Introduction: hollow e-lenses for LHC collimation

Stefano Redaelli, CERN, BE-ABP
Basic concepts

protons

Setup at the Tevatron, court.
of G. Stancari
Basic concepts

- **Hollow electron beams** running co-axial to the proton beam

  *Halo particles see a field that depends on their transverse position while the beam core is not affected!*

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  “Active halo control”: we decide *when* particles are lost and can control the static *halo population.*
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  *The whole collimation system remains in place...*
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S. Redaelli, ColUSM, 31-10-2014
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- Transverse operational range: **3-6 sigmas**
Beam lifetime during OP cycle

Couple of illustrative examples taken randomly from the LHC elogbook...
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Other requirements

- Continuous control of the tail population is deemed mandatory for using the crab cavities in the HL-LHC era!
- This requires scraping **during stable beams**: cannot be done by moving collimators!

**Other fast loss scenarios expected and not expected?**

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Other requirements

- Highly overpopulated tails observed: 
  - In horizontal plane about **4%** of beam beyond \(4\sigma_{\text{meas}}\)
  - Corresponds to \(\approx 20-25 \text{ MW}\) with HL-LHC parameters.

- Need to **deplete tails** (e.g. by **hollow electron lens**), such that crab cavity failures are compliant with collimation system specifications.

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Transverse Distribution

May, 11th 2012
Tobias Baer

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**Other fast loss scenarios expected and not expected?**
Recap. of our strategy
(established in Jan. 2013 with CERN directorate following the Nov. 2012 review, then within HL)

Proposed CERN strategy

Taking into account the present financial situation and the manpower commitment to the LS1 activities, CERN cannot decide now on the installation of the available Tevatron hardware in the SPS or the LHC.

This also takes into account that firm indications of LHC critical performance limitations without scraping, can only become apparent after some operational experience at energies near to 7 TeV.

The CERN management fully supports the studies on hollow e-lens and strongly recommends to work with high priority towards the preparation of a possible production of 2 hollow e-lens devices optimized for the LHC parameters.

- **Design** of a LHC optimized device, with optimum e-beam parameters for 7 TeV and improved integration into the LHC infrastructure.
- Actively **participate** to beam tests worldwide on this topic. Specifically, CERN endorses the setup of hollow e-beam tests in RHIC.
- Start building competence at CERN on the hollow e-beam hardware.
- Work with very high priority on improving the halo diagnostic capabilities at the LHC in the context of the HL-LHC study.
- Continue working on alternative methods for halo scraping.

Today we will see where we are with this workplan!
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We plan to hire a PhD student in Dec. to study “Comparative assessment of different active halo excitation techniques”, but for the moment studies rely on the collaboration with FNAL within US-LARP.
Considerations on time-line

☑ Main goals as of our strategy established in 2012-13:
   Be ready with a design at the beginning of the post-LS1 operation.
   Address experimentally alternative methods with beams at ~6.5TeV.
   Finalization of the strategy to be tailored depending on OP experience...

☑ Scenarios for deployment of hollow e-lenses
   1. Full deployment in LS3 (1 device per beam)
      → Halo losses and collimation cleaning under control at top energy
   2. Full deployment in LS2 (1 device per beam)
      → Post-LS1 operation shows major issues with halo handling that cannot
         satisfactorily be addressed by alternative methods
   3. One lens in LS2 for prototyping, another in LS3
      → No major limitations until LS3, but we decide to have one to validate
         its operation with LHC beams and gain experience.
   4. No need of hollow e-lenses
      → Things go so well at ~7TeV that one expect no issues also for HL-LHC.

☑ Important to have adequate priority on halo and collimation studies!

☑ Remark: Experience at the Tevatron showed the crucial role of e-beam
   test stands to improve the performance with circulating beams!
Synergies with other studies

- Machine protection studies
  - Operation with crab cavities
  - Fast losses, like orbit of one beam when
    other beam dumped (other surprises?)

- Long-range beam beam compensation
  Under study: 8 e-lenses for LRBB compensation, alternative to standard wires.

- Electron beams for ELENA cooler

- Halo diagnostics

- At RHIC: e-beams for beam-beam compensation
  → watching carefully the status of their developments
  and considering beam test with hollow beams there...
**Agenda of this meeting**

<table>
<thead>
<tr>
<th>Time</th>
<th>Session</th>
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</thead>
</table>
| 14:00 - 14:15 | **Introduction** 15’  
   Speaker: Dr. Stefano Redaelli (CERN) |
| 14:15 - 14:45 | **Hollow lenses design for the LHC and status of simulations 30’  
   Speaker: Giulio Stancari** |
| 14:55 - 15:15 | **Status of mechanical design for IP4 integration 20’  
   Speaker: Diego Perini (CERN)** |
| 15:25 - 15:45 | **Coffee Break** |
| 15:45 - 16:05 | **Plans for beam test on alternative methods 20’  
   Speaker: Dr. Roderik Bruce (CERN)** |
| 16:10 - 16:30 | **Ideas for TEL-2 at CERN: electron beam test stands 20’  
   Speaker: Dr. Hermann Schmickler (CERN)** |
| 16:35 - 16:55 | **Status of ELENA electron cooler 20’  
   Speaker: Dr. Gerard Tranquille (CERN)** |

**Other goals:** information within CERN of progress done and review of results recently presented (IPAC, HB2014, ...)

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S. Redaelli, CoUoSM, 31-10-2014
Reserve slides
Integration in multi-stage cleaning

- Primary collimator
- Secondary collimators
- Shower absorbers
- Tertiary collimators

Circulating beam → Cleaning insertion ← Arc(s)

Primary beam halo
Secondary beam halo + hadronic showers
Tertiary beam halo + hadronic showers

Illustrative scheme
Integration in multi-stage cleaning

- Primary beam halo
- Secondary beam halo + hadronic showers
- Cleaning insertion
- Arc(s)

- Tertiary beam halo + hadronic showers
- Tertiary collimators
- SC Triplet
- Illustrative scheme
Integration in multi-stage cleaning

- **Primary beam halo**
- **Primary collimator**
- **Secondary collimators**
- **Secondary beam halo + hadronic showers**
- **Tertiary beam halo + hadronic showers**
- **Shower absorbers**
- **Tertiary collimators**
- **Hollow e-lens**
- **Cleaning insertion**
- **Arc(s)**
- **Circulating beam**
- **Illustrative scheme**

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S. Redaelli, ColUSM, 31-10-2014
Integration in multi-stage cleaning

- **Primary collimator**
- **Secondary collimators**
- **Shower absorbers**
- **Tertiary collimators**

- **Primary beam halo**
- **Secondary beam halo** + hadronic showers
- **Tertiary beam halo** + hadronic showers

- **Circulating beam**
- **Cleaning insertion**

- **Hollow e-lens**

- **Illustrative scheme**

- **Local loss rate (flux)**
  \[ R \propto -D \cdot \left[ \partial_x f \right]_{x=x_c} \]

- **Beam population**
- **Diffusion speed**

- **Beam population density, f(x, t)**

- **Transverse position, x [σ]**

- **Hollow electron beam**

- **COLLIMATOR**

- **HOLLOW ELECTRON BEAM**

- **COLLIMATOR**

- **Arc(s)**

- **IP Triplet**

- **Tertiary collimators SC Triplet**
The classical **multi-stage collimation** concept is maintained.
- No need to change present hierarchy
- Ensures a full compatibility with present and future schemes
  - E.g., compatible with crystals and also for ions.
- “Hole” around core make losses insensitive to orbit drifts.
- Lens does not need to be in IR7
  - Indeed, it better be elsewhere!
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills

Ramp  Squeeze  Physics  2011
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills

- Ramp
- Squeeze
- Physics

Ramp
Squeeze and adjust
Physics

Legend:
- Fill 2215 during FillInterval
- Fill 2216 during FillInterval
- Fill 2217 during FillInterval
- Fill 2218 during FillInterval
- Fill 2219 during FillInterval
- Fill 2623 during FillInterval
- Fill 2624 during FillInterval
- Fill 2625 during FillInterval
- Fill 2626 during FillInterval
- Fill 2627 during FillInterval
- Fill 2628 during FillInterval
- Fill 2629 during FillInterval
- Fill 3265 during FillInterval
- Fill 3266 during FillInterval

Time from interval start [s]
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills

Major change for 2012:
“Tight” collimator settings
TCP gaps in mm as for 7TeV
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills

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TCP gaps in mm as for 7TeV

2011: losses during cycle dominated by the setup of collisions!
Losses during the LHC cycle

Beam transmission from start of ramp for a few random fills

**2011**

- **Ramp**
- **Squeeze**
- **Physics**

**2012**

- **Ramp**
- **Squeeze**
- **Physics**

Major change for 2012:

*“Tight” collimator settings*

TCP gaps in mm as for 7TeV

**2011**: losses during cycle dominated by the setup of collisions!

**2012**: Beam losses at the ramp end, more sensitive to orbit jitters (squeeze), increased impedance. But smaller beta*!!
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The 2012 losses are likely more representative of the 7 TeV OP.
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![Transmission during squeeze in 2011](image-url)
Losses during the LHC cycle

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Orbit and losses during squeeze

Example from “tight” setting tests in 2011

Intensity transmission (collimator tight settings)

Orbit at the TCP-B2

1 %

200 μm
Orbit and losses during squeeze

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Intensity transmission (collimator tight settings)

Orbit at the TCP-B2

1% Intensity transmission (collimator tight settings)

200 μm

Courtesy of J. Wenninger
Orbit and losses during squeeze

Example from “tight” setting tests in 2011

Intensity transmission (collimator tight settings)

Situation improved significantly in 2012, but the issue remains. Presently, after optimization of orbit during squeeze, depleting tails over 100 um around the core could avoid loss spikes from fast orbit drifts. No obvious gain for losses determined by beam instabilities.

Courtesy of J. Wenninger
Scraping at top energy (1)

- One test done in 2011 at the end of a physics fill with 1400b at 3.5 TeV
- The scraping took more than 30 minutes, limited by high loss spikes.
- Can we do it at 7 TeV with reduced margins for quench?
- TCP smallest gap limited by impedance?