Fermilab U.S. DEPARTMENT OF ENERGY Office of Science

Fermilab Accelerator Science & Technology (FAST) Facility

Philippe Piot* on the behalf of the FAST-IOTA team

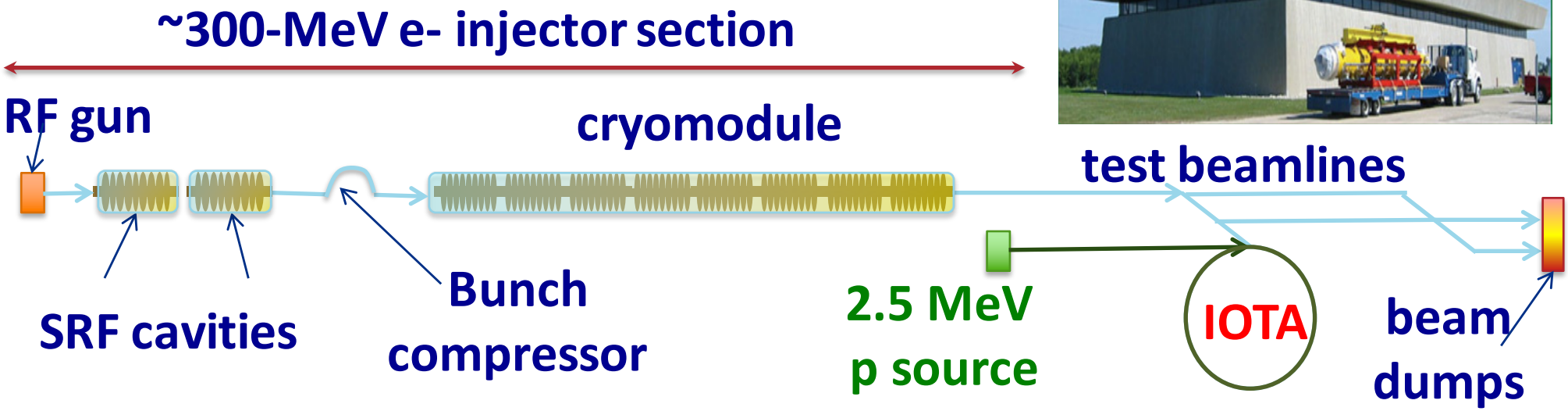
49th Fermilab Users Meeting

June 16th, 2016

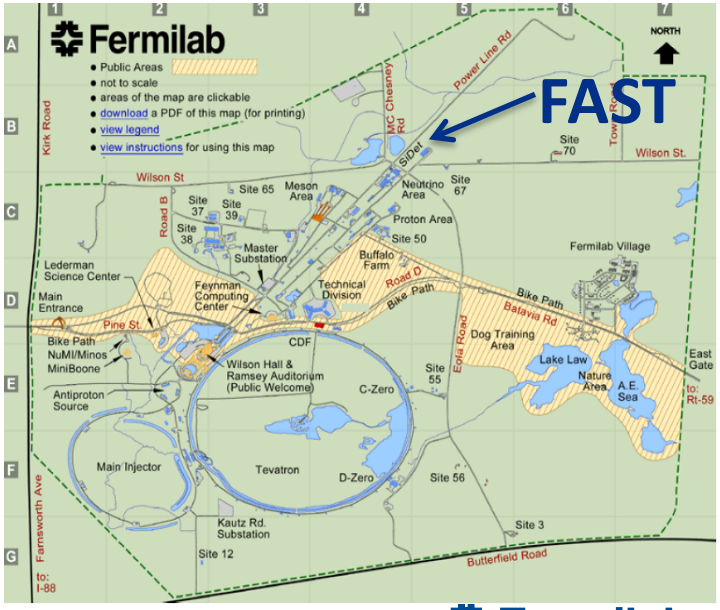
http://fast.fnal.gov/

*Fermilab/Northern Illinois University joint appointee

The FAST/IOTA complex @ NML



- FAST-IOTA facility complex includes:
  - IOTA (integrable-optics test accelerator) ring,
  - An electron linear accelerator (that nominally serves as an **electron injector** to IOTA),
  - A **proton source & injector** for IOTA
- Facility is located in the New Muon Lab (NML) building



Research enabled: HEP & beyond

Instrumentation

Human capital + education

Simulation Tools

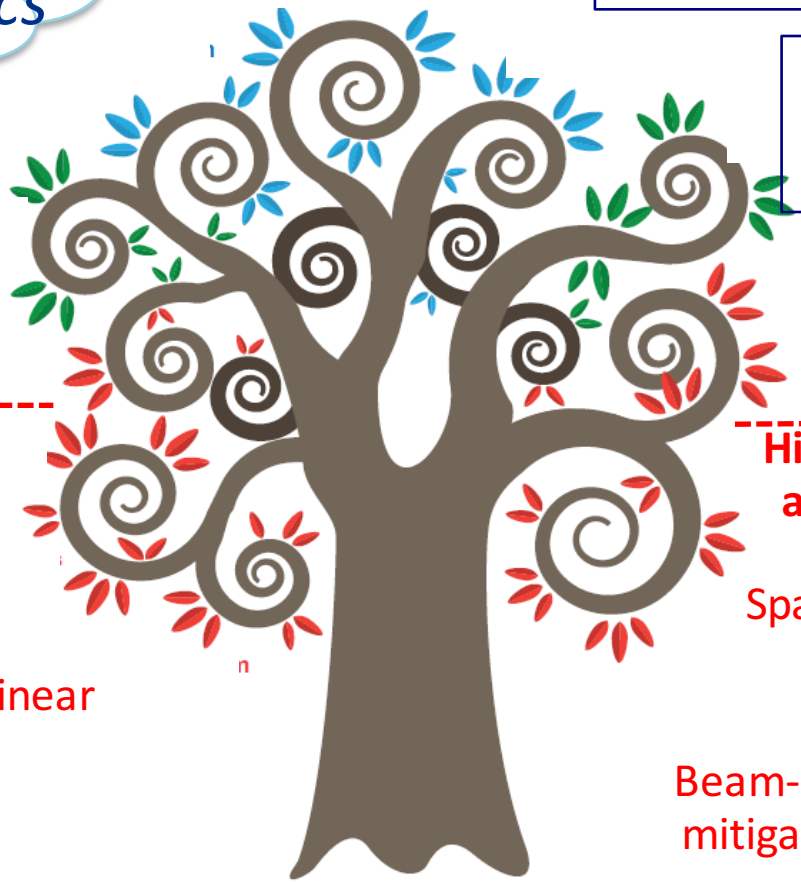
Fundamental Beam Physics

Application to energies frontier

R&D superconducting linac

Novel accelerator-based light source concepts

Application of high-power e-beams



High-intensity frontier accelerators for HEP

2015

Beam-cooling methods

Space-charge control

Integrable nonlinear optics

Beam-halo mitigation

[Adapted from H. Kung, DOE]

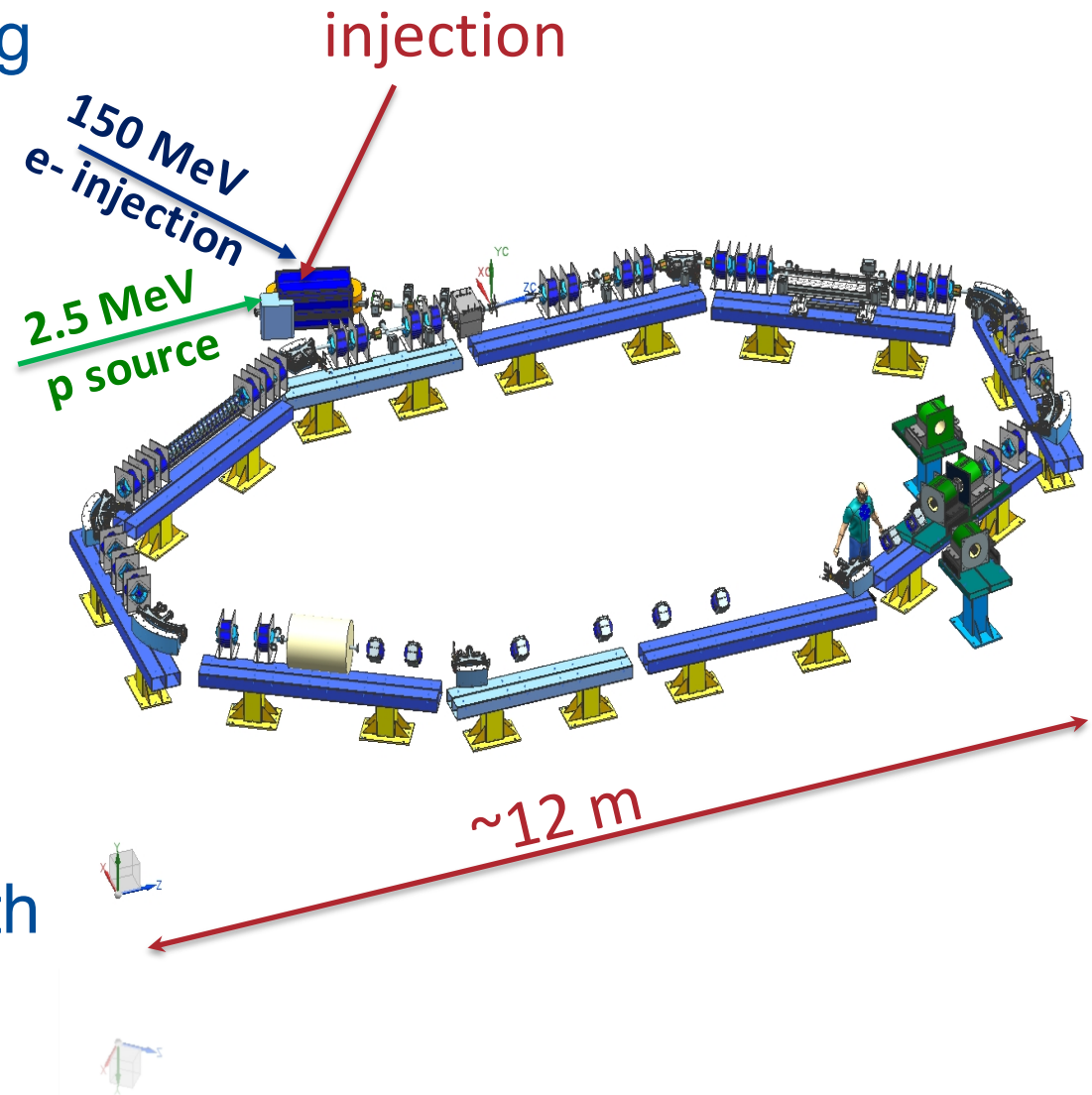
FAST/IOTA collaborative framework

- FAST/IOTA supports collaborative research opportunities with Universities and Industries over a wide range of topics:
  - Numerical simulation & machine control.
  - Beam instrumentation.
  - Experimental test of beam-dynamics concepts
    - Phase-space manipulation and cooling.
    - Advanced accelerator concepts.

- Several funding opportunities to carry out the type of research enabled by FAST/IOTA available from DOE, NSF, DOD (DHS, DARPA, DNDO)

IOTA: shifting the paradigm of future circular accelerator

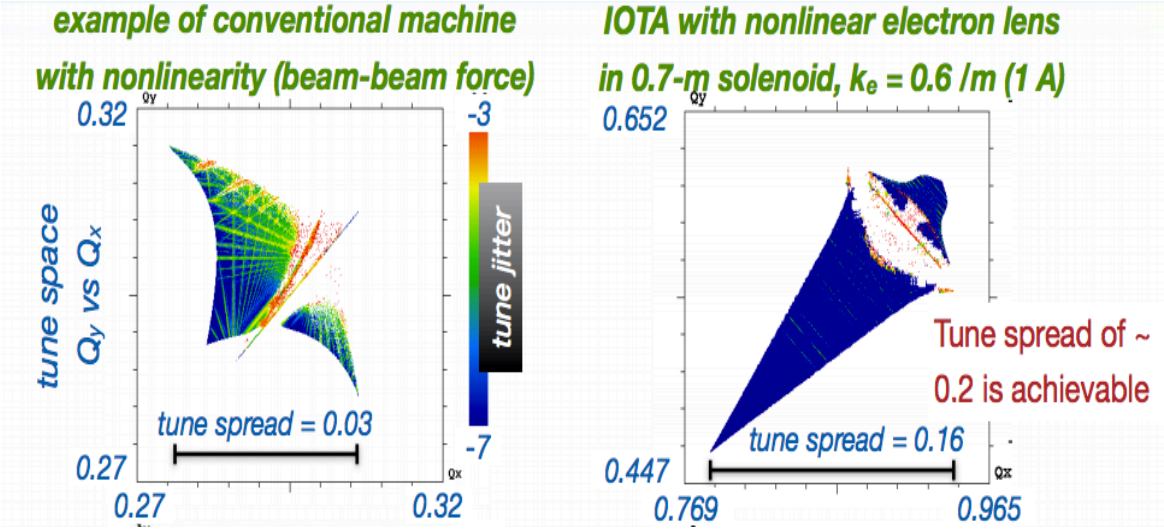
- Explore ways of increasing stored current in circular accelerators:
  - “Integrable” optics.
  - Space-charge-compensation methods.
- Investigate advanced beam-cooling methods
- Support fundamental science: quantum optics
- IOTA can operate with both electron (~150 MeV) or proton (2.5 MeV) beams.



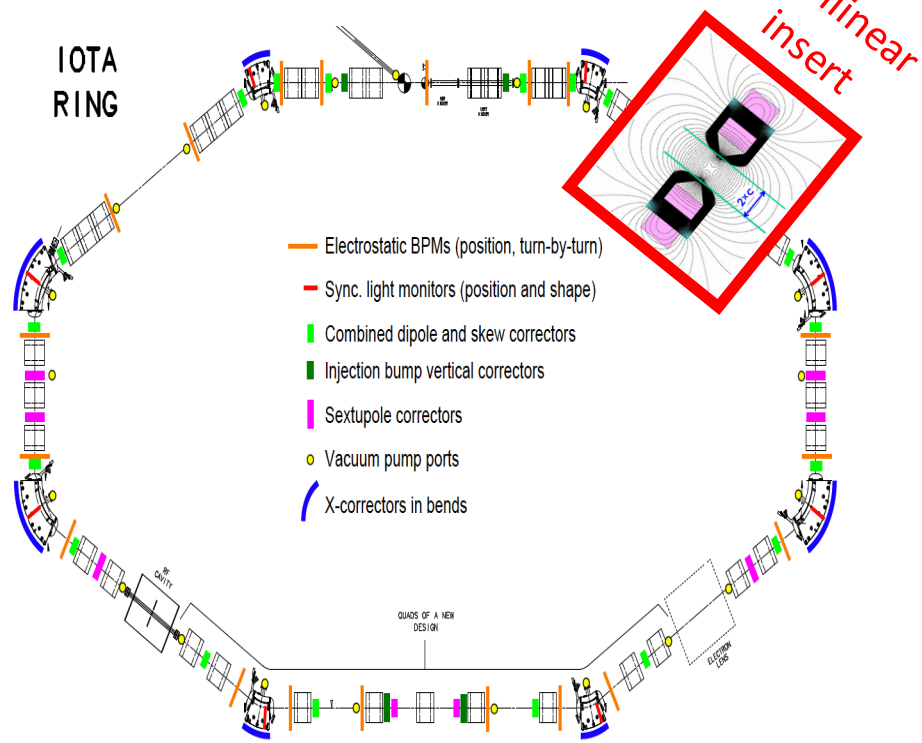
IOTA program with e-

- Integrable nonlinear optics: explore nonlinear inserts that yields integral of motions
  - Solenoids
  - electron lenses
  - With electron use pencil beam to characterize non-linear lattice in the single-particle regime

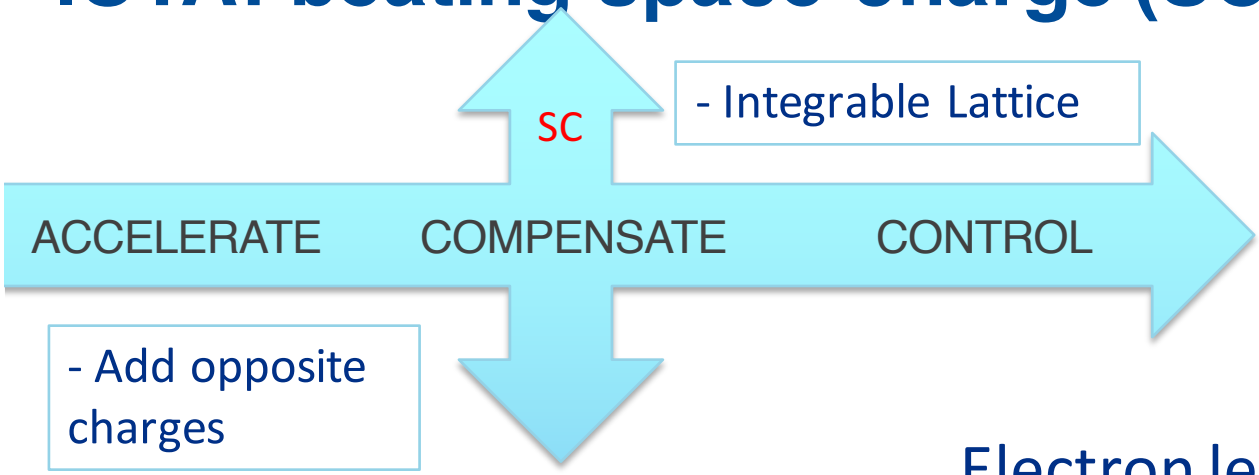
- Optical stochastic cooling

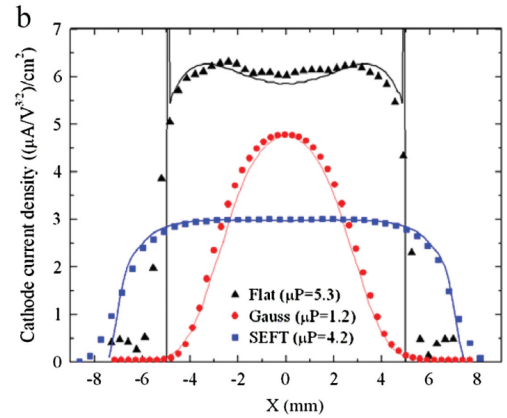


[Adapted from G. Stancari]



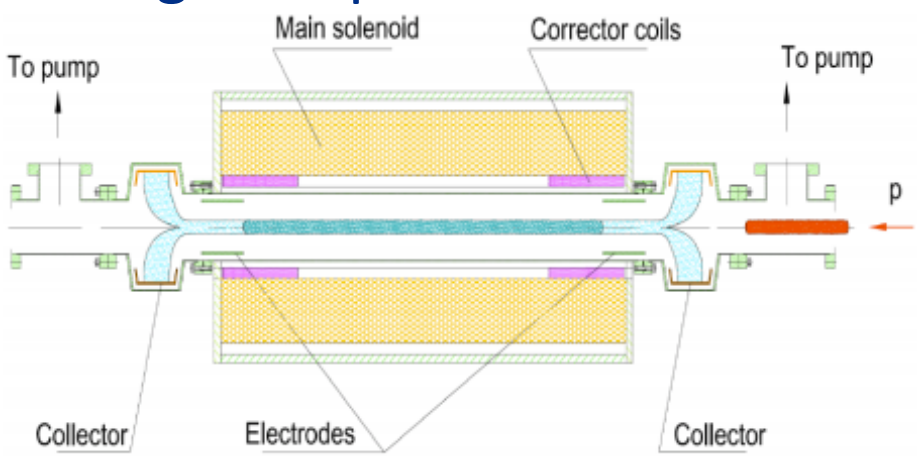
IOTA: beating space-charge (SC) limit

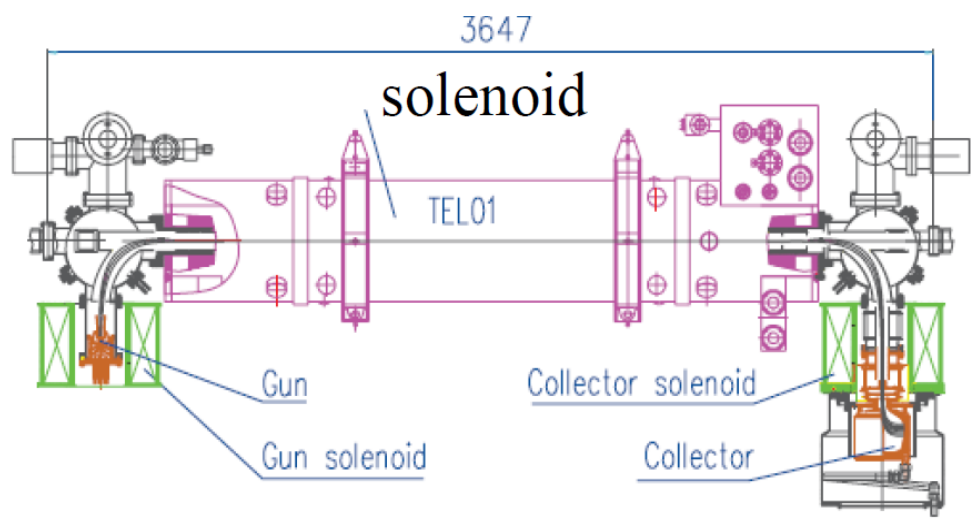




Electron lens (comp. or control)

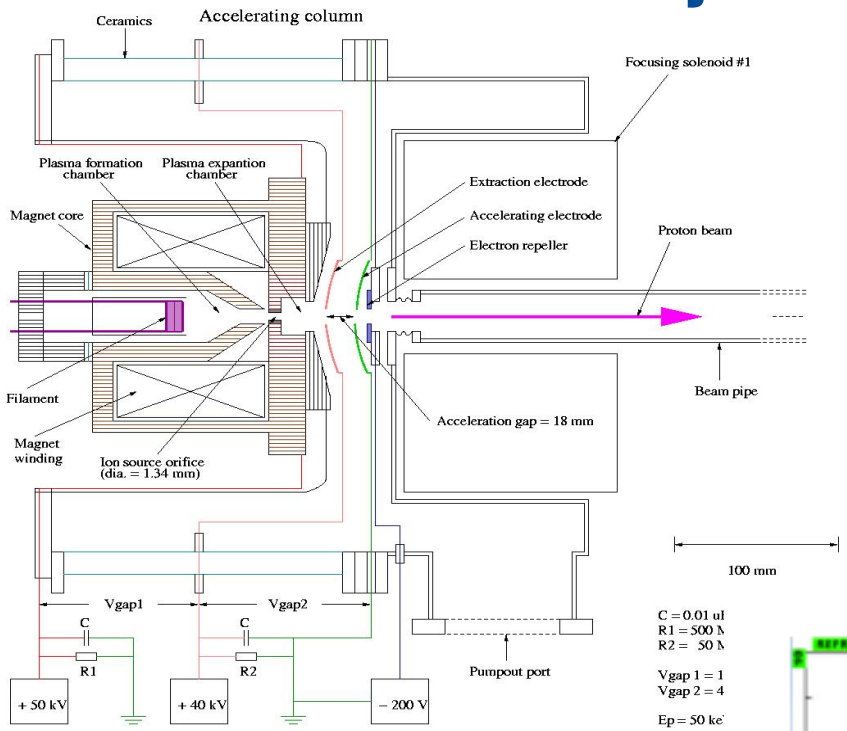
Self-ignited plasma column





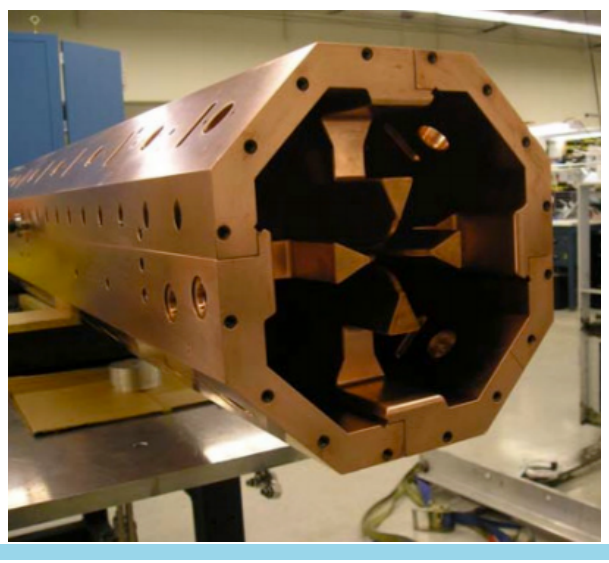
[Adapted from C. ShikPark/V. Shiltsev]

Proton-source injector

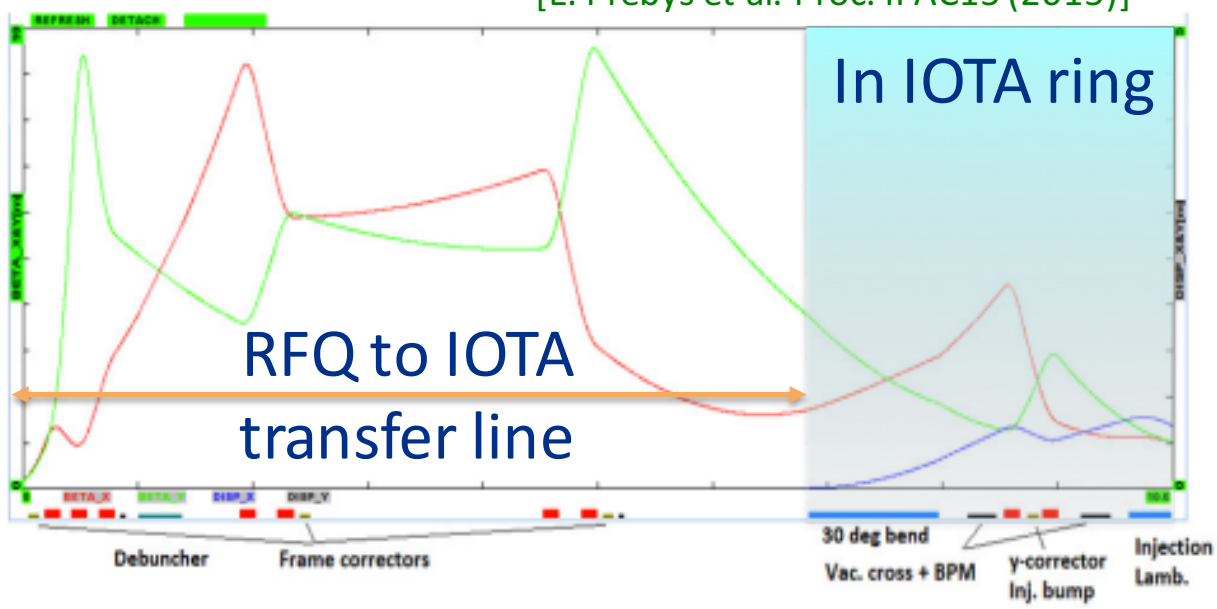


Based on component available from the HINS Test Facility:

- 50-kV proton source
- Radiofrequency quadrupole (RFQ) section 325 MHz
- A de-bunching cavity

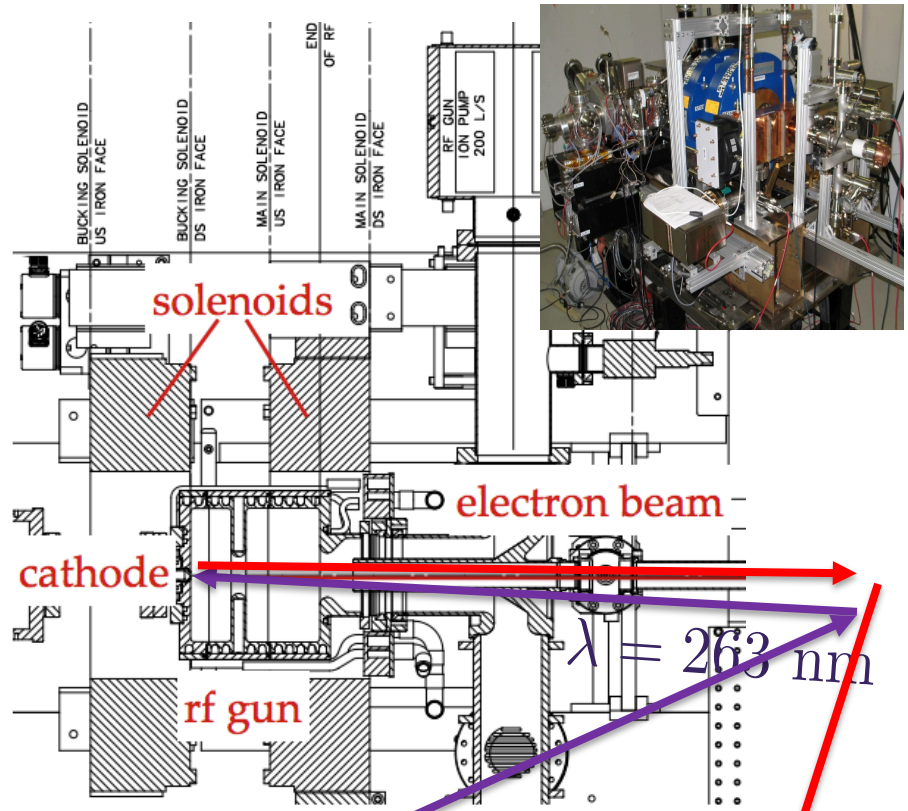


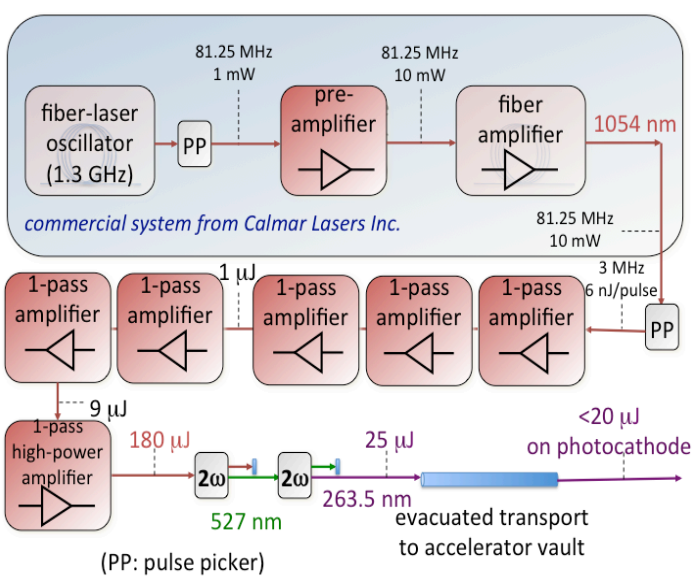
[E. Prebys et al. Proc. IPAC15 (2015)]

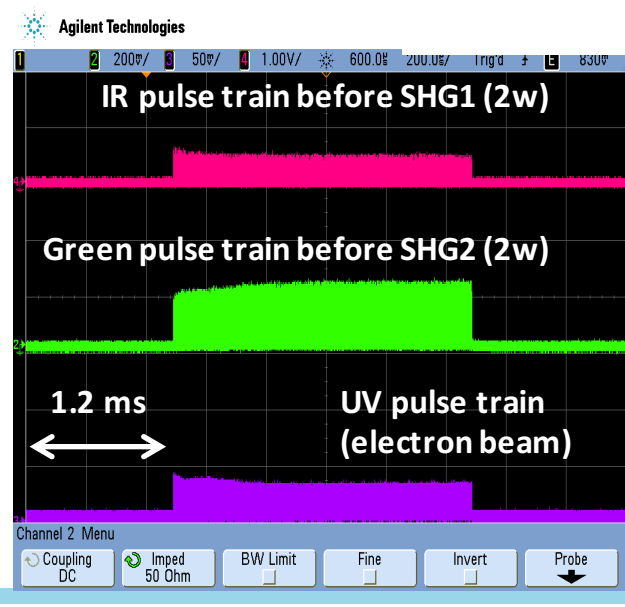


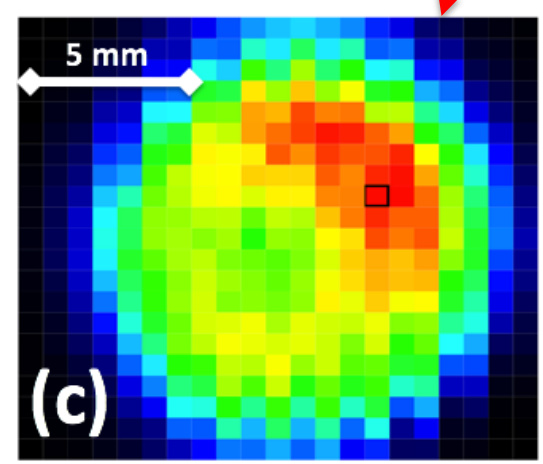
Electron Source

- e- source based on a radio-frequency (RF) gun coupled to
  - A high-power laser
  - A high-quantum efficiency photocathode (Cs_2Te)
- Capable of forming high-brightness electron beams arranged as bunch trains





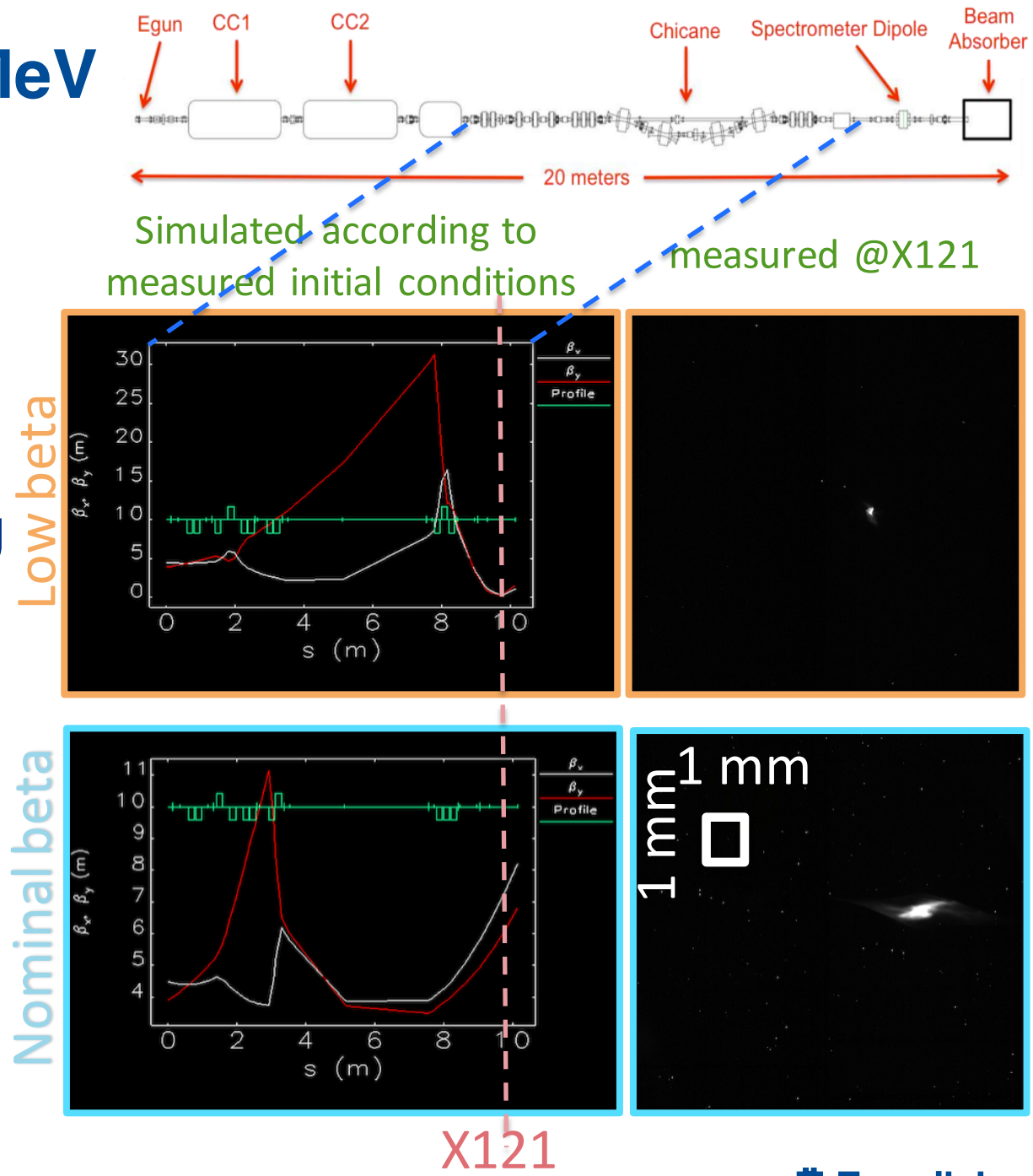




Acceleration to 50 MeV

- e- source is coupled to two SRF cavities
- Beam accelerated to 50 MeV (5/17/16)
- Characterization and beam control coupling machine control system to simulation (6/4/16)
- Developed python-wrapper around ACNET system to switch acc. settings w. online simulation

[A. Romanov, H. Halavanau, et al.]



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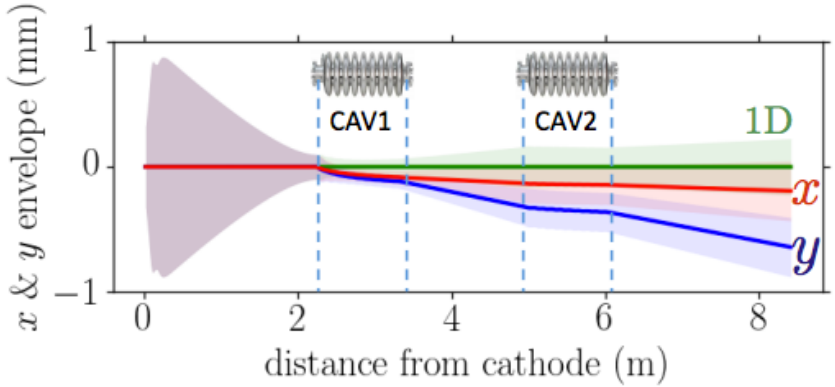
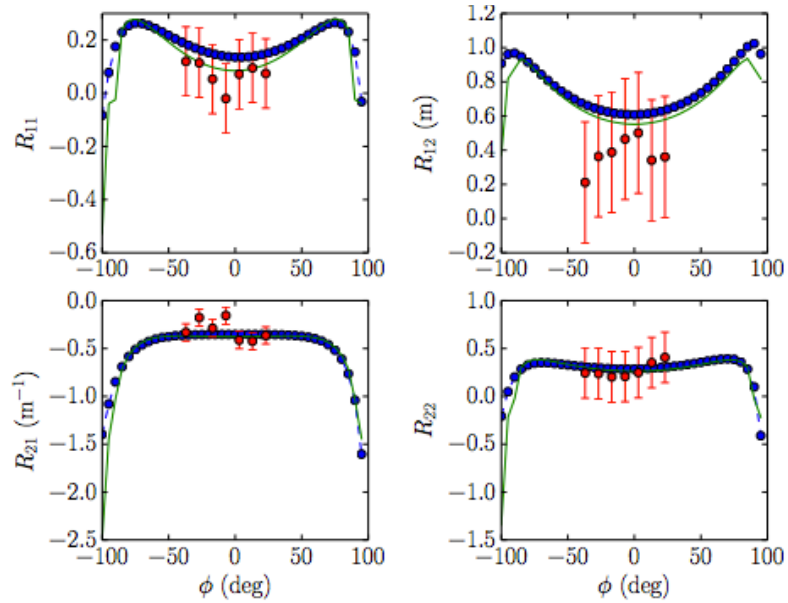
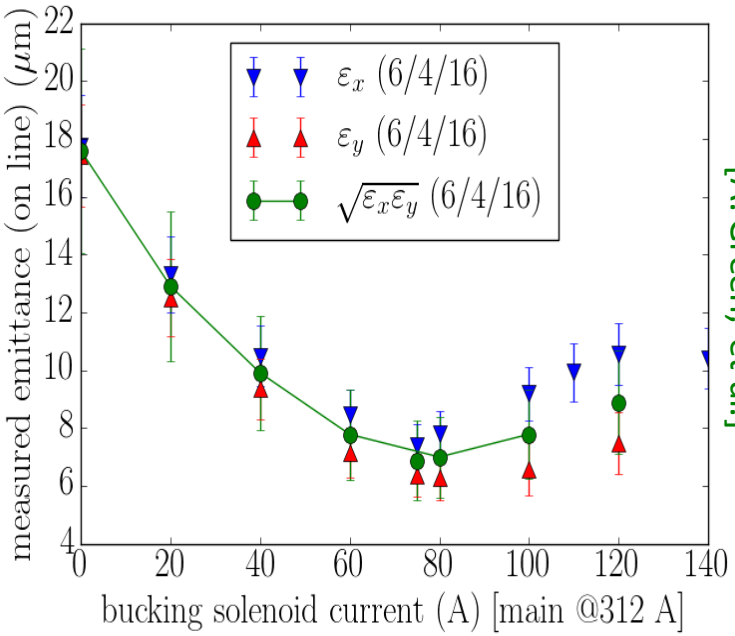
Experiments at 50 MeV

- Understanding beam dynamics in SCRF cavities:
  - transverse focusing properties of SCRF cavity when $G_{rf} \sim E_{in}$
  - Exploring impact of imperfections due to auxiliary systems (6/4/16)





[A. Halavanau, et al. IPAC16 (2016)]

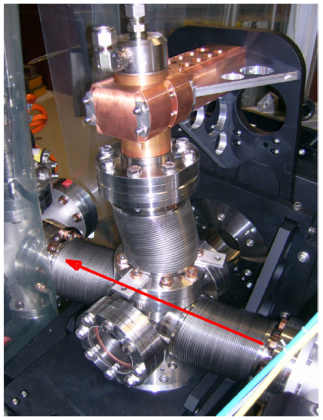


[A. Green, et al.]

- Charactering & optimizing the e- beam properties (work in progress)

Experiments at 50 MeV: Xrays via channeling in crystals

NIU/FNAL/KEK/HZDR (Dresden)/KU/VU

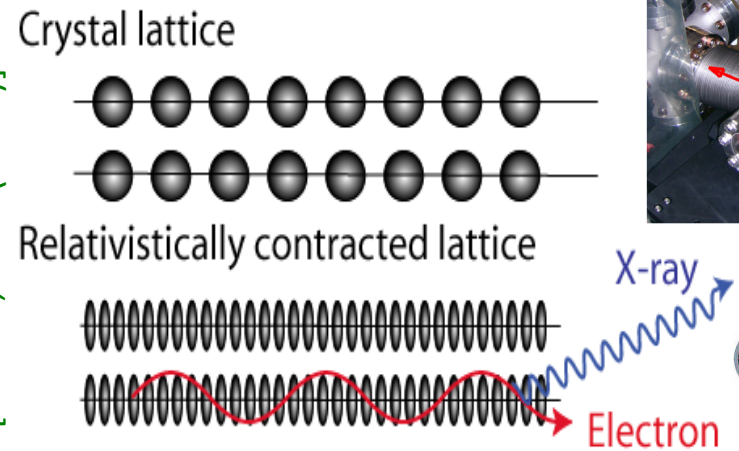


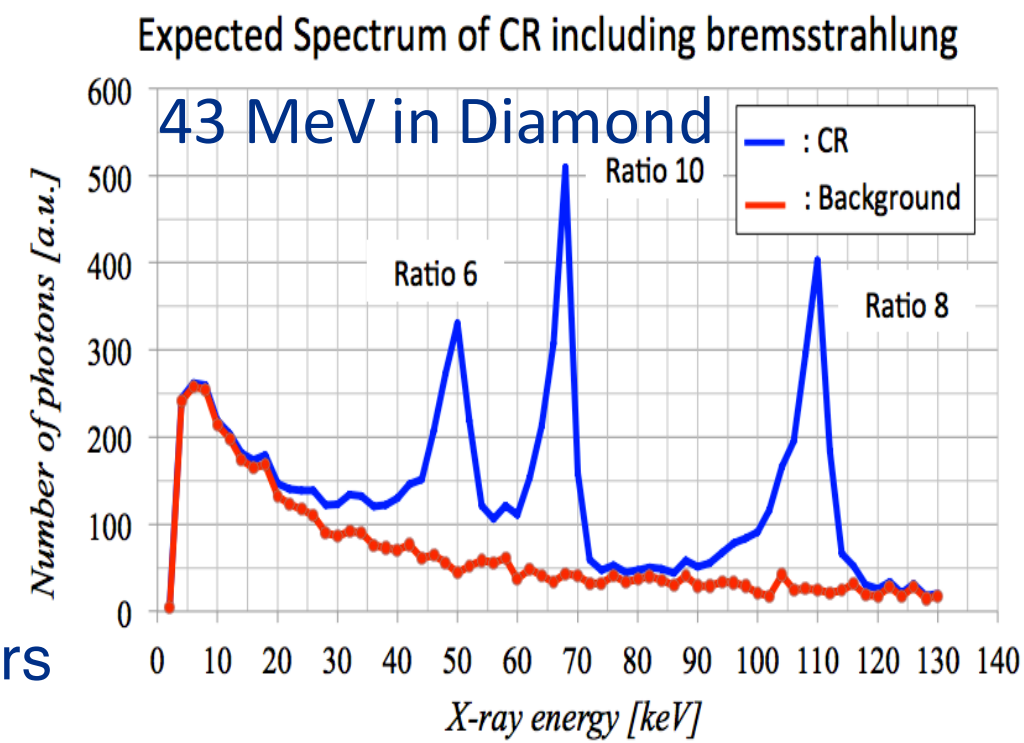
- Channeling radiation occurs as electrons propagate in Xtals with angle below critical angle
- Brightness expected to scale as:

$$\mathcal{B} \simeq \frac{I_{avg}}{e} \frac{\gamma^2 Y \sigma'^2_e \times 10^{-3}}{\varepsilon_n^2 \delta} F\left(\frac{\psi_c}{\sigma'_e}\right)$$

- FAST injector is an ideal candidate to produce high brightness X-rays
- If successful technique could be scaled to smaller footprints by combining w. , e.g., laser-driven accelerators

[C. Brau, et al. (2013)]

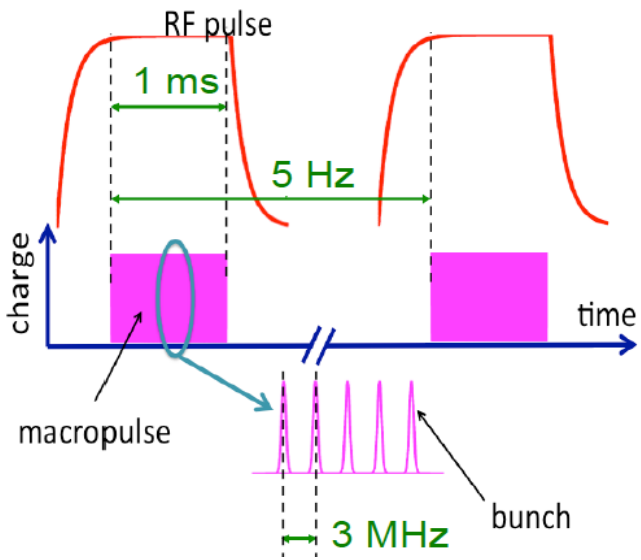


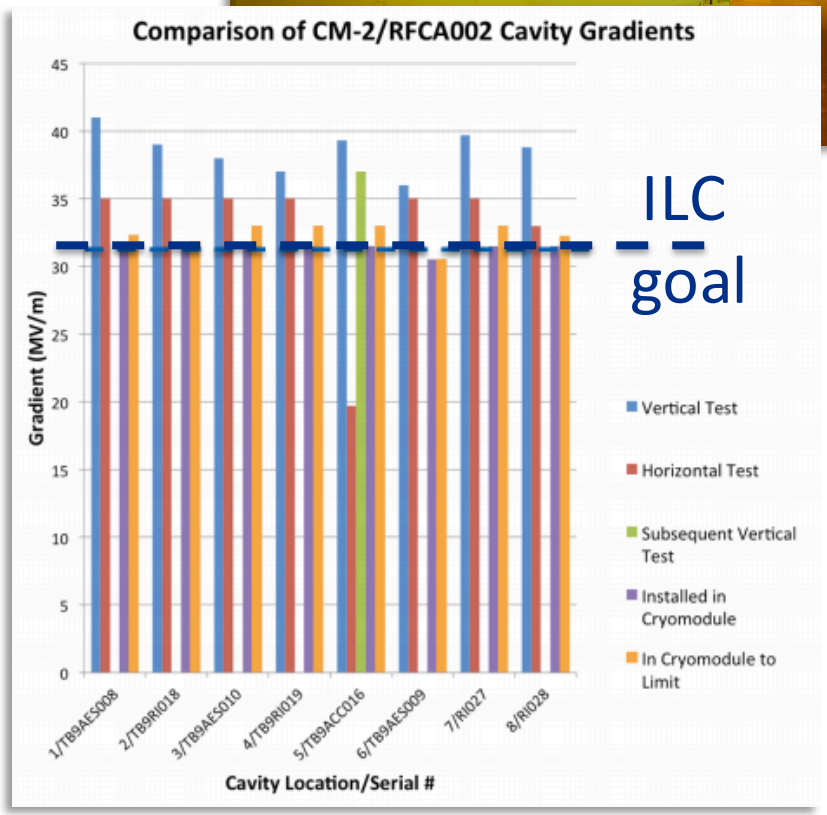


[J. Hyun (KEK, SOKENDAI U.]

Acceleration to ~300 MeV

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





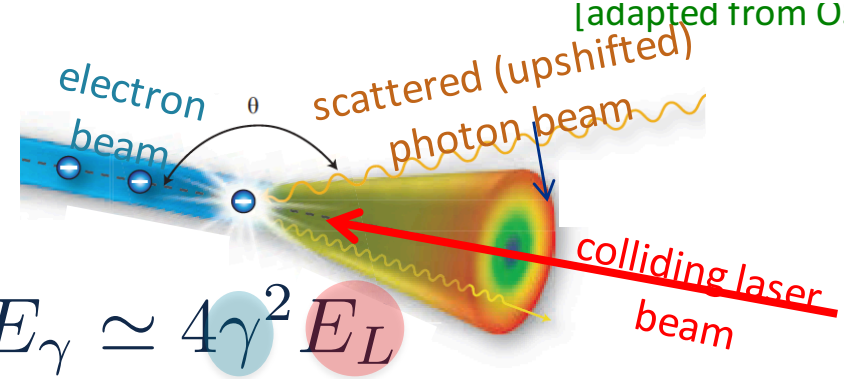
[E. Harms, et al. SRF2015 (2015)]

- IOTA requires 150-MeV e-beams.

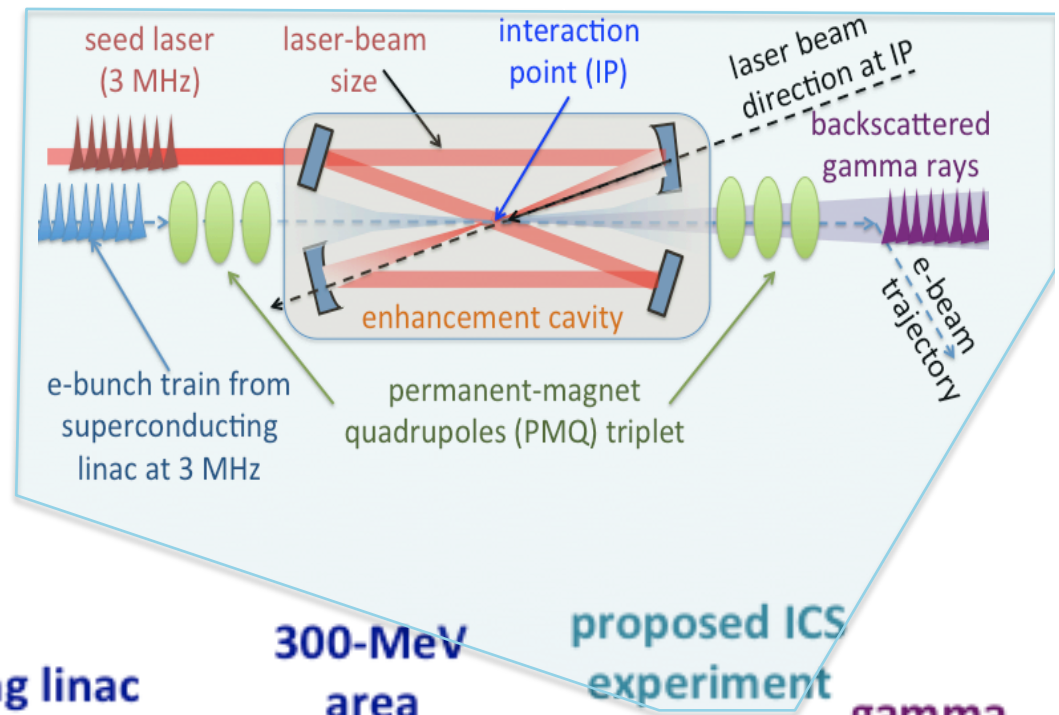
[adapted from OSA]

γ-ray source R&D @ 300 MeV

- Inv. Compton Scat. (ICS): "collide" 300-MeV e- beam against a 1 μm IR laser
- high rep. rate achieved w.
  - enhancement IR cavity
    - ➔ high energy IR pulses,
  - beam from SCRF linac
    - ➔ high repetition rate
- high-brilliance γ rays with Watt-level average power



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



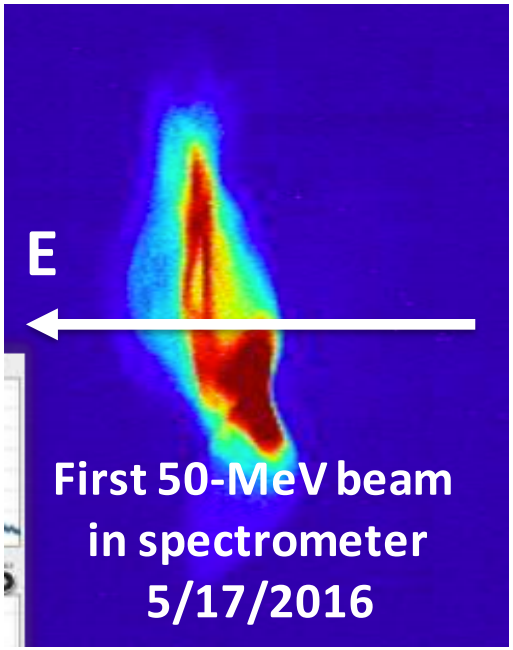
A look ahead (slide from V. Shiltsev)

	Electron Injector	Proton Injector	IOTA Ring
FY15	20 MeV *e*- commiss'd beam tests	Re-assembly began @MDB	50% IOTA parts ready
FY16	50 MeV *e*- commiss'd beam tests	50 keV *p*+ commiss'd	IOTA parts 80+% ready
FY17	150-300 MeV *e*- beam commissioning/tests *	2.5 MeV *p*+ commiss'd beam tests @ MDB	IOTA fully installed first beam ? *
FY18	*e*- injector for IOTA + other research	*p*+ RFQ moved from MDB to FAST *	IOTA commiss'd with *e*- **Research starts (NL IO)**
FY19	*e*- injector for IOTA + other research	2.5 MeV *p*+ commiss'd beam tests	**IOTA research with *e*-** IOTA commiss'd with *p*+
FY20	*e*- injector for IOTA + other research	*p*+ injector for IOTA	**IOTA research with *p*+***

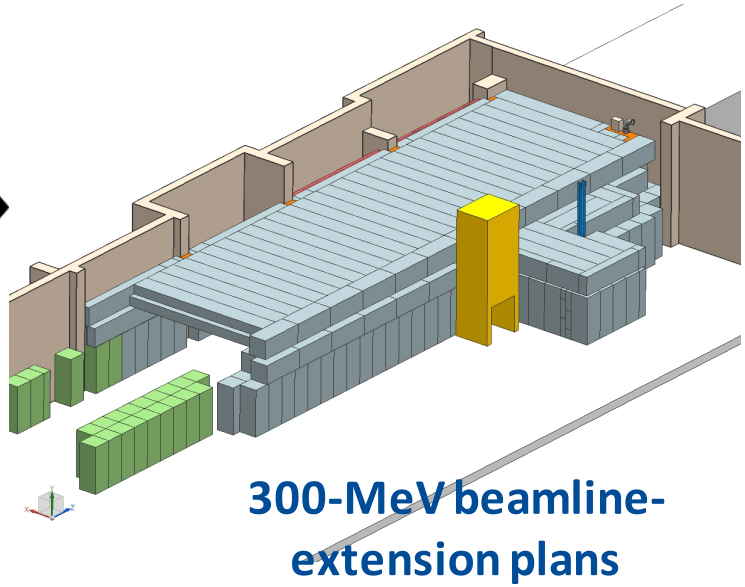
beam operations

Summary

- FAST electron injector is being commissioned
  - 1st 50-MeV beam produced 5/17/16
  - Beam dynamics studies currently on-going
  - 1st experiment on X-ray channeling radiation in progress
- 300-MeV electron beamline and IOTA ring are under construction
- FAST-IOTA welcome collaboration on all research topics to be enabled by the facility



First 50-MeV beam in spectrometer 5/17/2016



300-MeV beamline-extension plans

http://fast.fnal.gov/

Fermilab

- Thank you for your attention -

Credits

- Materials presented in this slides has been freely borrowed from members of the FAST-IOTA team

- Especially from the recent workshop help on 6/13; see

  https://indico.fnal.gov/conferenceDisplay.py?confId=11852

IOTA-Ring parameters (from A. Valishev)

Nominal kinetic energy	e^-: 150 MeV, p+: 2.5 MeV
Nominal intensity	e^-: 1×10^9, p+: 1×10^{11}
Circumference	40 m
Bending dipole field	0.7 T
Beam pipe aperture	50 mm dia.
Maximum b-function (x,y)	12, 5 m
Momentum compaction	0.02 ÷ 0.1
Betatron tune (integer)	3 ÷ 5
Natural chromaticity	-5 ÷ -10
Transverse emittance r.m.s.	e^-: 0.04 μm, p+: 2μm
SR damping time	0.6s (5×10^6 turns)
RF V,f,q	e^-: 1 kV, 30 MHz, 4
Synchrotron tune	e^-: 0.002 ÷ 0.005
Bunch length, momentum spread	e^-: 12 cm, 1.4×10^{-4}
Beam lifetime	e^-: 1 hour, p+: 1 min

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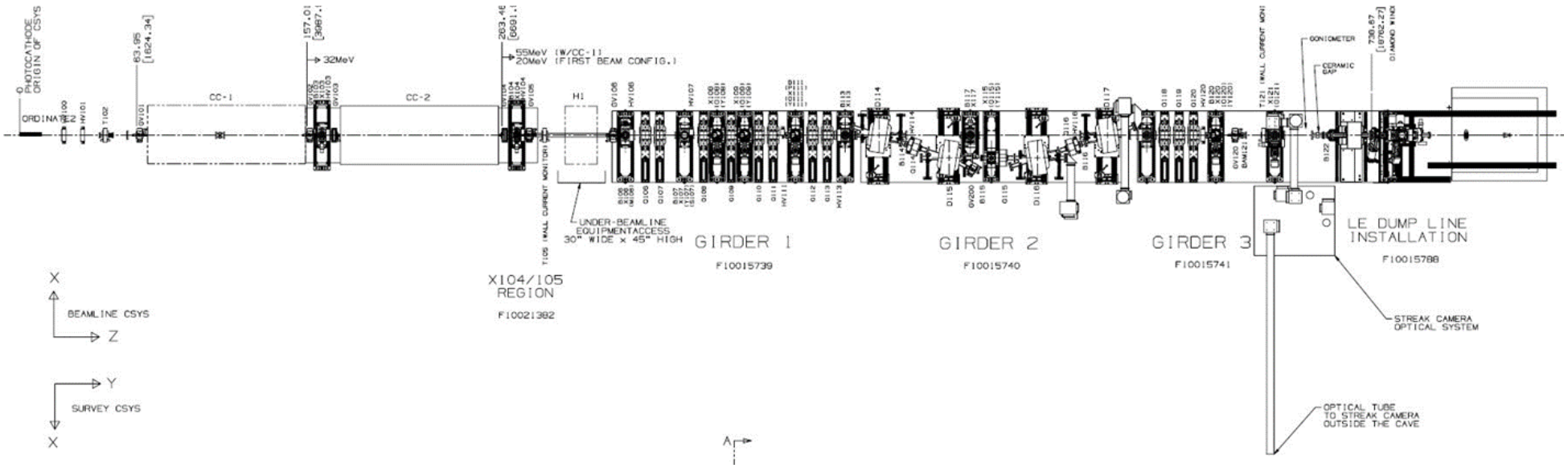
Electron injector parameters (from D. Broemmelsiek)



Parameter	Value	Unit
Bunch charge	0.02 – 3.2	nC
Bunch train duration	1	ms
Bunch frequency within train	3	MHz
Number of bunches/train	1 – 3000	
Bunch train frequency	1 – 5	Hz