Hollow Electron Lens Update

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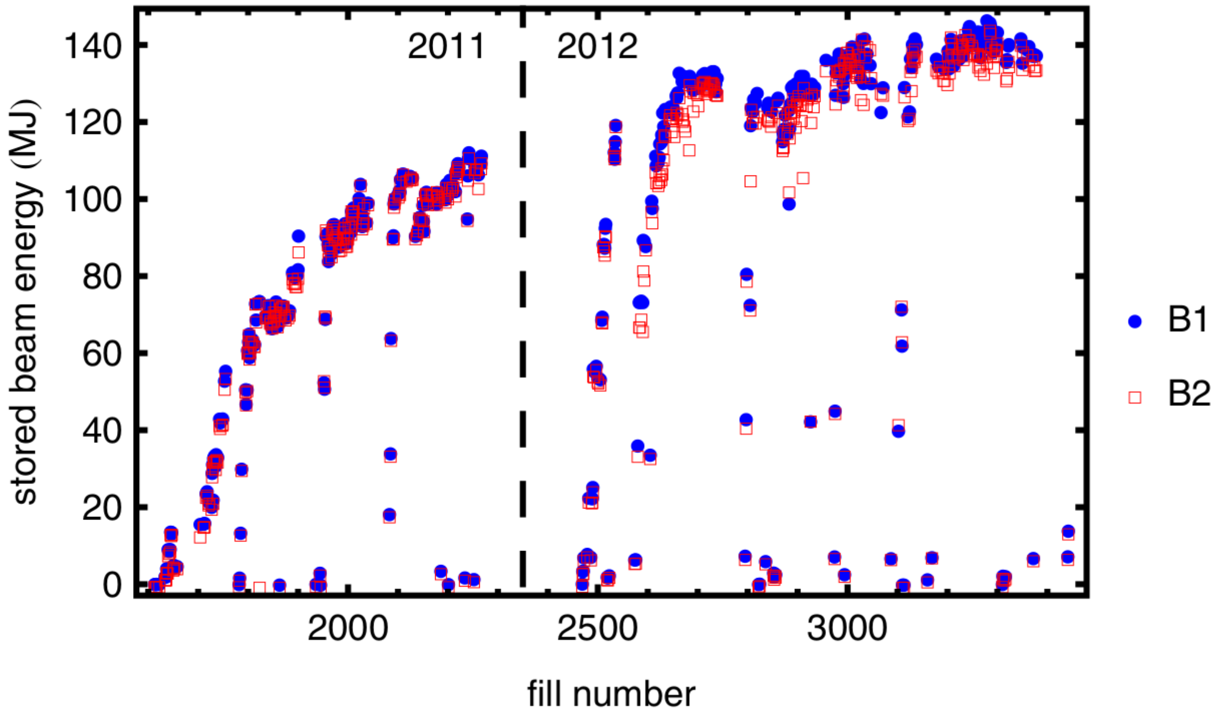
Stored energy in Run 1

- LHC collimation worked very well in Run I at 4 TeV (2010-2013) with routinely stored ~140 MJ beams over hours without accidental quenches



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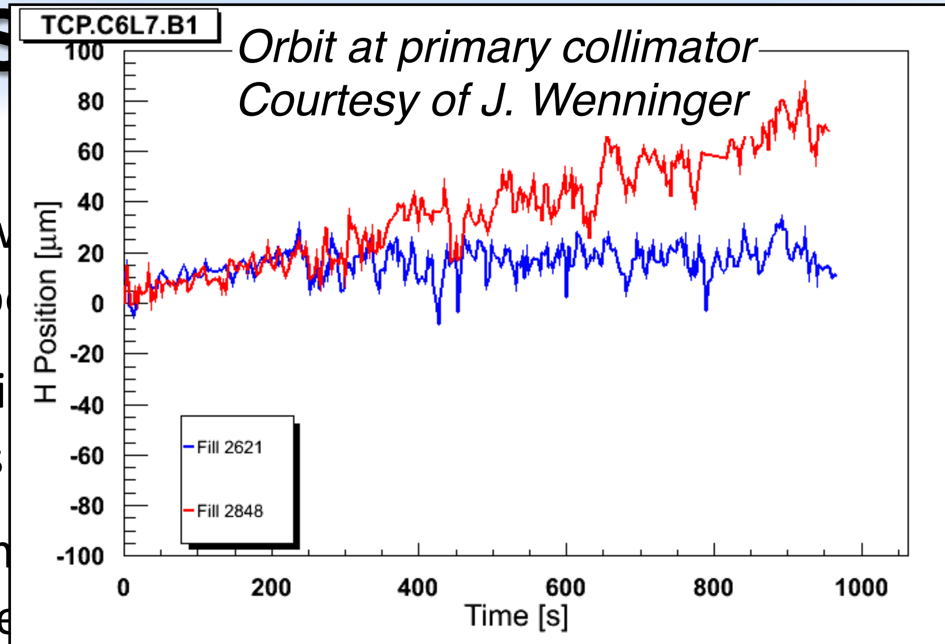
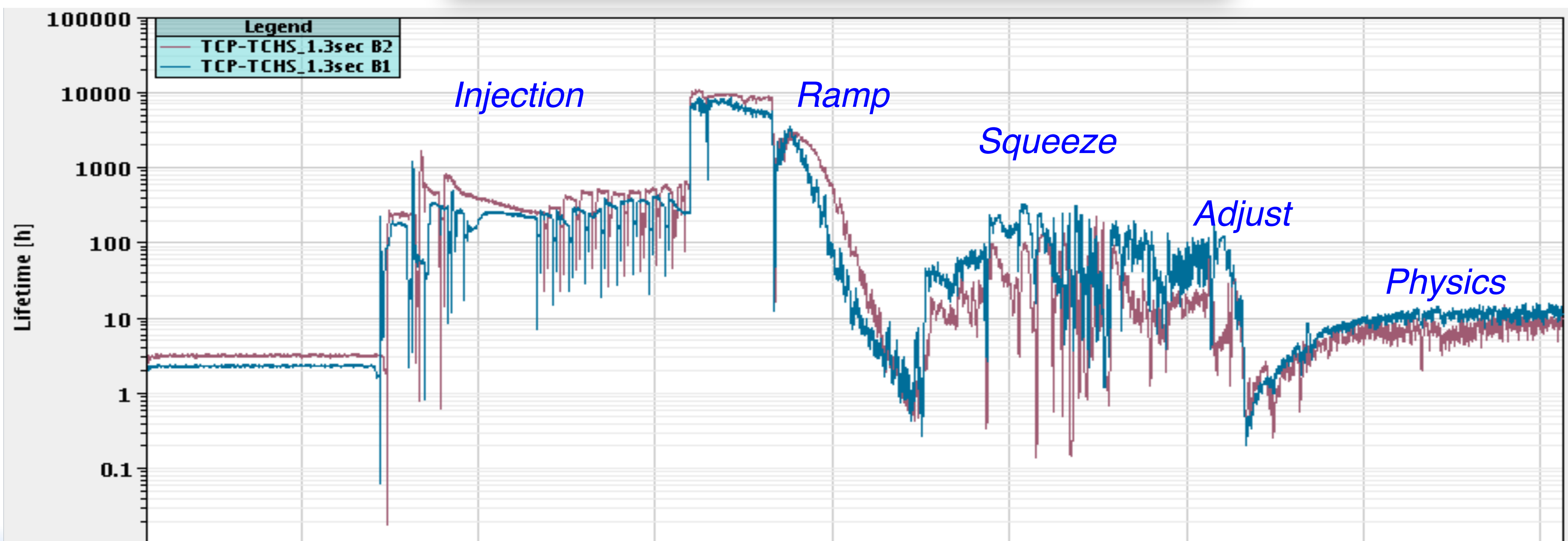
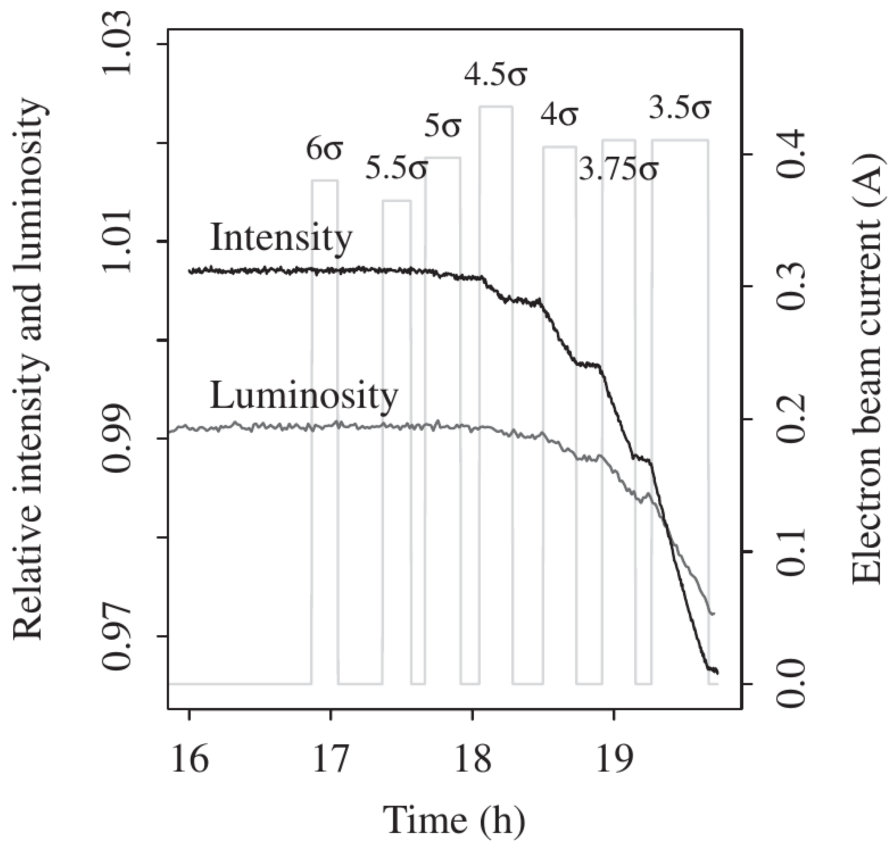


- LHC collimation w… 3) with routinely stored ~140 MJ b… es
- However, operati… orrelated to fast orbit movements
- Huge stored bean… configuration, 675 MJ for planne…



Methods for halo scraping

- Hollow electron lens
  - Solid experimental proof of principle at Tevatron
  - Requires new hardware
  - Advantage : closer to beam without impedance
- Alternatives under parallel study:
  - Put halo on resonance using a tune ripple or transverse damper
  - Relies on very good knowledge of tune and detuning with amplitude – not evident!
  - Does not require new hardware and shall be tested in the LHC

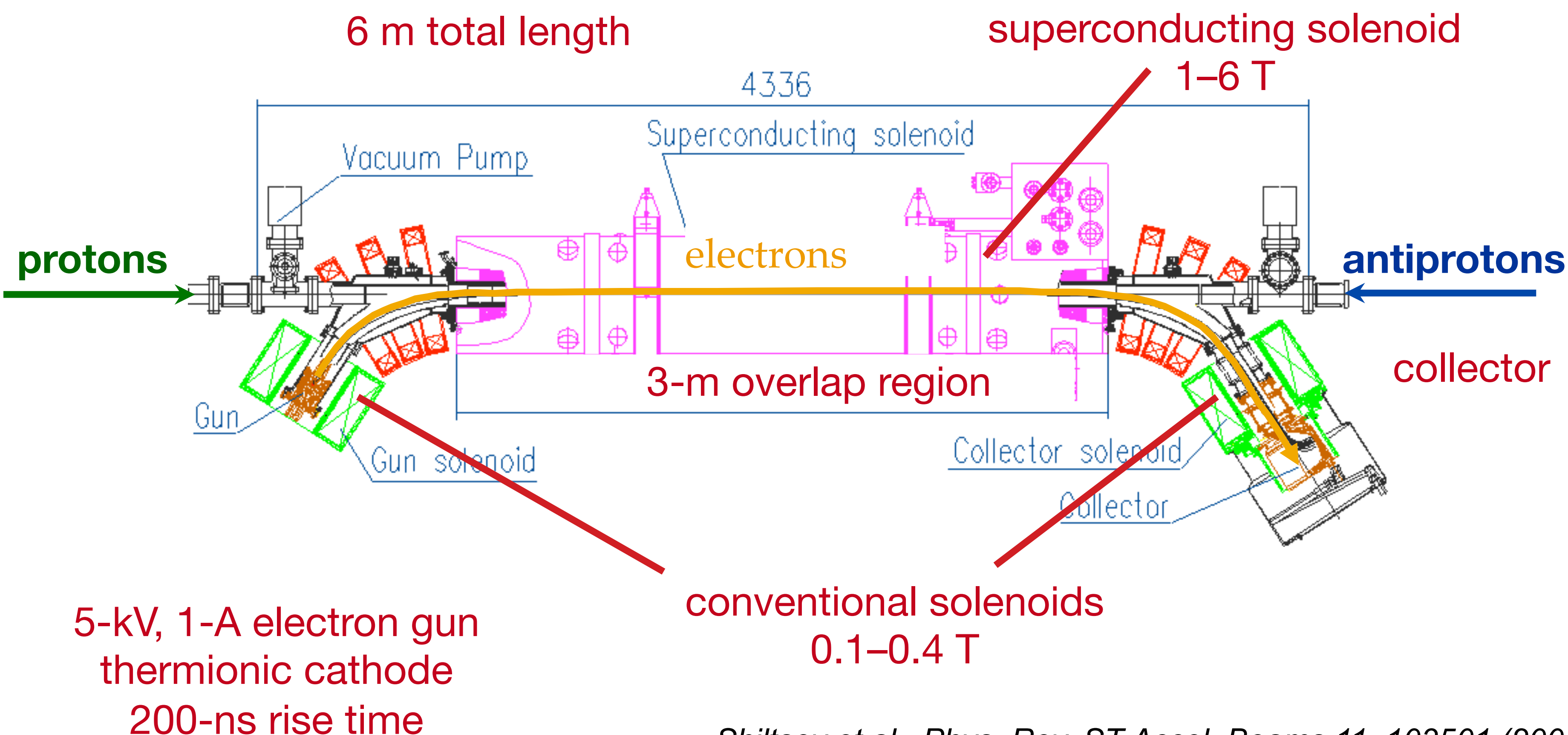


Stancari et al., Phys. Rev. Lett. 107, 084802 (2011)

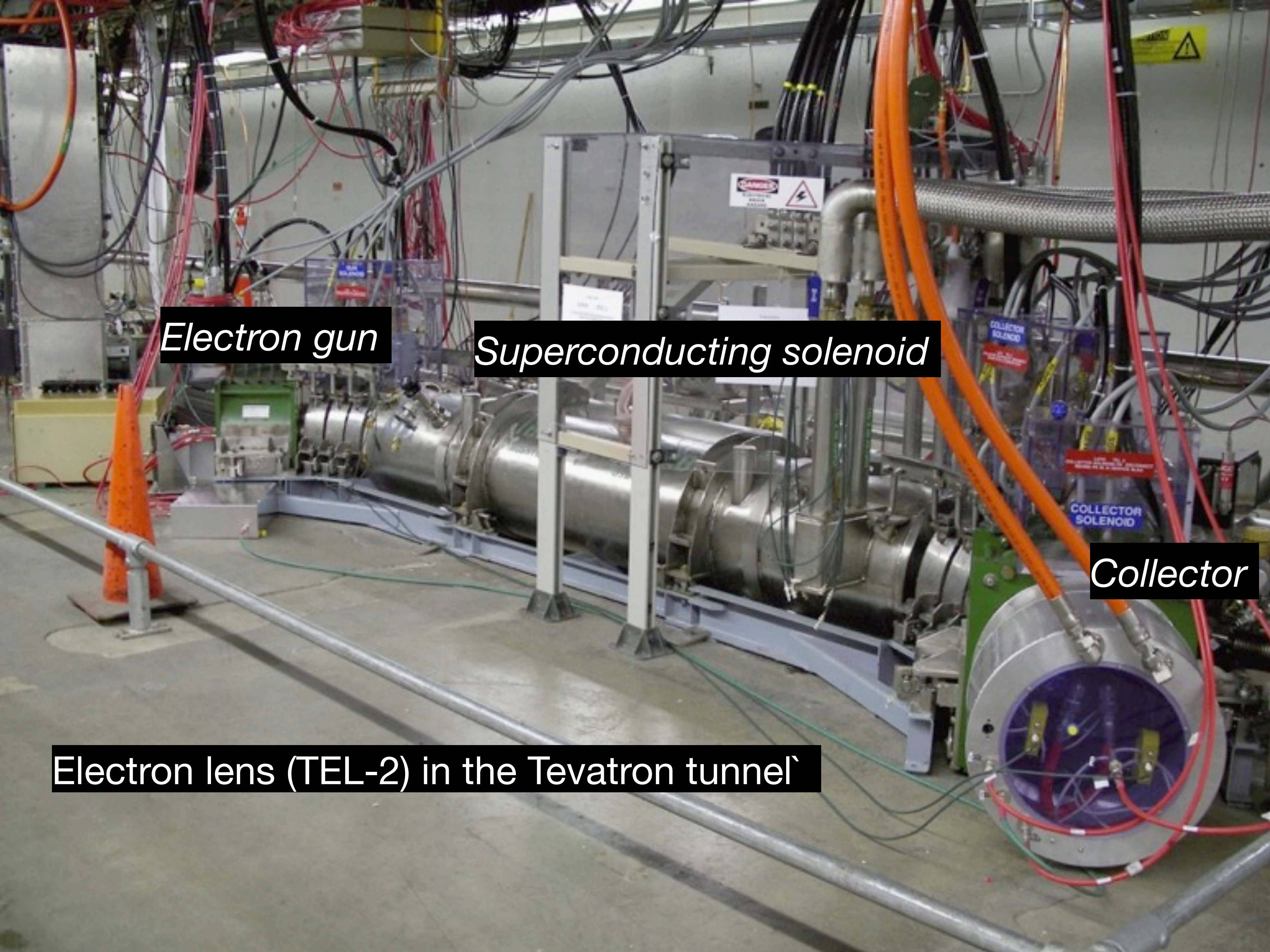
See also
Shiltsev, BEAM06, CERN-2007-002
Shiltsev et al., EPAC08
Shiltsev et al., Phys. Rev. STAB11, 103501 (2008)

Tevatron electron lens layout

- Pulsed, magnetically confined, low-energy electron beam
- Tunable transverse halo kicks ~0.1 μrad

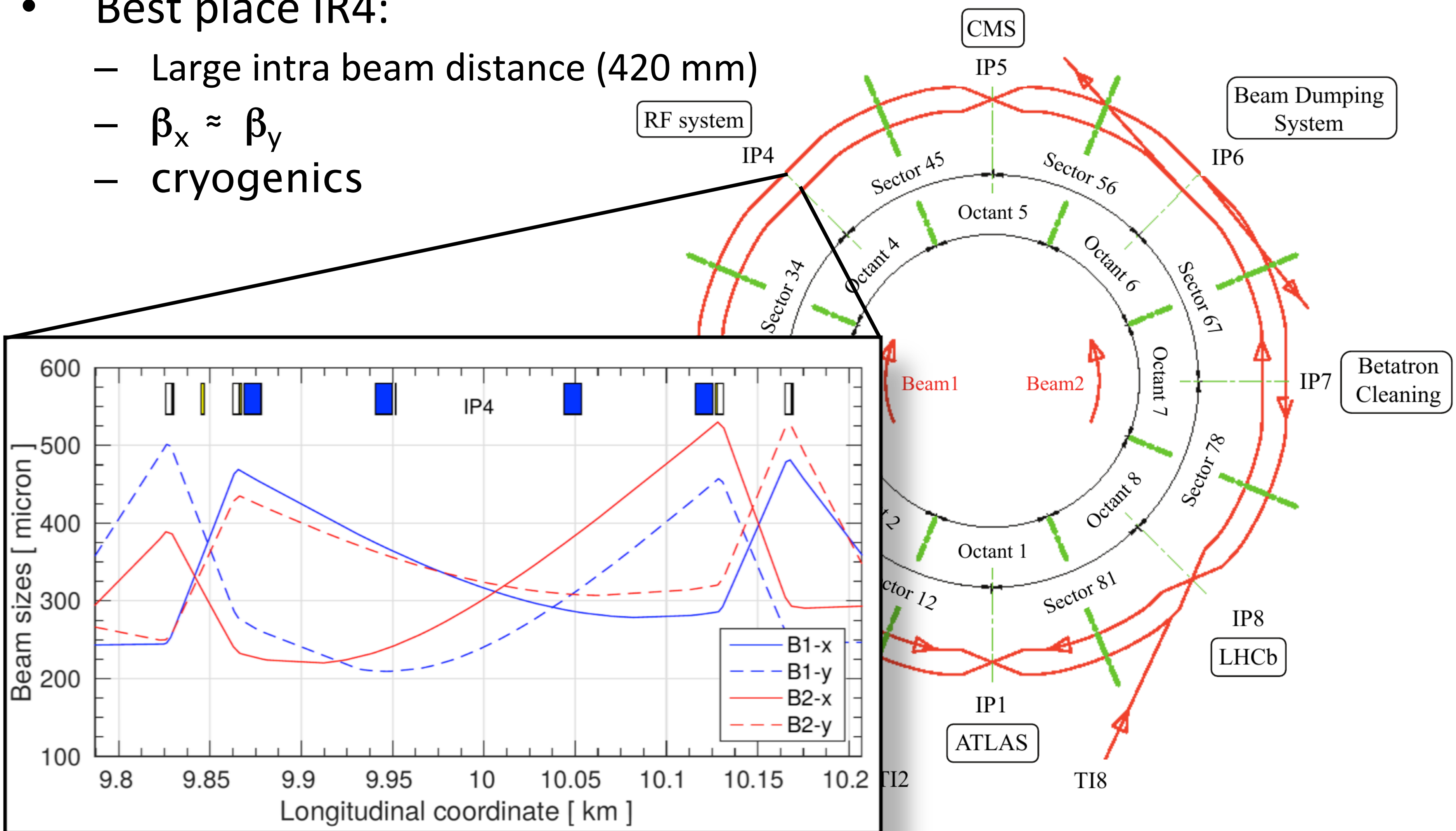


Shiltsev et al., Phys. Rev. ST Accel. Beams 11, 103501 (2008)


Electron gun
Superconducting solenoid
Collector
COLLECTOR SOLENOID
Electron lens (TEL-2) in the Tevatron tunnel`

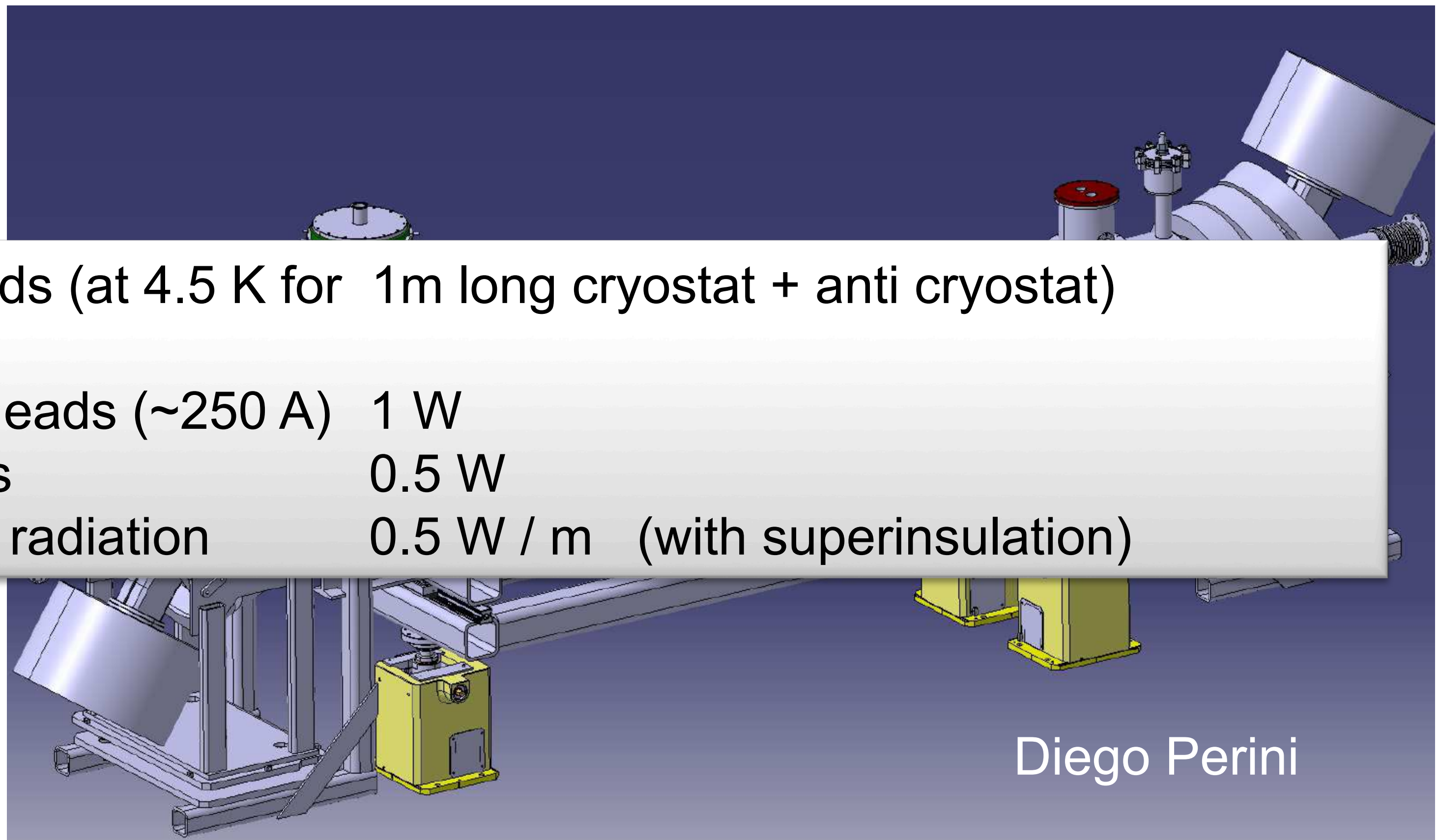
Proposed location in the LHC

- Best place IR4:
  - Large intra beam distance (420 mm)
  - $\beta_x \approx \beta_y$
  - cryogenics



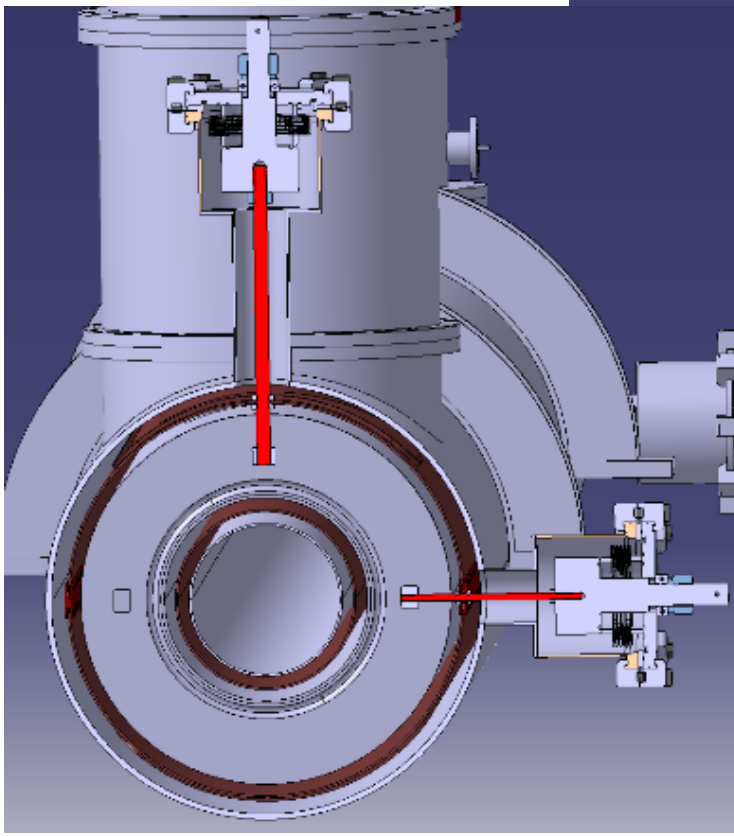
Technical design (CERN)

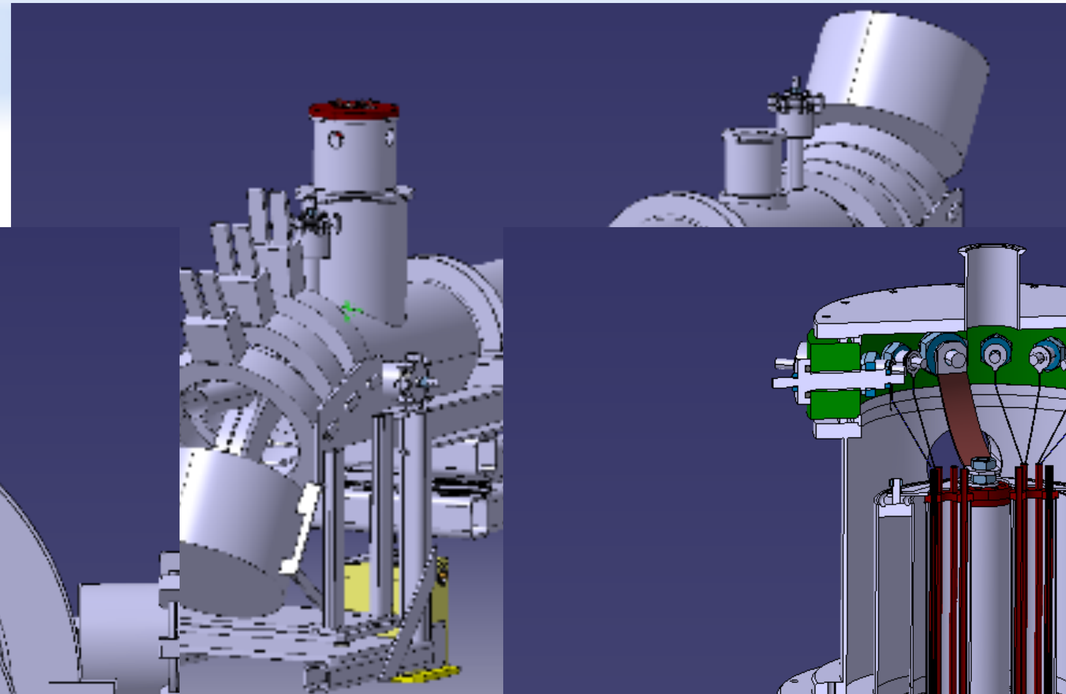
- S-shaped to compensate for the asymmetric electron beam distributions seen by the main beam
- Gun and collector stick out in vertical plane to fit in LHC tunnel

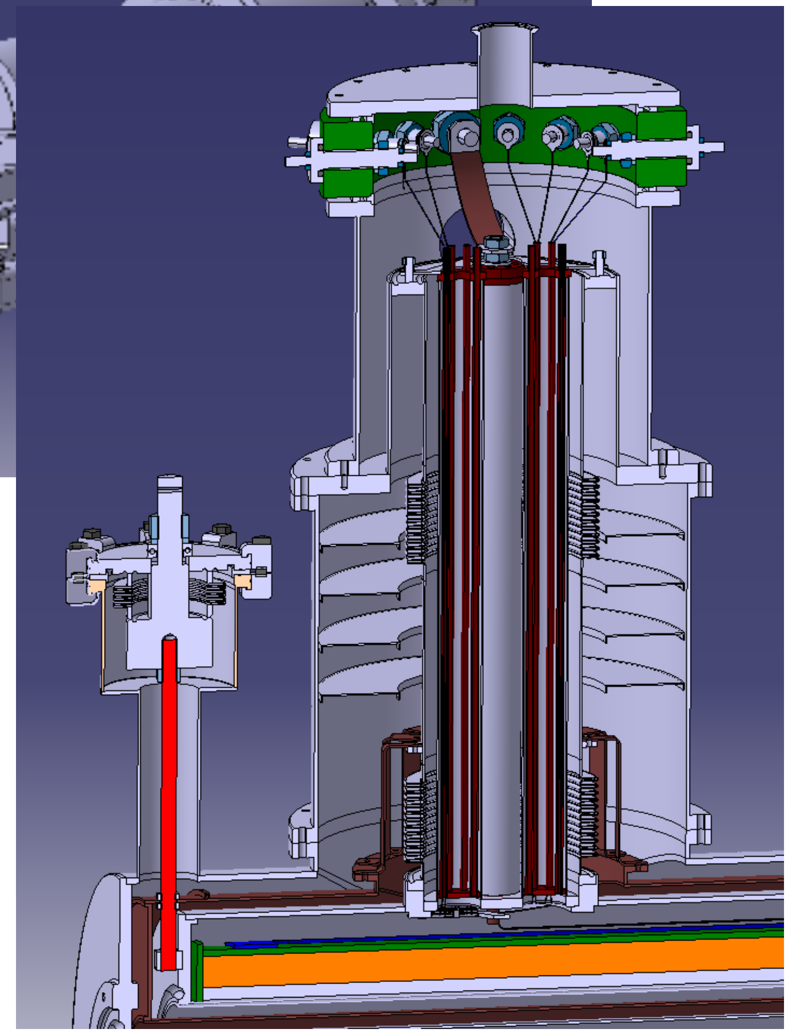


Heat loads (at 4.5 K for 1m long cryostat + anti cryostat)

Current leads (~250 A)	1 W
Supports	0.5 W
Thermal radiation	0.5 W / m (with superinsulation)





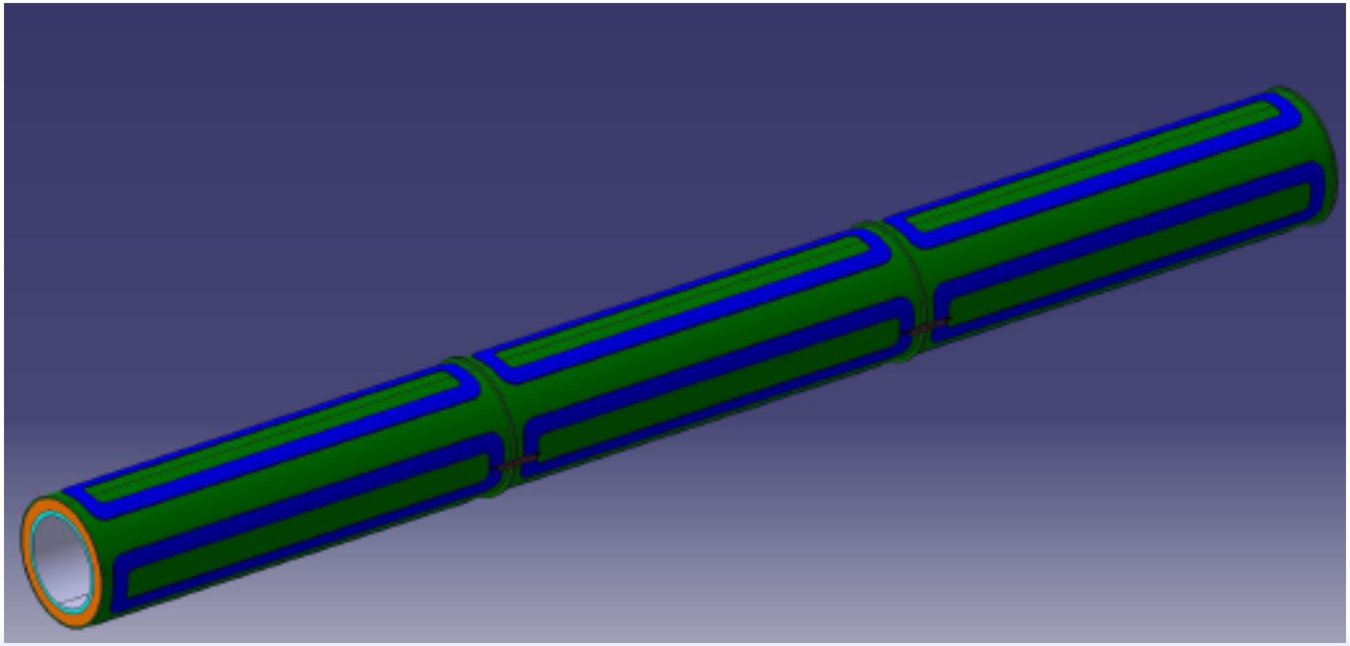


- 3D design ready to go into production drawings

Superconducting solenoid (CERN)

- 3 x 1 m long, 250 A current, 5T field, cooled with He to 4.2 K
- Includes 6 correction coils for alignment of electron beam
- Includes (not in the figure) the quench protection system
- 1 m magnet could be used for test bench
- Overall design may evolve with the integration of instrumentation

see H. Schmickler's talk



Parameter	Value or range
Beam and lattice	
Proton kinetic energy, T_p [TeV]	7
Proton emittance (rms, normalized), ε_p [μm]	3.75
Amplitude function at electron lens, $\beta_{x,y}$ [m]	200
Dispersion at electron lens, $D_{x,y}$ [m]	≤ 1
Proton beam size at electron lens, σ_p [mm]	0.32
Geometry	
Length of the interaction region, L [m]	3
Desired range of scraping positions, rmi [σ_p]	4–8
Outer cryostat diameter	250
Inner cryostat diameter [mm]	154
Max. vacuum chamber flange OD [mm]	150
Inner vacuum chamber diameter [mm]	? (80)
Temperatures	
Cold mass operating temperature [K]	4.2
Gun solenoid (resistive), B_g [T]	0.2–0.4
Main solenoid (superconducting), B_m [T]	2–6
Main solenoid current [A]	200–250
Positioning solenoid current [A]	25 x 12
Collector solenoid (resistive), B_c [T]	0.2–0.4
Collector solenoid current [A]	(?) 50 x 3 x 2
Compression factor, $k \equiv \sqrt{(B_m/B_g)}$	2.2–5.5
Electron gun	
Inner cathode radius, rgi [mm]	6.75
Outer cathode radius, rgo [mm]	12.7
Gun perveance, P [μperv]	5
Peak yield at 10 kV, I_e [A]	5
High-voltage modulator	
Cathode-anode voltage, V_{ca} [kV]	10
Rise time (10%–90%), τ_{mod} [ns]	200
Repetition rate, fmod [kHz]	35

Going from Conceptual Design Report (CERN-ACC-2014-0248, FERMILAB-TM-2572-APC and arXiv:1405.2033 – written in collaboration between US LHC Accelerator Research Program (LARP), LHC collimation team, and HL-LHC Project) to Technical Design Report

Required parameters

- Kick given by electron lens

$$\theta_r = \frac{2\, I_r\, L\, (1 \pm \beta_e \beta_p)}{r\, \beta_e\, \beta_p\, c^2\, (B\rho)_p} \left(\frac{1}{4\pi\epsilon_0} \right)$$

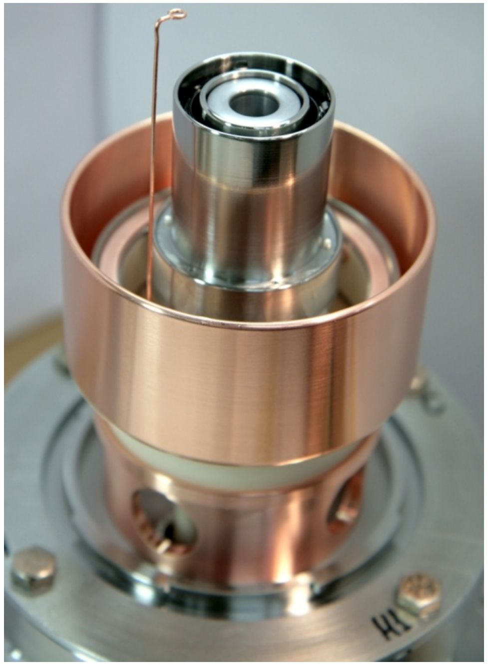
- Keeping the Tevatron hardware, kicks given to protons would be factor ~7 less from magnetic rigidity
  - Increase electron current to compensate (or length – less attractive)
- Halo removal rate depends not only on kick but also on lattice non-linearities
  - Simulations (LifeTrack and SixTrack) demonstrate desired halo depletion with 5A current and stochastic excitation mode

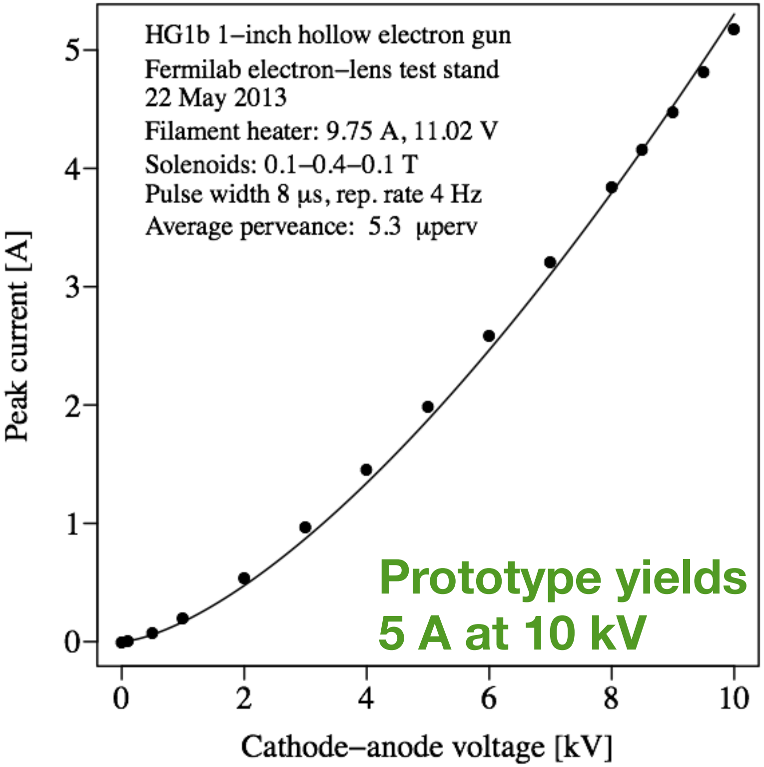
A. Valishev, FERMILAB-TM-2584-AP (2014)

Hollow electron gun (1)

- New gun needed for higher current and adjusted electron beam size
- First prototype designed, built and tested at Fermilab can provide 5A.
- Tungsten dispenser cathode with BaO:CaO:Al2O3 impregnant, 1400 K

First prototype of hollow cathode

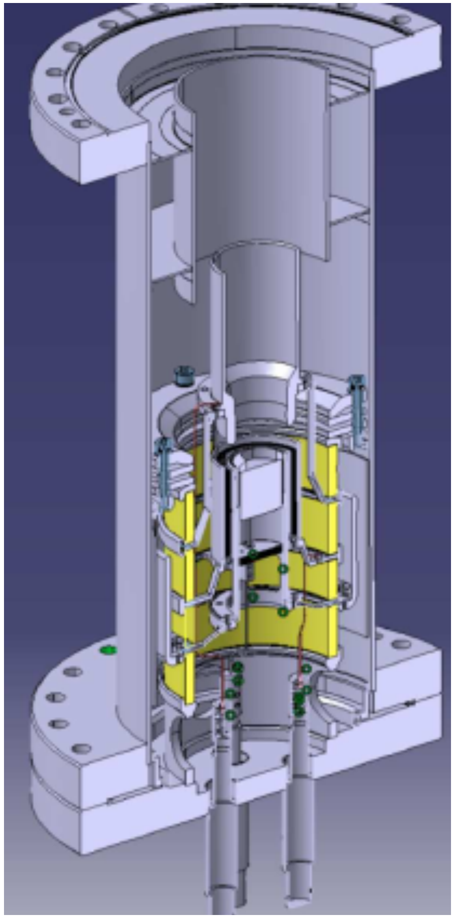




Hollow electron gun (2)

- Next gun with slightly reviewed design w.r.t. FNAL one to be built at CERN
  - Test stand planned to be set up at CERN (SM18) but initial tests at FNAL (LARP)
- Powering
  - 10 kV modulator used to power the gun
  - If we want to act on a subset of bunches: Need very fast rise time
  - 200 ns allows to switch on and off between bunch trains
- Cathode: one student to increase current

Present cathode design



Instrumentation

- Need to monitor position of electron beam and proton beam
  - Requirement: About 20 μm accuracy (0.1 σ of proton beam), time resolution of 1 ns (protons) and 100 ns (electrons).
- Need to monitor electron current at cathode and collector
- Need to monitor electron beam profile
- Sensitive loss monitors can be placed downstream
- In addition: need halo monitor for the LHC proton beam to study population in various scenarios, independently of e-lens
- Detailed design of instrumentation not yet started

Timeline

- Collimation needs can only be defined in detail after gaining operational experience at 6.5 TeV (end of 2015)
  - Uncertainties: cleaning efficiency, beam lifetime, quench limits, impedance
  - Final decision on installation to be taken based on Run II experience but Hollow Electron Lens already considered for HL-LHC baseline
- Meanwhile, proceed with design of 2 devices (1 per beam)
  - Estimated time needed: about 3 years
  - If technical design is finalized in 2015, could aim at installation during long shutdown in 2018 (LS2)

CERN/FNAL studies

- **CERN/FNAL**: PhD student (Frankfurt U) will start in July with joint supervision. Work on simulations e-lens related, continuing work of A. Valishev and V. Previtali
- **FNAL**: Toohig student would be very useful for tests and simulations on halo diffusion
- **CERN**: students working on designing the test bench solenoid (production drawings)
- **CERN**: Master student (Darmstadt U) on material science to start in October improving e-gun to extract higher current

Main conclusions

- 2 Hollow Electron Lenses for collimation are being proposed as **baseline** for the HL-LHC
- New electron gun will built at CERN and first tested at FNAL
- 3D main design of solenoid magnet is ready to be used for 2D production drawings
- 1m prototype solenoid will be used in the test bench (ready in about 12 months + design completion)
- Results on instrumentation (overlap monitor) may bring to some modifications to the overall design
- Design will be used later on for LRBB compensation E-lens
- Studies in collaboration between CERN/FNAL ongoing