Particle physics colliders and beamlines

Stephen Gibson

JAI Advisory Board

7th April 2022

Overview

- ***EU strategy, technology pillars & EU Accelerator Roadmap***
- ***High-Luminosity LHC - UK phase II***
  - ***Machine protection: crystal collimation*** *and* ***triplet stabilisation***.
  - ***Diagnostics****:* ***Electro-Optical & IR BPMs****, BGV, SR monitor.*
- ***Linear Colliders: ILC & CLIC***
  - *Leading contributions to the international development team & diagnostics*
- ***Future Circular Collider:***
  - *IR optics, dynamic aperture, ion collimation & FCC Innovation Study*
- ***Physics Beyond Colliders:***
  - ***Fixed target beamlines for NA61/SHINE & NA62/ Klever***
  - ***Use of LHC accelerator model for FASER & FPF***
- ***Muon Collider*** *& nuSTORM*

Key technologies for future accelerators

- ***Five technologies pillars were identified in the 2020 EU strategy and by CERN Council / SPC / LDG.***

High-priority future initiatives

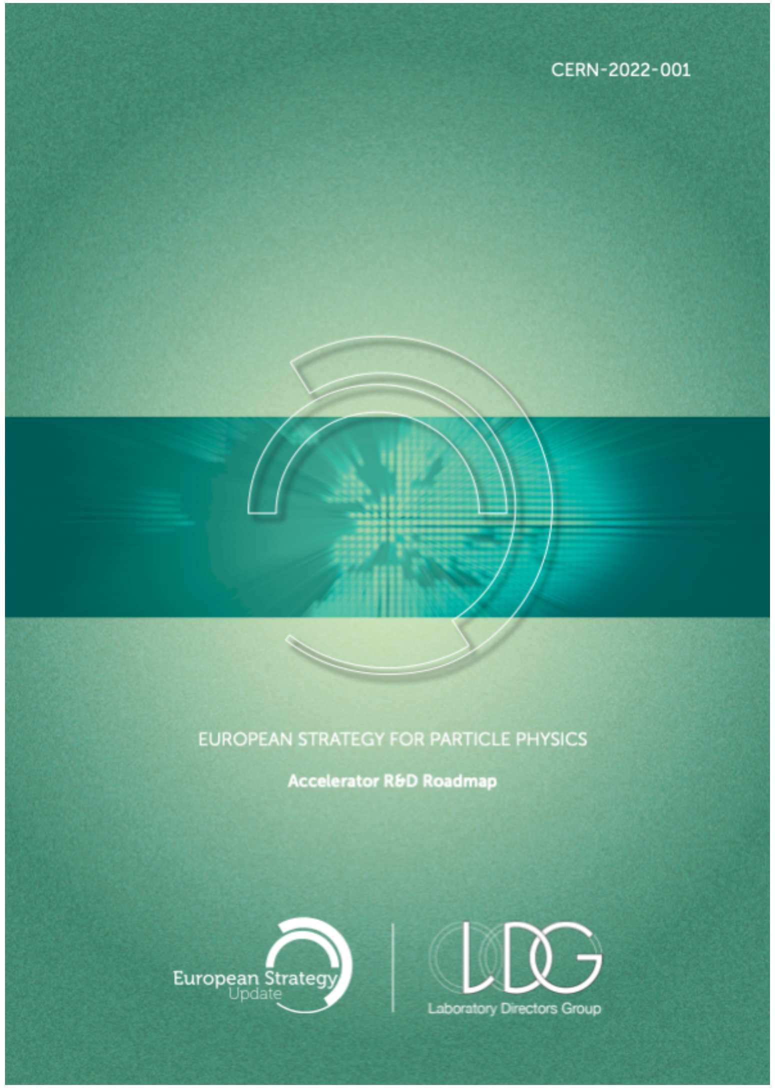
B. Innovative accelerator technology underpins the physics reach of high-energy and high-intensity colliders. It is also a powerful driver for many accelerator-based fields of science and industry. The technologies under consideration include high-field magnets, high-temperature superconductors, plasma wakefield acceleration and other high-gradient accelerating structures, bright muon beams, energy recovery linacs. ***The European particle physics community must intensify accelerator R&D and sustain it with adequate resources. A roadmap should prioritise the technology, taking into account synergies with international partners and other communities such as photon and neutron sources, fusion energy and industry. Deliverables for this decade should be defined in a timely fashion and coordinated among CERN and national laboratories and institutes.***

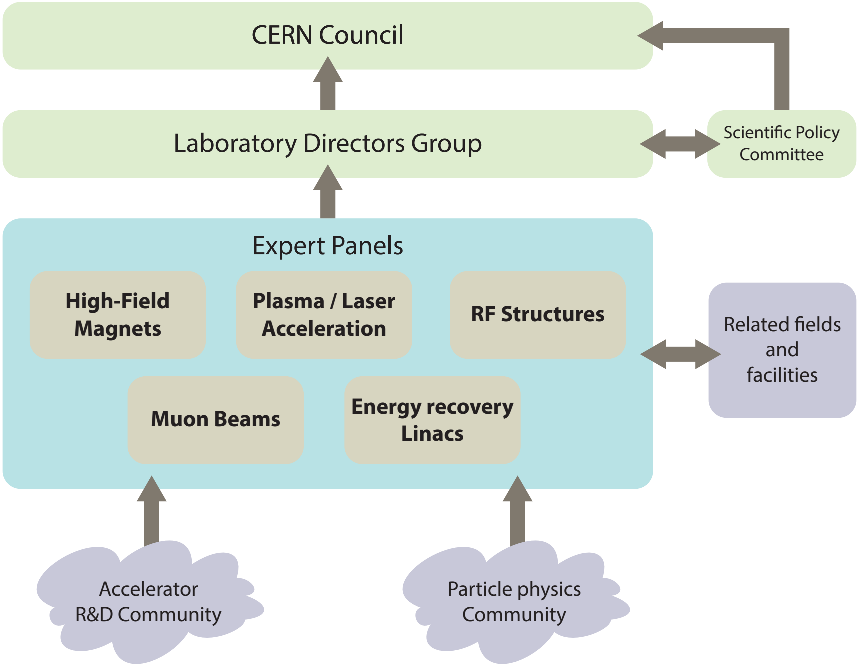
- *9th July 2021:* ***Symposium on the Accelerator R&D Roadmap for the HEP community***
  - https://indico.cern.ch/event/1053889/

- ***High-field magnets***
- ***High-gradient plasma / laser acceleration***
- ***High-gradient RF structures***
- ***Muon beams***
- ***Energy-recovery linacs***

Accelerator R&D Roadmap, published January 2022

arXiv:2201.07895 CERN-2022-001





- ***UK contributing to all five technology pillars, with JAI efforts focused on:***
  - ***High gradient plasma & laser accelerators*** → *see Zulfikar's talk*
  - ***Bright muon beams & muon colliders*** → *see later slides*

European Strategy for Particle Physics - Accelerator R&D Roadmap

Editor: N. Mounet[a]

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Introduction and Conclusion

Author: D. Newbold[h,*]

High-field magnets

Panel members: P. Védrine[b,†] (Chair), L. García-Tabarés[k] (Co-Chair), B. Auchmann[g], A. Ballarino[a], B. Baudouy[b], L. Bottura[a], P. Fazilleau[b], M. Noe[o], S. Prestemon[p], E. Rochepault[b], L. Rossi[q], C. Senatore[r], B. Shepherd[s]

High-gradient RF structures and systems

Panel members: S. Bousson[c,‡] (Chair), H. Weise[e] (Co-Chair), G. Burt[d], G. Devanz[b], A. Gallo[f], F. Gerigk[a], A. Grudiev[a], D. Longuevergne[c], T. Proslier[b], R. Ruber[t]

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High-gradient plasma and laser accelerators

Panel members: R. Assmann[e,f,+] (Chair), E. Gschwendtner[a] (Co-Chair), K. Cassou[c], S. Corde[z], L. Corner[i], B. Cros[aa], M. Ferrario[f], S. Hooker[bb], R. Ischebeck[g], A. Latina[a], O. Lundh[cc], P. Muggli[dd], P. Nghiem[b], J. Osterhoff[e], T. Raubenheimer[w,ee], A. Specka[ff], J. Vieira[gg], M. Wing[hh]

Associated members: C. Geddes[p], M. Hogan[w], W. Lu[v], P. Musumeci[ii]

Bright muon beams and muon colliders

Panel members: D. Schulte[a,△] (Chair), M. Palmer[jj] (Co-Chair), T. Arndt[o], A. Chancé[b], J.-P. Delahaye[a], A. Faus-Golfe[c], S. Gilardoni[a], P. Lebrun[a], K. Long[h,kk], E. Métral[a], N. Pastrone[ll], L. Quettier[b], T. Raubenheimer[w,ee], C. Rogers[h], M. Seidel[g,mm], D. Stratakis[nn], A. Yamamoto[y]

Associated members: A. Grudiev[a], R. Losito[a], D. Lucchesi[oo,pp]

Energy-recovery linacs

Panel members: M. Klein[i,▽] (Chair), A. Hutton[x] (Co-Chair), D. Angal-Kalinin[qq], K. Aulenbacher[rr], A. Bogacz[x], G. Hoffstaetter[ss,jj], E. Jensen[a], W. Kaabi[c], D. Kayran[jj], J. Knobloch[tt,uu], B. Kuske[uu], F. Marhauser[x], N. Pietralla[vv], O. Tanaka[y], C. Vaccarezza[f], N. Vinokurov[ww], P. Williams[qq], F. Zimmermann[a]

Associated members: M. Arnold[vv], M. Bruker[x], G. Burt[d], P. Evtushenko[xx], J. Kühn[uu], B. Militsyn[qq], A. Neumann[uu], B. Rimmer[x]

Sub-Panel on CERC and ERLC: A. Hutton[x] (Chair), C. Adolphsen[w], O. Brüning[a], R. Brinkmann[e], M. Klein[i], S. Nagaitsev[nn], P. Williams[qq], A. Yamamoto[y], K. Yokoya[y], F. Zimmermann[a]

The FCC-ee R&D programme

Authors: M. Benedikt[a,◁], A. Blondel[yy,r,▷], O. Brunner[a], P. Janot[a], E. Jensen[a], M. Koratzinos[zz], R. Losito[a], K. Oide[y], T. Raubenheimer[w,ee], F. Zimmermann[a,**]

ILC-specific R&D programme

Authors: S. Michizono[y,††], T. Nakada[mm], S. Stapnes[a]

CLIC-specific R&D programme

Authors: P. N. Burrows[bb], A. Faus-Golfe[c,‡‡], D. Schulte[a], S. Stapnes[a]

Sustainability considerations

Authors: T. Roser[jj,++], M. Seidel[g,mm,△△]

UK authors
CI/Daresbury
JAI/RAL

Future colliders: how to beat the synchrotron limit?

Synchrotron energy loss per turn

$$\Delta E_s = \frac{e^2}{3\epsilon_0} \times \frac{E^4}{(mc^2)^4} \times \frac{1}{R}$$

Increase m, same R:
reuse LEP tunnel with
protons -> **LHC,**

and in near future:

HiLumi
HL-LHC PROJECT

switch to higher lepton mass

International
MUON Collider
Collaboration

Challenge is to
produce and
capture intense
beams of short-
lived muons

set R to infinity

ilc

clic

Linear colliders require **high gradient acceleration:**
SCRF structures,
drive beams or
advanced accelerator
concepts (plasma wakefield)

+ energy recovery linacs

increase R
(and B)

Circular colliders, e.g.

FCC
hh ee he

FCChh in 100 km tunnel
requires **high-field magnets**

HL-LHC-UK phase I

1 Major developments

HiLumi HL-LHC PROJECT

with the innovative experimental techniques developed at the LHC experiments and their planned detector upgrades, a significantly enhanced physics potential is expected with the HL-LHC. The required high-field superconducting Nb_3Sn magnets have been developed. ***The successful completion of the high-luminosity upgrade of the machine and detectors should remain the focal point of European particle physics, together with continued innovation in experimental techniques. The full physics potential of the LHC and the HL-LHC, including the study of flavour physics and the quark-gluon plasma, should be exploited.***

UK institutes on ***HL-LHC-UK***

£8M CERN-STFC investment in UK

The University of Manchester

The Cockcroft Institute of Accelerator Science and Technology

Lancaster University

University of Liverpool

Royal Holloway University of London

JAI John Adams Institute for Accelerator Science

University of Huddersfield

2019: JAI AB wholeheartedly supports and strongly encourages the continuation of these efforts and recommends to form strategically organized participation by expert members of JAI in addition to those from RHUL, in particular at Oxford."

WP1 Collimation
WP2 Crab cavities
WP3 Beam Diagnostics
WP4 Cold Powering

HL-LHC-UK phase II announced by STFC

HiLumi HL-LHC PROJECT

https://stfc.ukri.org/news/project-to-upgrade-the-large-hadron-collider-now-underway/

Upgrade to Large Hadron Collider underway

ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITY OF OXFORD

11 September 2020

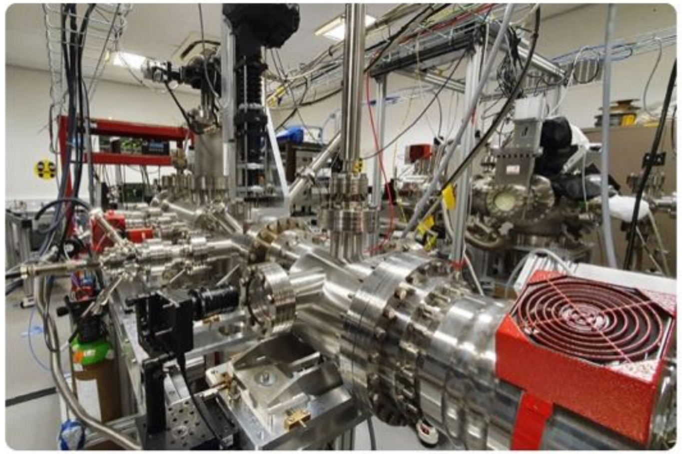
Scientists, engineers and technicians from the UK have embarked on a £26 million project to help upgrade the Large Hadron Collider (LHC) at CERN, on the French/Swiss border near Geneva.

The collaboration is between the Science and Technology Facilities Council (STFC), CERN, the Cockcroft Institute, the John Adams Institute, and eight UK universities. STFC is contributing £13.05 million.

Science Minister Amanda Solloway said:

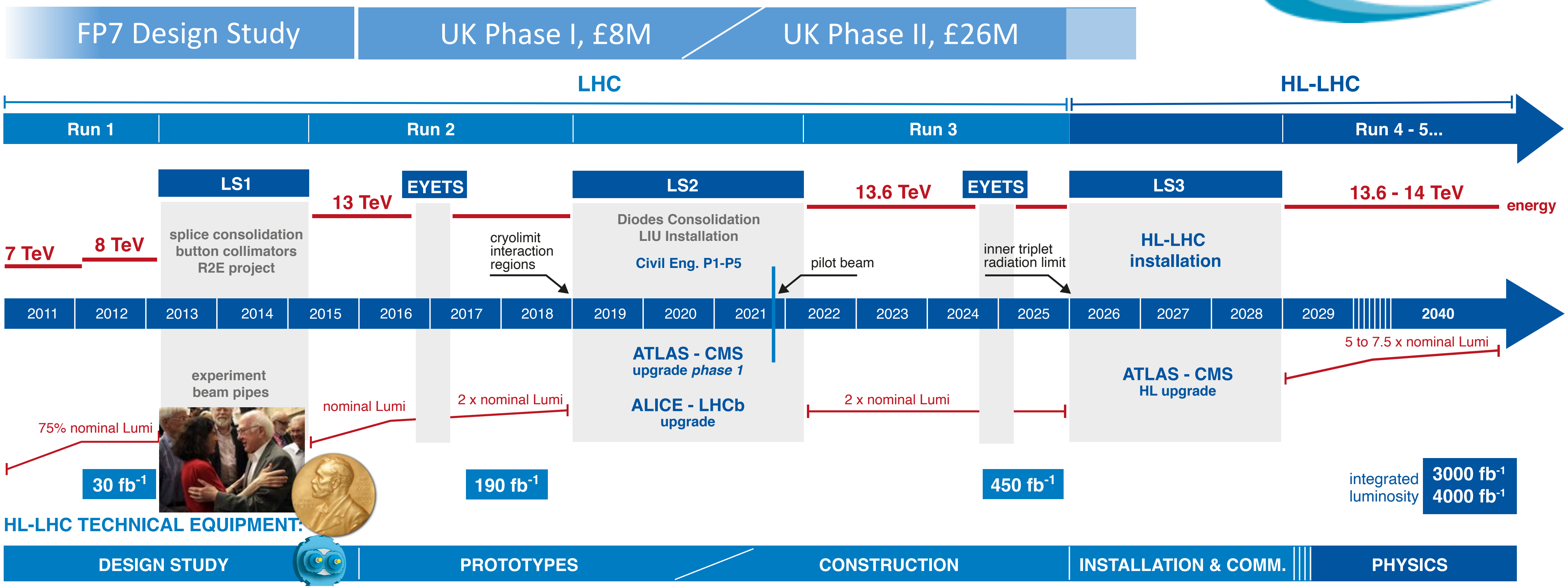
"Ever since it first switched on in 2008, CERN's Large Hadron Collider has been working to answer some of the most fundamental questions of the universe.

"I am delighted that the UK's science and research industry will play a central role in upgrading what is the world's largest and highest energy particle collider, enabling leading physicists to continue making monumental discoveries."



Gas jet beam profile monitor setup at the Cockcroft Institute.

The path to High Luminosity LHC



2021: The AB is deeply impressed by the work presented on future colliders at this meeting, in particular, but not limited to, HL-LHC. The AB wholeheartedly supports and strongly encourages the continuation of these efforts.

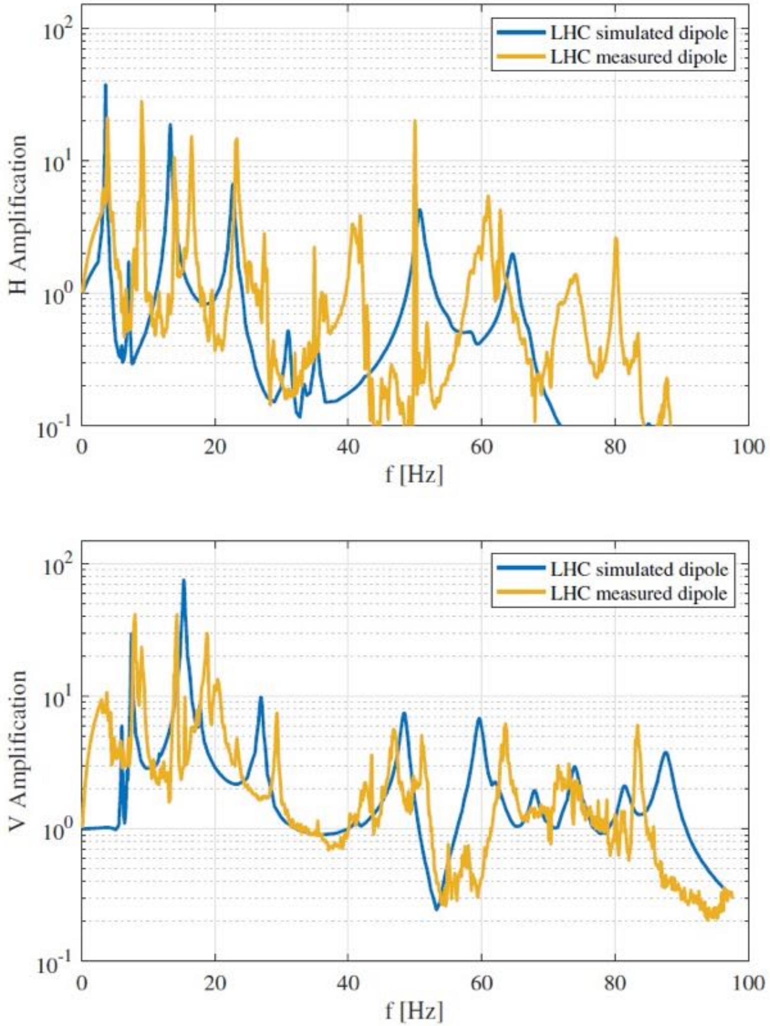
Machine protection at HL-LHC: triplet stability & novel collimation

HL-LHC Ground Motion studies

H. Garcia-Morales et al

UNIVERSITY OF OXFORD

- *To evaluate the impact of the Ground Motion in the HL-LHC quadrupole triplet, measurements of the LHC dipole Transfer Function (TF) were carried out.*
- *Due to mechanical designs, the LHC dipole TF and the HL-LHC quadrupole triplet TF are expected to be similar*
- *From measurements we extracted that:*
  - Simulations of the transfer function seem to be accurate enough.
  - The impact of Ground Motion on the HL-LHC beam stability is expected to be relatively small.
- *According to these results, a new active beam feedback system is not required.*
- *However, once the HL-LHC quadrupole triplets are available and installed in the IT string, new measurements are required to fully confirm the results.*
- Paper submitted to PRAB:
  M. Schaumann, H. Garcia-Morales et al. "The Effect of Ground Motion on the LHC and HL-LHC Beam Orbit"



Dipole Transfer Function Measurement and comparison with the simulations in the horizontal (top) and vertical planes (bottom).

Collimation & optics studies

H. Garcia-Morales et al

UNIVERSITY OF OXFORD

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Focus this year has been on publications:

Nuclear Inst. and Methods in Physics Research, A 1010 (2021) 165494

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

Off-momentum cleaning simulations and measurements at the Large Hadron Collider

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ABSTRACT

The Large Hadron Collider is designed to collide proton beams with unprecedented energy in order to extend the frontiers of high-energy physics. Particles that have an energy different from the nominal one follow dispersive orbits and, if the energy offset is large enough, could be lost on the cold aperture and cause quenches of superconducting magnets. Therefore, particles with large energy offsets must be removed from the beam by the collimation system. Although the dynamics of such particles is well understood and the efficiency of the momentum cleaning is evaluated in measurements, in the past, there were not general simulations tools available for predicting the efficiency of the collimation system in scenarios where off-momentum particles are involved. In this paper we present a new set of tools to simulate off-momentum losses, the benchmarking of these tools with measurements and the evaluation of off-momentum losses in the future LHC upgrade, the HL-LHC. These new simulation tools are applied for simulating two of the main scenarios where off-momentum particles play an important role in the LHC: particles lost at the start of the energy ramp and simulations of the momentum cleaning at 6.5 TeV energy. In this study, the collimation process during dynamic changes in the machine is simulated, as opposed to previous studies in static conditions. This is the first time that this sort of comparison between different simulation methods and measurements is performed. The results are used to provide a better understanding the dynamics of such particles and, finally, these tools are used to estimate the influence of off-momentum losses in the future High-Luminosity LHC.

Accepted in PRAB, 10 March 2022

https://journals.aps.org/prab/accepted/d407dMd3Iaf19e04116281f42d0396e23b6090a99

Accepted Paper

Phase advance constraint in K modulation for precise β-function determination

Phys. Rev. Accel. Beams

H. Garcia-Morales, M. Hofer, E. H. Maclean, L. van Riesen-Haupt, and R. Tomás

Accepted 10 March 2022

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ISBN: 978-3-95450-214-1 ISSN: 2673-5490 doi:10.18429/JACoW-IPAC2021-MOPAB184

UNSUPERVISED LEARNING TECHNIQUES FOR TUNE CLEANING MEASUREMENT

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Abstract

Precise measurements of tune and its stability are crucial for various optics analyses in the LHC, e.g. for the determination of the β^* using K-modulation. LHC BBQ system provides tune measurements online and stores the tune data. We apply unsupervised machine learning techniques on BBQ tune data in order to provide an automatic outlier detection method for better measurements of tune shifts and unexpected tune jitters.

point are not always easily predicted and might be due to some disturbance such as unknown machine configuration changes [3]. Therefore, cleaning the tune time series is not always straightforward, in particular when there is a change in the working point. A possible strategy would be to treat the data by cleaning the different segments associated to the different working points, but this means that we need to re-adapt our cleaning algorithm every time. Therefore, it makes the cleaning process difficult to generalize using classical tools.

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HL-LHC LOCAL LINEAR OPTICS CORRECTION AT THE INTERACTION REGIONS

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E. Fol, R. Tomás García, CERN, Geneva, Switzerland

Abstract

Magnetic imperfections of the HL-LHC inner triplet are expected to generate a significant β-beating. For that reason, improved local optics correction techniques at the low-β insertions is essential to ensure a high luminosity performance in the HL-LHC. In this study, we compare different strategies for local optics correction at the Interaction Regions with respect to their final performance in terms of residual β-beating. Supervised learning techniques are also explored to predict the inner triplet magnetic error contributions.

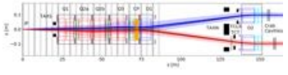

Figure 1: Sketch of the inner triplet region.

that this component can be predicted by applying supervised learning techniques to optics measurements around the ring.

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COMPARISON OF SEGMENT-BY-SEGMENT AND ACTION-PHASE-JUMP TECHNIQUES IN THE CALCULATION OF IR LOCAL CORRECTIONS IN LHC

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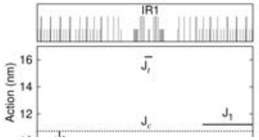
J. Cardona, Universidad Nacional de Colombia, Colombia
R. Tomás García, CERN, Geneva, Switzerland

Abstract

The correction of the local optics at the Interaction Regions of the LHC is crucial to ensure a good performance of the machine. In this paper, we compare two different techniques for local optics correction: Action-Phase Jump and Segment-by-Segment techniques. The comparison is made in view of future machine configurations such as Run 3 LHC optics and HL-LHC optics.



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RECONSTRUCTION OF LINEAR OPTICS OBSERVABLES USING SUPERVISED LEARNING

E. Fol*, H. Garcia-Morales, R. Tomás
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Abstract

In the LHC, most of the optical functions can be obtained from turn-by-turn beam centroid data. However, the measurement of such observables as β^* and the dispersion function require special dedicated techniques and additional operational time. In this work, we propose an alternative approach to estimate these observables using supervised machine learning, in case the dedicated measurements are not available but turn-by-turn data are. The performance of developed estimators is demonstrated on LHC simulations. Comparison to traditional techniques for the computation of β-function will be also provided.

advance deviations from nominal design. To implement the supervised learning approach, a data set consisting of correlated input and output variables needs to be provided. Since the relation between phase advances and the optics functions to be predicted is linear, a linear regression model, so called *Ridge Regression* [5] is applied. This choice allows faster training and ease the model parameter tuning in comparison to non-linear complex models, such as neural networks.

The Ridge regression model minimises the residual sum of squares between the true targets in the training data, and the targets predicted by the linear approximation. The tuning

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OPTICS MEASUREMENTS AND CORRECTION PLANS FOR THE HL-LHC

T. Persson, X. Buffat, F. Carlier, J. Coello, R. De Maria, J. Dilly, E. Fol, D. Gamba, H. García Morales, A. García-Tabares, M. Giovannozzi, M. Hofer, E. Jaccheri Høydalsvik, J. Keintzel, M. Le Garrec, E. H. Maclean, L. Malina, P. Skowronski, F. Soubelet, R. Tomás, F. Van der Veken, L. Van Riesen-Haupt, A. Wegscheider, D. W. Wolf, CERN, Geneva, Switzerland

Abstract

The High Luminosity LHC (HL-LHC) will require stringent optics correction to operate safely and deliver the design luminosity to the experiments. In order to achieve this, several new methods for optics correction have been developed. In this article, we outline some of these methods and we describe the envisioned strategy of how to use them in order to reach the challenging requirements of the HL-LHC physics program.

- The octupolar errors in the triplet should be locally corrected to keep the generated amplitude detuning within design tolerances for Landau damping [2].
- The corrections of the nonlinear multipolar components should be within 30% of the ideal ones in order not to significantly impact the dynamic aperture [3].

MEASURING AND CORRECTING β^*

During the LHC Run 1, the local optics corrections close

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OPTICS CORRECTION STRATEGY FOR RUN 3 OF THE LHC

T. Persson, R. De Maria, J. Dilly, H. G. Morales, E. Fol, M. Hofer, E. J. Høydalsvik, J. Keintzel, M. Le Garrec, E. H. Maclean, L. Malina, F. Soubelet, R. Tomás, L. Van Riesen-Haupt, A. Wegscheider, D. W. Wolf, CERN, Geneva, Switzerland
J. Cardona, Universidad Nacional de Colombia, Bogotá, Colombia

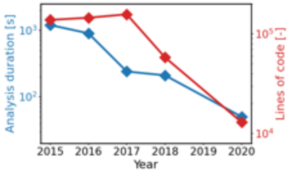
Abstract

The Run 3 of the LHC will continue to provide new challenges for optics corrections. In order to succeed and go beyond what was achieved previously, several new methods to measure and correct the optics have been developed. In this article we describe these methods and outline the plans for the optics commissioning in 2022.

INTRODUCTION

The correction strategy planned for Run 3 has significantly evolved since the first optics corrections in the LHC in Run 1 [1]. In Run 1 the Interaction Region (IR) corrections were based on the phase advance measurement obtained from the Turn-by-Turn (TbT) measurement and only linear corrections were considered. In Run 2 K-modulation measurements were used to better constrain the correction and the nonlinear corrections up to octupolar components were

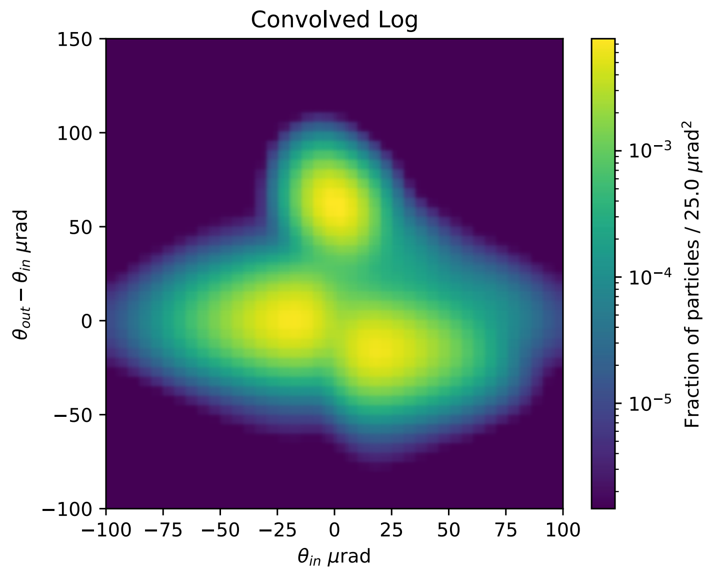
erators. Figure 1 shows the increase in speed to perform a full analysis of measurement in the LHC and how the number of lines of code have shrunk versus time. The points in 2017 and 2018 show intermediate development steps in the old codebase, while 2020 shows omc3.



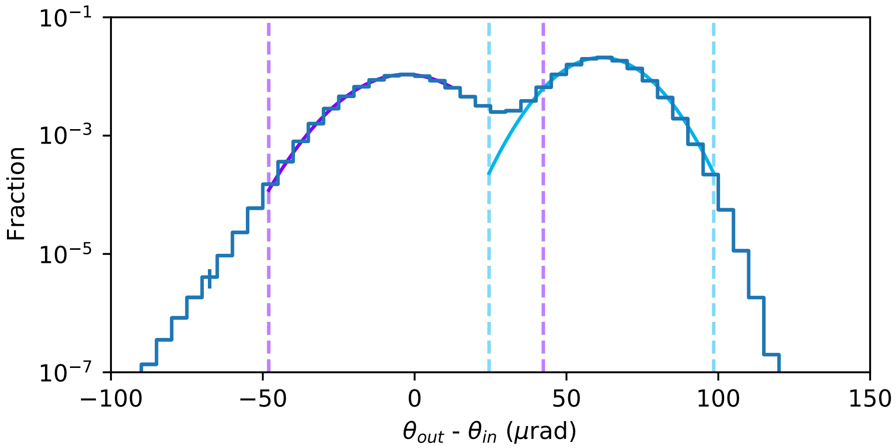
Crystal collimation for Run 3

L. Nevay et al

- *Crystal collimation will be used for Pb run of the LHC in 2022 onwards (few weeks / year)*
- *Ion collimation cleaning generally worse than protons due to fragmentation*
  - *crystals allow us to strongly steer ions deep into a collimator*
- *Geant4 crystal channelling model extended for ions*
- *Fixes for Electromagnetic Dissociation (EMD) now in Geant4*
- *Integrated into SixTrack with interface to BDSIM*
  - *SixTrack linked with both FLUKA & Geant4*
  - *option of crystal in Geant4 and other collimators in FLUKA*
  - *validation of combined tools largely complete*
  - *resolved issue of diffractive proton physics missing in Geant4*
- *Single pass models compared to 400 GeV/c fixed target data from H8 beam line at CERN*
- *for protons only - Pb data not available*
- *Extensions to model will be added to Geant4 this year*



change in angle due to crystal vs input angle

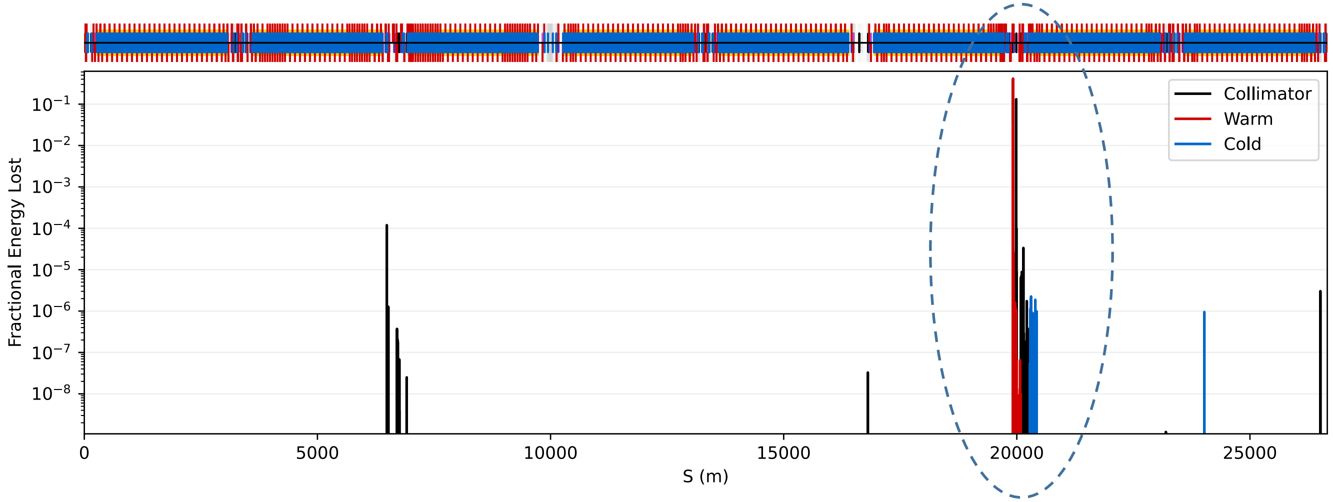


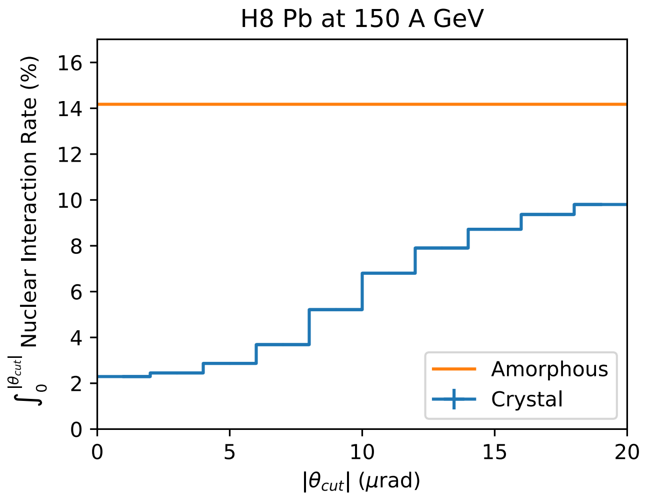
channelling efficiency plot for 400 GeV/Z Pb^{82+}

6.37 TeV/Z Pb^{82+} LHC Loss Maps

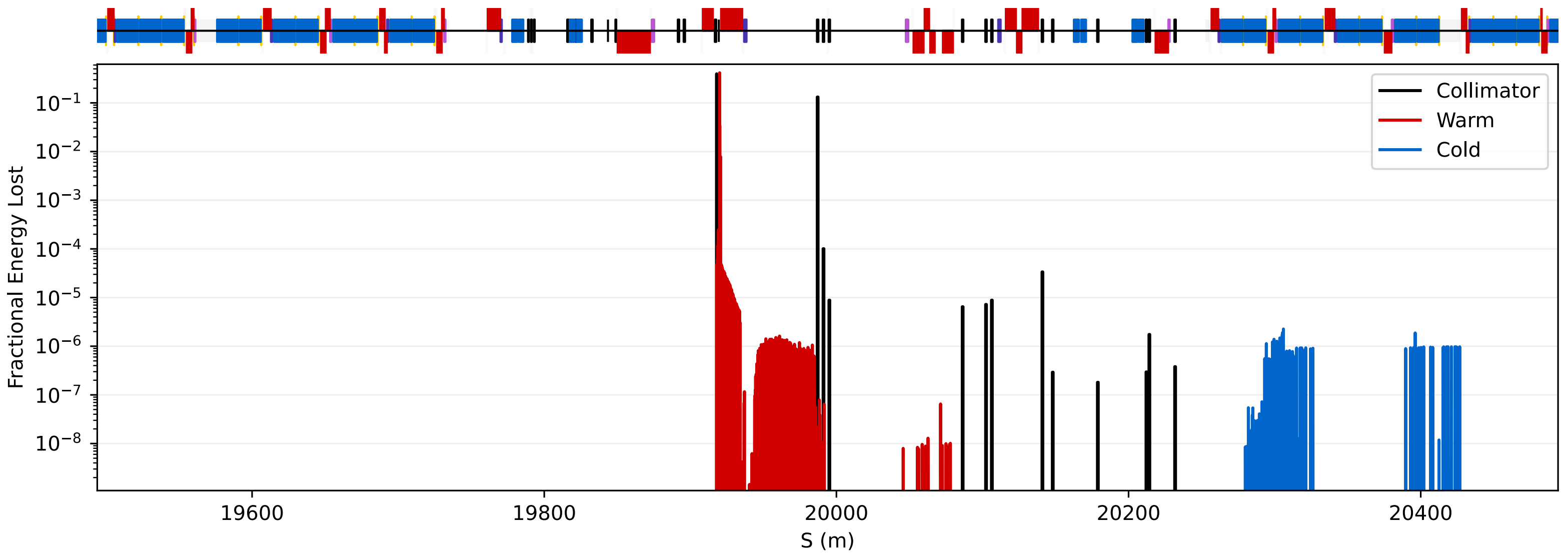
L. Nevay et al

- *Initial loss maps with 2018 optics*
  - *crystals in perfect alignment*
- *Broadly correct form of losses*
- *Comparison with loss maps from previous Run II ongoing*
- *Expect publication summer 2022*





validated nuclear interaction rate vs range of angles entering the crystal



crystal in Geant4; collimators in FLUKA; tracking in SixTrack

Diagnostics for HL-LHC

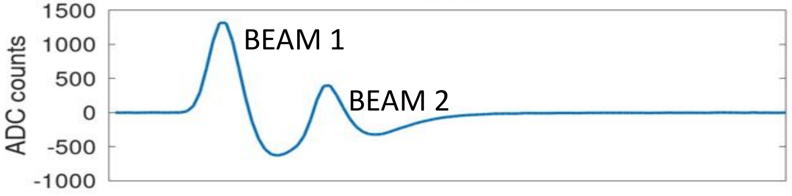
Interaction Region BPMs

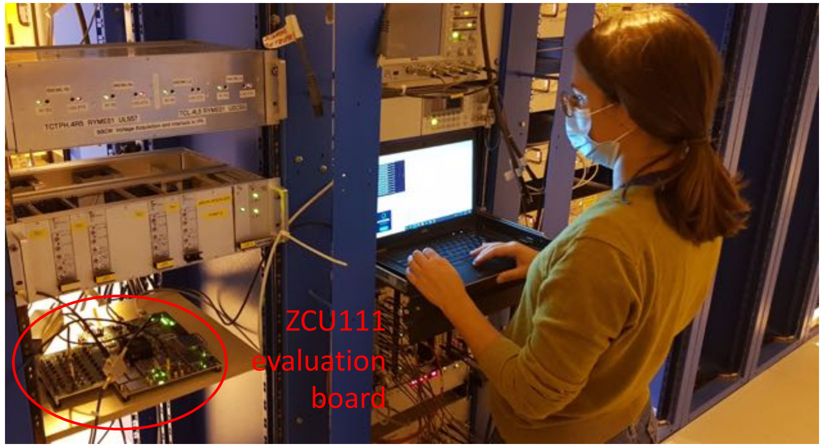
Doug Bett, Irene Degl'Innocenti, Phil Burrows et al

UNIVERSITY OF OXFORD

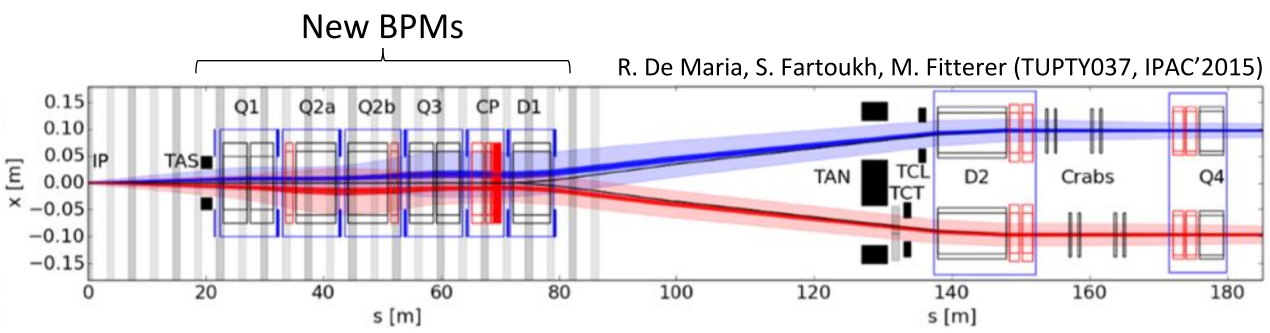
- New BPMs to be installed in IP5/IP8 where the two beams are contained in a single pipe and their signals overlap
- RFSoC device combining FPGA-style programmable logic with a CPU and RF-ADCs will be used for direct digitization

Simulated two-beam waveform





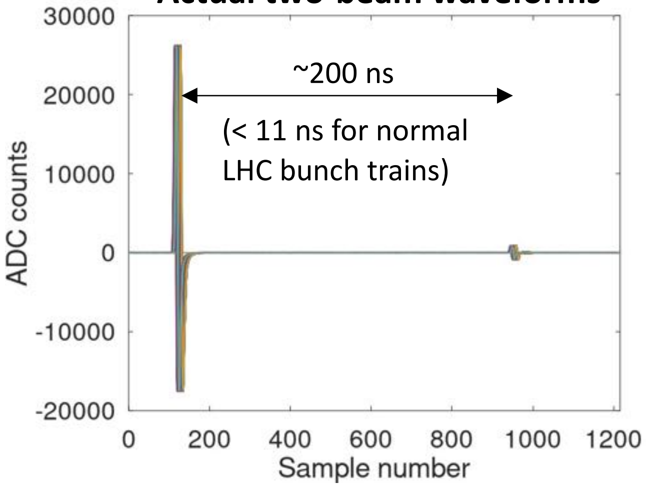
Photograph of the RFSoC in situ at LHC Point 5



Real BPM data has been taken using the RFSoC

- Simple measurement-only firmware designed by Irene Degl'Innocenti (pictured)
- 3 data taking sessions 27 Oct – 31 Oct; board used with two different BPMs and with multiple configurations of signal ports to ADC channels

Actual two-beam waveforms

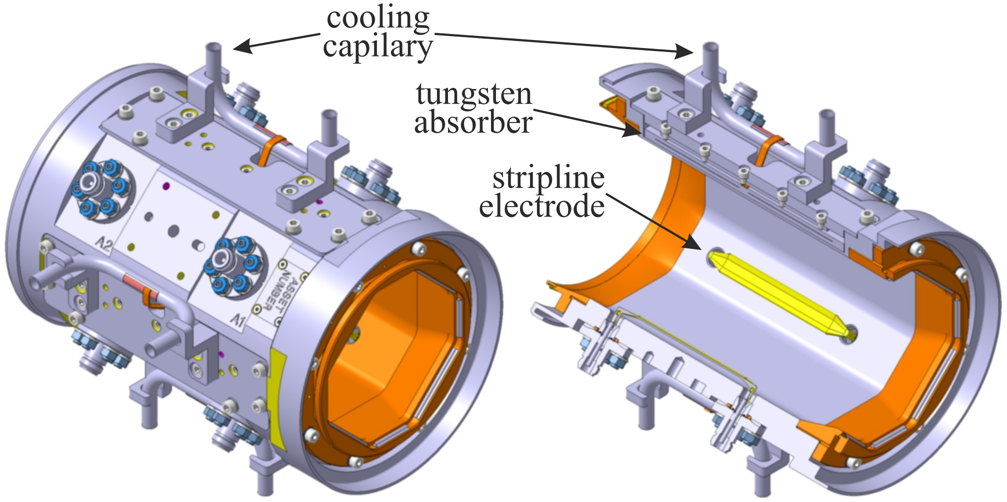


- Single-port signals will be compared to model results to validate the simulation framework
- Bunch crossing timing much larger than in the actual use case; however, signals can be manipulated to get an idea of the performance of the compensation algorithm

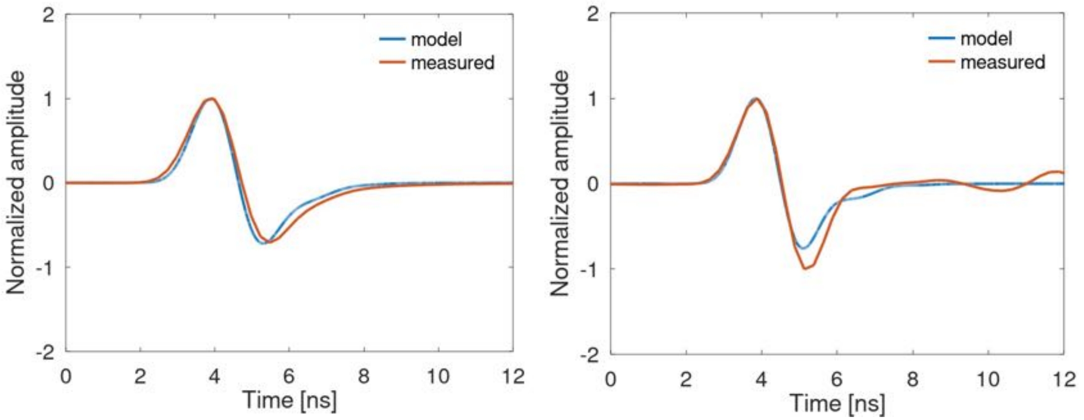
Interaction Region BPMs

Doug Bett, Irene Degl'Innocenti,
Phil Burrows et al

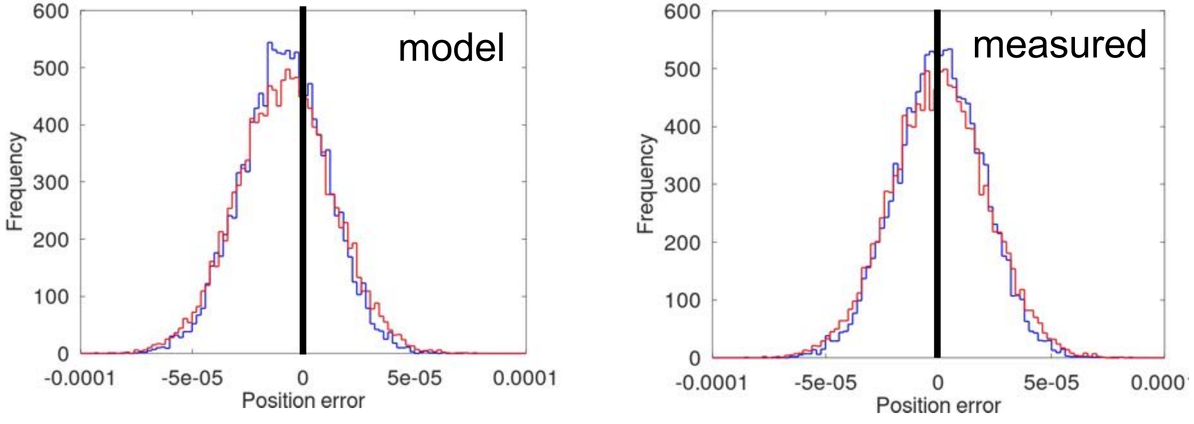
Tungsten-shielded cryogenic directional coupler BPM design



- Predicted signals from simulation framework compared against actual signals
- Power compensation algorithm tested using parameters derived from both model and measured waveforms
- Best performance when using measured waveforms; measuring them would be part of the calibration procedure



Histograms of corrected positions



See IBIC 2020 & 2021 proceedings:

https://doi.org/10.18429/JACoW-IBIC2020-WEPP12

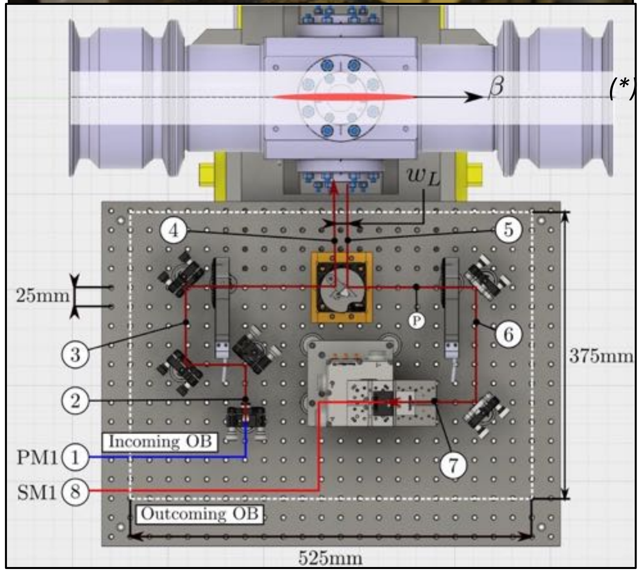
https://doi.org/10.18429/JACoW-IBIC2021-MOPP24

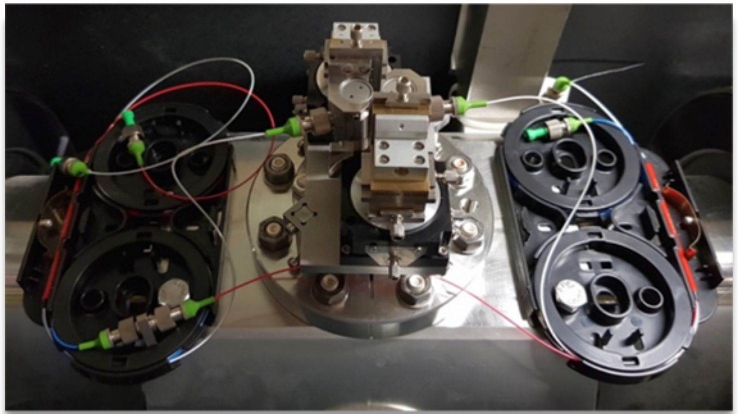
High-bandwidth EO-BPM development for HL-LHC

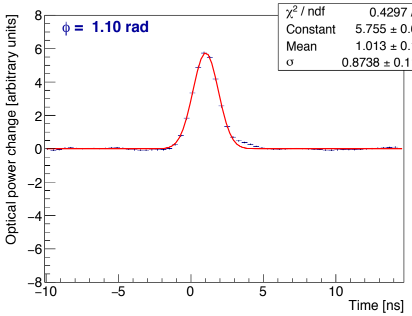
A. Arteche,
S. Gibson et al

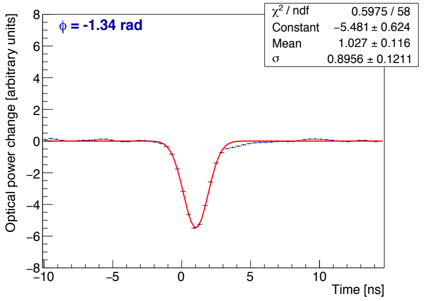
ROYAL HOLLOWAY UNIVERSITY OF LONDON

SPS Prototype → Miniaturisation → HL-LHC compatible waveguide design

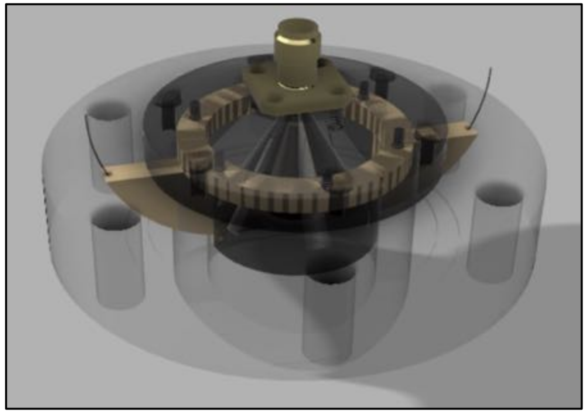


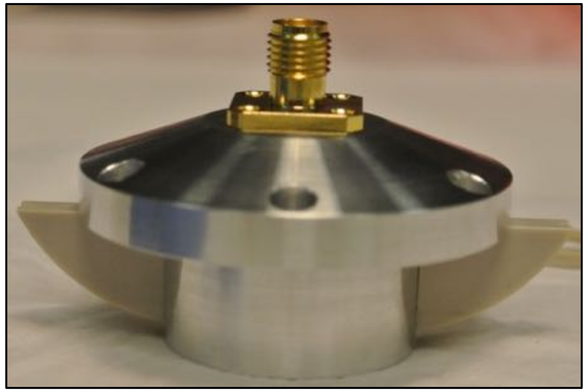






- Bulky side boxes replaced by more compact fibre-optic design and finally became totally fibre-coupled for the waveguide design.



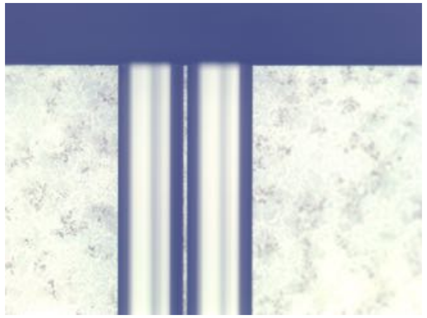


New EO waveguide design shipped to CERN for beam tests

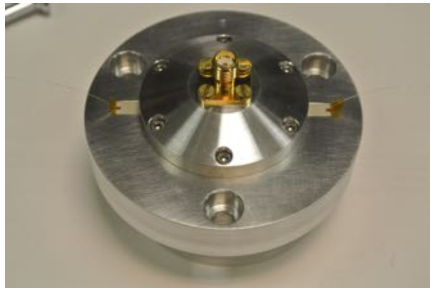
A. Arteche,
S. Gibson et al

ROYAL HOLLOWAY UNIVERSITY OF LONDON

- EM simulations of pick-up performed in CST to optimise field strength at waveguide.
- Partnered with UK industry to produce waveguides suitable for our custom design:

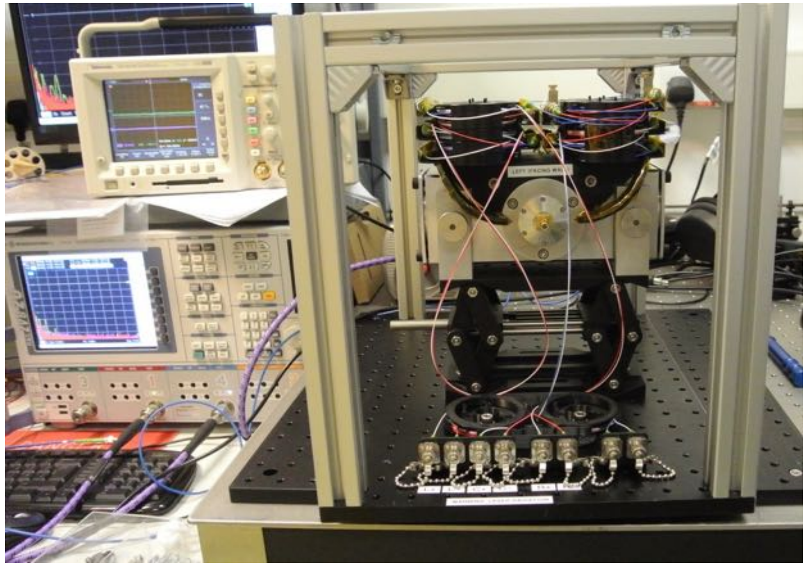


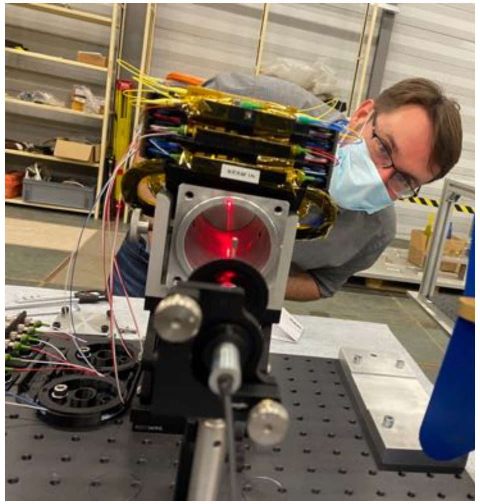
Optical inspection of waveguide in RHUL clean room

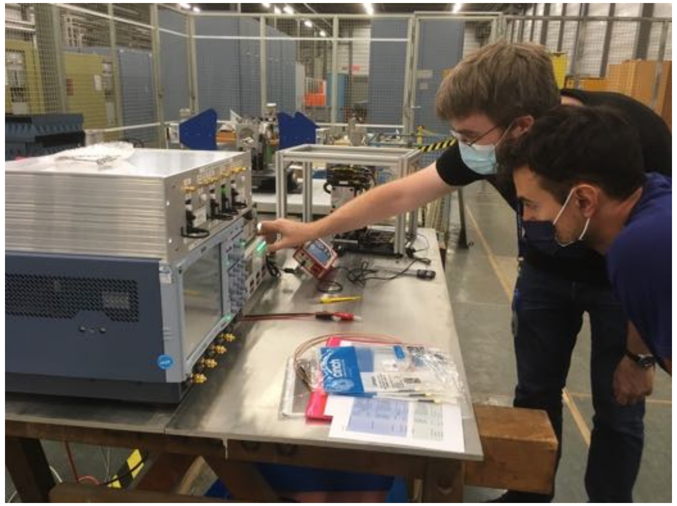


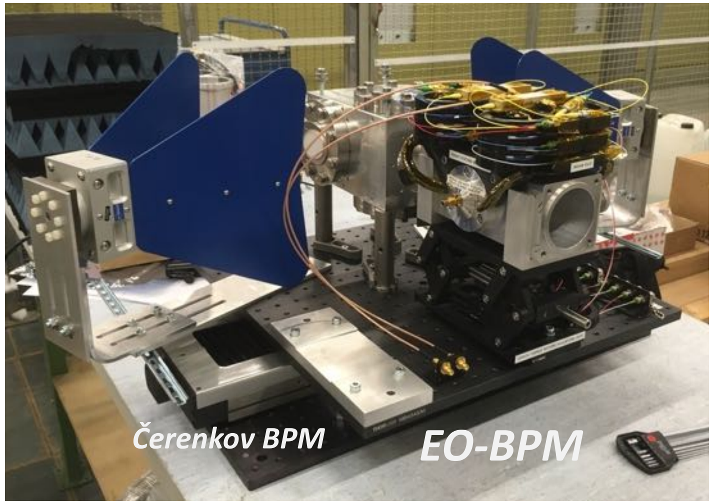
Compact fibre-coupled waveguide pick-up

EO-BPM manufacture & VNA tests at RHUL







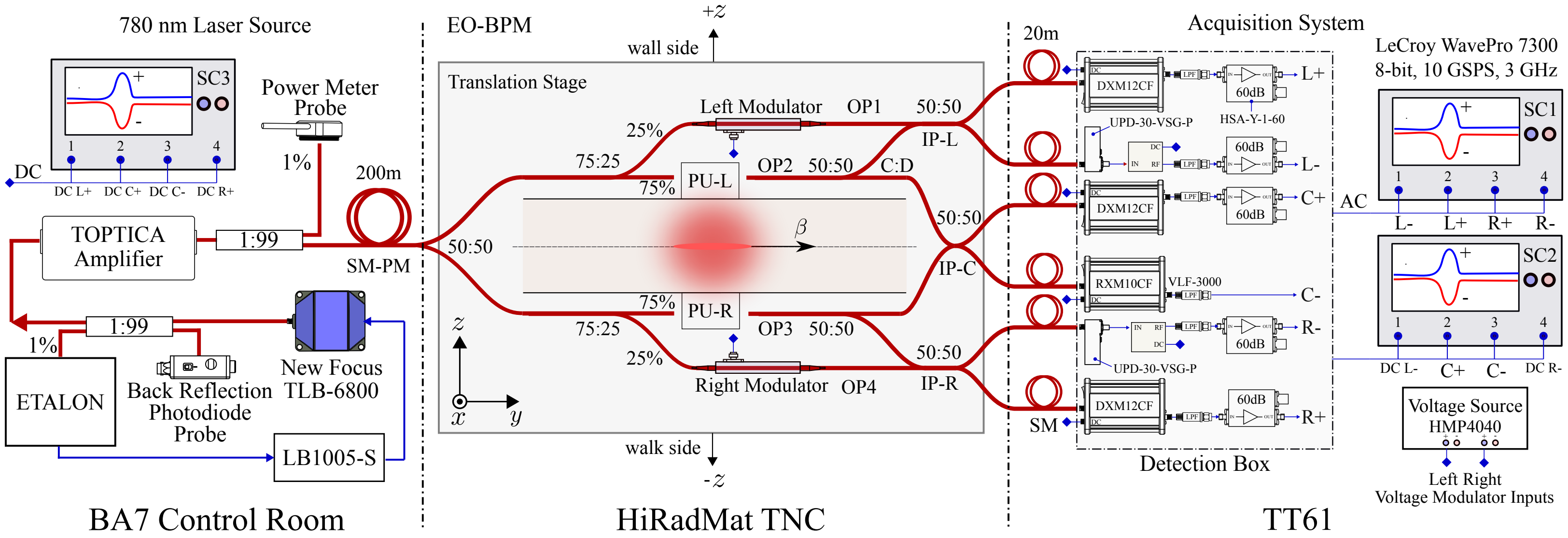


EO-BPM reception tested at CERN and laser-aligned with dielectric BPM on shared translation table

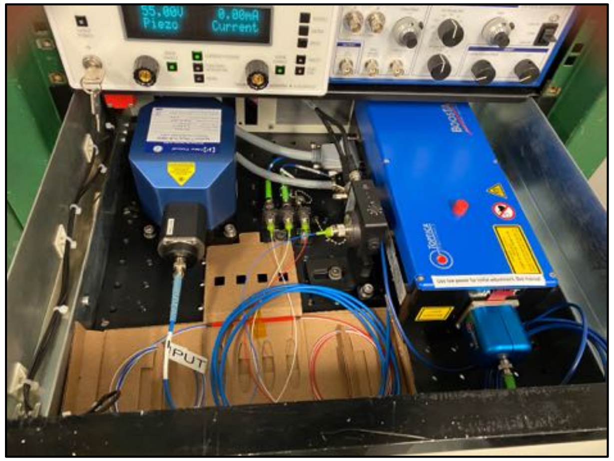
EO-BPM installation in HiRadMat facility

A. Arteche,
S. Gibson et al

ROYAL HOLLOWAY UNIVERSITY OF LONDON



780nm laser source in BA7

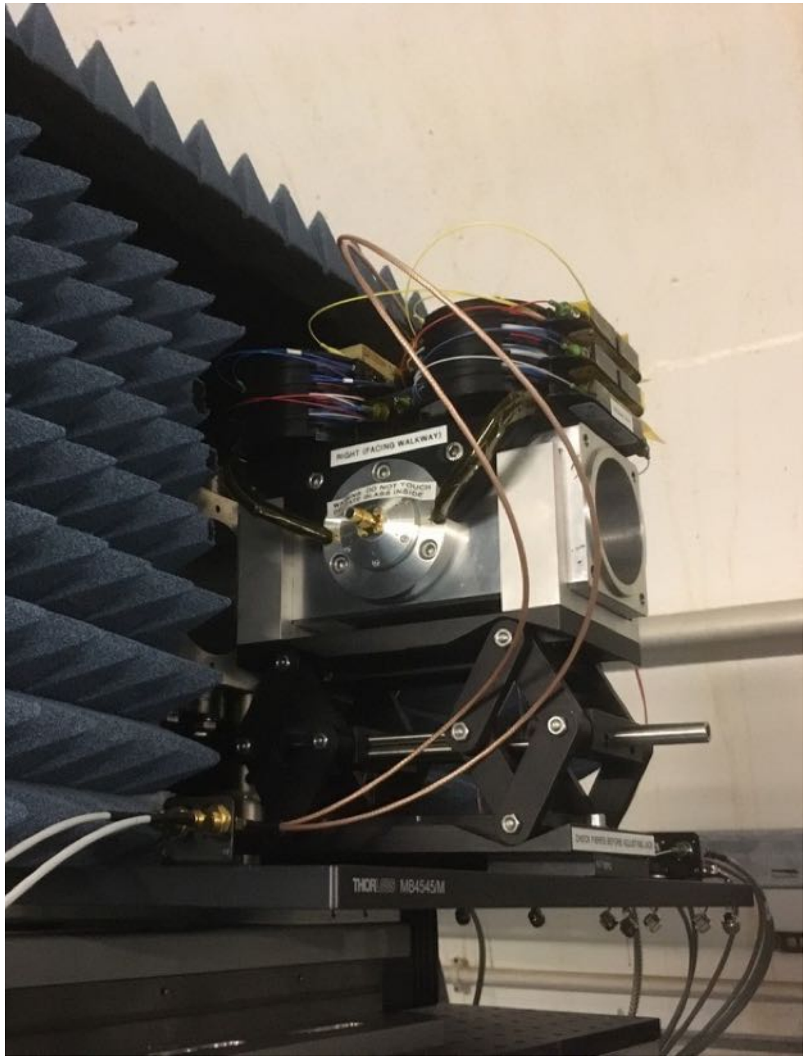


EO-BPM at HiRadMat extraction line

Acquisition system:

EO-BPM installation in HiRadMat facility

A. Arteche,
S. Gibson et al



Successful first beam test at HiRadMat

A. Arteche,
S. Gibson et al

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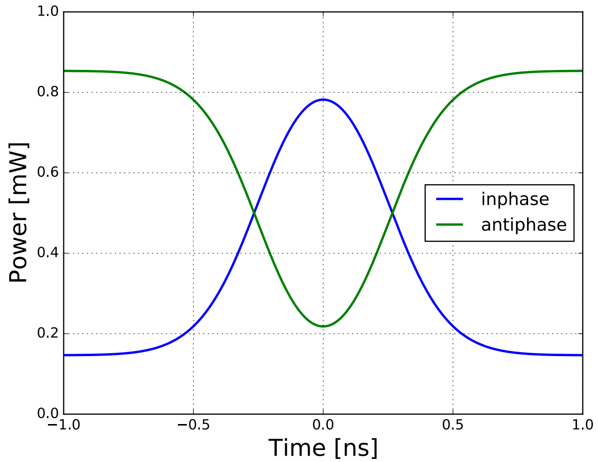
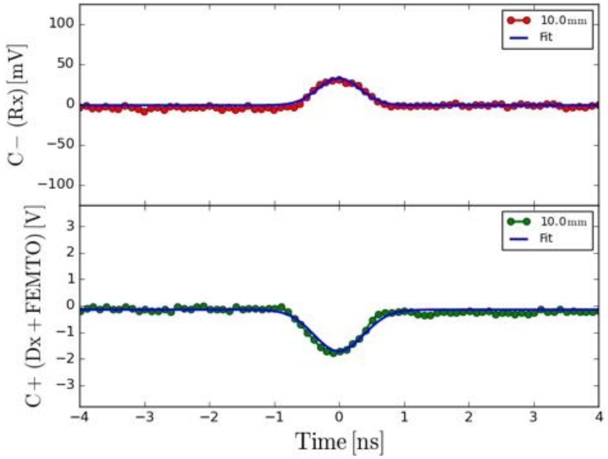
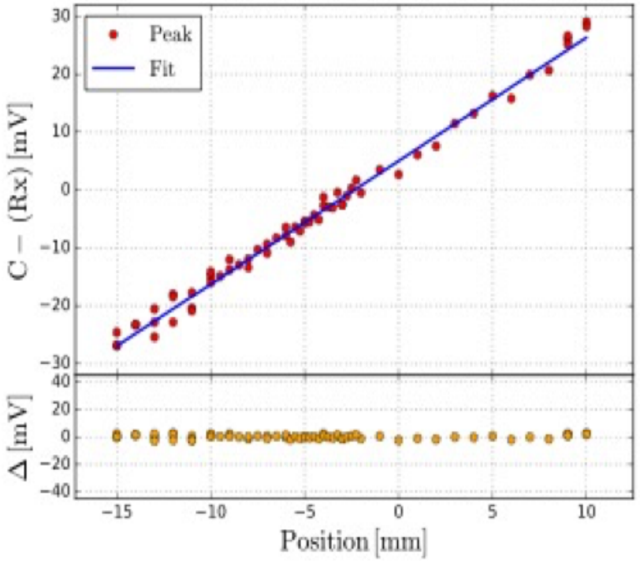




Single-shot measurements using optical difference signal

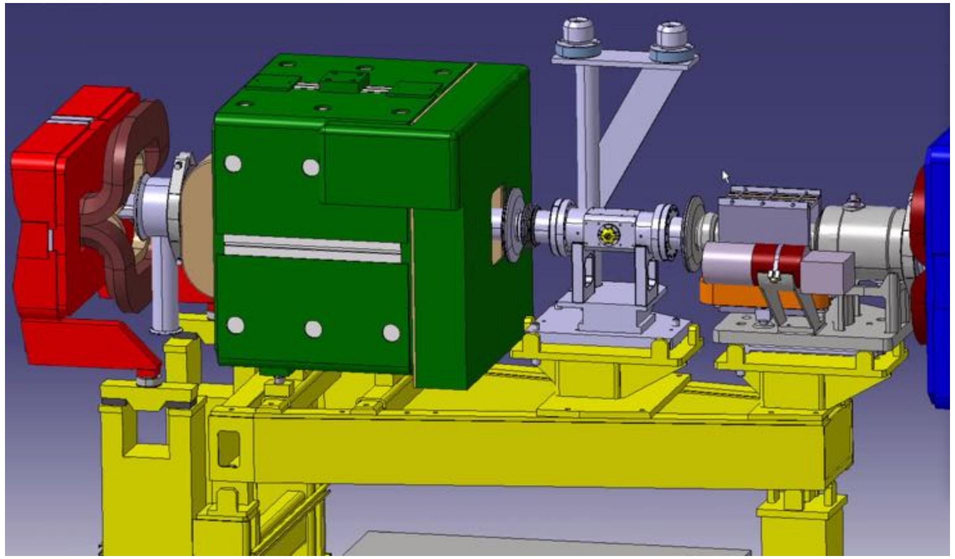


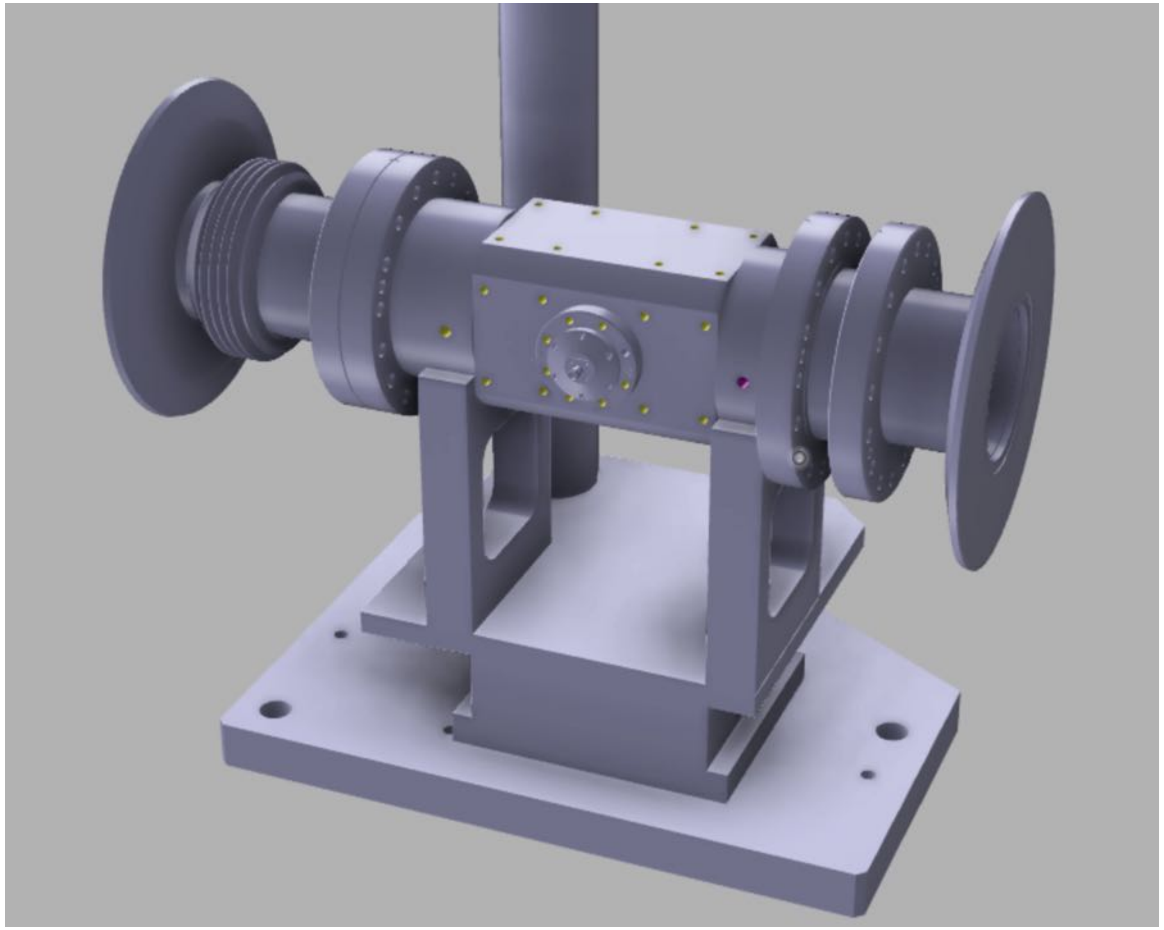
- **Major improvement performance** enabled **first single-shot measurements of each passing bunch**.
- EO-BPM also **sensitive to low intensity bunches**.
- Laser scanning technique developed to **automate operation** of electro-optic interferometer.
- Translation of EO-BPM across the HiRadMat extraction line: ***first bunch by bunch position measurements:***

Invited talk at IBIC 2022

EO-BPM future HL-LHC demonstrator in SPS

- HiRadMat EO-pick-up design incorporated into an in-vacuum design for the next phase of project.
- Excellent progress in recent months on CERN engineering drawings and vacuum brazing.
- **EO-BPM demonstrator** will be built and installed in **SPS**, for operation in Run 3.



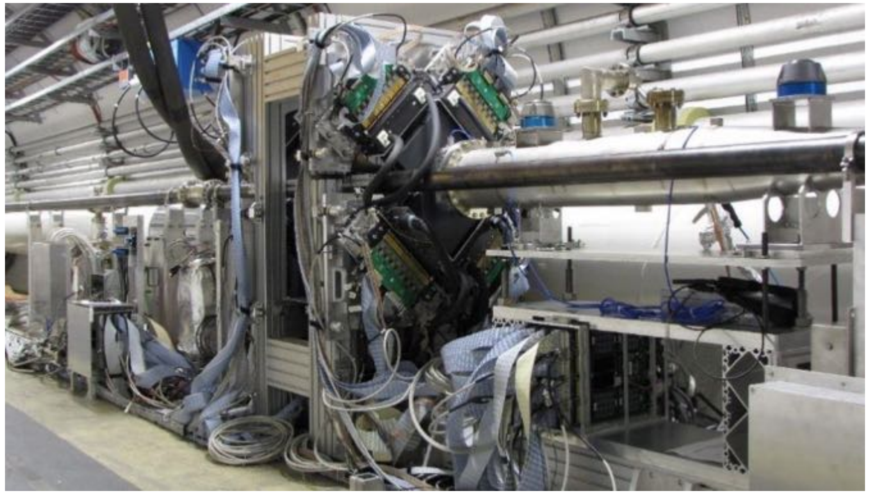


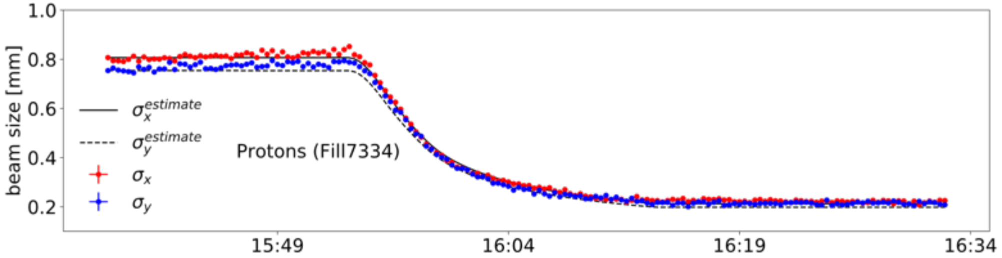
HL-LHC Beam Gas Vertex Detector

H. Guerin & BGV team

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Prototype beam gas vertex detector *demonstrated on online beam size measurements, with resolution down to 3µm in Run II. Two tracking layers.*

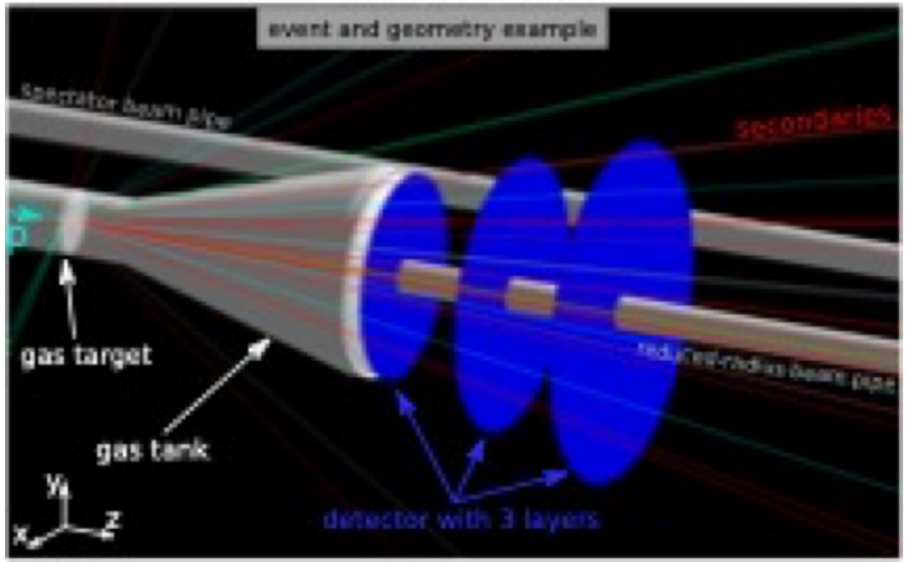




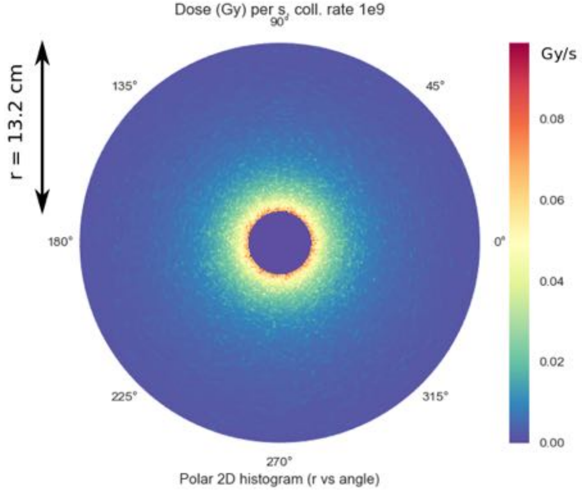
Courtesy, R. Jones

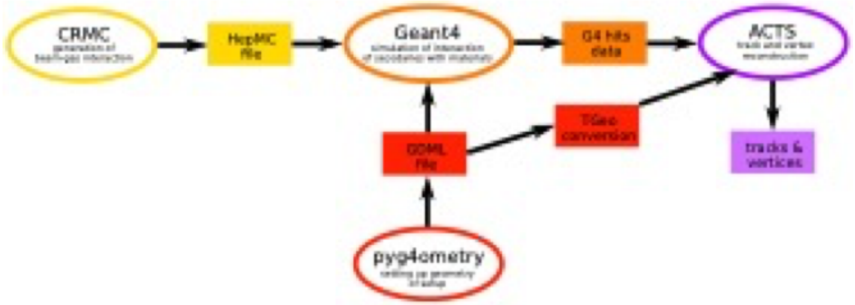
Hélène Guerin, CERN-RHUL Doctoral student studies of BGV:

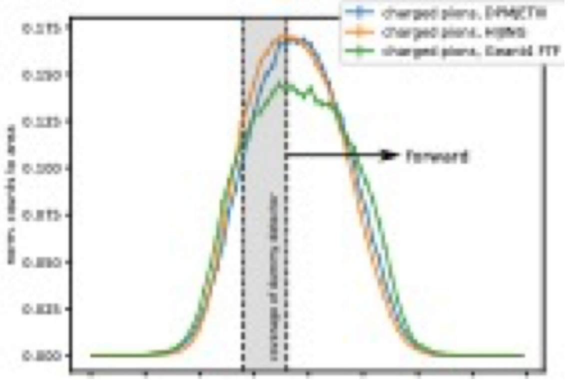
Geant4 simulations of design for HL-LHC with three layers, with geometry build using pyg4ometry (RHUL / BDSIM), gas-jet target.



Radiation dose







Progress on HL-LHC Beam Gas Vertex Detector

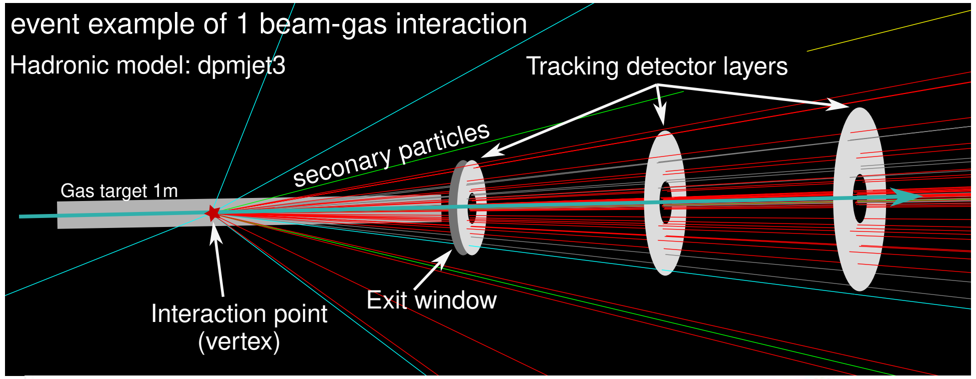
H. Guerin & BGV team

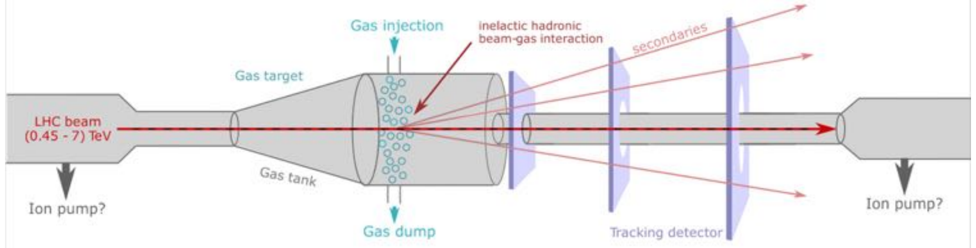
ROYAL HOLLOWAY UNIVERSITY OF LONDON

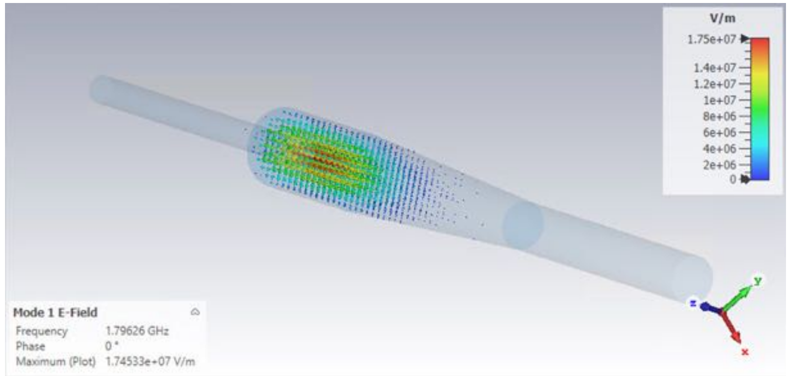
Simulated performance has no showstopper for a distributed gas target, although a gas-jet target would improve performance; results point towards a high resolution, compact tracker.

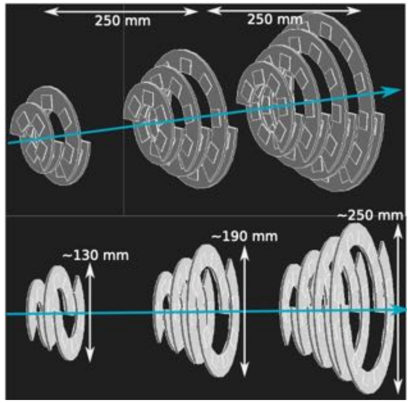
- ***Decision for TimePix4*** hybrid pixel detectors tracker (design and produced with Oxford: D. Hynds and R. Plackett).
- ***Tank design optimised*** to increase the tracker acceptance and reduce the tank impedance.
- Baseline is an ***upgraded distributed gas target***; a ***gas-jet target option*** is being assessed for performance and implementation requirements.
- Possible locations for the Beam 1 instrument identified, ***estimating radiation induced*** downstream by BGV operation.
- ***Event reconstruction***: work ongoing to unfold the beam profile from the distribution of reconstructed vertices.

• *Design report for Summer 2022 with review by end of the year.*







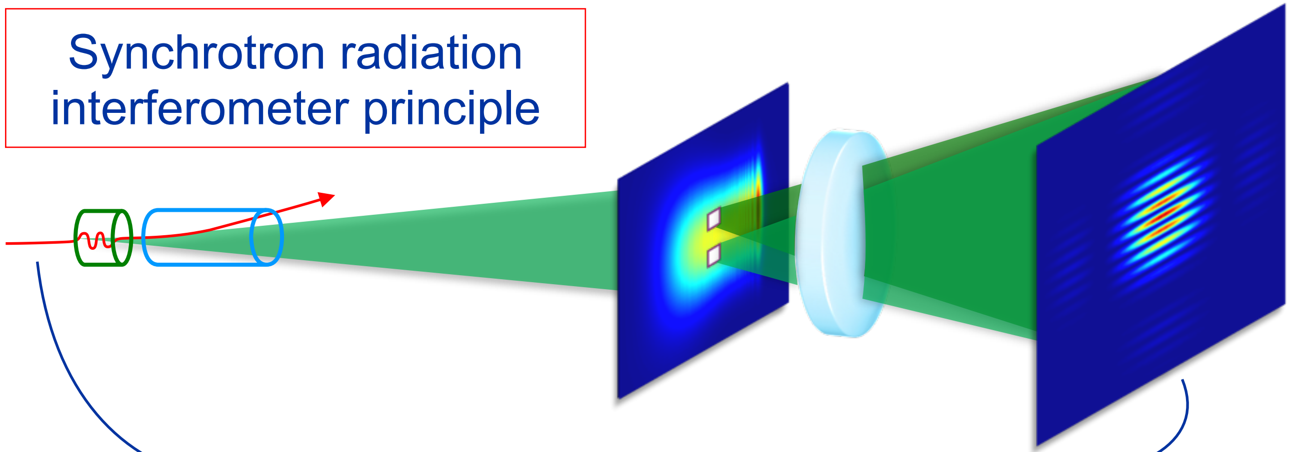


HL-LHC Synchrotron Radiation Monitor

D. Butti & CERN BI

ROYAL HOLLOWAY UNIVERSITY OF LONDON

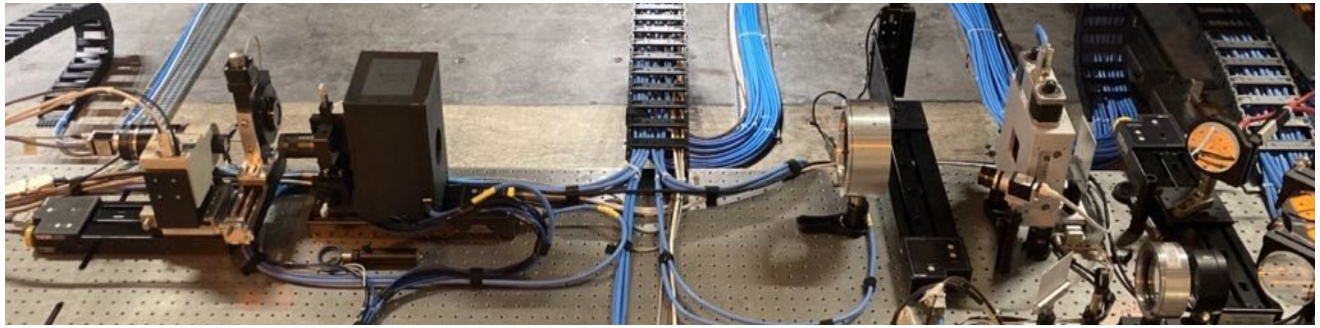
Synchrotron radiation interferometer principle



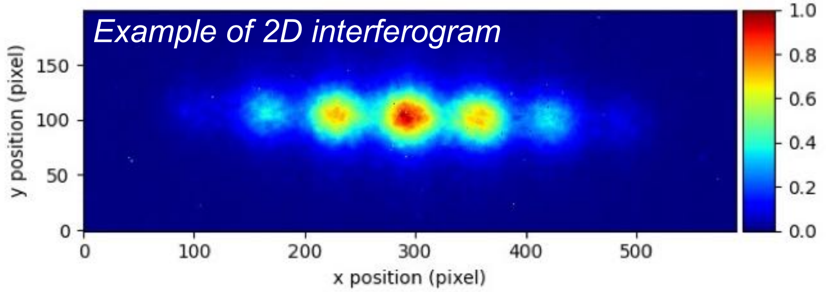
source size ↔ interferogram visibility

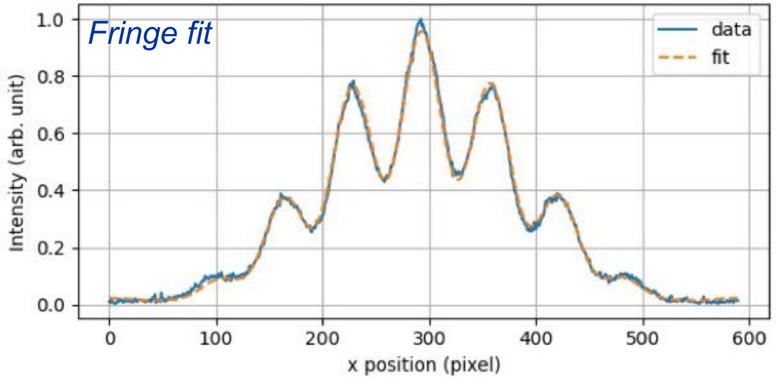
Goal: provide an absolute and non invasive transverse size measurement for HL-LHC

Instrument refurbished and ready for LHC Run 3

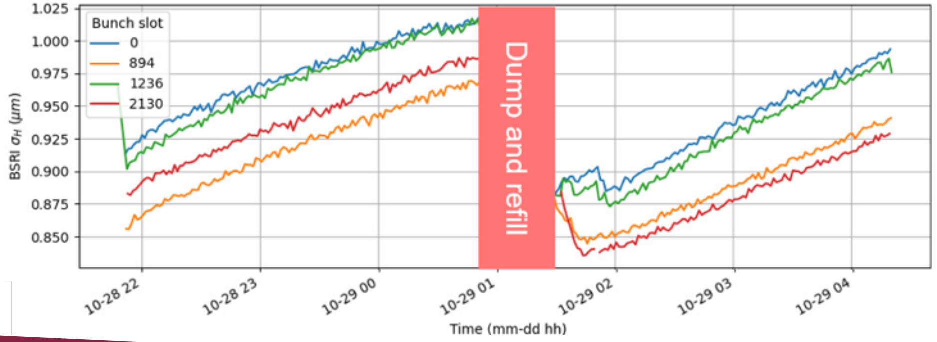


First measurements from October 2021 beam test





Real-time monitoring of transverse size during two fills

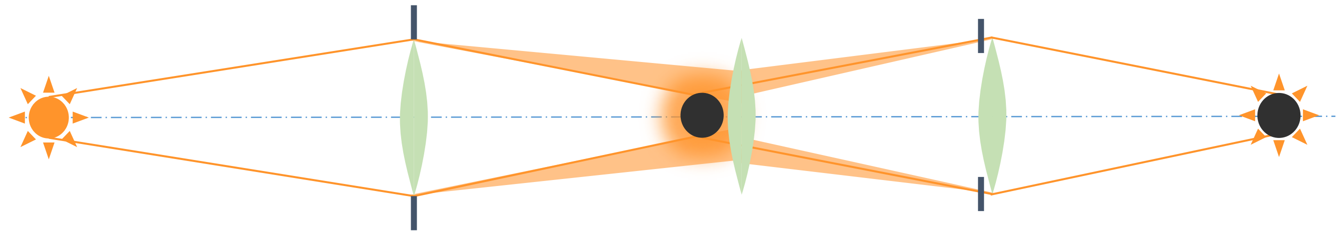


HL-LHC Synchrotron Radiation Monitor

D. Butti & CERN BI

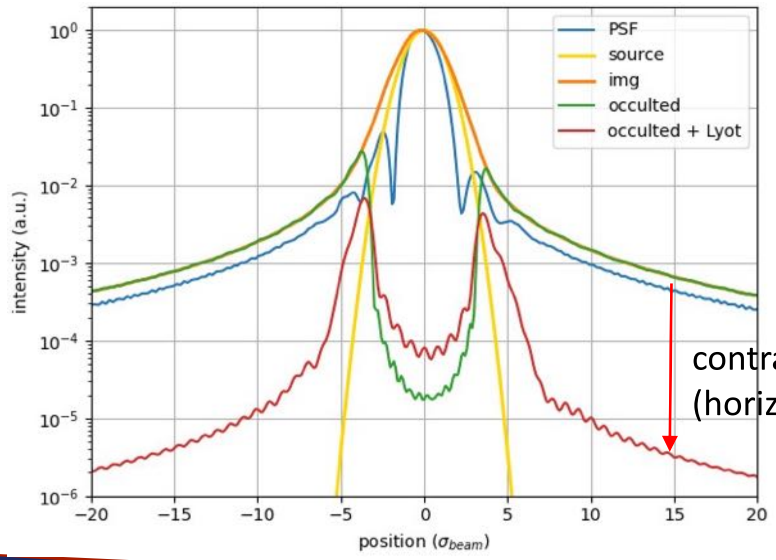
Coronagraph principle

Achieve high-contrast imaging by suppressing diffraction background



Propagation of diffraction: "created" by aperture → refocused by field lens → scraped by Lyot stop → image w/o diffraction halo

Goal: measure the halo population of HL-LHC beams

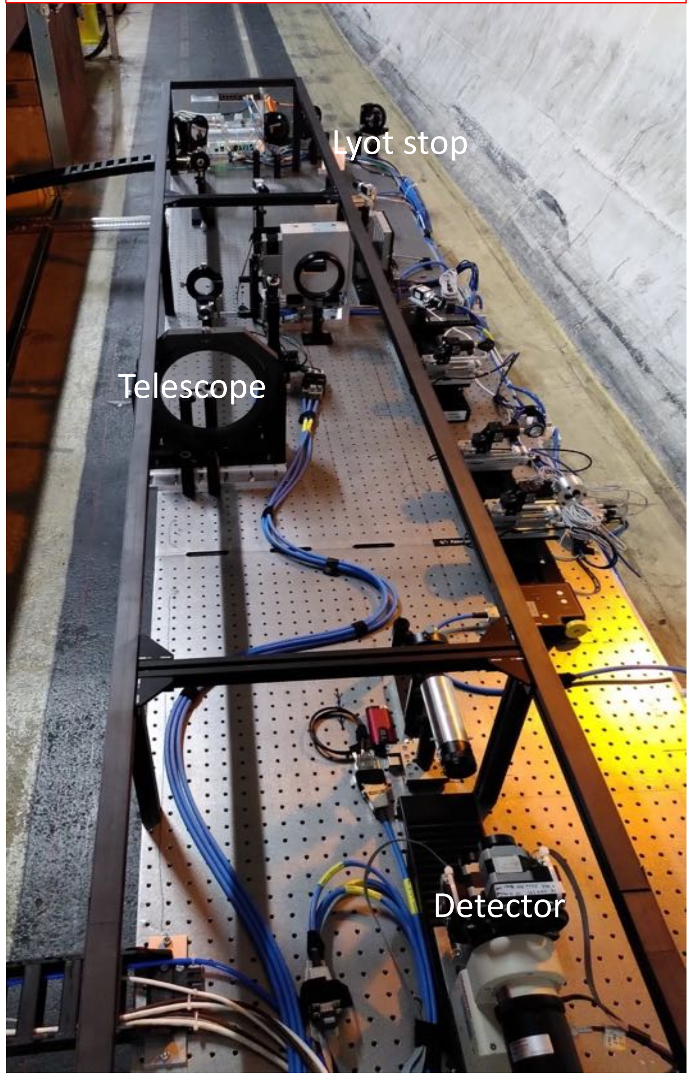


Simulations

Applicability of coronagraph to synchrotron radiation not trivial:
→ extensive simulations

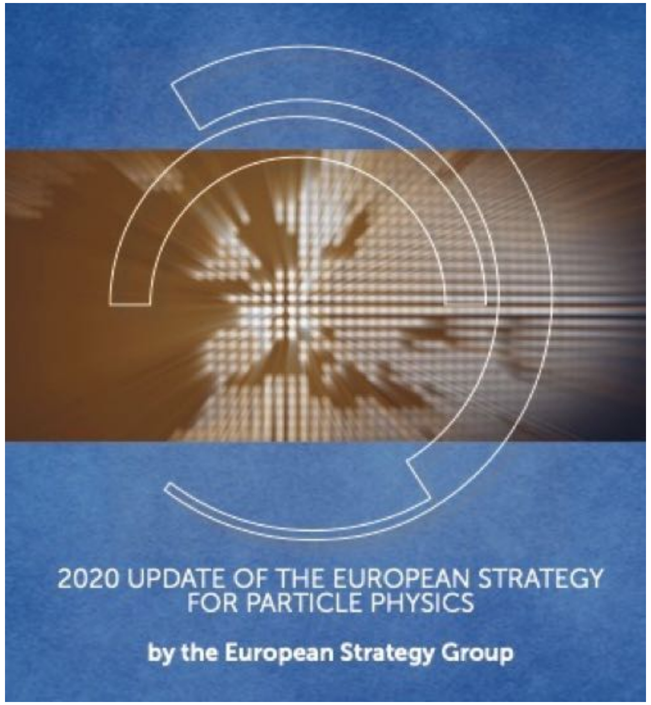
contrast gain in diffraction background (horizontal direction only)

Test setup installed in LHC to benchmark simulations



2020 update of European Strategy

3 **High-priority future initiatives**

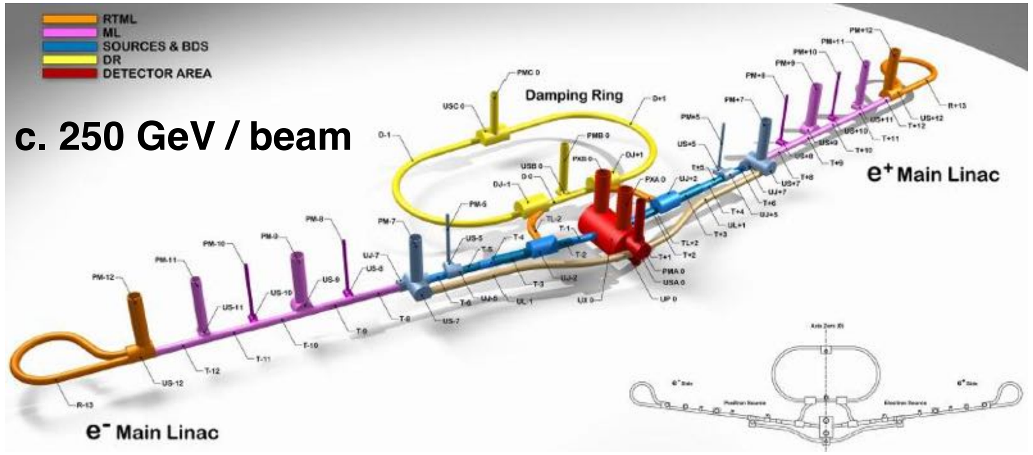


The vision is to prepare a Higgs factory, followed by a future hadron collider with sensitivity to energy scales an order of magnitude higher than those of the LHC, while addressing the associated technical and environmental challenges

A. An electron-positron Higgs factory is the highest-priority next collider. For the longer term, the European particle physics community has the ambition to operate a proton-proton collider at the highest achievable energy. Accomplishing these compelling goals will require innovation and cutting-edge technology:

The timely realisation of the electron-positron International Linear Collider (ILC) in Japan would be compatible with this strategy and, in that case, the European particle physics community would wish to collaborate.

Higgs factory e^+e^- collider for precise measurements of Higgs & top ++, complementary to ***LHC***



31 km

Future e^+e^- colliders - executive summary

P. Burrows

JAI has a very strong background in relevant technologies and systems:

Beam delivery system, machine-detector interface, luminosity beam-collision feedback, beam dynamics, instrumentation, alignment …

ILC: August 2020 ICFA mandated the International Development Team (IDT) to steer ILC towards an international project

WG1: Pre-lab setup: Foster UK lead

WG2: Accelerator: Burrows UK lead

WG3: Physics/detectors: Robson UK lead, Burrows on Steering Group

- ILC proposal (PI: Burrows) submitted via STFC to UKRI IAC (2020) and ‘noted’
- ILC recognised positively in European Strategy (2013+2020) + UK PPAP (2021)
- 2 meetings of MEXT, STFC, DoE, BMBF, MESRI to discuss ILC: ‘chicken and egg’ issue
- MEXT ILC Advisory Panel latest report March 2022 was ‘lukewarm’

CLIC (‘Plan B’ at CERN): technology industrialisation → Project Readiness Report

- After 7 years as spokesperson Burrows stepped down March 2021

Currently zero dedicated direct UK R&D £ for any of the above, though modest indirect ‘spare-time’ support via JAI grant, PP grants, and EU projects

JAI expertise equally applicable to FCCee: JAI/Oxford in EU FCC-IS design study

Recent ILC publications

PHYSICAL REVIEW ACCELERATORS AND BEAMS **25**, 022801 (2022)

High-resolution, low-latency, bunch-by-bunch feedback system for nanobeam stabilization

D. R. Bett,[†] N. Blaskovic Kraljevic,[‡] T. Bromwich,[§] P. N. Burrows,
G. B. Christian,[∥] C. Perry, and R. Ramjiawan[*,¶]
John Adams Institute for Accelerator Science at University of Oxford, Denys Wilkinson Building, Keble Road, Oxford, OX1 3RH, United Kingdom

(Received 14 December 2021; accepted 11 February 2022; published 22 February 2022)

We report the design, operation, and performance of a high-resolution, low-latency, bunch-by-bunch feedback system for nanobeam stabilization. The system employs novel, ultralow quality-factor cavity beam position monitors (BPMs), a two-stage analog signal down-mixing system, and a digital signal processing and feedback board incorporating a field-programmable gate array. The field-programmable gate array firmware allows for the real-time integration of up to fifteen samples of the BPM waveforms within a measured latency of 232 ns. We show that this real-time sample integration improves significantly the beam position resolution and, consequently, the feedback performance. The best demonstrated real-time beam position resolution was 19 nm, which, as far as we are aware, is the best real-time resolution achieved in any operating BPM system. The feedback was operated in two complementary modes to stabilize the vertical position of the ultrasmall beam produced at the focal point of the ATF2 beamline at KEK. In single-BPM feedback mode, beam stabilization to 50 ± 5 nm was demonstrated. In two-BPM feedback mode, beam stabilization to 41 ± 4 nm was achieved.

PHYSICAL REVIEW ACCELERATORS AND BEAMS **23**, 121004 (2020)

Wakefield effects and mitigation techniques for nanobeam production at the KEK Accelerator Test Facility 2

Pierre Korysko[*,†] and Philip N. Burrows
Department of Physics, University of Oxford, Oxford OX1 3PU, United Kingdom

Andrea Latina
European Organization for Nuclear Research, Geneva CH-1211, Switzerland

Angeles Faus-Golfe
IJCLab, CNRS/IN2P3, Université Paris-Saclay, Orsay 91898, France

(Received 13 November 2020; accepted 9 December 2020; published 31 December 2020)

The ATF2 beam line at KEK was built to validate the operating principle of a novel final-focus scheme devised to demagnify high-energy beams in future linear lepton colliders; to date vertical beam sizes as small as 41 nm have been demonstrated. However, this could only be achieved with an electron bunch intensity ~10% of nominal, and it has been found that wakefield effects limit the beam size for bunch charges approaching the design value of $10^{10}e^{-}$. We present studies of the impact of wakefields on the production of "nanobeams" at the ATF2. Wake potentials were evaluated for the ATF2 beam line elements and incorporated into a realistic transport simulation of the beam. The effects of both static (component misalignments and rolls, magnet strength errors and beam position monitor resolution) and dynamic (position and angle jitter) imperfections were included and their effects on the beam size evaluated. Mitigation techniques were developed and applied, including orbit correction, dispersion-free steering, wakefield-free steering, and interaction point tuning knobs. Explicit correction knobs to compensate for wakefield effects were studied and applied, and found to significantly decrease the intensity dependence of the beam size.

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ACCEPTED: *November 2, 2020*
PUBLISHED: *January 11, 2021*

A sub-micron resolution, bunch-by-bunch beam trajectory feedback system and its application to reducing wakefield effects in single-pass beamlines

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[b] *High Energy Accelerator Research Organization (KEK), 1-1 Oho, Tsukuba, Japan*
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ABSTRACT: A high-precision intra-bunch-train beam orbit feedback correction system has been developed and tested in the ATF2 beamline of the Accelerator Test Facility at the High Energy Accelerator Research Organization in Japan. The system uses the vertical position of the bunch measured at two beam position monitors (BPMs) to calculate a pair of kicks which are applied to the next bunch using two upstream kickers, thereby correcting both the vertical position and trajectory angle. Using trains of two electron bunches separated in time by 187.6 ns, the system was optimised so as to stabilize the beam offset at the feedback BPMs to better than 350 nm, yielding a local trajectory angle correction to within 250 nrad. The quality of the correction was verified using three downstream witness BPMs and the results were found to be in agreement with the predictions of a linear lattice model used to propagate the beam trajectory from the feedback region. This same model predicts a corrected beam jitter of c. 1 nm at the focal point of the accelerator. Measurements with a beam size monitor at this location demonstrate that reducing the trajectory jitter of the beam by a factor of 4 also reduces the increase in the measured beam size as a function of beam charge by a factor of c. 1.6.

Recent CLIC publications

P. Burrows

John Adams Institute for Accelerator Science

PHYSICAL REVIEW ACCELERATORS AND BEAMS **23**, 101001 (2020)

Luminosity performance of the Compact Linear Collider at 380 GeV with static and dynamic imperfections

C. Gohil,[1,2,†] P. N. Burrows,[1] N. Blaskovic Kraljevic,[2,*]
A. Latina,[2] J. Ögren,[2] and D. Schulte[2]
[1] *John Adams Institute (JAI), University of Oxford, Oxford, OX1 3RH, United Kingdom*
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(Received 6 March 2020; revised 6 August 2020; accepted 30 September 2020; published 15 October 2020)

The Compact Linear Collider is one of the two main European options for a collider in a post Large Hadron Collider era. This is a linear e^+e^- collider with three center-of-mass energy stages: 380 GeV, 1.5 TeV, and 3 TeV. The luminosity performance of the first stage at 380 GeV is presented including the impact of static and dynamic imperfections. These calculations are performed with fully realistic tracking simulations from the exit of the damping rings to the interaction point and including beam-beam effects in the collisions. A luminosity of $4.3 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$ can be achieved with a perfect collider, which is almost three times the nominal luminosity target of $1.5 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$. In simulations with static imperfections, a luminosity of $2.35 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$ or greater is achieved by 90% of randomly misaligned colliders. Expressed as a percentage of the nominal luminosity target, this is a surplus of approximately 57%. Including the impact of ground motion, a luminosity surplus of 53% or greater can be expected for 90% of colliders. The average expected luminosity is $2.8 \times 10^{34}\ \mathrm{cm^{-2}\,s^{-1}}$, which is almost twice the nominal luminosity target.

Nuclear Inst. and Methods in Physics Research, A 988 (2021) 164904

Contents lists available at ScienceDirect

Nuclear Inst. and Methods in Physics Research, A

journal homepage: www.elsevier.com/locate/nima

ELSEVIER

Magnetic characterization of Mumetal® for passive shielding of stray fields down to the nano-Tesla level

Pasquale Arpaia [a,*], Philip Nicholas Burrows [b], Marco Buzio [c], Chetan Gohil [b,d], Mariano Pentella [c,e], Daniel Schulte [d]
[a] Department of Electrical Engineering and Information Technology, University of Naples "Federico II", 80138 Naples, Italy
[b] John Adams Institute (JAI), University of Oxford, Oxford, OX1 3RD, United Kingdom
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ARTICLE INFO

Keywords:
CLIC
Compact Linear Collider
Stray magnetic fields
Magnetic shielding
Magnetic materials
Mumetal®

ABSTRACT

The luminosity of a particle collider is an extremely crucial performance parameter describing its capability of producing interactions in the collision point. However, imperfections in a collider can lead to luminosity loss. Among different imperfections, an important one is stray magnetic fields. For the Compact Linear Collider (CLIC), a collider being considered as one of the main options in Europe after the Large Hadron Collider, simulations showed an unprecedented sensitivity of the machine to fields on the order of 0.1 nT. Hence, such tight constraints require special design considerations to prevent performance loss. Different shielding techniques are available in the literature, typically relying on an active shielding strategy and capable of reducing the magnetic field amplitudes down to the nano-Tesla level. However, measuring fields with such amplitudes is challenging by using state-of-the-art commercially available sensors and therefore, a passive shielding strategy, consisting in enveloping sections of the beamline with a magnetic shield, is a more attractive option. For CLIC, Mumetal®, a Ni–Fe alloy with advertised relative permeability above 100,000, was chosen. In this paper, the DC and AC magnetic characterization of two samples of Mumetal®, one annealed in its final form and the other one non-annealed is presented, showcasing how the annealing results in a boost of the magnetic permeability of more than order of magnitude. As a case study, the shielding performance of a 1-mm thin layer of Mumetal® enveloping CLIC's beamline is estimated.

JINST

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Measurements of sub-nT dynamic magnetic field shielding with soft iron and mu-metal for use in linear colliders

C. Gohil,[a,b,1] P. N. Burrows[a] N. Blaskovic Kraljevic[b,2] D. Schulte[b] and B. Heilig[c]
[a] *John Adams Institute, University of Oxford, Oxford, United Kingdom*
[b] *European Organization for Nuclear Research, Geneva, Switzerland*
[c] *Mining and Geological Survey of Hungary, Budapest, Hungary*
E-mail: chetan.gohil@physics.ox.ac.uk

ABSTRACT: There is an increasing need to shield beams and accelerator elements from stray magnetic fields. The application of magnetic shielding in linear colliders is discussed. The shielding performance of soft iron and mu-metal is measured for magnetic fields of varying amplitude and frequency. Special attention is given to characterise the shielding performance for very small-amplitude magnetic fields.

A. Curcio, M. Bergamaschi, R. Corsini, W. Farabolini, D. Gamba, L. Garolfi, R. Kieffer, T. Lefevre, S. Mazzoni, K. Fedorov, J. Gardelle, A. Gilardi, P. Karataev, K. Lekomtsev, T. Pacey, Y. Saveliev, A. Potylitsyn, and E. Senes

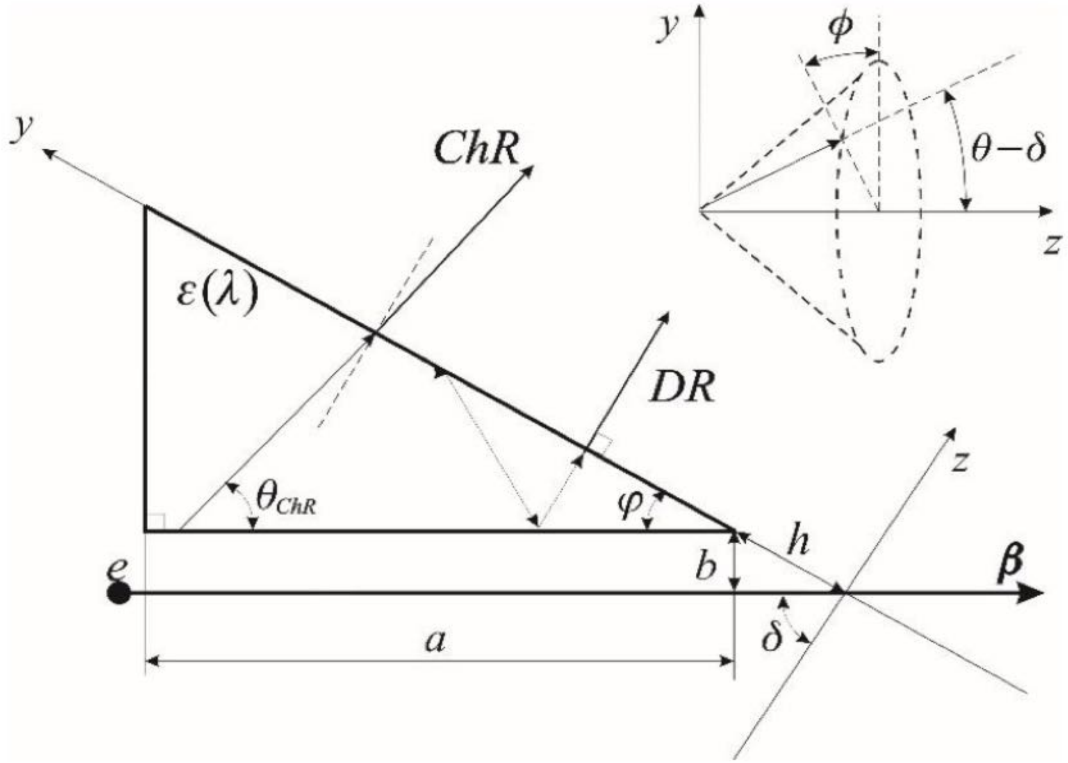
Achieved so far

- **The bunch length measurement system has been designed and installed in Beam Area 1 of CLARA facility in Daresbury Lab;**
- **The bunch length and profile has been measured and analyzed;**
- **The method has been crosschecked with the measurements at CLEAR facility at CERN;**
- **Fundamental properties of ChDR have been measured;**
- **The first studies of coherent ChDR with an Electro Optic method have been performed.**

Current Status

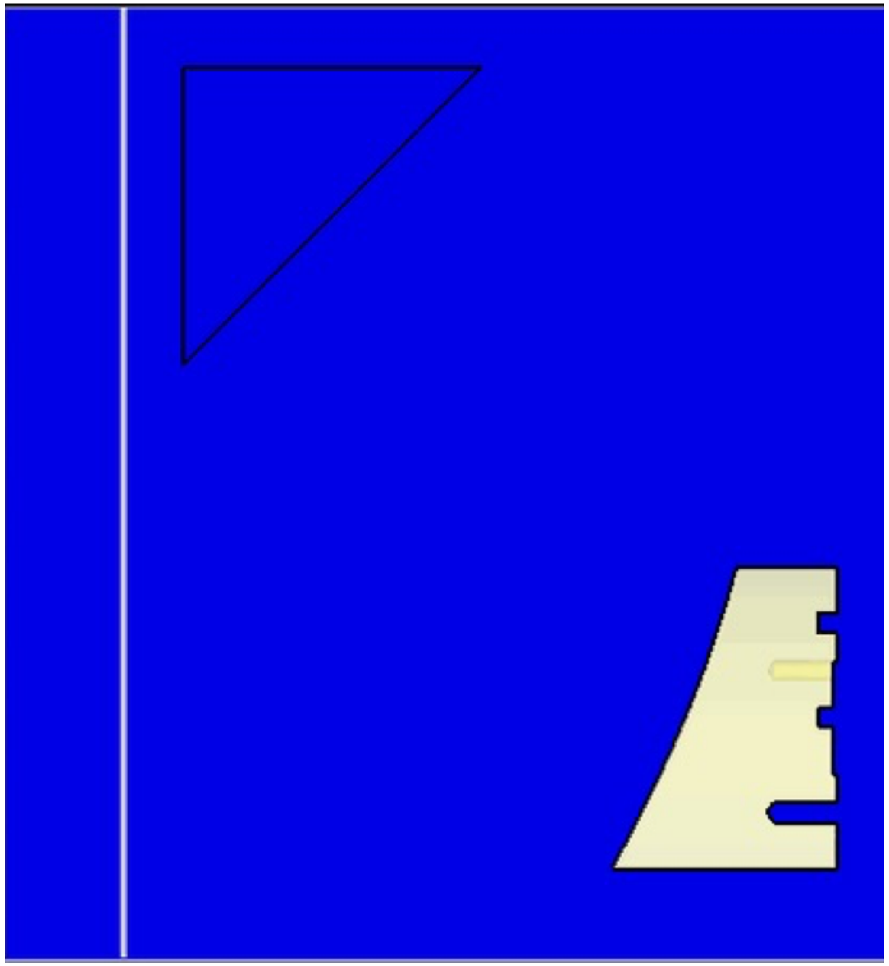
- **A bunch length monitor prototype for CLARA Phase II is being designed**

General geometry:



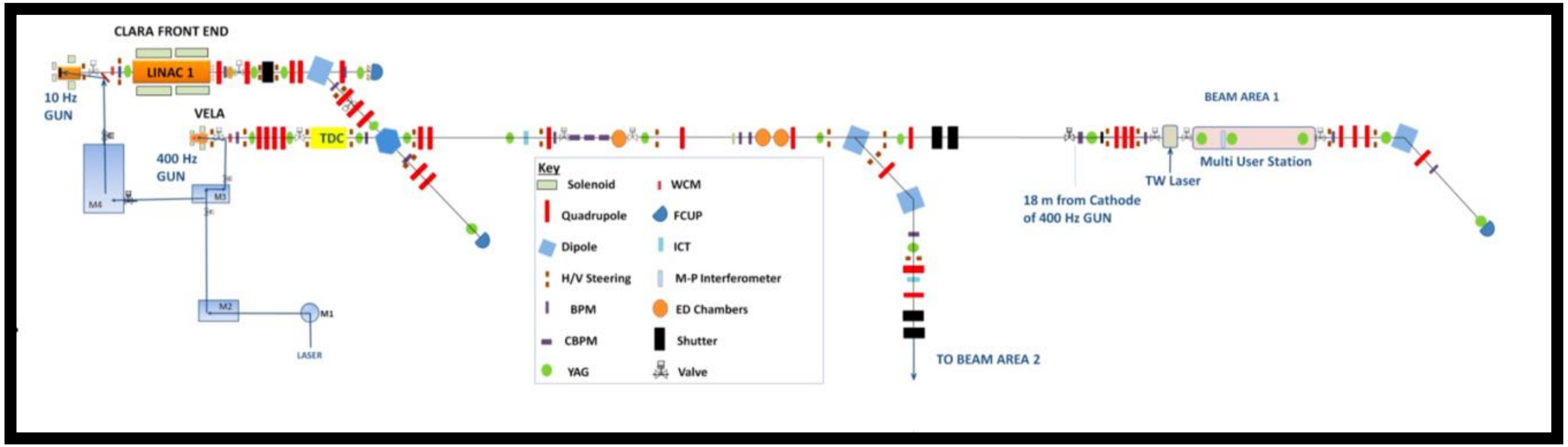
ChDR geometry

CST simulations



Clara layout and experimental arrangement

K. Fedorov, P. Karataev

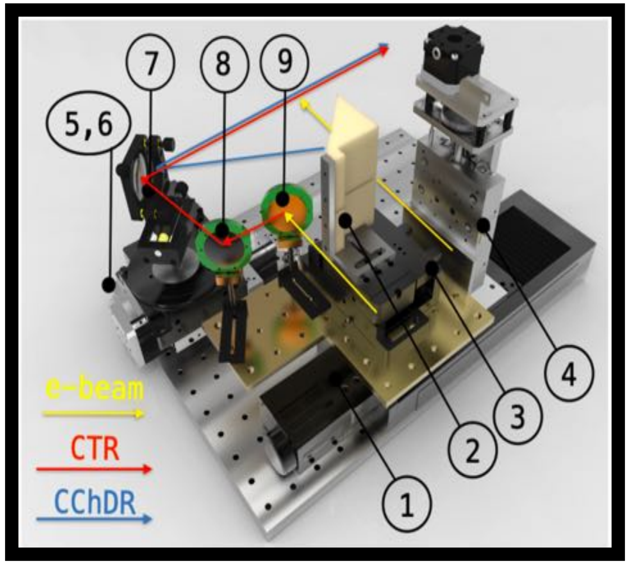


Parameters:

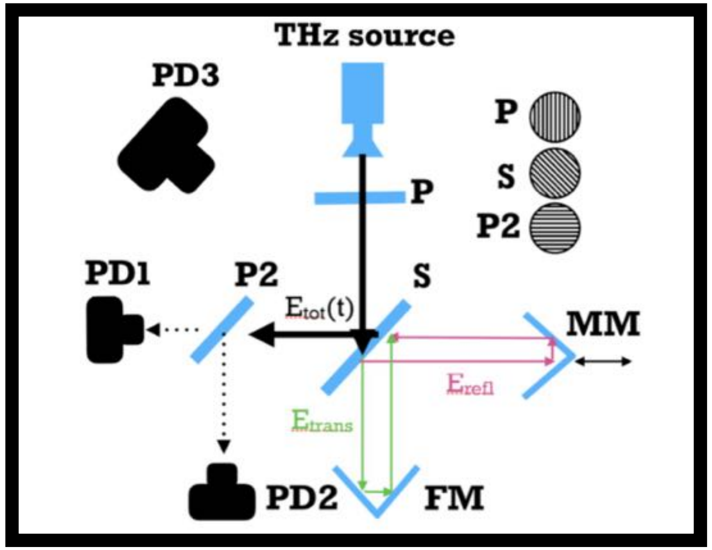
Repetition frequency ≈ 10 Hz
Bunch lengths ≈ 500 fs
Energy ≈ 35 MeV
Charge ≈ 50 pC
Transverse size ≈ 200 um

Vacuum chamber

Target assembly



Martin – Puplett interferometer



K. Fedorov -> graduated, now at RAL CLF

Bunch length measurements and comparison with CLEAR

P. Karataev et al

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Non-invasive beam instrumentation exploiting Coherent Cherenkov Diffraction Radiation

- *A. Curcio, M. Bergamaschi, R. Corsini, W. Farabolini, D. Gamba, L. Garolfi, R. Kieffer, T. Lefevre, S. Mazzoni, K. Fedorov, J. Gardelle, A. Gilardi, P. Karataev, K. Lekomtsev, T. Pacey, Y. Saveliev, A. Potylitsyn, and E. Senes, Noninvasive bunch length measurements exploiting Cherenkov diffraction radiation, Phys. Rev. Accel. Beams **23** (2020) 022802.*

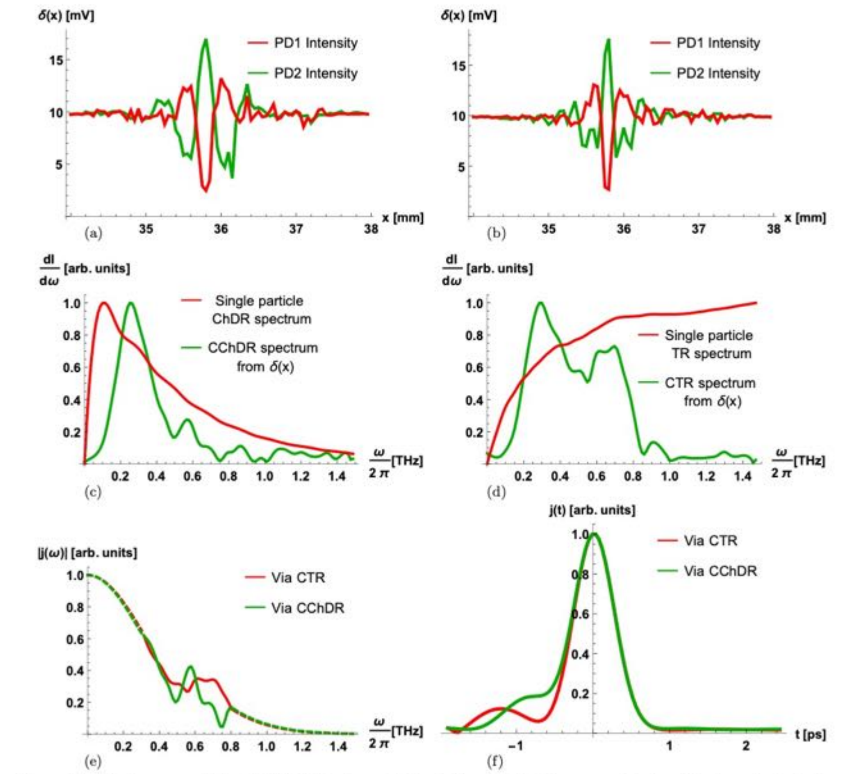


Figure 12. Interferograms of the CChDR diffraction radiation **(a)** and CTR **(b)** measured by two detectors; single electron (red) and spectra of CChDR **(c)** and CTR **(d)** derived from the corresponding interferograms; **(e)** is the extrapolated $|j(\omega)|$ for both CChDR and CTR; **(f)** is the bunch profile reconstruction via CChDR and CTR for the same accelerator settings.

CLARA

CLEAR

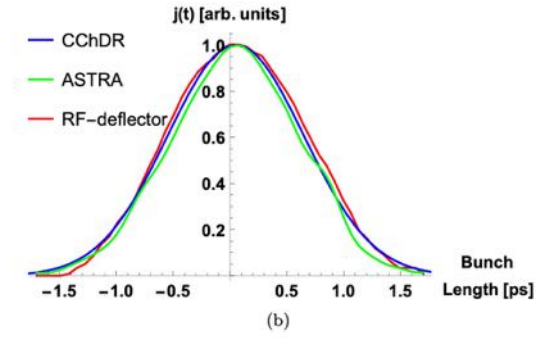


Figure 9. Top figure **(a)**: Direct comparison between the rms bunch length of Gaussian bunches as measured with the RF-deflector and by detection of CChDR. Simulation results are also reported. Bottom figure **(b)**: Comparison among bunch profiles obtained with CChDR, with RF-deflector and simulated with ASTRA, corresponding to the bunch length ~ 0.6 ps rms in Fig. 9(a).

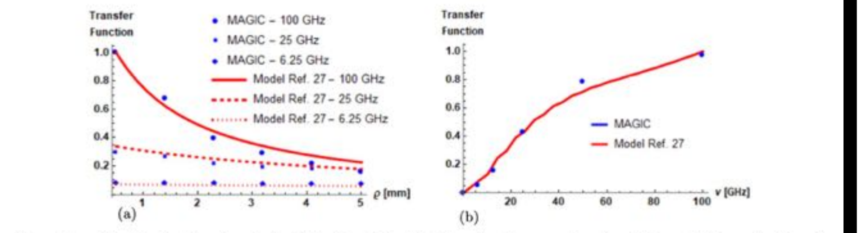
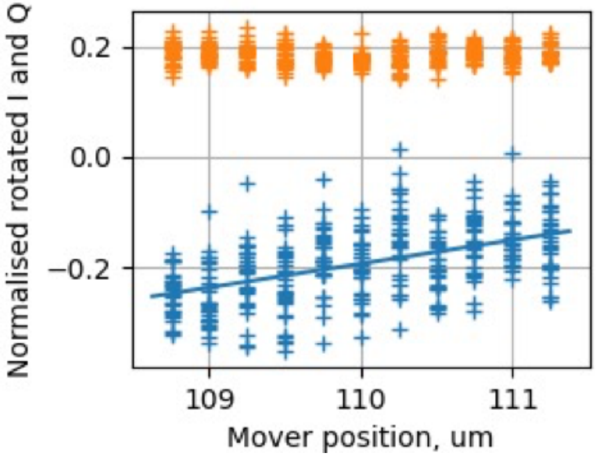


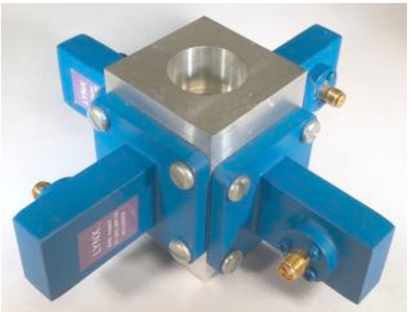
Figure 4. **a:** Transfer function of conical radiator ($\varepsilon = 2.1$) with internal radius ϱ ranging from 0.5 mm to 5 mm. **b:** Transfer function of the hollow conical radiator ($\varepsilon = 2.1$) as a function the radiated frequency.

K. Fedorov, P. Karataev, Y. Saveliev, T. Pacey, A. Oleinik, M. Kuimova, and A.Potylitsyn, Development of longitudinal beam profile monitor based on Coherent Transition Radiation effect for CLARA accelerator, Journal of instrumentation, JINST 15 C06008 (2020)

- *High resolution cavity BPMs at CLEAR*
  - 15 GHz demonstrator system for CLIC
  - Single BPM measurements successful
  - Decision for a 3-BPM test made, upgrades to a full system underway, measurement in Sept-Oct



Single CBPM test with new electronics (left): 250 nm mover steps can be observed (right)

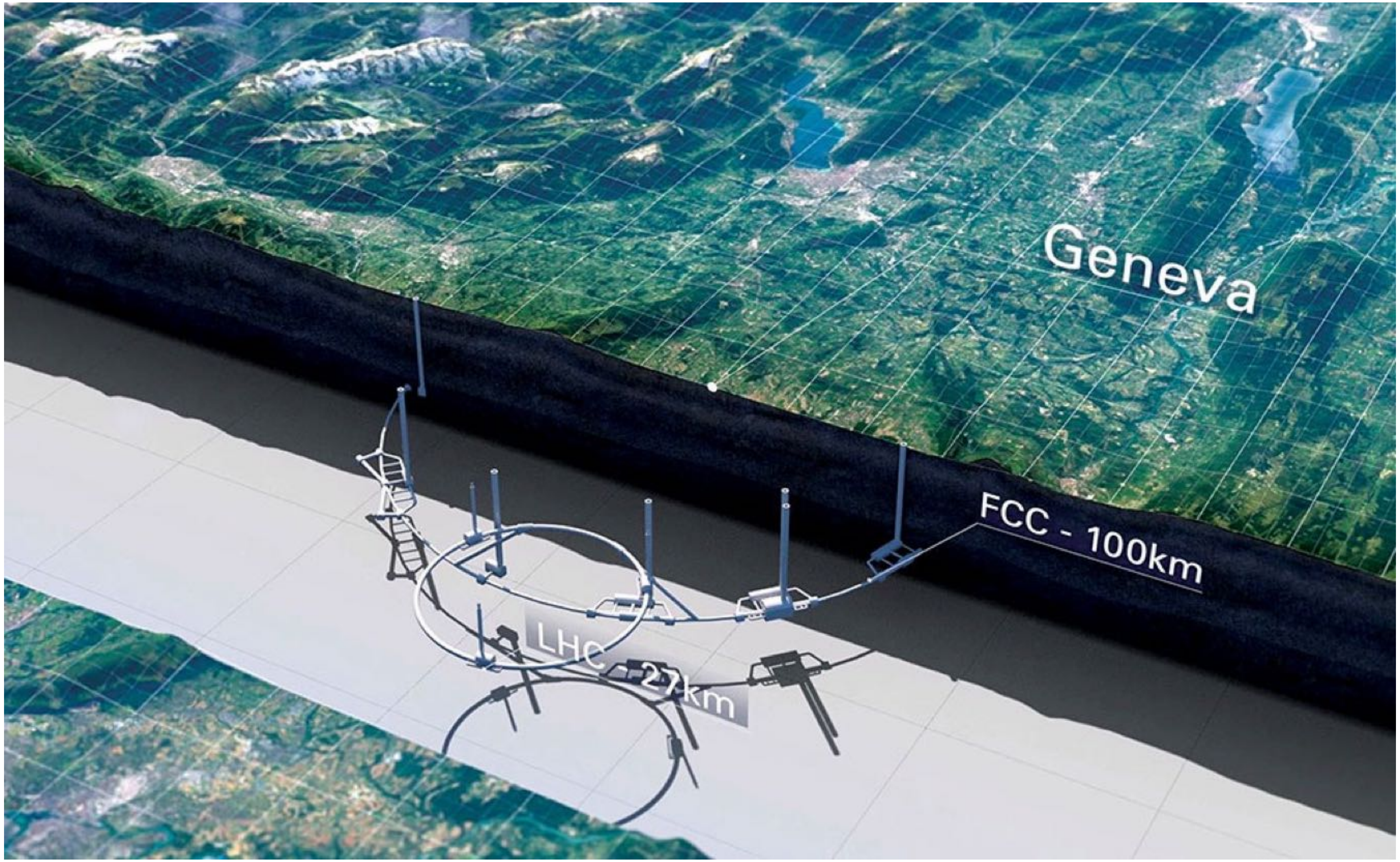


- *Waveguide BPMs*
  - Wide bandwidth
  - Design work finished, now prototyping
  - Next steps: additional funding -> beam tests

- *ATF collaboration*
  - Royal Society travel grant -> support for ATF activities
  - New ideas on long-term calibration stability and in-situ calibration

- *Wakefield evaluation for crab cavities*
  - Use GdfidL @RHUL cluster
  - Input into selecting the best design

Future Circular Collider



JAI contributions to the Future Circular Collider (ee & hh)

- *Several studies presented at last AB:*
  Consideration of various lattices & dynamic aperture ***(E. Cruz)***
  - *Determine where non-linear correctors in interaction region are needed*
  - *Explore β* options for the baseline design.*

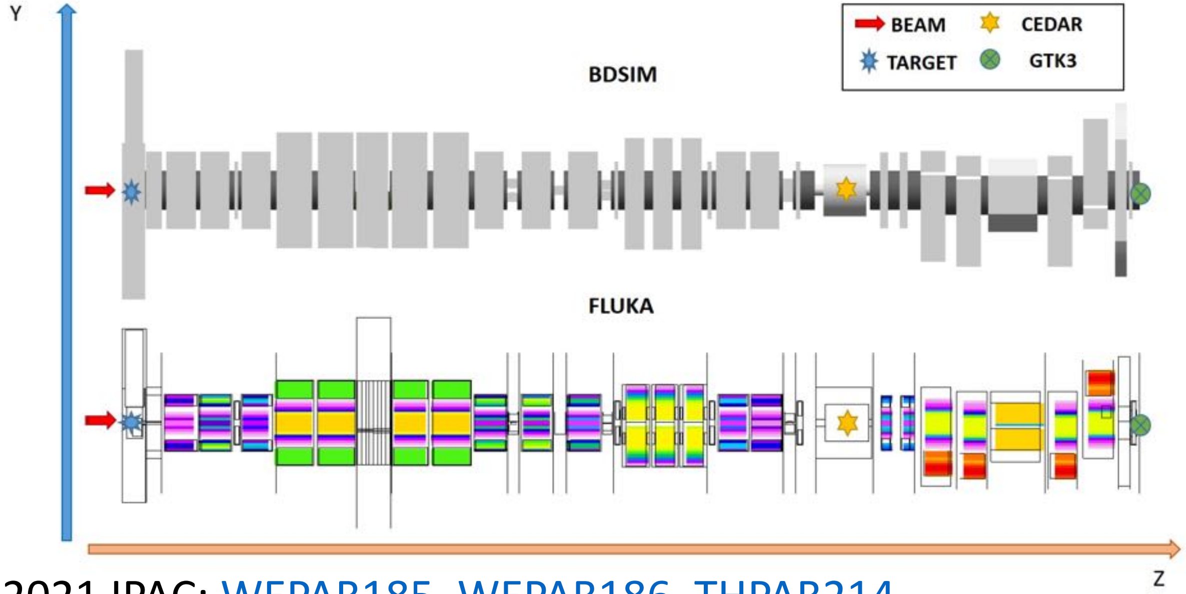
  FCC-hh ion collimation and betatron loss maps: (A. Abramov)
  - *"Ion Beam Collimation for Future Hadron Colliders', PhD thesis 2020"*
  - *A. Abramov continues with studies on FCCee collimation & tracking as a CERN Fellow:*
  - *https://indico.cern.ch/event/1085318/contributions/4582724/subcontributions/357241/attachments/2356463/4021460/CollimationSimulations-FCCISWP2-20211201.pdf*

- ***FCC-Innovation Study 2020-2024***
  - *Oxford continues as a Partner in the EU H2020 FCCIS design study project 2020-24.*
  - *Invited to consider design of the IP collision feedback system.*
  - *CERN Doctoral Student recruitment in 2022 on FCCee beam instrumentation.*
  - ***See 1st year students' presentation this afternoon on their FCC-ee Design Study (+ last year's eSPS report)***

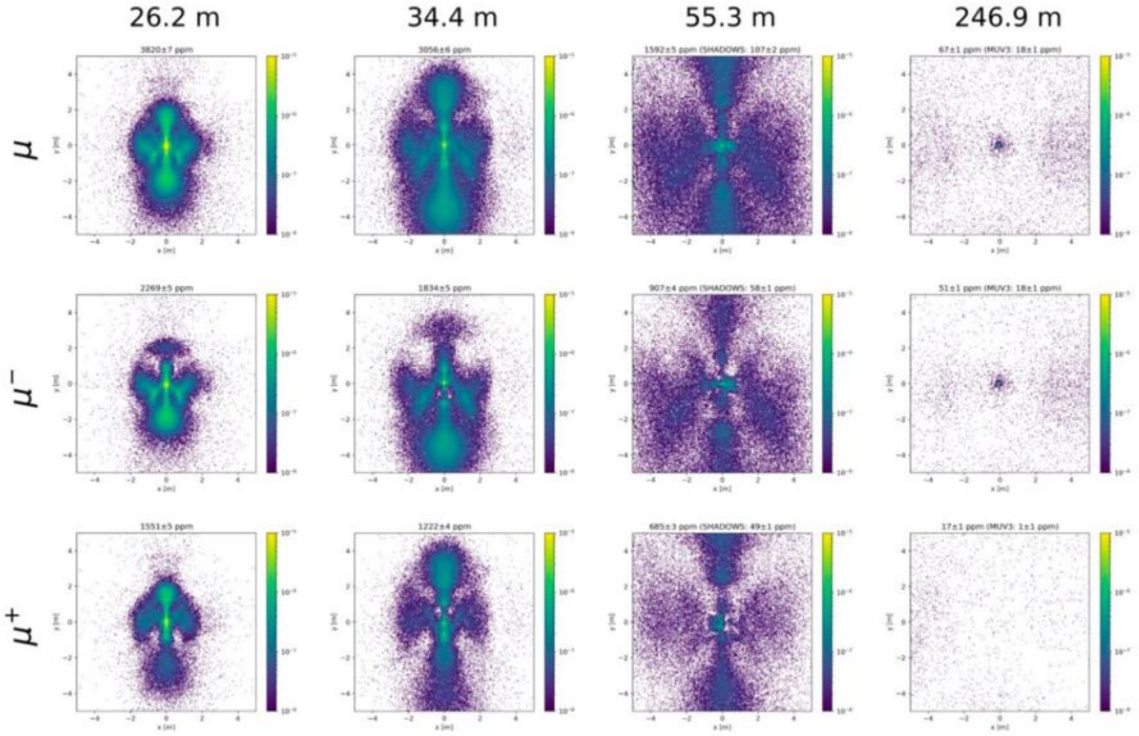
G.L. D'Alessandro, R. Murphy,
F. Stummer, + C. Mussolini (Ox)
ROYAL HOLLOWAY UNIVERSITY OF LONDON

NA62 / KLEVER

- NA62 at CERN to study rare charged Kaon decay
- Highly detailed model built by Gian Luigi D'Alessandro et al,
  - —**Successful thesis viva in Feb 2022**
- Model now integral part of MC chain for experiment



muon distribution at various planes



2021 IPAC: WEPAB185, WEPAB186, THPAB214
2021 CERN seminar: https://indico.cern.ch/event/1091199/
2022 NIM B: https://doi.org/10.1016/j.nimb.2021.11.021

A new low energy beamline for NA61/SHINE

C. A. Mussolini,
N. Charitonidis

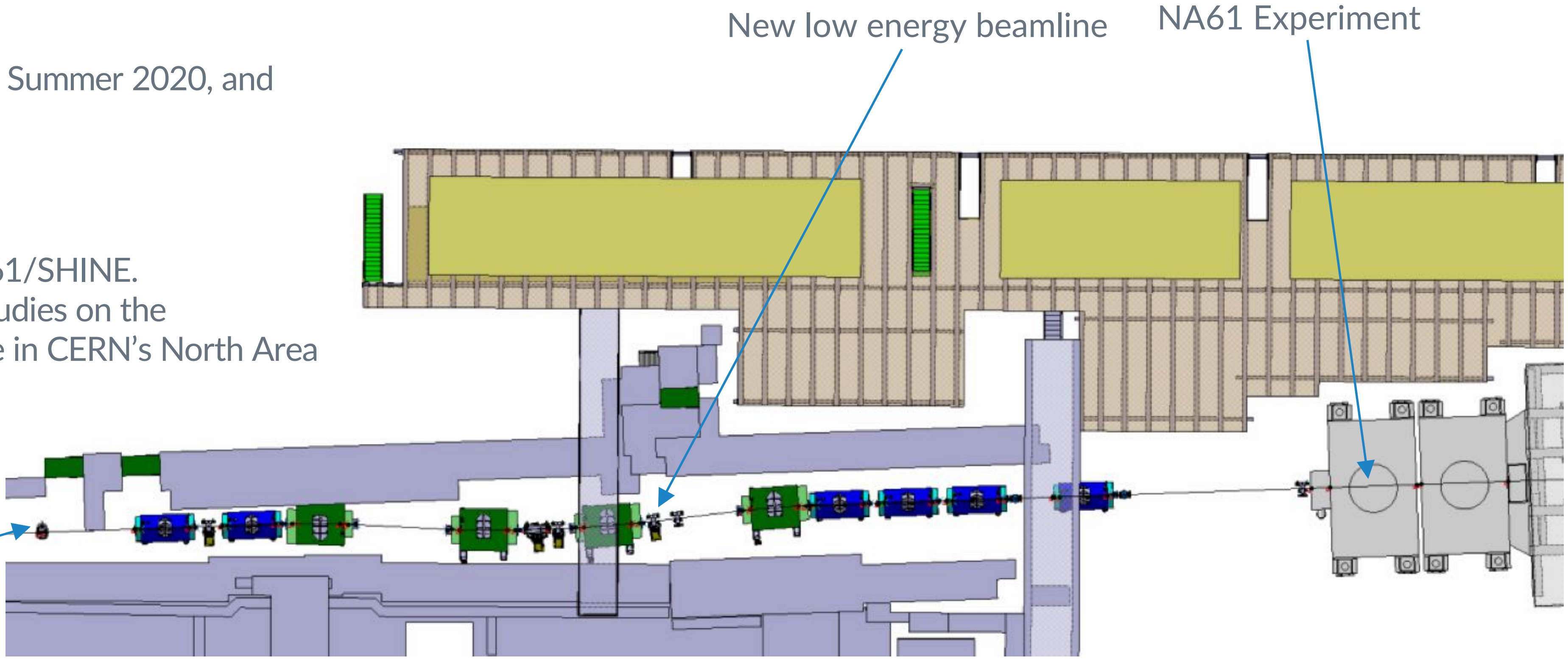
UNIVERSITY OF OXFORD

There is a lack of particle production data in the 1 – 13 GeV/c momentum range, results obtained by NA61/SHINE using this beamline could prove to be of great use in reducing the systematic uncertainties of many experiments [1]

Work on the beamline began in Summer 2020, and now we have selected:

- Targets
- Beamline optics
- Instrumentation

Which satisfy the needs of NA61/SHINE.
We are currently performing studies on the implementation of the beamline in CERN's North Area



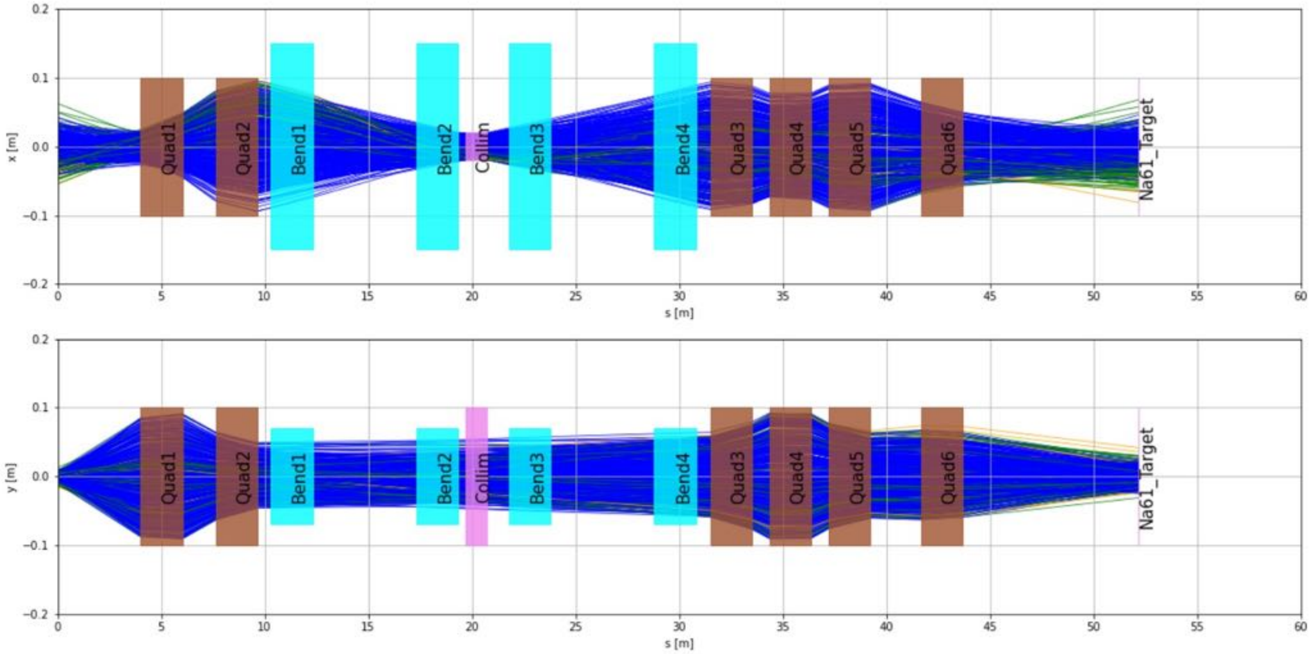
[1] "NA61/SHINE at Low Energy" workshop, December 2020

Expected performance:

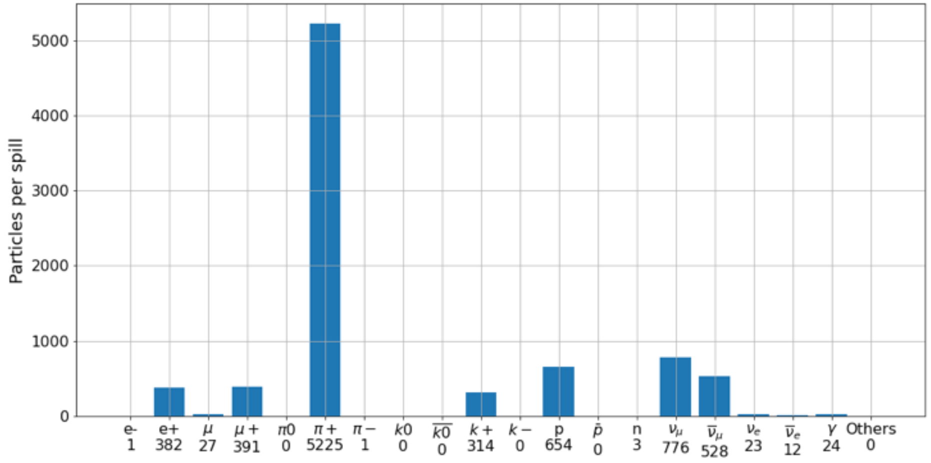
C. A. Mussolini,
N. Charitonidis

The new beamline has been extensively simulated, and the performace is meeting the requirements imposed by NA61/SHINE

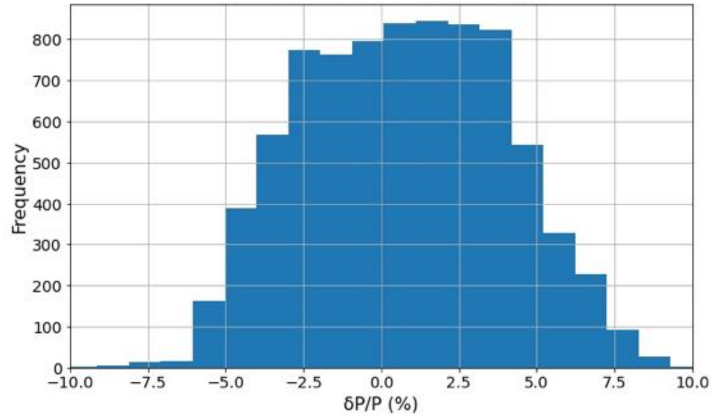
Beamline optics



Particle rates at 13 GeV/c (3000 spills/day)



Beamline relative momentum distribution



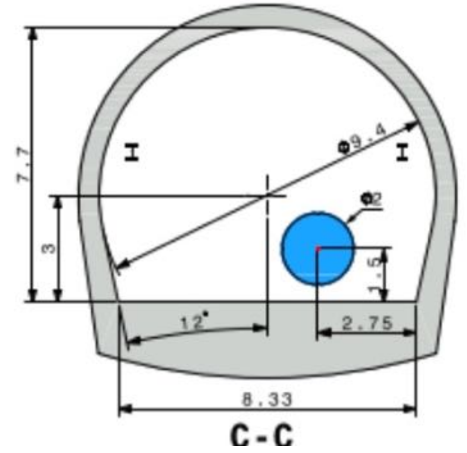
More information on the beamline, its aims and the current status can be found in the ["Addendum to the NA61/SHINE Proposal: A Low-Energy Beamline at the SPS H2"]

Forward Physics Facility (FPF) at the LHC

L Nevay, H Lefevre, S. Boogert, S Gibson

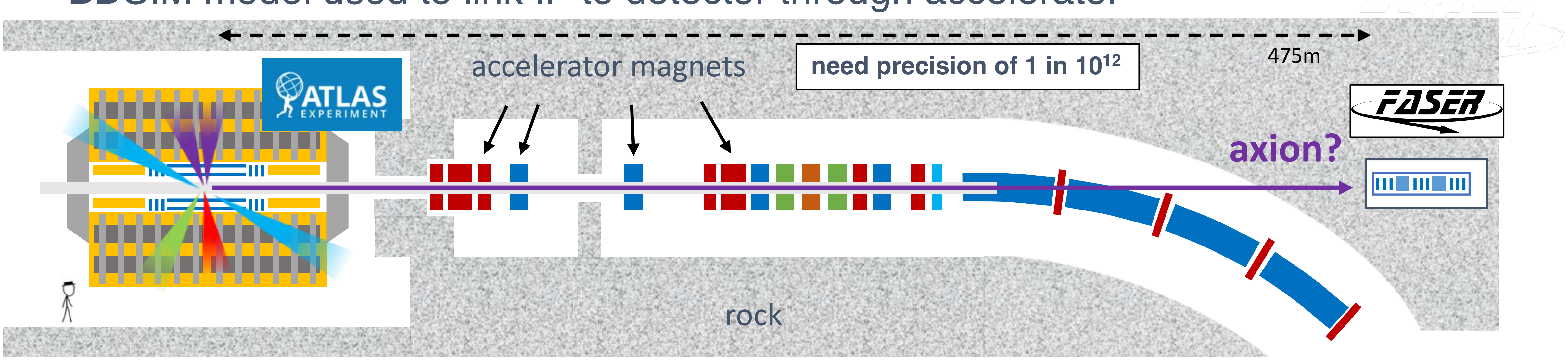
ROYAL HOLLOWAY UNIVERSITY OF LONDON

- FASER is a new experiment looking for axion-like DM
  - also measure collider-produced neutrinos for the first time
  - precision look at far-forward collision products
- FPF is a proposed new dedicated facility
  - for HiLumi LHC era (2027…)
  - workshop and Snowmass white paper early 2022



FPF new cavern cross section

- BDSIM model used to link IP to detector through accelerator



Forward Physics Facility (FPF) at the LHC

L Nevay, H Lefevre, S. Boogert, S Gibson

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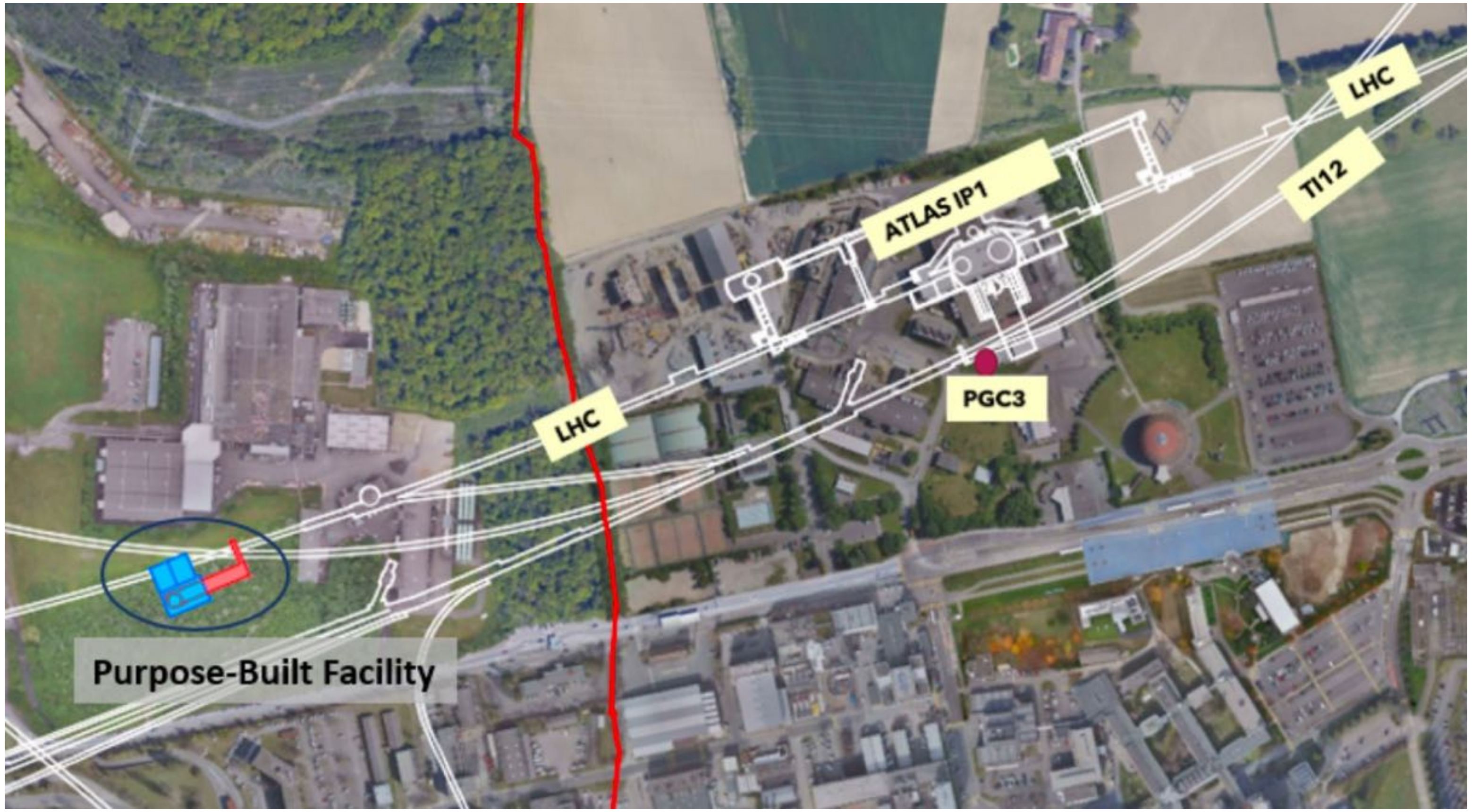

FASER collaboration meeting in June 2022
Snowmass FPF: https://arxiv.org/abs/2203.05090
Snowmass Event Generators: https://arxiv.org/abs/2203.11110

Forward Physics Facility Whitepaper
FACILITY AND EXPERIMENTS SECTIONS

Jean-Marco Alameddine,[1] Akitaka Ariga,[2,3] Tomoko Ariga,[4] Kincso Balazs,[5] Alan J. Barr,[6] Jianming Bian,[7] Stewart T. Boogert,[8] Francesco Cerutti,[5] Matthew Citron,[9] Jean-Pierre Corso,[5] Giovanni De Lellis,[10,11] Albert De Roeck,[5] Antonia Di Crescenzo,[10,11,5] Milind V. Diwan,[12] Lucie Elie,[5] Jonathan L. Feng,[7,*] Stephen Gibson,[8] Christopher S. Hill,[13] Angelo Infantino,[5] Richard Jacobsson,[5] Helena Lefebvre,[8] Josh McFayden,[14] Angel Navascues Cornago,[5] Laurence J. Nevay,[8] John Osborne,[5] Filippo Resnati,[5] Wolfgang Rhode,[1] Tim Ruhe,[1] Marta Sabate-Gilarte,[5] Alexander Sandrock,[15] Pierre Thonet,[5] Yu$_{Dai}Tsai$,[7]Wenjie Wu,[7] and Heinz Vincke[5]

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CONTENTS

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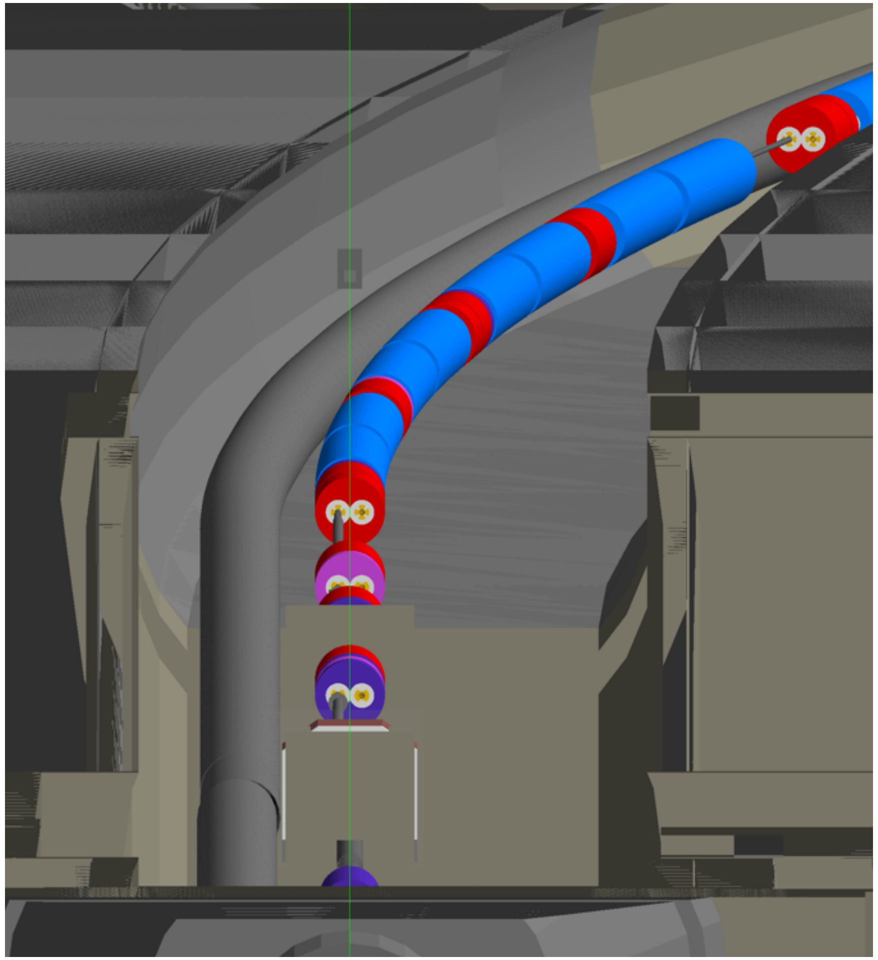
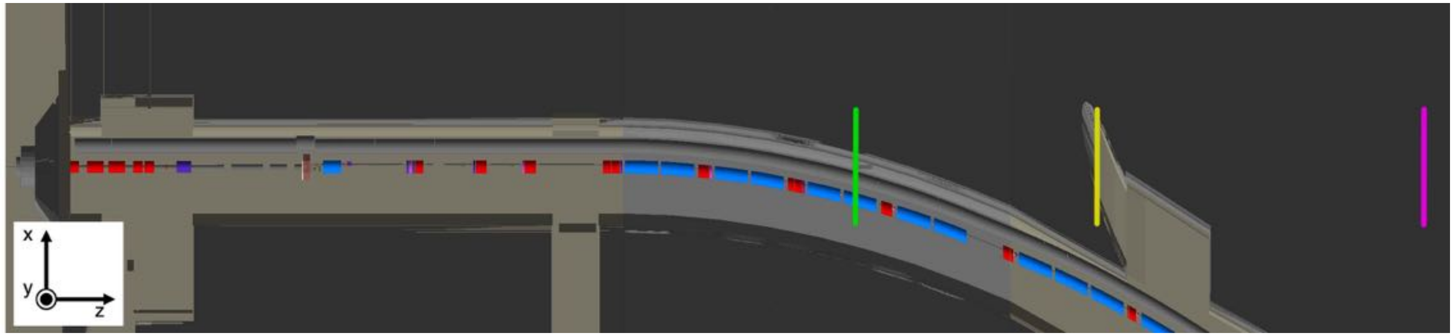
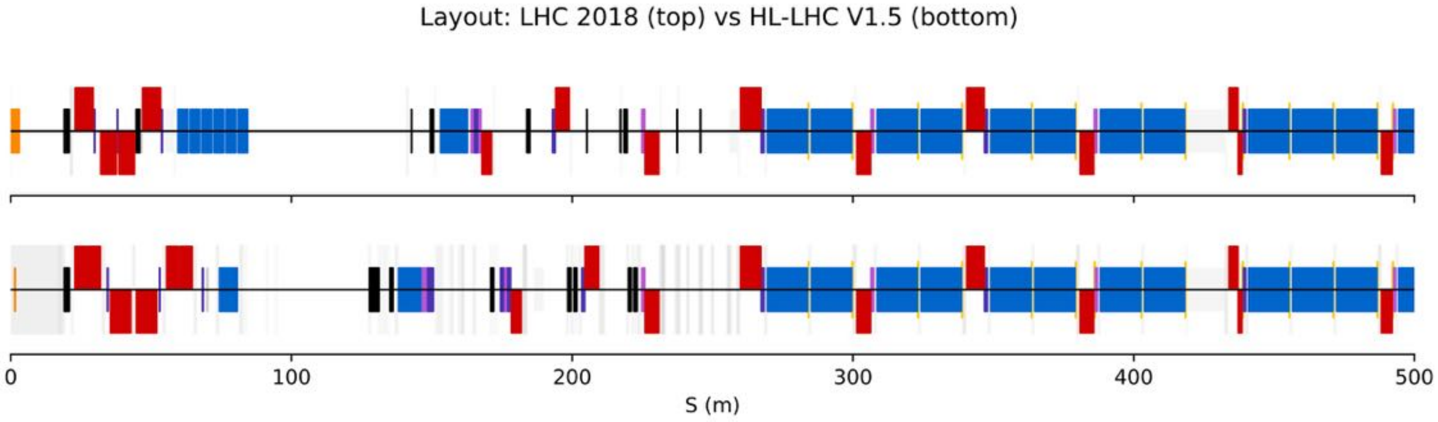
Model in BDSIM

L Nevay, H Lefevre,
S. Boogert, S Gibson



beam line view from IP1 towards FPF





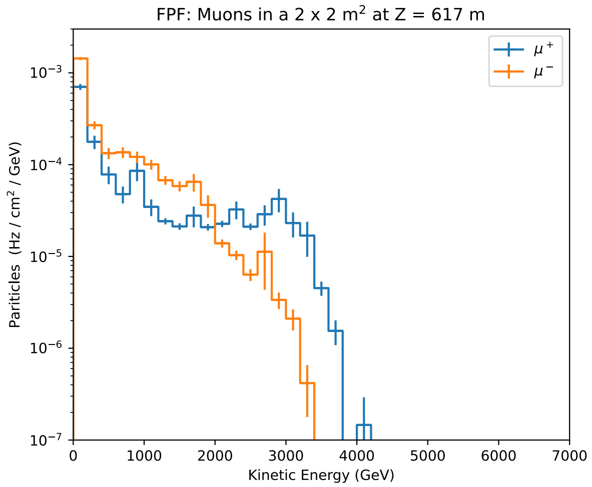
LHC vs HL-LHC machine layout along S

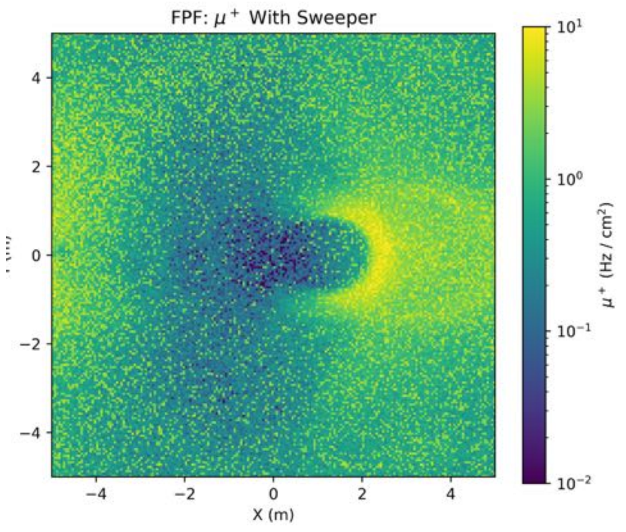
Geometry composited using [pyg4ometry](https://doi.org/10.1016/j.cpc.2021.108228)
Comp. Physics Com. 272, March 2022, 108228.
https://doi.org/10.1016/j.cpc.2021.108228

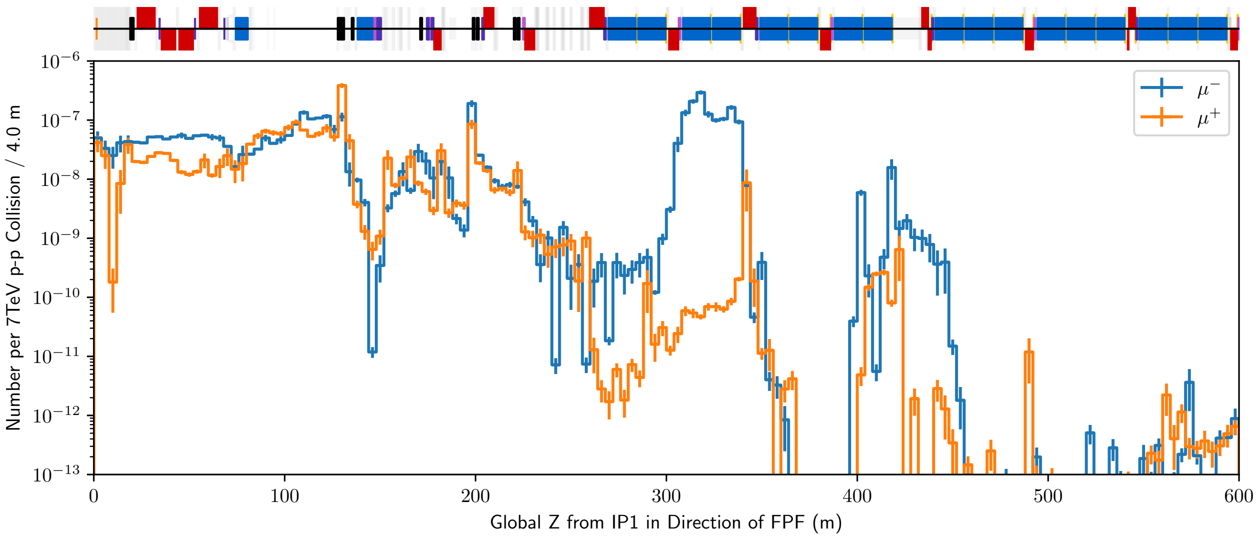
FASER & FPF Fluxes

L Nevay, H Lefevre,
S. Boogert, S Gibson

- Detailed LHC and HL-LHC models created
  - geometry composited with pyg4ometry
- Muon and neutrino fluxes predicted for FASER and FPF
- BDSIM making crucial contribution to predicting and understanding the origins of backgrounds as well as signal propagation
  - for both FASER and FASERν
- Investigation of sweeper magnet(s) for FPF being investigated
  - muons are critical background for proposed experiments
- Cross-section and splitting biasing schemes required
  - require precision of 1 in 10^{12} (1x simulation = 100k cpu-hours)
  - new muon splitting (+ other biasing) reduces to ~5k cpu-hours (potential application to NA62)
- Presented at 4th FPF Workshop
  - https://indico.cern.ch/event/1110746/







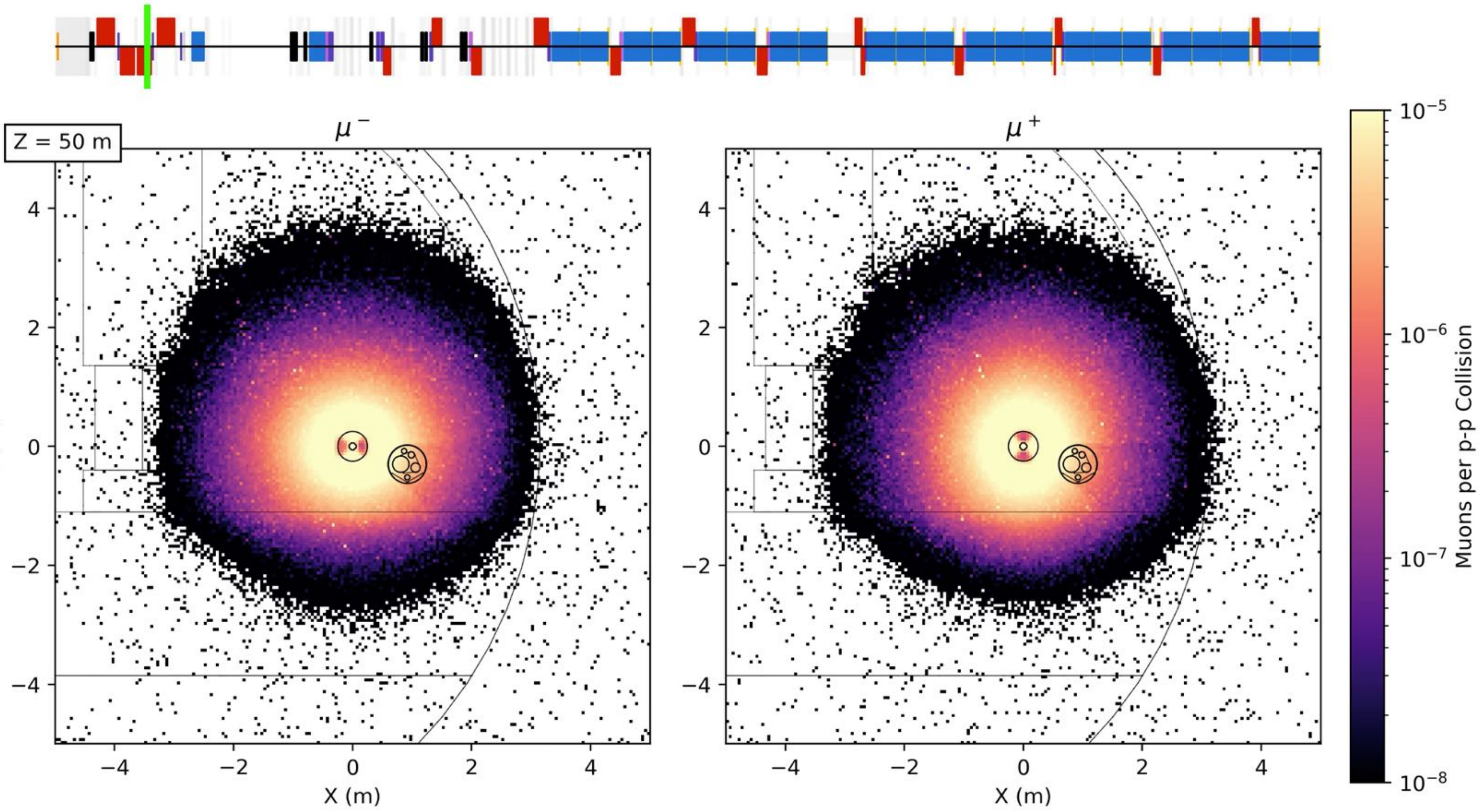
L Nevay, H Lefevre,
S. Boogert, S Gibson

BDSIM's particle filtering capabilities allow us to understand the origin of backgrounds, e.g.:

Muon flux at HL-LHC when looking back at IP1 and moving backwards along global Z in 2m steps

Lower right shadow is the QRL cryogenic line

Dispersion ramping up in the arc causes a little beam loss at end, which in turn produces muons.

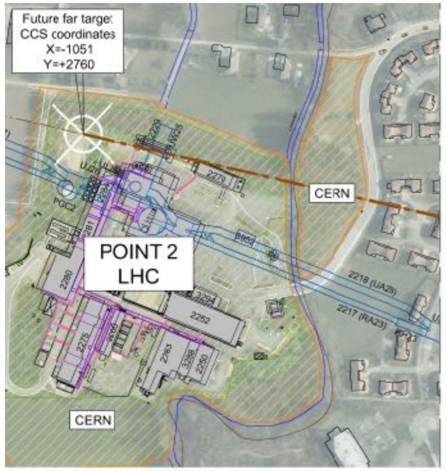


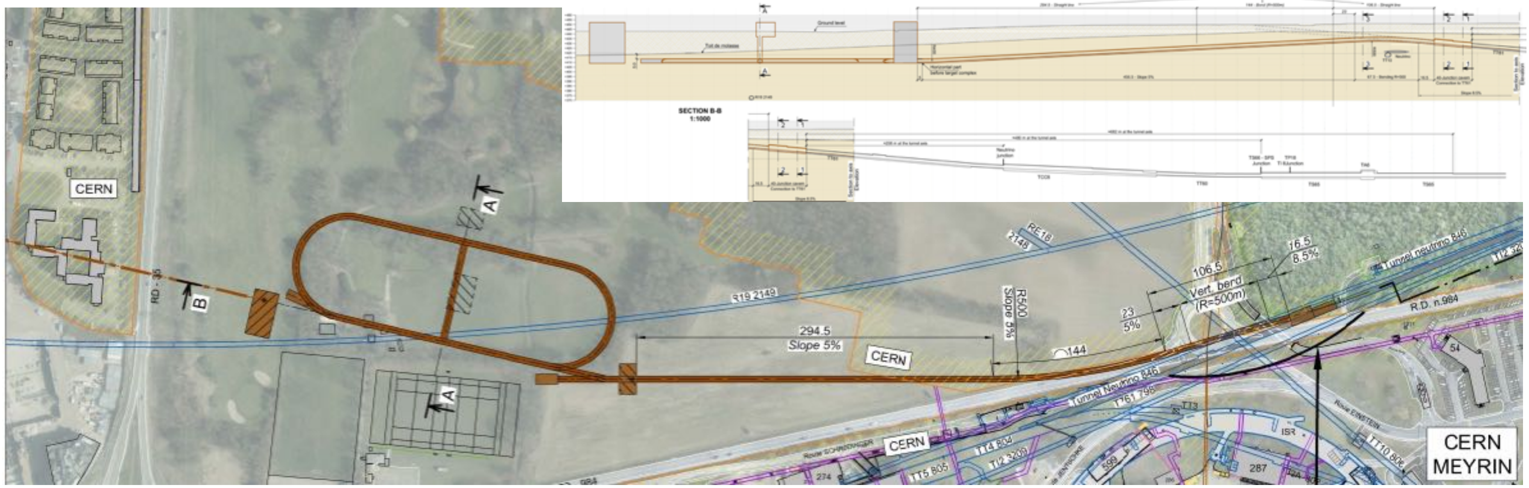
nuStorm overview:

Ken Long
Imperial College London

CERN-PBC-2019-003

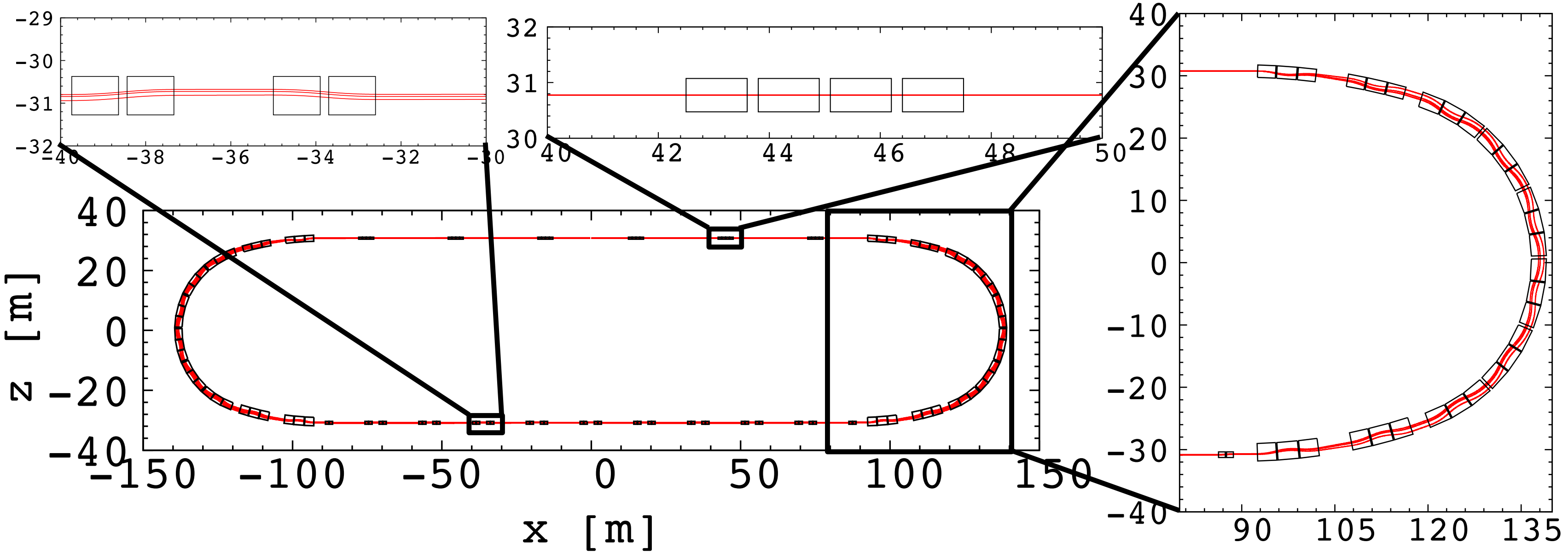
Extraction from SPS through existing tunnel
Siting of storage ring: Allows measurements to be made 'on or off axis'
Preserves sterile-neutrino search option





New design for decay ring:

- Central momentum between 1 GeV/c and 6 GeV/c;
- Momentum acceptance of up to ±16%

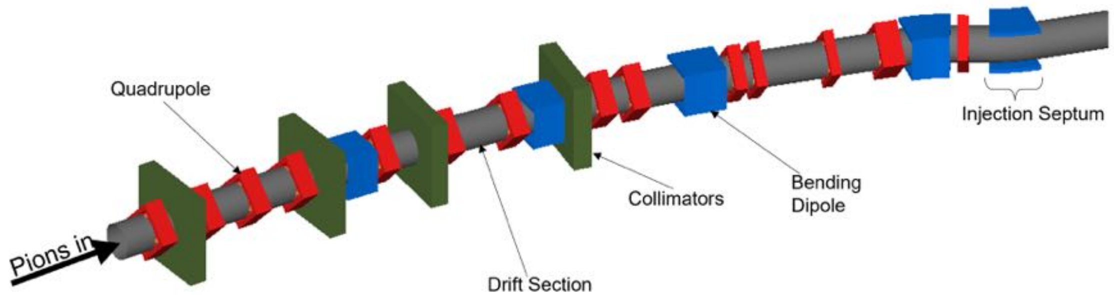


Studies of the nuSTORM facility

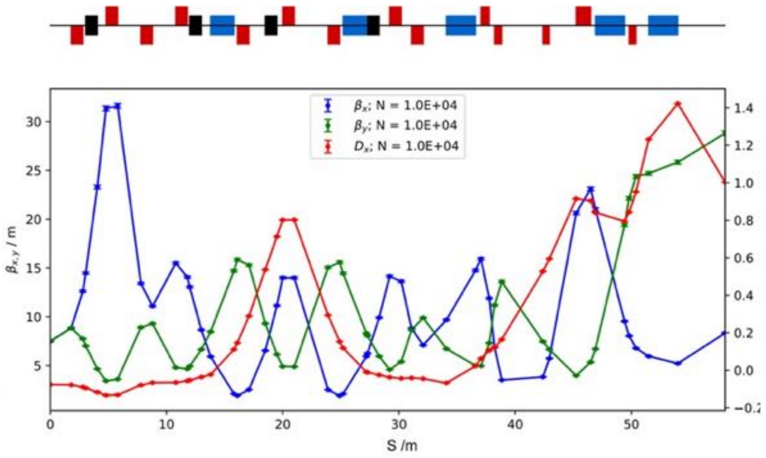
J. Pasternak, K. Long et al

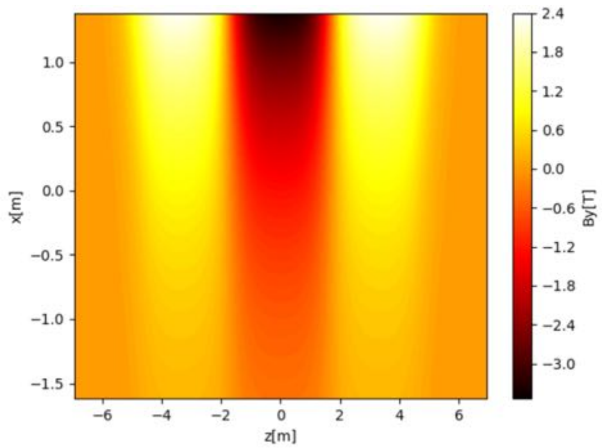
Imperial College London

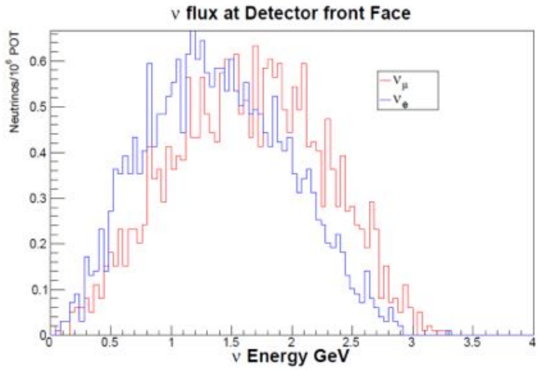
- BDSIM model of the pion injection line was created (T. Alves)
  - New simulation of pion production at the target was performed using FLUKA and used as the input
    - Comparison with MARS shows promising agreement
  - Matching to the ring injection system was improved
  - Approximate model of the Orbit Combination Section (OCS) was created together with the BDSIM model of the production straight
    - 2D field map of the proper OCS was created
    - Muon capture efficiency was estimated
- This study allowed to make the first attempt to estimate the expected flux per POT for different energies (M. Pfaff)



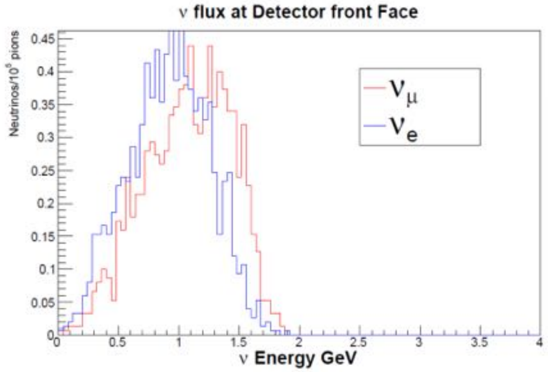
Layout of the pion injection line created using BDSIM







Flux for 5 GeV/c pions storage



Flux for 3 GeV/c pions storage

Future plans:

- 3D field map for the OCS
- Extension of the BDSIM model to incorporate the full ring
- Design of the ring instrumentation
- R&D for Muon Collider (6D Cooling Demo) using the nuSTORM facility – see next slide

Studies of a Muon Collider

J. Pasternak, K. Long et al

Imperial College London

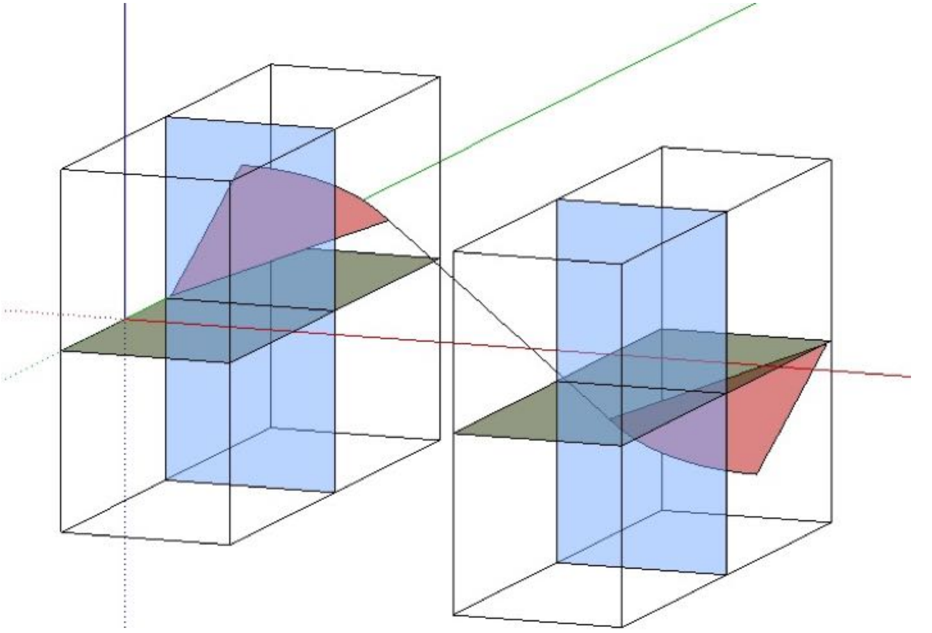
International MUON Collider Collaboration

Recent studies include:

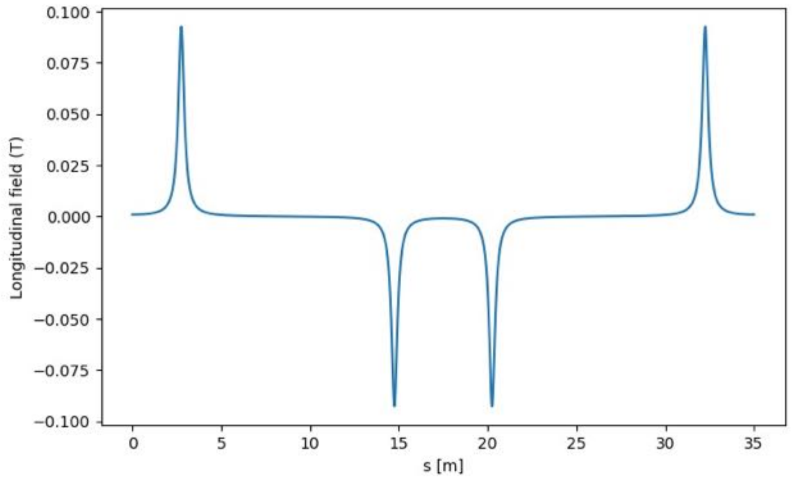
- R&D on VFFA – a candidate for a muon accelerator
  - Modelling of the optics in VFFA (M. Topp-Mugglestone)
  - Design of the extraction system
  - Studies focus on the demonstrator in the context of R&D for ISIS-II
- Investigation of the use of the nuSTORM facility to feed the 6D Cooling Demo
- Building model of the 6D Cooling Demonstrator in BDSIM (see next slide)

Future plans (subject to a success of the EU-DEV grant, UK PI - C. Rogers):

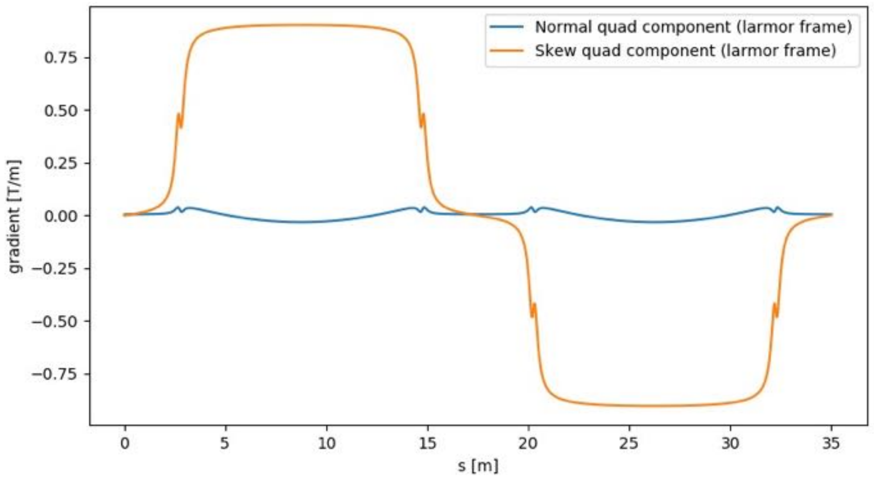
- Work on MDI - Oxford
- Further work on 6D Cooling DEMO – (Imperial, RHUL)



3D orbit geometry in the FODO cell of a muon accelerator for a MC



Longitudinal field along the orbit in the FODO cell of a muon accelerator for a MC

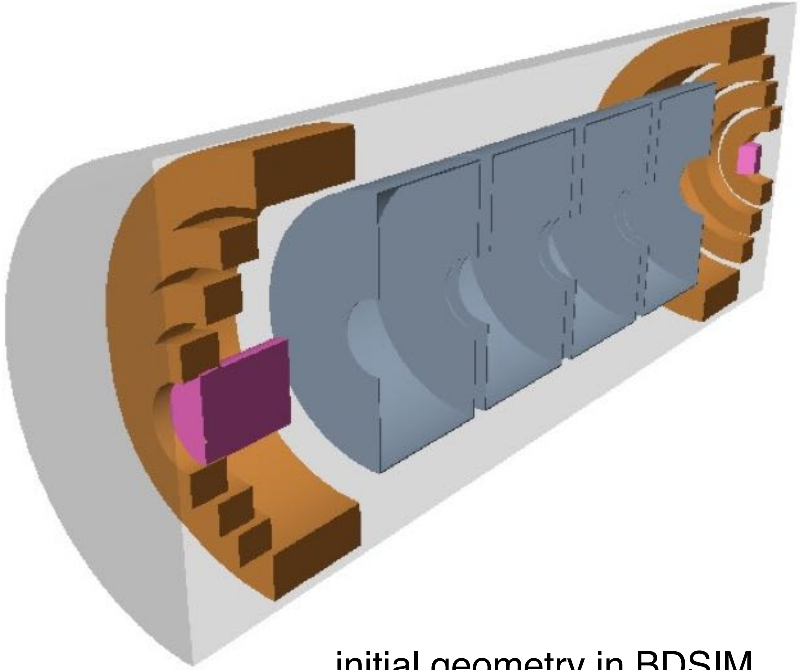


Normal and skew quad components along the orbit in the FODO cell of a muon accelerator for a MC

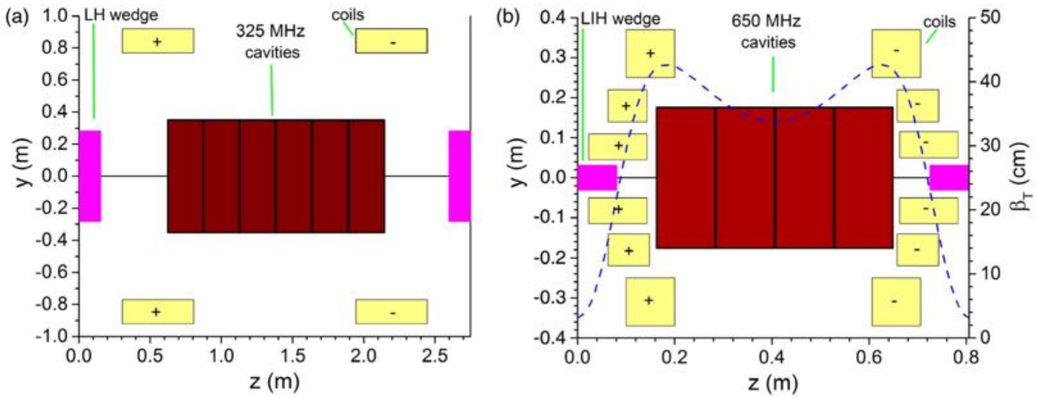
Implementation of Muon Cooler

C. Rogers (STFC)
L. Nevay, S. Boogert

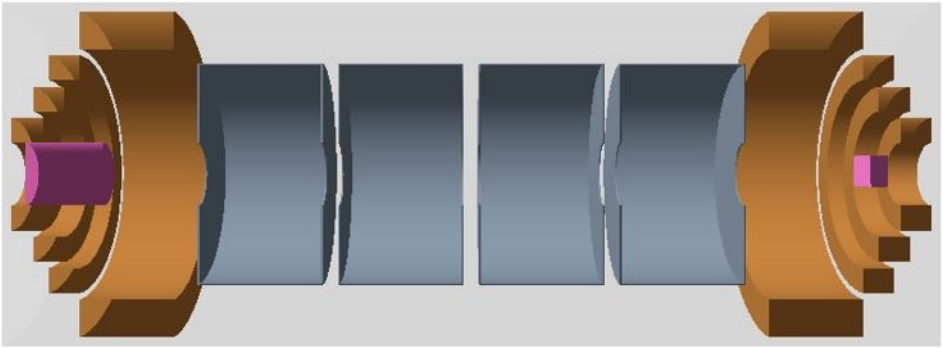
- *Aim to reproduce 6D muon cooling with BDSIM and compare to ICOOL*
  – access the latest Geant4 physics and other BDSIM geometry
- *Variety of solenoid coils; absorber wedges and RF cavities required*
  – Complex field generated based on user-input describing coils
- *Initial geometry and 'sheet' solenoid field created*
  – further work for full 3D coil summation
- *Presented at UK Muon Collider and nuSTORM 2nd Collaboration Meeting*



initial geometry in BDSIM



PR-STAB 18 031003 (2015) https://doi.org/10.1103/PhysRevSTAB.18.031003



Moon beams ?

A very high energy hadron collider on the Moon

James Beacham[1,*] and Frank Zimmermann[2,†]

[1] *Duke University, Durham, N.C., United States*

[2] *CERN, Meyrin, Switzerland*

(Dated: June 17, 2021)

The long-term prospect of building a hadron collider around the circumference of a great circle of the Moon is sketched. A Circular Collider on the Moon (CCM) of ∼11000 km in circumference could reach a proton-proton center-of-mass collision energy of 14 PeV — a thousand times higher than the Large Hadron Collider at CERN — optimistically assuming a dipole magnetic field of 20 T. Siting and construction considerations are presented. Machine parameters, powering, and vacuum needs are explored. An injection scheme is delineated. Other unknowns are set down. Through partnerships between public and private organizations interested in establishing a permanent Moon presence, a CCM could be the (next-to-) next-to-next-generation discovery machine and a natural successor to next-generation machines, such as the proposed Future Circular Collider at CERN or a Super Proton-Proton Collider in China, and other future machines, such as a Collider in the Sea, in the Gulf of Mexico. A CCM would serve as an important stepping stone towards a Planck-scale collider sited in our Solar System.

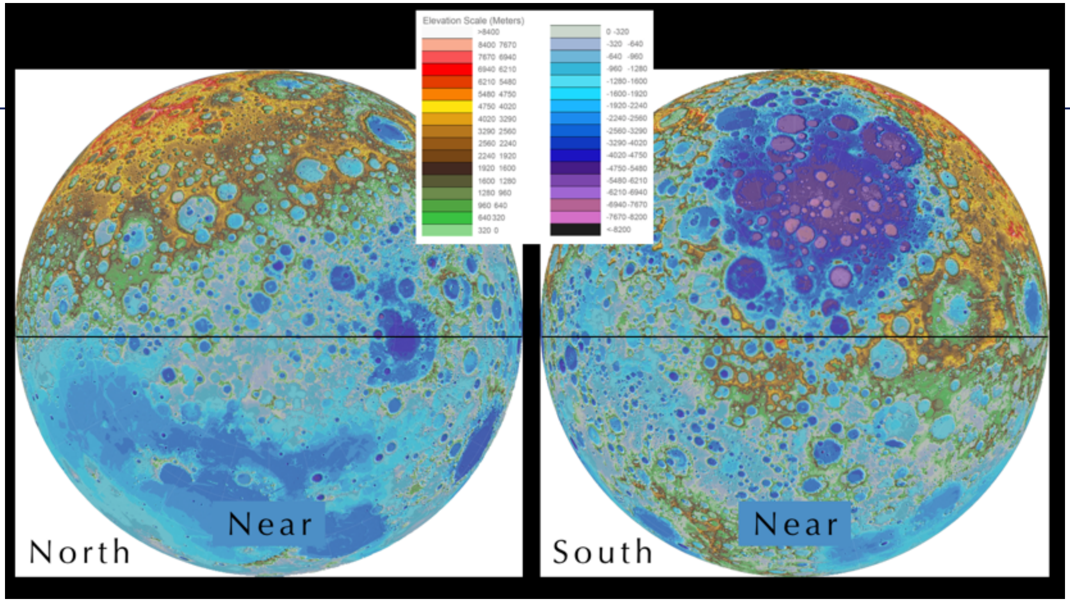


FIG. 2. Schematic possible trajectory (black line) of a Circular Collider on the Moon (CCM) that could potentially avoid several major elevation changes, though not all. In the left image the north pole of the Moon is centered, while in the right image the south pole is centered. Images modified from Ref. [31]; the originals were constructed with data collected by the Lunar Reconnaissance Orbiter [32–36].

Parameter	CCM	FCC-hh	HL-LHC
Max. beam energy E_{beam} [TeV]	7,000	50	7
Circumference C [km]	11,000	97.8	26.7
Arc dipole magnet field B_{dip} [T]	20	16	8.3
Luminosity / IP L [10^{34} cm^{-2}s^{-1}]	∼20,000	∼30	5 (leveled)
Number of events/crossing (pile-up)	$\sim 10^6$	∼1000	135
Max. integrated lum./experiment [ab^{-1}/y]	∼2000	1.0	0.35

TABLE I. Tentative proton-proton parameters for CCM, compared with FCC-hh and HL-LHC [40].

Summary

- *EU Accelerator Roadmap published with UK & JAI authors, in all 5 technology pillars.*
- *Collaborative UK effort on funded HL-LHC phase-II project, with leading JAI contributions:*
  - *Optics studies published, crystal collimation for Run 3, successful beam tests of EO-BPM+SR diagnostics.*
- *Strategically positioned to help guide next steps for a international linear collider with leading contributions to final beam delivery, Cherenkov and CBPM diagnostics.*
- *FCC-IS underway, building on previously reported JAI studies.*
- *Physics Beyond Colliders: a rich and growing programme that benefits from BDSIM and geometry software: NA61&62, KLEVER, SHADOWS, FASER, FPF…*
- *JAI expertise also being applied to nuSTORM & muon collider studies.*
- *JAI is making key contributions to future colliders & beamlines!*

Thank you!