# Overview of HL-LHC-UK, and the collimation activities

**Rob Appleby**, Sam Tygier, Haroon Rafique, Scott Rowan, Roger Barlow, Tom Furness, Simon Fletcher, Stephen Gibson, Andrey Abramov, Stewart Boogert, Hector Garcia-Morales, Laurie Nevay, Stuart Walker, Luke Dyks, Maxime Rey, Daniele Mirarchi

HL-LHC collaboration meeting
CERN, 16th October 2018

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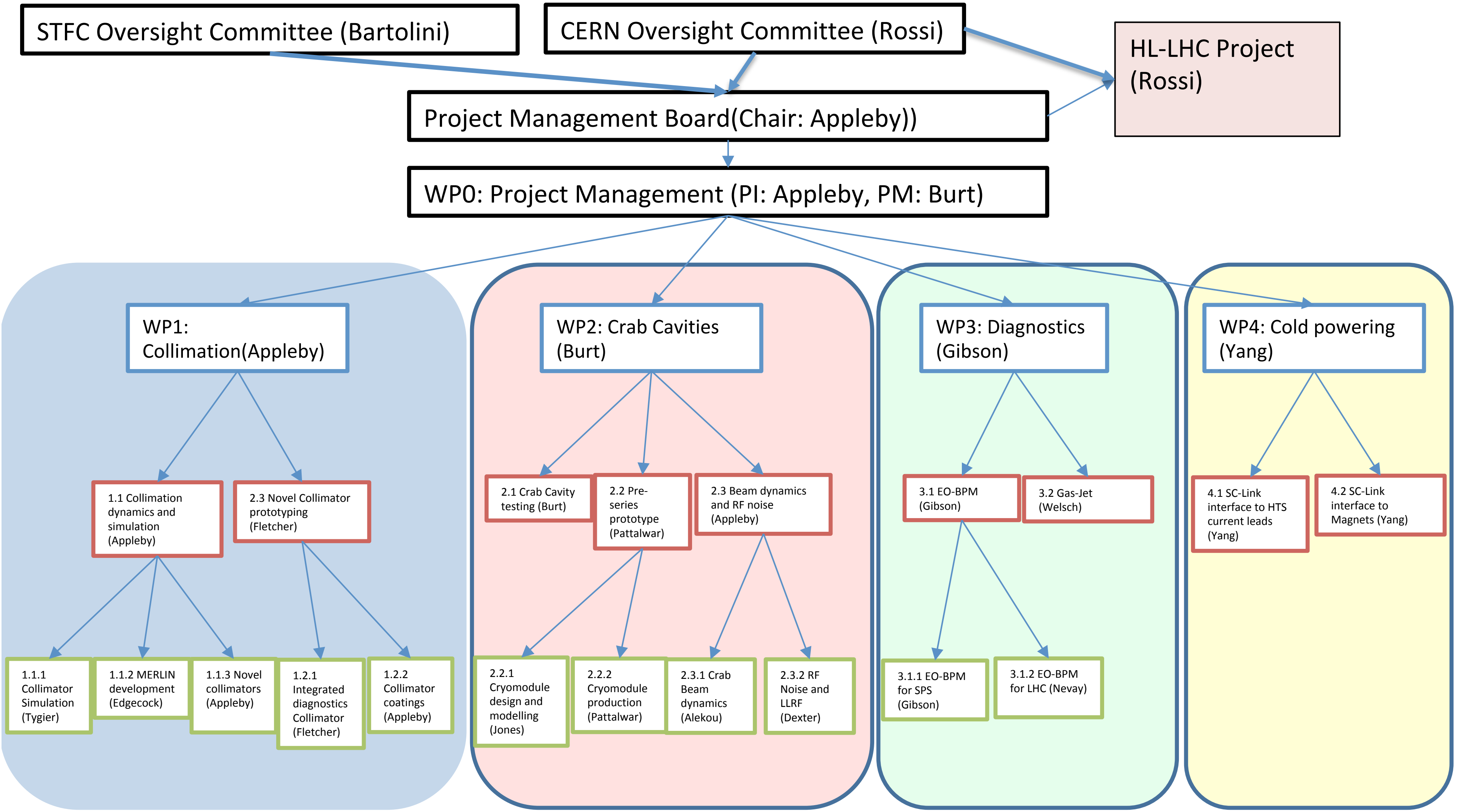
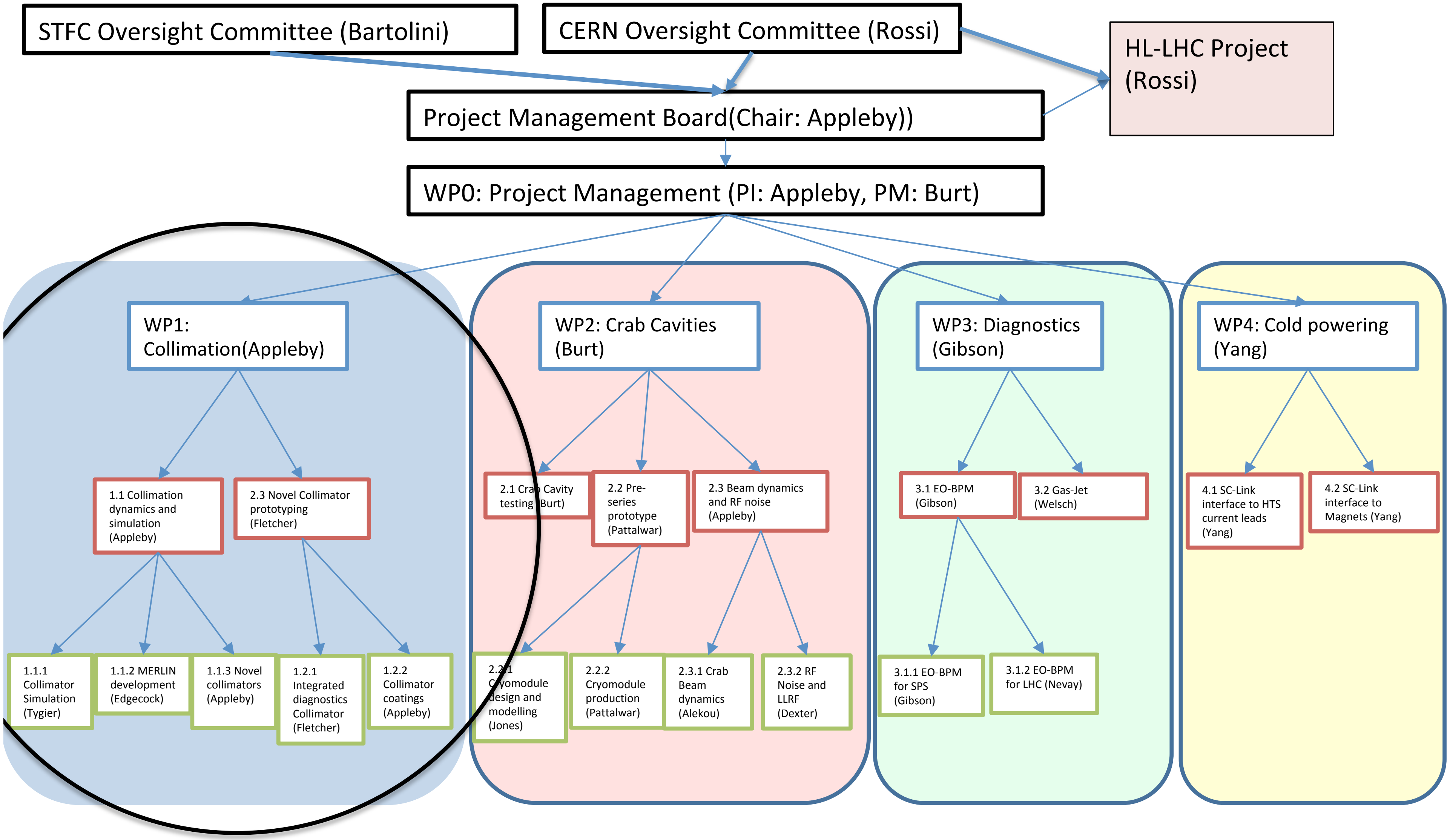
# HL-LHC-UK

- ***HiLumi*-LHC** design study FP7 2011-2015
- The UK hosted the *HL-LHC* kick-off meeting at Cockcroft Institute in November 2013.
- Discussions with STFC for UK project followed, with early SoI for LHC-UK
- SoI (final one) submitted early 2015
- Proposal submitted in March 2016
- CERN finance approved October 2015
- STFC finance approved March 2016
- CERN-UK contract signed April 2017
- 7 UK institutes as members
  - £8M of UK and CERN funding over 4 years, with institute and university money combining with STFC
- Main UK activities:
  - *WP1 : Collimation*
  - *WP2 : Crab cavities*
  - *WP3 : Diagnostics*
  - *WP4 : Cold powering*

# HL-LHC-UK


STFC Oversight Committee (Bartolini)
CERN Oversight Committee (Rossi)
HL-LHC Project (Rossi)
Project Management Board(Chair: Appleby))
WP0: Project Management (PI: Appleby, PM: Burt)
WP1: Collimation(Appleby)
WP2: Crab Cavities (Burt)
WP3: Diagnostics (Gibson)
WP4: Cold powering (Yang)
1.1 Collimation dynamics and simulation (Appleby)
2.3 Novel Collimator prototyping (Fletcher)
2.1 Crab Cavity testing (Burt)
2.2 Pre-series prototype (Pattalwar)
2.3 Beam dynamics and RF noise (Appleby)
3.1 EO-BPM (Gibson)
3.2 Gas-Jet (Welsch)
4.1 SC-Link interface to HTS current leads (Yang)
4.2 SC-Link interface to Magnets (Yang)
1.1.1 Collimator Simulation (Tygier)
1.1.2 MERLIN development (Edgecock)
1.1.3 Novel collimators (Appleby)
1.2.1 Integrated diagnostics Collimator (Fletcher)
1.2.2 Collimator coatings (Appleby)
2.2.1 Cryomodule design and modelling (Jones)
2.2.2 Cryomodule production (Pattalwar)
2.3.1 Crab Beam dynamics (Alekou)
2.3.2 RF Noise and LLRF (Dexter)
3.1.1 EO-BPM for SPS (Gibson)
3.1.2 EO-BPM for LHC (Nevay)

# HL-LHC-UK




Note that some sub-tasks led by an academic may change to a PDRA once recruited

# Overall UK goals

## HL-LHC-UK collimation tasks

- **Task 1: Collimation and beam dynamics simulation [14 PDRA years - Man, RHUL, Hud].**
  1. Study of LHC loss maps in simulation and comparison with run II measurements, including participation in collimator data-taking.
  2. Investigation of novel collimation concepts, e.g. hollow electron lens and crystal collimation. Use of BDSIM developments (outside of HL-LHC-UK) to simulate novel collimation techniques.
  3. Further development of MERLIN at Manchester and Huddersfield, to provide 6D tracking and novel collimator materials. Revision and impact of scattering physics models.
  4. Continued use and development of SixTrack by RHUL to study new focusing scheme via aperture scans of the IR triplets. Investigate the effects on collimation settings from non-linear optics, including studies of off-momentum particles and the impact of chromaticity.

- **Task 2: Collimator prototyping [4 PDRA years - Man, Hud]**
  1. Investigate the possibility of Graphene monolayer coatings for ultra-low impedance collimators with a bench test in Manchester.
  2. Development of a collimator prototype with integrated diagnostics, which can actively compensate for the effects of adverse heating on jaw geometry.

# MERLIN++

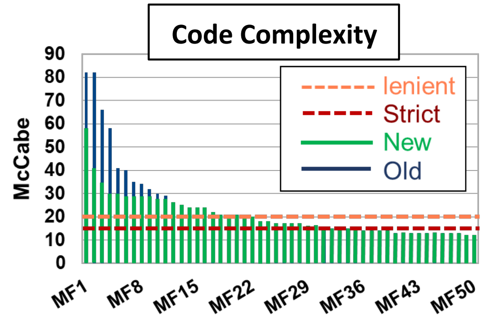
University of HUDDERSFIELD
Inspiring tomorrow's professionals

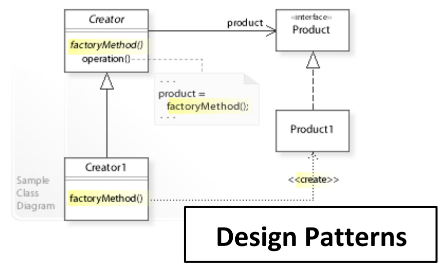
MANCHESTER 1824
The University of Manchester

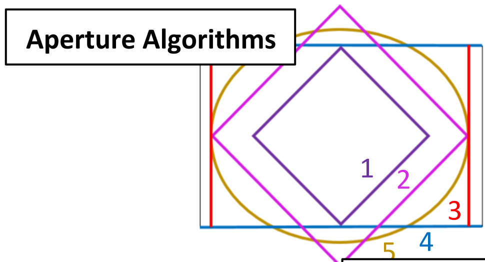
Software Sustainability Institute

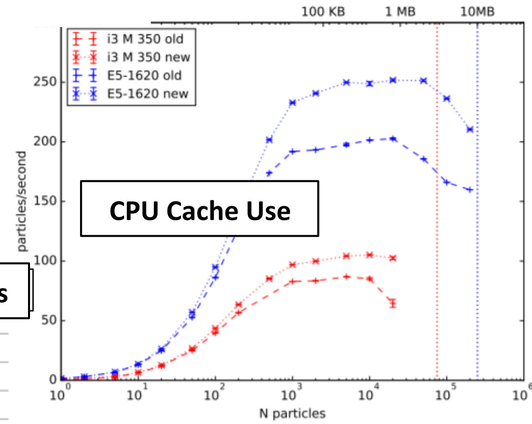
## *Significant Usability/Maintainability Improvements*

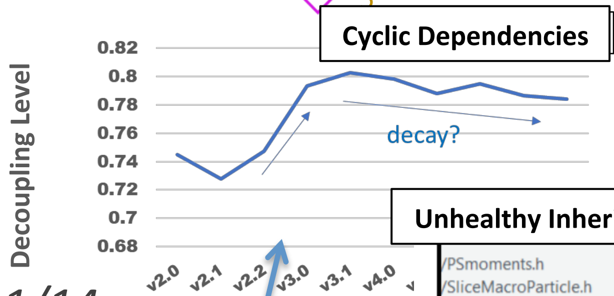
- **Usability**
  - → *New website*
  - → *Public Github repository*
  - → *Build/Install/IDE use guide*
  - → *Quick Start Guide*
  - → *Examples and Tutorials*
- **Maintainability**
  - → *Developer/Coding style guide*
  - → *API/Class library*
  - → *Growing Test suite*
  - → *Copyright revision to GPL2+*
  - → *Standardized code style*
  - → *Update of legacy code to C++11/14*

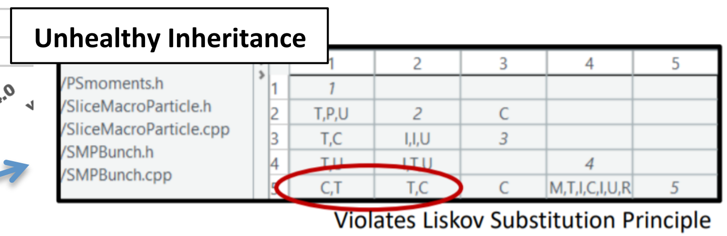
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CHEP proceedings

HiLumi HL-LHC PROJECT

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# MERLIN++

## *Current Investigations/Roadmap*

- **Merlin++ 5.02 Released!**
  - → *If anyone is interested we are happy to provide support*
- **Future Optimization/Scalability**
  - → *Hybrid parallelism, i.e. MPI* ***+ threading*** *(C++17?)*
  - → *Explicit vectorization, guided by Intel® Advisor (make use of modern cores)*
  - → *Make use of modern highly-optimized numerical libraries (LAPACK etc)*
- **Future Functionality/Simulations**
  - → *Development/implementation of composite materials code*
  - → *Validation/benching of composite materials code against SixTrack etc*
  - → *Active halo control with transverse damper*

  *Potential for…*
  - → *Crystal collimation studies*
  - → *Halo control through Integrable optics : IOTA at Fermilab*

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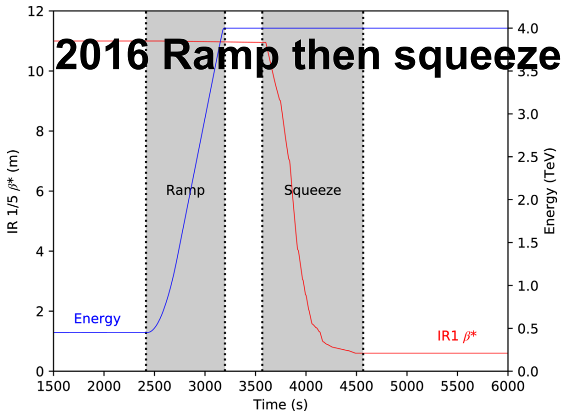
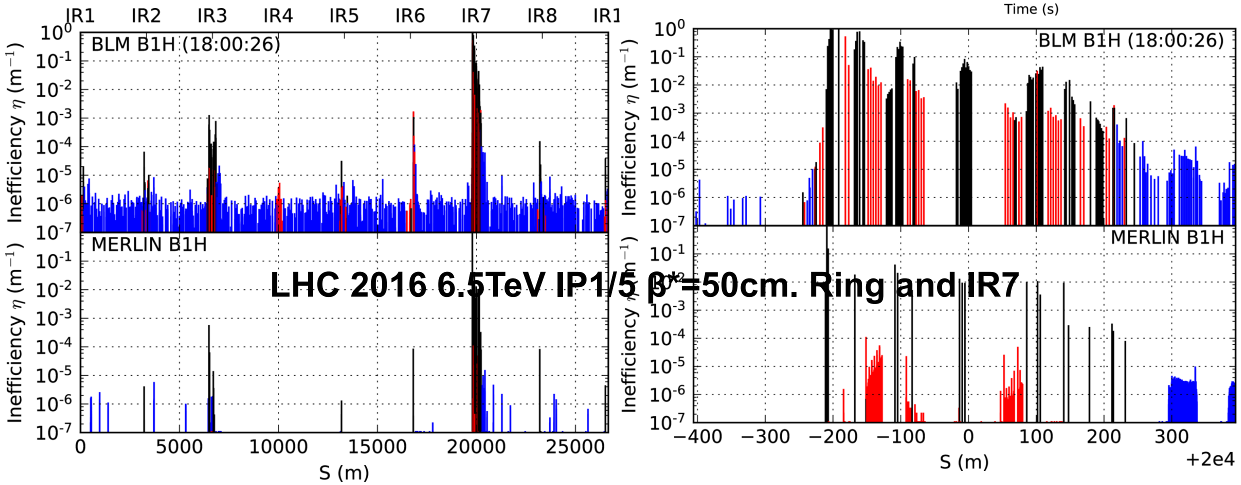
# Analysis of run 2 data

- Studied proton losses in Merlin with radiation showers recorded by BLMs
- Use squeeze during 2012 and 2016
- Combined ramp and squeeze 2018
- Range of energies and optics
- Used for HL-LHC validation

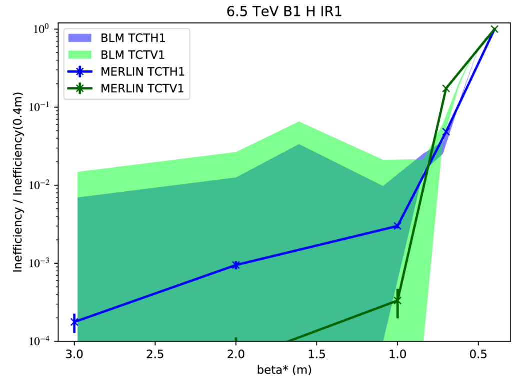


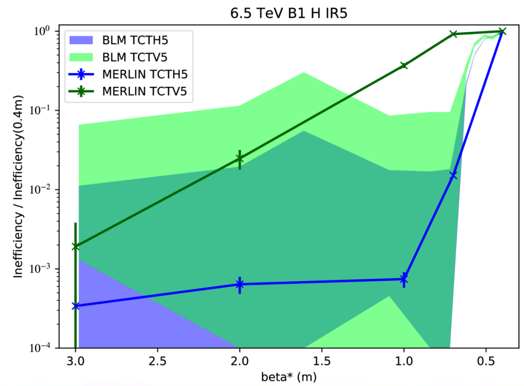

| Region | Type | Gap ($\sigma$) |
|---|---|---|
| IR7 | TCP | 5.5 |
| IR7 | TCS | 7.5 |
| IR7 | TCLA | 11.0 |
| IR3 | TCP | 15.0 |
| IR3 | TCS | 18.0 |
| IR3 | TCLA | 20.0 |
| IR1 | TCT | 23.0 $\rightarrow$ 9.0 |
| IR5 | TCT | 23.0 $\rightarrow$ 9.0 |
| IR2 | TCT | 37.0 |
| IR8 | TCT | 23.0 $\rightarrow$ 15.0 |

Collimator gap changes (2016)

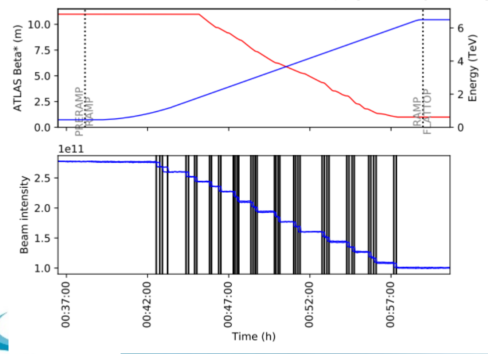


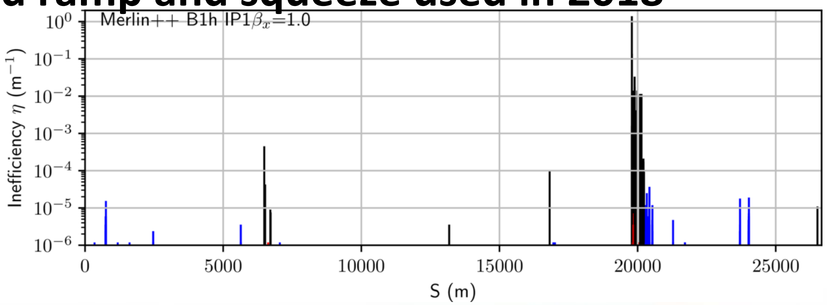

LHC 2016 6.5TeV IP1/5 β*=50cm. Ring and IR7




## Combined ramp and squeeze used in 2018

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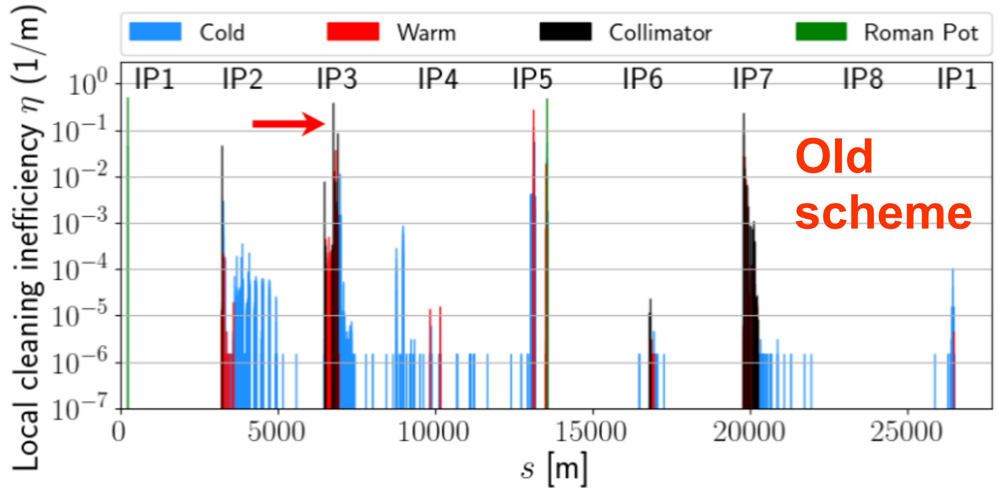
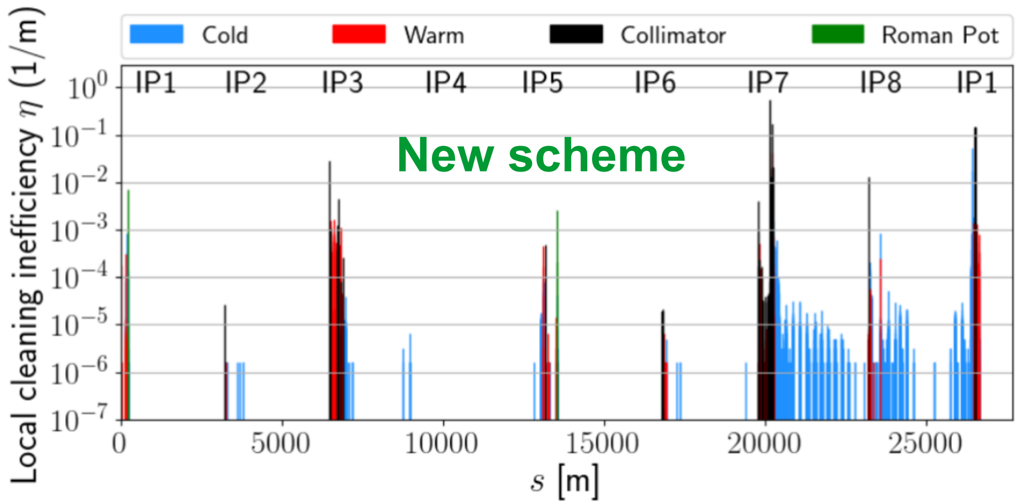
# Collimation system for Special Physics run

- A new collimation system has been introduced for the high-beta run at injection.
- The idea is to reduce the background deposition in the forward detectors (ALFA/ TOTEM roman pots) which have half-gaps of 3 sigmas.
- It is based on a two stage collimation using tungsten collimators (single previously)
- Primary collimator is at 2.5 sigma.
- Secondary collimators at 2.7 sigma.

| Collimator | Plane | IR | Half gap [$\sigma$] |
|---|---|---|---|
| TCLA.A6[R/L]7.B[1/2] | V | 7 | 2.5 |
| TCLA.A5[R/L]3.B[1/2] | V | 3 | 2.7 |
| TCTPV.4L2.B1 | V | 2 | 2.7 |
| TCTPV.4R8.B2 | V | 8 | 2.7 |
| TCTPV.4[L/R]1.B[1/2] | V | 1 | 2.7 |
| TCTPV.4[L/R]5.B[1/2] | V | 5 | 2.7 |
| TCLA.C6[L/R]7.B[1/2] | V | 7 | 2.7 |
| TCP.D[L/R].B[1/2] | V | 7 | 3.0 |
| TCP.6[L/R]3.B[1/2] | H | 3 | 5.3 |
| All TCSGs | H | 3 | 6.3 |
| All TCLAs | H | 3 | 9.0 |
| TCP.C6[L/R]7.B[1/2] | H | 7 | 4.0 |
| TCSG.B4[L/R]7.B[1/2] | H | 7 | 5.0 |
| TCSG.6[L/R]7.B[1/2] | H | 7 | 5.0 |
| TCLA.B6[R/L]7.B[1/2] | H | 7 | 8.0 |
| TCLA.A7[R/L]7.B[1/2] | H | 7 | 8.0 |
| Roman Pots | V | 1/5 | 3.0 |

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| TCTPV.4R8.B2 | V | 8 | 2.7 |
| TCTPV.4[L/R]1.B[1/2] | V | 1 | 2.7 |
| TCTPV.4[L/R]5.B[1/2] | V | 5 | 2.7 |
| TCLA.C6[L/R]7.B[1/2] | V | 7 | 2.7 |
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| TCSG.6[L/R]7.B[1/2] | H | 7 | 5.0 |
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| TCLA.A7[R/L]7.B[1/2] | H | 7 | 8.0 |
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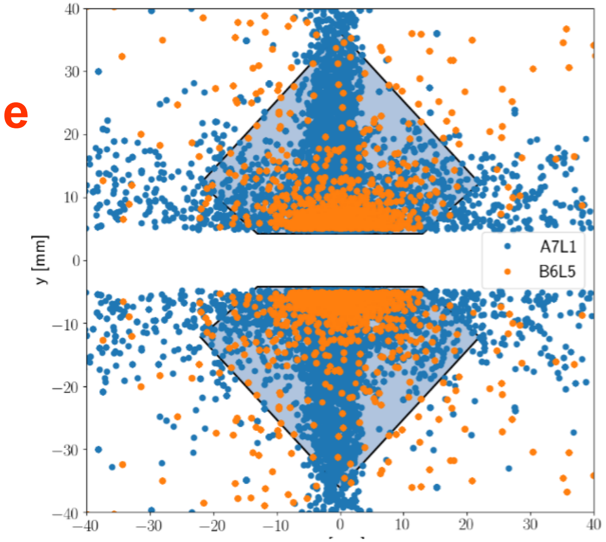
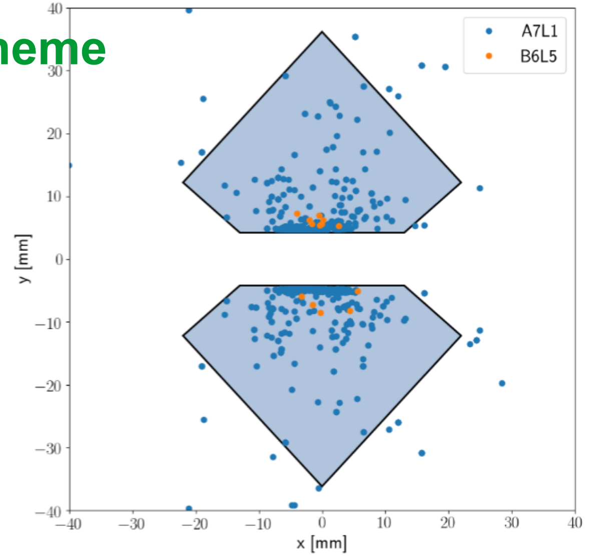
Old scheme




New scheme




Clear reduction at RP location

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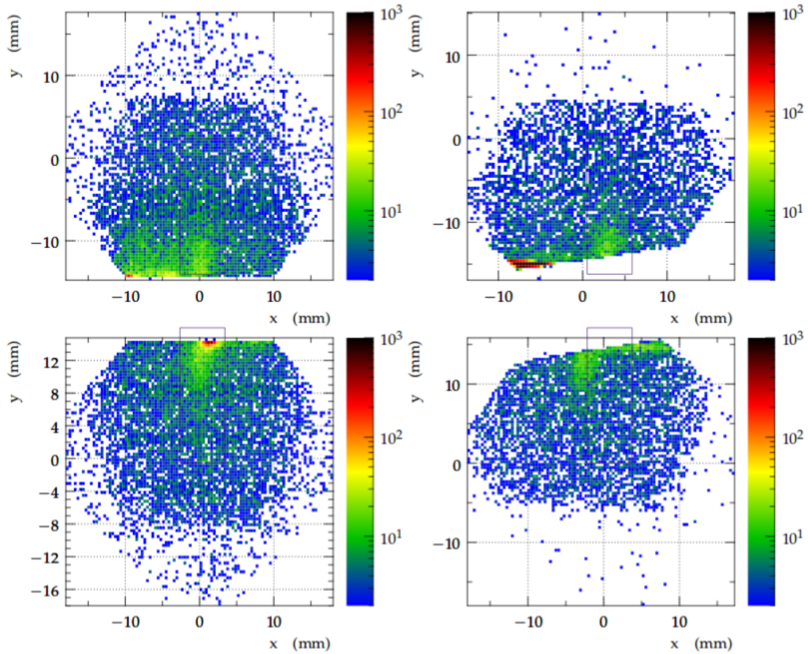
# Collimation system for Special Physics run

- This scheme was recently tested during the Special Physics run
- 
- Real success : showed a reduction in beam induced background similar to the one predicted by simulations.
- Experiments recorded more than 1M events under very clean conditions.
- Crystal collimation was used for the very first time in an actual Physics run (only MD so far).



Hit maps acquired by **TOTEM** during the test. One can clearly distinguish the central hot spot due to the elastic events.

**Important physics results very soon!**

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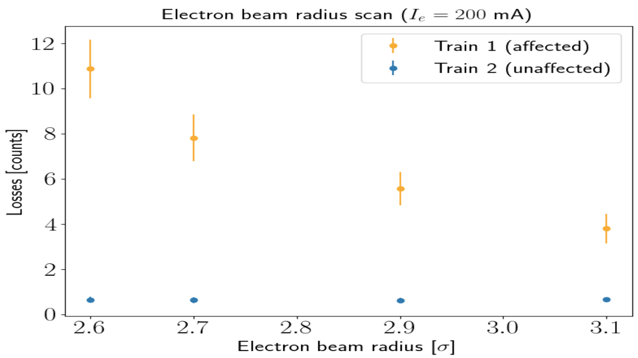
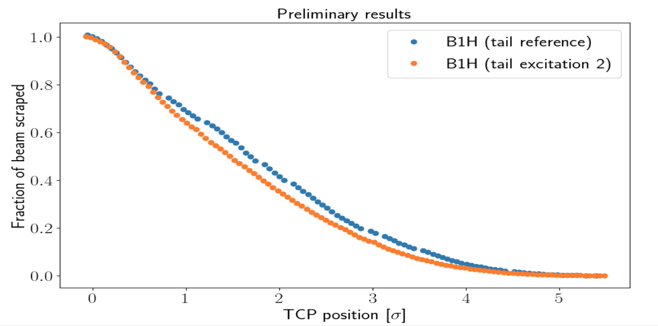
# Active halo control

- **RHIC e-lens test**
  - Electron lens is foreseen to be installed in HL-LHC for increasing the diffusion speed of particles in the tails.
  - To control tail population
  - First successful tests were carried out at Tevatron. Similar tests where carried out at RHIC in May08.
  - H.Garcia-Morales spent 10 days at RHIC doing tests. **More details in Hector's talk on Wednesday.**
  - **https://indico.cern.ch/event/742082/contributions/3085142/**




Bunch by bunch losses in RHIC as a function of the electron beam radius for Gold ions at 13.5 GeV

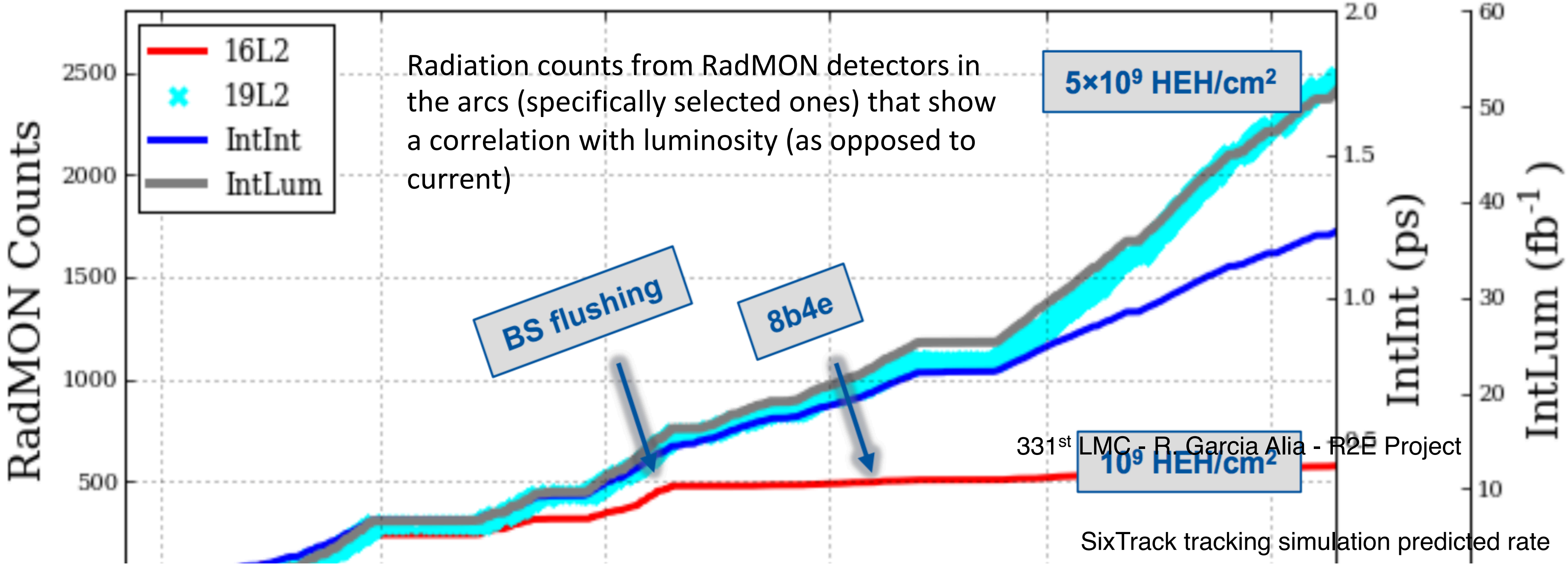
- **Colored noise**
  - We can actively control the halo particles by using narrowband or colored noise excitation using the transverse damper (ADT).
  - Relying on the detuning with amplitude, tail particles have different tunes that particles of the core.
  - Precisely selecting the excitation frequency we can, in principle, excite particles in the tails while leaving the core unperturbed.
  - This technique was tested in two different MDs. The analysis of the data is still ongoing.




**More details: CERN-ACC-NOTE-2018-0020 and a second note in preparation**

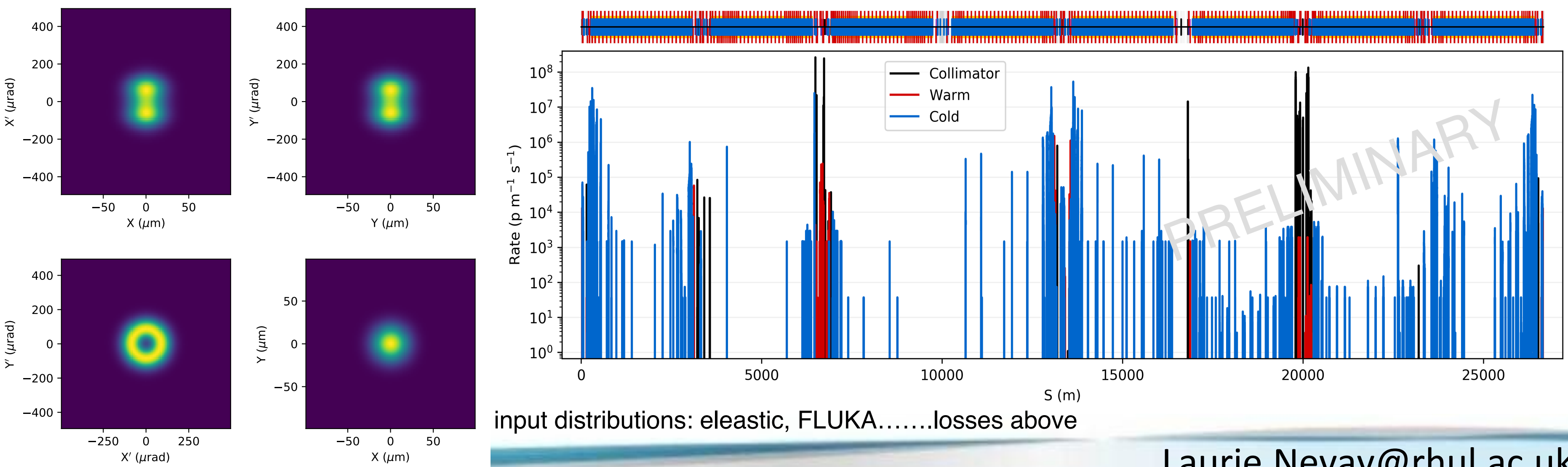
# Luminosity drive arc doses

*2017 RadMON levels*




331st LMC - R. Garcia Alia - R2E Project

SixTrack tracking simulation predicted rate




input distributions: eleastic, FLUKA…….losses above

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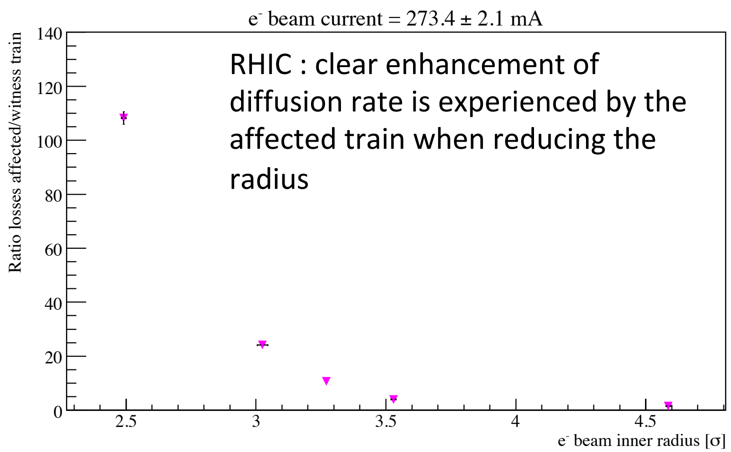
# Novel collimation schemes

- **Hollow electron lens studies for HL-LHC**
  - ✓ Preparation of **technical specifications**, covering the relevant **beam dynamics** aspects
  - ✓ Participation and analysis of **experimental tests at RHIC** (invited talk at HB2018)

Proceedings of HB2018, Daejeon, Korea - Pre-Release Snapshot 06-Jul-2018 09:00 (UTC+2)

**HOLLOW ELECTRON-LENS ASSISTED COLLIMATION AND PLANS FOR THE LHC**

D. Mirarchi*[1], H. Garcia Morales[2], A. Mereghetti, S. Redaelli, J. Wagner[3]
CERN, Geneve, Switzerland
W. Fischer, X. Gu, BNL, Upton, USA
G. Stancari, Fermilab, IL,Batavia, USA
[1]also at The University of Manchester, Manchester, UK
[2]also at Royal Holloway, Egham, UK
[3]also at Johann Wolfgang Goethe-Universitat, Frankfurt, Germany




- **Investigation for a possible insertion of crystal collimation in the HL-LHC baseline**
  - ✓ **Simulation**, **experimental test** at the LHC and **operational aspect** in view on HL-LHC
  - ✓ Setup of the **first operational use** of crystal collimation during **High Beta physics** run!
  - ✓ **See special crystal workshop Friday this week**

# Adaptive collimation system (task 2)

**Aim:** Various beam impact and loss scenarios can induce significant temperature gradients that cause deformation in collimator jaws. This can lead to a reduction in beam cleaning efficiency, which can have a detrimental effect on beam dynamics. This has led to the development of a new Adaptive Collimation System (ACS). The ACS is a re-design of a current collimator already in use at CERN, for use in the HL-LHC. The ACS will incorporate a novel fibre-optic-based measurement system and piezoceramic actuators mounted within the body of the collimator to maintain jaw straightness below the 100µm specification. These two systems working in tandem can monitor, and correct for, the jaw structural deformation for all impact events.

**Objectives:**

1. Quantify extents of jaw deformation under different scenarios, including vibrational frequency and amplitude.
2. Integrate robust active measurement system and dynamic actuation system into existing secondary collimator design, ensuring new systems can withstand harsh LHC environment.
3. Manufacture full size prototype ACS collimator for primary validation at UoH and future trials at CERN.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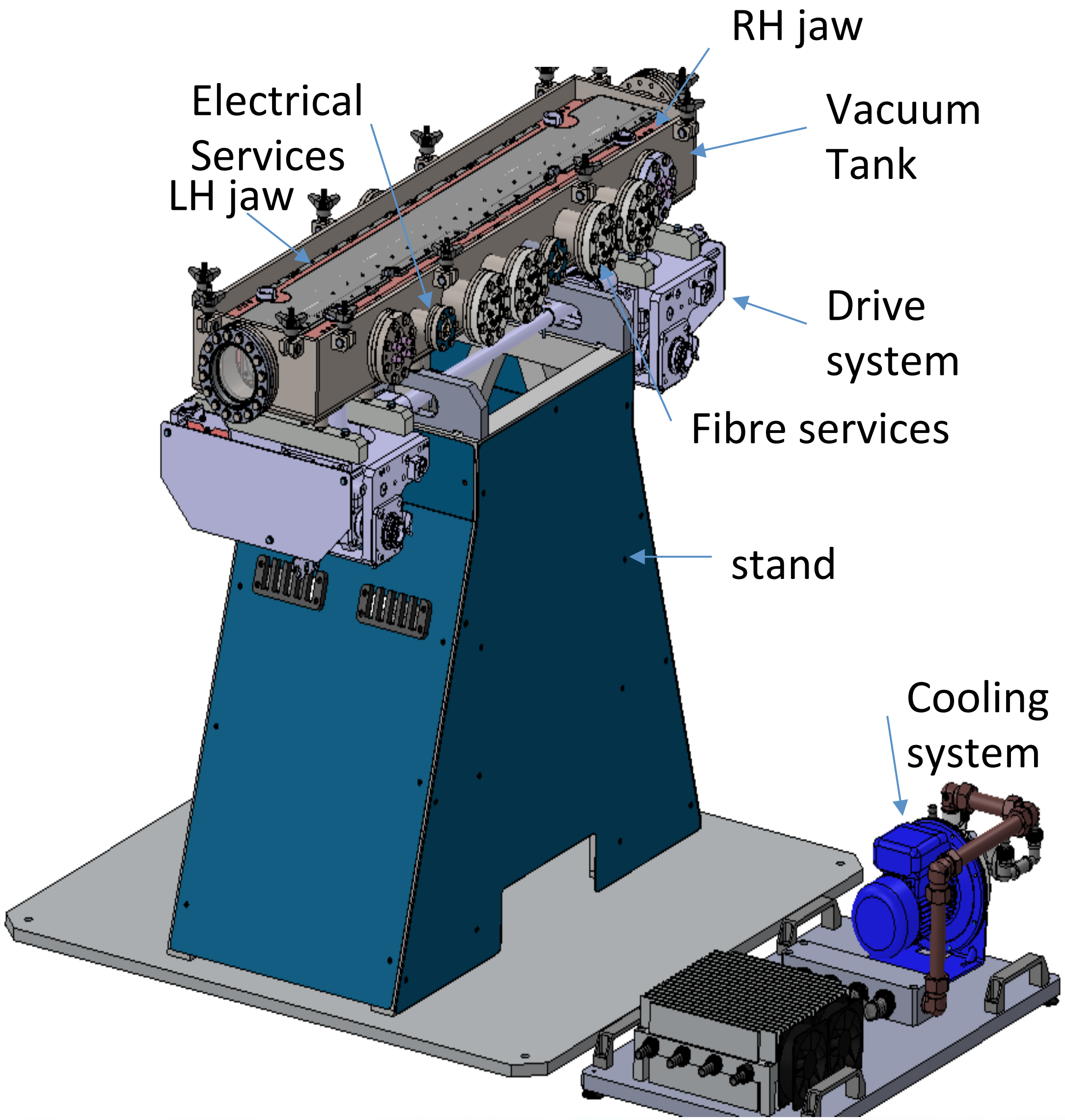
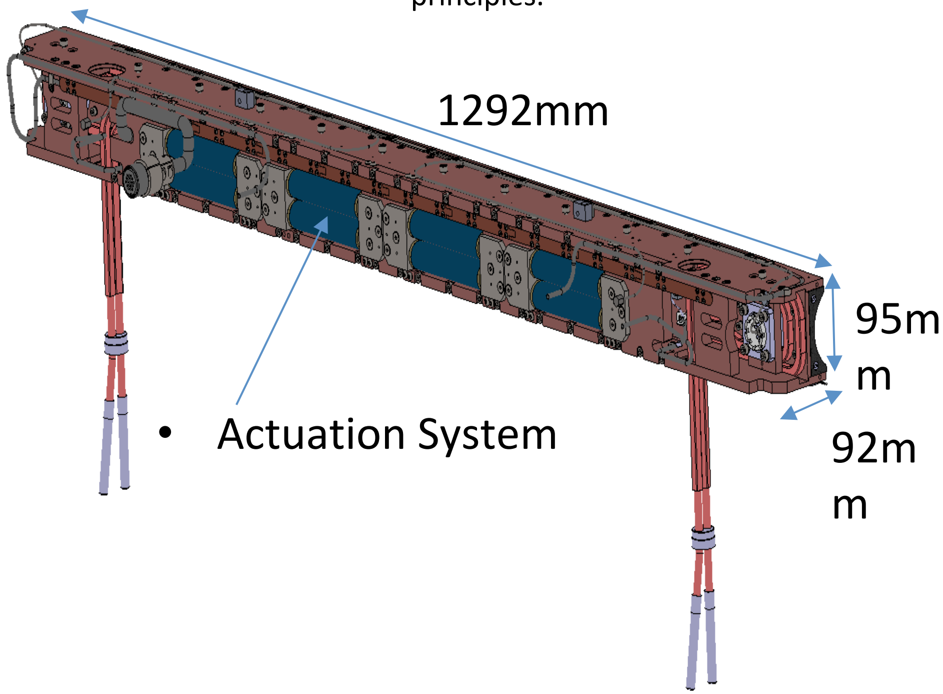
# Adaptive collimation system (task 2)

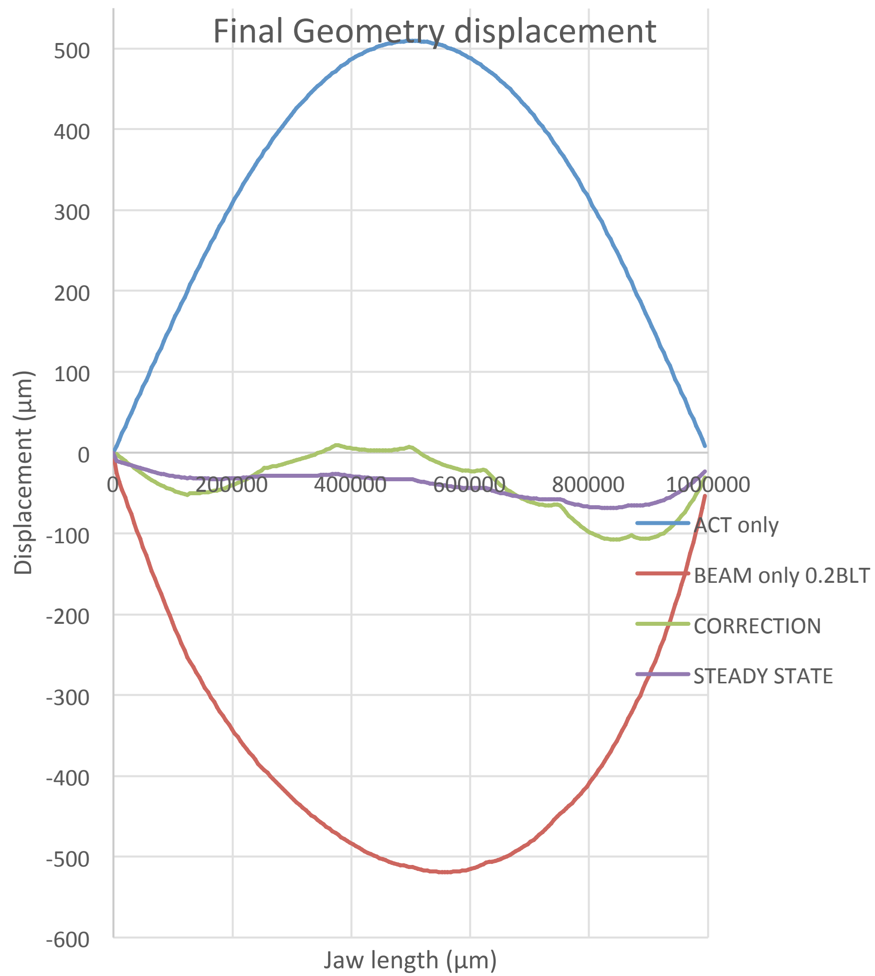
- Prototype Design (D1.11 Oct 2018)
  - Status – Design complete
- Prototype Manufacture (M1.14 Mar 2019 – On-track)
  - Tank- All parts in Production
  - Drive system – All parts in production
  - Stand – Completed
  - Jaws – Drawings Produced
  - Cooling system – Drawings Produced
- Key out-sourcing
  - Vacuum system – received
  - Cooling System – received
  - Jaw Blocks Ordered
  - Glidcop Blanks – TBO
  - Actuation system – In technical review at Pi Ceramic GmbH
  - Front Stiffener and Cooling Pipes – CERN TBC



# Jaw Design, prototype ,Validation, Simulation

Jaw scale model: to validate control and fibre optic measurement systems, as well as prove actuation design principles.



# Outreach

'The Big Bang Experience' lecture at the Royal Holloway Science Festival 2018.

Repeated at this year's 'Girls into Physics ' residential for GCSE and A-level students.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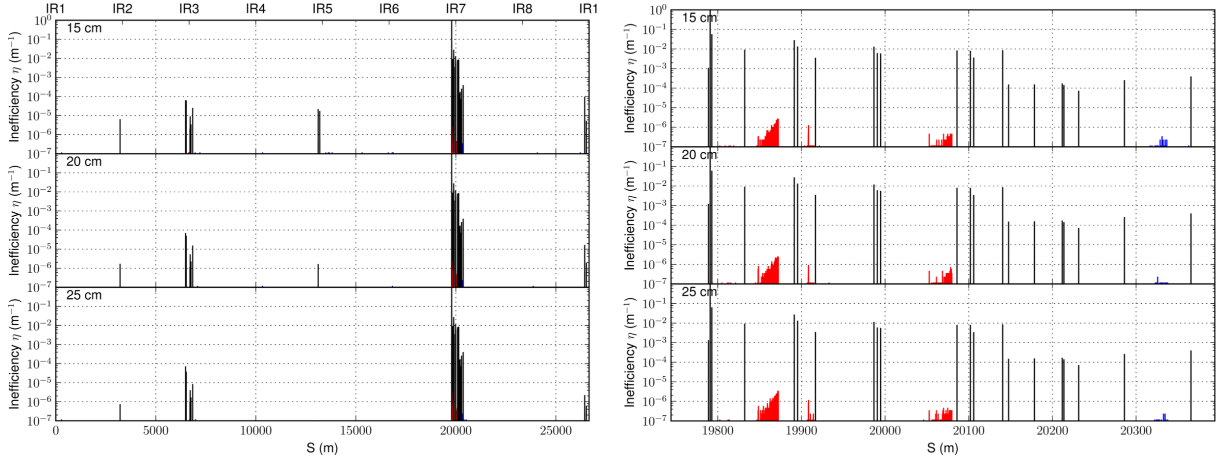
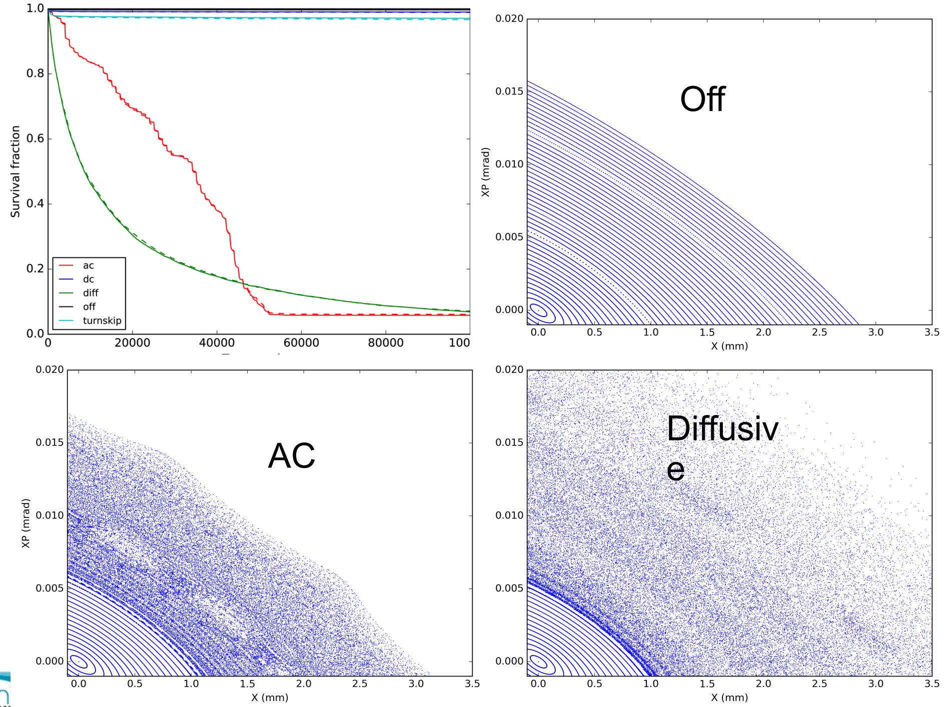
# Studies for HL-LHC

- Merlin used to calculate loss maps for future LHC configurations
- Novel collimation options
  - Hollow Electron lens
  - Active halo cleaning




HiLumi IP1/5 β*=15,20,25cm (2 TCLDs)

**Hollow electron lens**

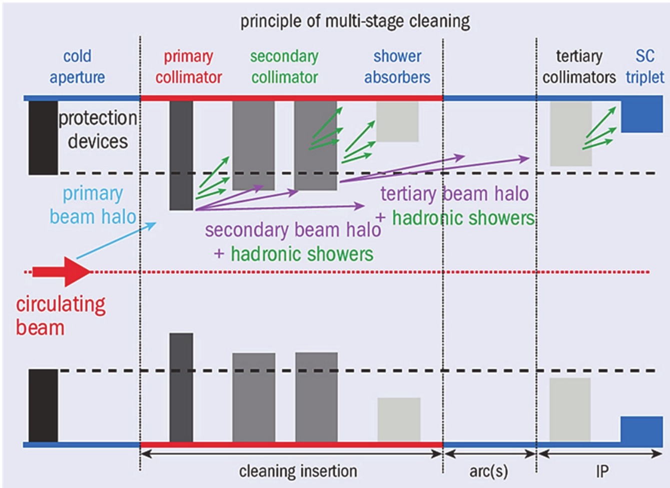


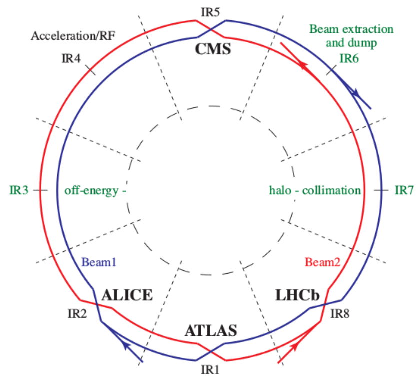

**Next steps**

- Active halo control with transverse damps
- ATS optics
- Non-linear multipoles

# WP1: Collimation simulations

- LHC stored energy of 362 MJ per beam (675 MJ for HL-LHC)
- Multi-stage collimation system needed
- Particles scattered by collimators can travel many km along beam pipe
- Carbon primary collimators in IR7 sit closest to the beam
- Secondary collimators (carbon) and absorbers (tungsten) intercept the scattered particles
- Tertiary collimators (tungsten) protect the detectors and the inner triplets



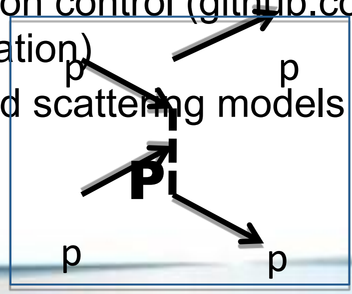

## Simulations

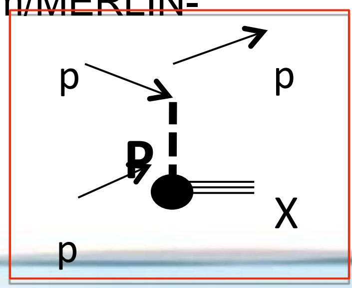
Want study

- Loss distributions around ring
- Performance of collimator configurations
- Effects of optics changes, collimator materials and novel collimation schemes

## Merlin++

- Accelerator simulation library
- Modular and extensible C++: easy to add new physics, tracking, element types
- 40,000 Lines of code (+4000 of examples, +3000 tests)
- Git revision control (github.com/MERLIN-Collaboration)
- Advanced scattering models

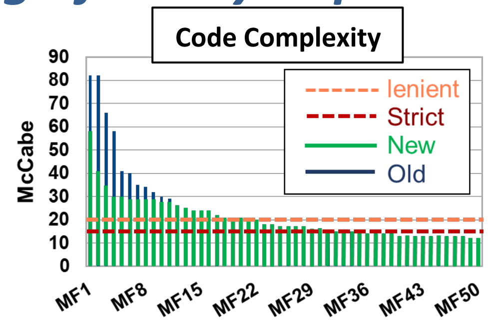


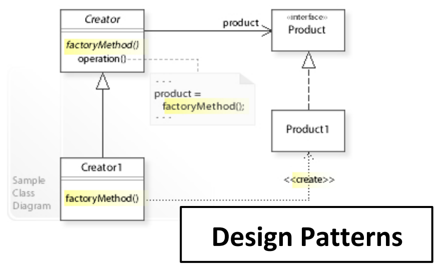



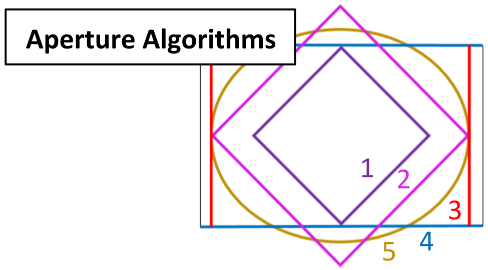
# Merlin++

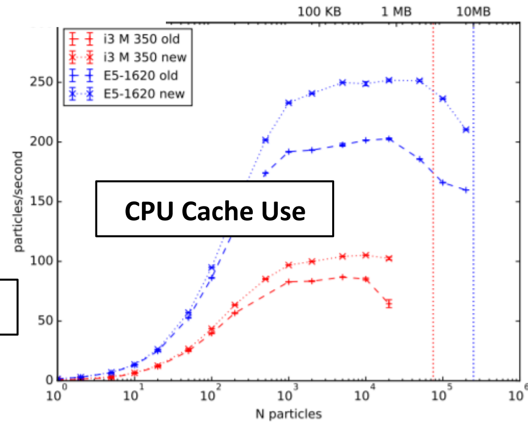
## *Code base thoroughly profiled/significantly improved upon*

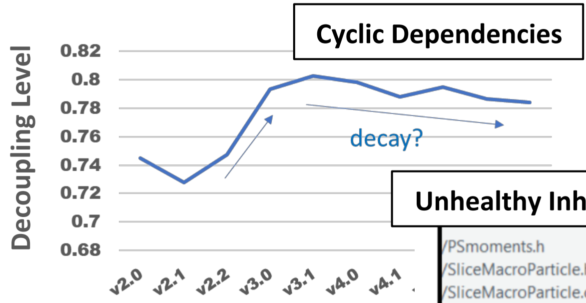
- **Static Analysis**
  - → *Cyclomatic Complexity*
  - → *Logical Source Lines Of Code*
  - → *Efferent Coupling*
- **Dynamic Analysis**
  - → *Runtime Bottlenecks*
  - → *Memory Leaks*
  - → *Speculation Misses*
- **Architectural Debt**
  - → *Design Structure Matrix*
  - → *Decoupling Level*
  - → *Propagation Cost*
  - → *Unhealthy Inheritance*

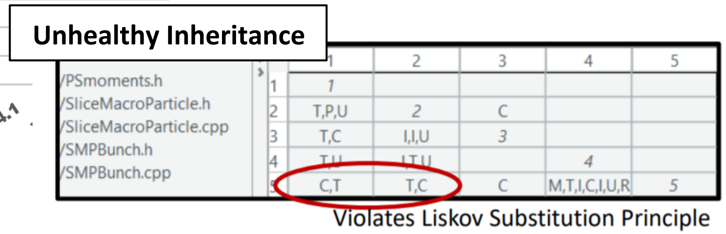


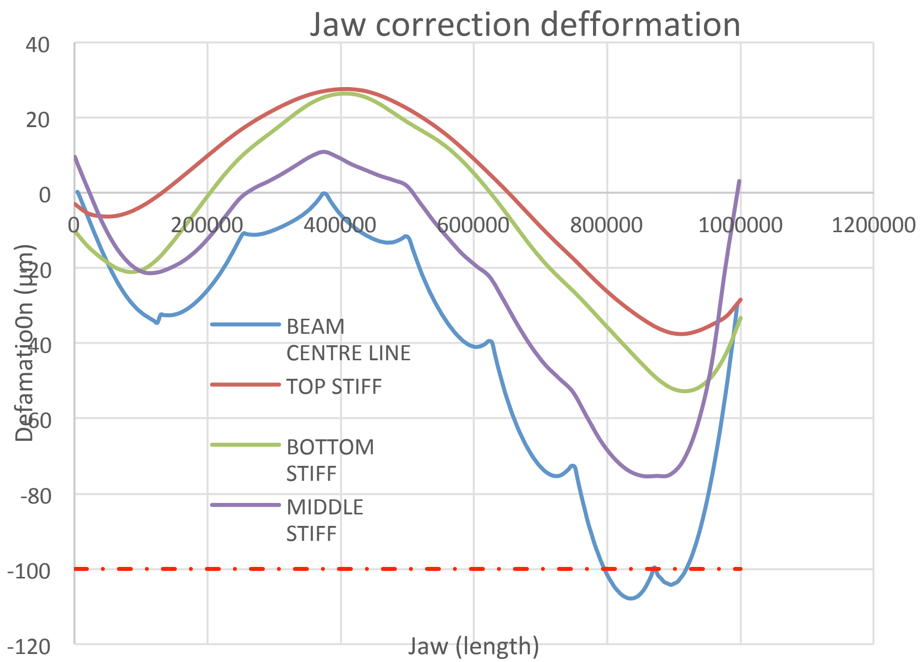



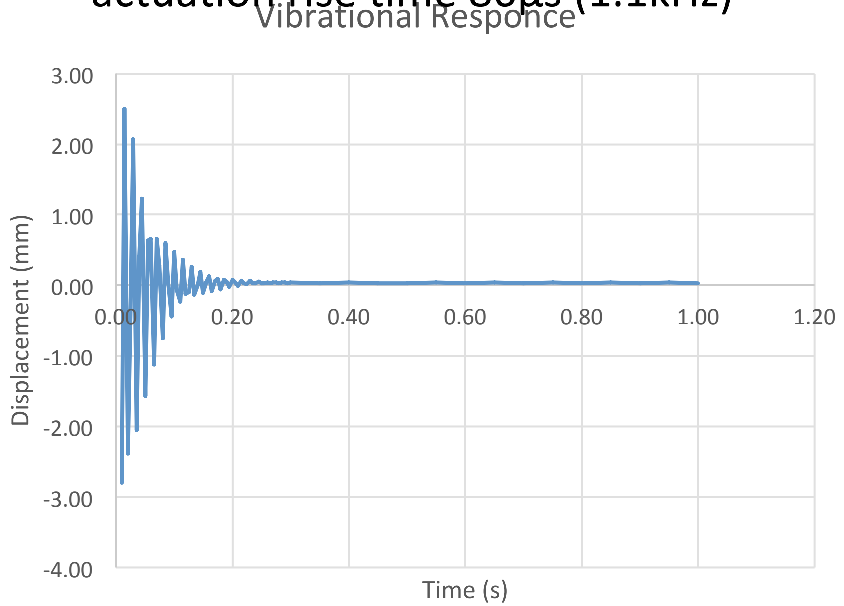



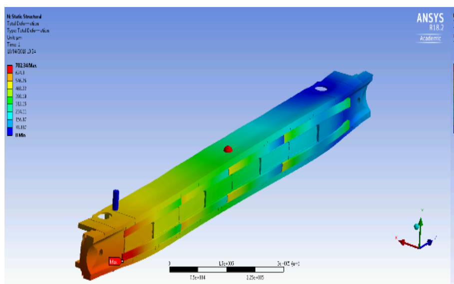



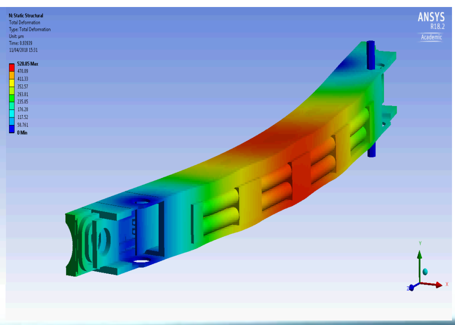
# Jaw design and validation system

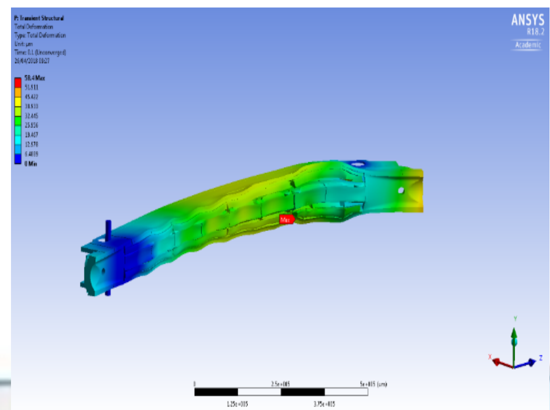
Induced vibrational response around 150Hz, measurement system captures at 1kHz, and actuation rise time 86µs (1.1kHz)



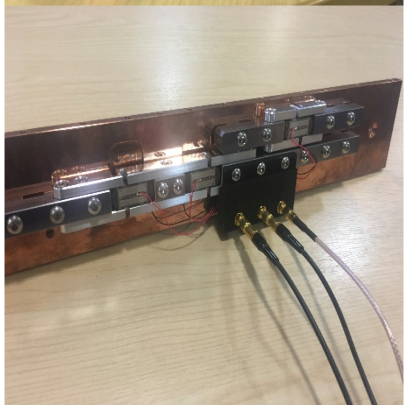



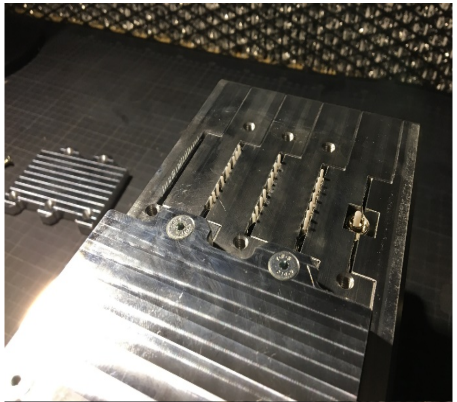



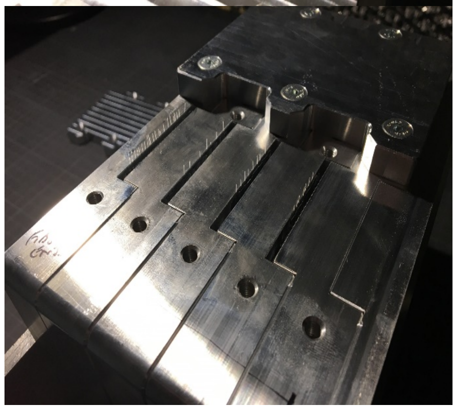



# Jaw design and validation system

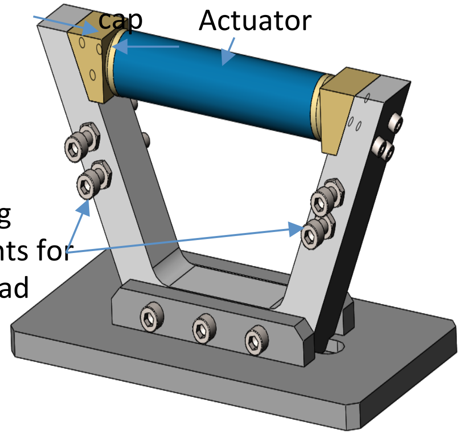


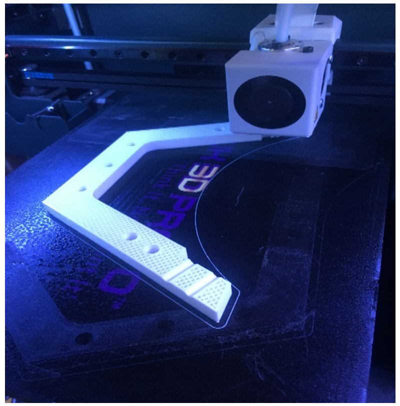
Jaw scale model: to validate control and fibre optic measurement systems, as well as prove actuation design principles





Fibre coatings: to increase amount of reflected light in the system to increase sensitivity



Surface coating: to ensure actuation contact regions do not wear and produce debris, several coatings are going to be trailed to ensure reduction in

# HL-LHC-UK WP1 : Collimation

***Task 1: Simulation and novel concepts:***

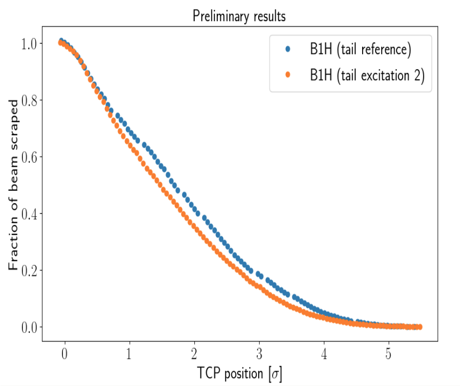
*University of Manchester/CI/RHUL/Hudd/CERN*

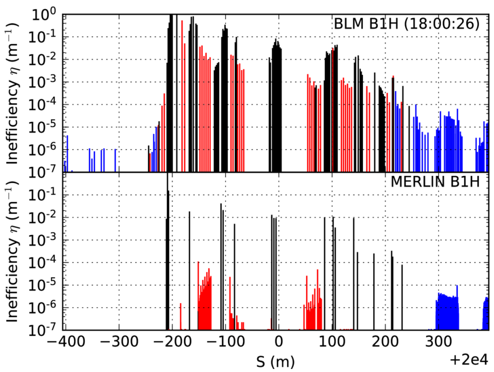
- ***Aim:*** **Explore collimation performance, develop new tools and create novel collimation schemes.**

**-> Design of two-stage collimation schemes, active halo control, tested experimentally.**

**-> Analysis of run 2 loss maps and verification of HL-LHC collimation scheme performance**

**-> New code development : MERLIN (and BDSIM)**



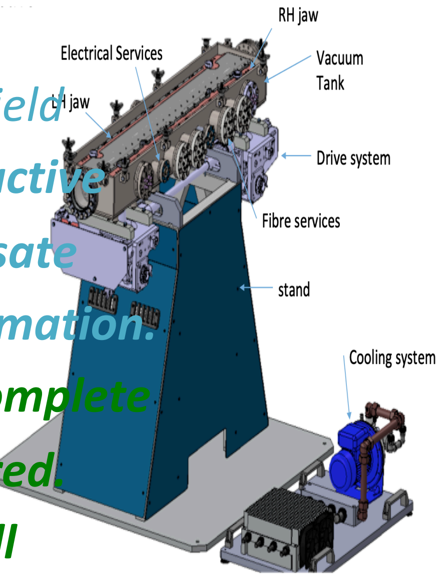




***Task 2) Adaptive collimation system (ACS)***

*University of Huddersfield*

- ***Aim: Develop a reactive Collimator to compensate For thermal jaw deformation.***

***-> Prototype design complete and being manufactured. Design validated in full Simulation suite.***




***HL-LHC-UK phase 2***

***Manchester and RHUL will perform beam related measurements in run 3, tied to an operation-focus simulation programme, and develop the novel collimation layouts and hardware.***