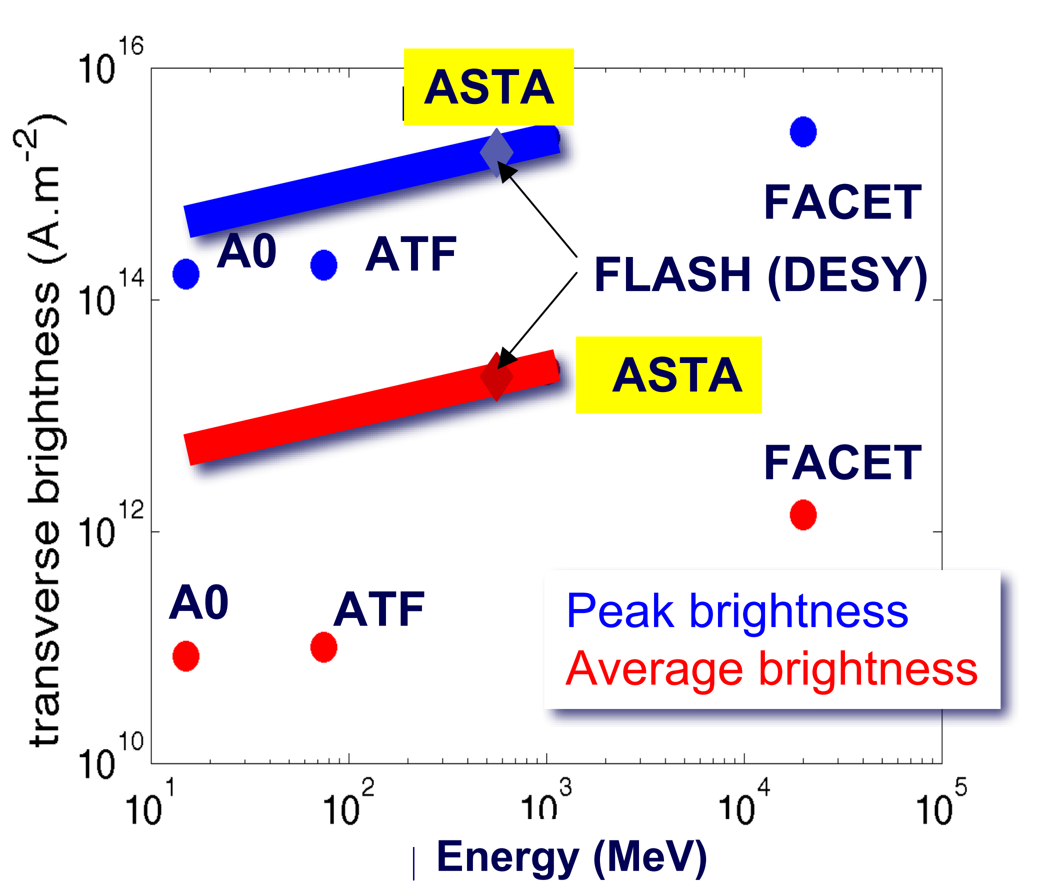


- **FY 15: 750 MeV beam to “users”**



  - beam manipulations?
  - more accelerations?

ASTA promise…

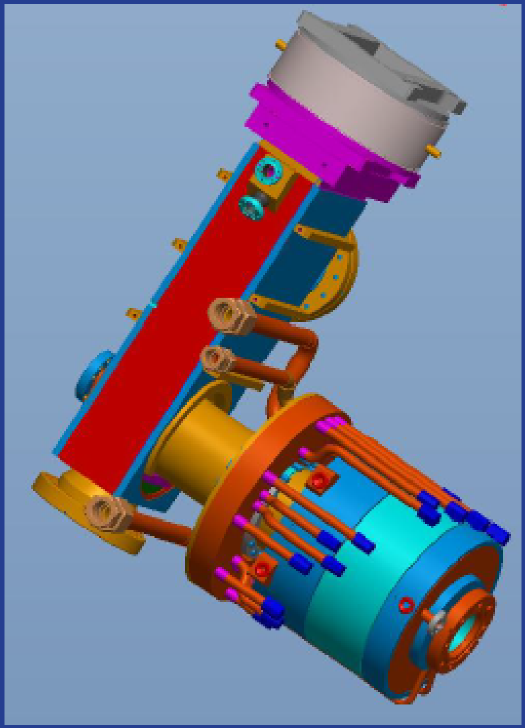


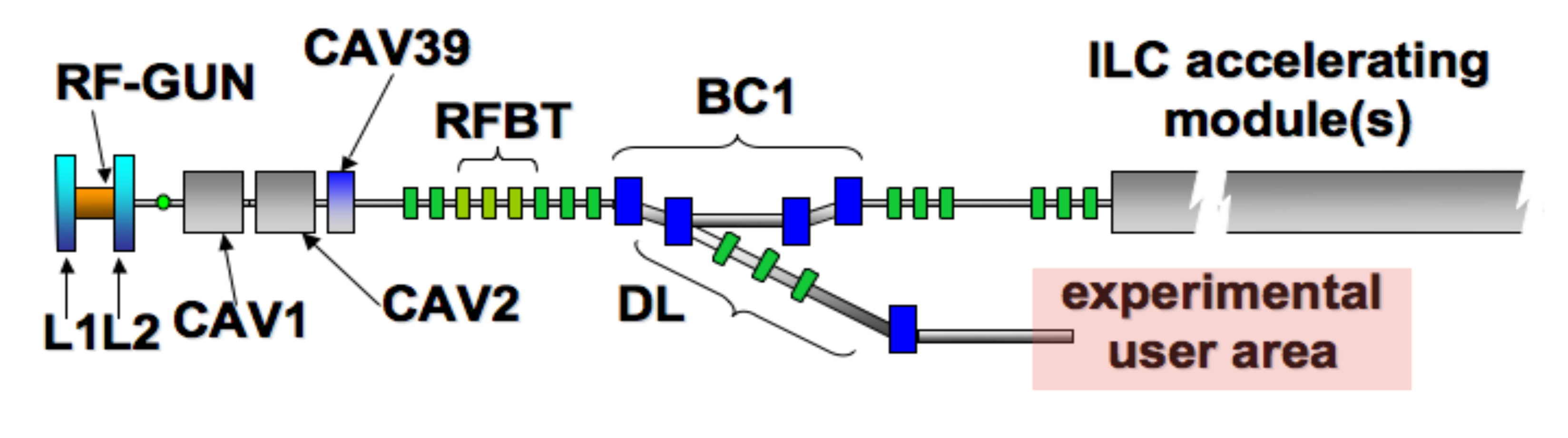
(ASTA performances are extrapolated from simulations of injector -- these are the best possible performances)

- Variable energy from ~40 to ~1 GeV,
- High-repetition rate (1-ms trains):
  - Exploration of dynamical effects in beam-driven acceleration methods.
- L-band SCRF linac:
  - Well suited for beam-driven acceleration,
- Photoinjector source:
  - Provides low-emittance beam,
- Arbitrary emittance partition:
  - repartition of phase spaces to match final applications,
  - Tailored current profiles.

Photoinjector design

- Uses FLASH-type L-band rf gun (~40 MV/m),
- Nominal laser is 3-ps possibility to have flat-top distribution (stacking with α-BBO crystals),
- Variable transverse emittance ratio (magnetized beam + round-to-flat-beam RFTB transform)
- 40-MeV off-axis user area

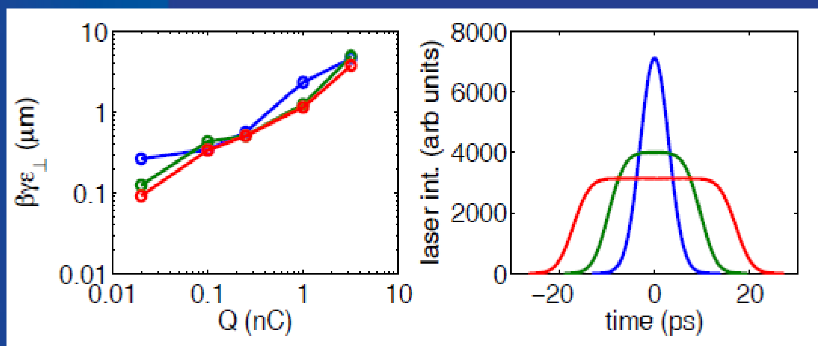




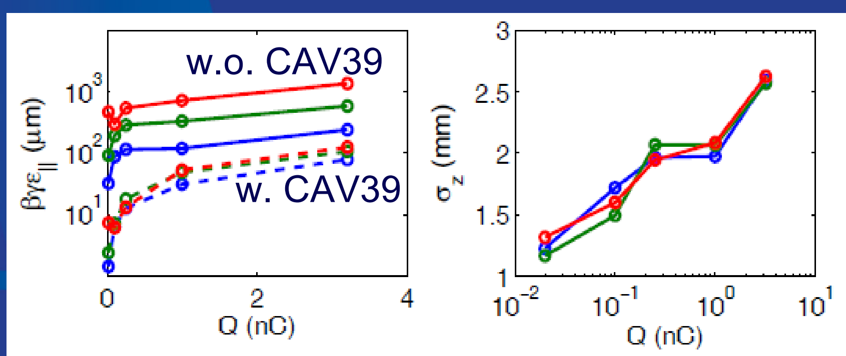
Photoinjector performances (simulations)

- Beam quality comparable to FLASH (uncompressed beam),

Transverse emittance

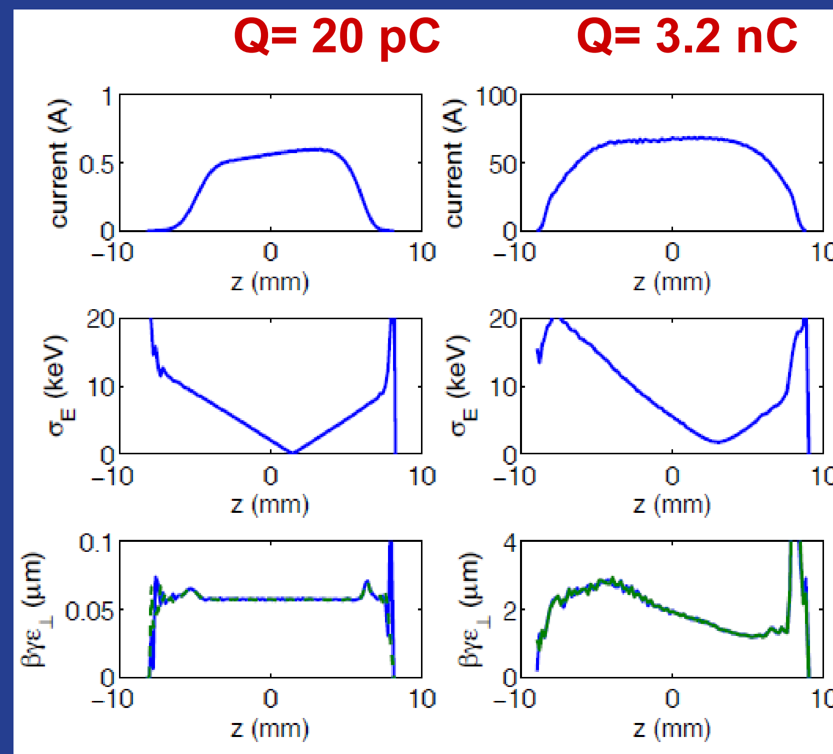


Longitudinal emittance & bunch length



[P. Piot, et al., IPAC10 (2010)]

Slice parameters



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Photoinjector configuration for 1st beam

- No 3rd harmonic cavity
  $\Rightarrow$ nonlinear compression,
- Satisfies the ILC requirements: ~1.2 kA peak current (corresponds to a 3.2-nC 300-μm Gaussian bunch in a cryomodule).

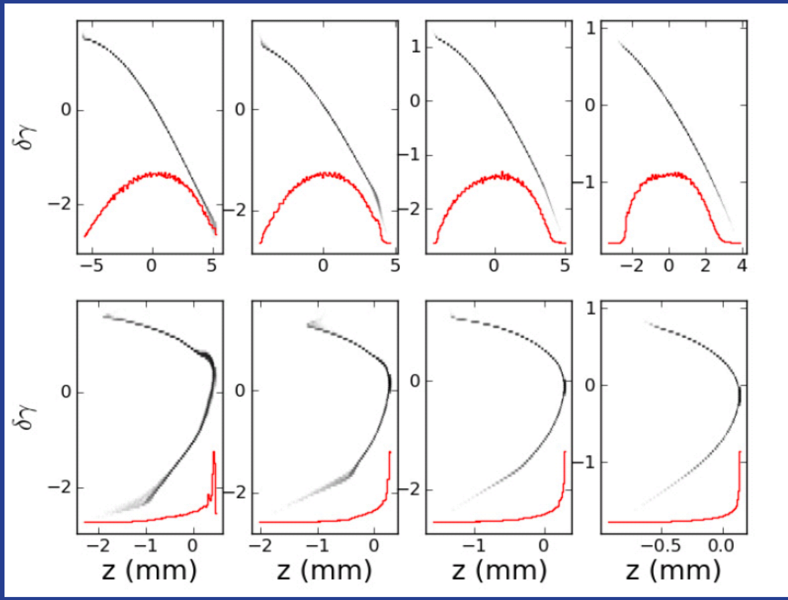
Q (nC)	ϵ_{nxi} (μm)	ϵ_{nxf} (μm)	ϵ_{nyi} (μm)	ϵ_{nyf} (μm)	σ_{zi} (mm)	σ_{zf} (mm)
3.2	4.62	13.40	4.61	8.099	2.60	0.53
1.0	2.33	3.393	2.32	2.472	1.97	0.33
0.25	0.598	1.25	0.598	1.392	1.95	0.38
0.02	0.279	0.459	0.279	.366	1.27	0.15

Transverse emittance before and after BC1 as function of charge

(simulations with IMPACT-Z)

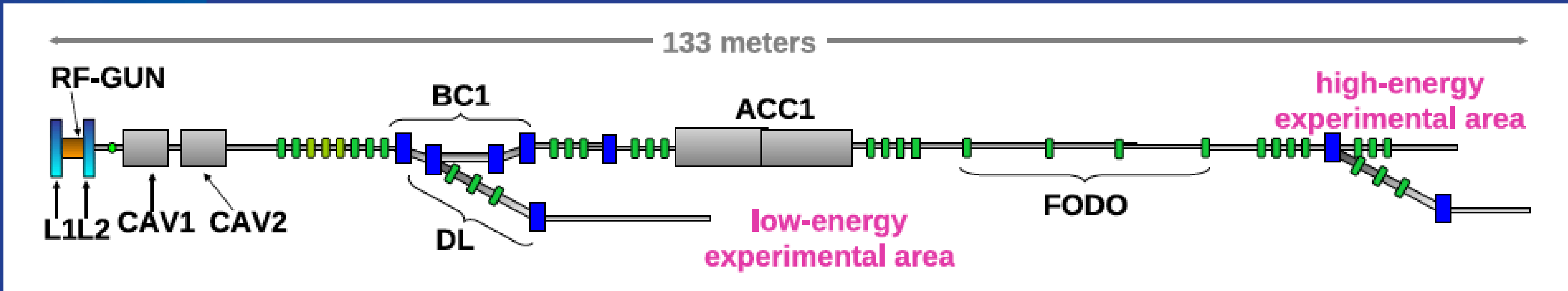
[C. Prokop, et al., (2011)]

Q= 3.2 1.0 0.2 0.02 nC

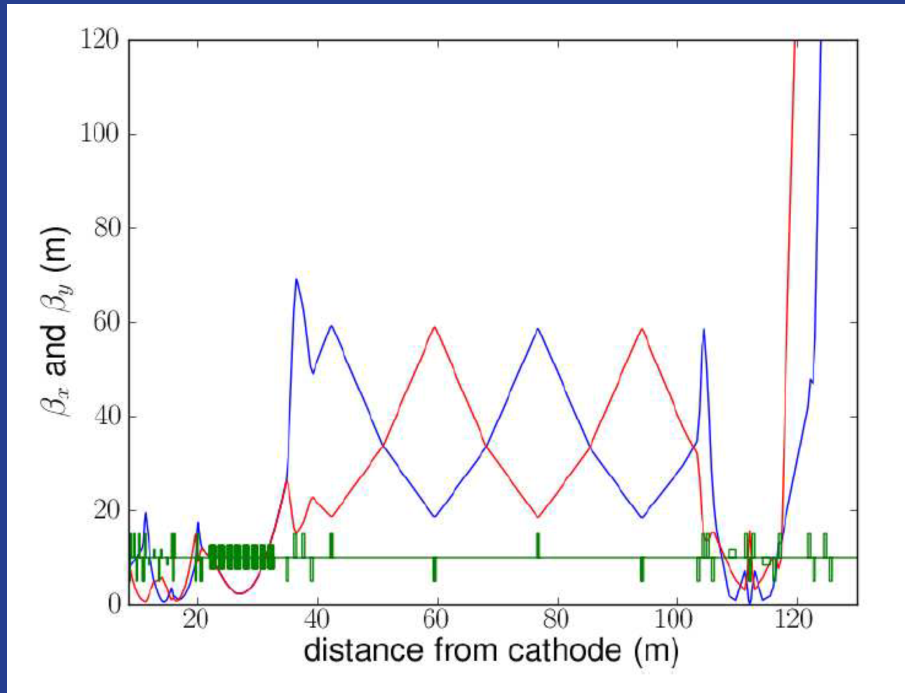


Longitudinal phase space upstream (top) and downstream (bottom) of BC1

Accelerator configuration for 1st beam



- Only one accelerating module available for first beam,
- Transport from cryomodule exit to spectrometer line with FODO
- High-energy spectrometer + user beamline(s)
- Off-axis dump to accommo-date possible extensions



[C. Prokop, et al., (2011)]

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Initial research themes:

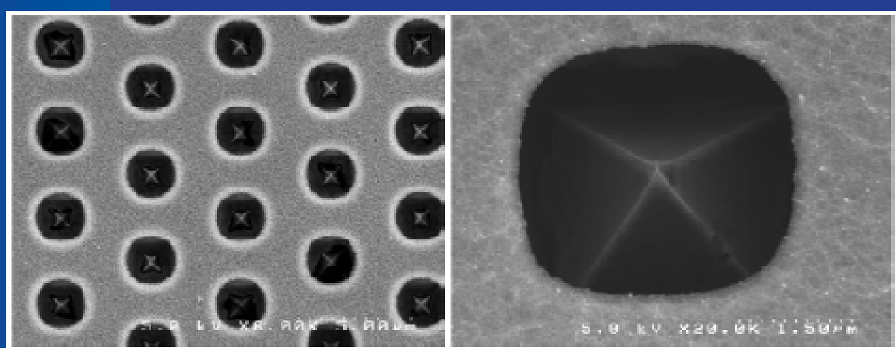
- Beam dynamics
  - Photoinjector characterization,
  - Low energy compression.
- Advanced phase space manipulations:
  - Flat beams and their compression,
  - Transverse-to-longitudinal phase space exchange (PEX),
  - Arbitrary repartitioning of emittances (flat beam + PEX)
- High-brightness electron beams
  - Channeling radiation (with Vanderbilt),
- Integrable-Optics Test Accelerator (Valishev's talk)
  - Small diameter ring downtream of cryomodule to test integrable optics concept.

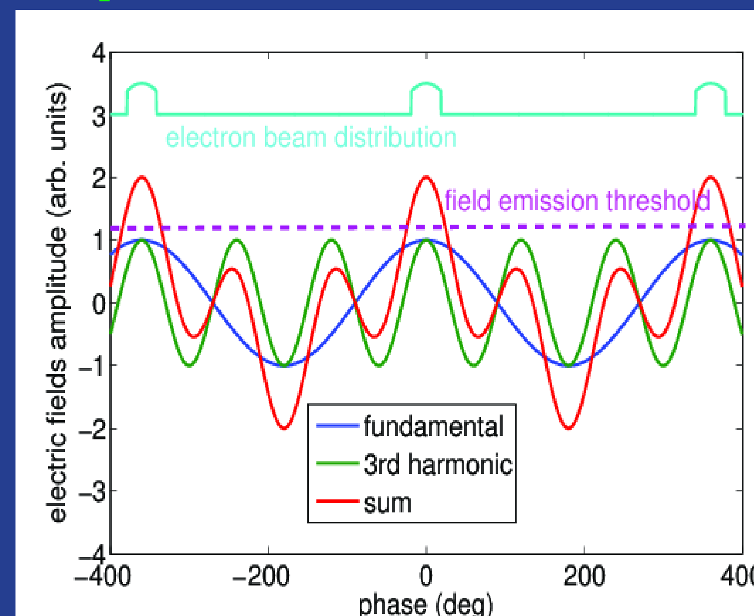
* to be done after at least 1 accelerating module

High-Brightness e- beams: possible production of field-emitted bunches

- During FY12-13, HBESL will support the development of a coaxial-line cathode holder
- Two-frequency gating of field emitters
- If successful this system could be used at ASTA

[J. Lewellen, PRSTAB 2006]

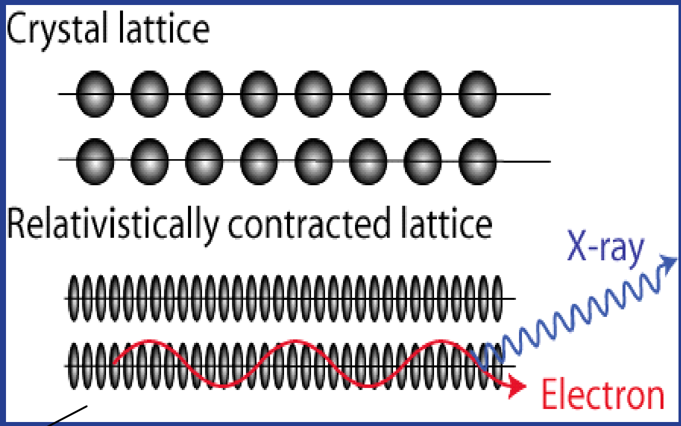


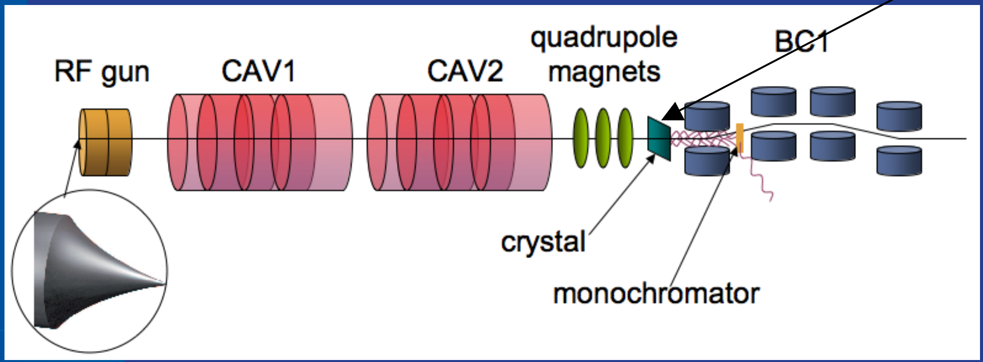


[collaboration with Vanderbilt and NIU (funded by DARPA)]

High-Brightness e- beam: applications to X-ray sources

- Bright electron beams from single-tip FE are planned to be used to produce X-rays via channeling radiation
- Expected brightness for 15 keV
  ~10^{12} photons/s-mm^2-mrad^2-0.1% BW
- Need 40 MeV bunches on a diamond crystal with ~1000 e-





[C. Brau et al, to appear in Sync. Rad. News (2012)]

- FE array cathodes could also be used to increase charge/bunch or open new manipulation opportunities (combination with PEX)

Next generations phase-space exchange (PEX) experiments

- Two stages:
  - Phase I: improved configuration (over A0 setup) in the 40-MeV beamlline
  - Phase II: installation downstream of cryomodules
- Conditions for phase space exchange:

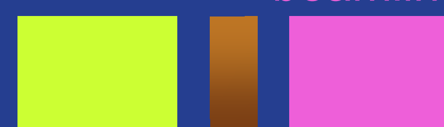
Dispersion vector downstream beamline

Transfer matrix of downstream beamline

$$\vec{\eta}_d = \begin{pmatrix} R_{11,d} & R_{12,d} \\ R_{21,d} & R_{22,d} \end{pmatrix} \vec{\eta}_u$$

Dispersion vector upstream beamline

$$\vec{\eta} \equiv (\eta, \eta' \equiv d\eta/ds)$$



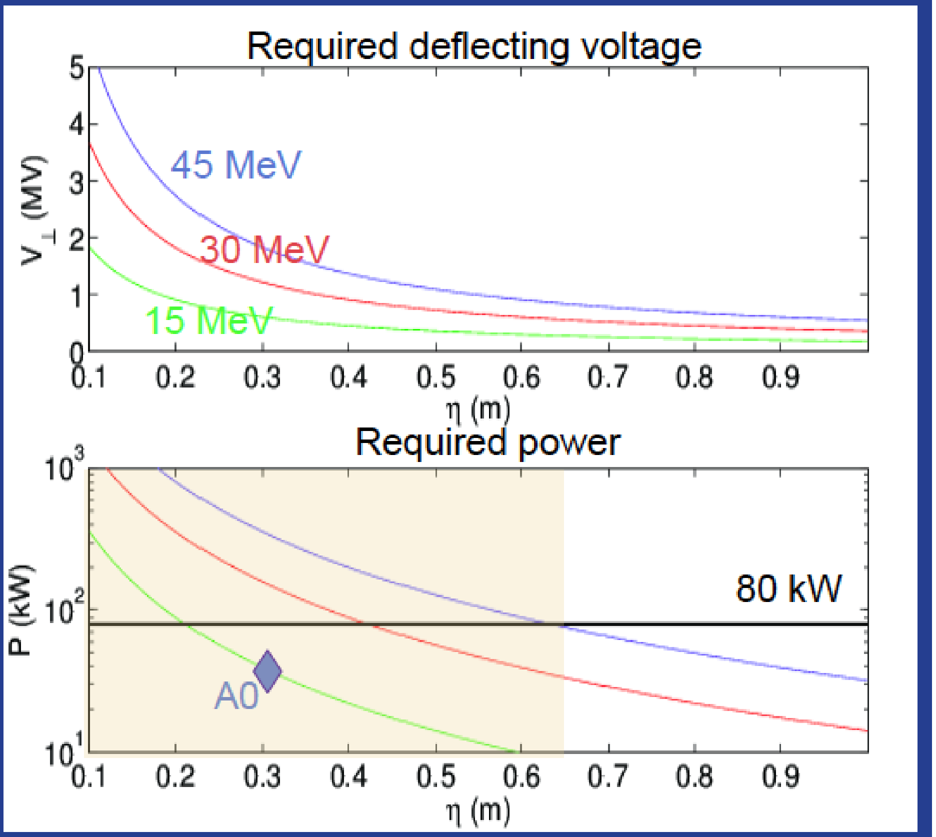
$$\kappa = \frac{1}{\eta_u}$$

$\Rightarrow$ Double-dogleg configuration not unique (or best) solution…

[R. Fliller, FNAL Beamdocs (2007)]

2nd-generation PEX experiments at ~40 MeV (1)

- Limitations of A0PI experiments:
  - limited diagnostics downstream PEX beamlines,
  - Imperfect exchange (?)
  - Limited in charge (15 MeV)
  - "Unpractical" double-dogleg configuration
- Improved setup at ASTA:
  - TM_{110}+ TM_{010} cavity,
  - Chicane-like PEX confi-guration,
  - Deflecting cavity down-stream of PEX
  - Emphasis on current shaping + combine with flat beams
- Experience will be transplanted on the high-energy PEX design



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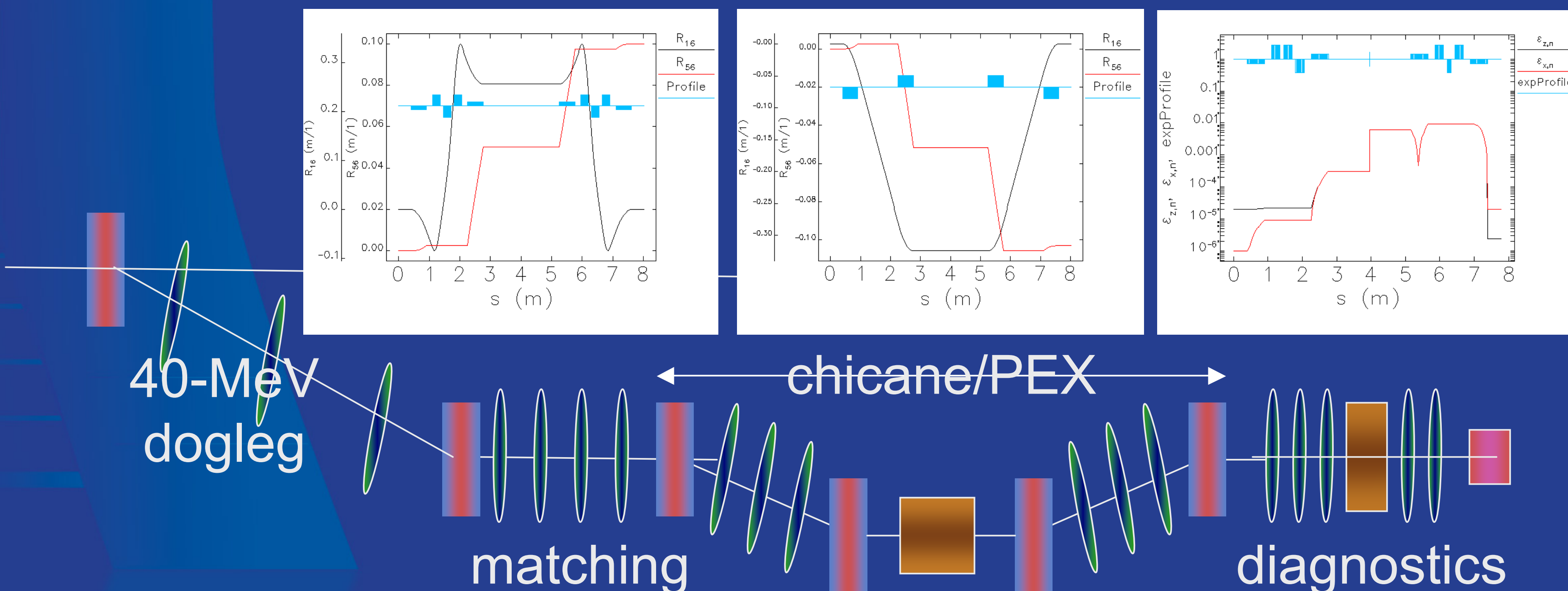
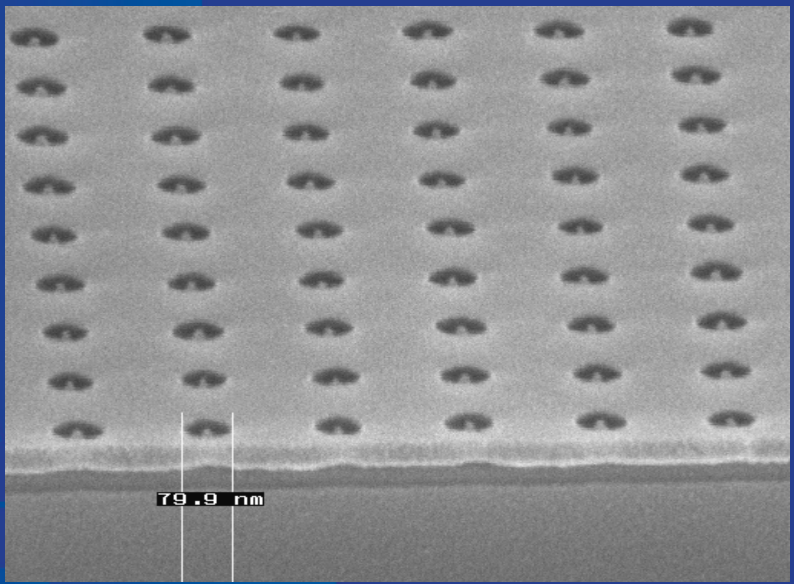
2nd-generation PEX experiments at ~40 MeV (2)

- Goals:
  - Arbitrary repartition of beam emittance within the 3 degrees of freedom (combined with round-to-flat beam transformer) [collaboration with Los Alamos MARIE's team]
  - Chicane/PEX will have a variable dispersion/R56 ⇒ study trade of between dispersion and cavity strength

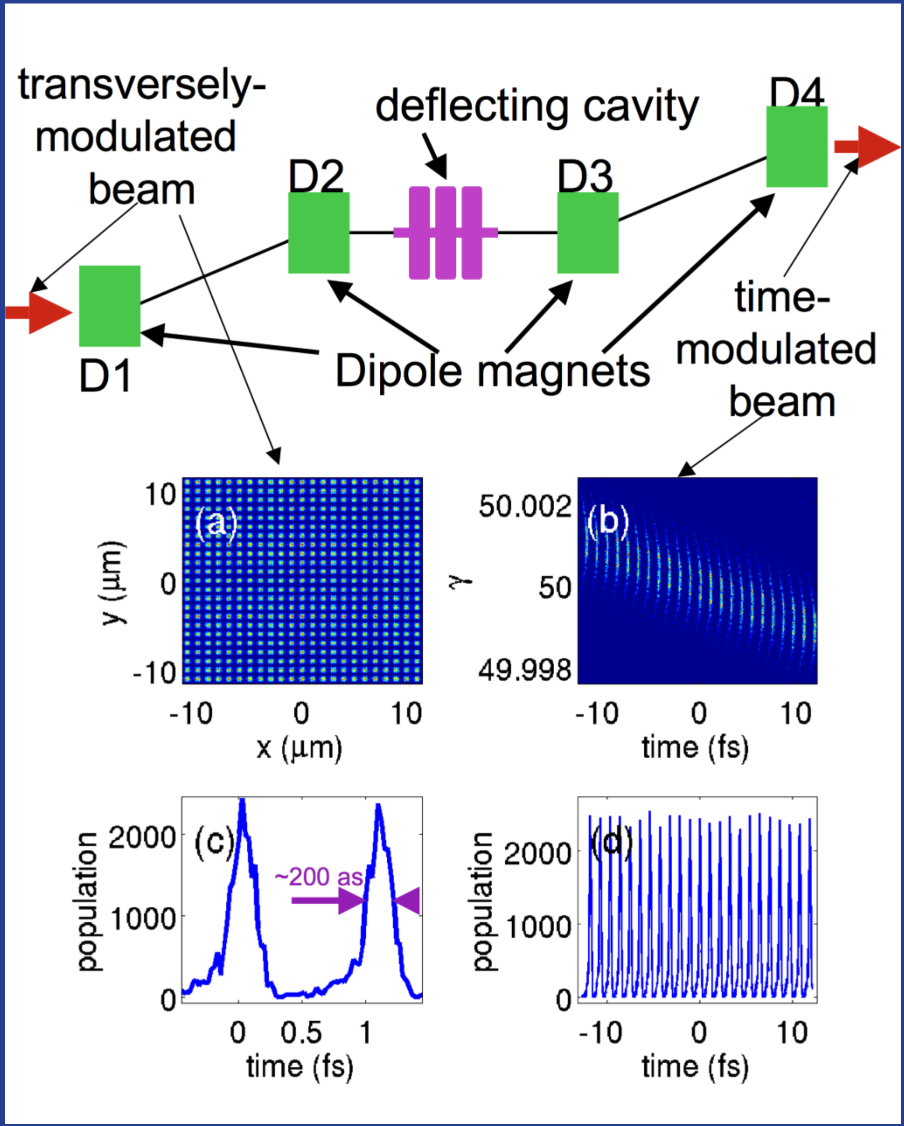


Combining field emitters with PEX beamlines

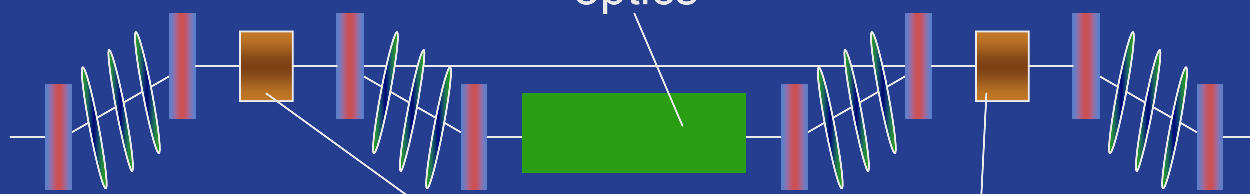
- Generation of train of attosecond bunches,
- Applications to short wavelength light sources (FEL, ICS,…)



[Graves, Kaertner, Moncton, Piot to be published (2011)]



PEX at higher energies [downstream cryomodule(s)]



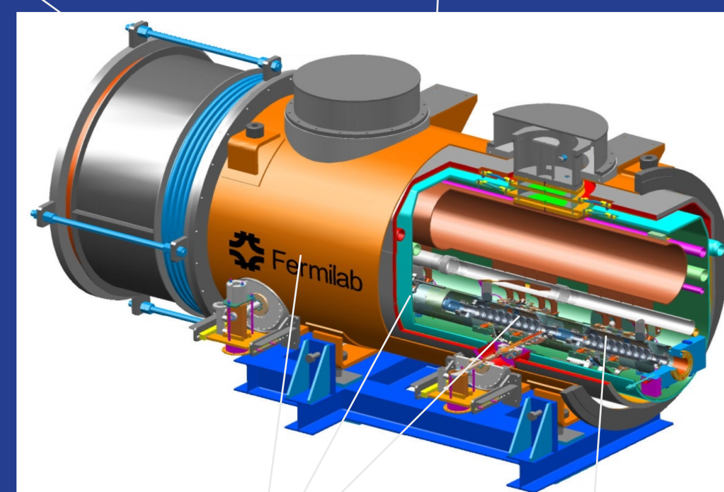
- Requirement on deflecting cavity kick can be alleviated with a higher dispersion

$$\kappa = 1/\eta_x$$

- But beam size should satisfy

$$\sigma_x \leq \lambda/(12\pi)$$

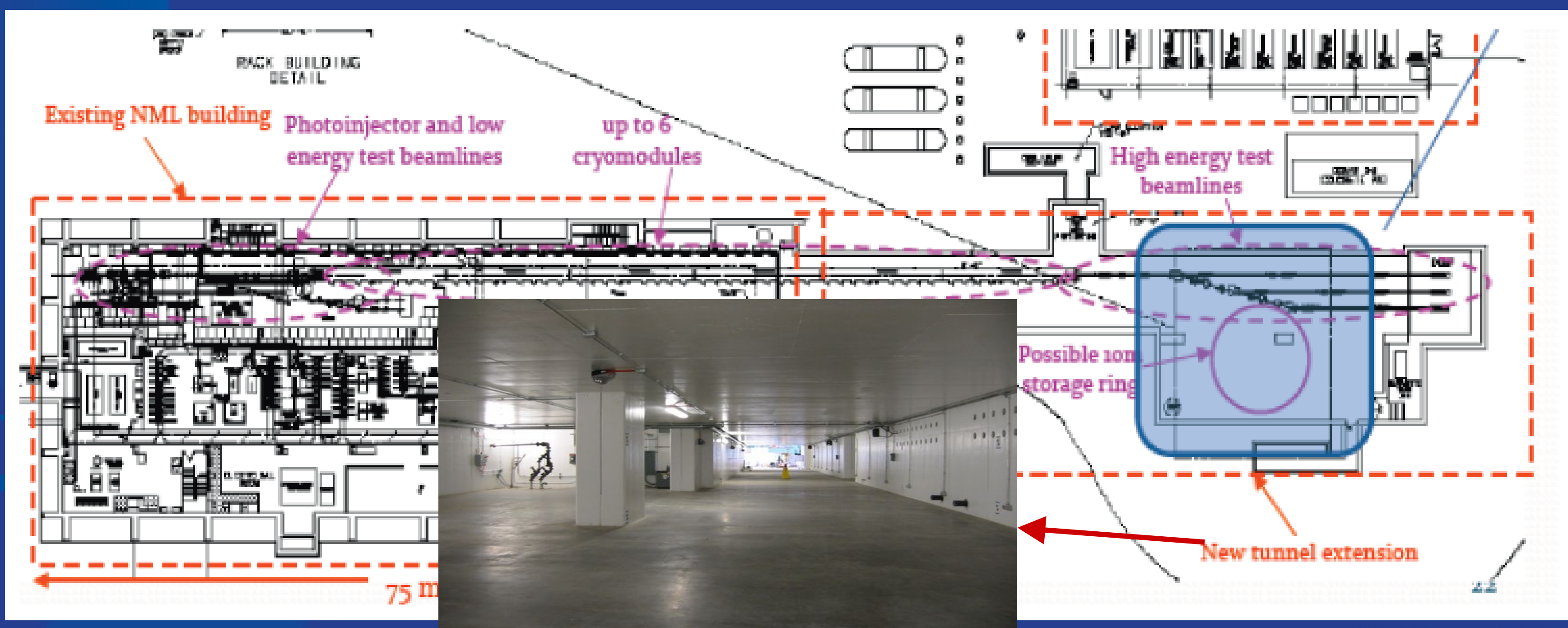
- At 3.9 GHz, we will have to go with a SCRF system (advantage to also do full exchange over a bunch train)



(adapted from Zholents APS/ANL)

Integrable-Optics Test Accelerator (1)

- ASTA facility provides the needed infrastructure to test other concepts,
- IOTA, a compact ring dedicated to test integrable optic (with ORNL),
- No stringent requirements on ~150-MeV beam quality,
- Can support experiment of optical stochastic cooling. (with MIT)



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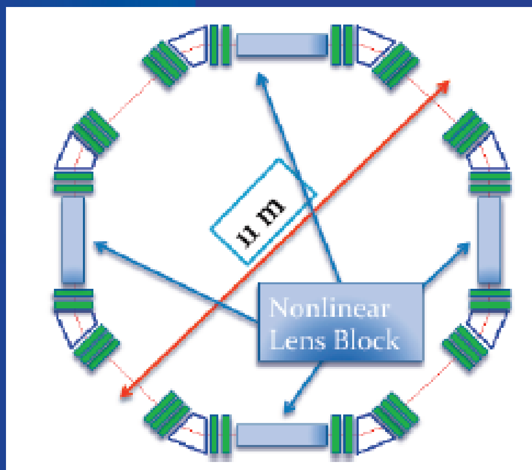
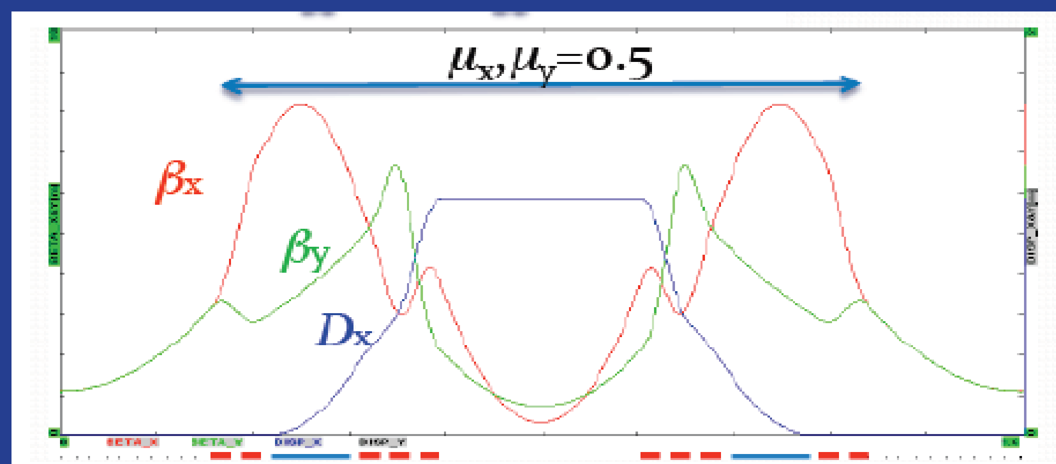
Integrable-Optics Test Accelerator (2)



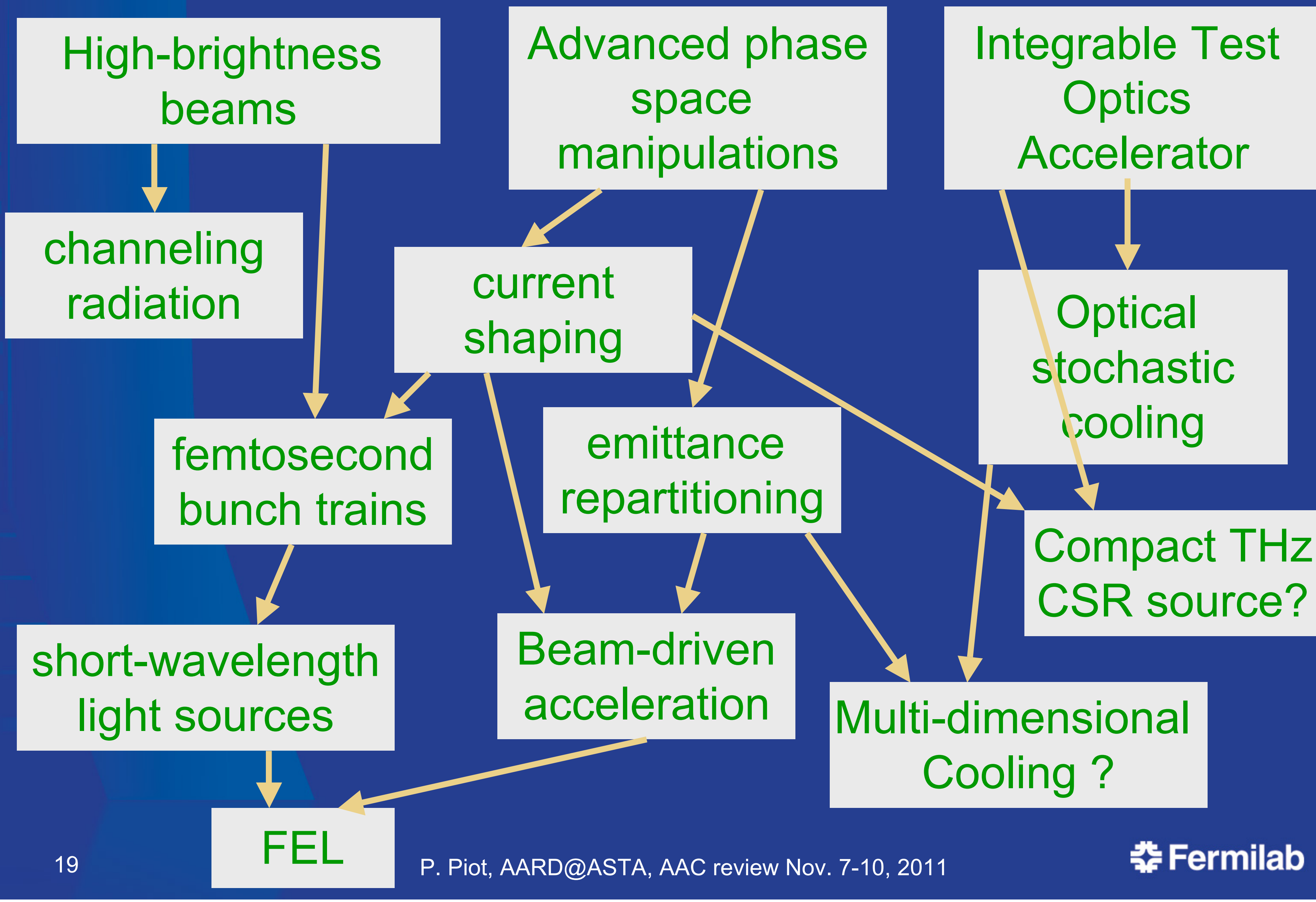
e- Energy	150 MeV
Circumference	32 m
Dipole field	0.5 T
Betatron tunes	Qx=Qy=3.2 (2.4 to 3.6)
Radiation damping time	1-2 s (10^7 turns)
Equilibrium emittance, rms, non-norm	0.06 μm

- Nonlinear integrable accelerator optics are being developed to enable stable operation of a completely nonlinear machine (tune spread up to 50%)
- Accelerators with very large tune spread will push the intensity limits of storage rings by suppressing collective instabilities through "better" Landau damping.



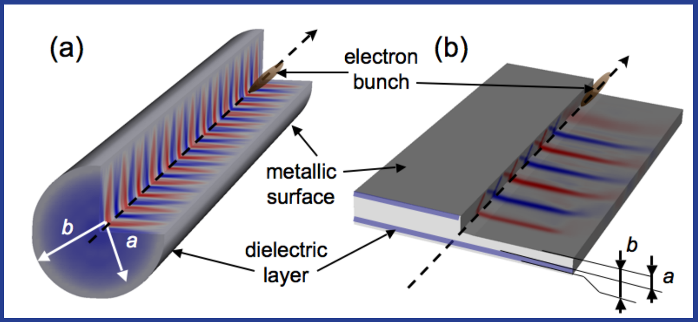
[Danilov, Nagaitsev, Valishev, 2011 see also PRSTAB 2010]

Further developments

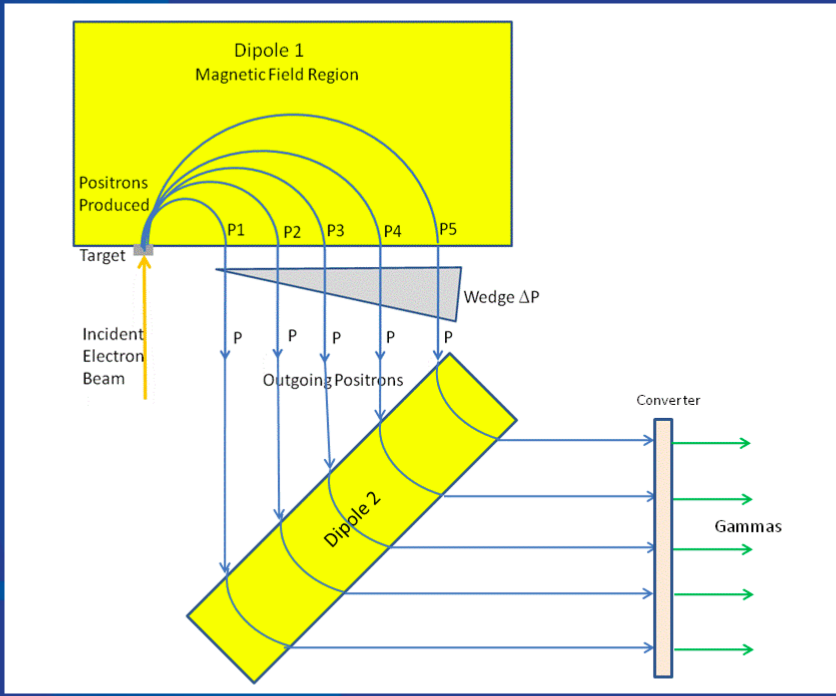


Other interests (1)

- Dielectric wakefield acceleration with tailored bunch (ramped current, flat beams),



- Narrow-band Gamma-ray (Muons Inc.)

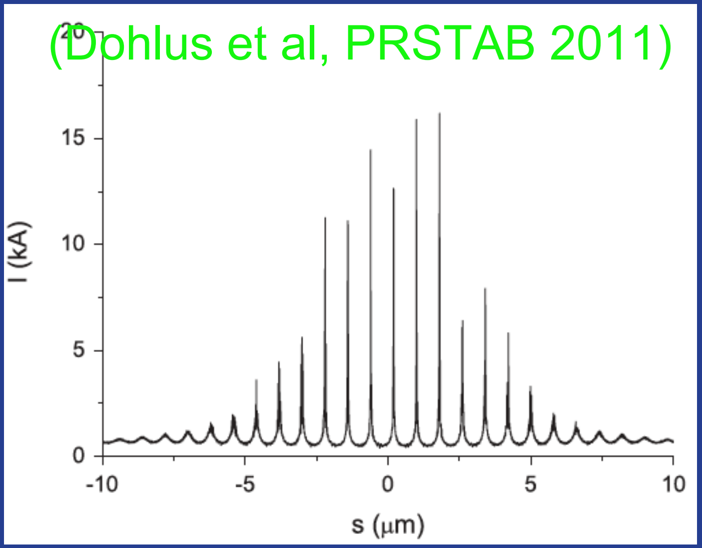


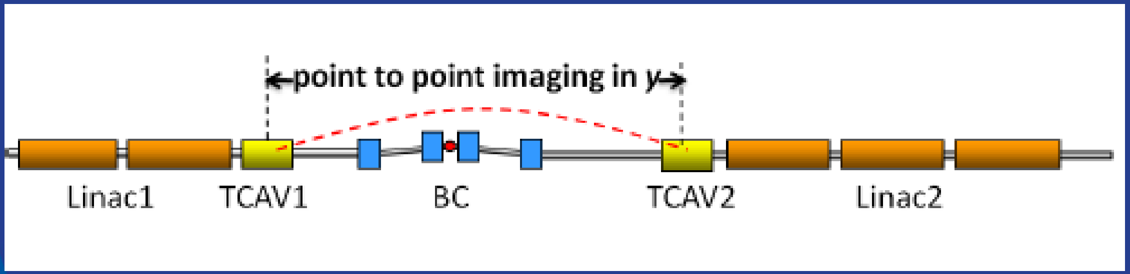
- Inverse Laser Compton Scattering for K-edge densitometry (collaboration with K Chouffani IAC / proposal to NEUP in preparation)

- positron source [test of "stand-by" ILC positron source -- suggested by W. Gai (ANL)]

Other interests (2)

- Space-charge driven broadband microbunching for attosecond VUV radiation (discussions with Schneidmiller and Yurkov, DESY),
- Optical stochastic cooling using the IOTA ring (collaboration with MIT)
- Reversible beam heater to improve the performance of short-wavelength FELs (interest from LBNL)





$$y' = \frac{e\omega V_y}{\gamma m c^3} z_0 \equiv \alpha z_0 \,, \quad \delta = \alpha y_0 \,,$$

(Behrens, Huang, Xiang, FEL11)

Discussions

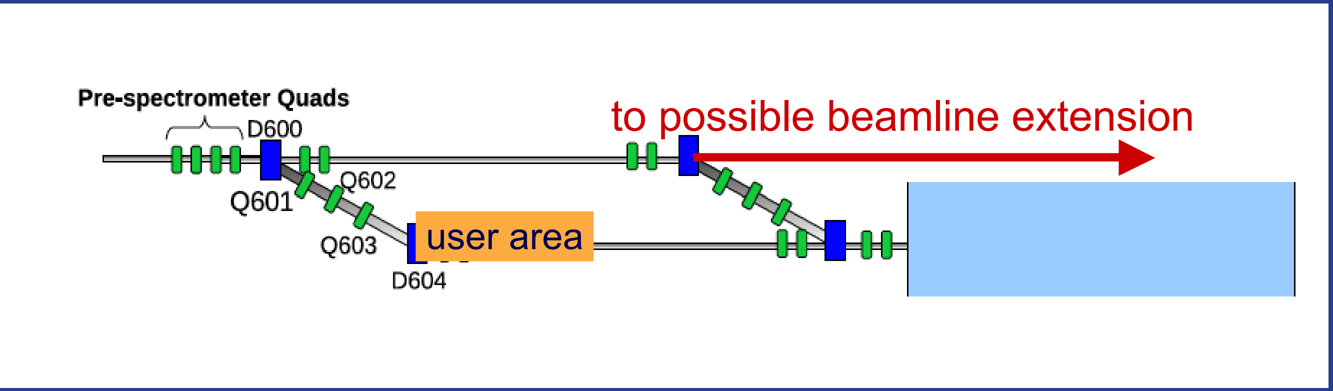
- ASTA has several unique features compared to existing facilities in the US,

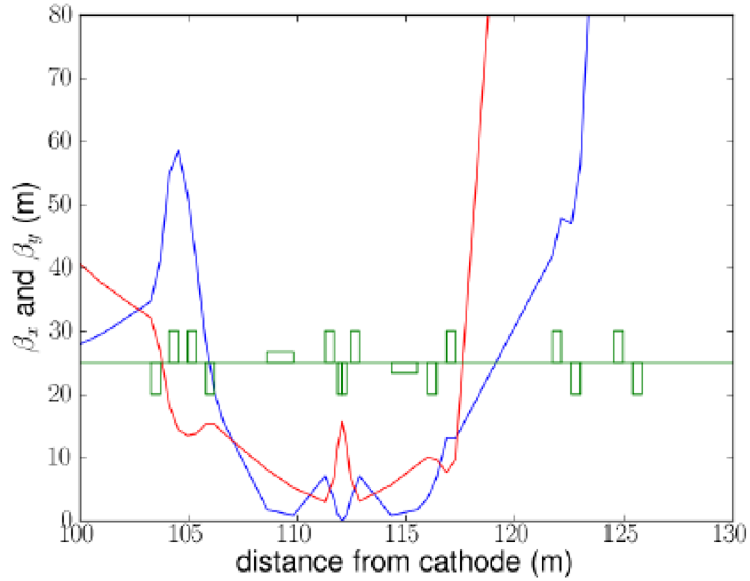
- Main limitation of the current design (devised to fulfill ILC requirements) stems from the low-energy compressor:
  - Eventually need to have a staged compression scheme,
  - In the shorter term: need a 3.9-GHz accelerating cavity to linearize the longitudinal phase space ⇒ improved beam parameters

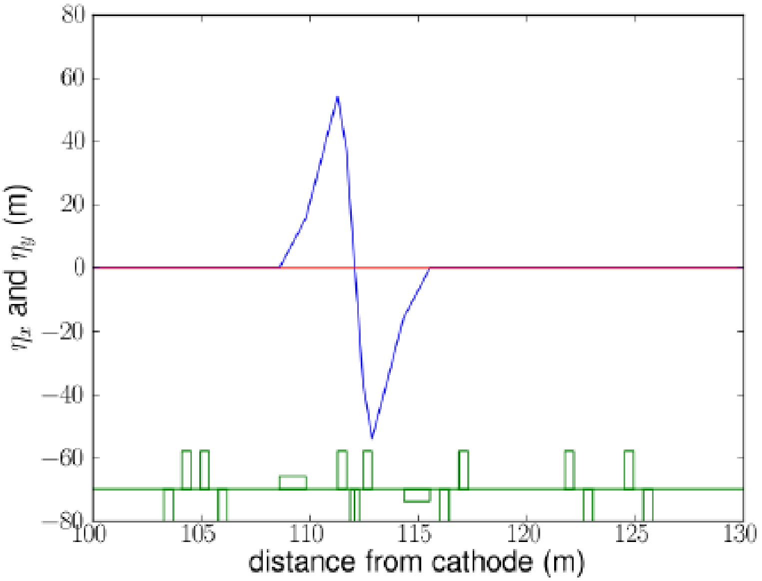
- If properly configured, ASTA could support an extensive R&D program in Accelerator Science and beyond,

Extra slides

High-energy user area + spectrometer







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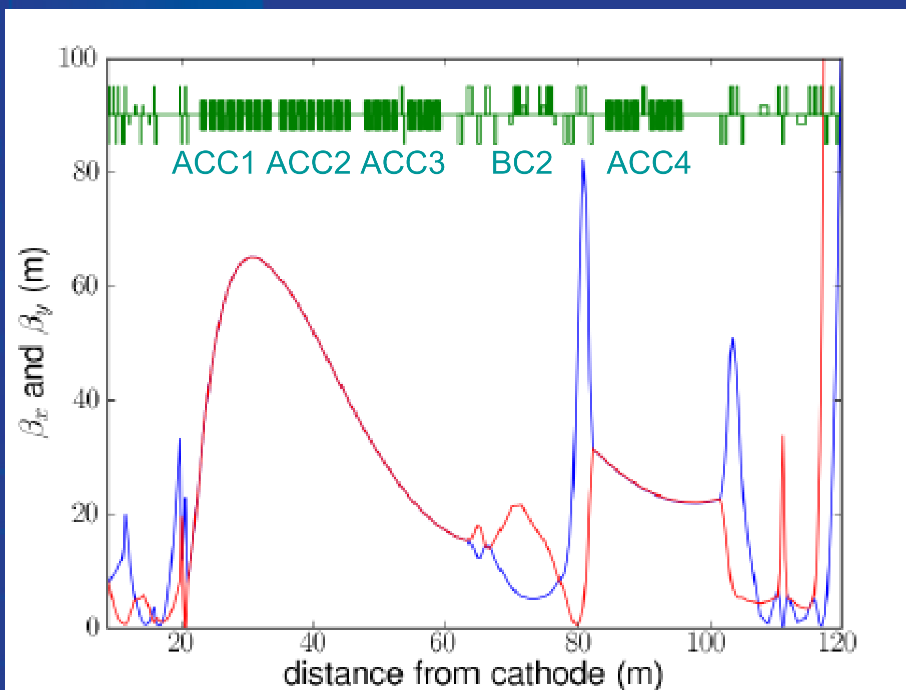
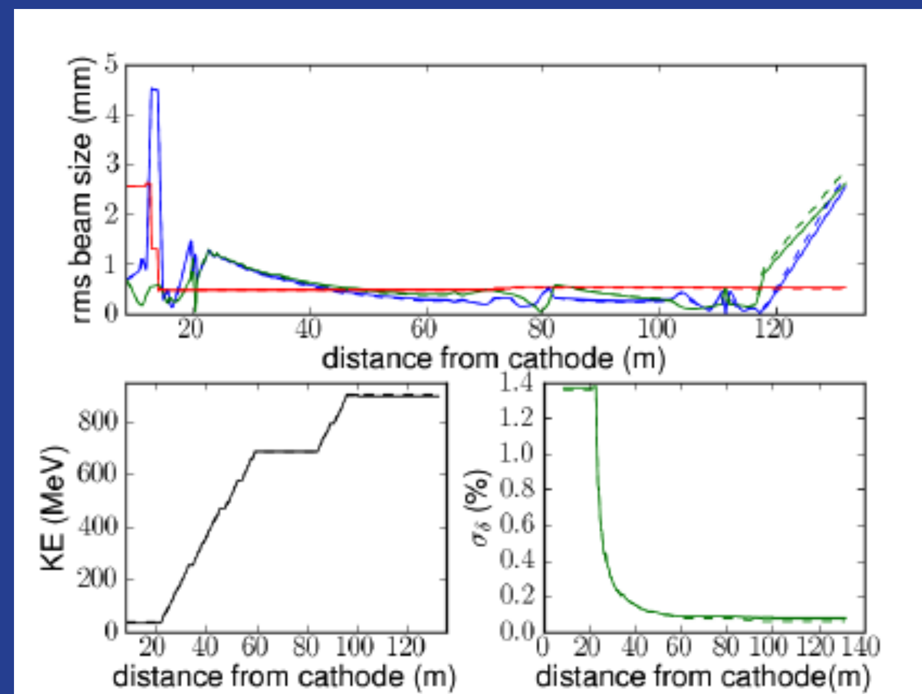
A possible configuration with 4 cryomodules

- BC2 can produce high-peak current ~10 kA
- Currently exploring trade off between peak current and emittance dilution,

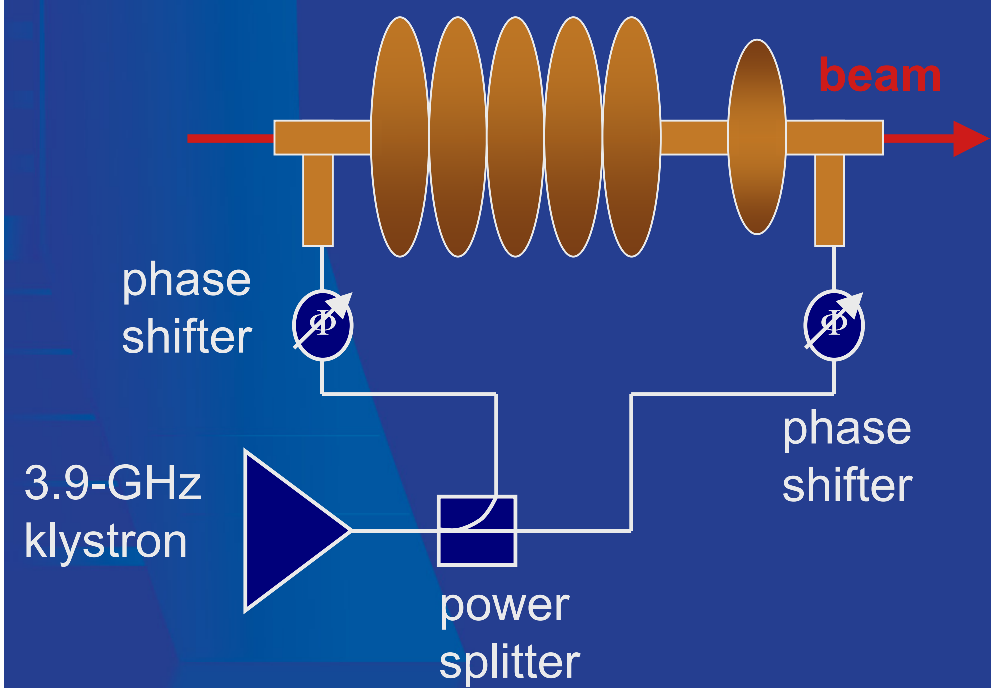


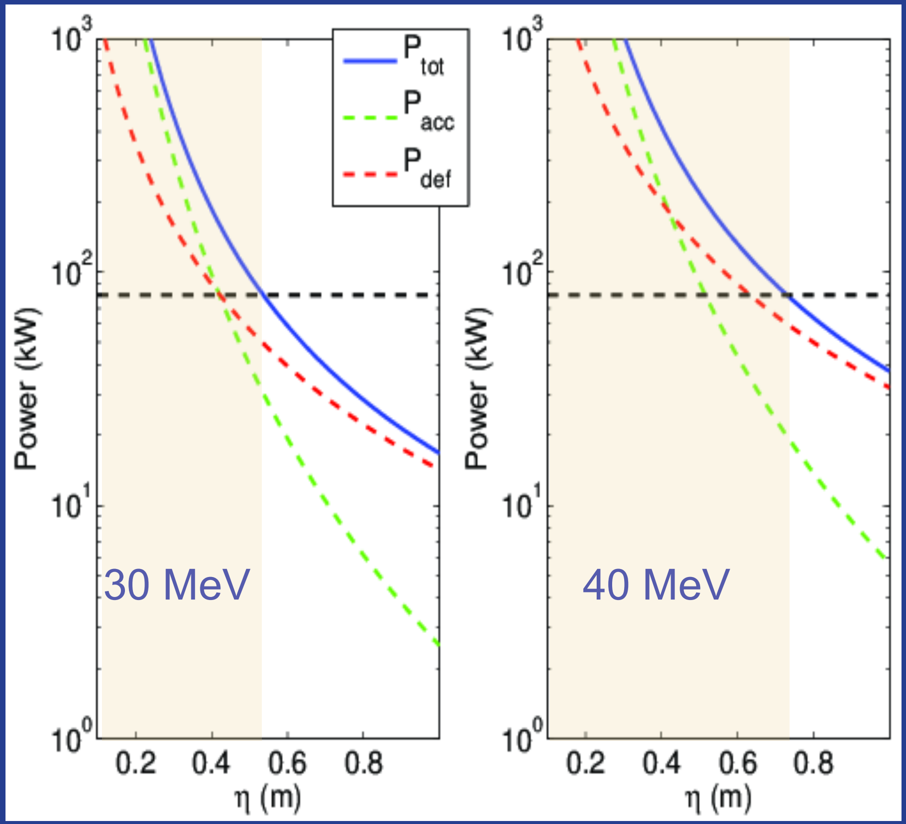


- Energy limited to 900 MeV (safety envelope)

Hybrid deflecting cavity for next-generation PEX beamlines

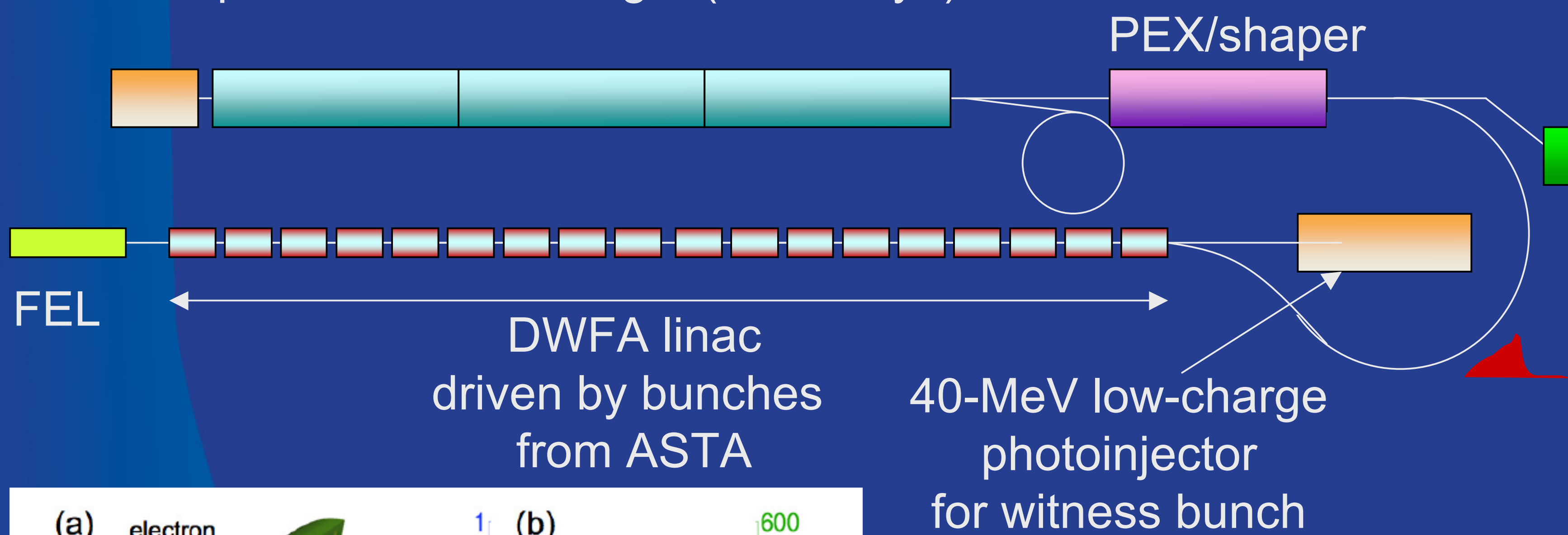
- TM_{110} deflecting-mode cavity followed by a TM_{010} cavity,
- 5-cell deflecting + 1-cell ac-cerating should be OK

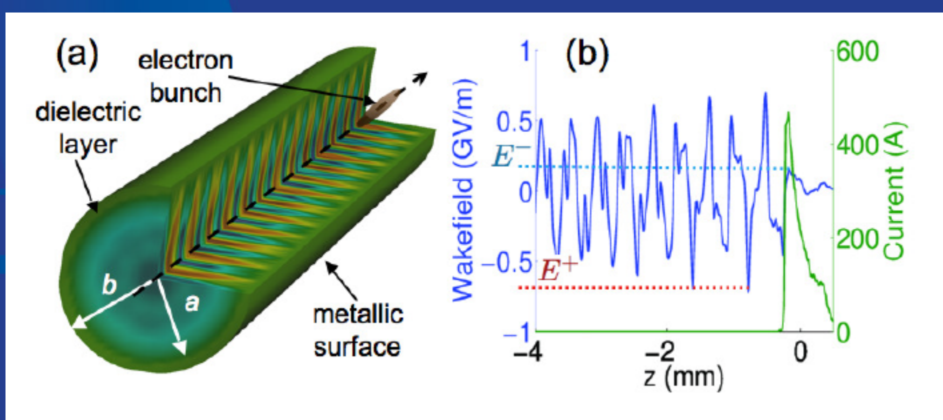




Towards next generation light sources

- Combining Fermilab’s phase space manipulation expertise with novel acceleration schemes
- Compact short-wavelength (soft x-ray?) FEL





(adapted from Jing, Power, and Zholents APS/ANL)