# Notes on Possible IOTA Electron Lens Engineering Projects with U. Chicago

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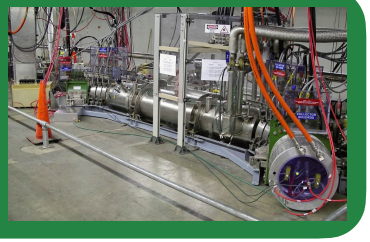
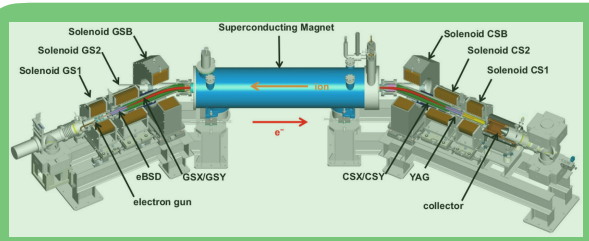
Fermilab

# Electron Lenses: Flexible Instruments for Beam Physics

*Fermilab Tevatron collider (2001-2011)*

- head-on and long-range beam-beam compensation
- abort-gap clearing
- first studies of halo scraping with hollow beams



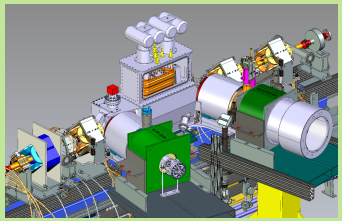


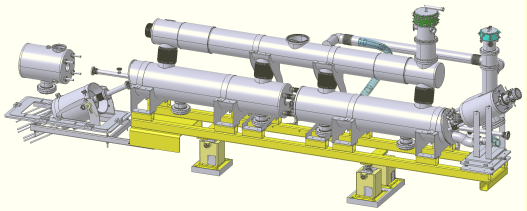

*RHIC at BNL (2015-present)*

- head-on beam-beam compensation
- further studies of halo scraping

*IOTA (starting in 2022?)*

- nonlinear integrable optics
- tune-spread generation
- space-charge compensation
- electron cooling of protons

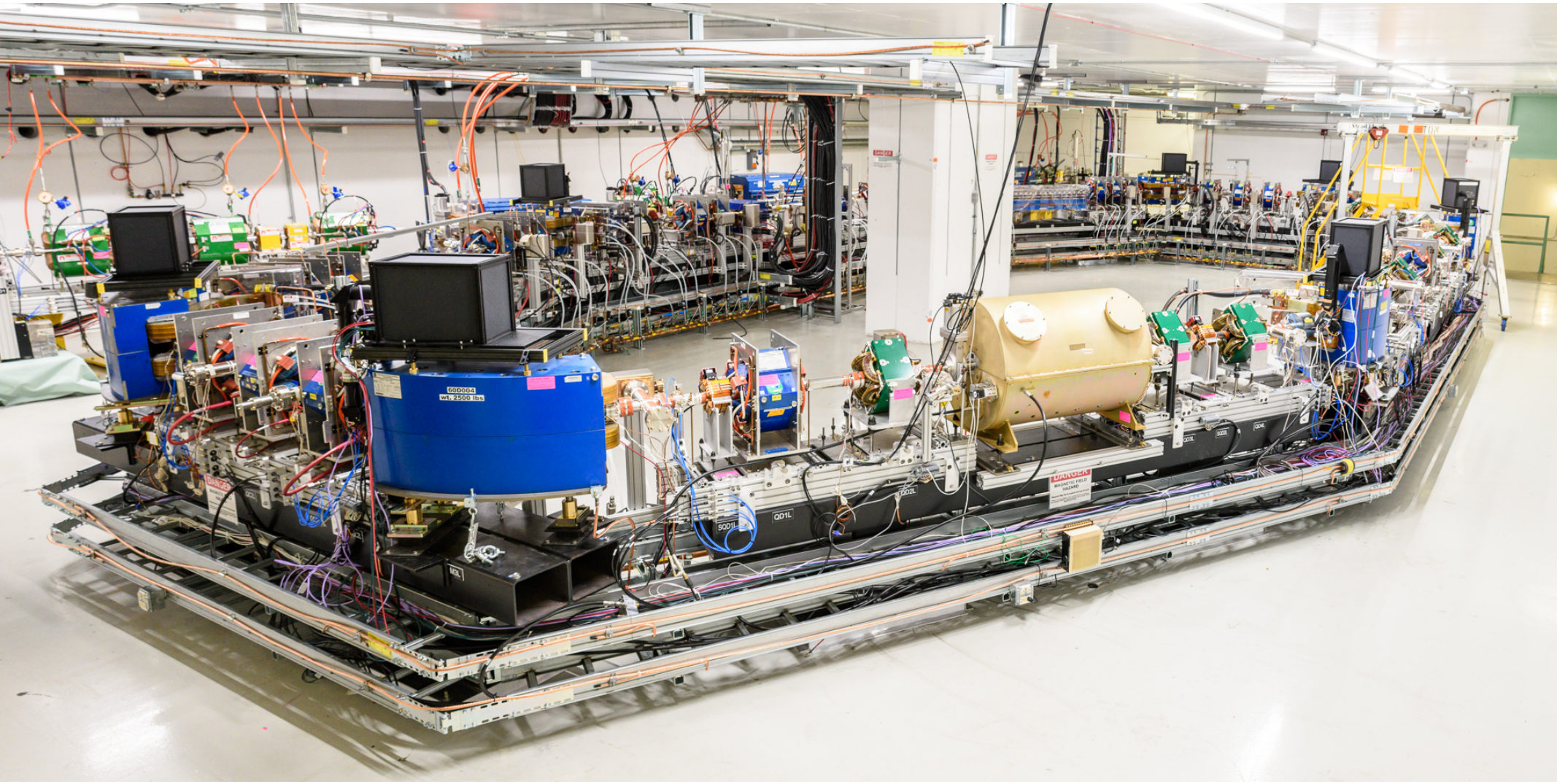




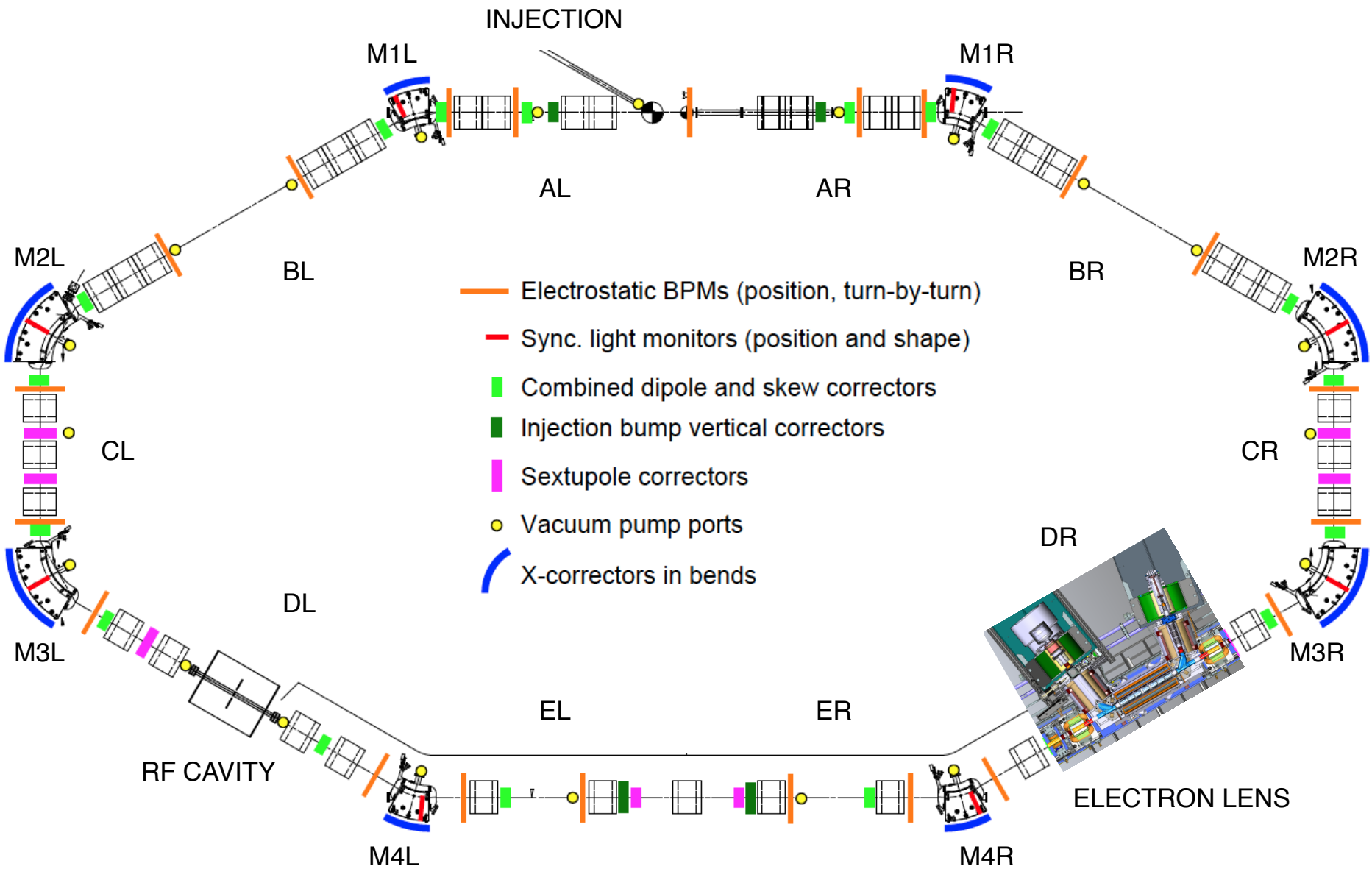
*LHC (2025 installation, 2027 run; part of HL-LHC)*

- active halo control with hollow beams
- option for tune-spread generation

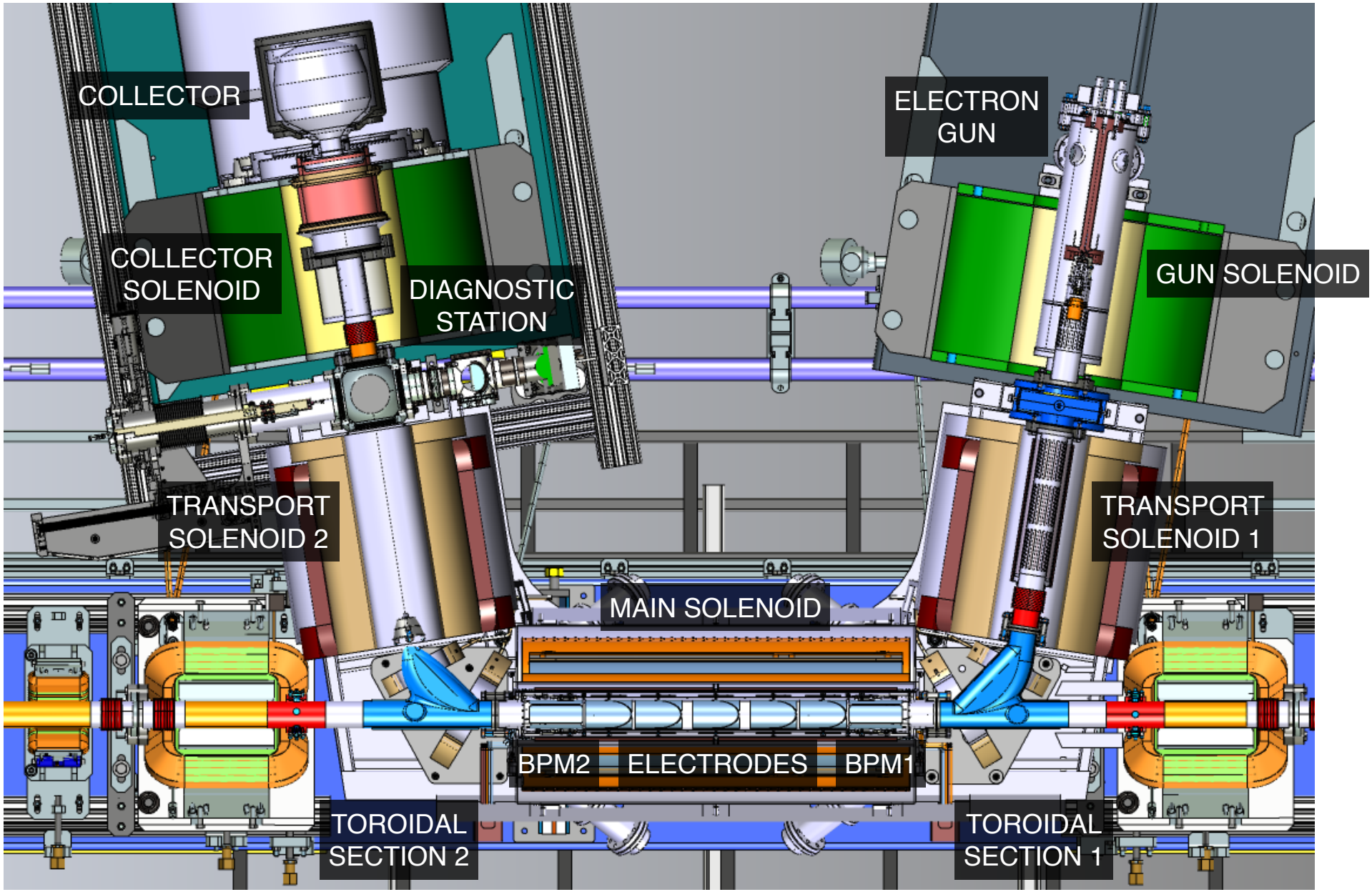
# The IOTA storage ring at Fermilab



# IOTA Layout


INJECTION
M1L
M1R
AL
AR
M2L
M2R
BL
BR
CL
CR
DR
DL
M3L
M3R
EL
ER
RF CAVITY
ELECTRON LENS
M4L
M4R
Electrostatic BPMs (position, turn-by-turn)
Sync. light monitors (position and shape)
Combined dipole and skew correctors
Injection bump vertical correctors
Sextupole correctors
Vacuum pump ports
X-correctors in bends

# IOTA Electron Lens Layout



# The 10.8 mm Gaussian electron gun

Reused from Tevatron beam-beam compensation studies

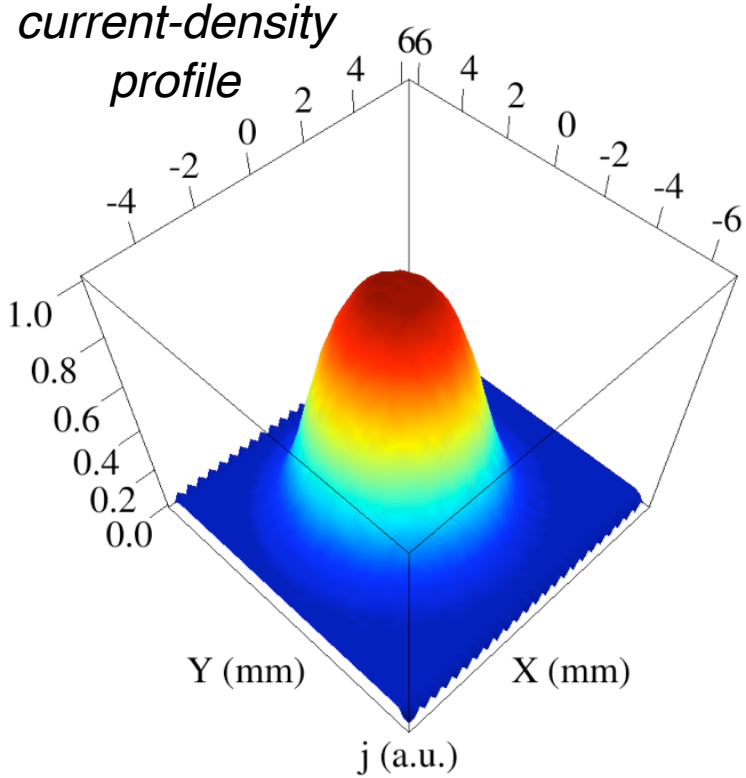
New tungsten dispenser cathodes available

In IOTA, it can be used as a model for tests of nonlinear integrable optics, electron cooling, and space-charge compensation

*side view*

*top view*

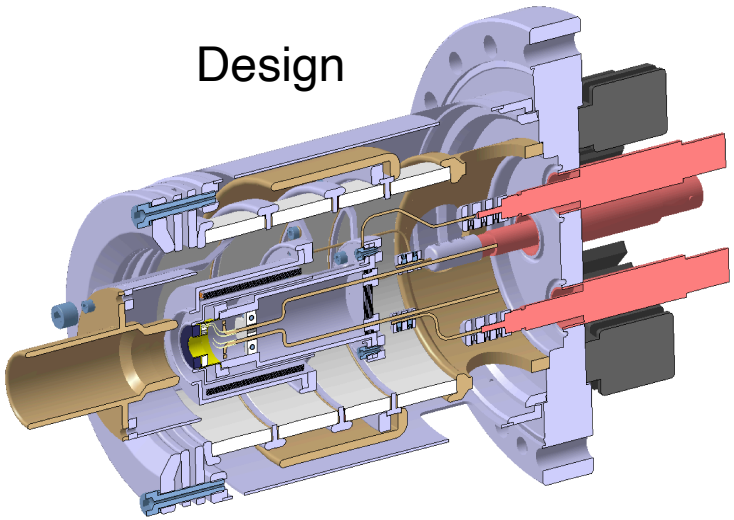
*measured current-density profile*

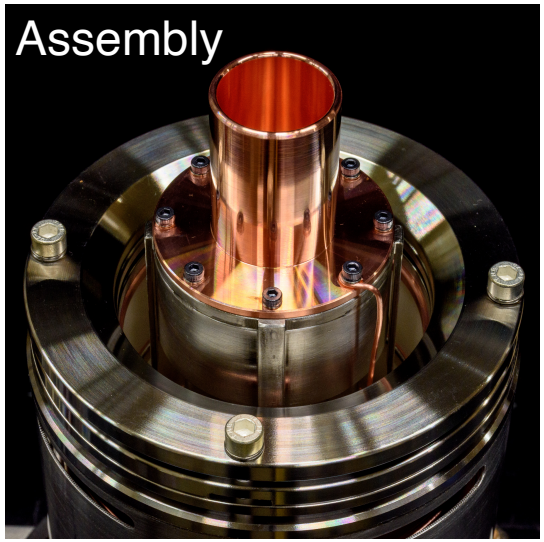


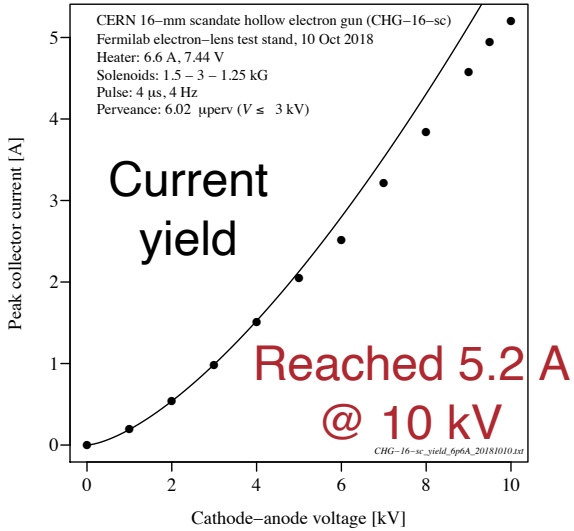

Yields 1.7 A at 5 kV

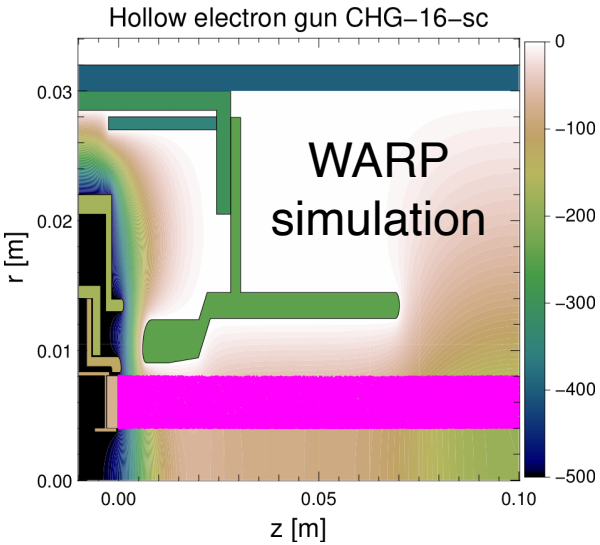
# Electron Gun Development at Fermilab and CERN

## Example: CHG-16-sc hollow gun

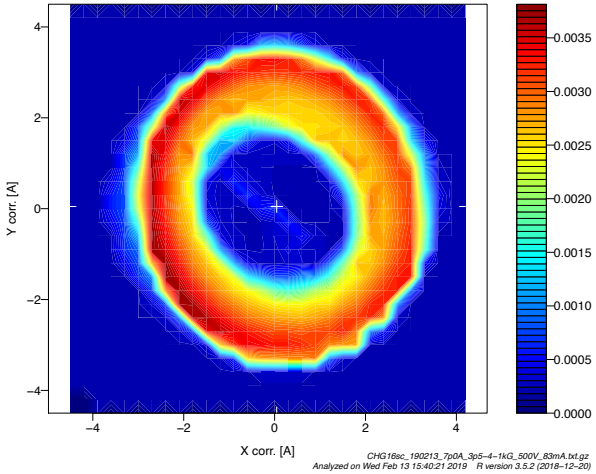


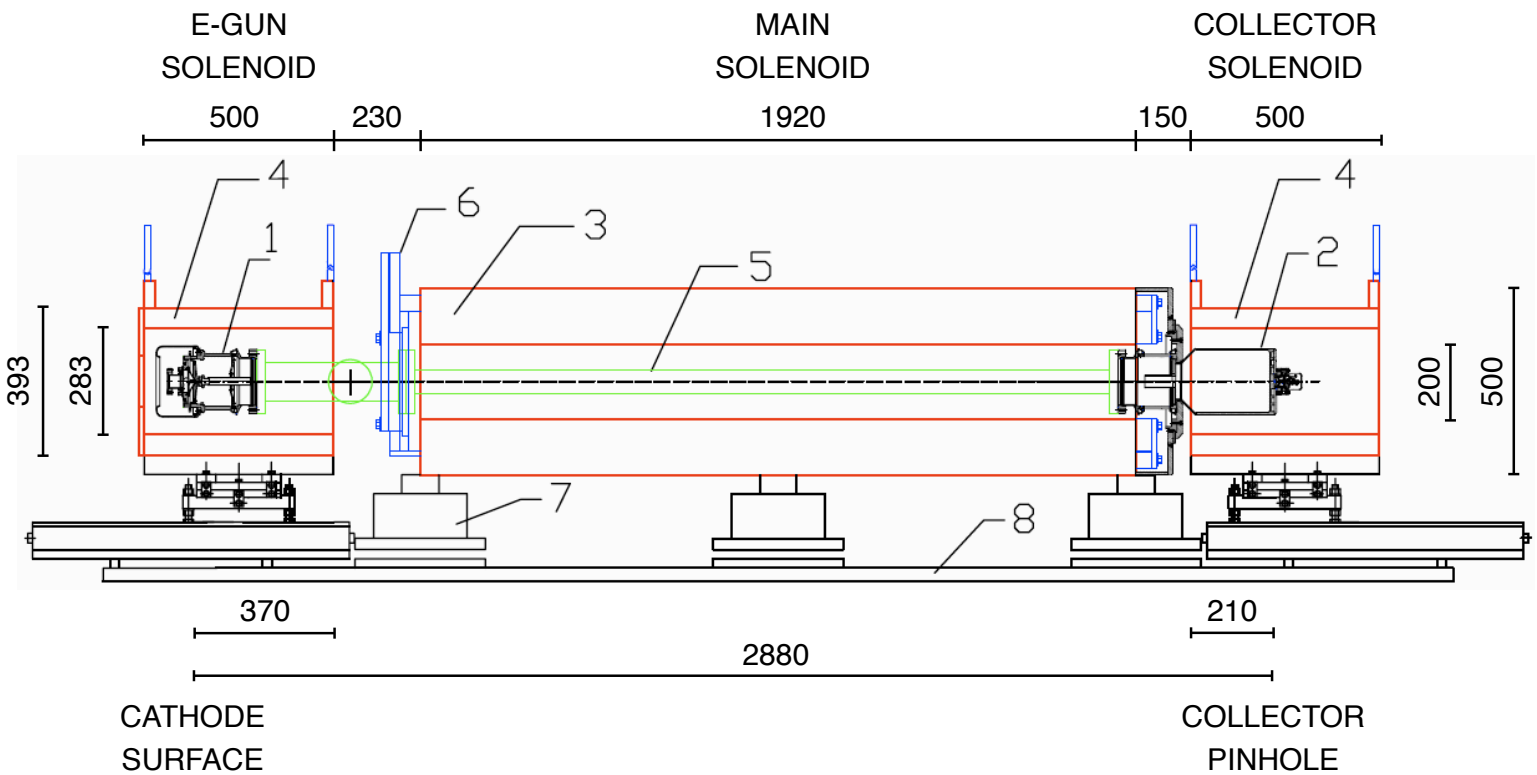



Measured current-density profile



# The Fermilab electron-lens test stand for e-gun characterization

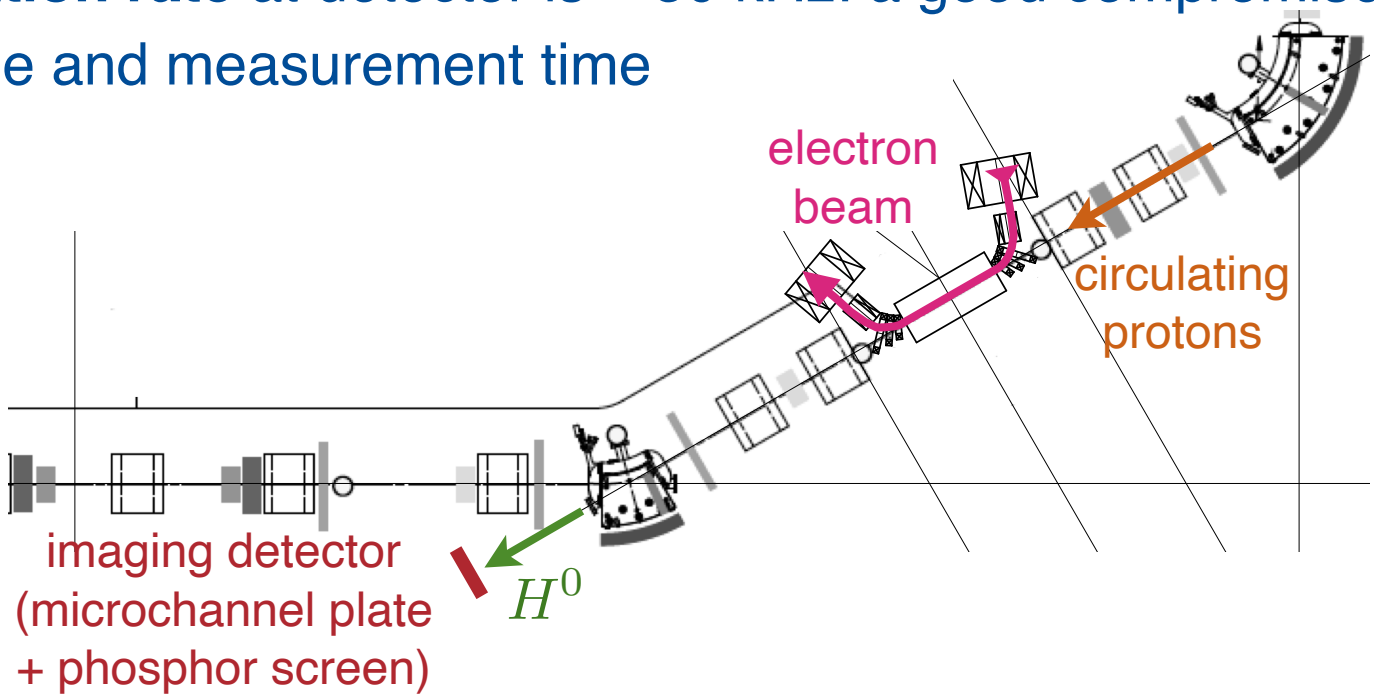


# Proton Beam Diagnostics through Recombination

**Spontaneous recombination** generates neutral hydrogen with distribution of Rydberg states, some of which are Lorentz-stripped in e-lens toroid and IOTA dipole

$$p + e^- \rightarrow H^0 + h\nu$$

**Recombination rate** at detector is ~ 50 kHz: a good compromise between beam lifetime and measurement time




A **critical diagnostic tool** for **cooling**, but also for **proton beam evolution**. Proton beam diagnostics in IOTA is scarce.

*Image from CERN's ELENA ring recombination monitor*
*Tests with $H^-$ stripping on residual gas*

# Summary

**Strengths and flexibility of electron lenses** in beam physics are mainly given by
–tunable current-density profiles
–synchronization and timing of the electron pulse
–stability given by the solenoidal field
They will be a **key part of the IOTA research program**

We need to maintain the capability to design and build 1-10 keV, 5 mA — 3 A **pulsed thermionic electron guns** with different current-density profiles for nonlinear integrable optics, electron cooling and space-charge compensation

When the IOTA proton program starts in 2021/2022, diagnostics for the study of beam stability (one of the main research goals) will be critical. A **neutralization monitor** will used for tuning the electron lens as a cooler and for non-invasive measurements of transverse beam profiles.