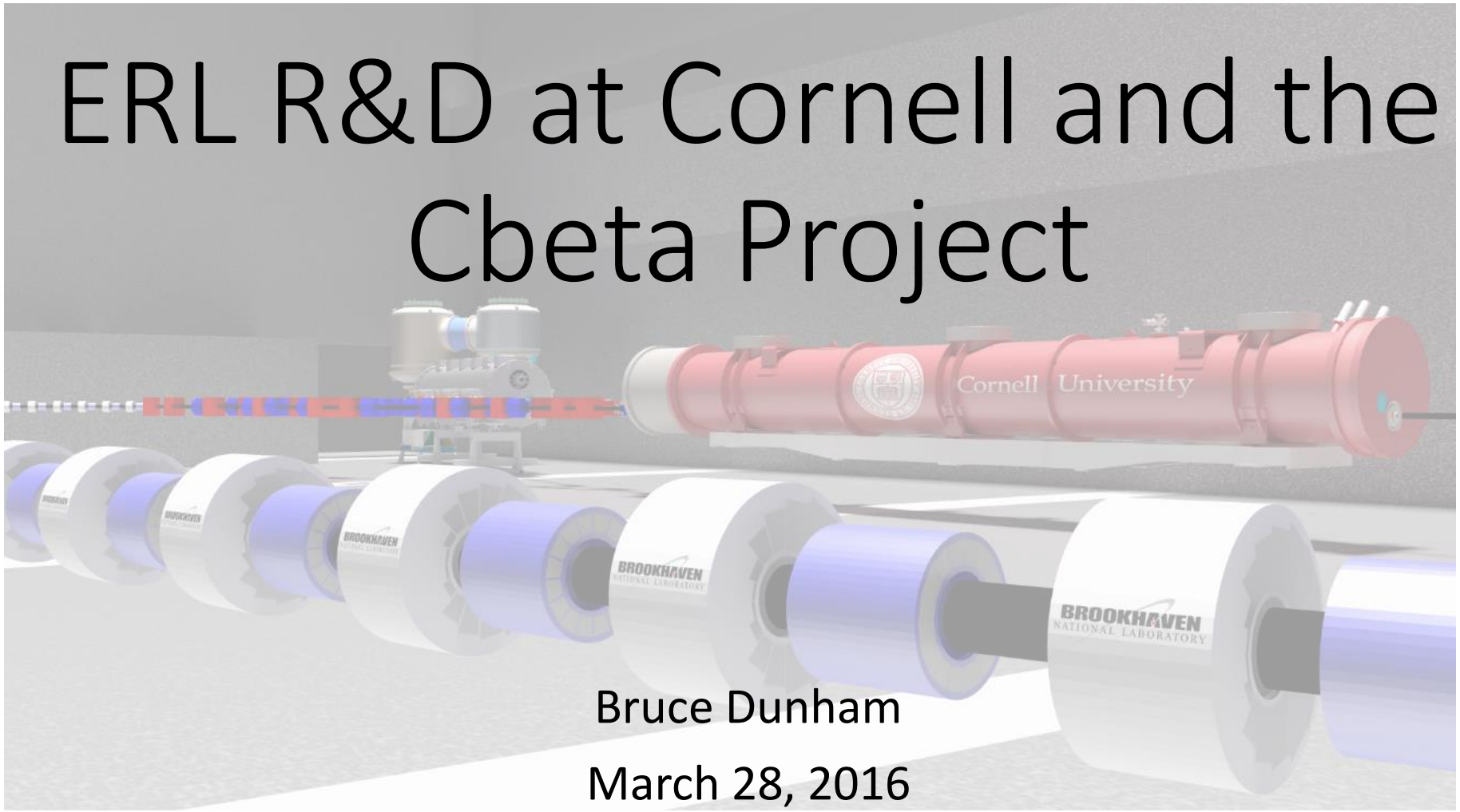
ERL R&D at Cornell and the Cbeta Project



Bruce Dunham

March 28, 2016

CLASSE (Cornell Laboratory for Accelerator SciencesS and Education) has had a long history of forefront accelerator development for lepton accelerators, educating graduate students, postdocs and leading accelerator physicists.

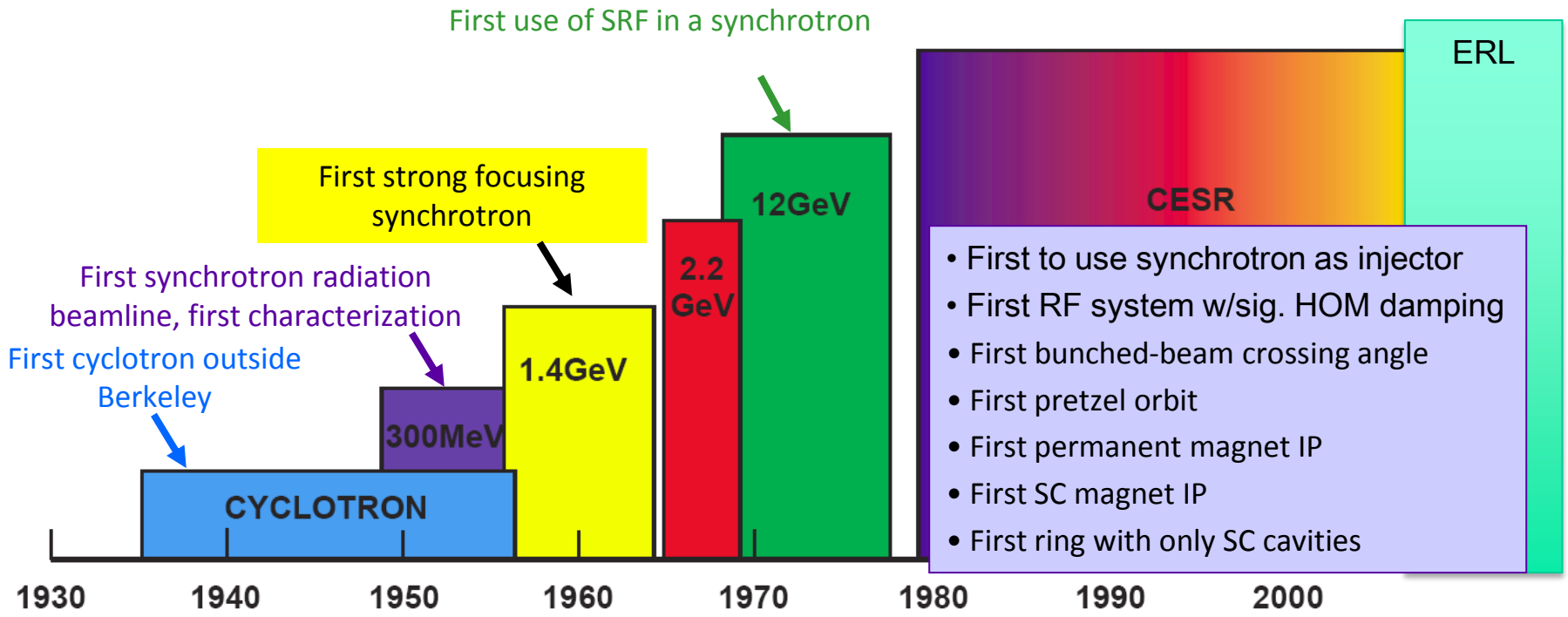


Figure from K. Berkelman,
"A personal History of CESR and CLEO"

LETTERE ALLA REDAZIONE

(La responsabilità scientifica degli scritti inseriti in questa rubrica è completamente lasciata dalla Direzione del periodico ai singoli autori)

A Possible Apparatus for Electron Clashing-Beam Experiments (*).

M. TIGNER

Laboratory of Nuclear Studies, Cornell University - Ithaca, N. Y.

(ricevuto il 2 Febbraio 1965)

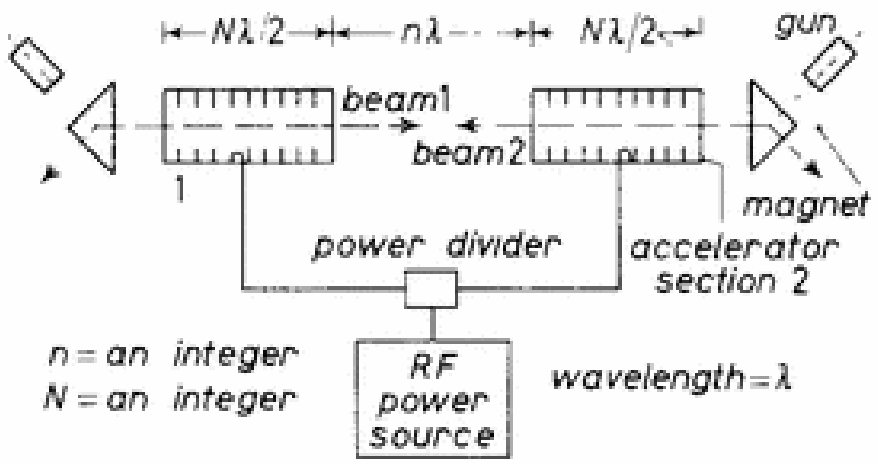


Fig. 2.

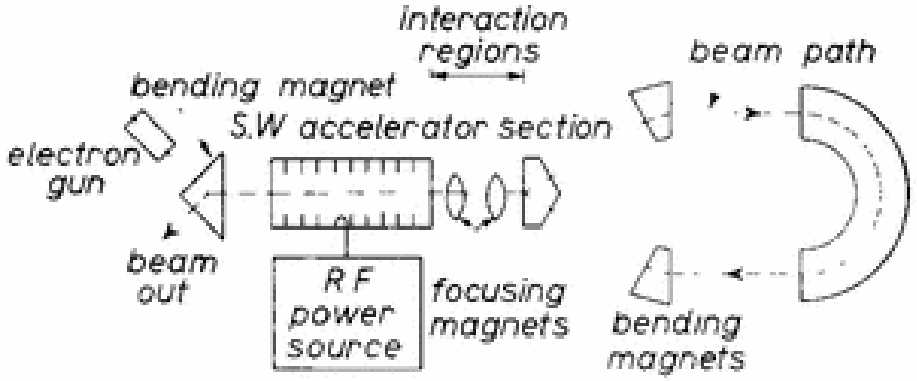
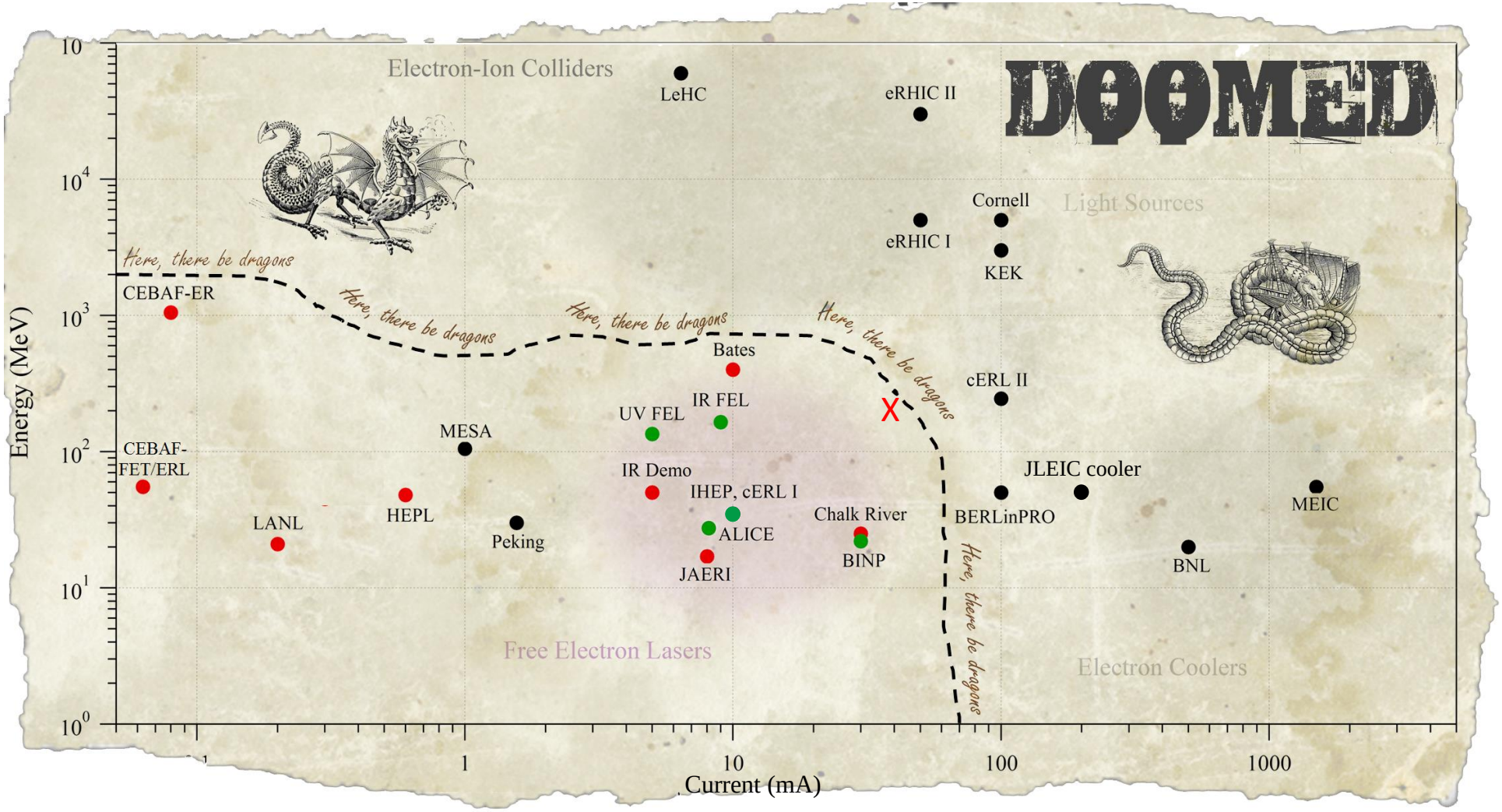


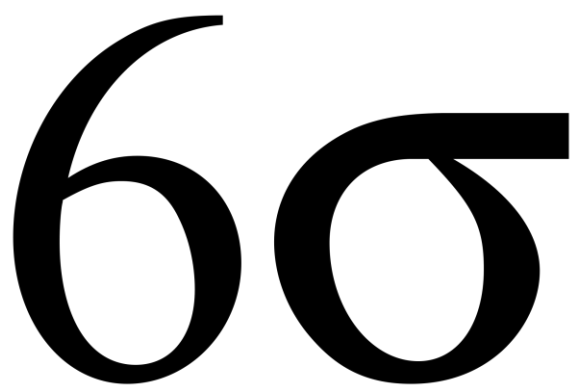
Fig. 3.

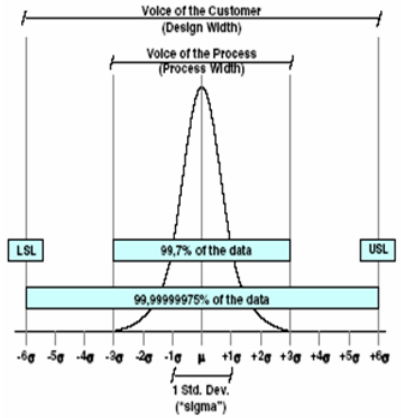
ERL's around the world



Courtesy of: C. Tennent and D. Douglas, Jlab

Six Sigma





LEAN SIX-SIGMA

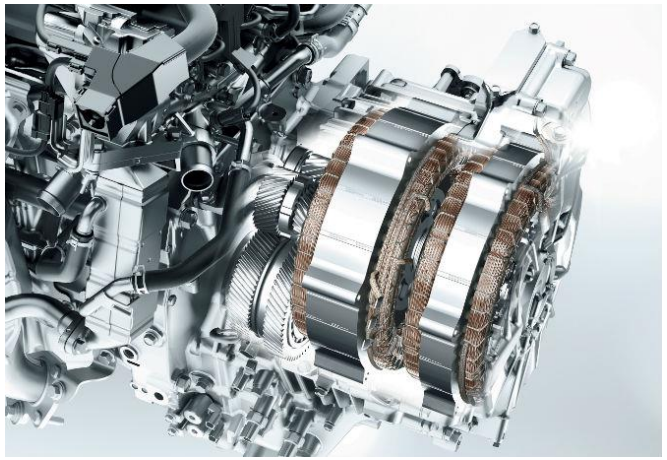
Toyota and Lean Manufacturing

Engines

Brakes

Manufacturing

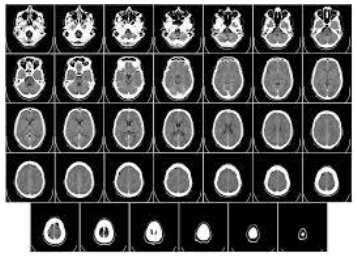
Batteries

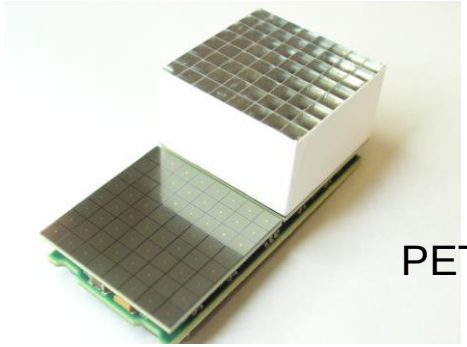


Transmissions

GE and Lean Six Sigma

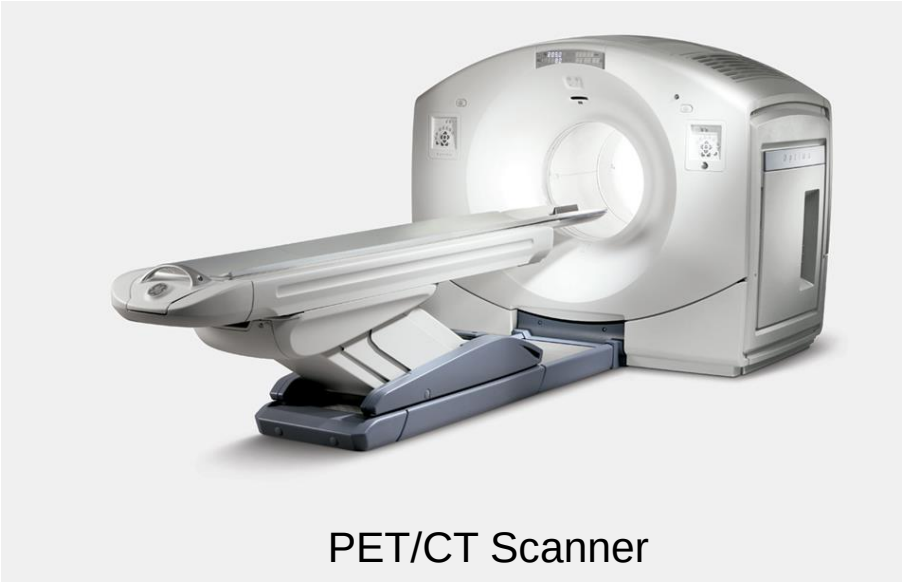
CT Reconstruction Algorithms





PET Detector Array

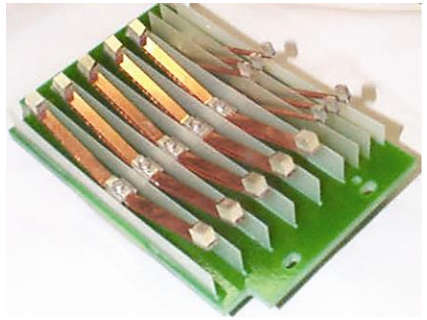
PET Reconstruction Algorithms



PET/CT Scanner

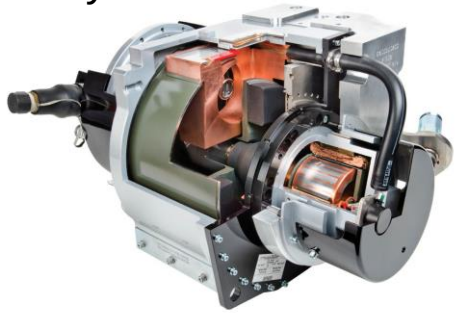
CT Detector Array

Slip rings



HV Power

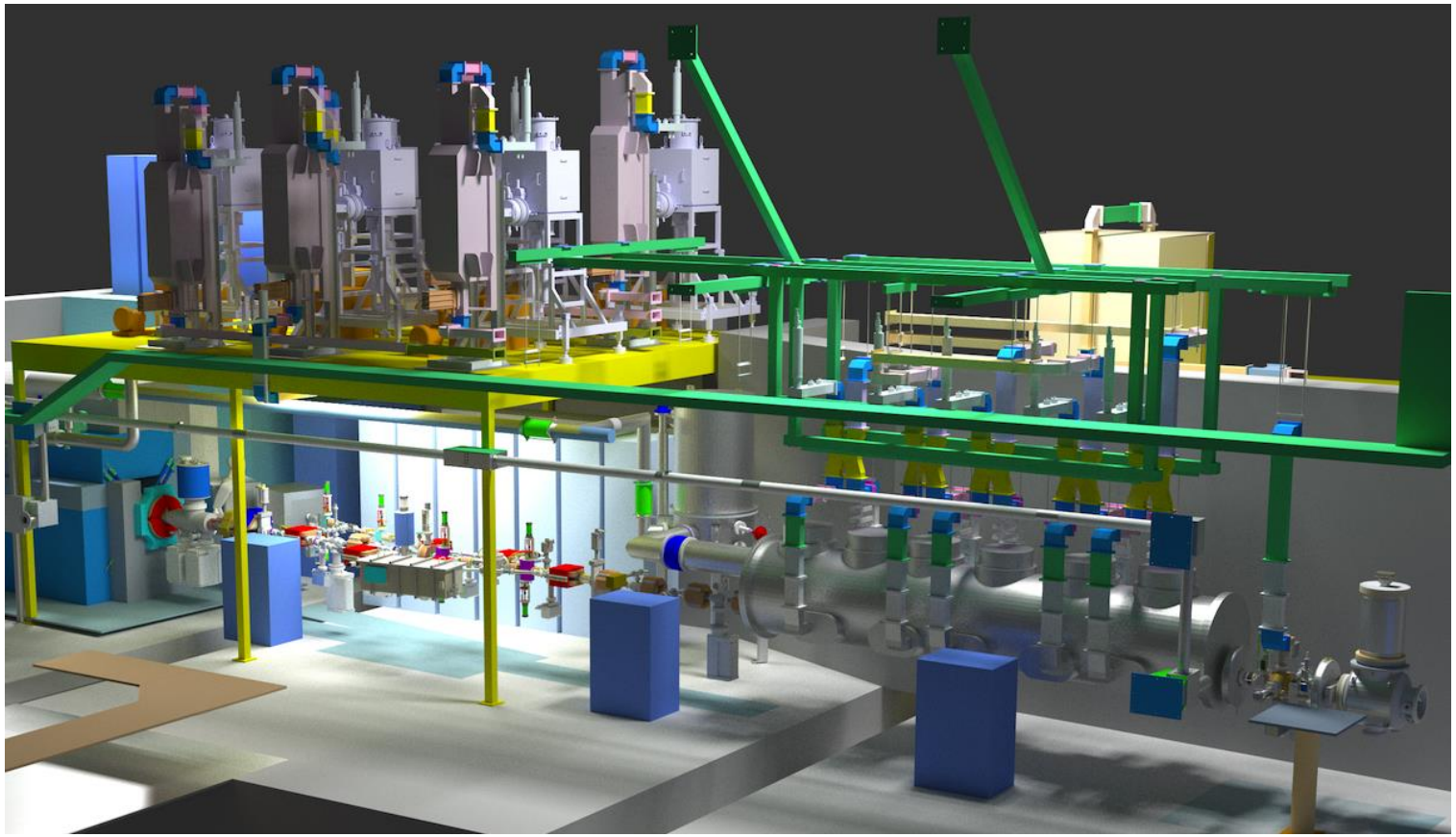
X-Ray Tubes



The Cornell ERL Injector

High Power RF Sources

Photocathodes



Fiber Lasers

High Power Beam Dump

HV Power Supplies

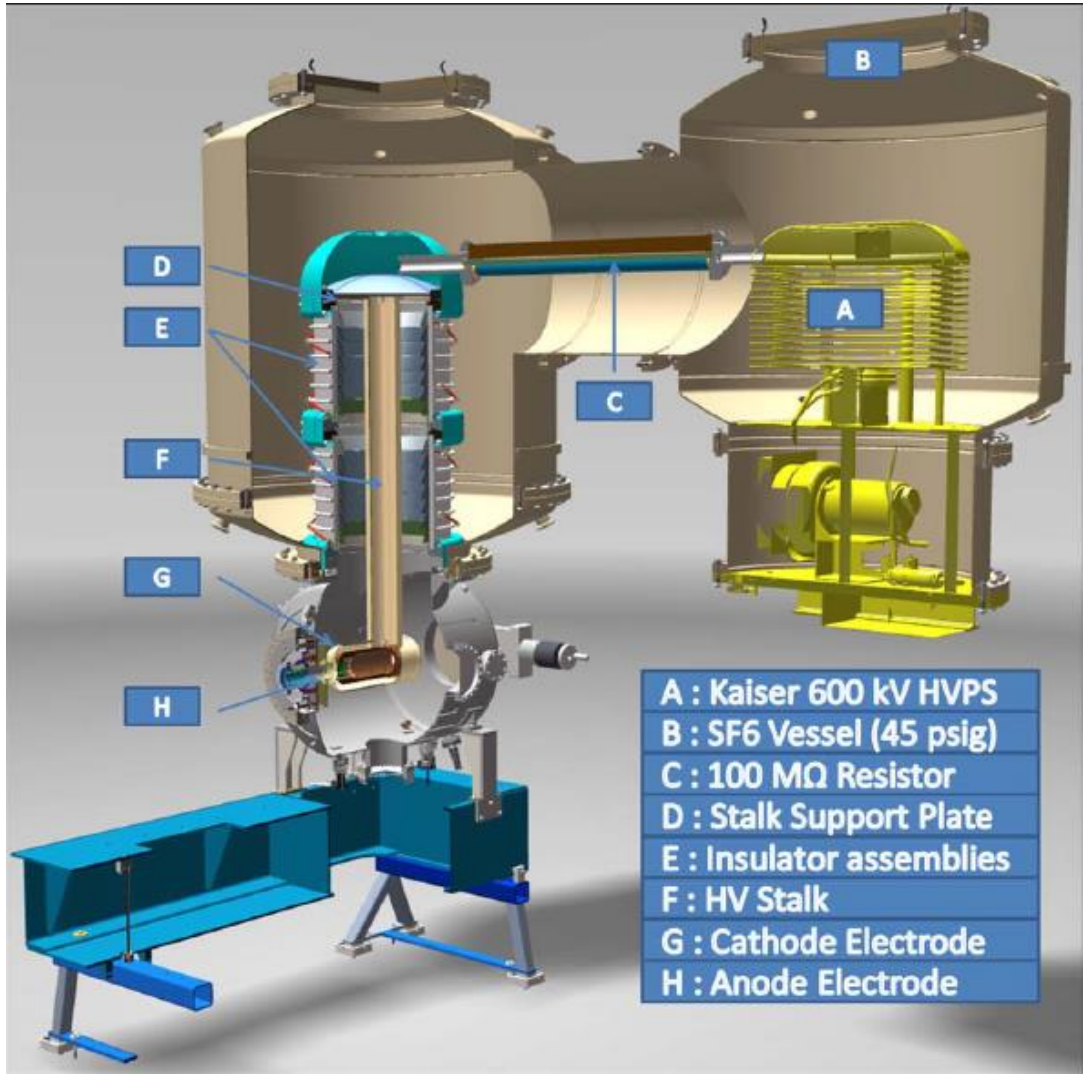
Non-interceptive Diagnostics

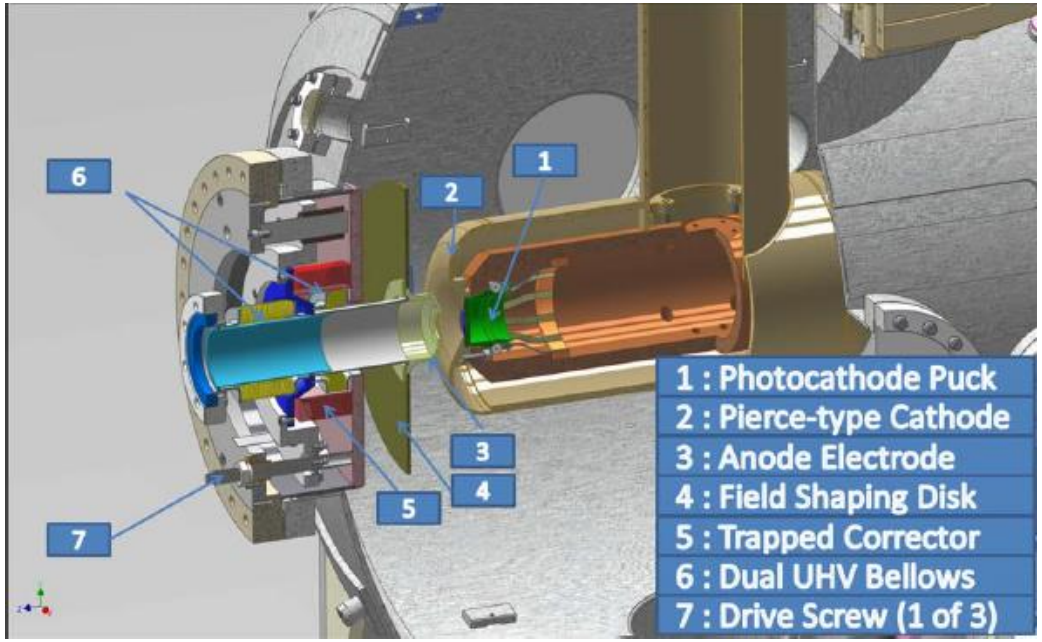
Electron Guns

Advanced Algorithms

Superconducting RF

Parts in the Toolbox: Guns





REVIEW OF SCIENTIFIC INSTRUMENTS **85**, 093306 (2014)

Gun Processing

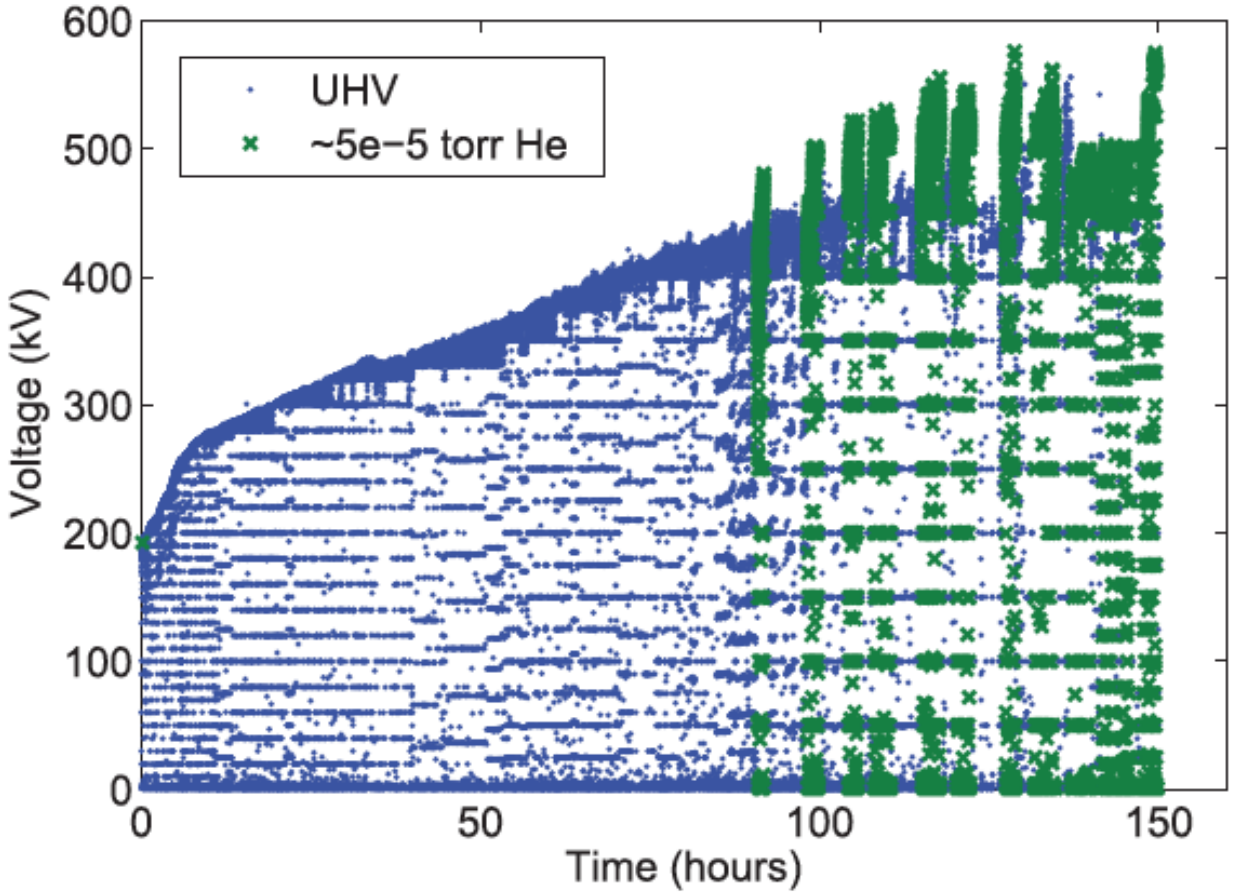
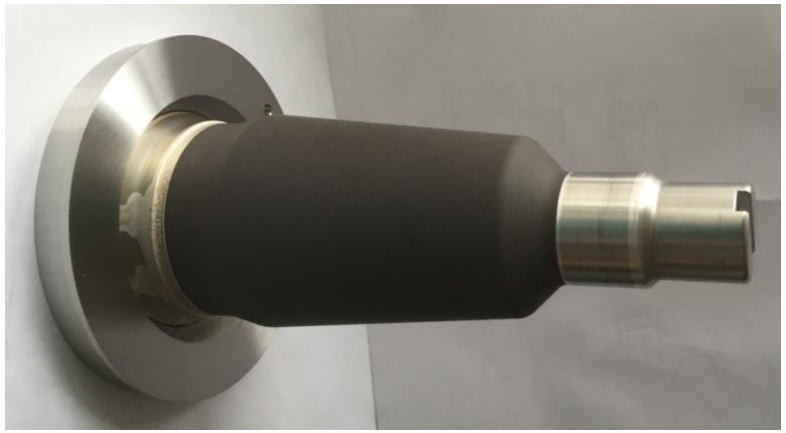


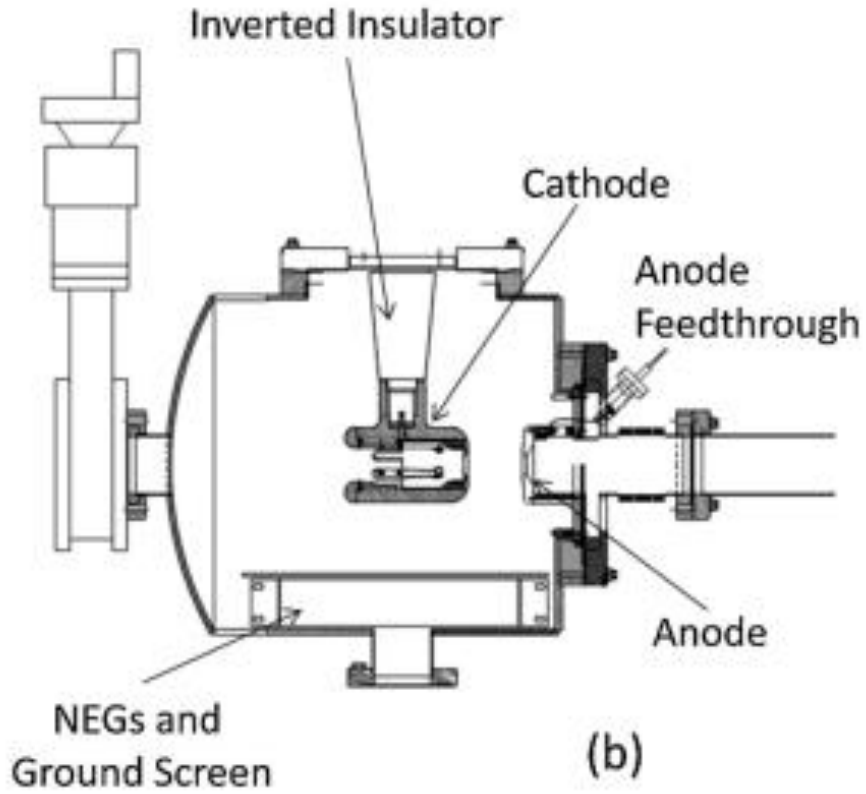
FIG. 5. The voltage applied to the gun during conditioning, corrected for the voltage drop across the processing resistor. Data points are colored for UHV (blue dot) and helium gas (green x) conditioning.

Parts in the Toolbox: Insulators

‘off-the-shelf’ industrial HV cables and insulators from X-ray tubes

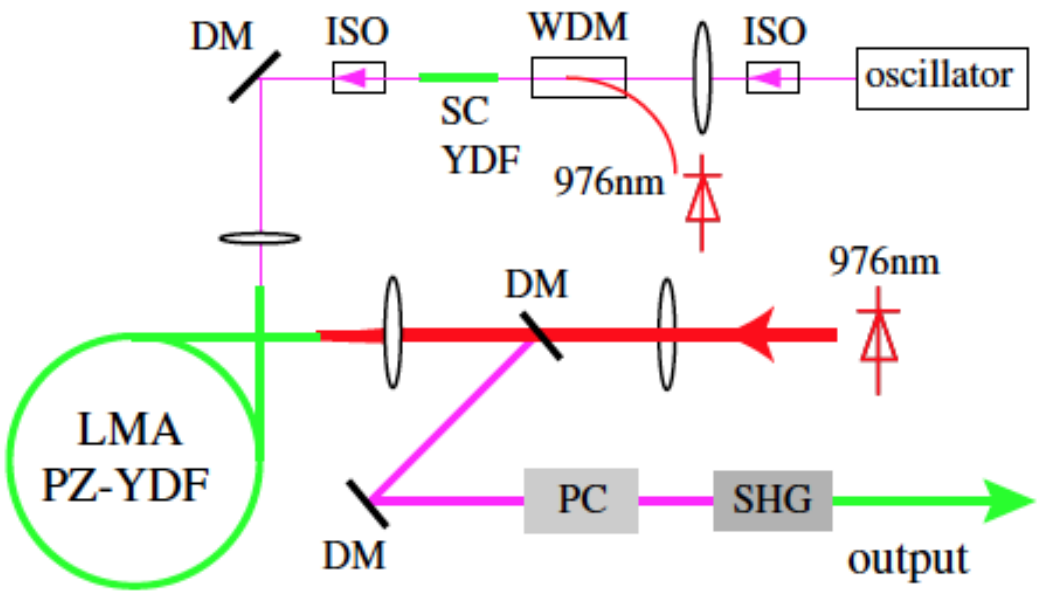


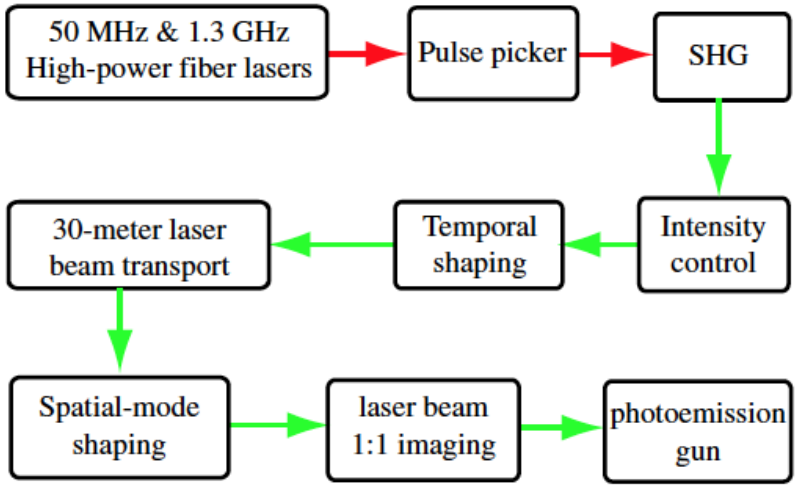
New Jefferson Lab polarized source – 200 kV



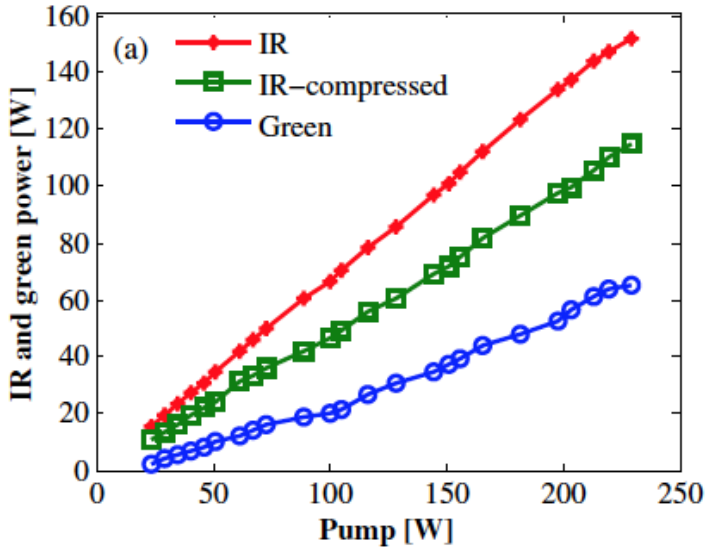
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **13**, 010101 (2010)

Parts in the Toolbox: Fiber lasers



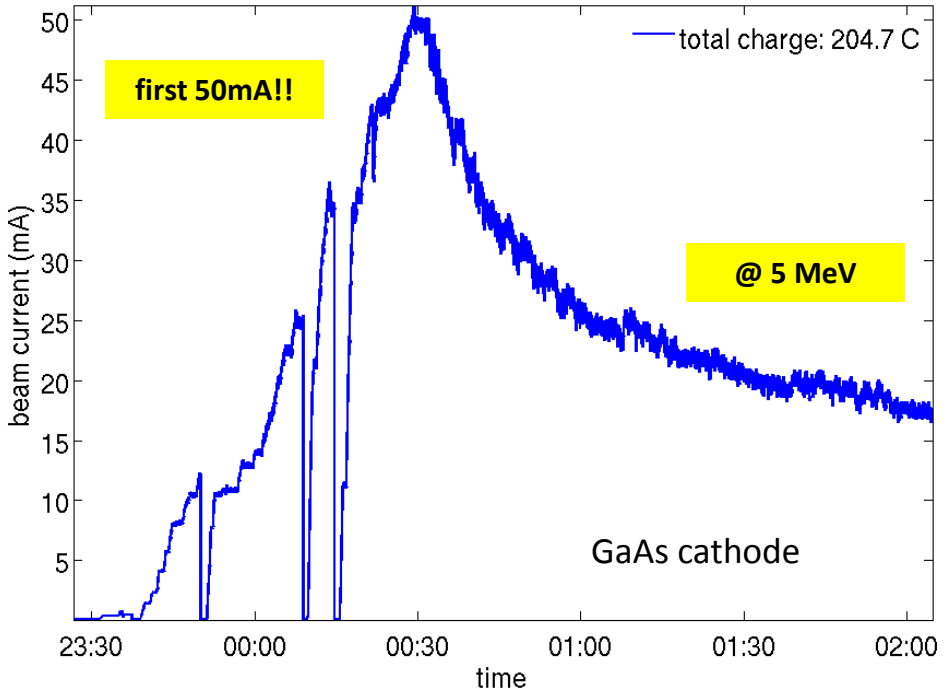


High average power, high rep rate lasers used to be a challenge…



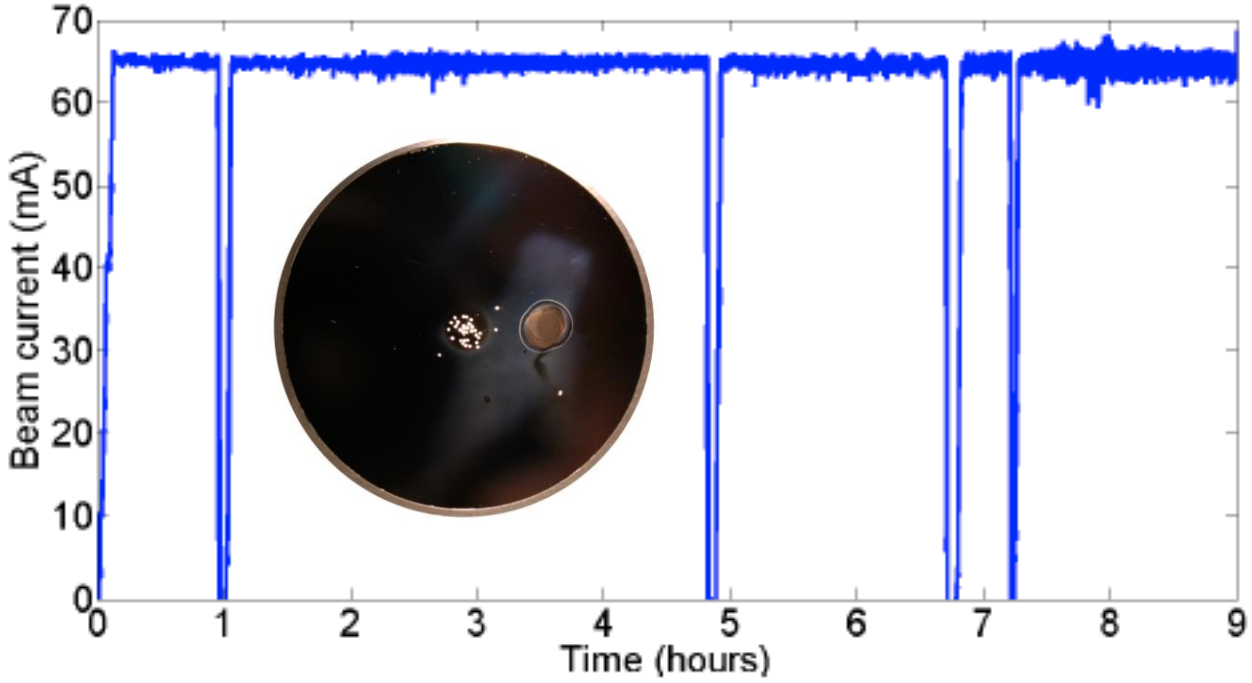
PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 053501 (2014)

Parts in the Toolbox: Cathodes



GaAs is very difficult to work with, and should only be used as a source of polarized electrons. It is also one of the 'coldest' cathodes know (25 meV thermal energy at room temperature)

Parts in the Toolbox: Photocathodes



- Peak current of 75mA (world record)

- NaKSb photocathode
- High rep-rate laser
- DC-Voltage source

Source achievements:

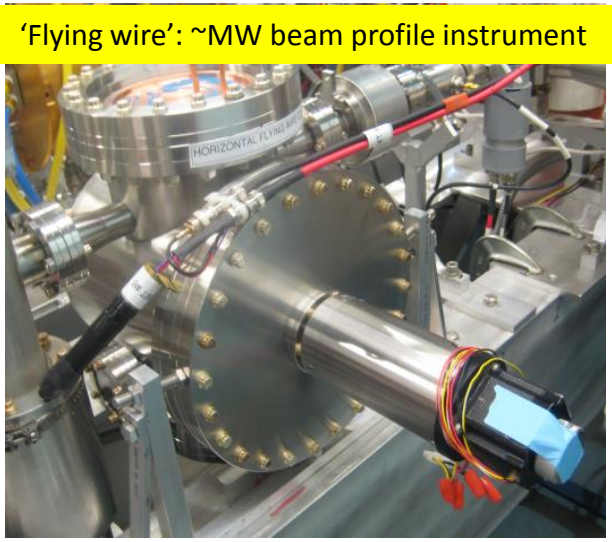
- 2.6 day 1/e lifetime at 65mA
- 8h at 65mA
- With only 5W laser power (20W are available)
- now pushing to 100mA

We have grown and tested most of the combinations of bi and tri-alkali cathodes. They all have similar MTE, although the wavelength response varies.

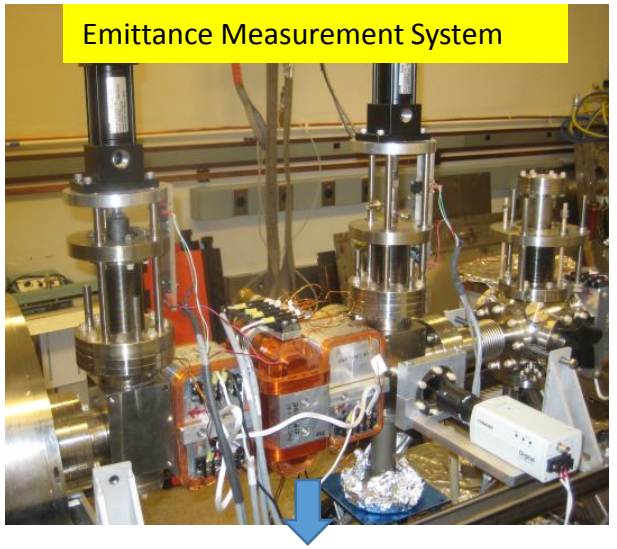
Parts in the Toolbox: Diagnostics

6D phase-space diagnostics

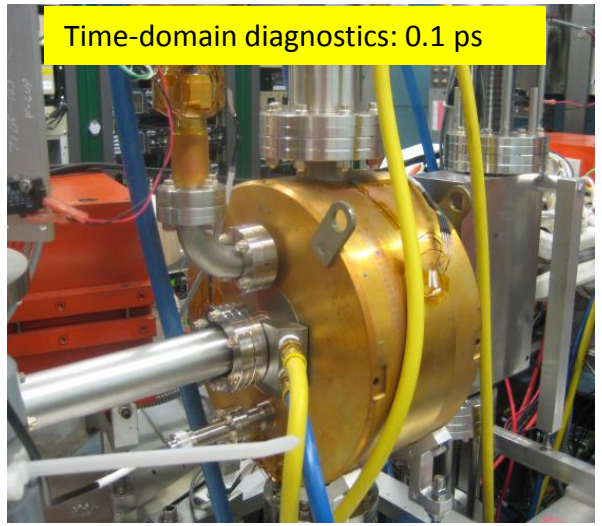
‘Flying wire’: ~MW beam profile instrument

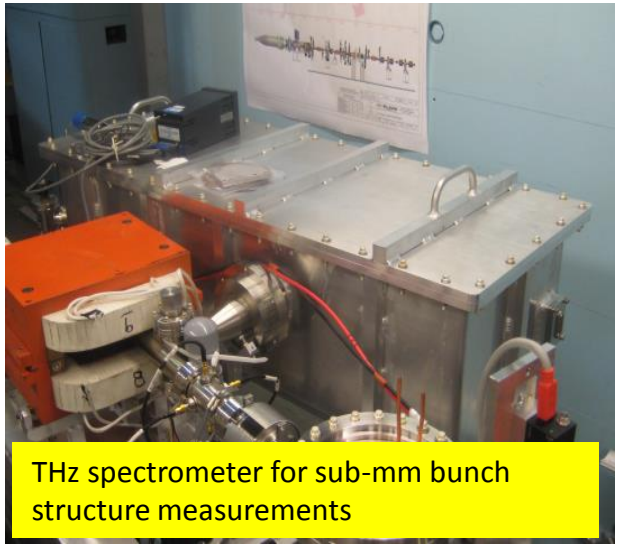


Emittance Measurement System

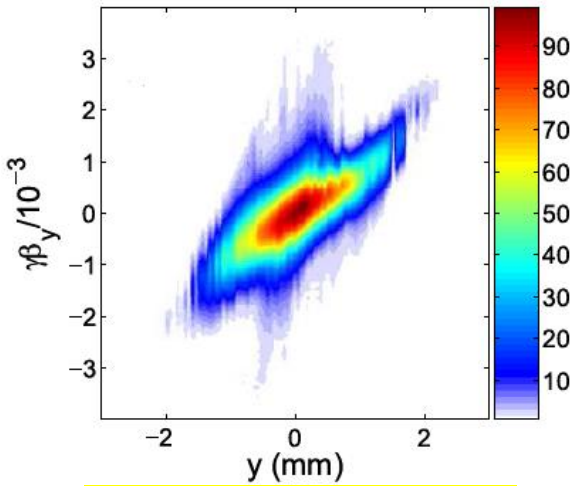


Time-domain diagnostics: 0.1 ps





THz spectrometer for sub-mm bunch structure measurements



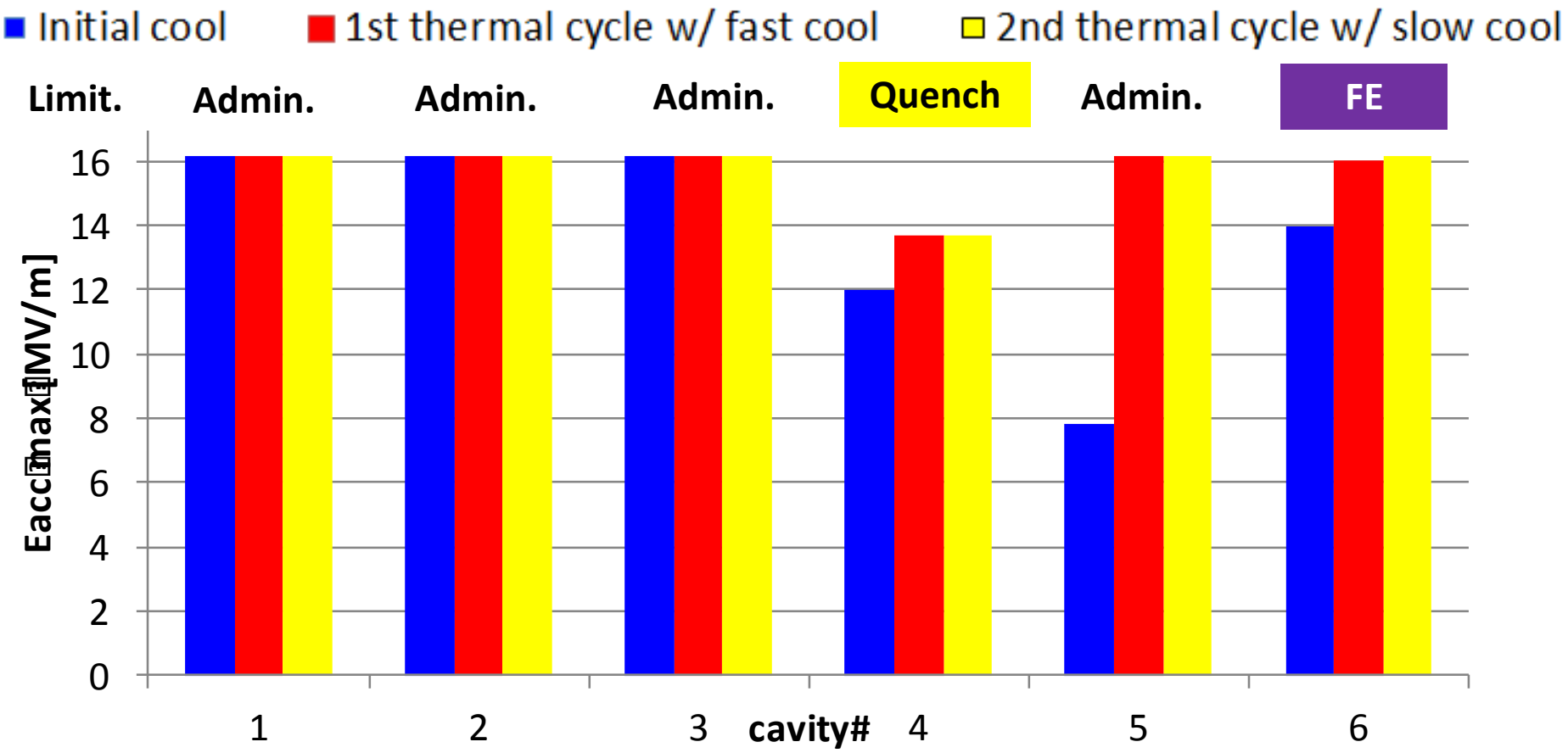
measured phase space

Key beam instrumentation and concepts from Cornell accelerator group have since been adopted/copied at several labs

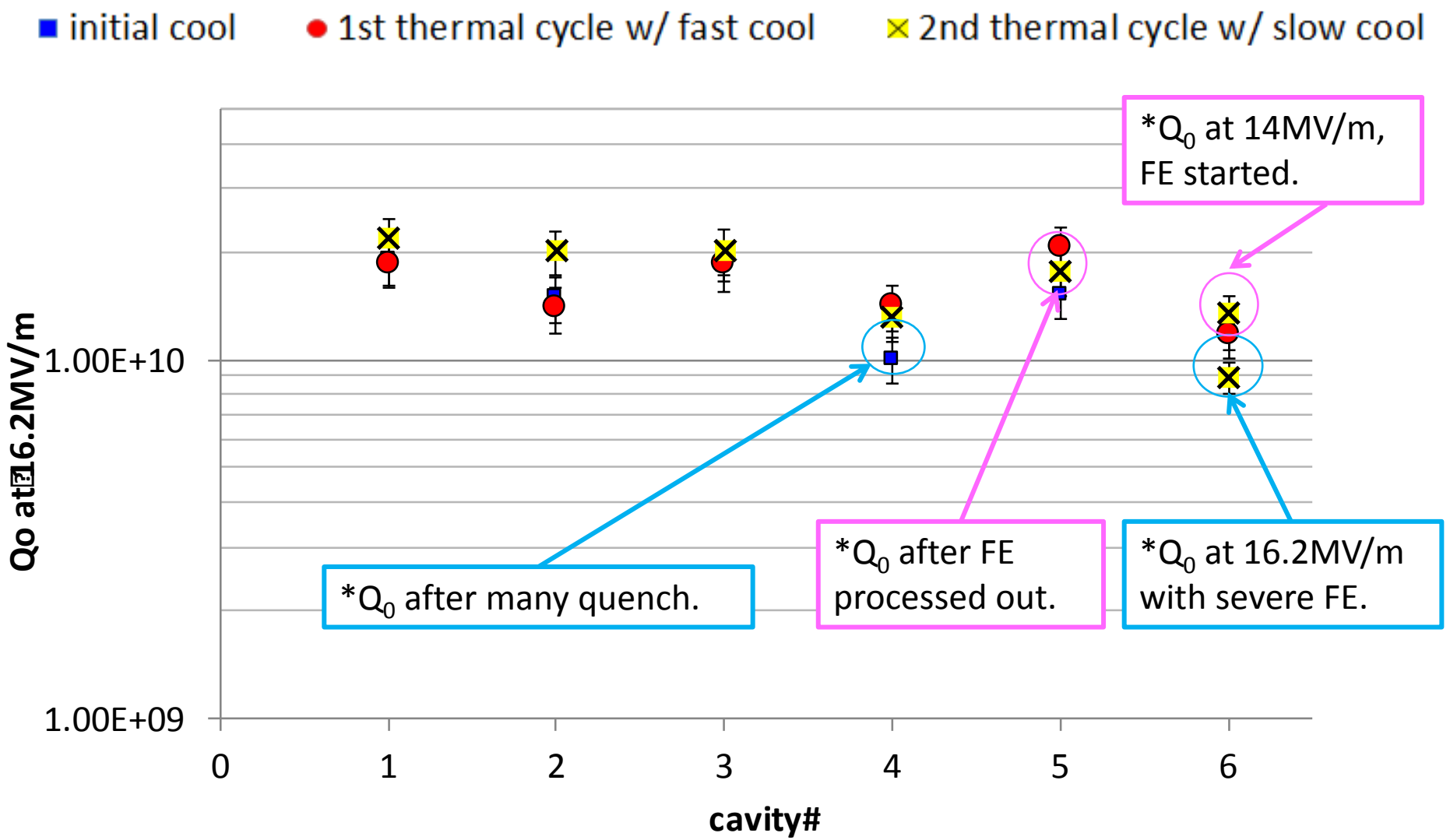
SRF Linac

- **6 ERL main linac 7-cell cavities**
- **Cavity preparation: bulk BCP, 650C outgassing, final BCP, 120C bake, HF rinse**

Initial Linac Results



Initial Linac Results



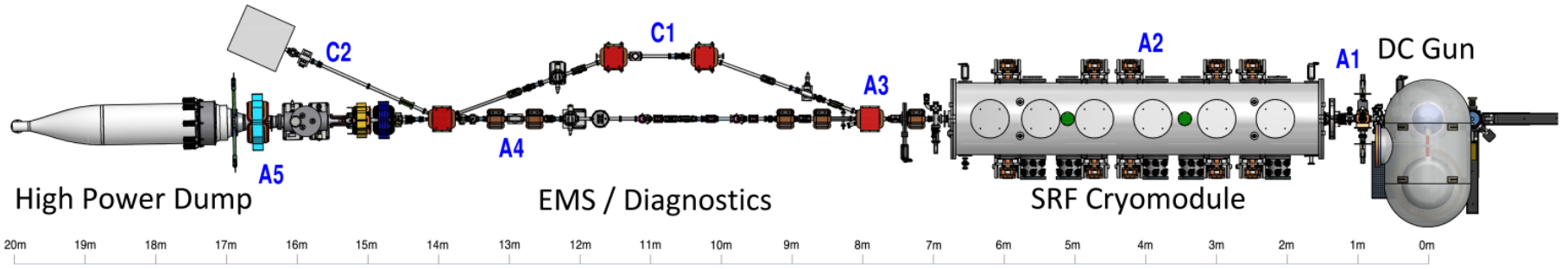
Next: microphonics measurements and piezo testing

Applications: LCLS2 Injector

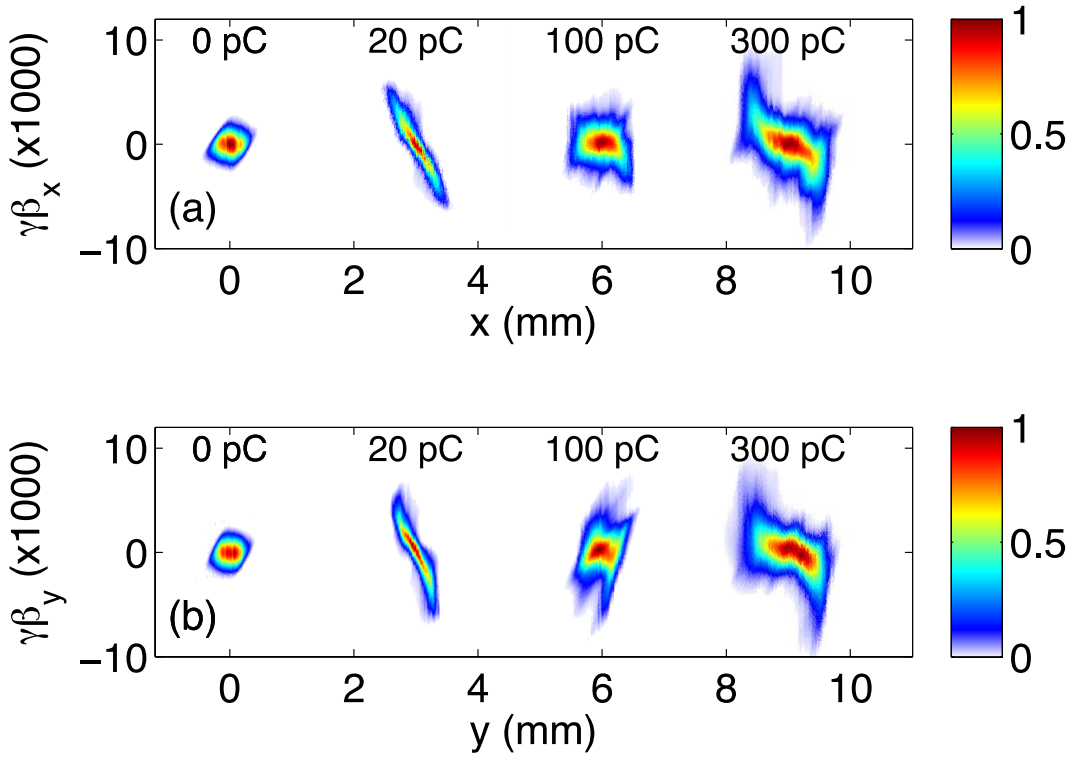
The ERL Injector as backup for LCLS2

- Higher energy (9.5 MeV)
- Lower average current (<1 mA), but increased bunch charge
- No merger section
- Slightly more aggressive emittances, at specified charge / peak current:

Bunch charge	Peak current	Emittance (95%)
20 pC	5 A	0.25 μm
100 pC	10 A	0.4 μm
300 pC	30 A	0.6 μm

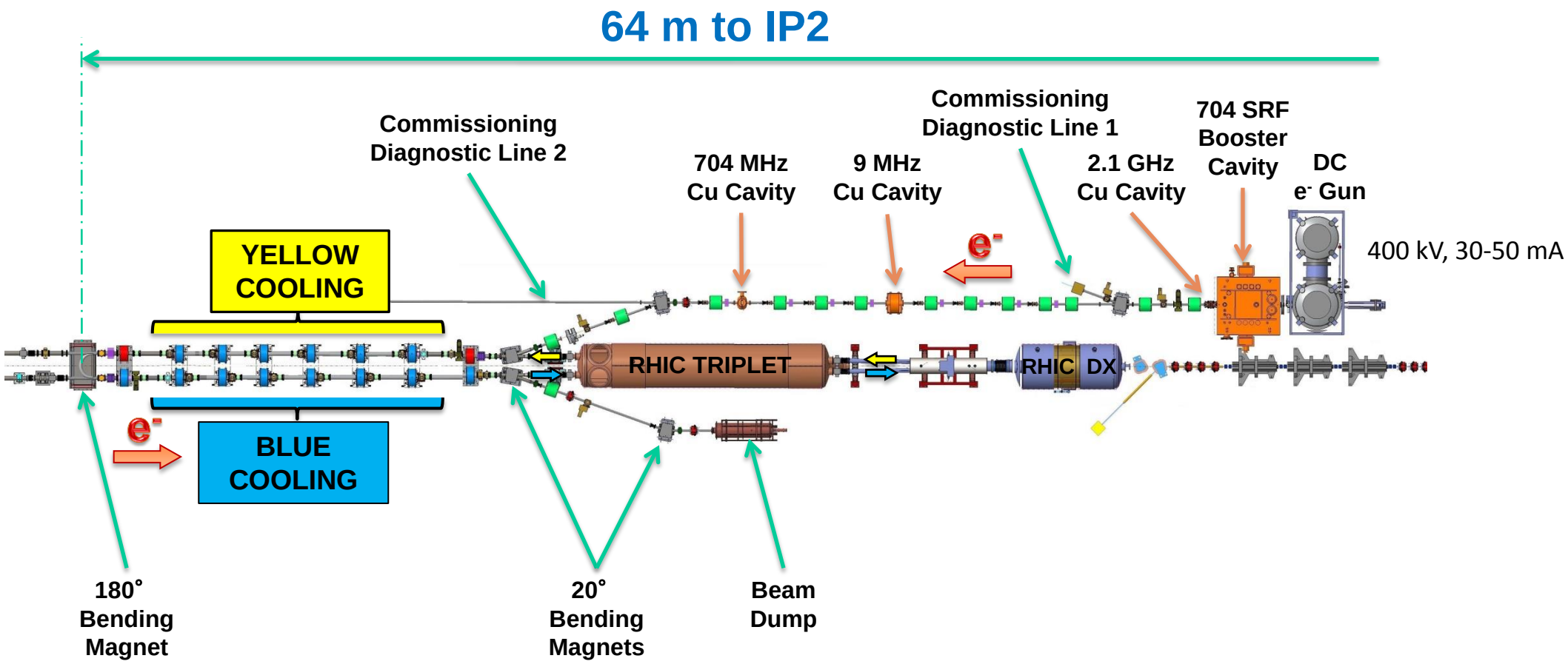


Applications: LCLS2 Injector



Q (pC)	I_{peak} Target (A)	I_{peak} (A)	ε_n Target (95%, μm)	ε_n (95%, μm)	$\varepsilon_{n,th}/\varepsilon_n$
20	5	5	0.25	**H:** 0.18, **V:** 0.19	**58%**
100	10	11.5	0.40	**H:** 0.32, **V:** 0.30	**80%**
300	30	32	0.60	**H:** 0.62, **V:** 0.60	**70%**

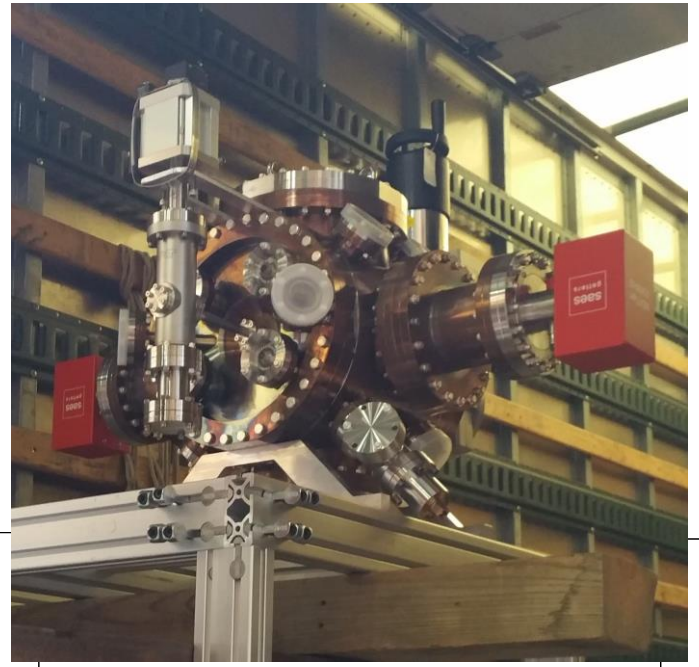
Bunched Beam Electron Cooling at RHIC



Courtesy of: Alexei Fedetov, BNL

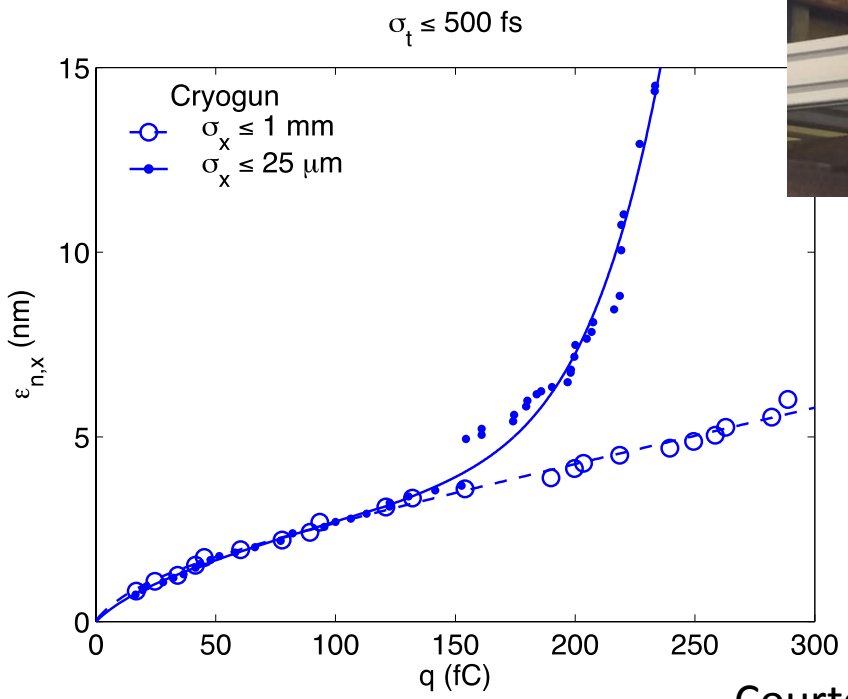
Applications: UED

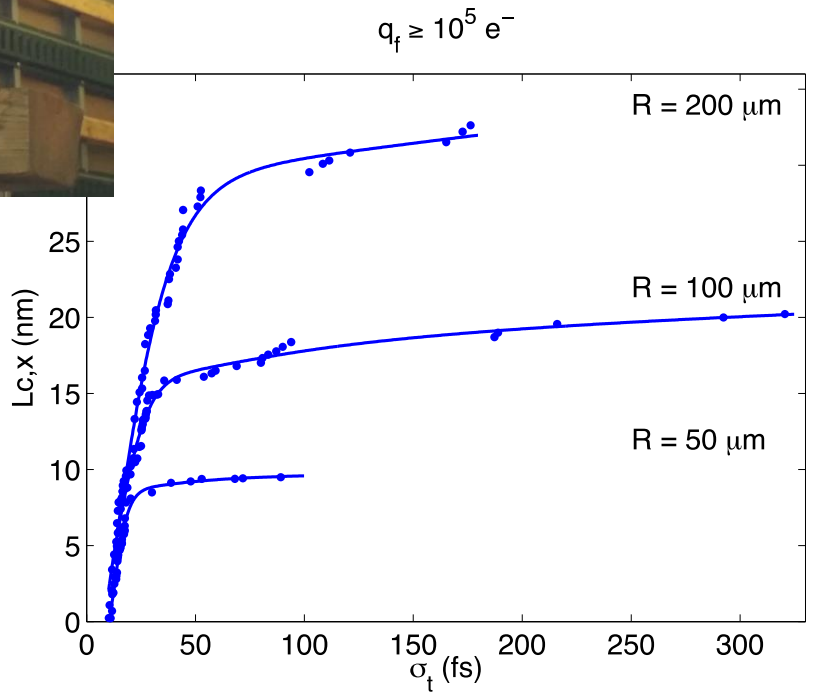
Ultra Fast Electron Diffraction: table top diffraction set-up with sub 100 fs time resolution, 225 kV beam



MOGA optimizations:
DC gun, buncher, solenoids, laser size and shape

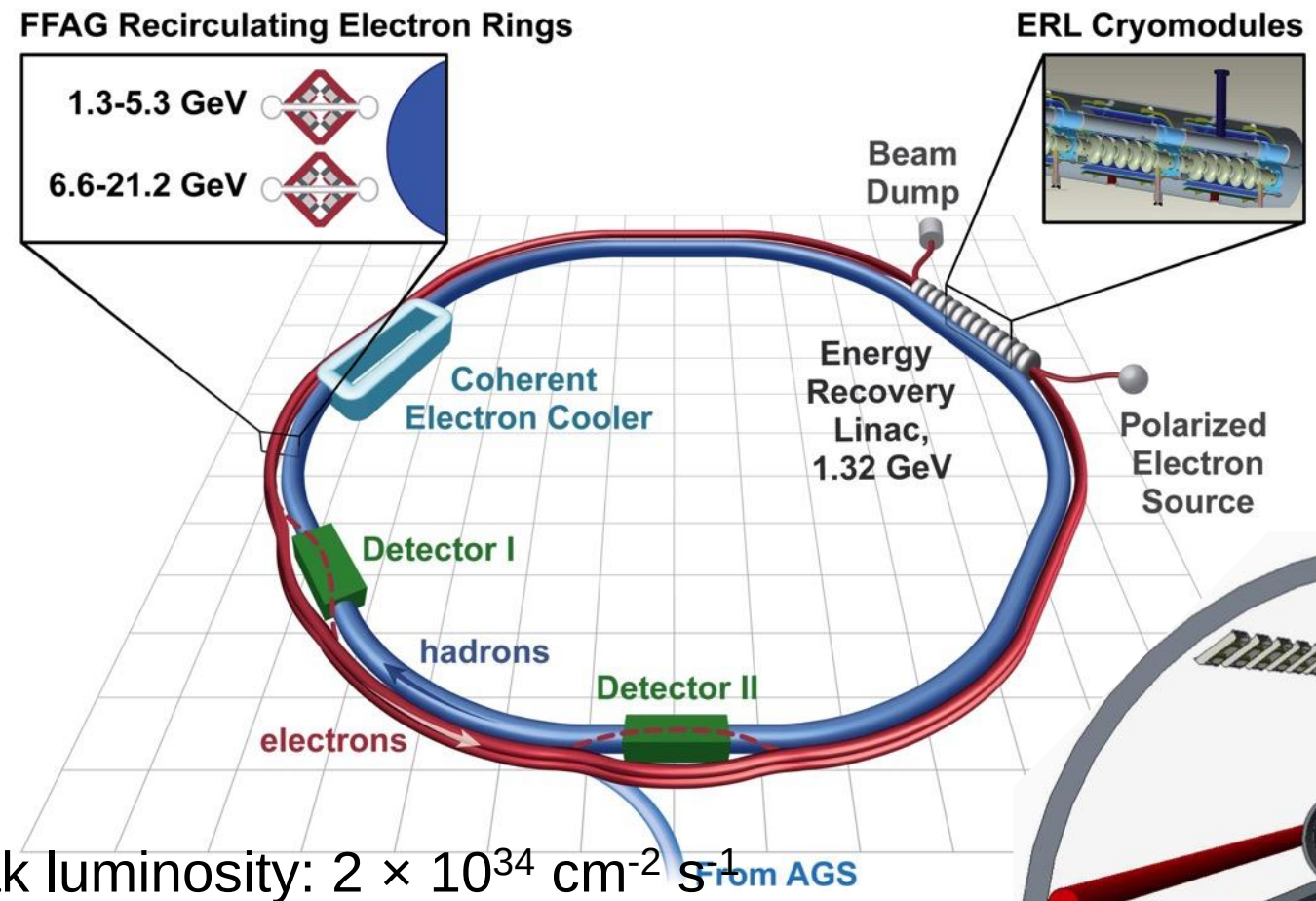
Assuming a 'cold' cathode with 5 meV thermal energy!

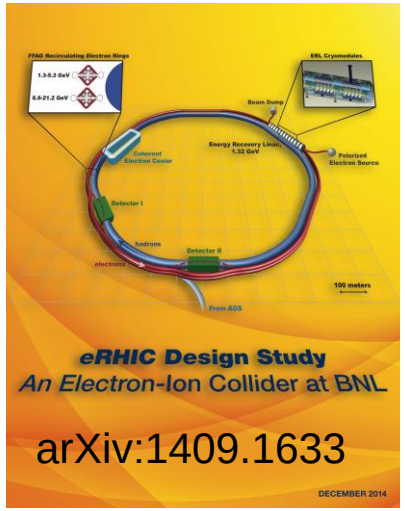


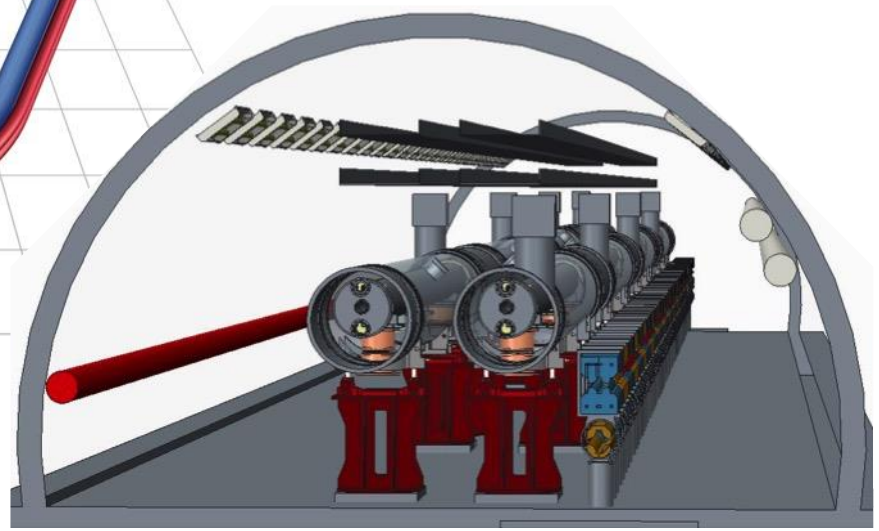


Courtesy of: Colwyn Gulliford

Final Application: eRHIC ERL prototype







- Peak luminosity: 2×10^{34} cm^{-2} s^{-1}
- ERL, permanent magnet arcs and strong cooling of proton beam greatly reduce electric power consumption to about 15 MW!

Courtesy of T. Roser

Final Application: eRHIC ERL prototype

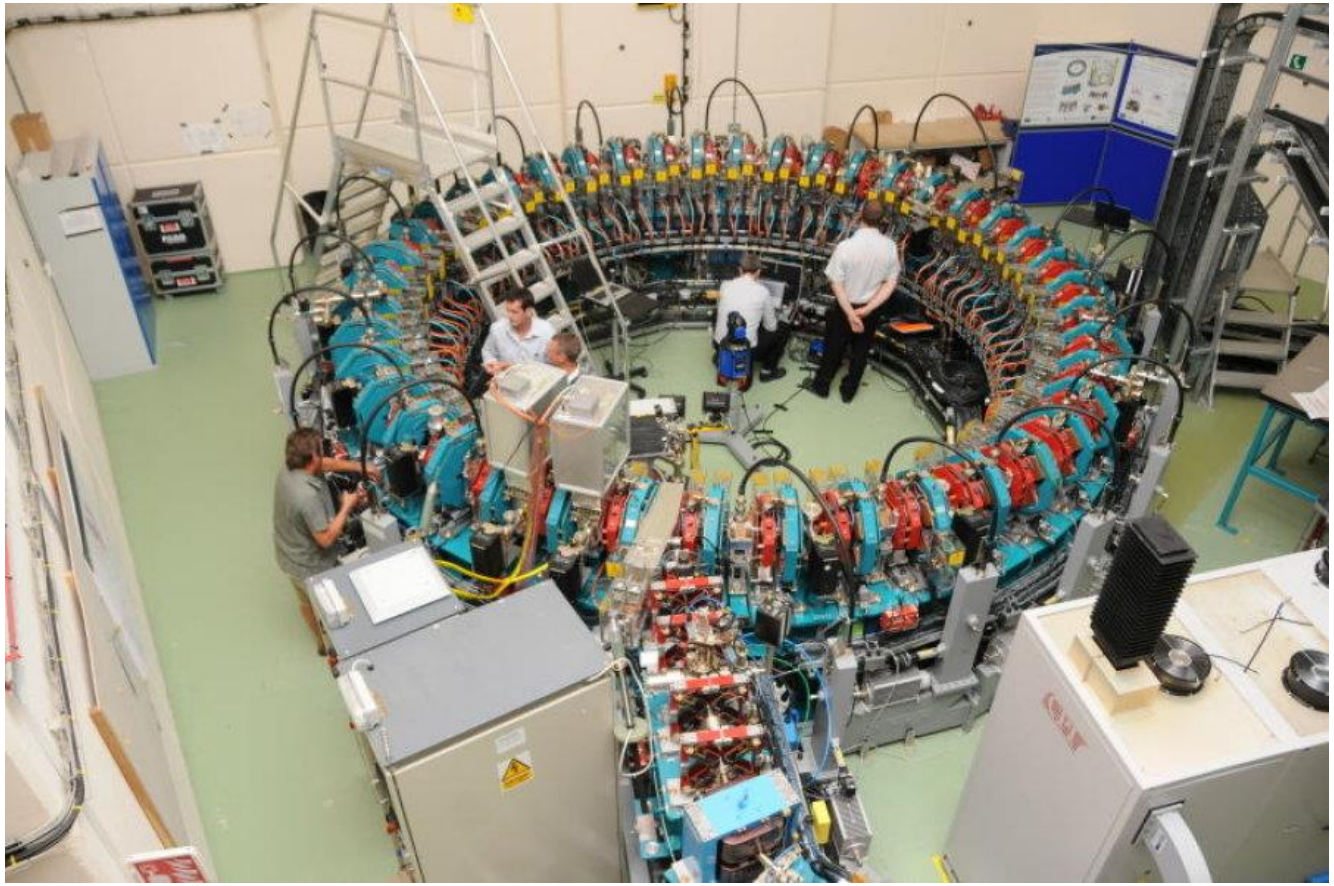
Some of the most important risk items for eRHIC:

1) FFAG loops with a factor of 4 in momentum aperture.
   a) Precision, reproducibility, alignment during magnet and girder production.
   b) Stability of magnetic fields in a radiation environment.
   c) Matching and correction of multiple simultaneous orbits.
   d) Matching and correction of multiple simultaneous optics.
   e) Path length control for all orbits.

2) Multi-turn ERL operation with a large number of turns.
   a) HOM damping.
   b) BBU limits.
   c) LLRF control and microphonics.
   d) ERL startup from low-power beam.

Need to retire or reduce these risks for a serious proposal

Final Application: eRHIC ERL prototype

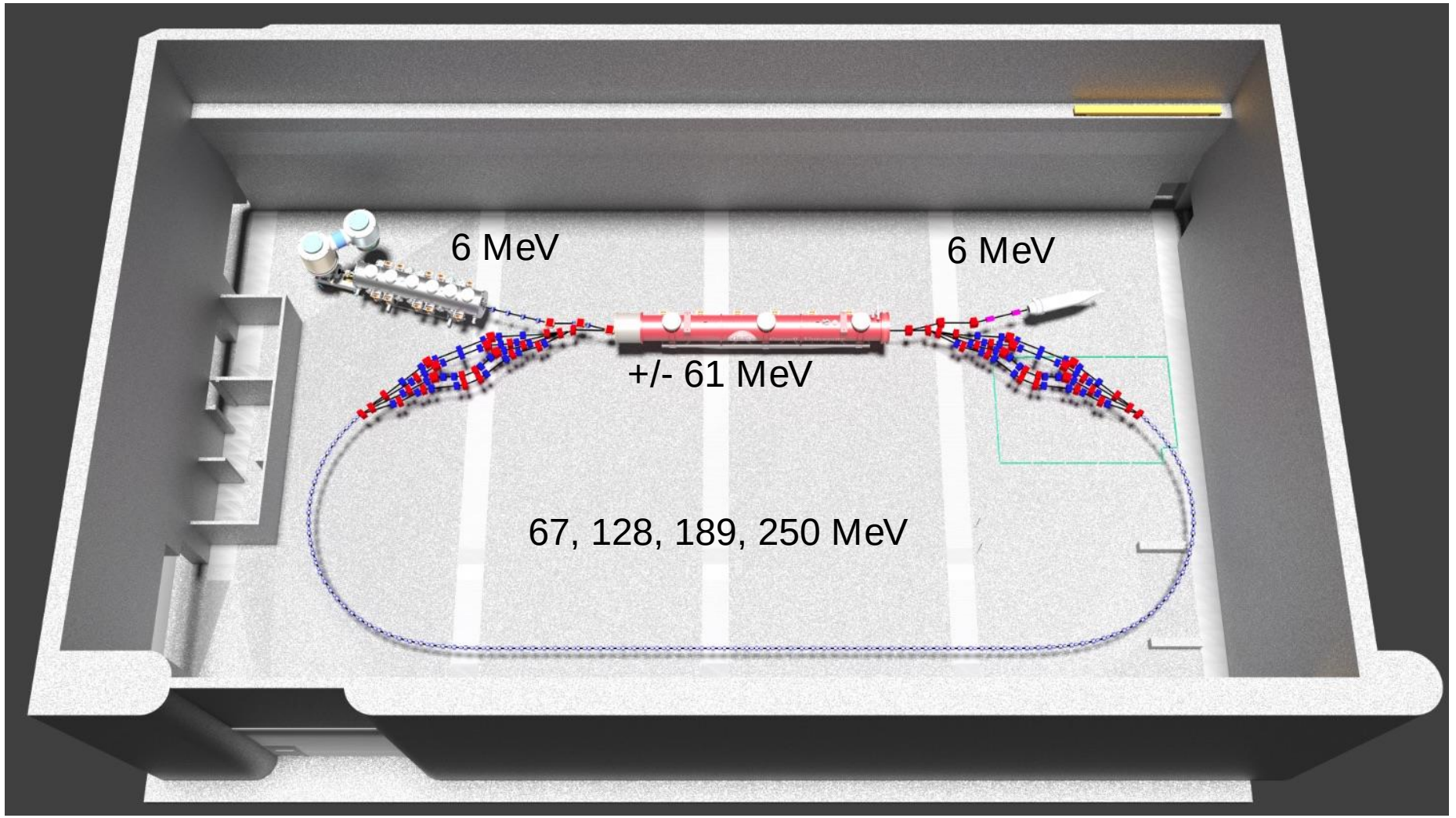


The first test of the FFAG (fixed-field, alternating gradient) concept with electrons was performed at Daresbury – EMMA

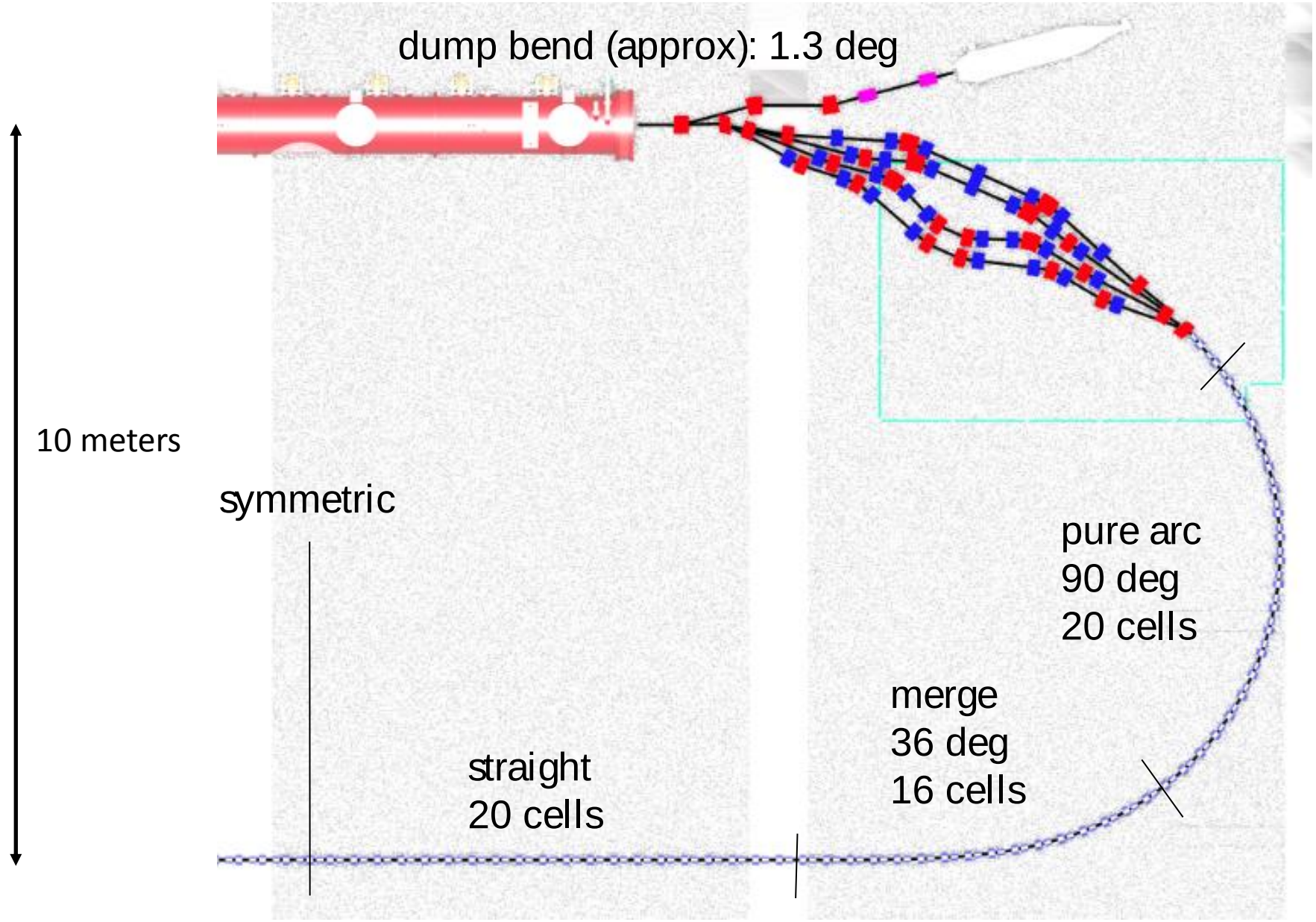
Nature Physics **8**, 243-247 (2012)

Final Application: Cbeta

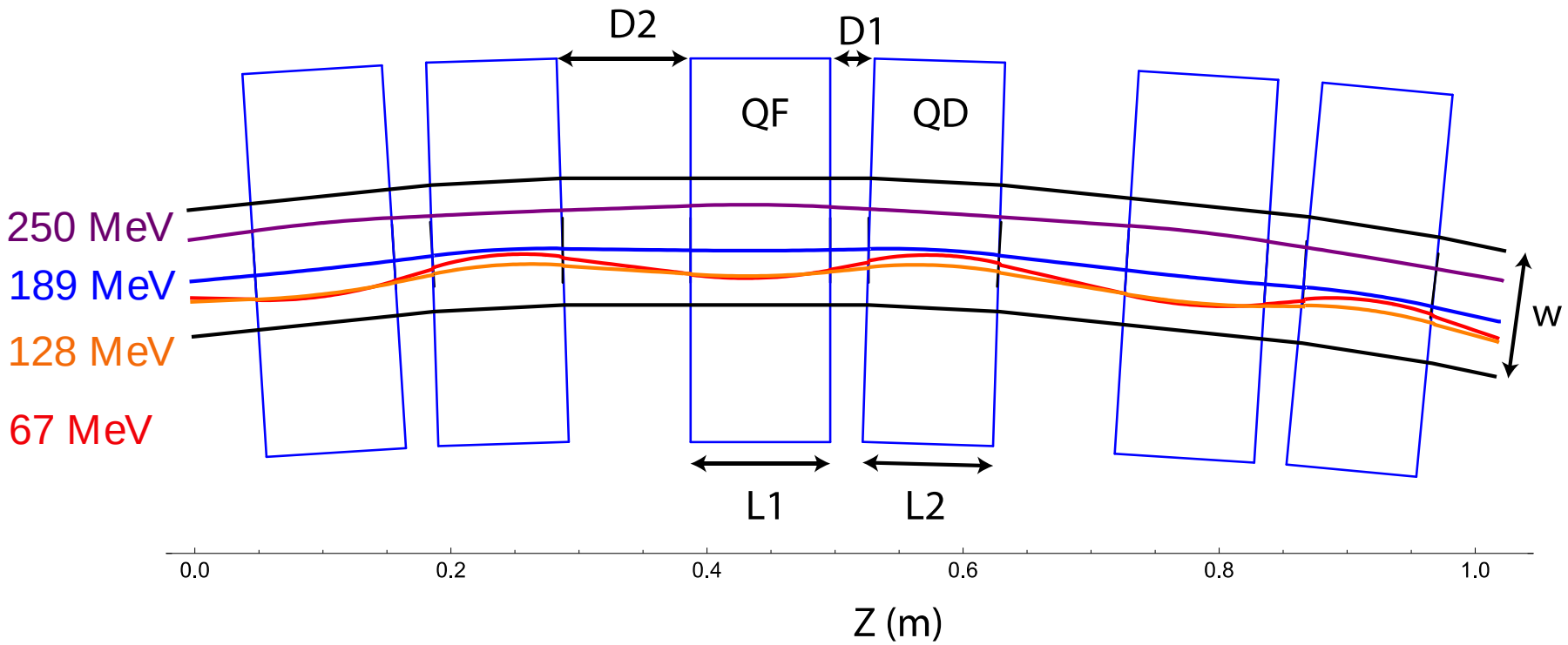
Cornell-Brookhaven Electron Test Accelerator



Cbeta Optics



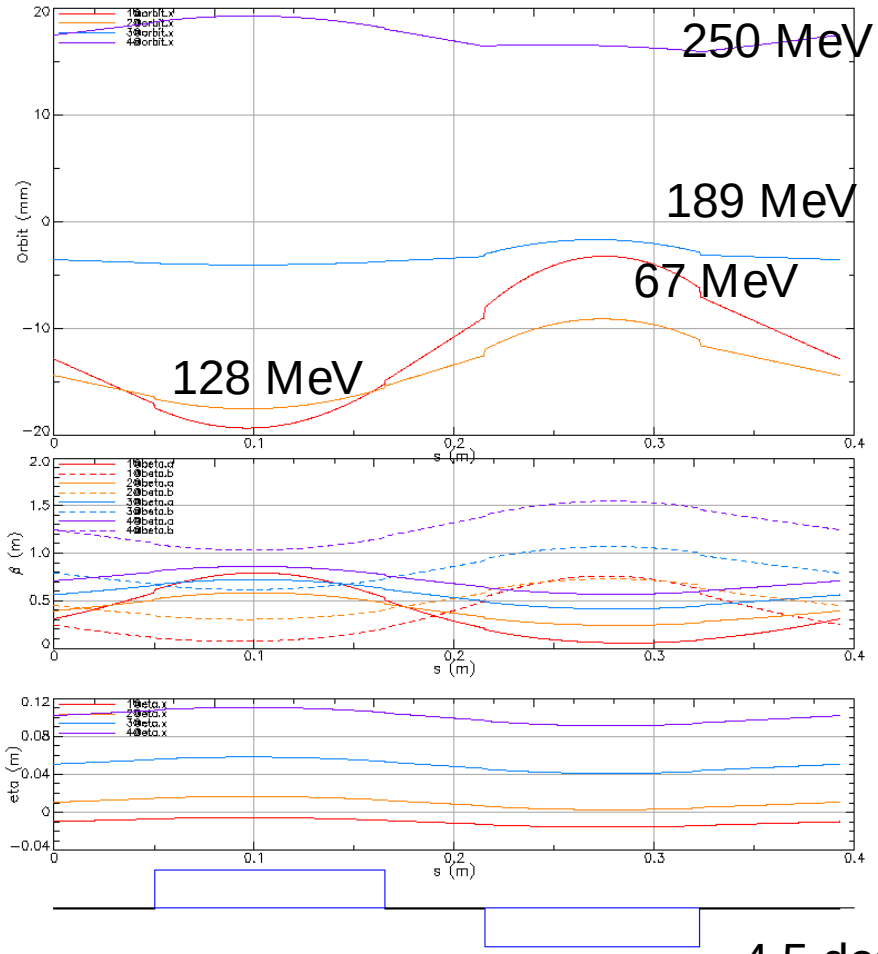
Arc Cell Geometry



D1 = 5 cm
D2 = 12 cm
L1,L2 = 11 cm
QF ~20 T/m
QD ~20 T/m with .5 T dipole field
4.5 degrees per cell

Cbeta Optics

Cell (4.5 deg)

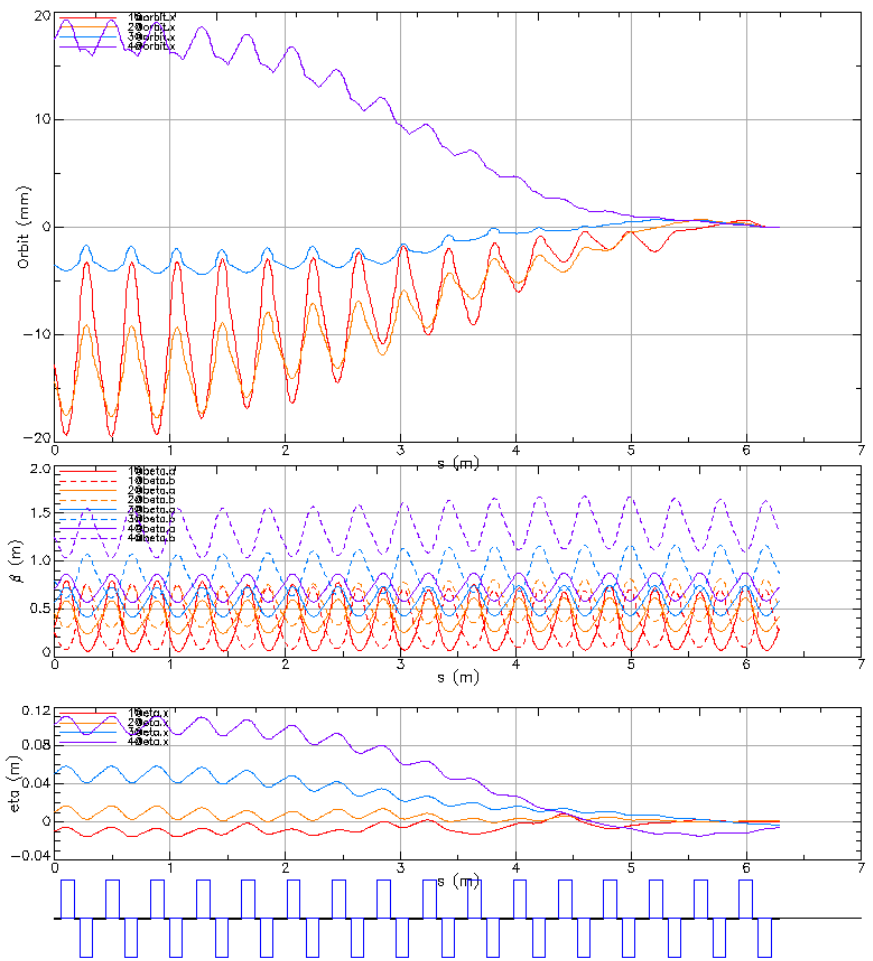


11.5 cm
21 T/m

10.7 cm
-20 T/m
0.514 T

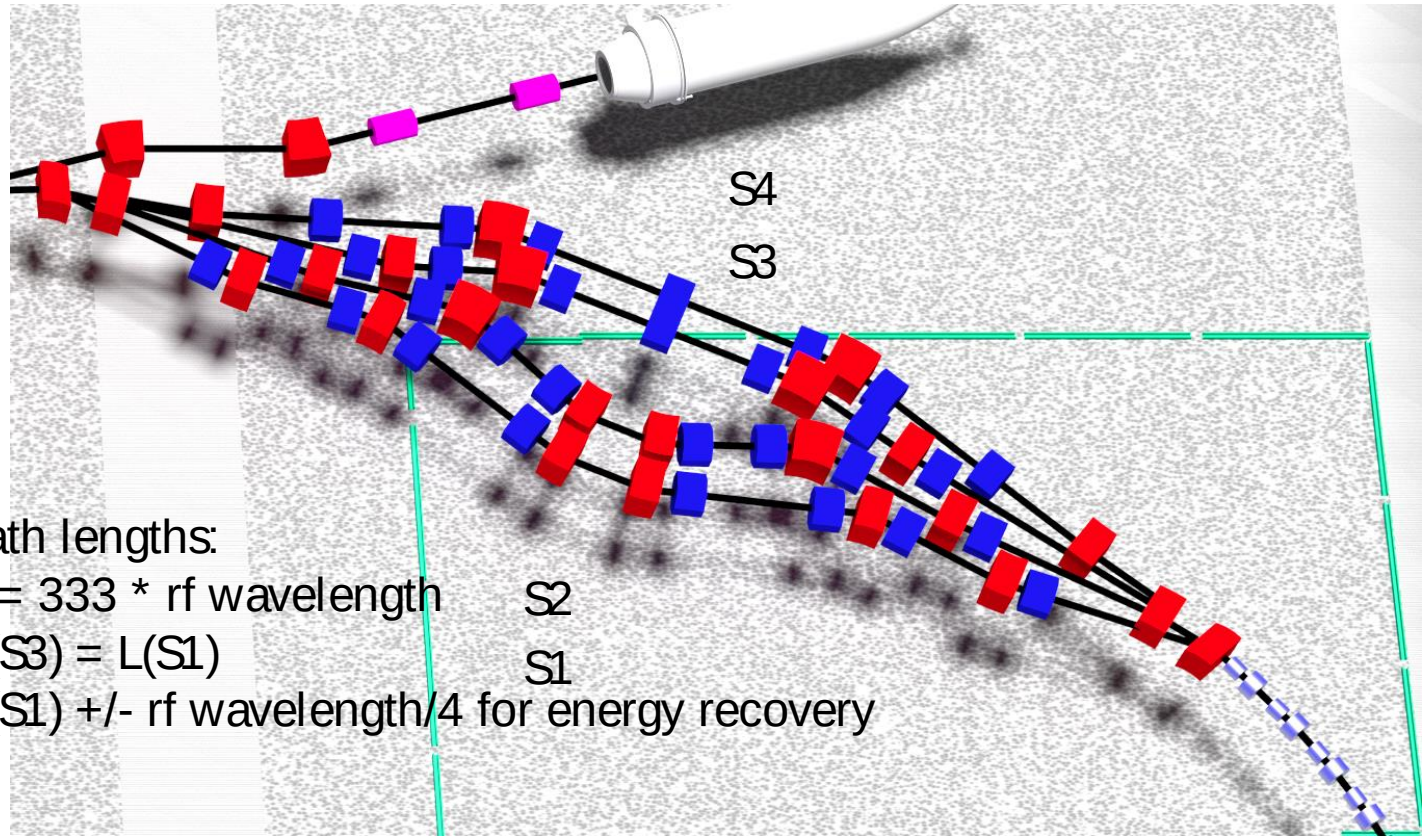
4.5 deg

Merge 16 cells (36 deg)



Spreader/Recombiner

- Accept large beams from Linac
- Steer onto FFAG closed orbits
- Match to FFAG optics
- r_{56} adjustment
- Path length tuning: coarse (angle adjustment) and fine (bellows)
- Total path lengths same for all beams
  (extra 0.5 rf wavelength for 250 MeV)

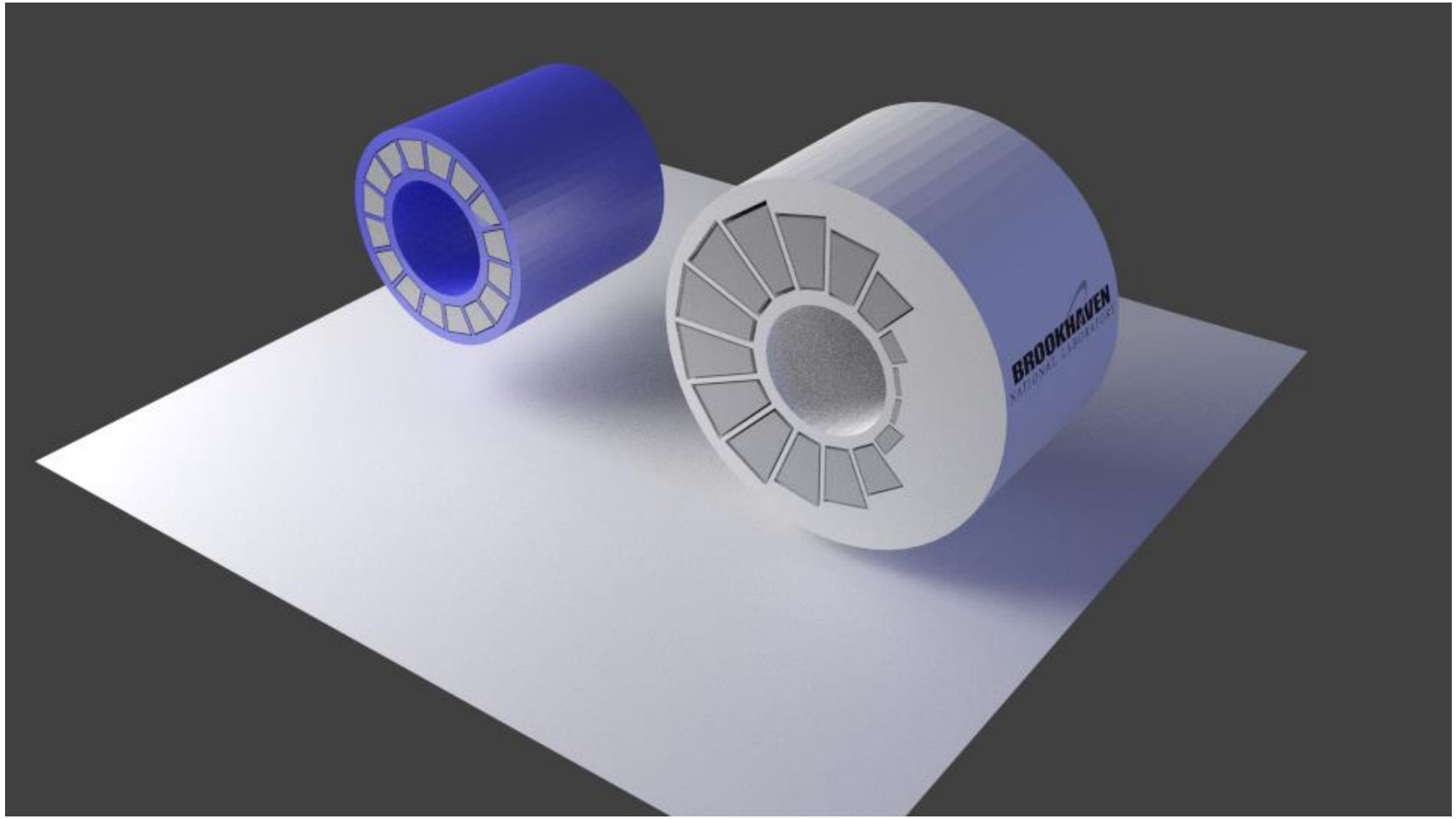


Splitter Path lengths:
L(pass 1) = 333 * rf wavelength
L(S2) = L(S3) = L(S1)
L(S4) = L(S1) +/- rf wavelength/4 for energy recovery

Remaining Optics Studies

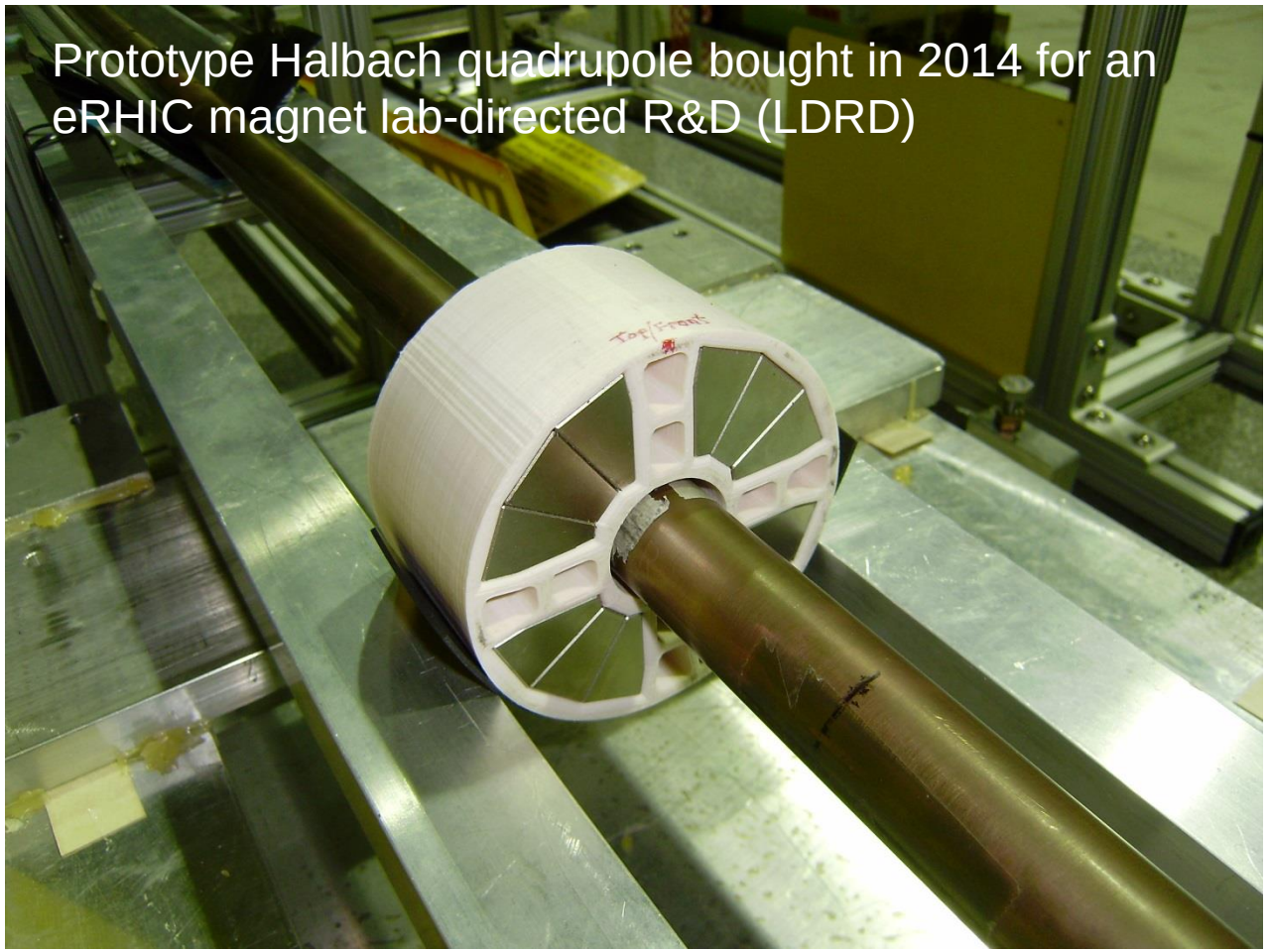
- Particle tracking with no collective effects
- Shrink splitters using realistic magnet sizes (another design round)
- Real fieldmaps (FFAG magnets, cavities, …)
- Wakefields (CSR, resistive wall, …)
- Injector + Linac space charge optimization
- Touschek scattering
- Dark current tracking & collimation
- BBU
- Ion trapping
- Orbit and optics correction
- Tolerance & stability analysis

Cbeta Magnets



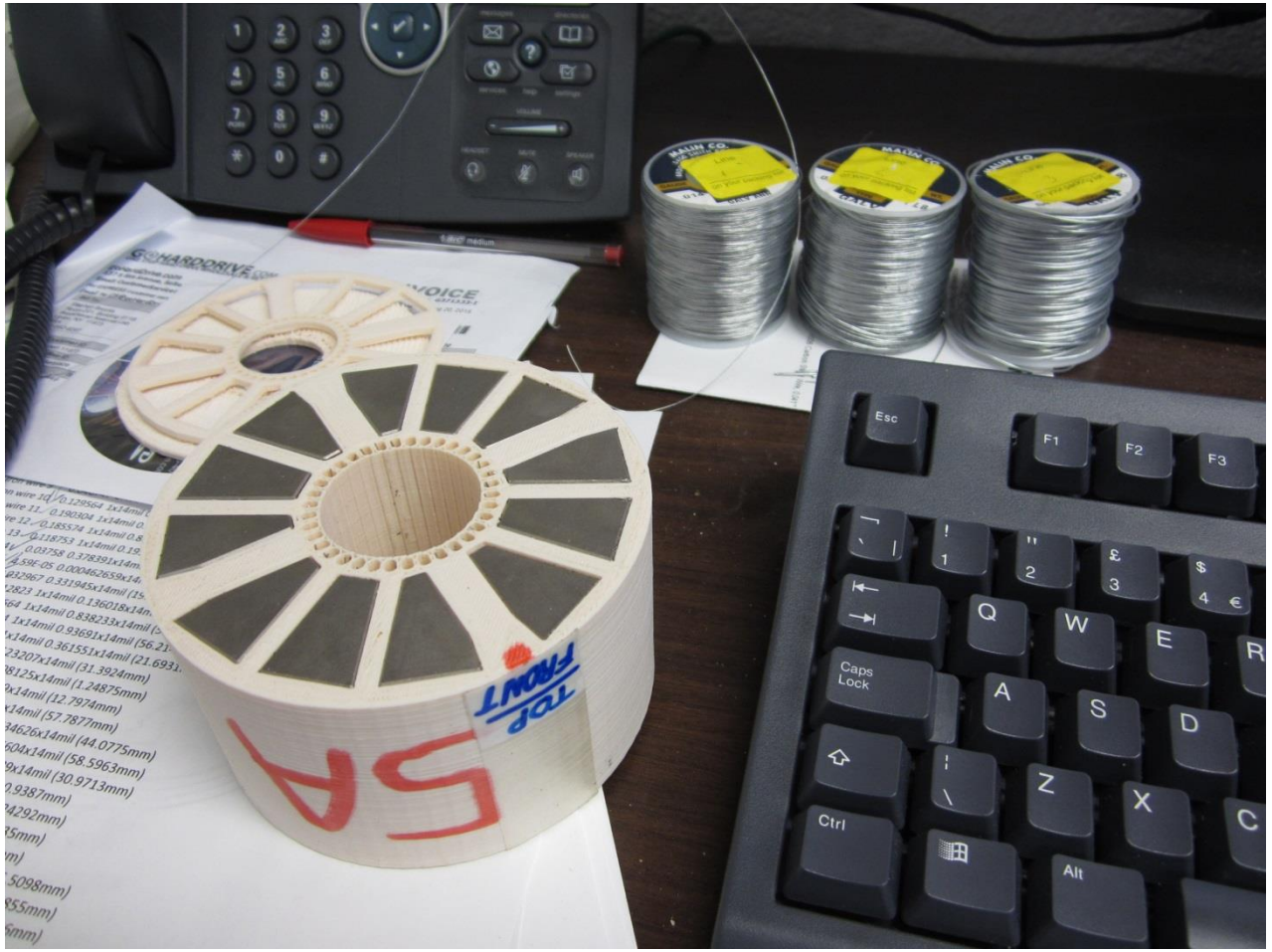
Halbach-type PM for the normal quad (left) and a modified Halbach-type for the quad/dipole combination (right)

Rotating Coil at BNL Magnet Dept.



Courtesy of: S. Brooks

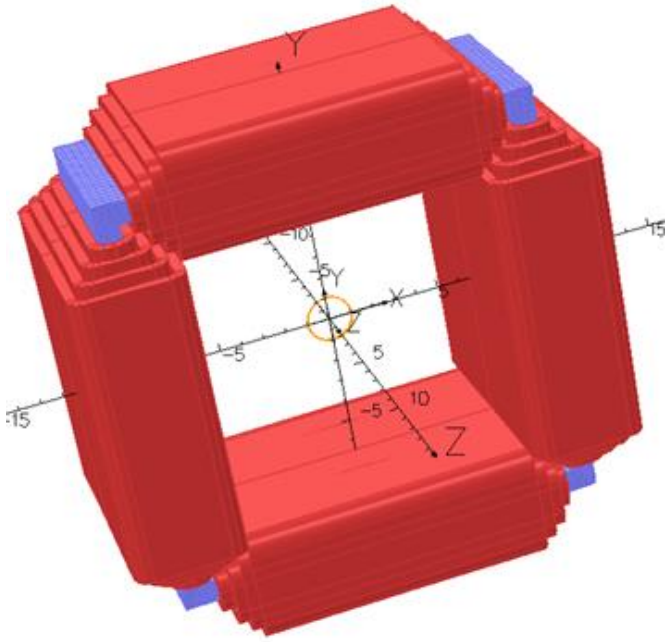
Cbeta Magnets



More recent prototyping, including small holes for shimming using iron wires

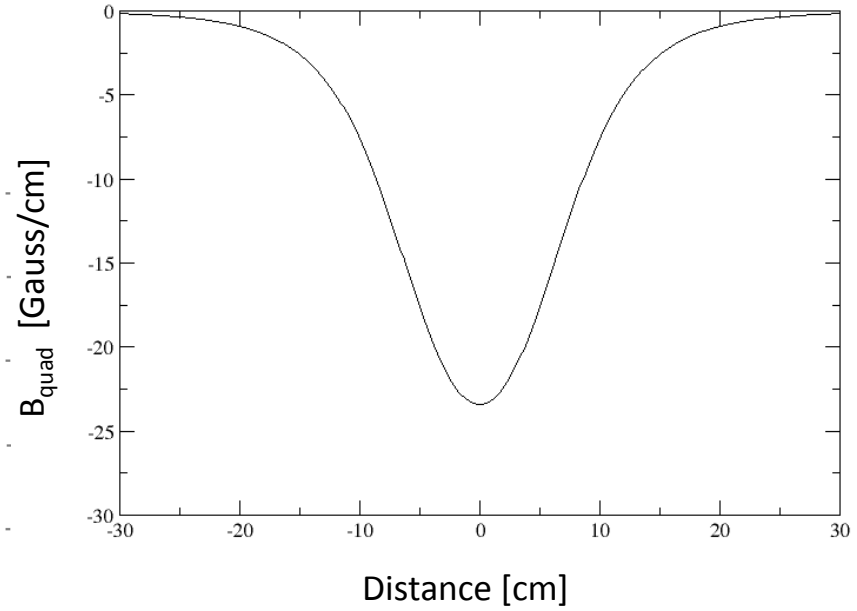
Courtesy of: S. Brooks

Cbeta Trim Coils



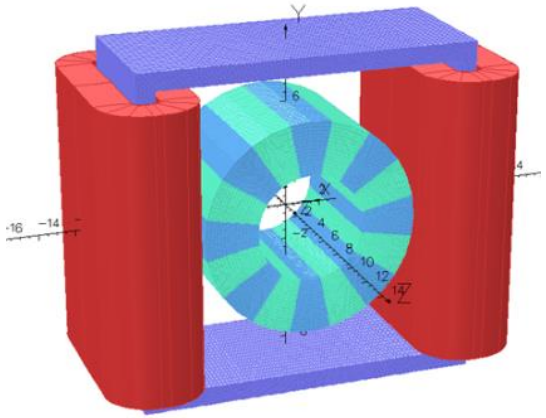
Gradient ~0.36 [T/m]
Integrated Gradient(at R=1cm)= 410 Gauss

The PM material (NdFeB) has a poor temperature coefficient, 10^{-3}/C, so we will have a quadrupole trim coil with a +/- 2% correction range.

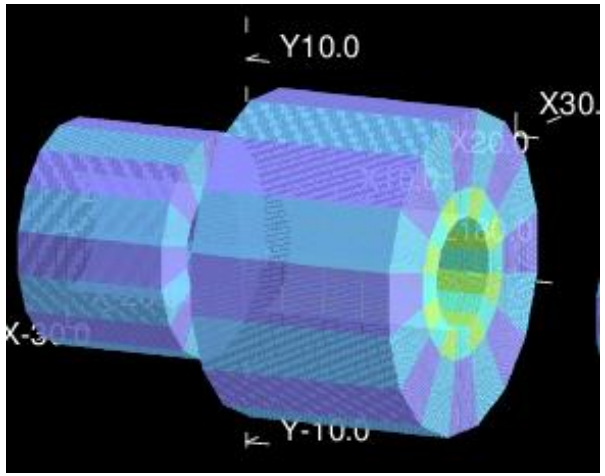


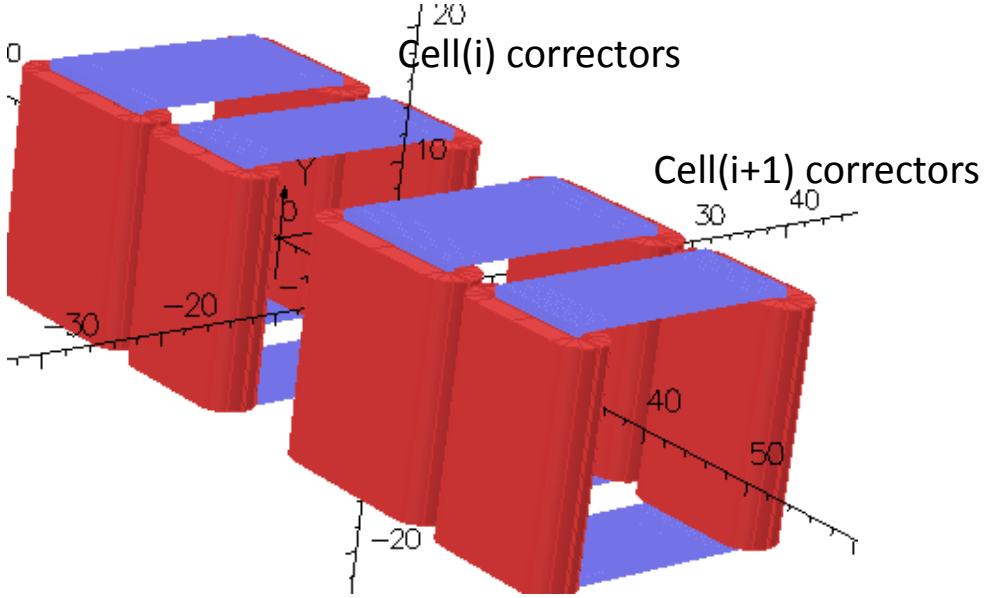
Courtesy of: N. Tsoupas

Cbeta Trim coils



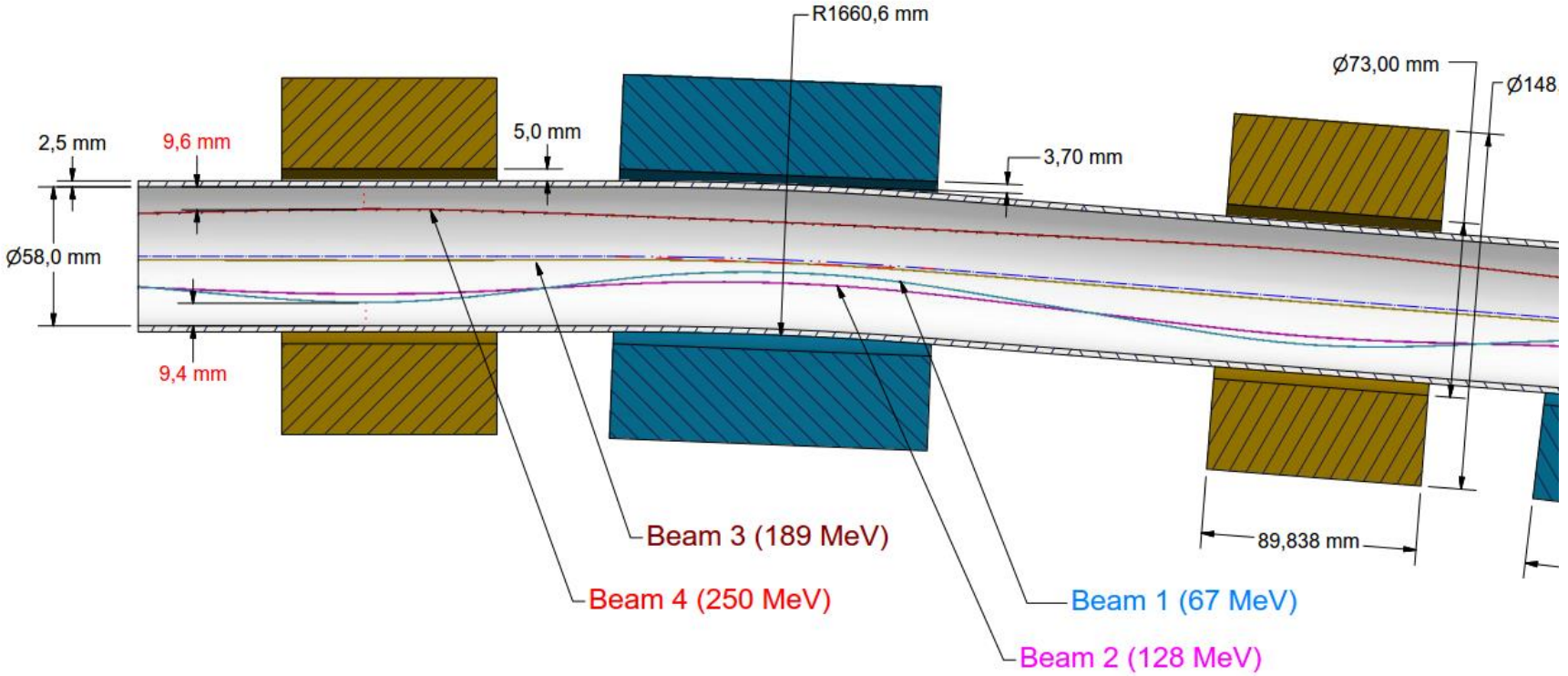
We will also have horizontal and vertical correction coils, in the same package as the trim quad





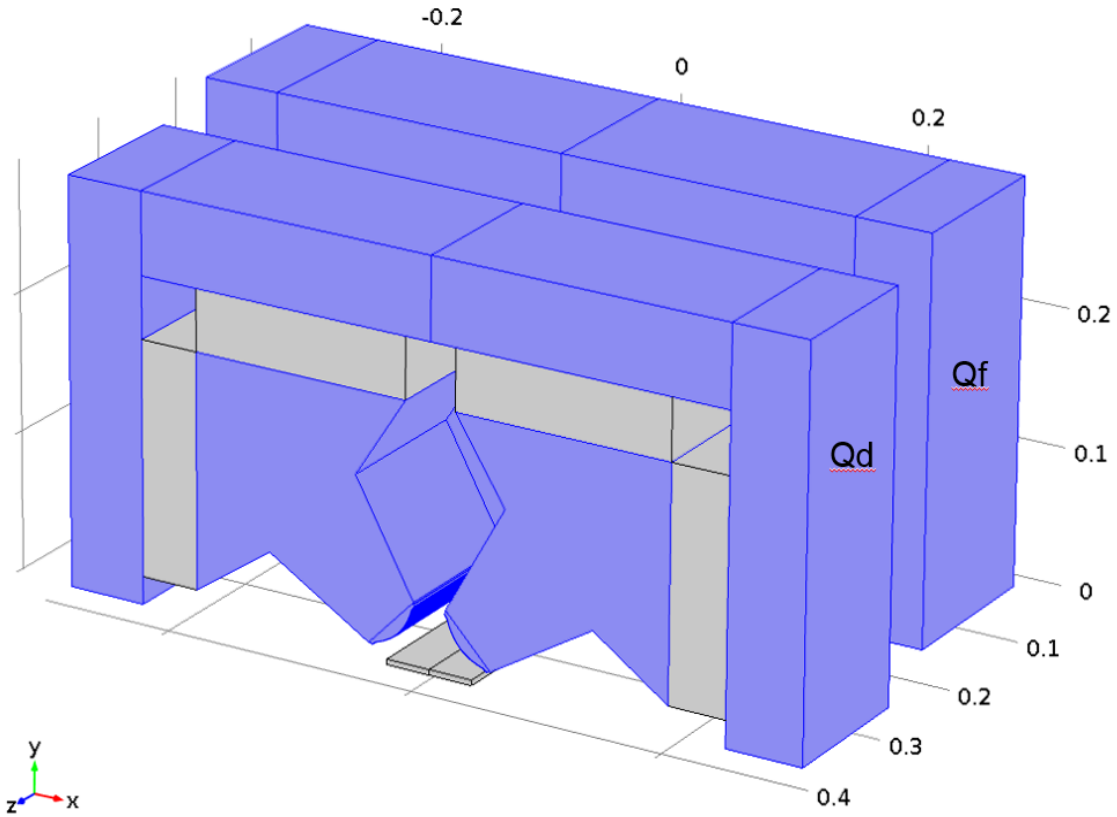
Courtesy of: N. Tsoupas

Vacuum Chamber



Extruded aluminum beam pipe, round or elliptical.
There will be button bpms in the short drift regions, and either NEG pumps, diagnostics, or bellows in the long sections

Alternate Magnet Design



We are also investigating other magnet designs. This one has iron poles with PM to drive the field. It has better field quality and less temperature drift, but is much larger and needs a big offset for the bending field

Courtesy of: H. Witte

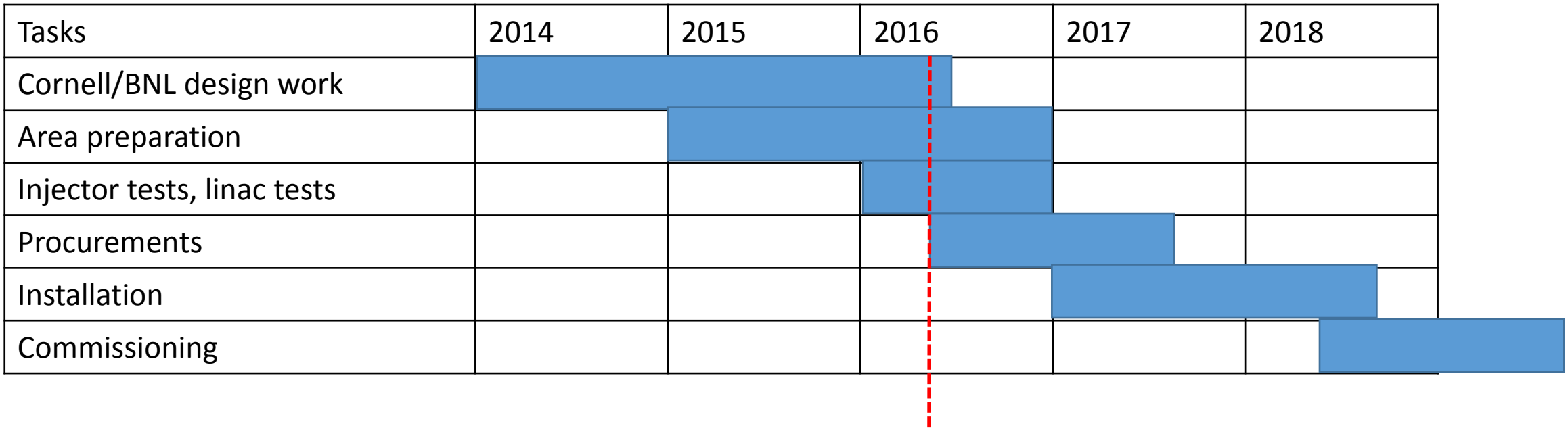
Cbeta Highlights

Cbeta will be the first accelerator of its kind, including the following novel items:

- An ERL using FFAG recirculating arcs
- An electron FFAG with a 4X momentum range
- Adiabatic transition from curved to straight section in an FFAG
- Permanent magnets used in an ERL loop
- A multi-pass, superconducting RF ERL

Cbeta Timeline

Tasks	2014	2015	2016	2017	2018
Cornell/BNL design work					
Area preparation					
Injector tests, linac tests					
Procurements					
Installation					
Commissioning					



Funding is due to start after April 1, 2016

Future Cbeta Applications

INTENSE ELECTRON BEAMS WORKSHOP

CORNELL UNIVERSITY, JUNE 17-19, 2015

With the advent of high power photoinjectors and high performance superconducting RF acceleration, there is the potential for low energy electron beams with currents up to 10 times higher that those generally available today. This workshop will explore the physics opportunities that will be opened up by such beams, focusing on **parity violation**, the search for **dark matter, dark photons and axions**, and **electromagnetic nuclear physics**, as well as the accelerator, detector, target and polarimetry **technologies** that make them possible. Discussion will focus on electron beams with energies up to 500 MeV and electron current of up to 100 mA (unpolarized) and 10 mA (polarized) with energy recovery, with the goal of answering:

1. What is the potential reach of experiments using very intense low energy electron beams?
2. What technical challenges need to be overcome to reach those goals?

Working Groups

- **Parity Violation** -- co-conveners: Kent Paschke (U. Virginia), Maxim Perelstein (Cornell)
- **Dark Matter, Dark Photons, Axions** -- co-conveners: Andrei Afanasev (George Washington University), Gordan Krnjaic (Perimeter Inst.), Bogdan Wojtsekhowski (JLAB), Philip Schuster (Perimeter Inst.)
- **Electromagnetic nuclear physics** -- co-conveners: Jan Bernauer (MIT), Ronald Gilman (Rutgers)
- **Technology** -- co-conveners: Vadim Ptitsyn (BNL), Joe Grames (JLAB), Alexander Nass (Fz. Jülich)

- Testing 650 MHz SRF modules with beam, for other machines – the optics are designed to work with 1300 or 650 MHz cavities.
- An intense hard x-ray/gamma ray source for material studies (Compton backscattering)
- Accelerator physics studies – multi-pass ERLs, BBU, ion effects, etc

I would like to end with a funny physics joke, but all the good ones Argon!