Other linac-based experiments downstream of the cryomodule

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IOTA/FAST 5th Users' meeting

June 6, 2017

* Joint appointee with Northern Illinois University

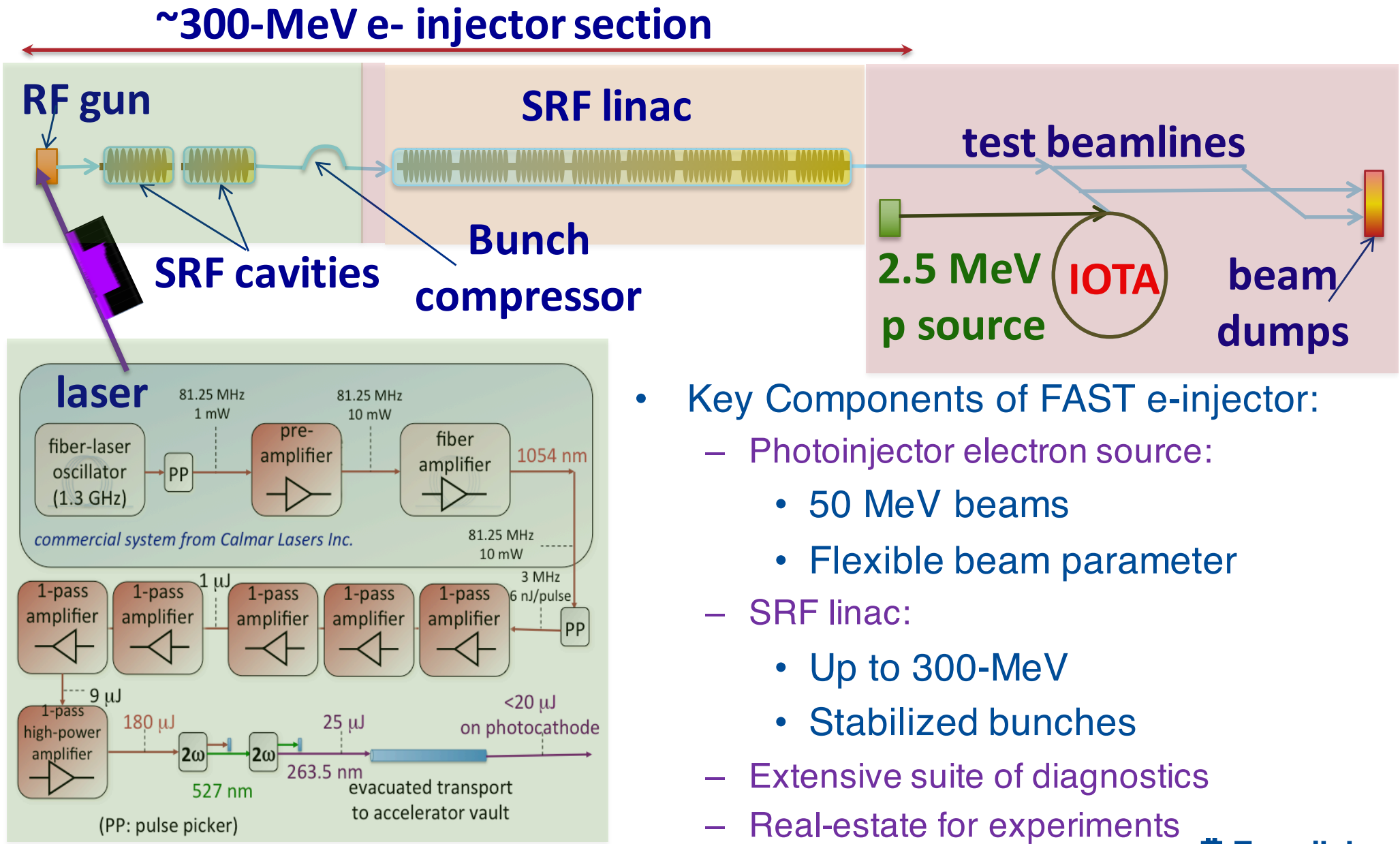
Research opportunities at the FAST e-injector

- FAST/IOTA supports collaborative research opportunities with Universities, National labs, and Industries

- e-injector can support research relevant to other (than HEP) programs within DOE:
  - **NP:** electron-cooling, phase space manipulations, magnetized beam in IOTA
  - **BES:** formation and diagnosis of bright e- beams, phase-space manipulations, electron-laser interactions
  - **NNSA:** tests of subsystems for MARIE (LANL)

- e-injector has been (and is being) leveraged to secure funding outside of DOE: e.g. NSF, DOD, DHS.

The IOTA/FAST Overview



- Key Components of FAST e-injector:
  - Photoinjector electron source:
    - 50 MeV beams
    - Flexible beam parameter
  - SRF linac:
    - Up to 300-MeV
    - Stabilized bunches
  - Extensive suite of diagnostics
  - Real-estate for experiments

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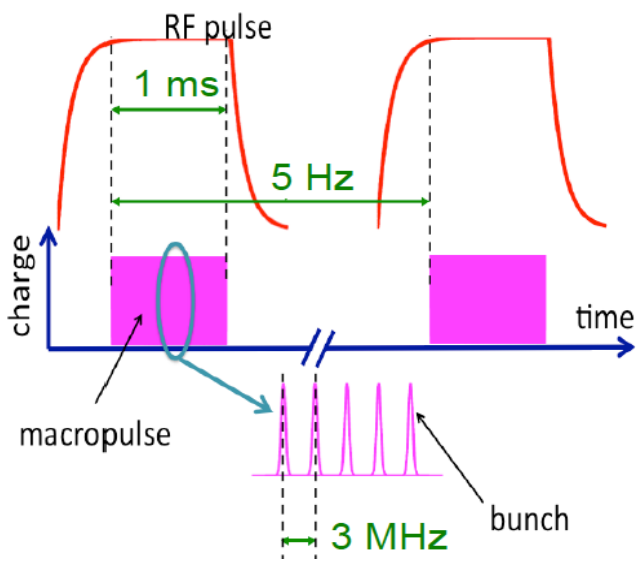
Experiments

- Acceleration to 300 MeV!
  - Beam characterization
- IOTA-related tests:
  - Beam diagnostics
  - Preparatory tests of subsystems for OSC
- Multi-bunch wakefield (B. Carlsten's talk)
- Gamma-ray source via ICS
- Longer term
  - Radiation/laser-based beam manipulations,
  - Interaction with crystals
  - Application of flat beams
  - Advanced acceleration/manipulations

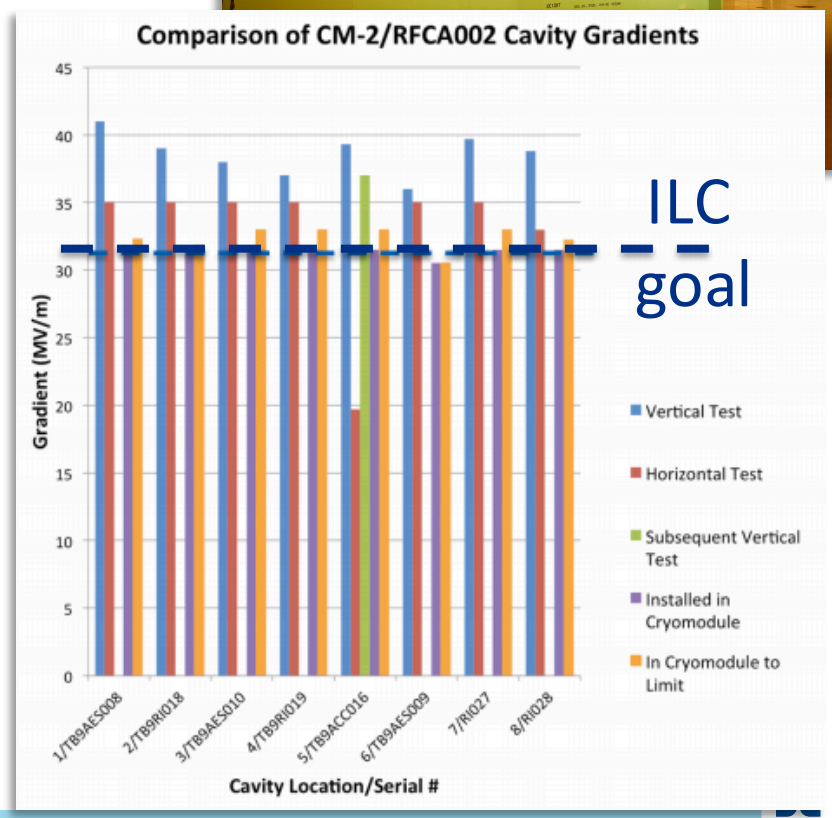
Acceleration to <300 MeV

Adapted from Elvin Harms

- The 50-MeV beam is accelerated in a cryomodule (8 SRF cavities)
- Produced *stable* beams with energies up to 300 MeV arranged as macropulses.



- IOTA requires ~150-MeV e-beams



[E. Harms, et al. SRF2015 (2015)]

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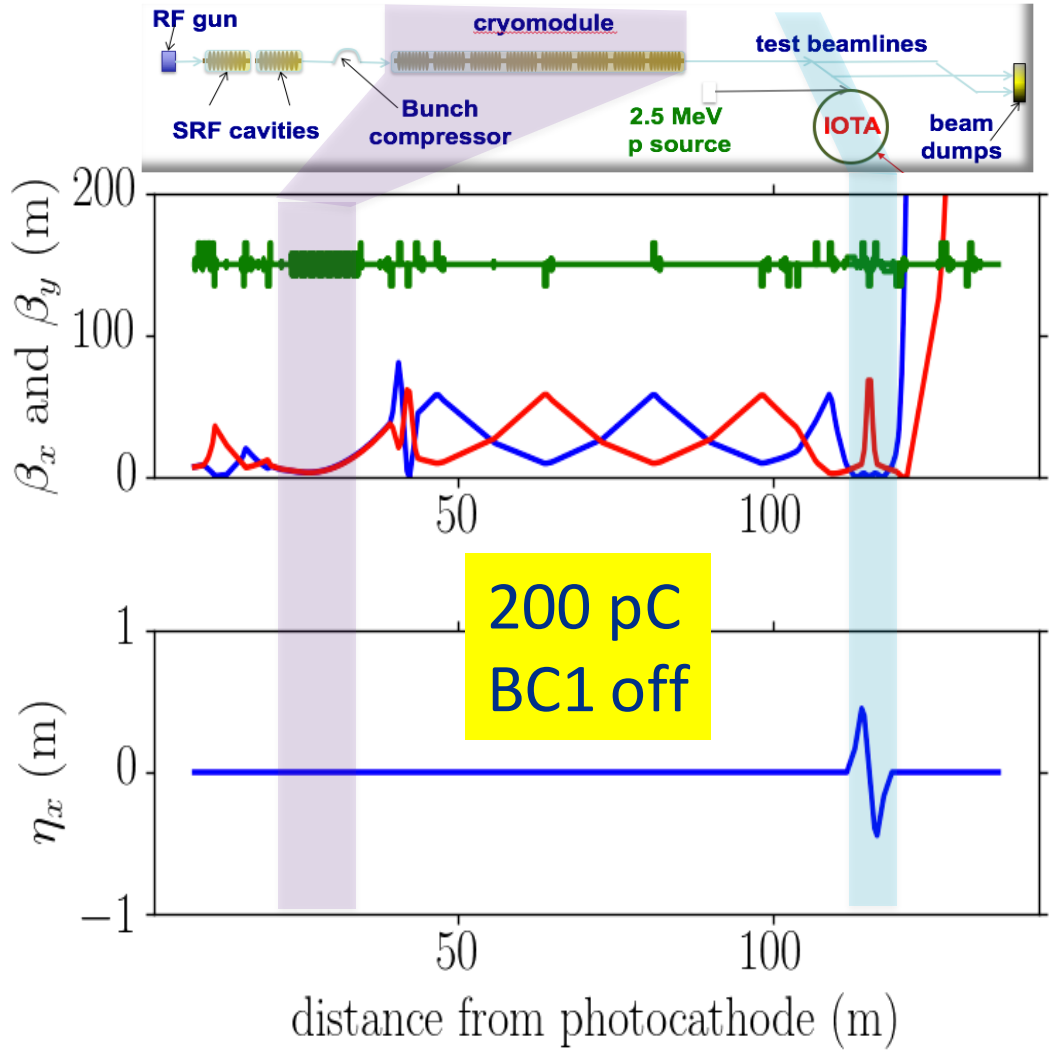
Acceleration to <300 MeV: beam optics

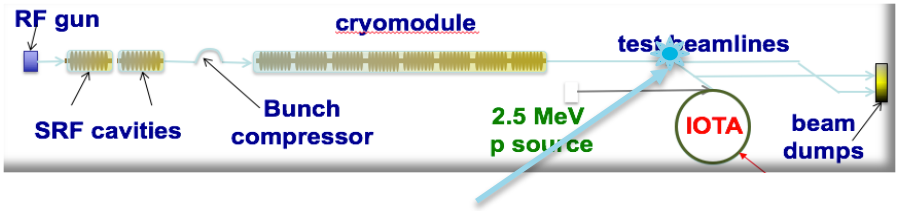
- Extensive models of the beamline.
- Nominal lattices available in ELEGANT (D. Broemmelsiek)
- ELEGANT used for single-particle optics.
- ASTRA & IMPACT-T used for the injector.
- IMPACT-T & IMPACT-Z used for the entire beamline.
- Start2End simulations and optimization performed with py-based GlueTrack (initiated at DESY).

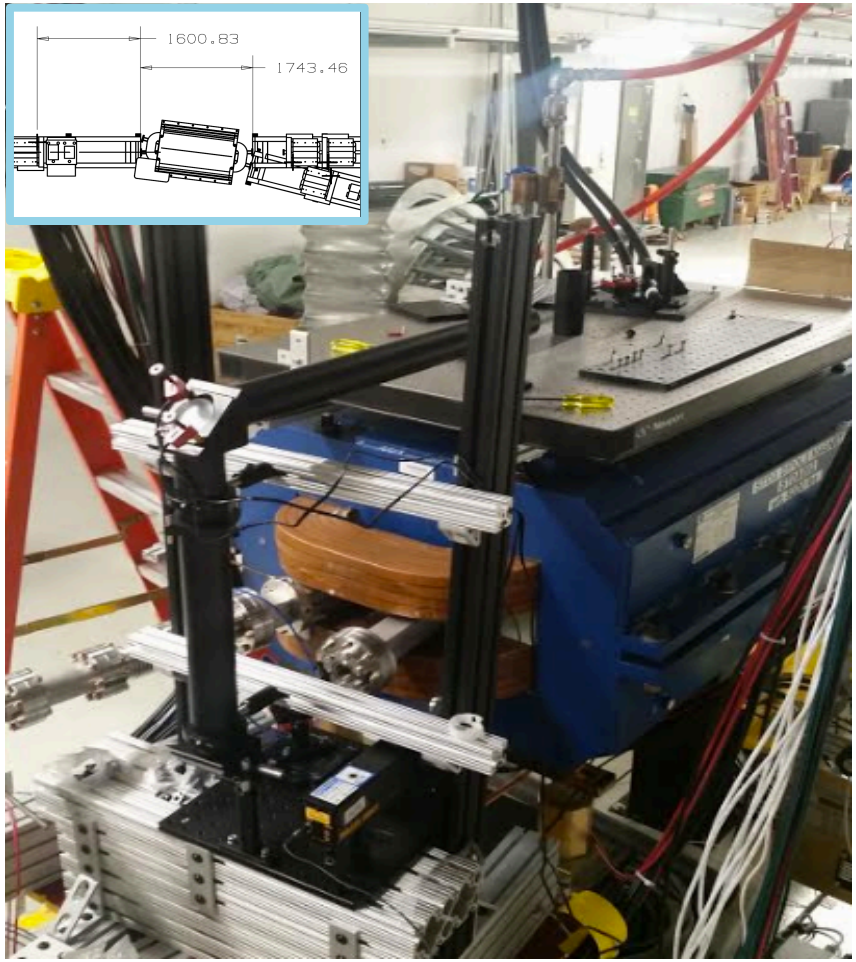


all ELEGANT lattices available at https://github.com/NIUaard/FAST

IOTA-related tests using D600 dipole magnet

- Imaging of SR for beam profile monitor for IOTA (Romanov, et al.)
- Single-photo detection using PMT (Stancari, et al.)
- Spectral measurement at 2 μm + amplification (Andorf, et al.)

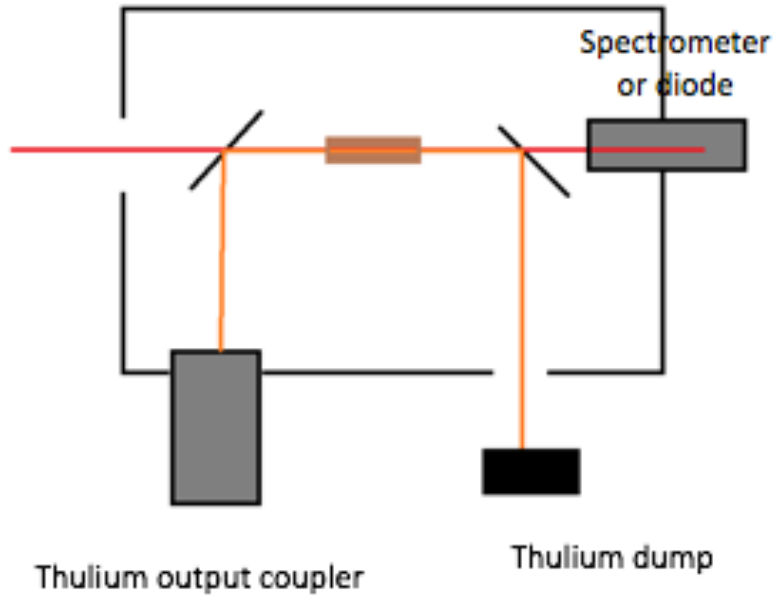


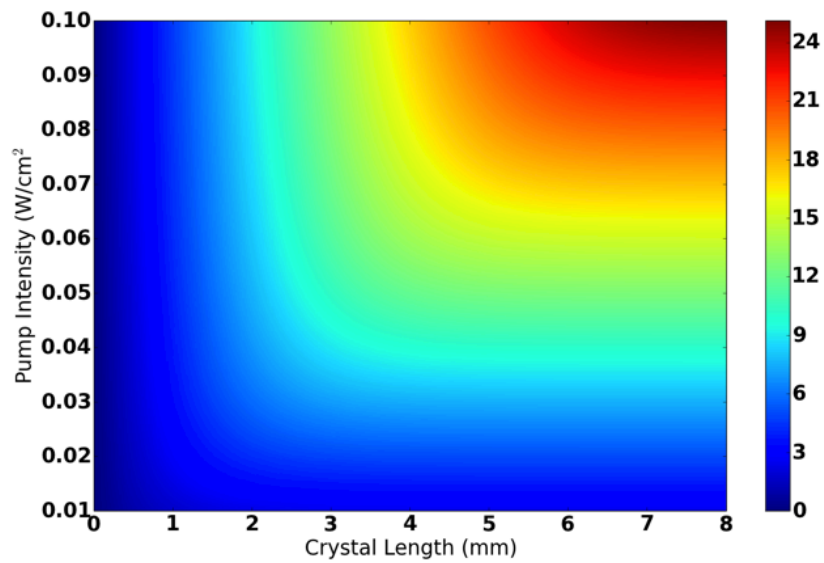


Energy (MeV)	Critical wavelength (nm)	photons in BW (%)	Energy flux per e- (J)
100	2734	15.8	2.66e-22
150	810	7.2	1.21e-22
200	342	3.0	5.0e-23

Test of OSC-experiment subsystem

- OSC will operate in the [2200,2900] nm spectral range
- Amplifier medium is a Cr:ZnSe pumped by a Thulium laser.
- Recently procured all the components necessary to assemble the amplifier.
- We are trying to get ready to perform an experiment in the summer demonstrating amplification of synchrotron radiation around ~2500 nm.

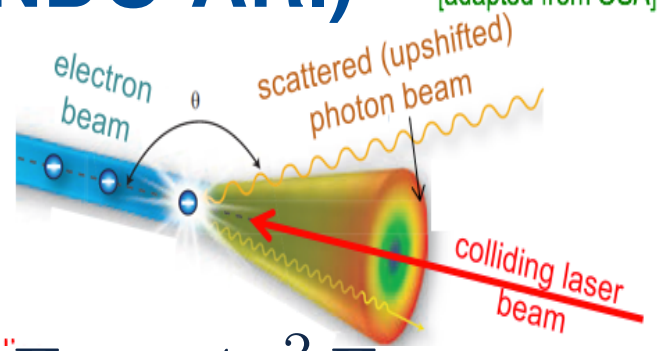




M. Andorf, et al., CLEO'17
https://doi.org/10.1364/CLEO_AT.2017.JW2A.90

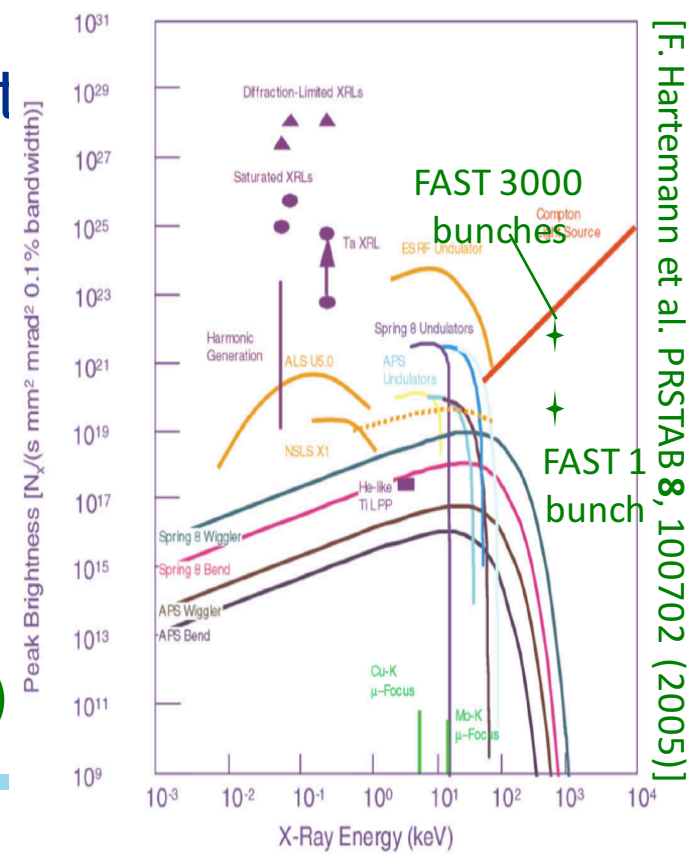
Inverse-Compton Scattering for high-flux gamma-ray production (funded by DHS DNDO-ARI)

[adapted from OSA]



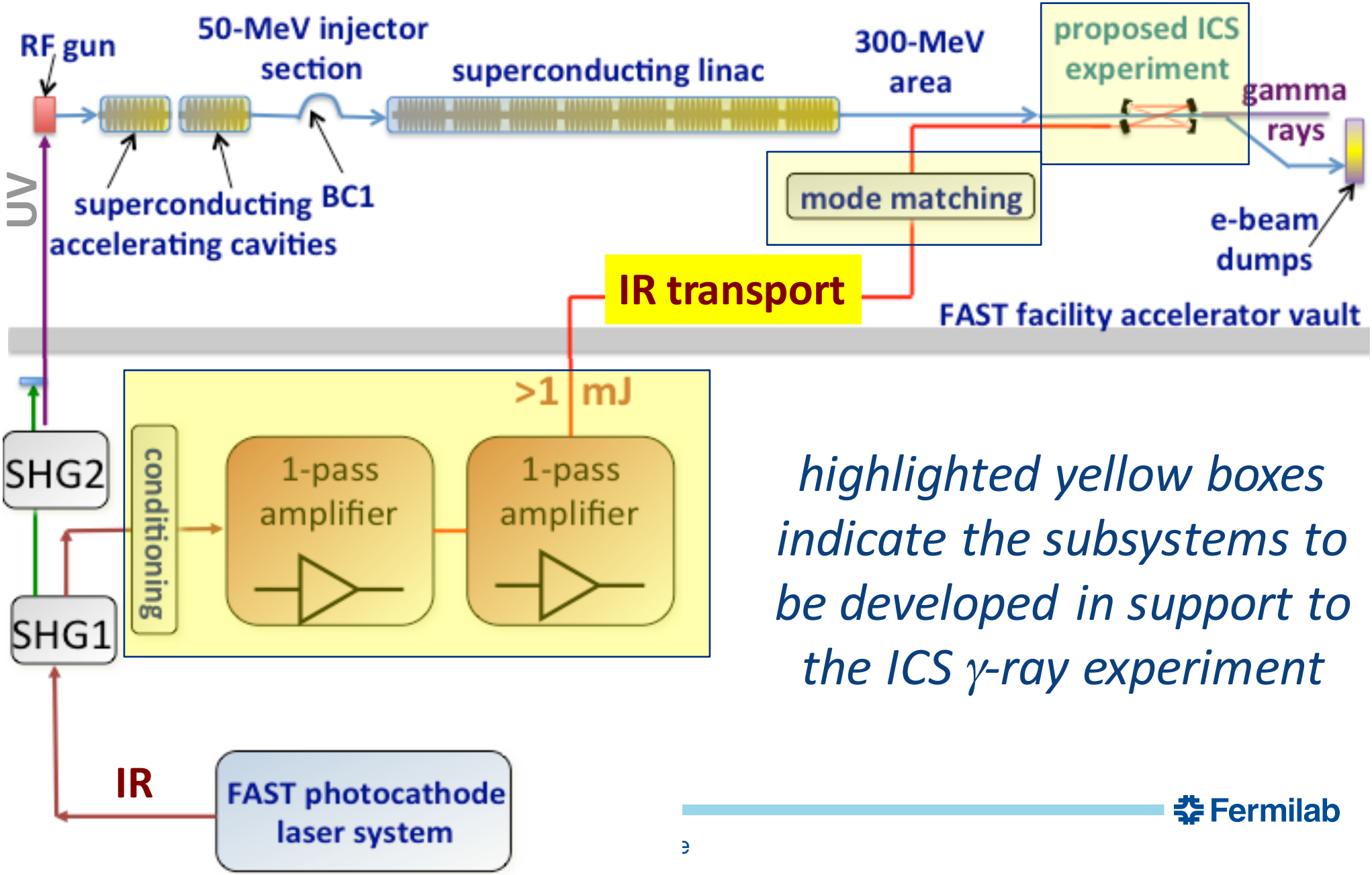
$$E_\gamma \simeq 4\gamma^2 E_L$$

- Use a conventional superconducting radiofrequency (SRF) linear accelerator which readily produce electron bunches at high frequencies.
- Develop a recirculation optical cavity to collide the e-bunches and laser pulses at high rep. rates
  - upgrade the laser currently available,
  - design and install a suitable interaction region.
- Combine SRF linac with optimized optical cavity to produce high-flux γ rays (we anticipate Watt level average power)



[F. Hartemann et al. PRSTAB **8**, 100702 (2005)]

Overview of the proposed experiment



highlighted yellow boxes indicate the subsystems to be developed in support to the ICS γ-ray experiment

γ-ray brightness optimization

Brightness in phot./sec/mm/mrd/0.1% BW

$$\mathcal{B} \propto N_\gamma f_c$$

# of γ photons

# of collision per sec 1 to 15,000 at FAST

# of γ photons

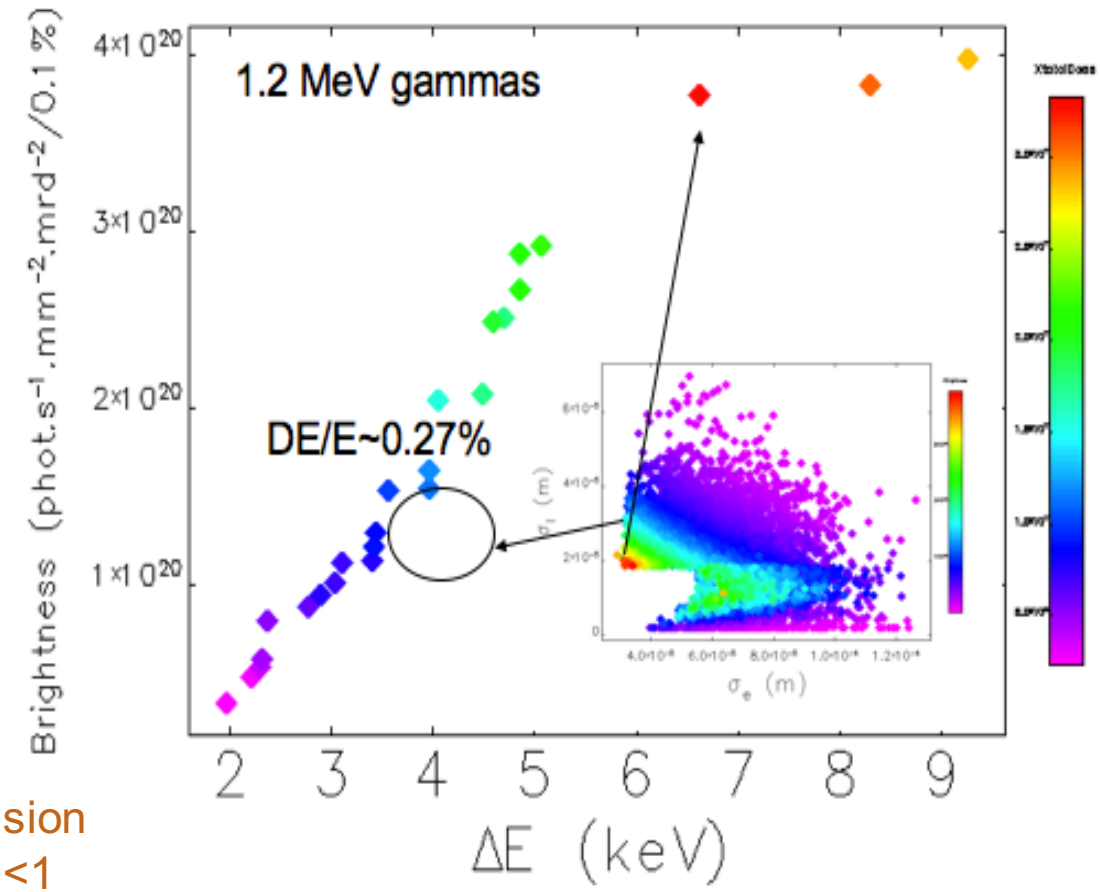
e-

colliding photon

suppression factor <1

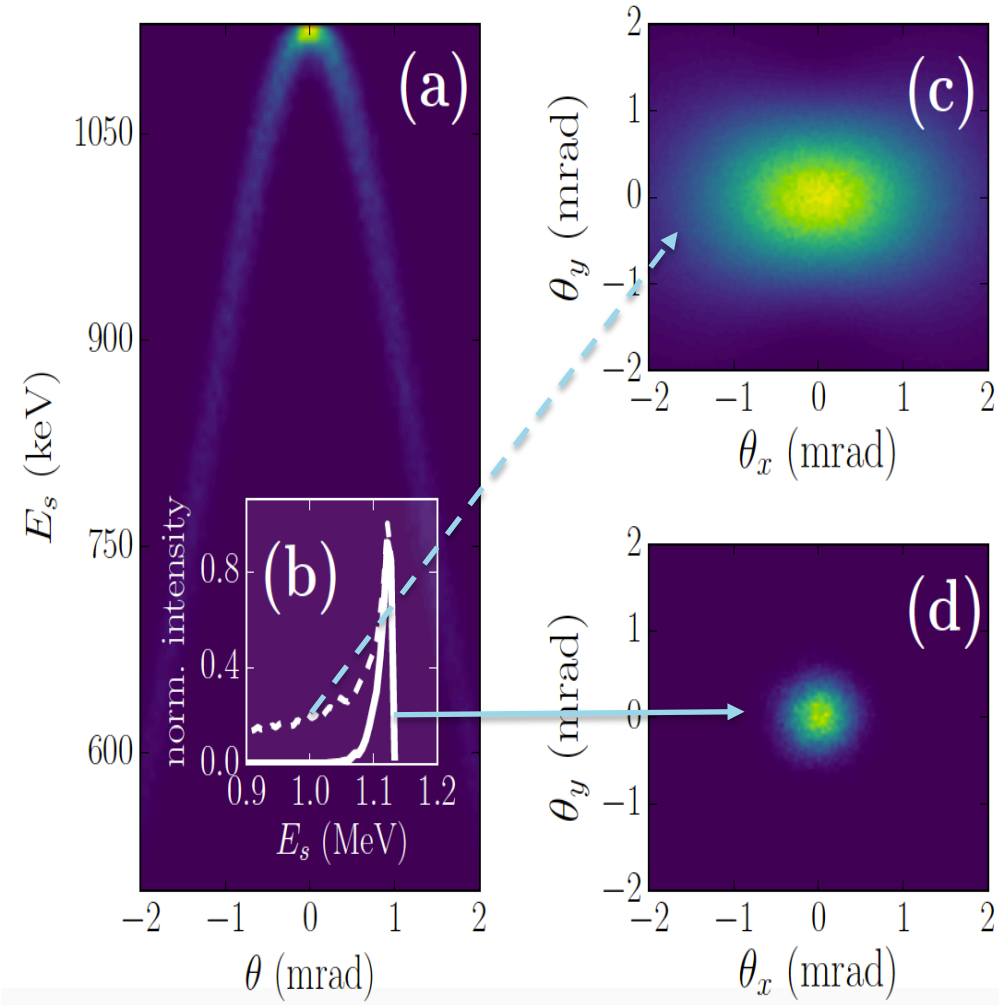
$$N_\gamma = \frac{N_e N_L \sigma_T}{2\pi(\sigma_{\perp,L}^2 + \sigma_{\perp,e}^2)} F$$

sizes of colliding laser (L) and electron(e) beams



D. Mihalcea et al., to appear in NIMB
http://dx.doi.org/10.1016/j.nimb.2017.03.140

Anticipated performances



- γ-ray parameters

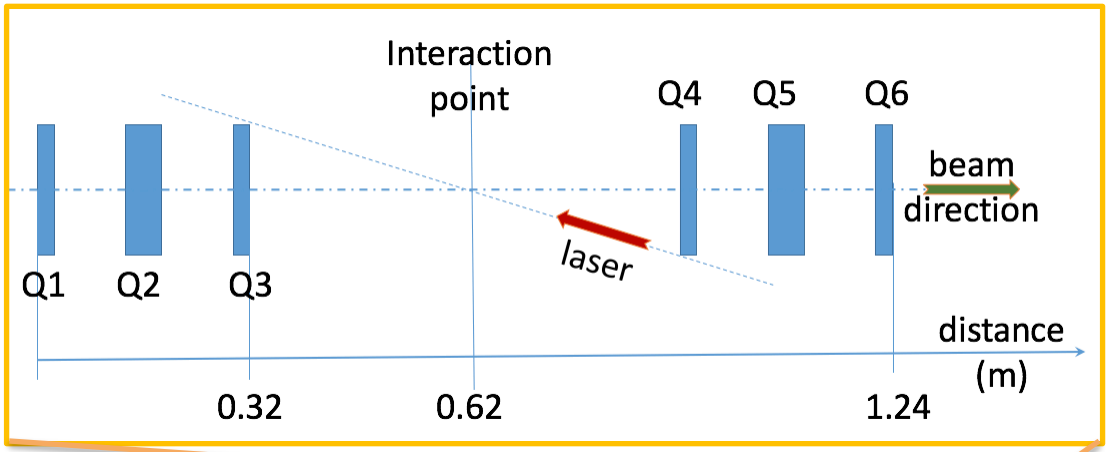
window	1 %	3 %	100 %
$\mathcal{B}_s$	2.7×10^{20}	2.1×10^{20}	1.1×10^{20}
N_s (phot.)	5.4×10^5	2.0×10^6	4.8×10^7
$\delta\omega_s/\omega_s$ (%)	0.25	0.82	2.2

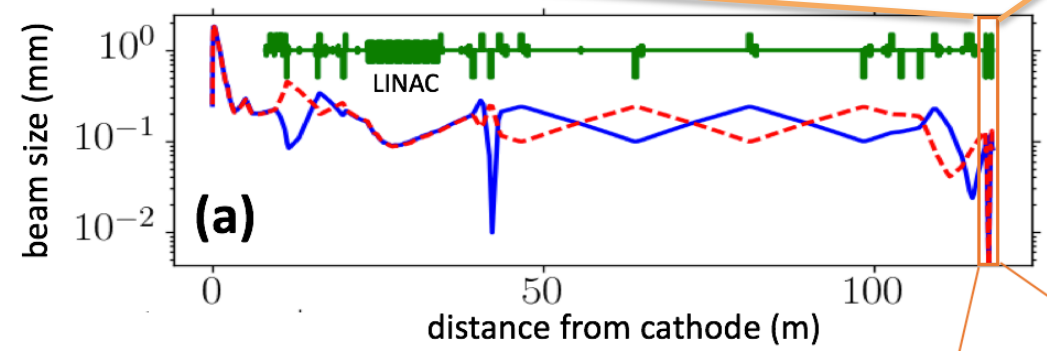
- e- & laser beams parameters

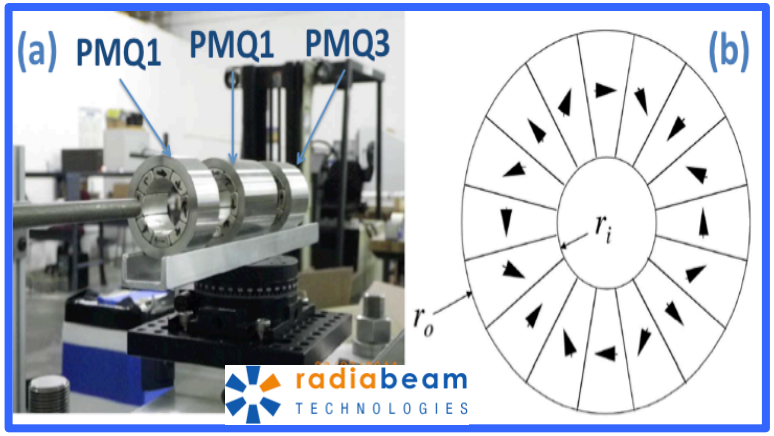
electron beam		laser pulse	
beam energy (MeV)	250.0	wavelength (nm)	1053
beam charge (pC)	200.0	pulse energy (J)	0.5
energy spread (%)	0.1	bandwidth (nm)	0.2
duration (ps)	3.0	duration (ps)	3.0
beam size (μm)	5.0	spot size (μm)	15.0
emittances (μm)	0.6		

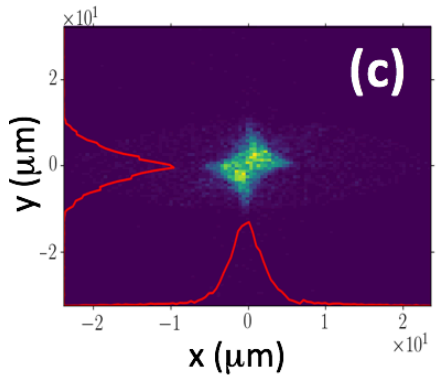
Beam dynamics Considerations

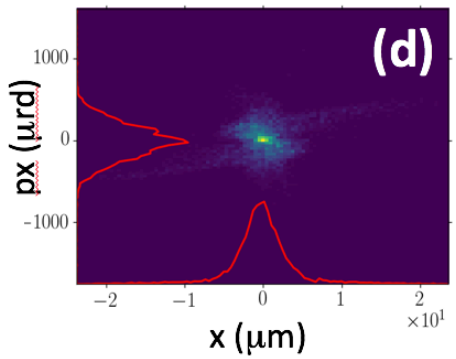
- ELEGANT matching + Impact-T tracking over the ~120 m (space-charge included only)
- Final focus needs to be compact and use PM quadrupole magnets
- Vibration is an issue

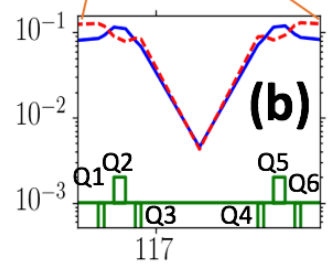




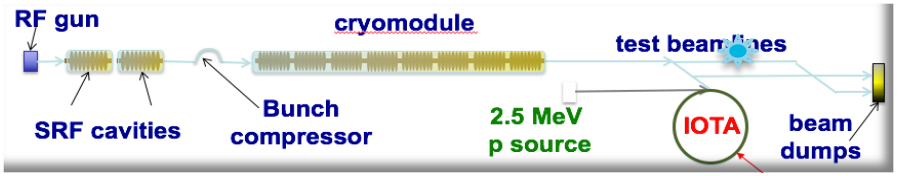




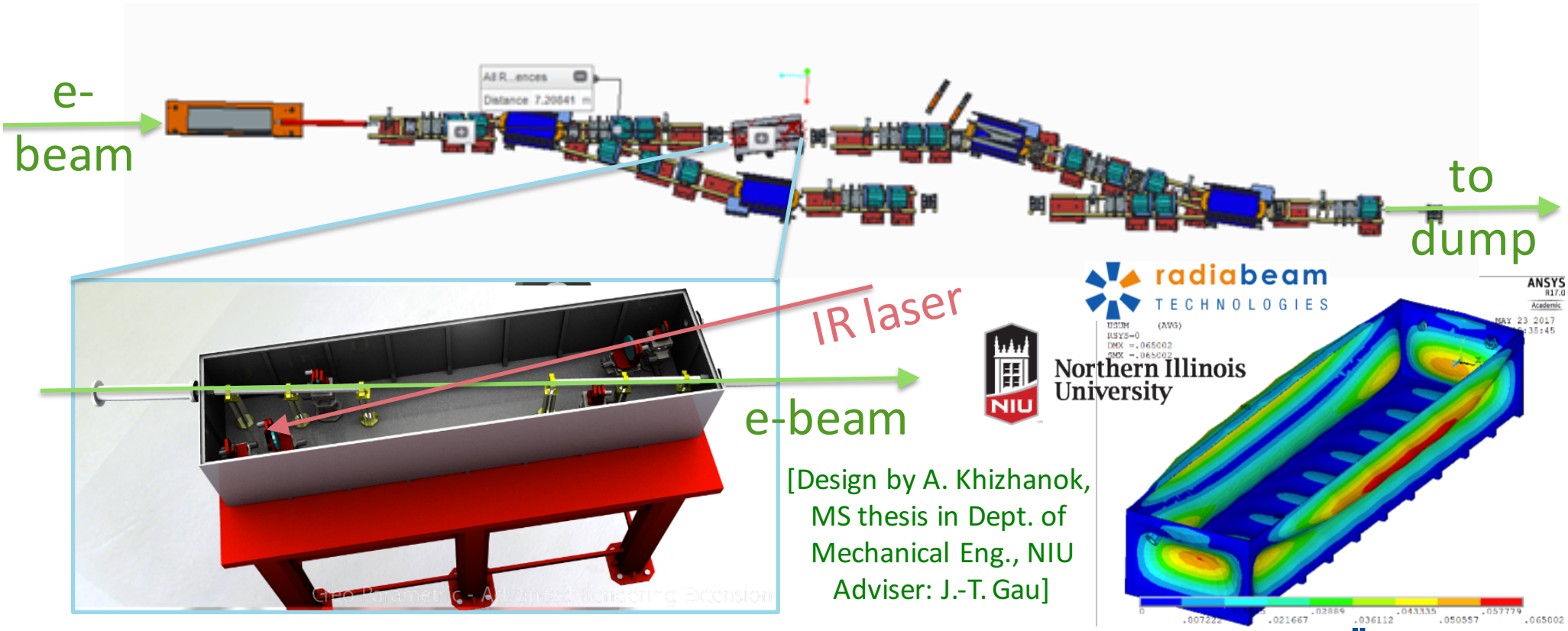




Possible interaction area



- Interaction region foreseen downstream of D600
  - Small-aperture permanent quadrupole
  - Decoupled from transport to HE dump /injection to IOTA
- Vibration measurement to be incorporated in design



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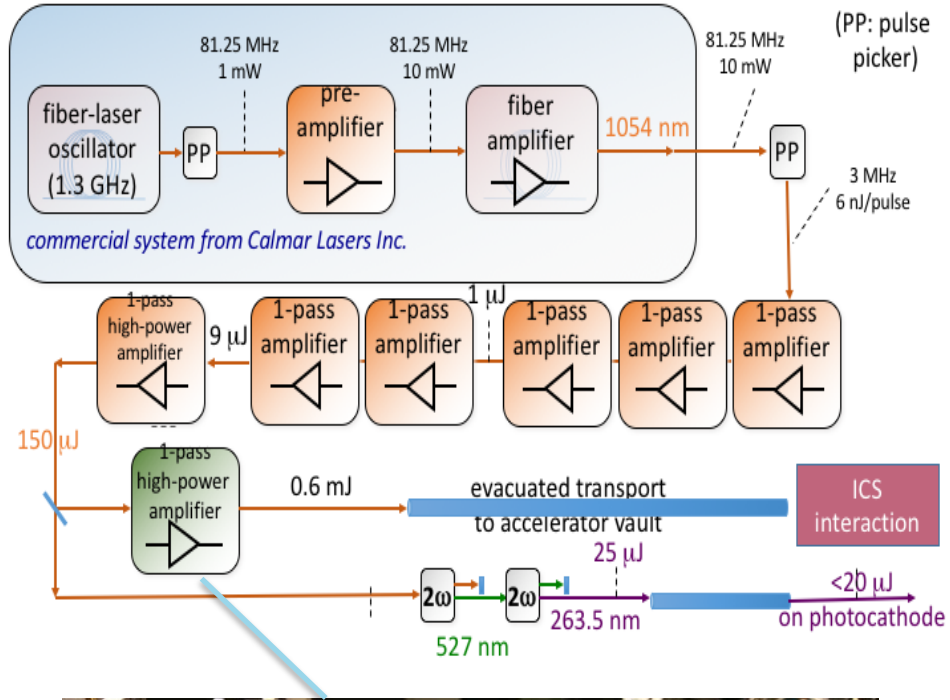
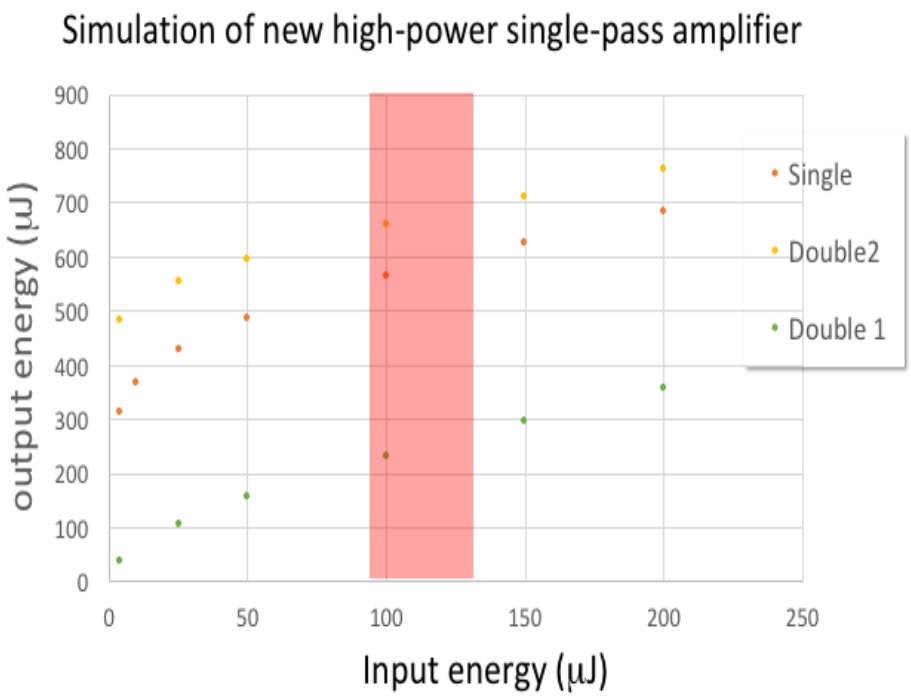
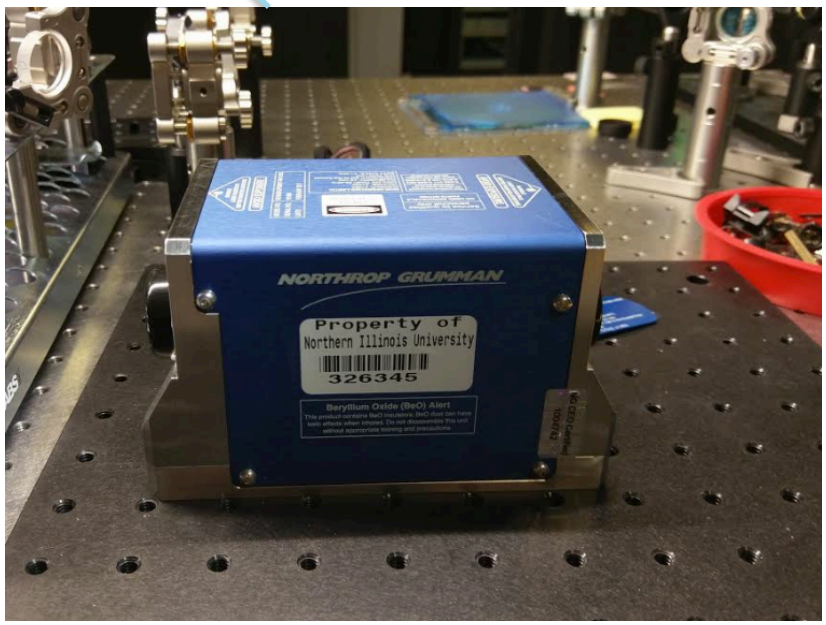
Progress on laser upgrade

- Current laser system was optimized (J. Ruan, et al.)
- 1st amplifier received from Northrop-Grumman to be tested (part of M. Urfer MS thesis)







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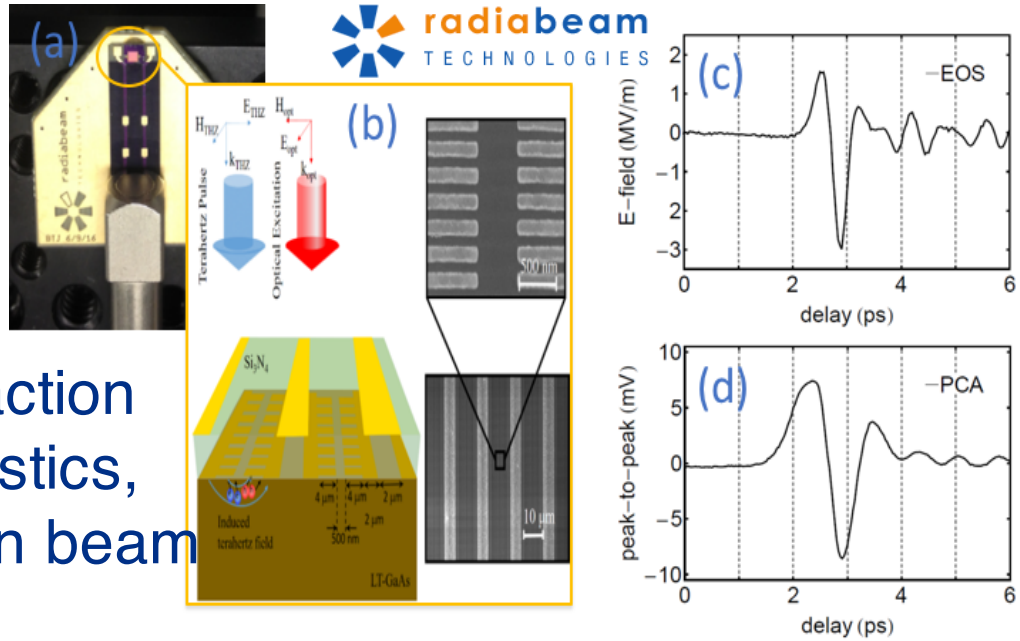
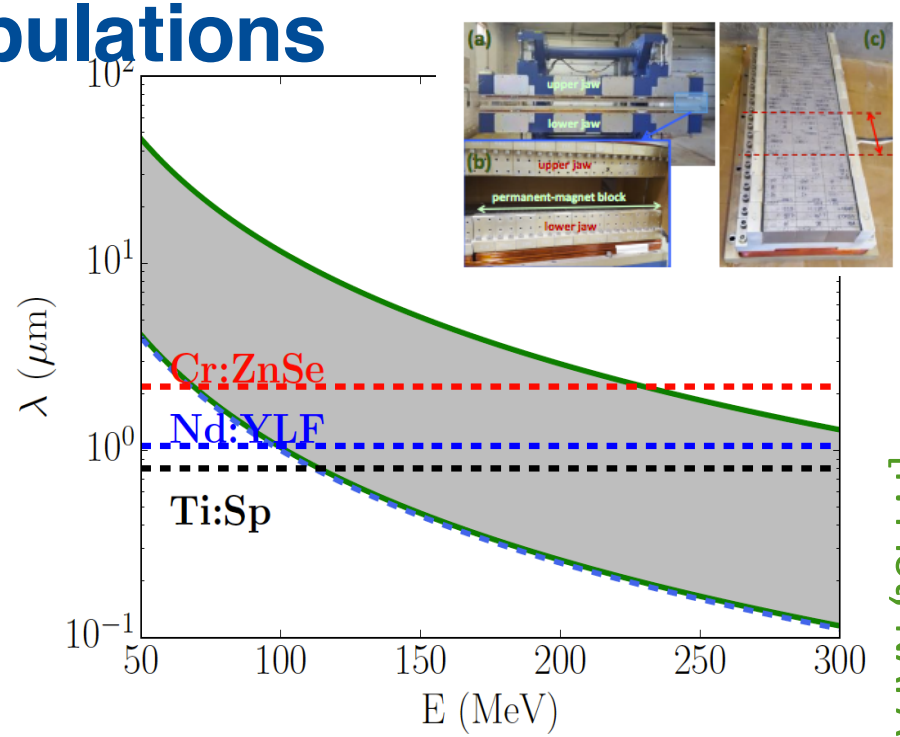
ICS timeline (still in discussion)

- 1st interaction planned in 2019
- Summer 2017:
  - Characterize beam downstream the cryomodule (especially transverse emittance & energy spread)
  - Commission the laser amplifier and demonstrate E>0.5 mJ
  - Finalize design of the optical cavity
- Fall 2017
  - Manufacture PMQ
  - Build optical transport line?
- Beyond
  - Finalize and construct interaction area with associated diagnostics, test some **diagnostics** when beam time available

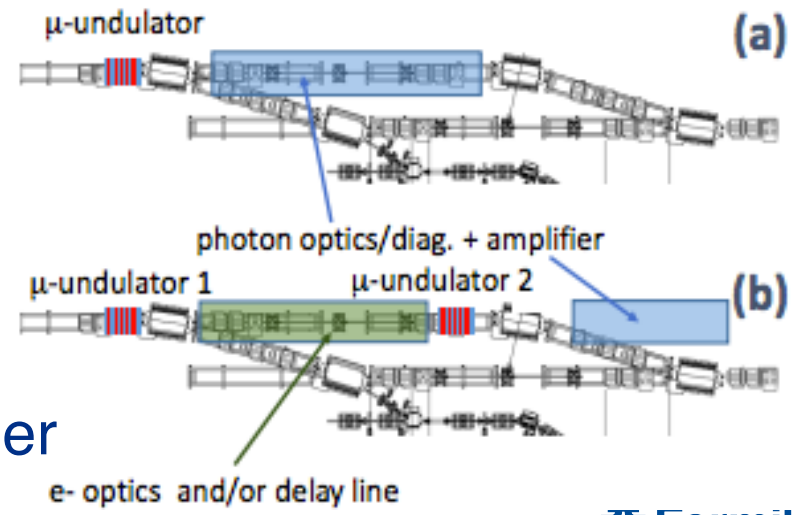


Possible longer-term experiments: laser/radiation-based manipulations

- Capitalize on the infrastructure available from the ICS
  - High-energy laser pulse
- Optical- or self-manipulation of e beams
  - OSC R&D (UR interference)
  - Energy/density modulation (optical-replica diagnostics, …)
  - Controlled chromatic aberrations aka beam conditioning (Zholents PRSAB 2005)
  - Radiation sources
  - Longitudinal-space-charge amplifier

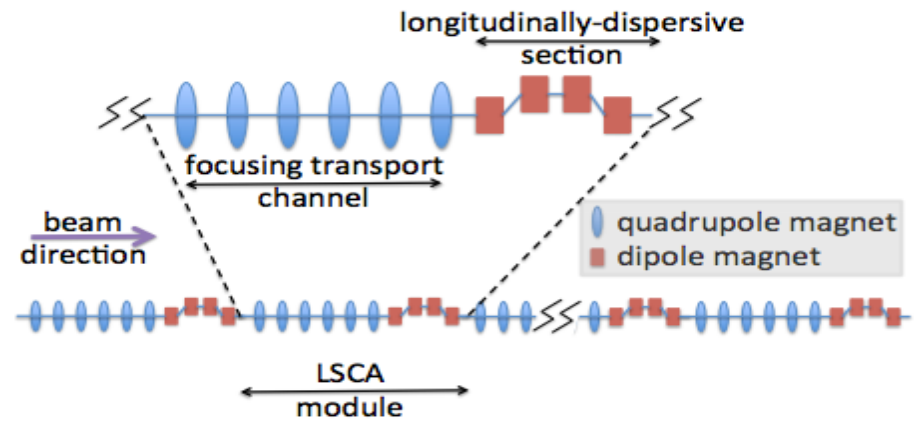


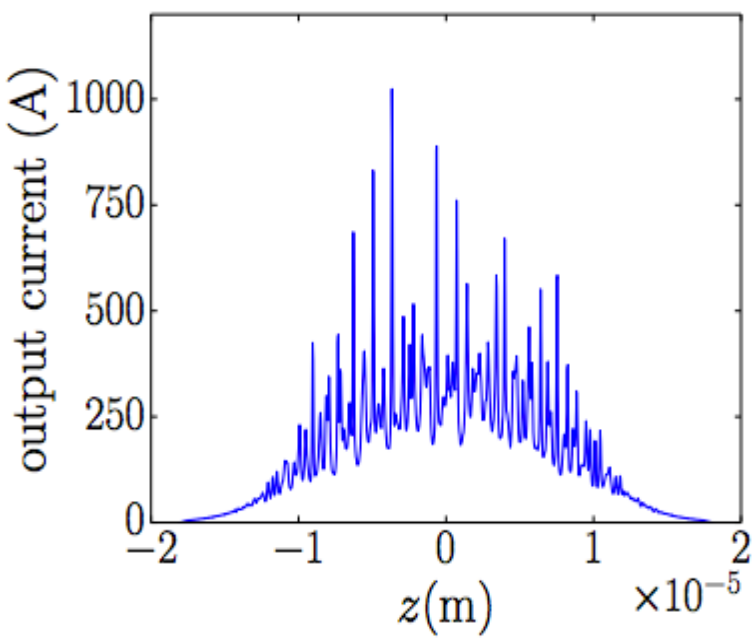
[P. Piot, NAPAC16]

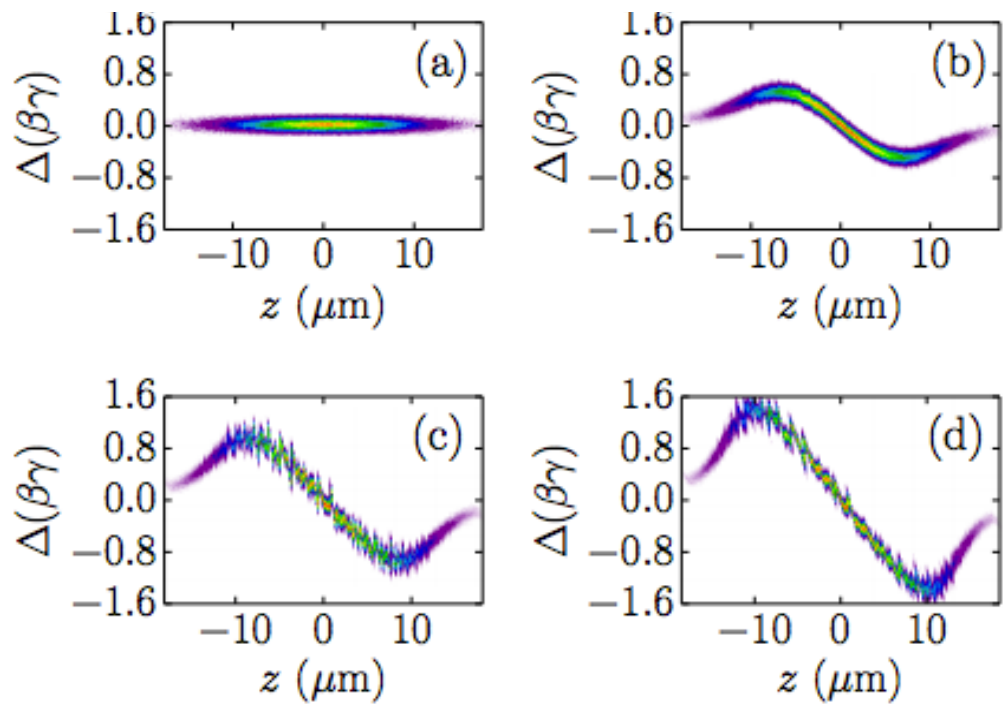


Possible longer-term experiments: LSCA

- Cascaded longitudinal space-charge amplifier was investigated in FAST using start-to-end simulations (simplified model)





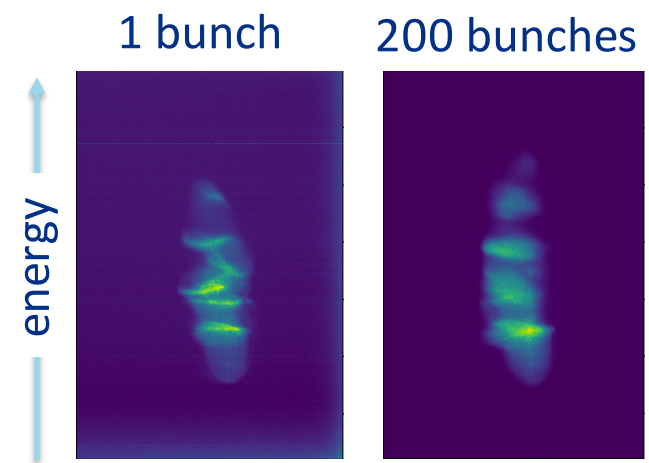


[H. Halavanau, 10.1016/j.nima.2016.03.002

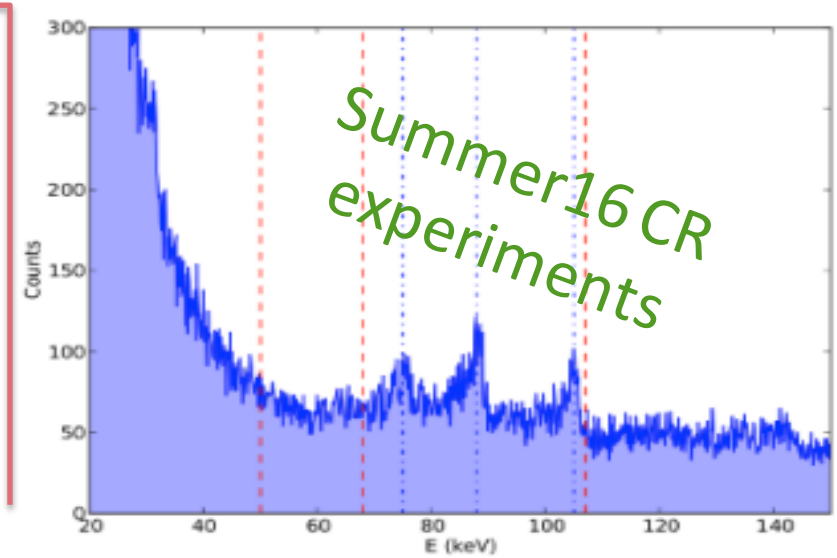
Final comments: other opportunities being explored

- Compatibility of high-repetition-rate beam driven acceleration concept (e.g. DWFA)
- Resuming the channeling radiation experiment in collaboration with MEPHI, IPN Lyon, U. Ferrara.
- Applications of ultra-relativistic flat beams (see Halavanau's talk):
  - Acceleration in DLAs (ACHIP collaborations)
  - Diving wakes in planar structures
  - Micro-undulator tests

Wakefield due to a bunch train in a DLW



[F. Lemeny, P. Piot @PITZ]



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