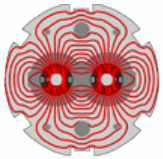


U.S. DEPARTMENT OF ENERGY | Office of Science

Electron Lens Activities

Giulio Stancari
Fermi National Accelerator Laboratory

DOE Review of LARP
Fermilab, July 13-15, 2016

Contributors

M. Fitterer, L. Valerio, A. Valishev (Fermilab)

R. Bruce, D. Perini, S. Redaelli, A. Rossi, H. Schmickler, G. Valentino, J. Wagner, C. Zanoni (CERN)

W. Fischer, X. Gu and BNL e-lens team

J.-L. Vay and LBNL Warp developers

New young members of the group

Miriam Fitterer, post-doctoral Toohig Fellow
March 2016 -
Electron lenses for collimation and beam-beam compensation

Joschka Wagner, joint PhD CERN/FNAL/IAP supported by CERN
August 2015 -
Active halo control methods in LHC: hollow electron beams, narrow-band excitation, and tune ripple

Summary

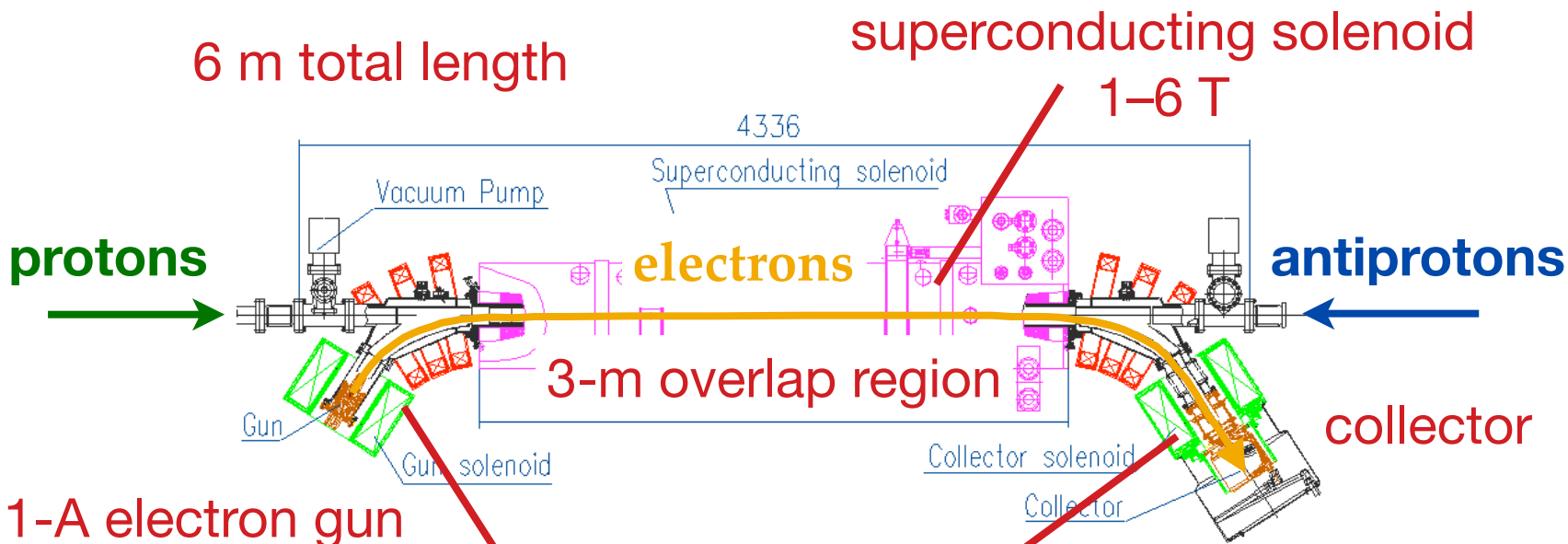
Recent achievements

Plans for 2017-18 (see also L. Valerio's talk)

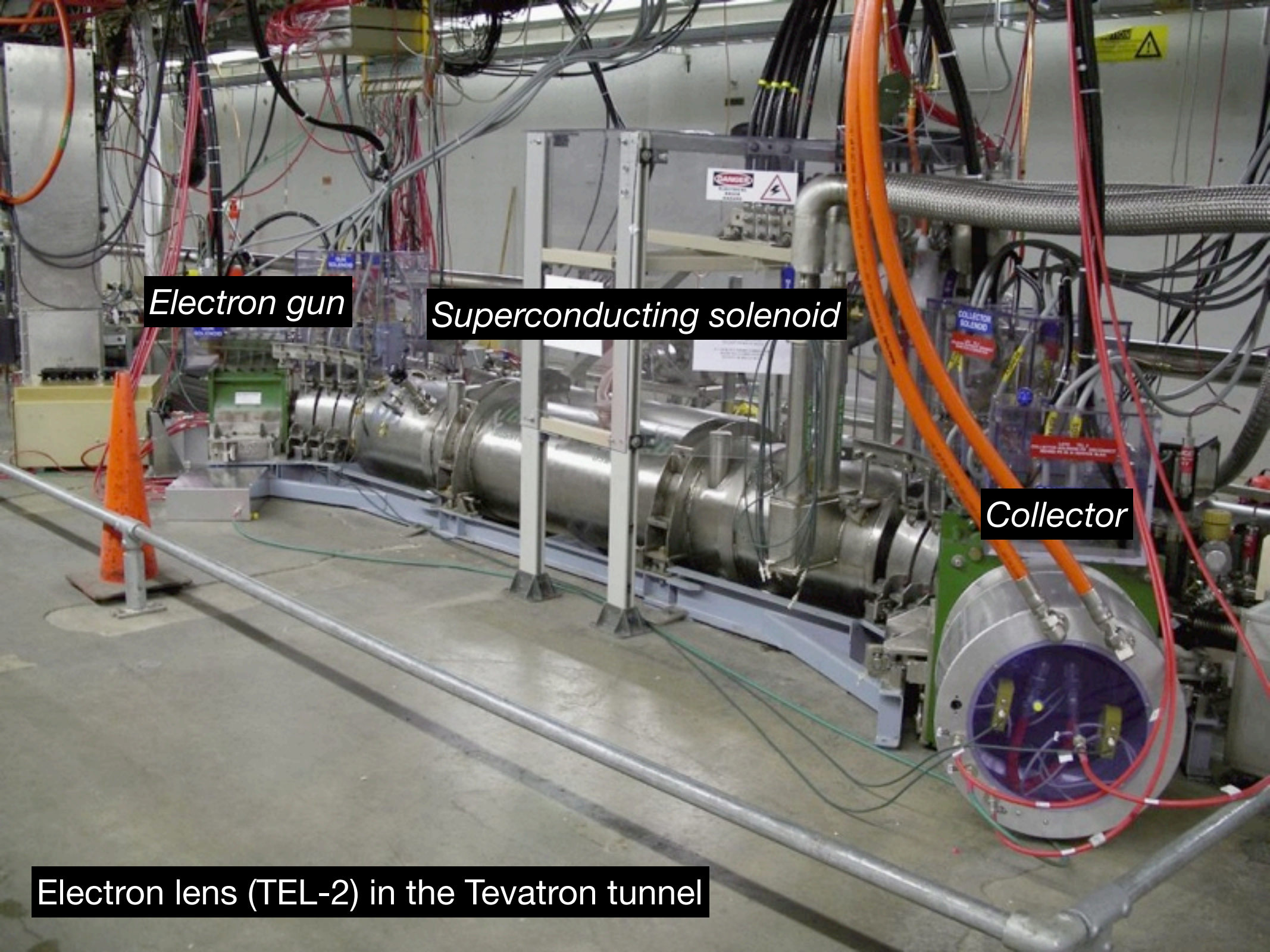
Proposals for LARP continuation

What's an electron lens?

- Pulsed, magnetically confined, low-energy electron beam
- Circulating beam affected by electromagnetic fields generated by electrons
- Stability provided by strong axial magnetic fields



Shiltsev et al., Phys. Rev. ST Accel. Beams **11**, 103501 (2008)

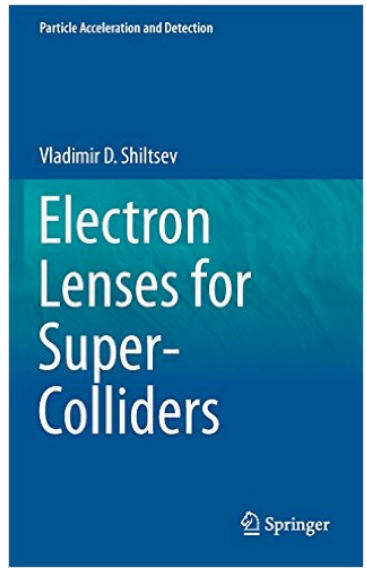


Electron lens (TEL-2) in the Tevatron tunnel

Applications of electron lenses

In the Fermilab Tevatron collider

- ***long-range beam-beam compensation (tune shift of individual bunches)***
  - Shiltsev et al., Phys. Rev. Lett. **99**, 244801 (2007)
- ***abort-gap cleaning (for years of regular operations)***
  - Zhang et al., Phys. Rev. ST Accel. Beams **11**, 051002 (2008)
- ***studies of head-on beam-beam compensation***
  - Stancari and Valishev, FERMILAB-CONF-13-046-APC
- ***demonstration of halo scraping with hollow electron beams***
  - Stancari et al., Phys. Rev. Lett. **107**, 084802 (2011)



Presently, used in RHIC at BNL for head-on beam-beam compensation, luminosity improvements

- Fischer et al., Phys. Rev. Lett. **115**, 264801 (2015)

Current areas of research

- ***generation of nonlinear integrable lattices*** in the Fermilab Integrable Optics Test Accelerator
  - Nagaitsev, Valishev et al., IPAC12; Stancari, arXiv:1409.3615, Stancari et al., IPAC15
- ***hollow electron beam scraping*** of protons in LHC
  - Stancari et al., CERN-ACC-2014-0248; Bruce et al., IPAC15
- ***long-range beam-beam compensation***

as charged, current-carrying “wires” for LHC

  - Valishev and Stancari, arXiv:1312.5006; Fartoukh et al., PRSTAB **18**, 121001 (2015)
- to ***generate tune spread for Landau damping***

of instabilities before collisions in LHC and for Recycler

Electron lens applications for LHC

Hollow electron beam collimation (HEBC)

- conceptual design completed [CERN-ACC-2014-0248]
- technical design based on existing technology
- close collaboration with LHC Collimation Team on beam halo studies and with EN/MME on hardware design
- review of LHC needs for HL-LHC baseline inclusion in Oct. 2016
- ongoing developments to extend performance

Long-range beam-beam compensation (LRBB) with "electron wires"

- at conceptual stage
- parameters developed in collaboration with beam-beam team (see also A. Valishev's talk)

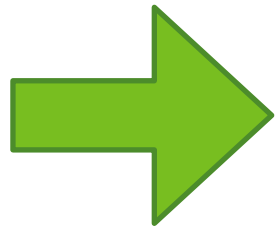
LARP activities and goals

Activities

-beam studies in LHC
-e-gun testing
-cathode development
-e-beam modeling
-tracking simulations

-design test stand at CERN

-develop general LRBB scenarios
-study e-wires for LRBB



Goals

support US-HL-LHC AUP

understand halo population, formation and diffusion in LHC

provide viable LRBB scenarios

strengthen e-beam competences in US and transfer relevant expertise to CERN

education and training

Hollow electron beam collimation

Beam studies in LHC and RHIC

Contributed to experiment design and data analysis.

Measurements of beam halo diffusion in LHC at 6.5 TeV

Valentino et al., CERN-ACC-Note-2016-0010 + recent w/300 bunches

Alternative halo control methods: narrow-band excitation and tune ripple

Wagner et al., IPAC16 Proc. + plans for July/August MD blocks

Effects of resonant excitation on core to simulate e-lens pulsing patterns

Fitterer et al., planned for August MD block

Effects of low-frequency noise on emittance

Fitterer et al., MD note + plans for August MD block

Extend Tevatron observations with experiments in RHIC

reduce project risk, but only possible in 2018

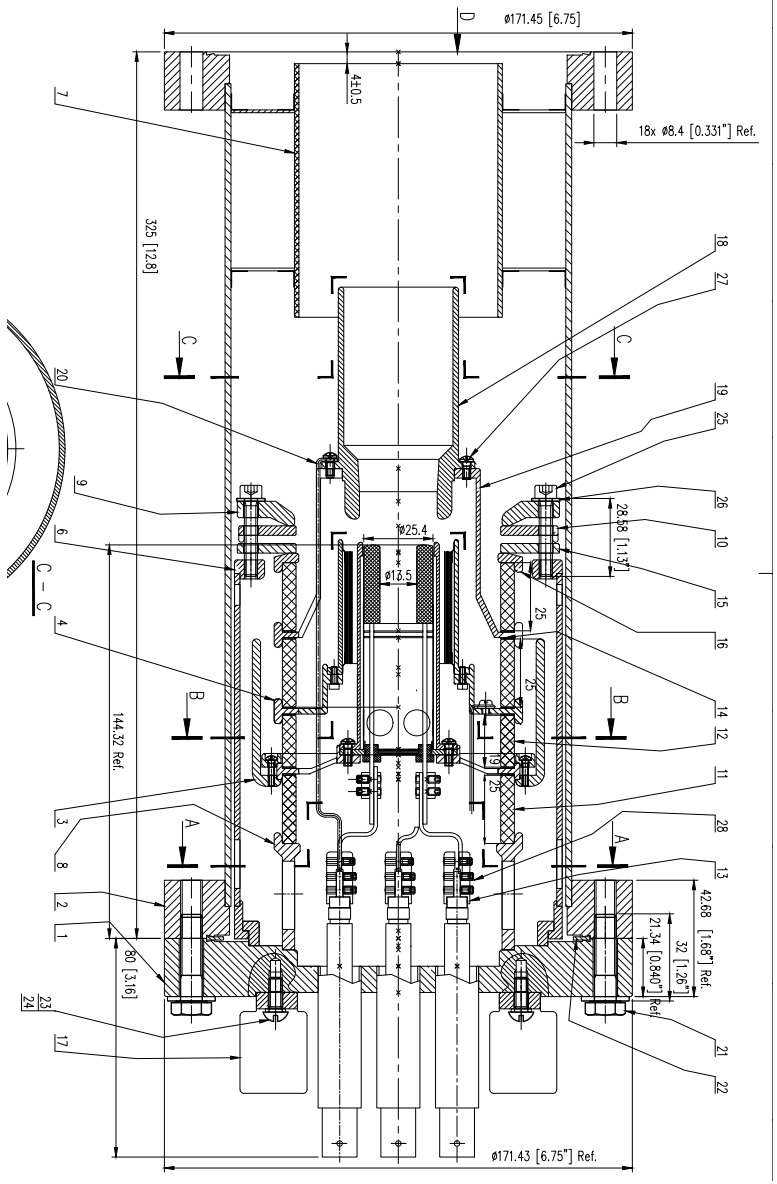
Electron gun design and testing

Hollow electron gun designed at Fermilab based upon Tevatron experience. Built and tested: 5 A at 10 kV, meets requirements for HL-LHC.

Design transferred to CERN. New gun built. To be shipped to FNAL (this month) for testing.

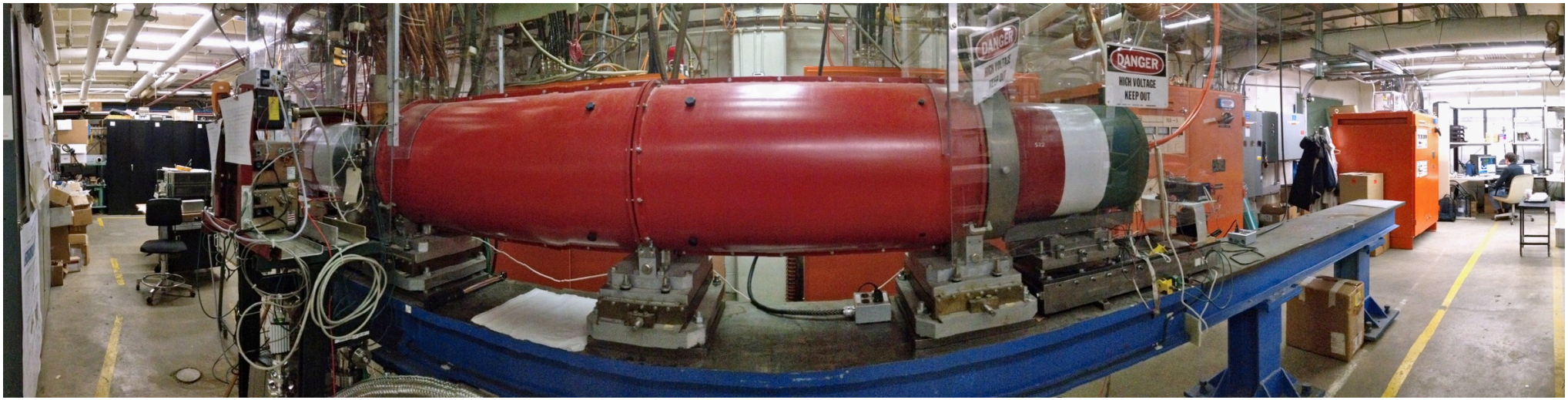
Electron guns

Fermilab design and prototype




First electron gun assembly at CERN

Fermilab electron-lens test stand



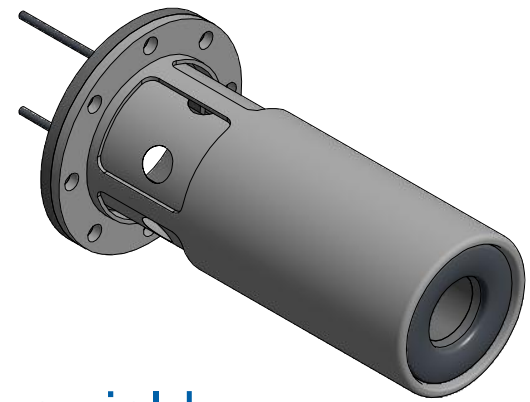
Only operational e-lens test stand in the world

Requires minor ongoing maintenance

Must be kept in operation, especially if e-lens in US-HL-LHC AUP (to be listed in key assumptions)

Cathode developments

Single historical cathode supplier (HeatWave) caused delay of a few months.
We have now obtained 2 hollow cathodes for CERN and 2 for Fermilab.
Sufficient for project.



Investigating other suppliers to reduce risk and improve yield:

- Ceradyne/3M in US and
- Brevetti Bizz in Italy

  same kind of dispenser cathode (barium oxide in tungsten matrix)
- Prof. Wang's group at Beijing U. Tech.

  scandate nanocomposite: much higher current density, lower operating temperature. Uniformity?

Electron beam design and simulations

Design of space-charge-limited electron gun

Single-particle transport through magnetic system

Transport with space charge through bends to evaluate profile distortions

Calculation of field maps for tracking of circulating proton beam

Tools:

Analytical models

Physics codes: EGUN, Warp, bender

Engineering codes: CST, Comsol

Tracking simulations

Calculation of expected halo removal rates and effects on core

Simulated LHC cases with Lifetrac code

Previtali, Valishev

Implemented hollow lens and frequency-map analysis in SixTrack

Fitterer, FERMILAB-TM (in preparation)

Next:

review expected performance with new HL-LHC lattices including imperfections (Fitterer, Wagner et al.)

Support of a test stand at CERN

An electron-lens test stand is being considered at CERN for HL-LHC and for other European projects:

- to test higher beam currents
- to develop new diagnostics
- to study faster modulations for bunch-by-bunch operations

We plan to contribute to

- the definition of the physical parameters
- experiment design and data analysis
- (no hardware)

Stancari, Rossi, Schmickler, FERMILAB-FN (in preparation)

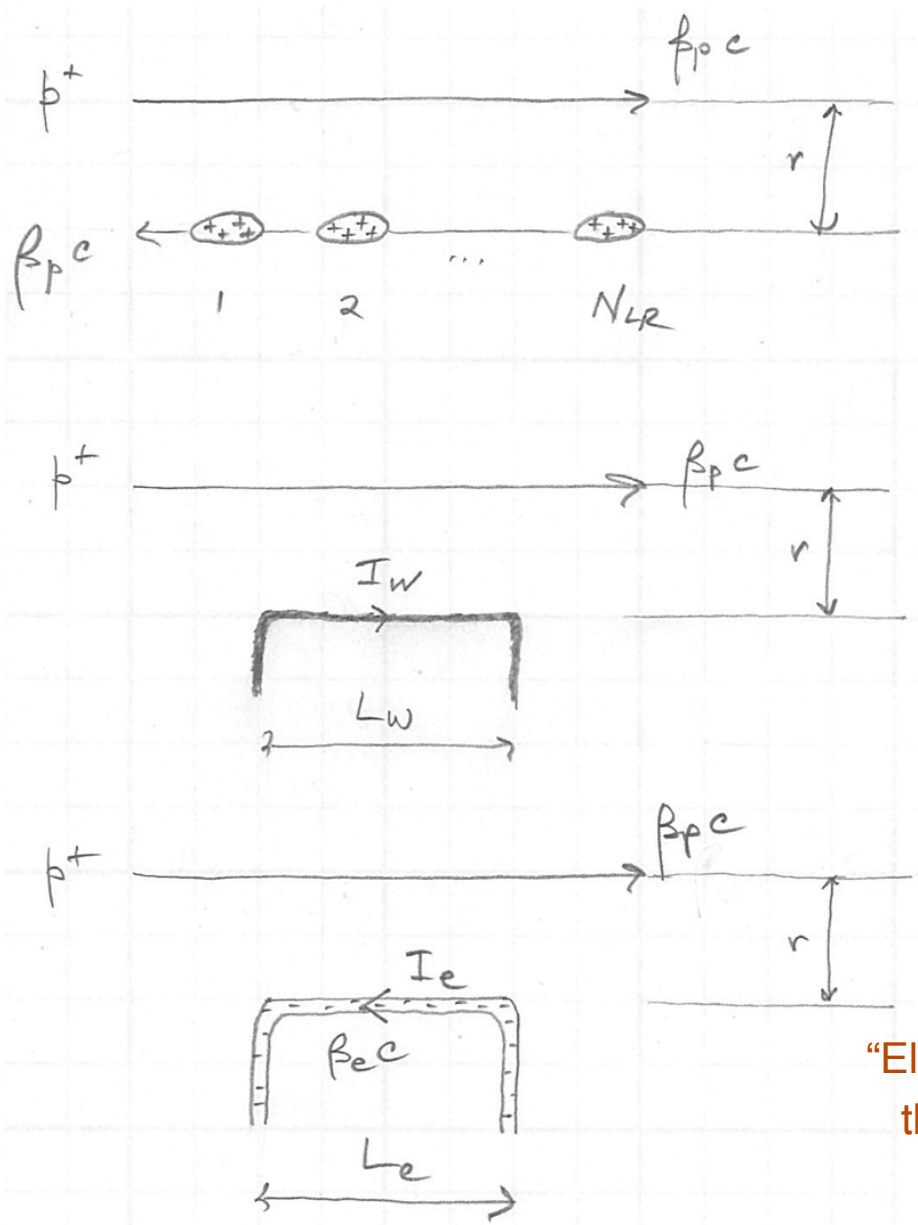
Long-range beam-beam compensation

Long-range compensation schemes

Long-range beam-beam

Wire

Electron beam



momentum transfer $\Delta p_\perp$

$$N_{\mathrm{LR}} N_p e c \frac{1+\beta_p^2}{2\beta_p} \left(\frac{\mu_0 e}{2\pi r}\right)$$

Beam-beam kick is proportional to bunch charge (N_p e) and to number of interactions N_{LR}

$$L_w I_w \left(\frac{\mu_0 e}{2\pi r}\right)$$

Wire strength is characterized by current times length

$$L_e I_e \frac{1 \pm \beta_e \beta_p}{\beta_e \beta_p} \left(\frac{\mu_0 e}{2\pi r}\right)$$

"Electron wire" is charged and slow, so the effect of the current is amplified

Luminosity scenarios in HL-LHC

- Considering both **round** (15/15) and **flat** (10/40) **optics**
- **Luminosity leveling** with beta*
- Assuming **compensation is needed at end of leveling**, when separation decreases to ~10 sigma, a few hours into the store
  - N_p = 1.5e11
- Optimal compensation strength requirements:
  - 131 A m (round)
  - 105 A m (flat)

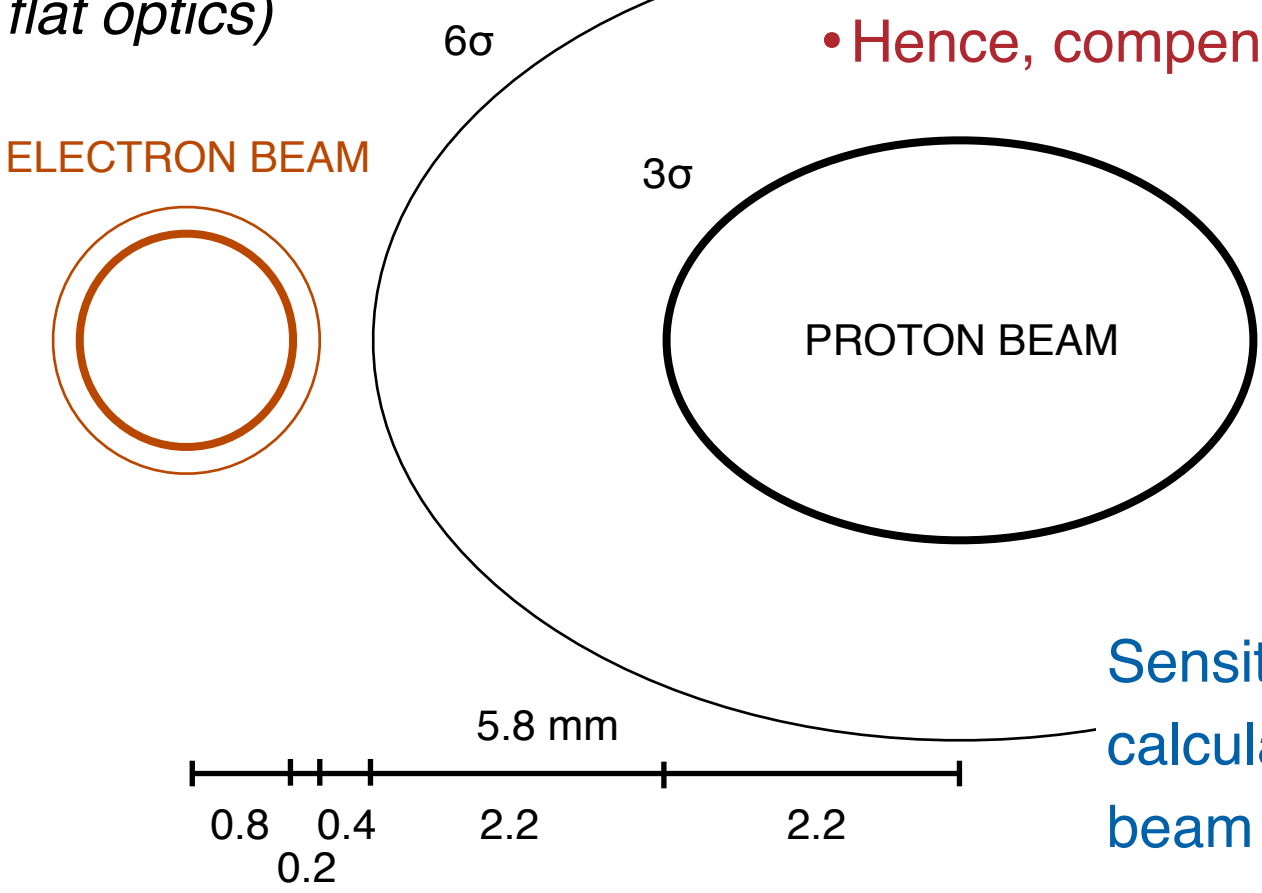
Fartoukh, Papaphilippou, Shatilov, and Valishev, PRSTAB **18**, 121001 (2015)

e-wire advantage: geometrical constraints

Beam 1, left of IP5, round optics (0.15 mm less margin with flat optics)

Requirements:

- Stay clear of 6 sigma dynamic aperture
- Allow for reasonable ~0.2 mm straightness and alignment margin
- Hence, compensator radius ~0.8 mm or less

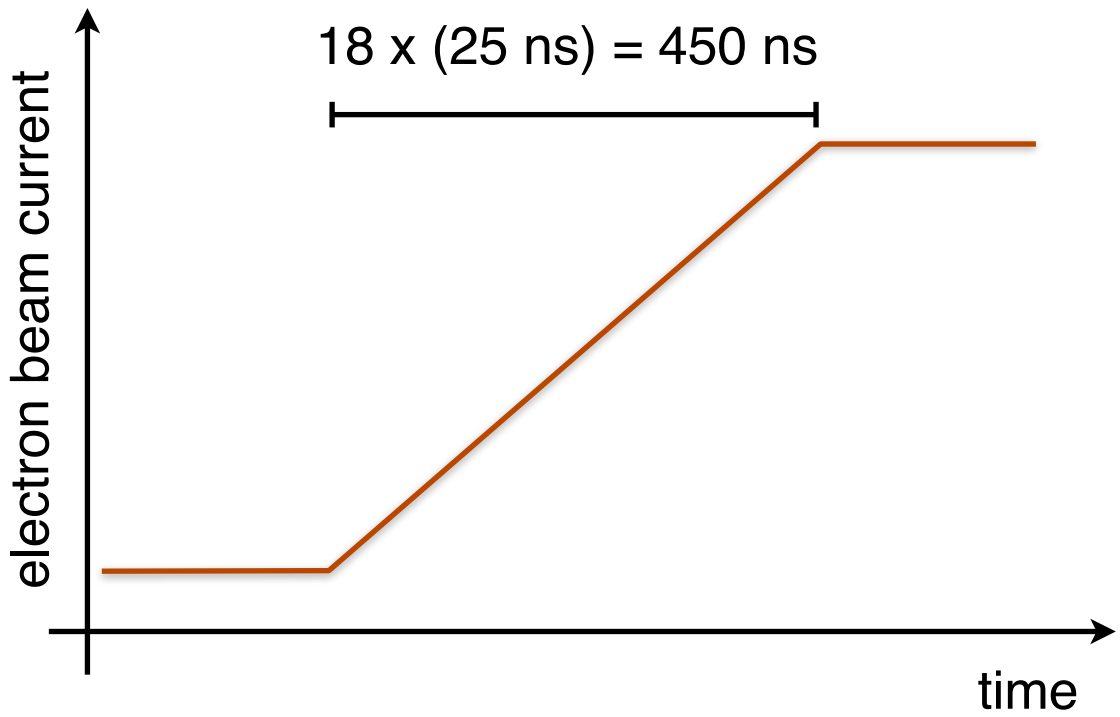


Very challenging for a metal wire

Sensitivity of configuration is being calculated: separation, wire size, beam shape, ...

e-wire advantage: tailored strength along train

- Possible to **ramp the electron beam current** up for the Pacman bunches
- The **required repetition rate** is an important input for modulator design



Research activities

Support wire-in-collimator experiments in LHC with simulations and data analysis in 2017-2018

Complete conceptual design of e-wire

For LARP continuation:

- Demonstrate electron gun with required current and current density
- Contribute to CERN test stand research and development

Proposals for LARP continuation

Three proposals for LARP continuation

1. **Development of long-range beam-beam scenarios**
2. **Electron lenses for long-range beam-beam compensation**
3. **Advances in hollow electron beam collimation**

Strong involvement of young researchers (training and education)

Based on core US competences, with synergies with electron cooling, integrable optics, beam-beam, particle-in-cell codes

Close collaboration with CERN Collimation, Beam-Beam, and Instrumentation

Multi-lab involvement: Fermilab, BNL, LBNL, with ties to SLAC halo monitoring

Fitterer, Stancari, Valishev, Fischer, and Vay, LARP-doc-1121

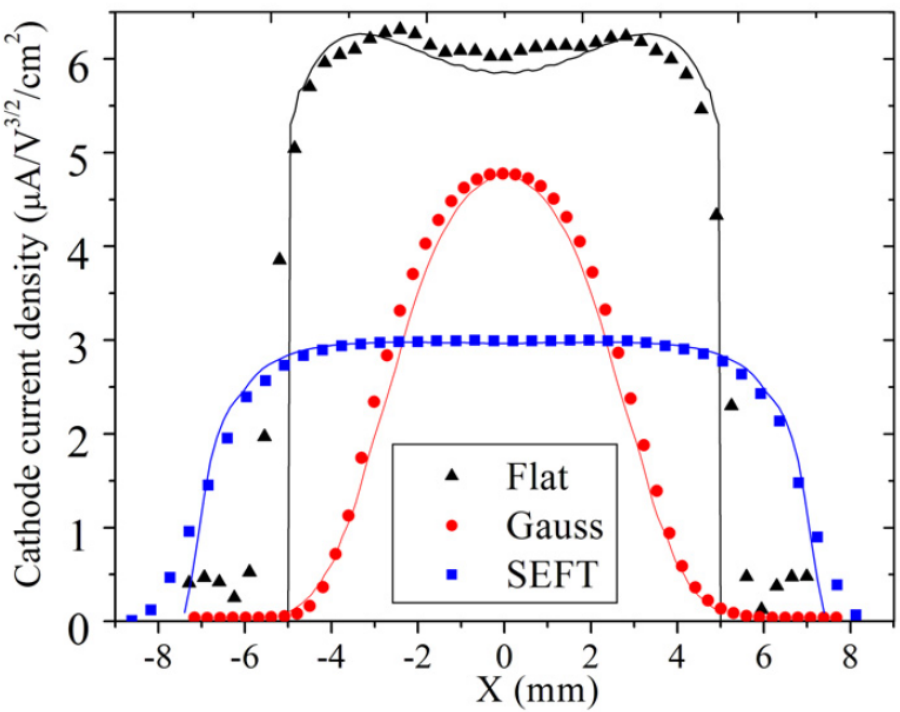
Thank you for your attention

Backup slides

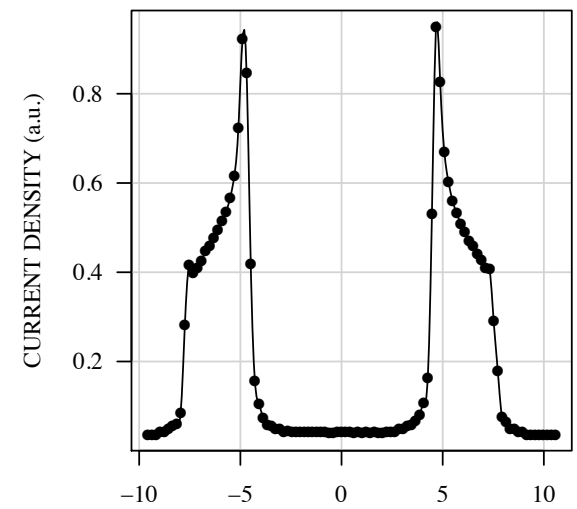
Control of electron beam profile

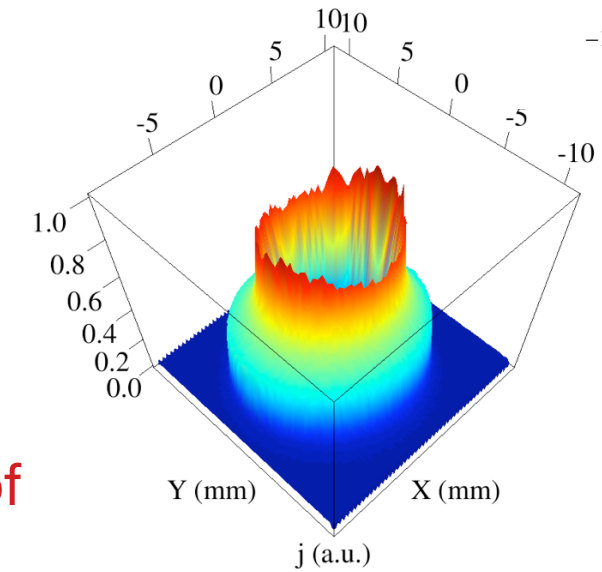
Current density profile of electron beam is shaped by cathode and electrode geometry and maintained by strong solenoidal fields

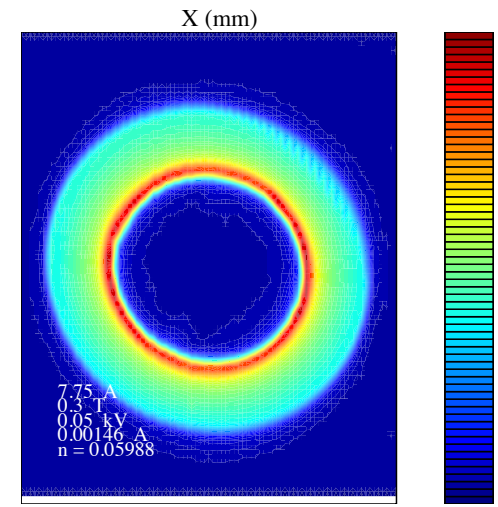
Flat profiles for bunch-by-bunch betatron tune correction



Hollow profile for halo scraping



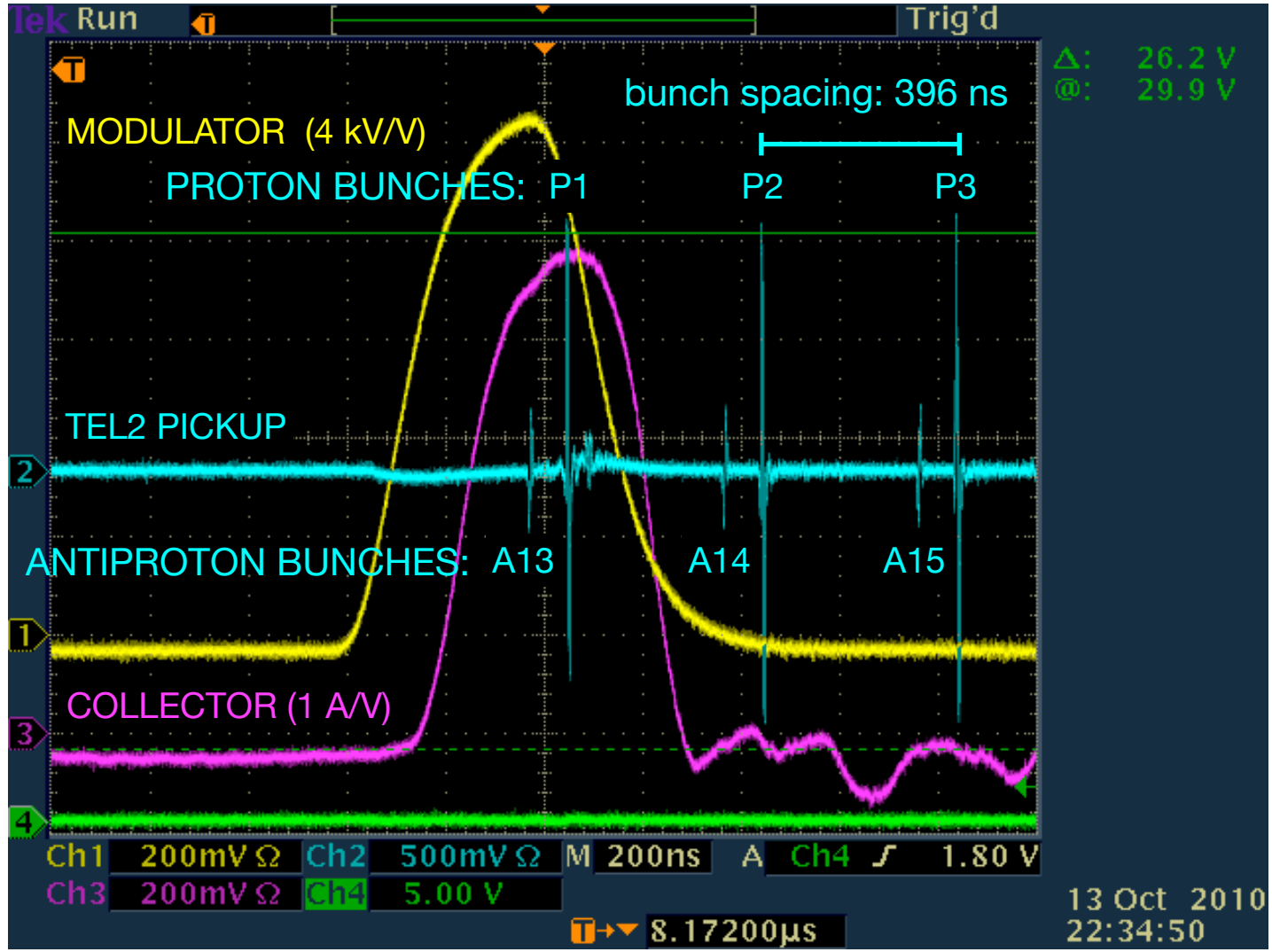




Gaussian profile for compensation of nonlinear beam-beam forces

Pulsed electron beam operation

Beam synchronization in the Tevatron



Pulsed electron beam could be **synchronized with any group of bunches**, with a different intensity for each bunch