LARP Collimation Activities

20 November 2014

Hi-Lumi/LARP CM23 Annual Meeting

KEK, Tsukuba, Japan

T. Markiewicz/SLAC

Outline

LHC Collimation Materials Irradiation Damage Study at BNL

- Slides and update material submitted by Nick Simos, BNL

Hollow Electron Lens Collimator

- Material from Giulio Stancari's presentation at 2014-10-31 4-hour long HEBC-devoted COLUSM meeting

Rotatable Collimator

- Update of status of tests performed at CERN over the last years drawing on material prepared by several CERN technical groups

LHC Collimation Materials Irradiation Damage Study at BNL

N. Simos

IRRADIATION

- 200 MeV proton irradiation at BNL Linear Isotope Producer (BLIP) of 4 candidate materials (Molybdenum, Glidcop, Mo-Graphite and Cu-CD (copper-diamond). Irradiation parameters: 8-weeks at 110 uA
- Neutron irradiation of Cu-CD from 118 MeV protons
- 28-MeV proton irradiation of Mo (including spallation neutron irradiation of Mo, Glidcop, Cu-CD and Mo-GR)

Thermo-Physical & Mechanical Characterization

- X-ray diffraction studies at NSLS X17B1/X17A beamlines (completed)
- X-ray diffraction studies at NSLS II XPD beamline (proposed)
- Comprehensive macroscopic analysis at BNL Isotope extraction facility (initiated)
- Spectral Analysis (initiated)
- Nano- micro-structural characterization at Center of Functional Nanomaterials (initiated)

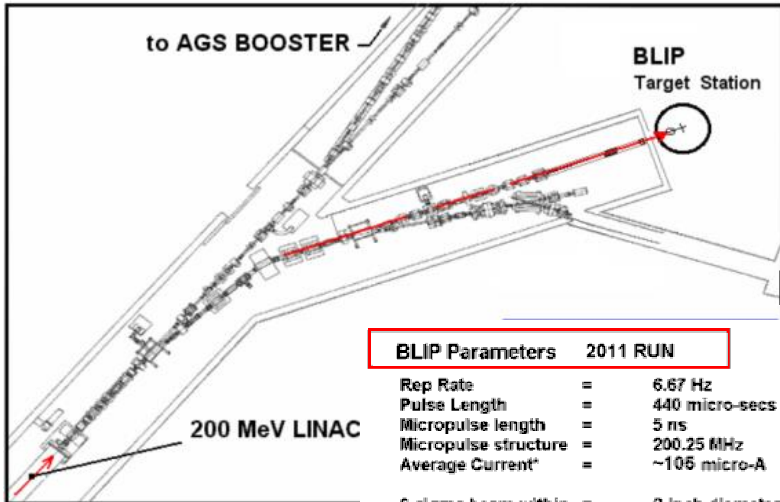
Irradiated LHC HiLuMi Collimation materials

Material Name	Density (g/cm3)	Element	Molar mass (g/mol)	Density (g/cm^3)	%W	Atomic fraction %	Average Atomic Number Z
Molybdenum	10.2	Mo	95.94	10.22	100%	100.000%	42
Glidcop AL-15	8.9	Cu	63.546	8.93	99.70%	99.813%	
		Al_2O_3	101.9633	3.96	0.30%	0.187%	29.03931
CuCD	5.4	Cu	63.546	8.93	0.62057	23.590%	
		B	10.811	2.34	0.00417	0.932%	
		CD	12.01	3.51	0.375261	75.478%	11.41645
MoGRCF	3.7	Mo	95.94	10.22	74.60%	21.515%	
		GR	12.01	2.25	24.80%	78.485%	13.74528

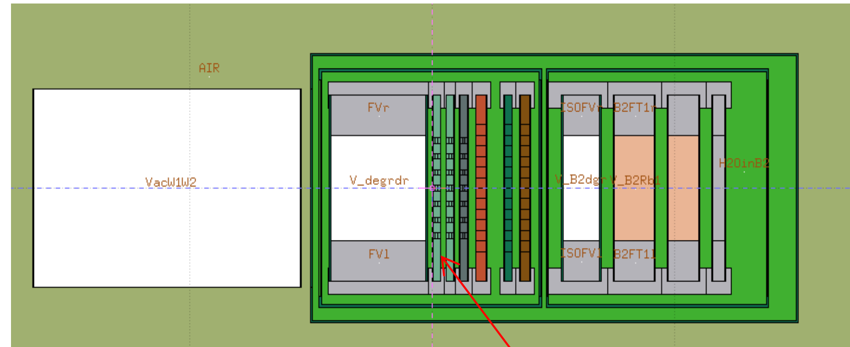
Preliminary Assessment:

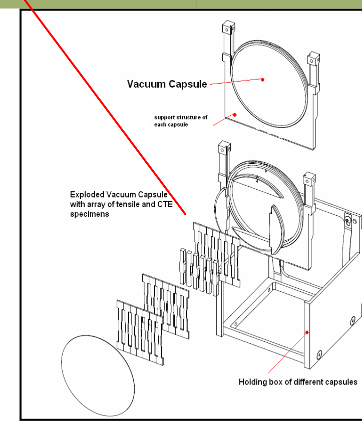
- 200 MeV heavily bombarded LHC array is still in cool-down mode due to high dose
- One of the two Molybdenum (Mo) capsules has been opened for visual examination. Mo samples appear to be fully intact.
- In coming weeks the proton irradiated array will be opened and examined (followed by transport to the PIE hot cells for sorting and studies)
- Neutron irradiated Cu-CD has seen no structural degradation
- 28 MeV protons and spallation neutrons at Tandem have not affected the structural integrity of the LHC HiLuMI array

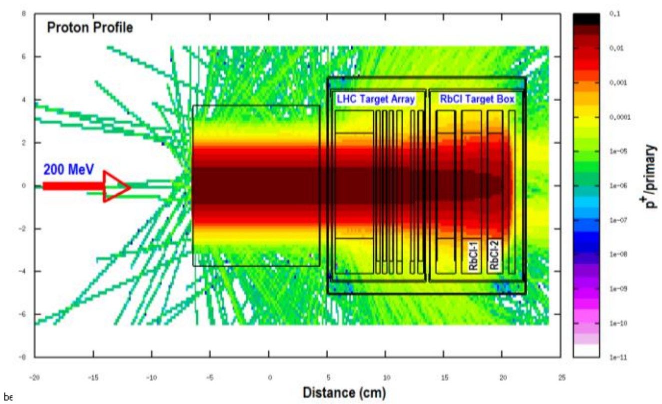
200 MeV Proton Irradiation

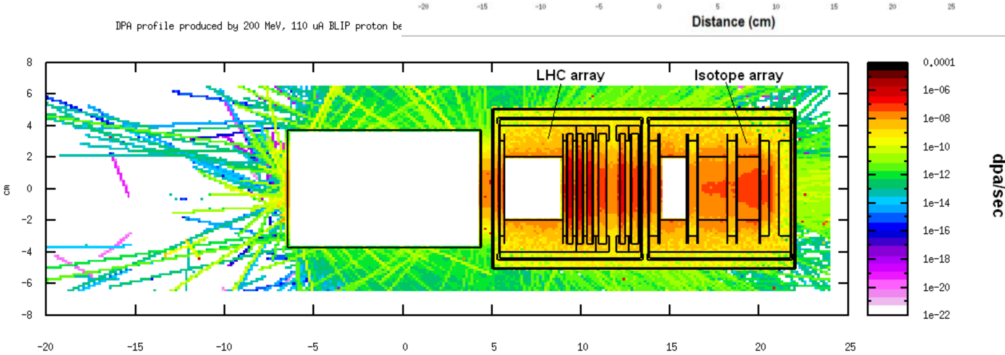


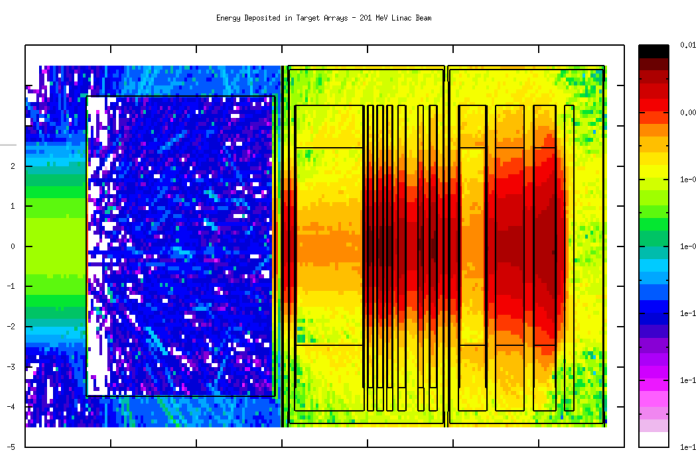
BLIP Parameters		2011 RUN
Rep Rate	=	6.67 Hz
Pulse Length	=	440 micro-secs
Micropulse length	=	5 ns
Micropulse structure	=	200.25 MHz
Average Current*	=	~105 micro-A
6 sigma beam within	=	2-inch diameter
Beam Gaussian	==>	1 sigma = 4.233 mm







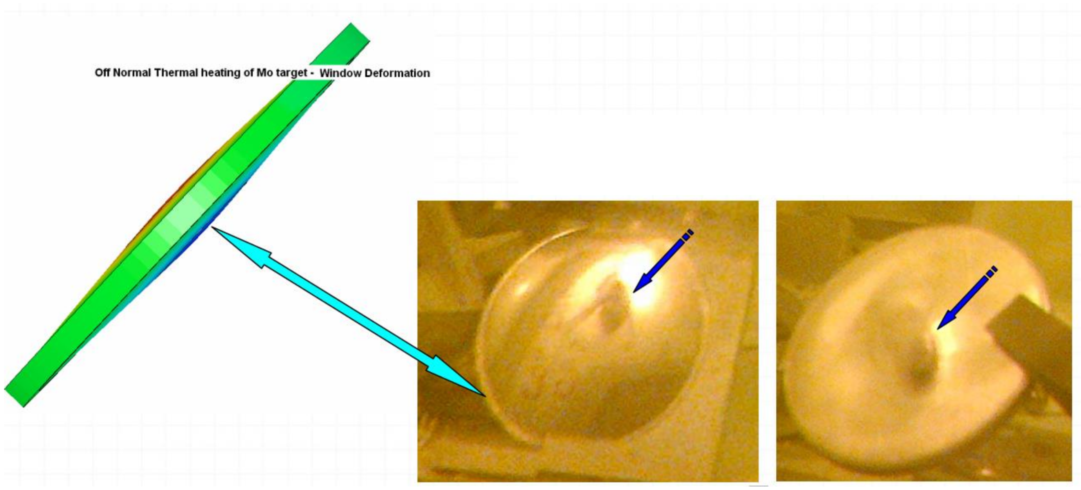




T. Markiewicz

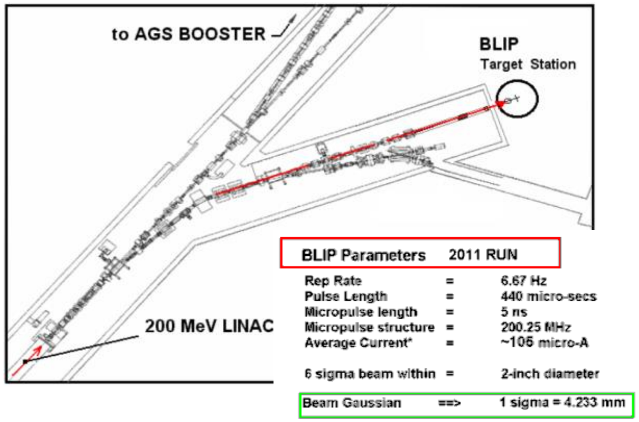
Status of Irradiation Study (as of May 2014)

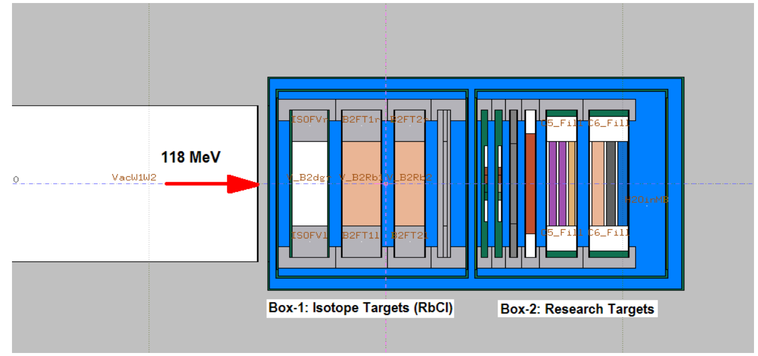
Capsule with Mo-Gr failed due to thermal stress & adjacent Cu-CD capsule damaged
2013 run halted to extract target box

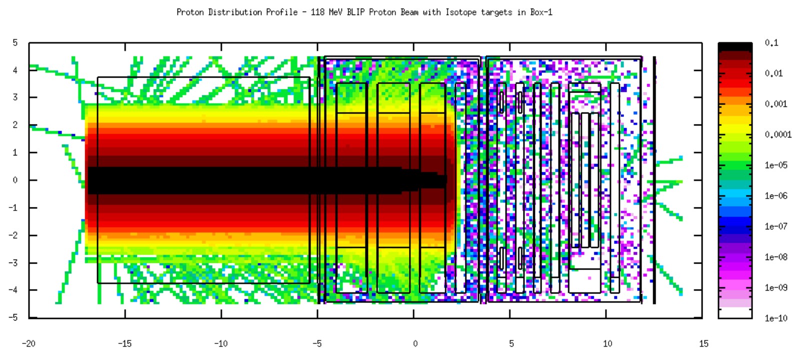


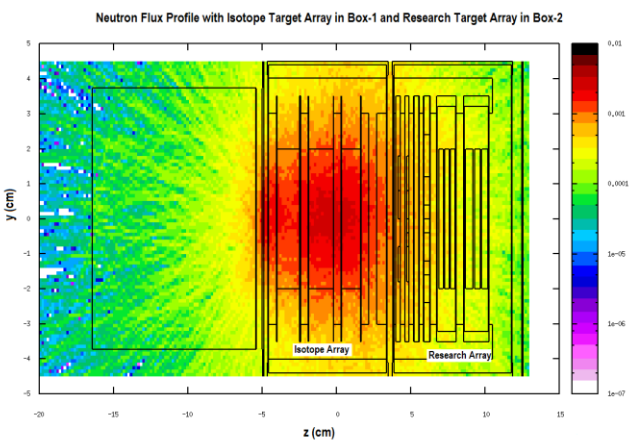
- Damaged capsules replaced by SS degrader with a new capsule support that allowed larger water channels
- Irradiation continued in 2013 up to 60% of required exposure
- Final 3.5 week irradiation BLIP NOW underway
- After cool down, post irradiation study of physical properties of the 5 of 7 remaining samples
- Neutron irradiation of a collection of new samples in a new target holder (downstream of the isotope production target)

Spallation Neutron Irradiation

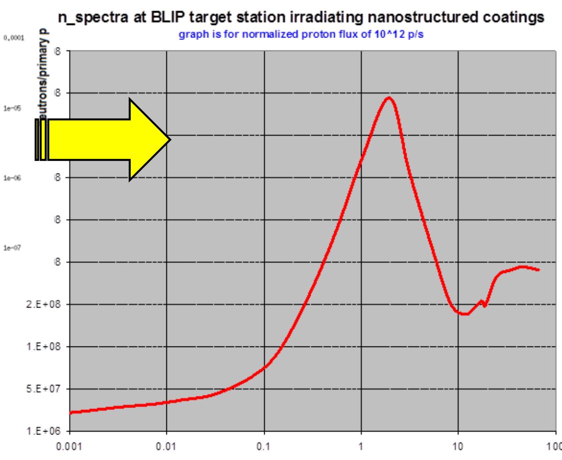


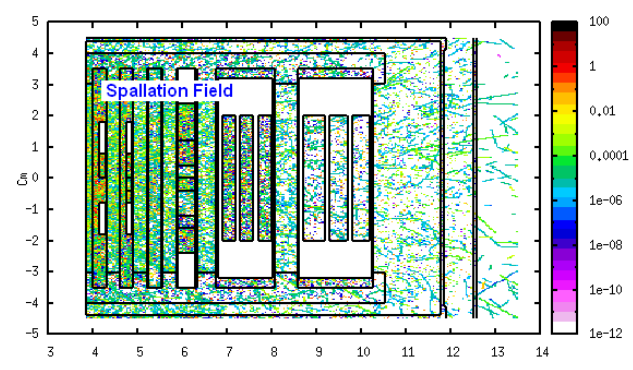






Neutron spectrum downstream of isotope target array



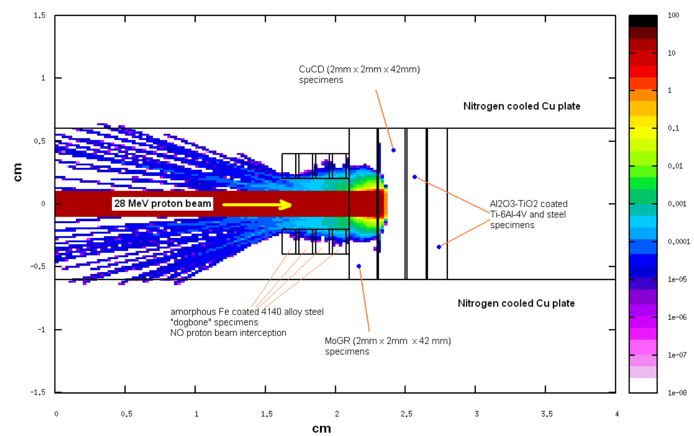


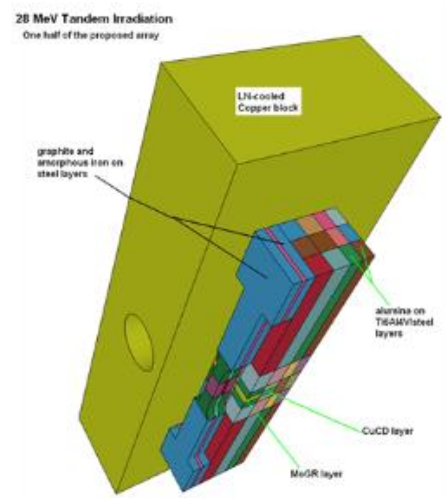
28 MeV Proton (plus spallation neutron) irradiation at Tandem

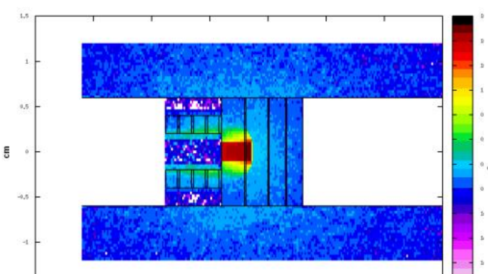
28 MeV (1 uA, 200 x 200 um x um) protons

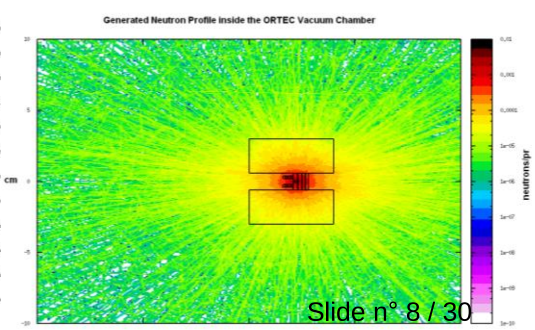
Mo – direct 28 MeV protons

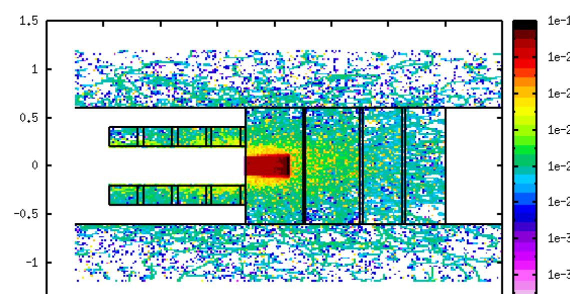
Mo/MoGR/CuCD/Glidcop: spallation neutrons





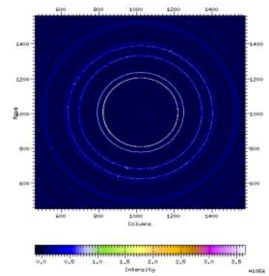


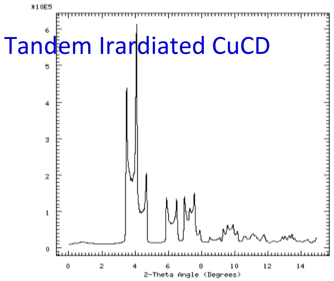


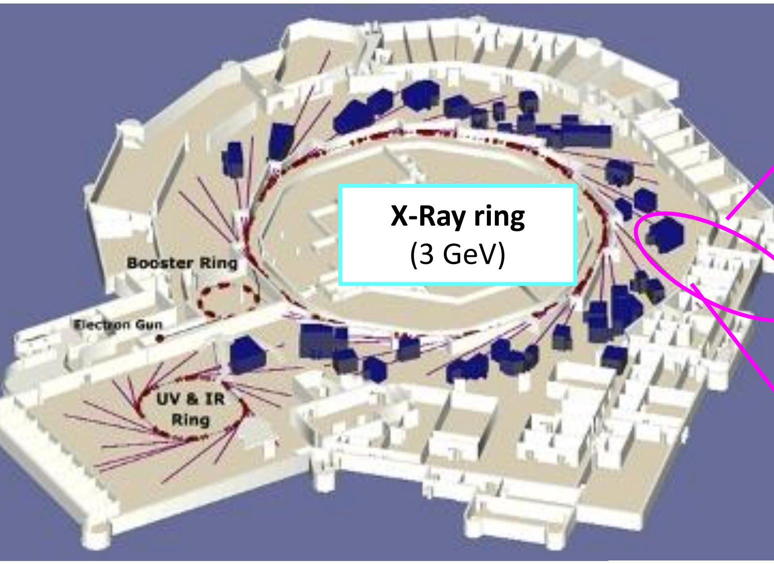


X-ray diffraction studies at NSLS

- Monochromatic 70 KeV beam (X17A beamline)
- White beam 200 KeV, X17B1 beamline

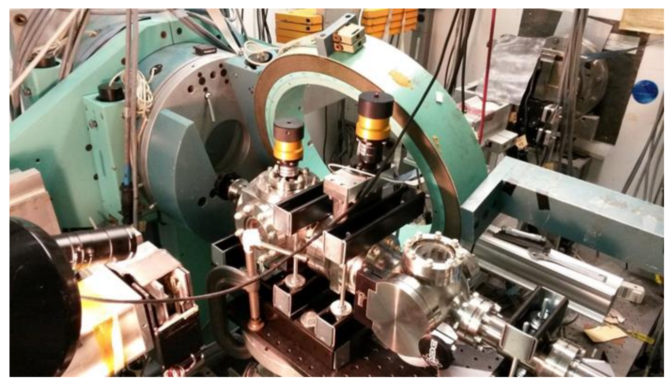


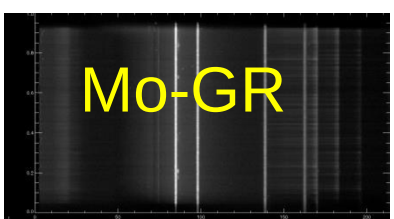


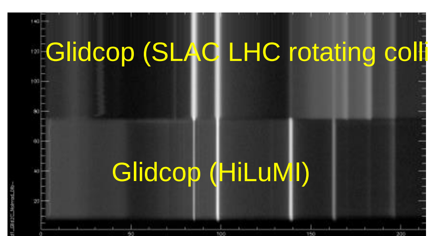


X17A (monochromatic x-rays)

X17B1

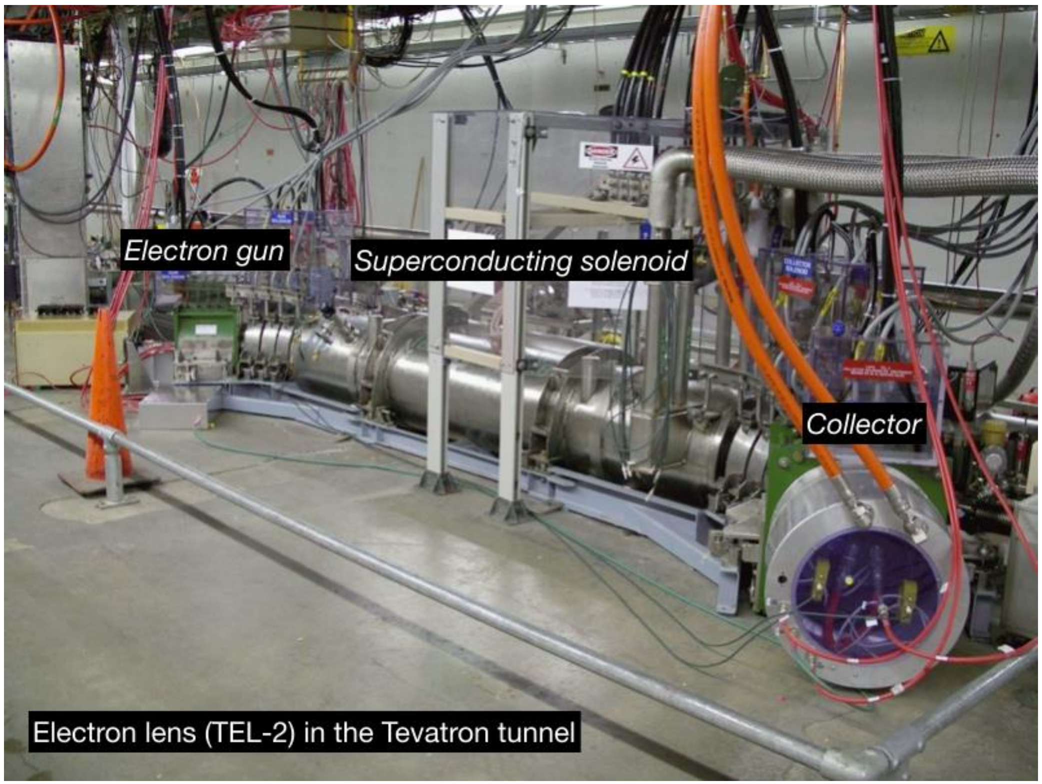




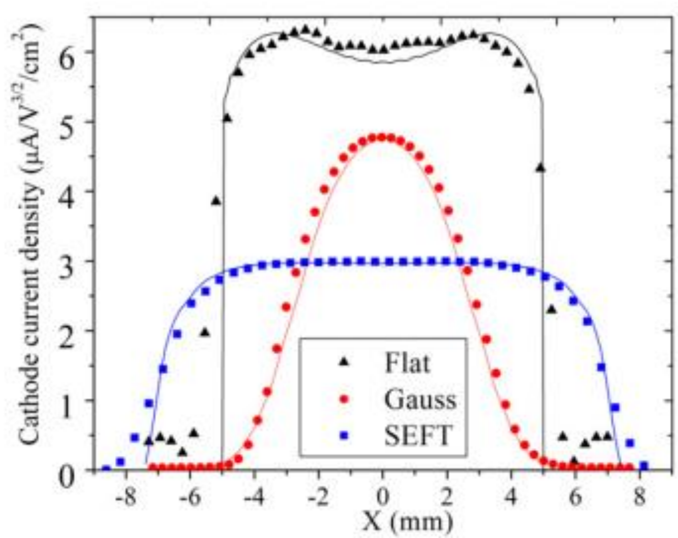


Collimation with Hollow Electron Beams

Giulio Stancari, A. Valishev (Fermilab)
R. Bruce, S. Redaelli, A. Rossi, B. Salvachua Ferrando (CERN)



Electron beam current profile shaped by cathode geometry and maintained by strong solenoid field

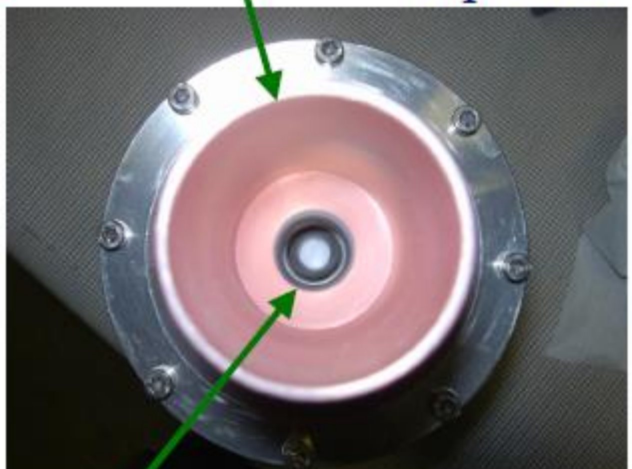


In Tevatron used for:

- Beam-Beam compensation
- Betatron Tune correction
- Abort Gap Cleaning

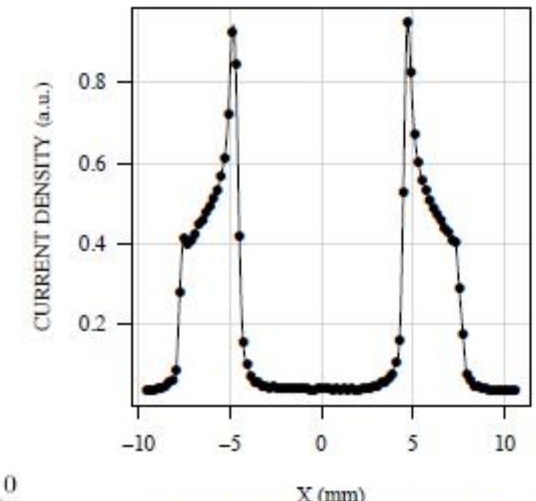
~2009: Develop Cathode for 15mm Hollow Electron Profile to use E-Lens as a Halo Scraper

side view Copper anode *top view*

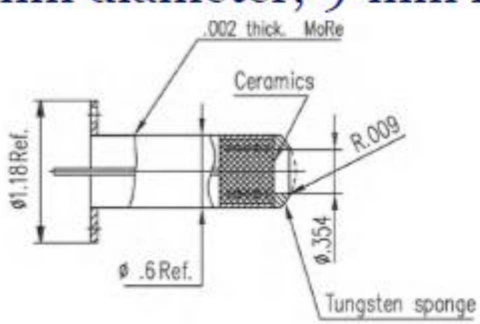


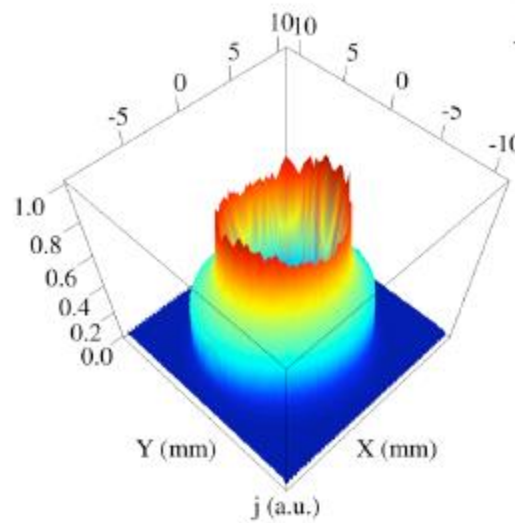
Yield: **1.1 A** at 4.8 kV

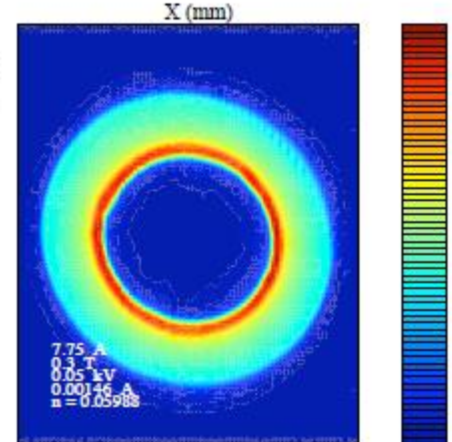
Profile measurements



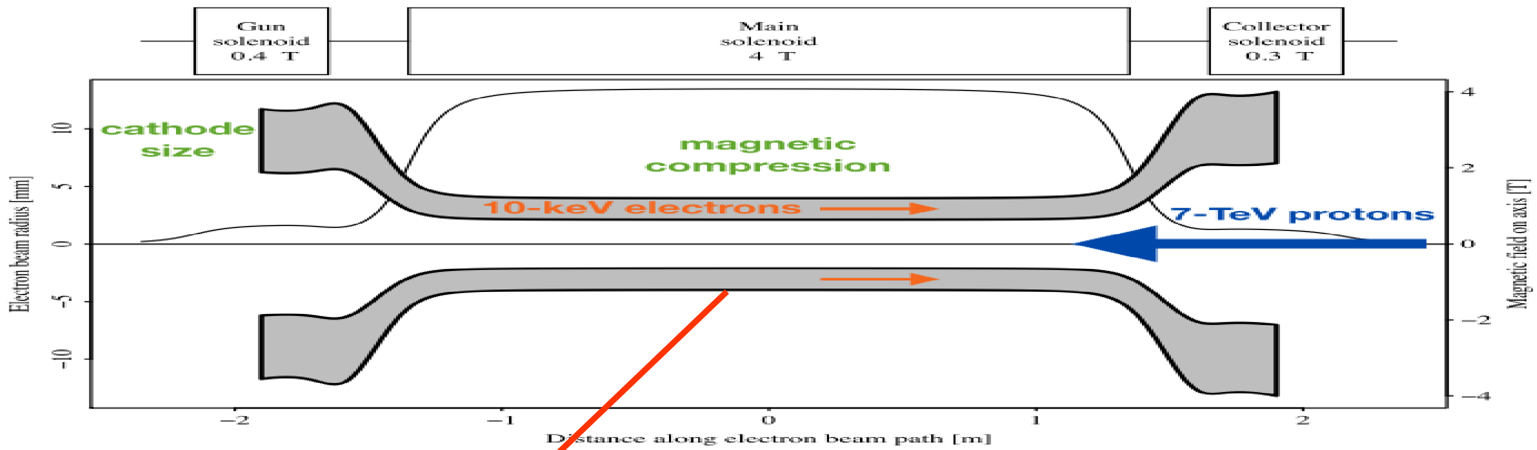
Tungsten dispenser cathode
with convex surface
15-mm diameter, 9-mm hole



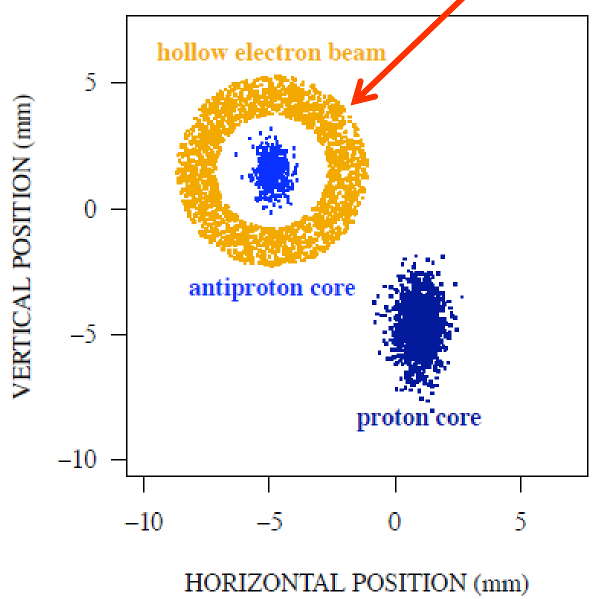




Hollow Electron Beam Gun in Tevatron



Transverse separation is 9 mm



Pulsed electron beam can be synchronized with any group of bunches

Main solenoid controls diameter of electron ring

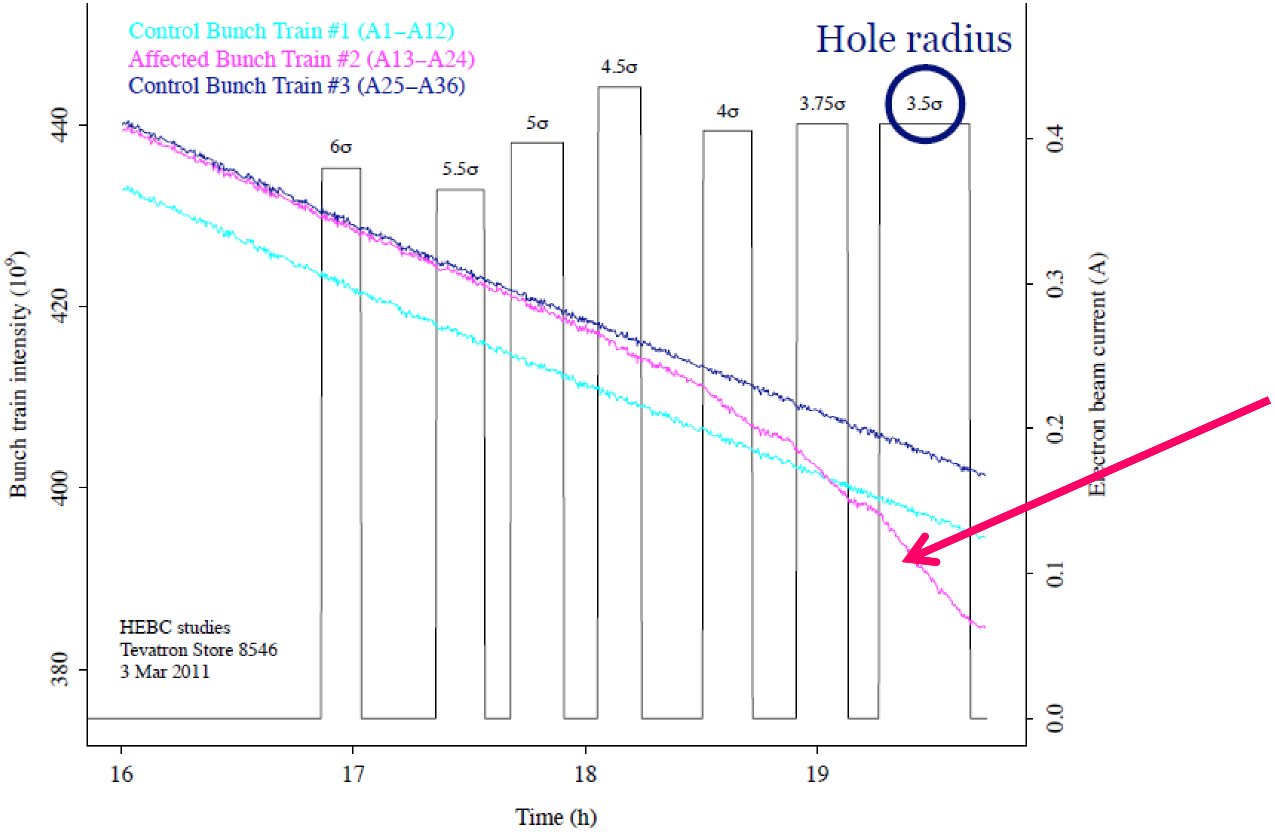
18 experiments 2010.10-2011.06

- Tail of selected bunch depopulated
- Control bunches & core of selected bunch unaffected

Example HEBC Result:
Selected & Control Bunch Intensity vs. Beam Size

Excellent progress in understanding of hollow beam collimation

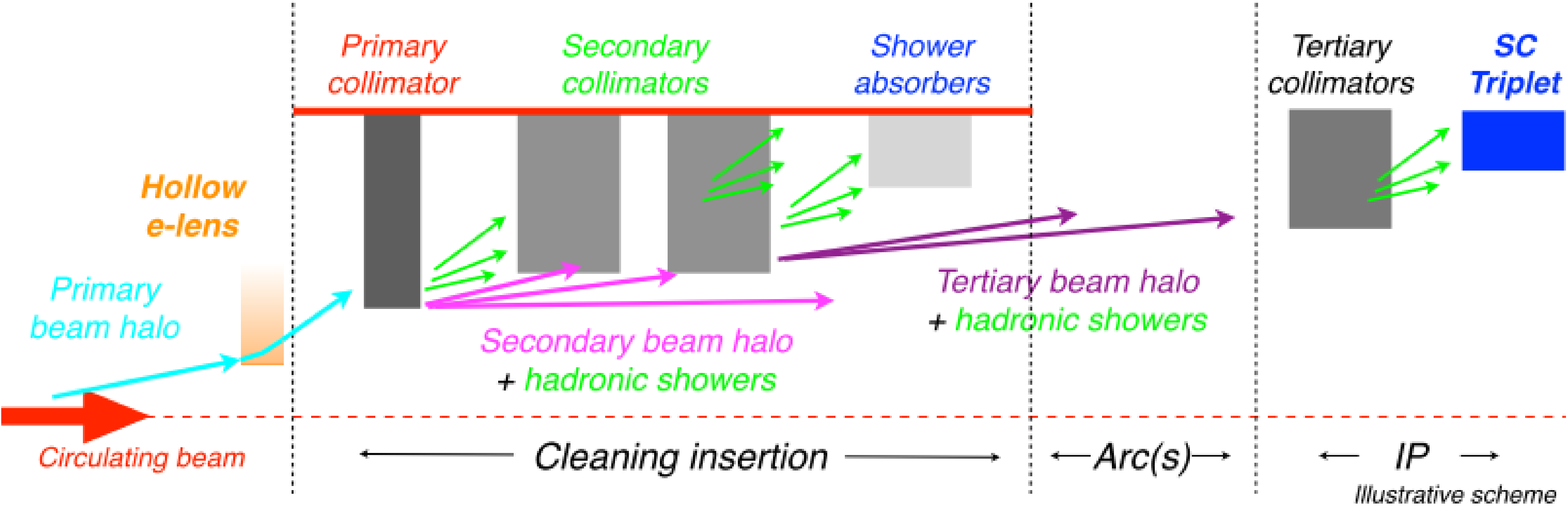
Many new observations: halo removal rates, effects on core, diffusion, fluctuations in losses, collimation efficiencies, ...

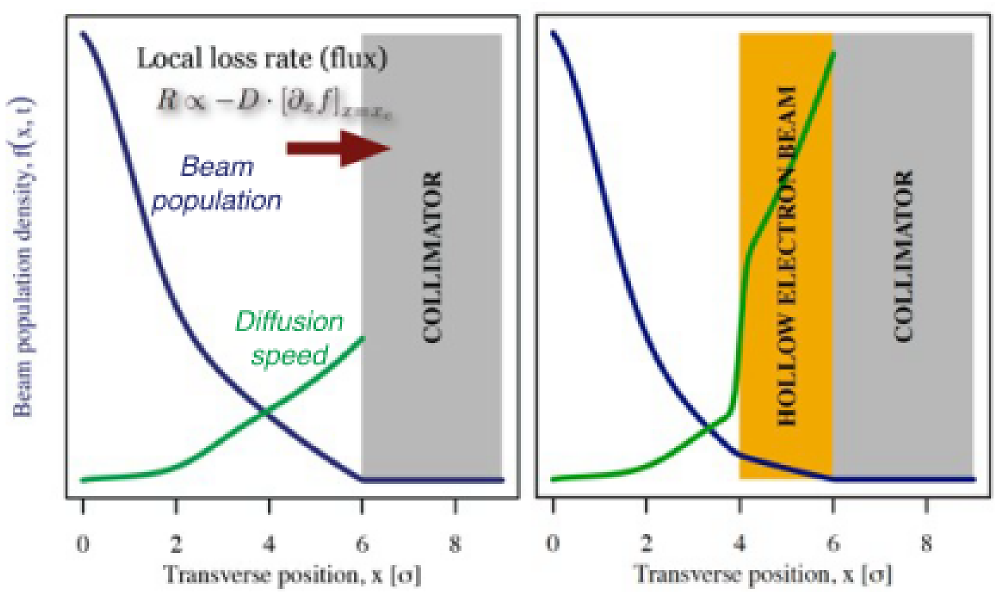


Pulse Gun for synched to one bunch train and look at Intensity decrease as diameter of the electron current ring decreases

Stancari et al., Phys. Rev. Lett. 107, 084802 (2011)
Stancari et al., IPAC11 (2011)
Stancari, APS/DPF Proceedings, arXiv:1110.0144

Integration in multi-stage cleaning





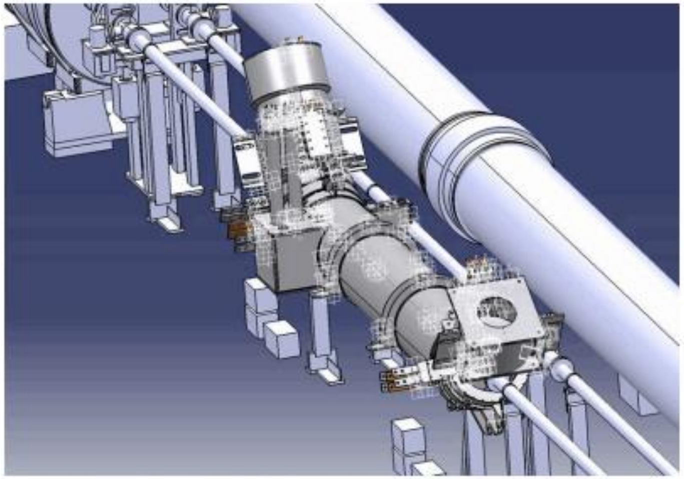
- The classical **multi-stage collimation** concept is maintained.
  - *No need to change present hierarchy*
- Ensures a full compatibility with present and future schemes
  - *E.g., compatible with crystals and also for ions.*
- "Hole" around core make losses insensitive to orbit drifts.
- Lens does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

Feasibility for LHC Studied & Conceptual Design Report Written

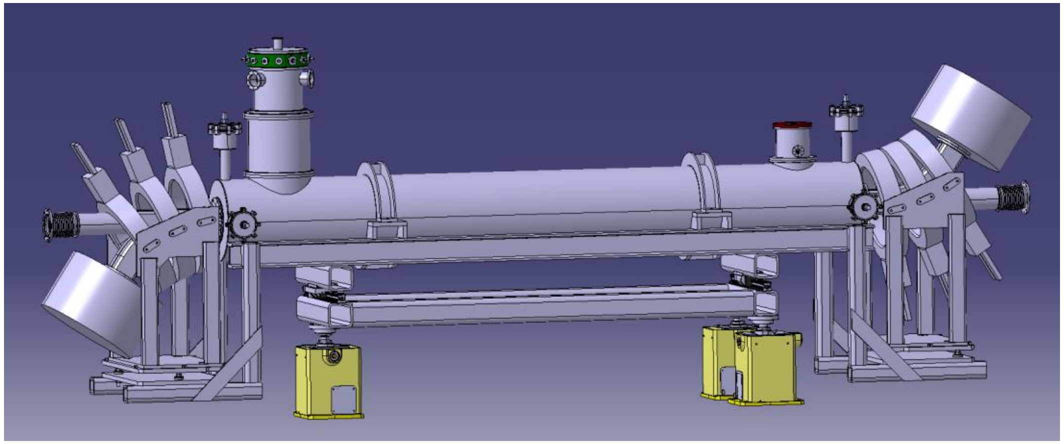
Candidate location RB-46

LHC E- Gun Prototype

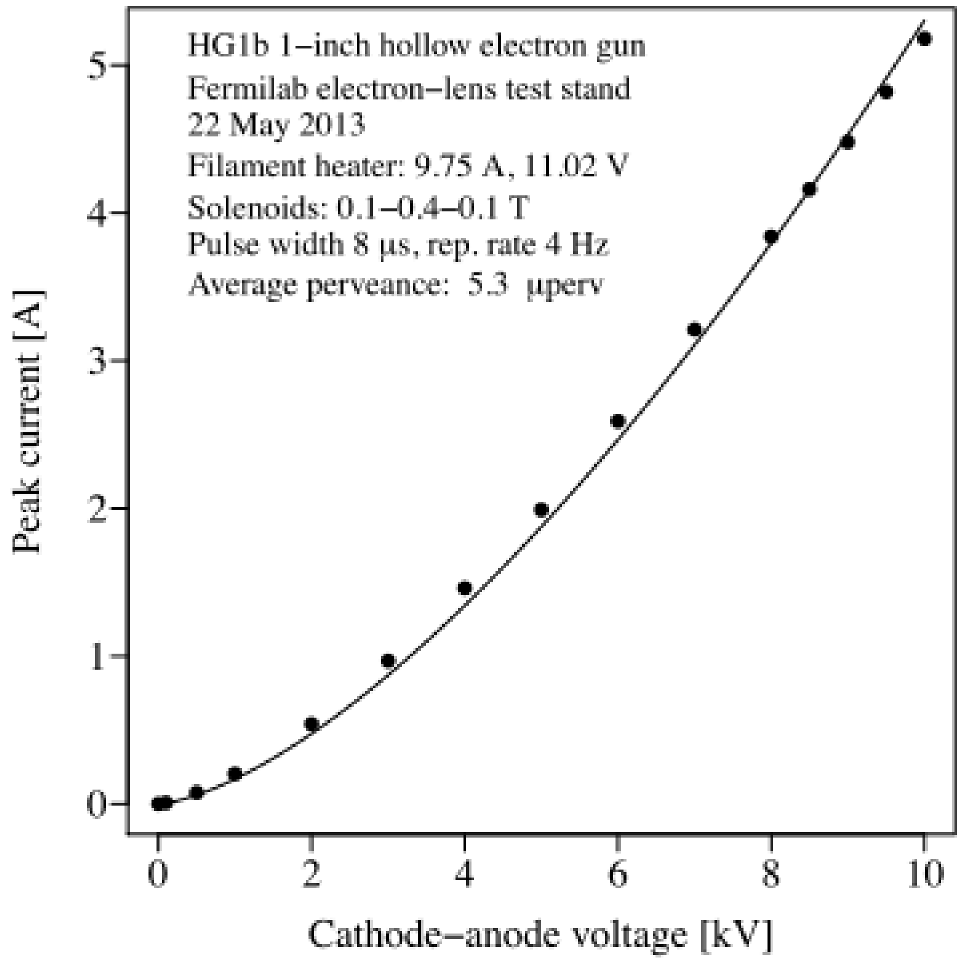
Mechanical Integration



Gun & Collector Opposite to Minimize Inj./Ext. Effects



LHC E-Gun Tests at Fermilab



Goals of the Numerical Simulations

Would hollow electron beam collimation be effective in the LHC?

- The kicks are nonlinear, with a small random component. Halo removal rates are expected to depend on magnetic rigidity of the beam, machine lattice, and noise sources. Nontrivial extrapolation from Tevatron to LHC.

Which modes of operation would be useful?

- **continuous**: same electron current every turn
  - most of Tevatron experiments done in this mode
- **resonant**: current modulated to excite betatron oscillations (sinusoidal or skipping turns)
  - used for clearing abort gap in Tevatron
- **stochastic**: random on/off, or constant with random component

Would there be any adverse effects on the core, such as lifetime degradation or emittance growth?

- No effects were seen in the Tevatron in continuous mode. Effects of asymmetries in resonant operation?

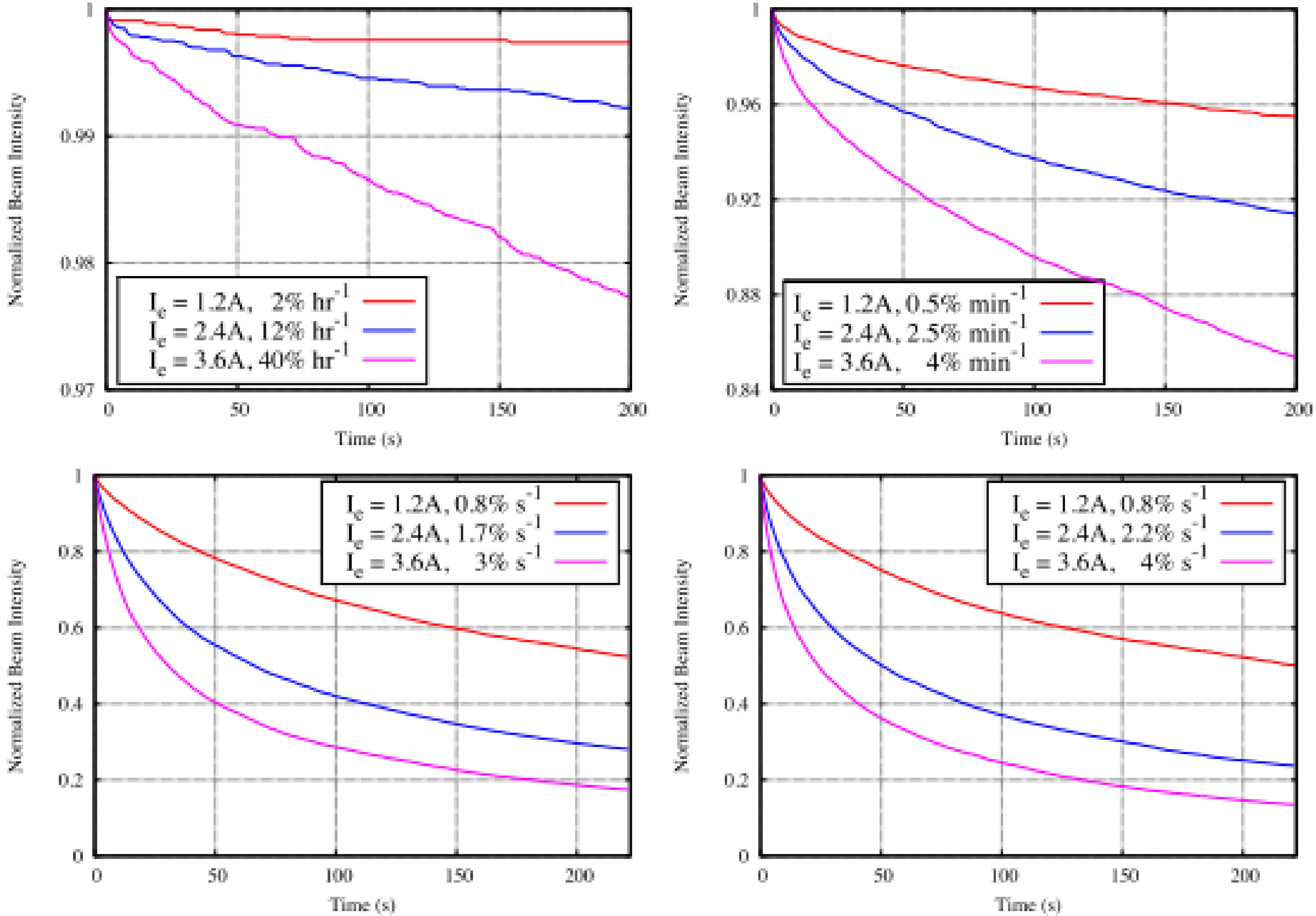
Previtali et al., FERMILAB-TM-2560-APC (2013)
Valishev, FERMILAB-TM-2584-APC (2014)

Calculated Halo Removal Rates vs. Electron Current

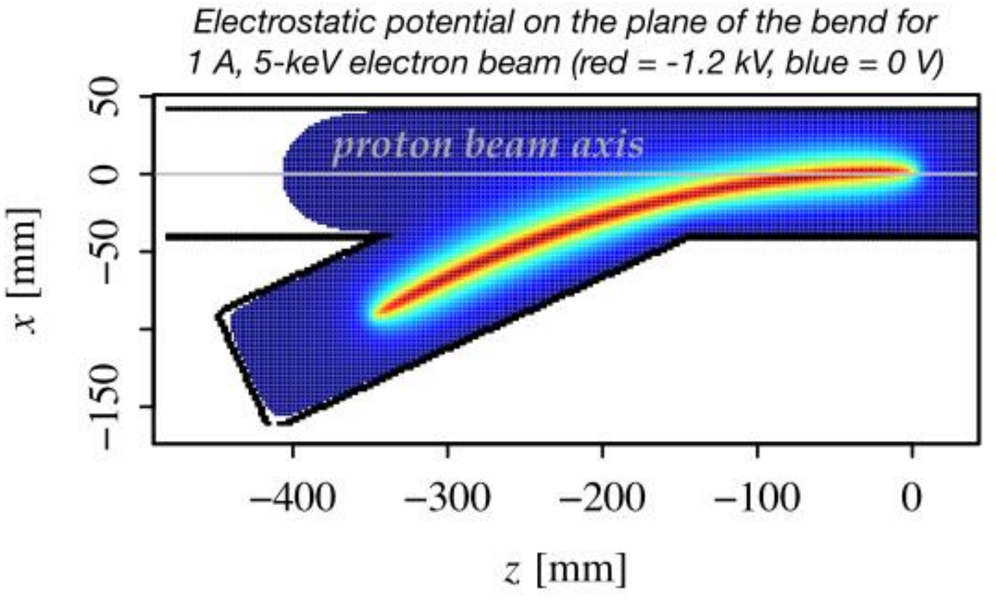
without collisions | with collisions

continuous mode

stochastic mode



Effect of injection/extraction bends



In continuous mode, no impact on emittances or luminosity

In stochastic mode, with U-layout (gun and collector on same side), dipole kick generates emittance growth (e.g., 10% modulation, 0.3 um/h)

In stochastic mode, with S-layout (gun and collector on opposite sides of ring), small contribution to luminosity lifetime (90 h, or 1%/h)

If pulsed operation is required, then S-layout is necessary

Outlook for a Hollow Electron Beam Scraper for LHC

Next steps

- technical design
- electron-lens test stand at CERN
- beam halo in LHC: machine studies and monitoring techniques
- electron lens and diagnostic studies at RHIC
- alternative schemes
- US LARP and US-HL-LHC contributions
- collaborations, personnel exchanges

Resources required if decision to implement is made

- Construction cost of 2 devices for the LHC (1 per beam) is about 5 M$ in materials and 6 M$ in labor
- Construction in 2015-2017 and installation in 2018 is technically feasible
    - Info from this meeting: Hi-Lumi Steering Committee looking for new collaborators who may want to fabricate (Russia?)
- Reuse of some Tevatron equipment is possible (superconducting coil,
- resistive solenoids, electron guns, ...)

The LARP Rotatable Collimator Prototype Candidate for a Phase II Secondary Collimator

Two jaw collimator made of Glidcop

- Rotate jaw after 1MJoule beam abort failure accident occurs

Each jaw is a cylinder with an embedded brazed cooling coil

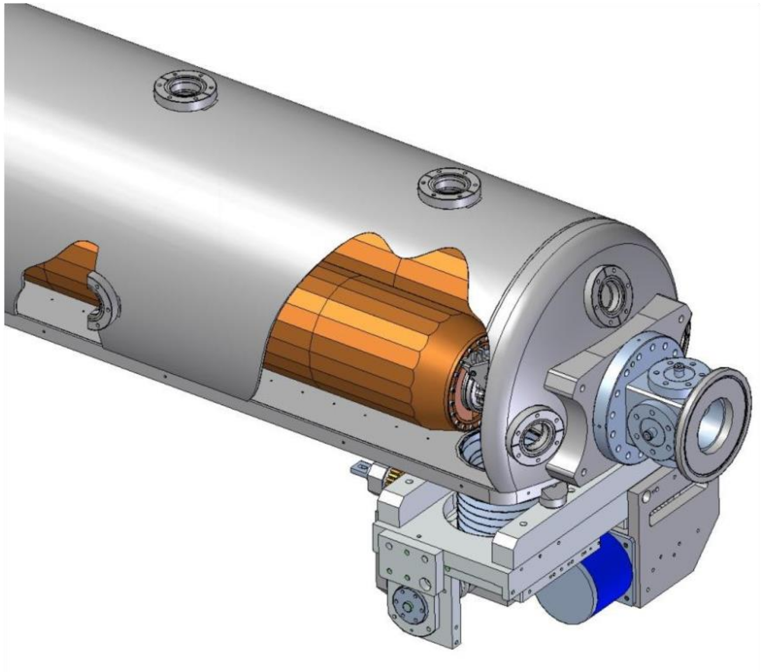
- No vacuum-water braze; 12kW/jaw cooling; minimal thermal distortion
- Maximum radius cylinder possible given beam pipe separation
- BPMs integrated on ends of tank

Advantages:

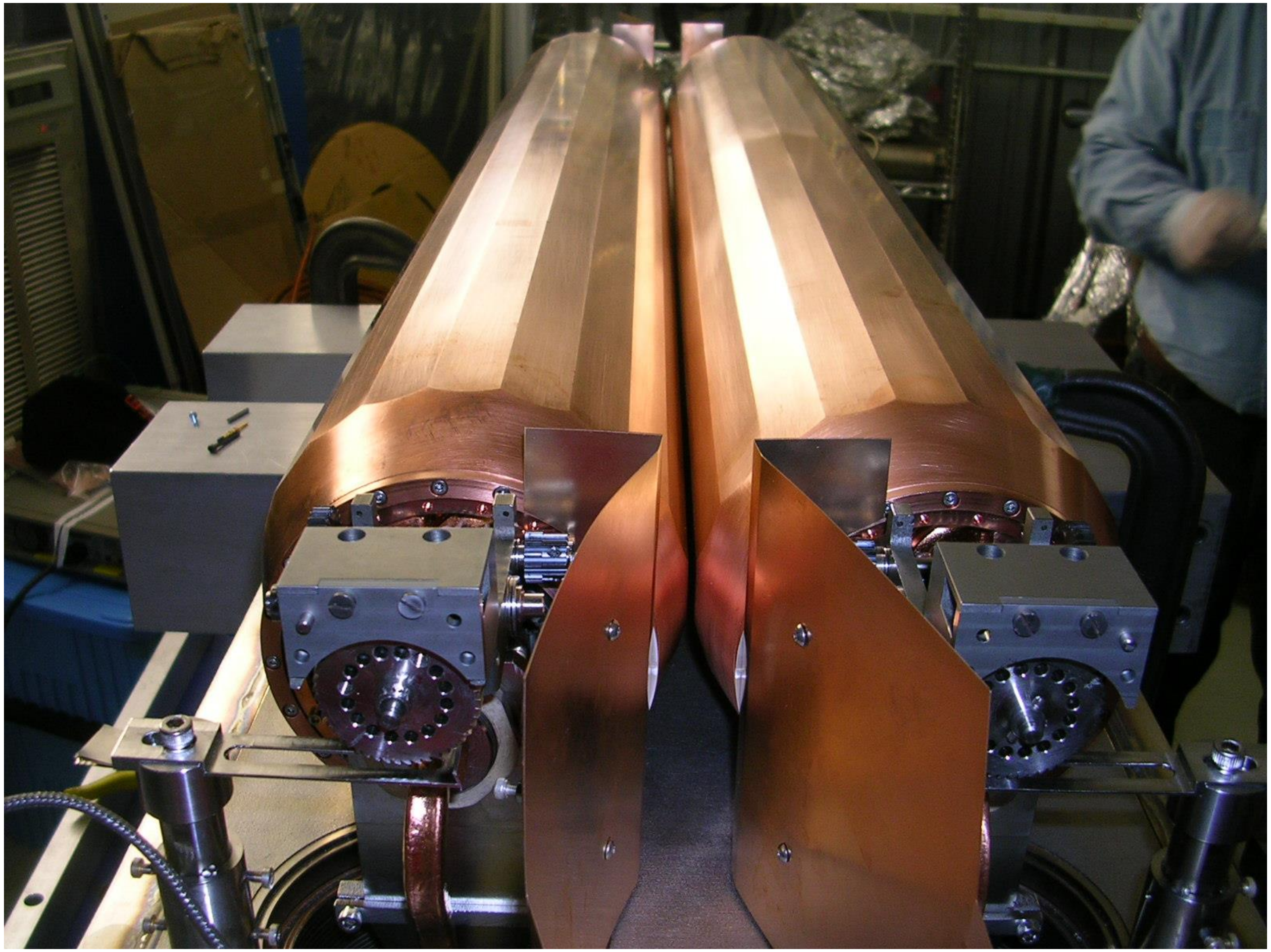
- Not exotic material
- High Z for better collimation efficiency & more debris absorption
- Low resistance for better impedance
- Elemental for high radiation resistance

Disadvantages:

- Glidcop WILL be damaged in asynchronous beam abort



Prototype Collimator Assembled 18-Sept-13
Mechanical & Resistance Tests Good



SLAC Rotatable Collimator

- The SLAC RC was built as part of the US-LARP collaboration
- **Objective**: produce a machine-ready prototype for beam tests in SPS/LHC
- **Rotatable jaw concept**: offers up to 20 collimating surfaces in case of beam damage

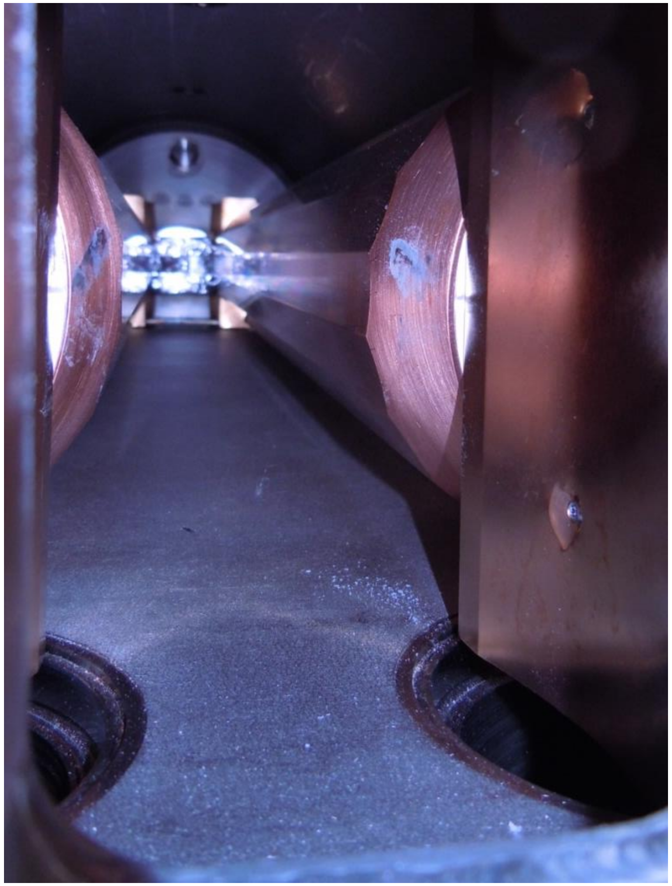
Test Timeline

➡ 11.2013: SLAC collimator received at CERN
➡ 02.2014: Tank opened
➡ 03.2014: first leakage test
➡ 03.2014: First jaw movement tests
➡ 03.2014: First wire impedance tests
➡ 04.2014: Controls (rotation, LVDT, …) tests
➡ 07.2014: Found UHV compliant
➡ 08.2014: Additional controls tests
➡ 11.2014: Metrology tests (for positioning)

From Federico Carra's talk 19 Nov

RC Testing at CERN

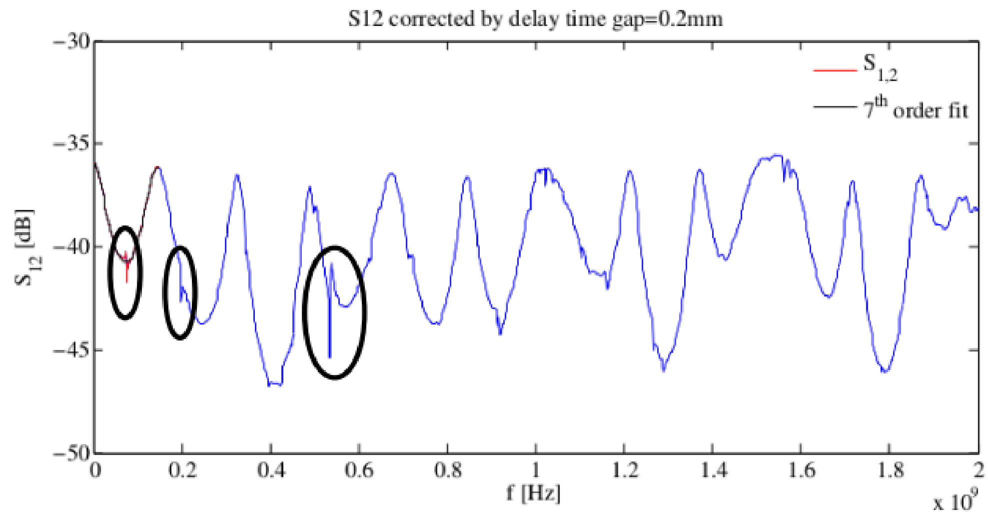
Reception, Unpacking, Visual Inspection



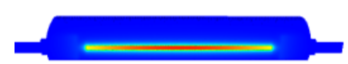
Impedance Measurements at CERN

NB! Preliminary

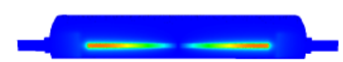
Measuring the S12 with a single wire, attenuators and matching resistors.



Very small gap (0.2 mm)
Visible modes at ~90, ~200 and ~550 MHz → Impedance estimation on-going!



F=80.485, Q0=260,
R/Q_t=9.4e5Ω/structure



F=202.29, Q0=488,
R/Q_t=2.2e4Ω/structure

Consistent with SLAC Calculations

SLAC collimator with larger EM foils

Gap=2mm				Gap=2.5mm			
F (MHz)	Q	Ry(Ω/mm)	K(V/nC/mm)	F (MHz)	Q	Ry(Ω/mm)	K(V/nC/mm)
80.5	260	~4.4e5	~200	83.8	269	~3.4e5	~166
202	488	~4.5e4	~29	204	526	~4.5e4	~27

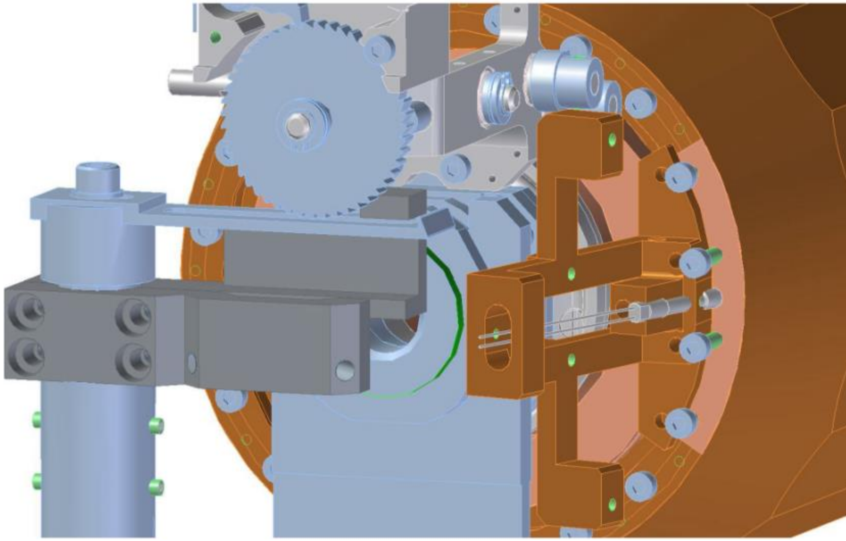
Status of CERN Impedance Measurements

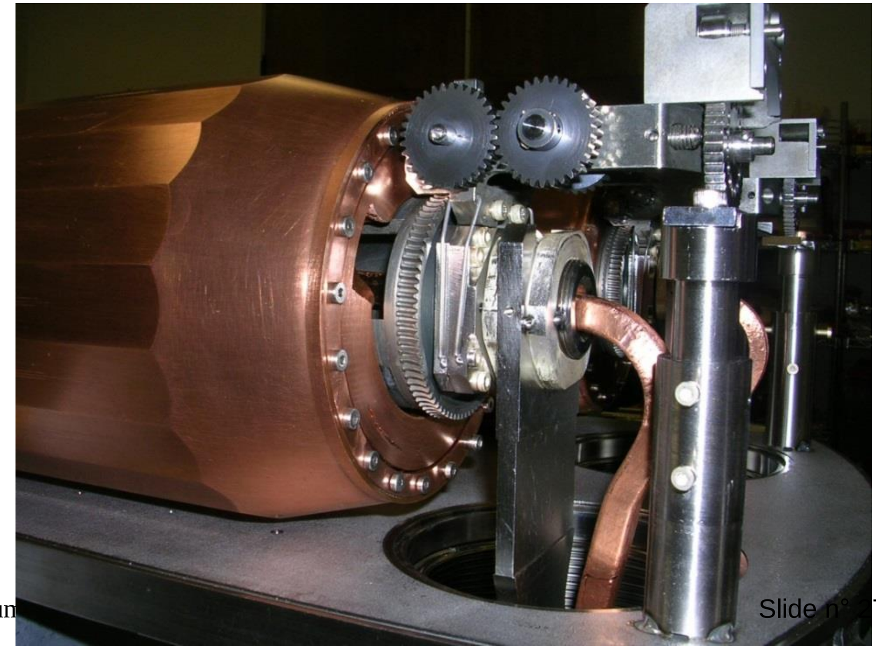
A first set of measurement with single wire and probe was taken	DONE
The presence of the expected transverse modes at ~90MHz and ~200MHz has been confirmed. Other modes are as well present.	DONE
First analysis shows small horizontal impedance.	DONE
Perform two wires measurements.	TO DO
Q measurements with probes. What modes are we interested in?	TO DO
Repeat the measurement with ferrite to demonstrate the killing of transverse mode.	TO DO
….	TO DO

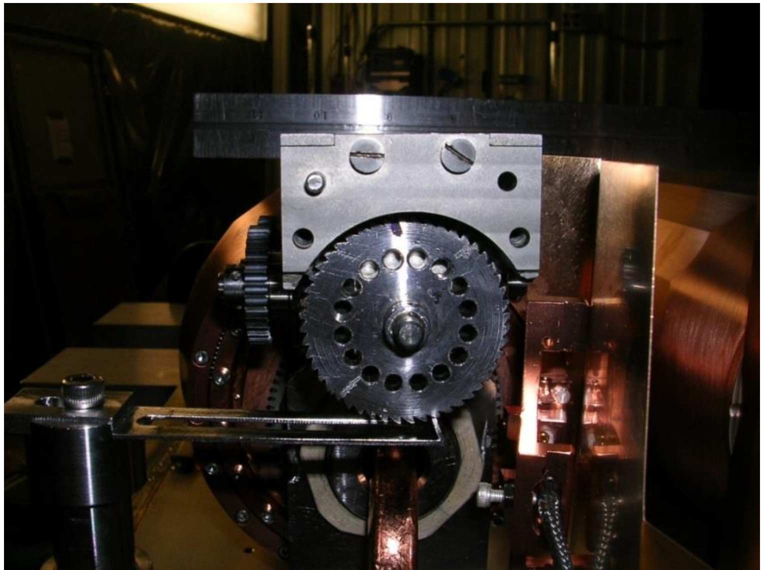
Drive Mechanism Tests Before and After Bakeout

Drive Mechanism tested 22-23 April 2014 and August 2014 after bakeout

- 384 “ratchets” to rotate 1 more “facet”
- In April, required adjustment of actuator w.r.t. to toothed drive wheel
  - Presumed due to tight tolerance & transport jolts

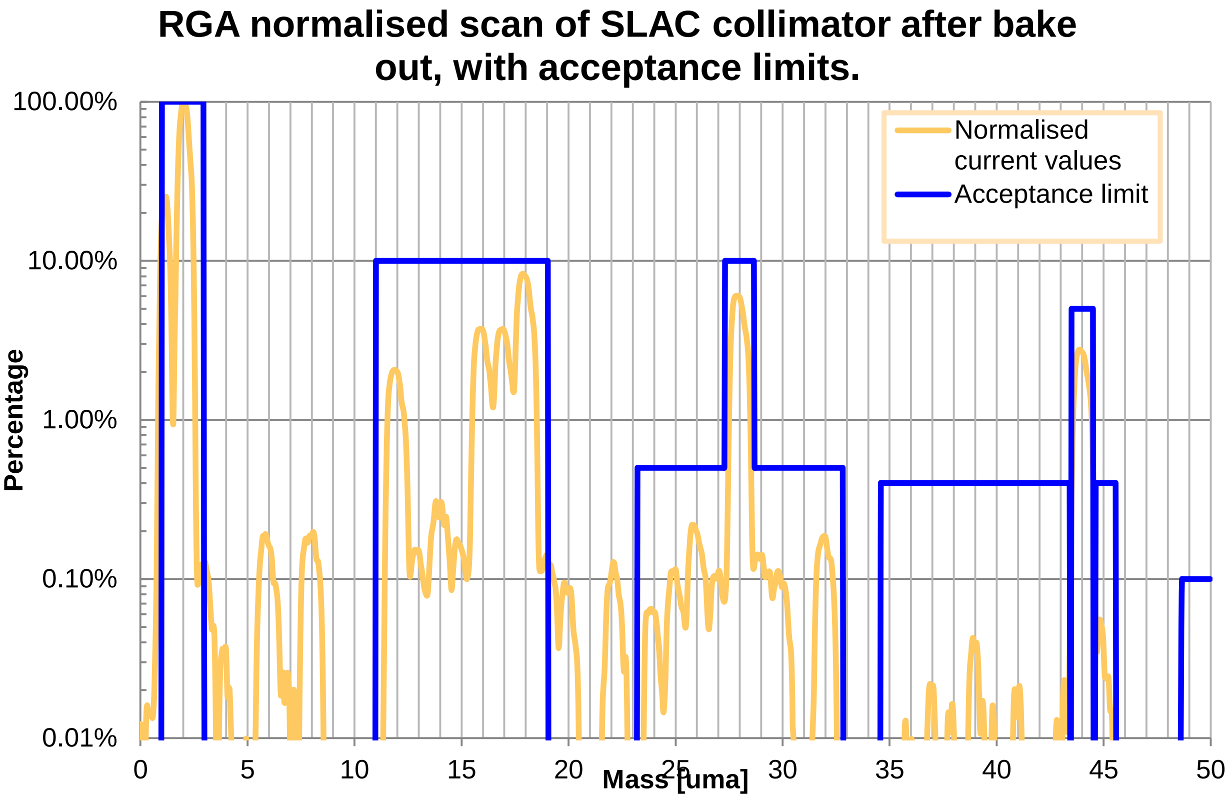






Vacuum test Results: 07.2014

Outgassing test cycle (with bake-out ramped up to 180° C and slow cool-down)



HRMT-21 SLAC Rotatable Collimator: Goals

LARP

- To assess damage limits in case of accident scenarios
- To test rotation mechanism functionality to beam impacts with increasing intensity

From Federico Carra's talk 19 Nov

- Test 1: To assess Glidcop onset of damage (6 shots between 25% and 150% of the expected damage limit (**0.14 MJ**) followed by 1-3 facet rotation to distinguish damage extension)
- Test 2: To assess functionality after HL-LHC asynchronous beam dump (82b for a total of $1.39e^{13}$ at 440 GeV or **1.0 Mjoule=8 7-TeV LHC bunches @ 1.15E11p/bunch**)
- Test 3: To assess functionality after HL-LHC injection error (288b for a total of $4.90e^{13}$p at 440GeV or **3.5 MJ**)

Schedule and Actions

- SLAC RC is proposed for installation in the SPS for **MD in 2015**:
  - Vacuum and impedance compliant with SPS requirements
  - ECR prepared and to be circulated soon
- Test of SLAC RC in HiRadMat likely in **2016 (HRMT-21 experiment)**
  - Exact details flexible at this point

From Federico Carra's talk 19 Nov

The End