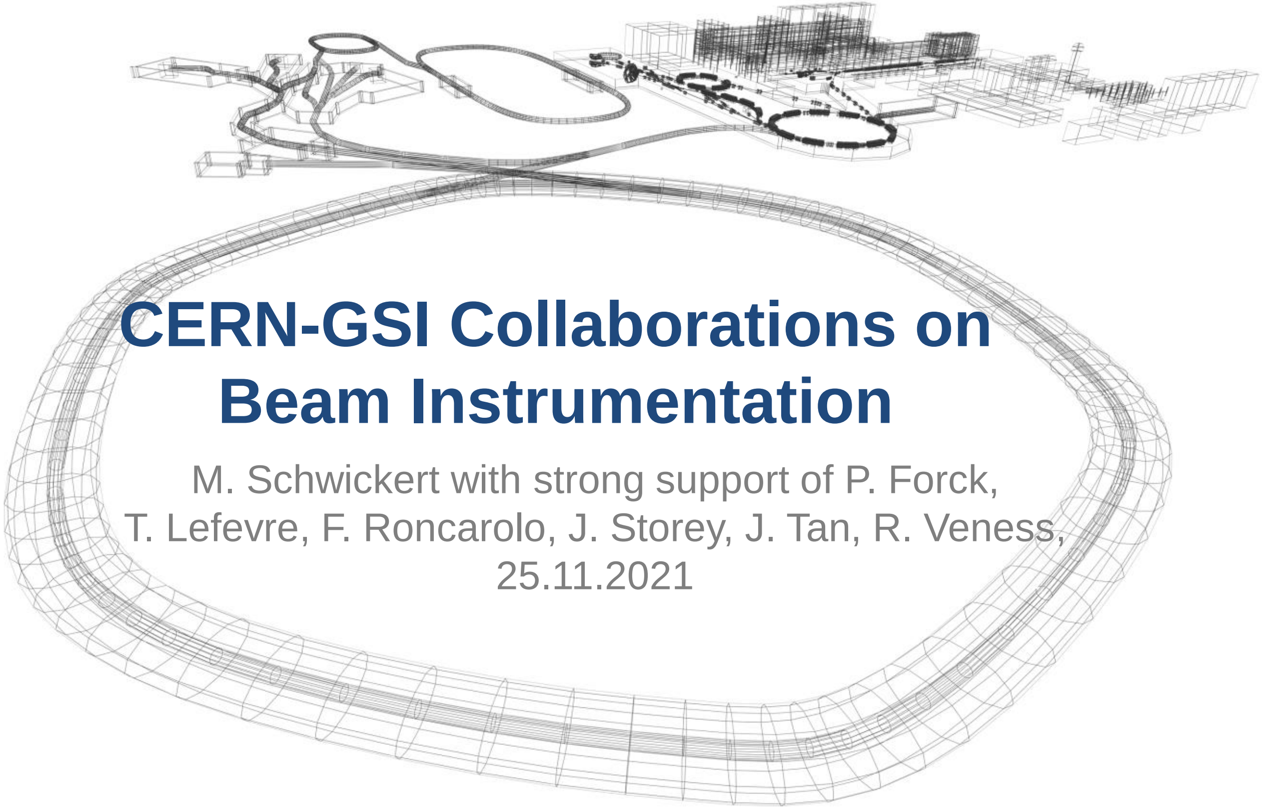


CERN-GSI Collaborations on Beam Instrumentation

M. Schwickert with strong support of P. Forck,
T. Lefevre, F. Roncarolo, J. Storey, J. Tan, R. Veness,
25.11.2021

Outline

- Fields of Collaboration between BI departments at CERN and GSI

  1. Collaborative support for development of **Cryogenic Current Comparators**
  2. GSI Support to CERN **e-lens** studies
  3. Common developments on **FESA integration** of diagnostic devices
  4. Software and data analysis for **Ionization Profile Monitor**
  5. Control system integration of **Bunch Shape Monitor**
  6. **SEM-Grid** developments for high-intensity beams

- Summary and Next Steps

Cryogenic Current Comparator

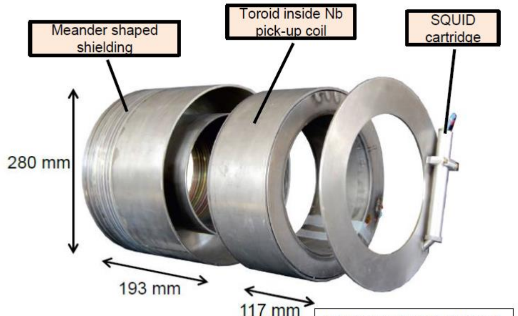
- Cryogenic Current Comparators can measure very low beam currents in nano-ampere range
- CCC Detectors were developed **in large collaboration:** GSI, CERN, University Jena, Helmholtz-Institute Jena, IPHT Jena and TU Darmstadt (partly funded by German Science Ministry, "Verbundforschung")
- One CCC developed in this collaboration, is a standard tool used at the **CERN AD**
- **Five CCCs required for FAIR** (storage rings and transfer lines for slow extraction)
- CCC is being considered for **CERN-ELENA**, or recently for **slow extraction from SPS**
- Common developments e.g. for a cost-effective magnetic shielding and liquid-He-cryostat as well as the improvement of noise reduction
- Proposal to install a CCC at **COSY / Jülich**

Successfully accomplished:

GSI + Verbundforschung-Partner:
CCC prototype, improvement of CCC detector, e-m simulation of magnetic shield, flux concentrator, SQUID system and readout electronics

CERN:
development, installation and commissioning of CCC for AD

CCC detector developed by U Jena / HIM / GSI, now installed in CERN-AD



[Figures: courtesy R. Geithner]

Future topics at rings and transfer lines

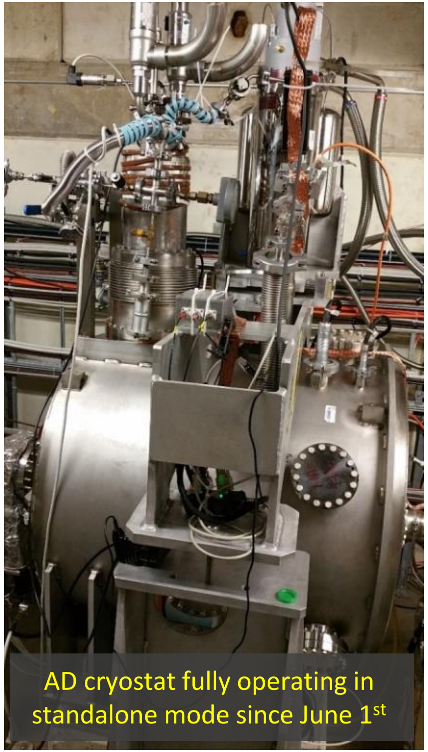
CERN: - development of CCC for ELENA
- participate in CCC series production for FAIR, e.g. for slow extraction from SPS

GSI: - optimization of first-of-series CCC inside Cryring
- manufacture and installation of 5 CCCs for FAIR (German In-Kind)

Involved Persons CERN:
J. Tan, L. Soby, M. Wendt, R. Jones

Involved Persons GSI:
T. Sieber, D. Haider,
L. Crescimbeni, M. Schwickert
+ U Jena + Helmholtz Institute Jena
+ TU Darmstadt + IPHT Jena

Cryogenic Current Comparator

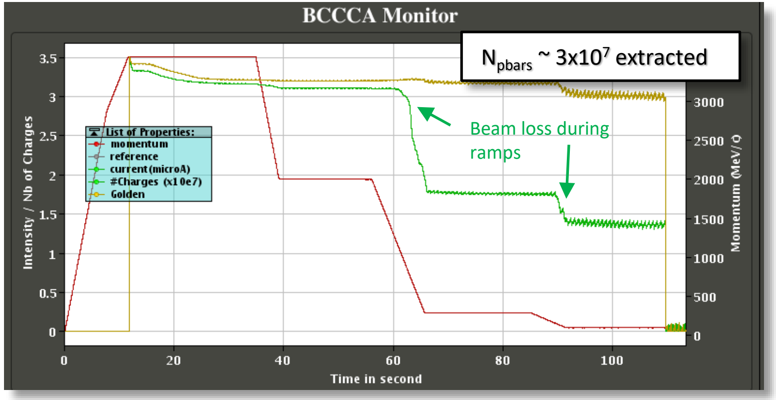


Highlights of the AD's CCC

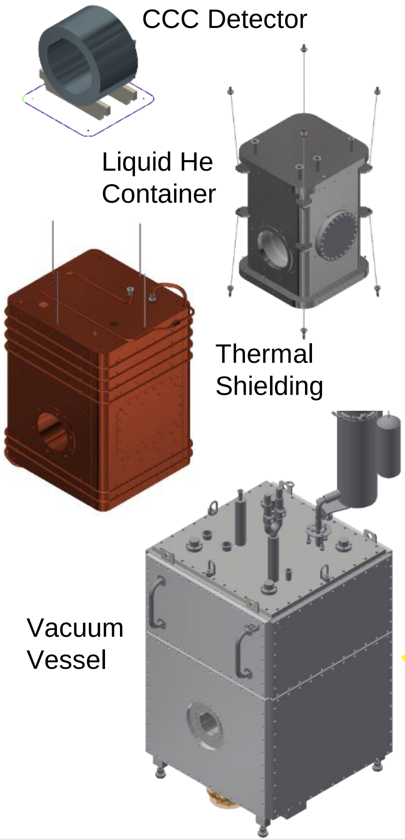
- Absolute beam intensity monitor, for DC and bunched beams – 6.6 nA resolution.
- Number of particles normalized with new B-train distribution: White Rabbit protocol.
- CERN Cryogenics expertise: Achieved standalone mode operation of the cryostat. LHe bath now at constant level since June.

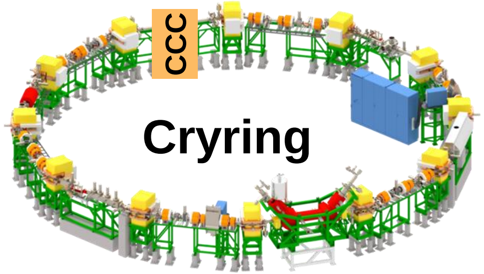
Collaborative support

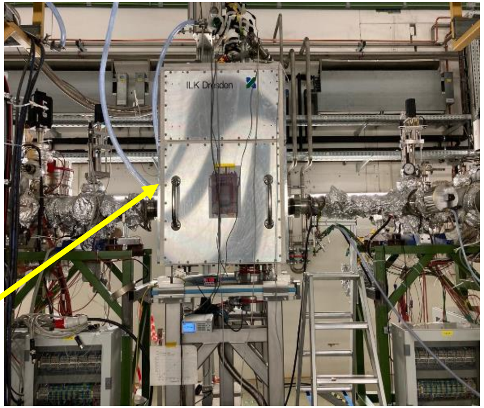
- CERN: Electronics drawings of power supply sent to GSI.
- ELENA: OP puts higher priority for transfer lines' diagnostics than for a current monitor in the ring.
- FAIR: Five CCCs planned to monitor spills along the transfer lines.
- The SPS transfer line towards the targets has no reliable spill monitor: It could profit from series production for FAIR.



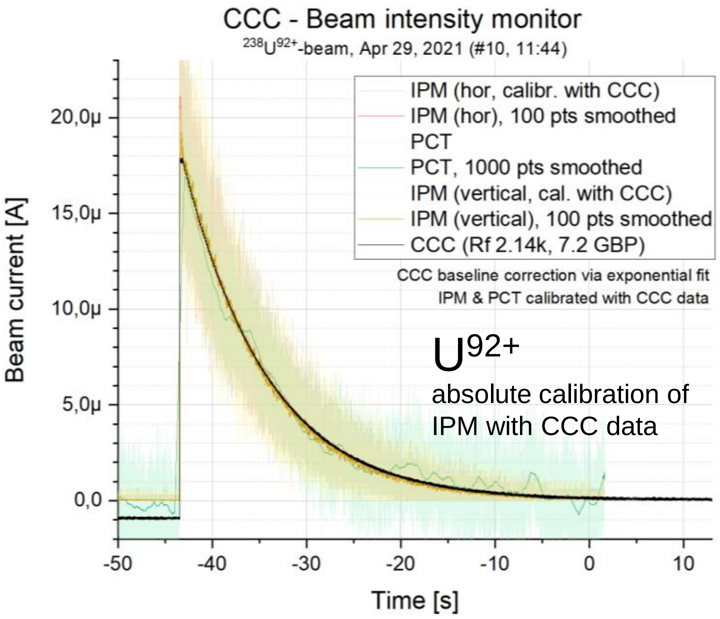
CCC at GSI (inside Cryring as prototype for FAIR)







CCC installed in Cryring Experimental Section

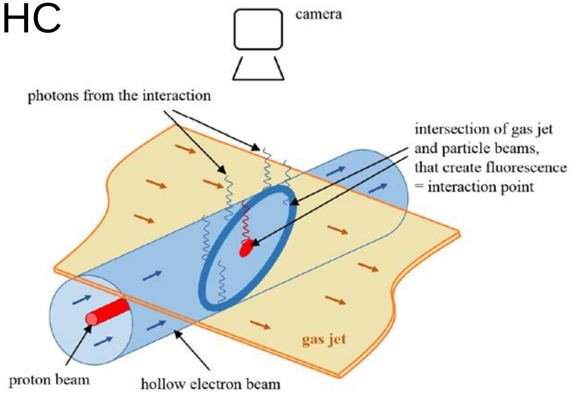


Instrument Calibration with CCC

D. Haider, PhD Thesis

Support to CERN e-lens

- Hollow electron lenses (e-lens) are under development for HL-LHC



- Very **precise alignment** between the ion beam and electron beam required

- Collaboration of CERN, Cockcroft Institute and GSI: **beam diagnostics set-up with intersecting gas sheet**, observation of beam induced fluorescence

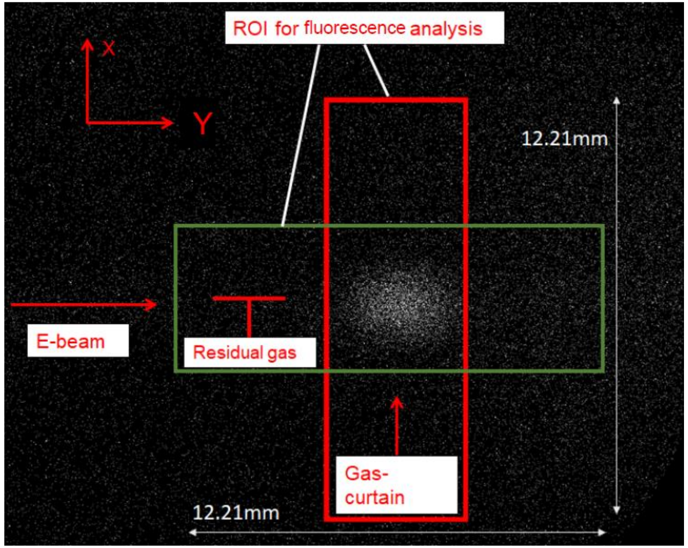
- **Addendum #10 accomplished**: “Delivery of a luminescence profile monitor for observing the interaction of a proton and electron beam with a gas jet target for the High Luminosity Large Hadron Collider“

- Ongoing development at CERN and GSI continually supports the project by expert know-how on luminescence profiling techniques

Actual BGC tests at Cockcroft Institute

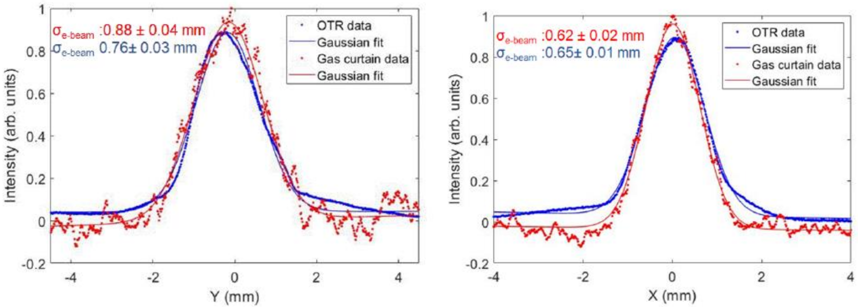
Detector principle proven:
All parameter reached at test
with 0.3 – 0.7 mA electron beam:
Remark: HEL beam current 1 A

Gas jet fluorescence at CI test bench



Parameter: 5 keV electron beam 0.66 mA, N_2 gas jet, stagnation pressure 5 bar, 200 s observation

Version 2 – First BIF monitor at the CI for performance measurements and optimization



Installation of BGC at Hollow Electron Lens & LHC

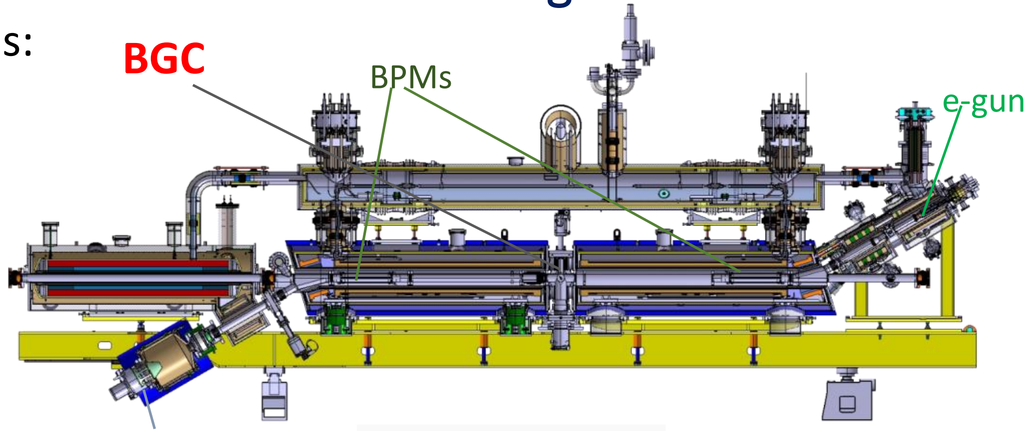
BGC for alignment of LHC merged beams:

- Simultaneous observation of e^- and p beam
- Correlation with halo cleaning achievements

Two tests measurements:

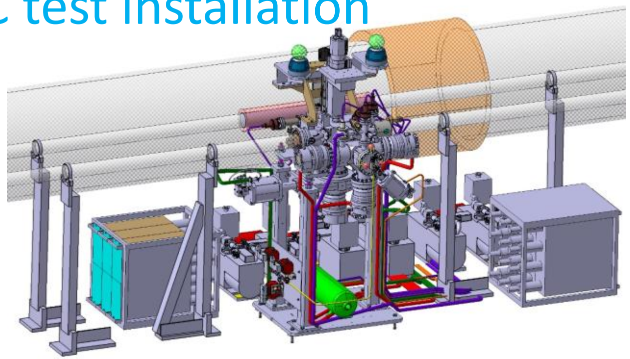
- **HEL test-stand,** in operation in 2022
  $\Rightarrow$ 1 A electron beam observation
- **Installation at LHC**, completion during next YETS
  $\Rightarrow$ Test of fluorescence with proton beam

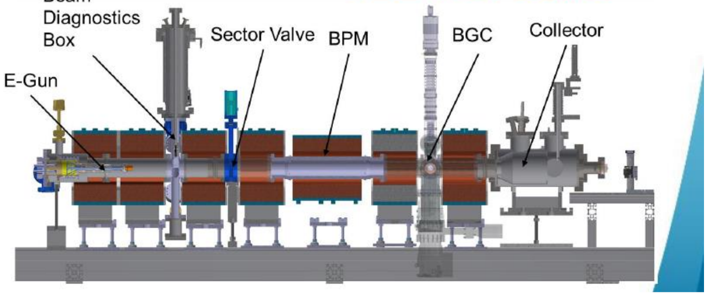
Actual HEL design for LHC



Courtesy of A. Kolehmainen

LHC test installation





Role of GSI in e-lens collaboration

Expertise of GSI: GSI is 'junior partner' within the collaboration;
however, GSI has long lasting experiences with fluorescence monitors

Actions during design and realization phase:

- Atomic physics basis of fluorescence for various gases (detailed evaluation for Ne, Ar & N_2)
- Technical design of optics & image intensifier system
- Data analysis and interpretation for various experimental conditions at CI
- General consultancy of experimental investigations

Actual topics for 2022:

- Participation at **HEL test-stand** investigations
  Challenges: high e^- beam current, strong magnetic field, limited insertion space
  Investigations: Possible effects for fluorescence levels, trapping of ion and electrons, space charge influence
- Participation at **LHC** proton beam measurements using fluorescence monitor
  Challenges: Stable operation of the monitor, background due to shower particles & synchrotron radiation
  Investigations: Signal-to-noise determination & interpretation, mitigation strategies

Future: Consultancy for BGC installation and operation at HEL@LHC within HL-LHC upgrade

Involved persons @ GSI: Peter Forck & Serban Udrea

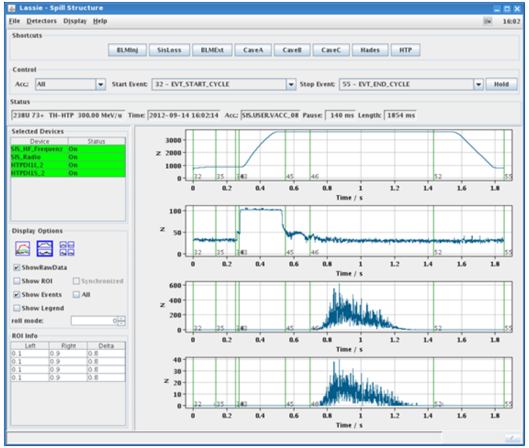
CERN GSI UNIVERSITY OF LIVERPOOL The Cockcroft Institute of Accelerator Science and Technology

FESA Integration of Beam Diagnostics

- Strong interest of GSI to collaborate with CERN BI on FESA software for beam diagnostic data acquisition

- Examples:
    - FESA integration of Bunch Structure Monitor (Feschenko-type)
    - FESA integration of the cryogenic current comparator (see above)

- In cases where identical HW is operated at CERN and GSI a further stepping-up of common FESA software developments is in the interest of GSI

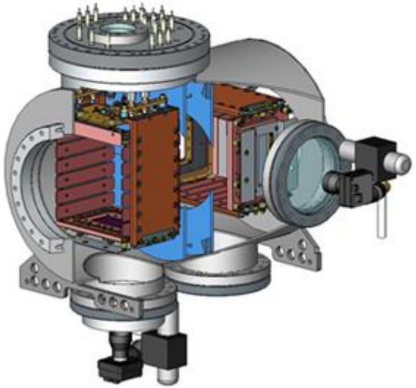


- Proposal to identify instruments with hardware overlap for possible common FESA developments

- Involved persons: T. Hoffmann, M. Schwickert (GSI), S. Jackson? (CERN)

Ionization Profile Monitor

- In the past: **Mutual technical exchange** based on the ARIES-ADA Workshops
- Various realizations of IPMs exist both, at CERN and GSI
- Important challenge is **code development for image reconstruction** caused by the beam’s space charge broadening
- Development of the **“Virtual IPM” software** (see next slides)
- GSI proposes to enhance the existing technical exchange on:
  - advanced **machine learning** reconstruction techniques
  - **common code developments** and long-term code maintenance (depending on availability of D. Vilsmeier)
  - detailed **validation procedures**



IPM at GSI SIS18

GSI – CERN BI Collaboration on the Simulation of IPM’s

Simulation of Ionisation Profile Monitors

Informal collaboration between GSI, CERN, ESS, J-PARC & Fermilab to develop simulation of IPM's, that can be used to optimise the design of IPM instruments (Virtual-IPM).

Kick-off meeting in March 2016 (CERN) and subsequent meetings in 2017 (GSI) & 2018 J-PARC (2018) during IPM workshops.

Kick-off meeting at CERN (2016)

IPM workshop at GSI (2017)

Virtual-IPM

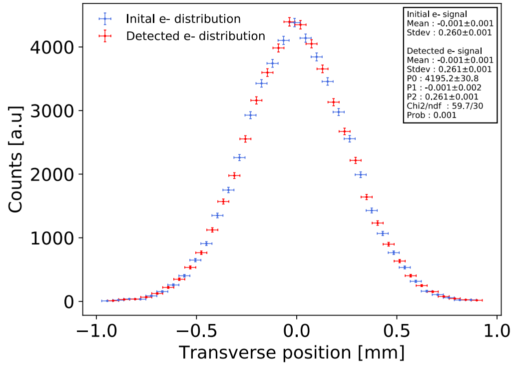
Virtual-IPM developed by Kenichirou Sato while on secondment at CERN and Dominik Vilsmeier at GSI (https://ipmsim.gitlab.io/Virtual-IPM/index.html).

Simulates the physical process of IPM instruments, including: beam-gas ionisation; electron/ion trajectories; effect of beam space charge & guiding field non-uniformities, etc.

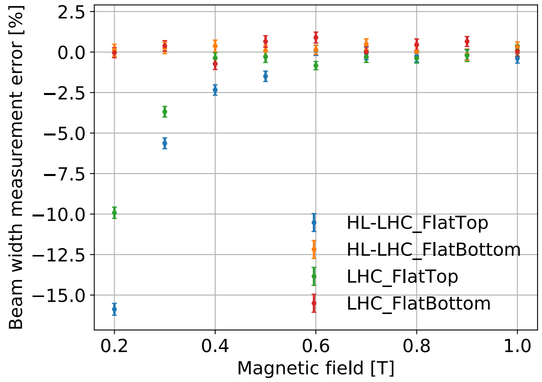
Has already been **used extensively at CERN to design the new Timepix3-based IPM's** for the PS and is currently being used to develop IPM designs for the SPS & LHC.

Using Virtual-IPM helped to identify simplifications to the PS IPM design (e.g. no need for field-shaping side electrodes) and is an invaluable tool to identify the magnetic field requirements for future LHC IPM's.

Virtual-IPM simulation of LHC IPM design with 0.6T magnet



VirtualIPM simulation of LHC IPM with varying B-field strengths



Future collaboration plans

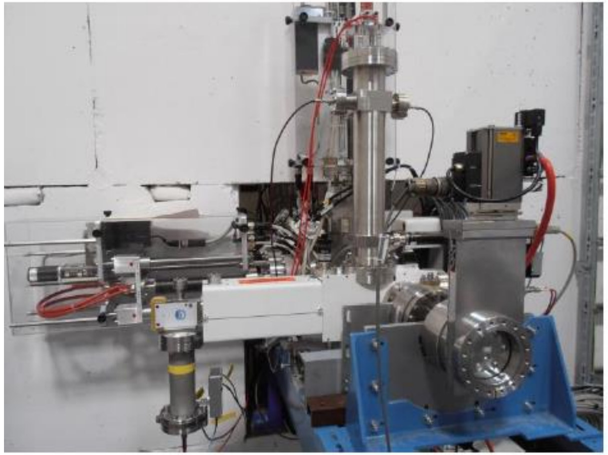
Since the beginning Virtual-IPM has been maintained & developed by Dominik Vilsmeier at GSI – who has been central to the success of this simulation tool.

We propose to maintain the collaboration between CERN BI & GSI on this topic, which from the CERN perspective has been critical to the development of the new generation of Timepix3-based IPM designs.

On the CERN BI side we would propose to enhance our involvement in the maintenance of the Virtual-IPM software.

p-Linac Diagnostics: Bunch Shape Monitor

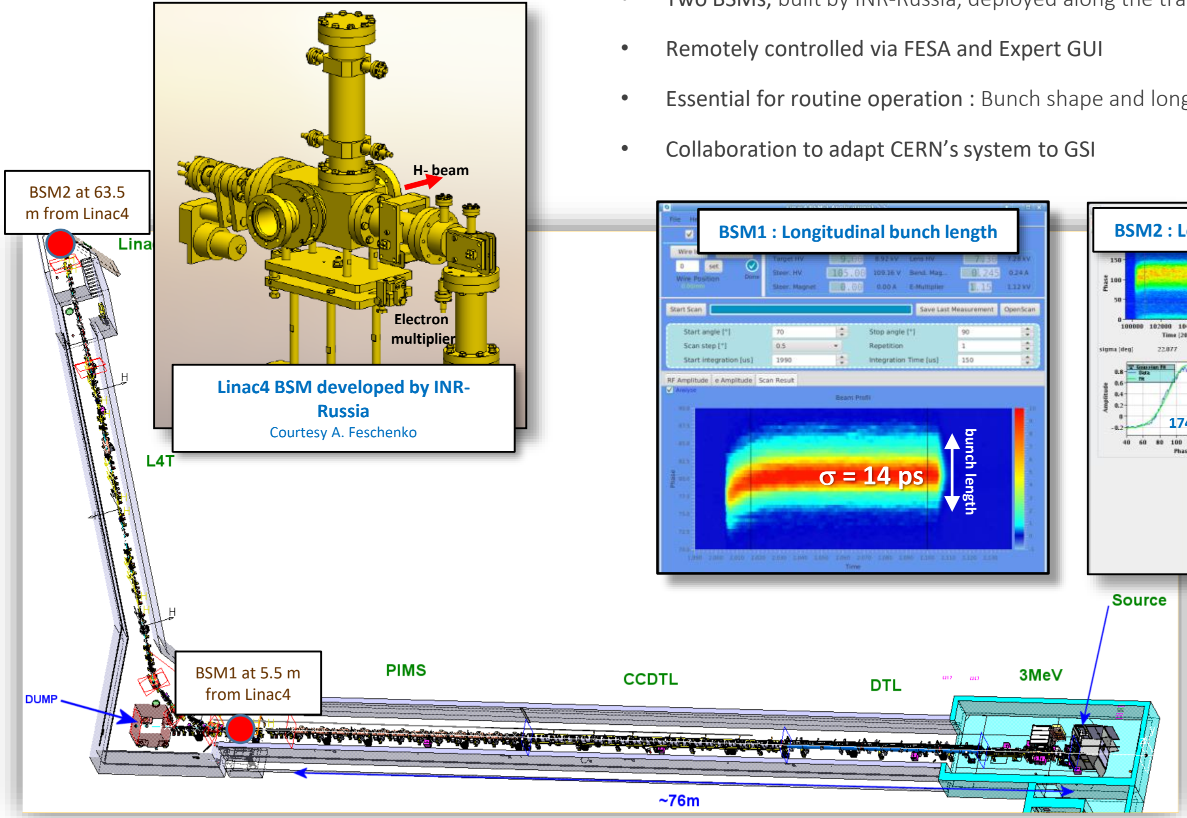
- Hardware is turn-key system purchased from the Russian Institute for Nuclear Research (INR)

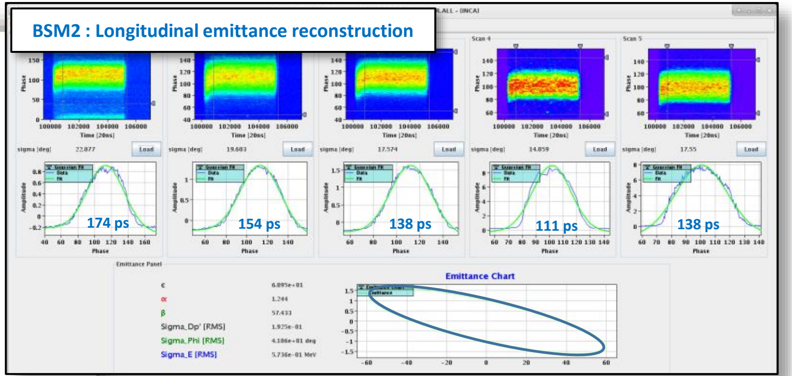


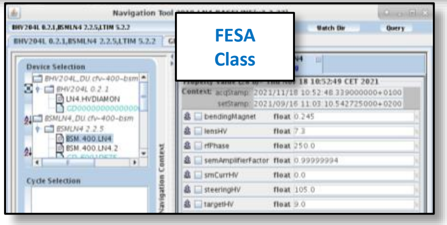
- Functionality of the system well proven at CERN, GSI, SNS, FRIB
- Migration of complex controls for the system from LabVIEW to FESA and a corresponding GUI realized at CERN, in operation
- GSI's interest is an adaptation of the CERN FESA software to FAIR control system.
- Reconstruction of the longitudinal emittance is performed at both institutes using different methods
- Exchange about the performance is of great interest for both partners
- Involved persons: J. Tan (CERN), P. Forck, T. Sieber (GSI)

pLinac Diagnostics: Bunch Shape Monitor

- Used during Linac4 staged commissioning : from 3 MeV to 160 MeV
- Two BSMs, built by INR-Russia, deployed along the transfer line
- Remotely controlled via FESA and Expert GUI
- Essential for routine operation : Bunch shape and longitudinal emittance reconstruction GUIs
- Collaboration to adapt CERN's system to GSI

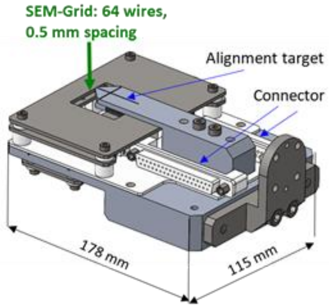




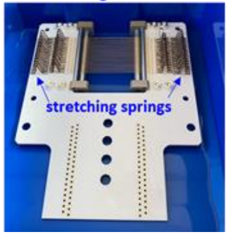


p-Linac Diagnostics: SEM-Grid Development

- Important **standard tool for profile and emittance measurement**
- SEM-Grids for **FAIR pLINAC: smaller beam size** than at UNILAC, requires smaller wire distance of 0.5 mm.
- In the past: informal discussions and knowledge exchange between CERN and GSI BI departments
- We propose common studies of CERN detector technology and GSI **development with PROACTIVE** (Spain)
- Compare CERN standard SEM-grids at GSI target location to understand possible **destruction mechanisms including thermal simulations**
- **CERN experts are invited to join GSI beam times** to test commercial SEM-grids
- Involved persons: F. Roncarolo (CERN), P. Forck, T. Sieber (GSI)



Ceramic PCB with novel stretching mechanism

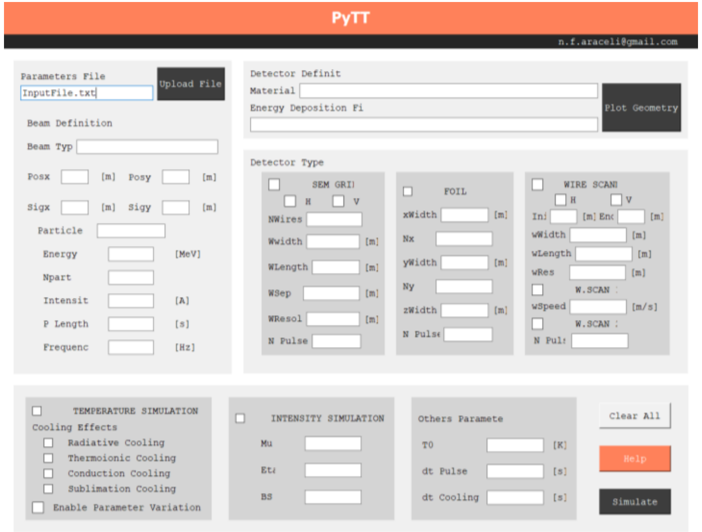


SEM-Grid developed with Co. Proactive

Development of a Thermal Response Model for Profile Monitors and Benchmarking.

- A comprehensive model to describe interactions between thin target detectors and the beam of particles has been implemented. This tool has been based on the models implemented by M. Sapinski for fast wire scanners [1].

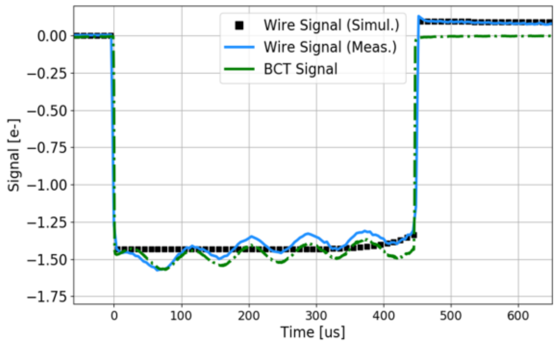
[1] M. Sapinski, Model of carbon Wire Heating in Accelerator Beams, Geneva, CERN, 2008.



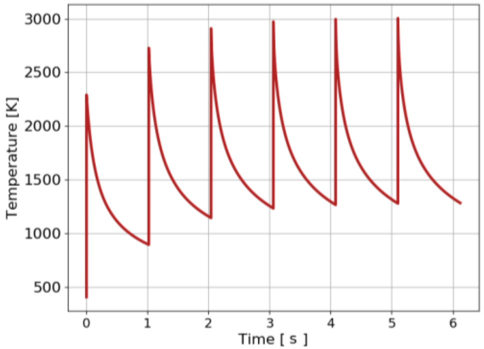
User friendly interface for the simulation tool.

Check Me!

- The output gives a prediction of detector signal, temperature evolution and Sublimation conditions (If applicable).
- The model has been applied to the wire grids of the CERN LINAC4 160 MeV H- beam and compared to experimental measurements.



Signal generated in the wire intercepting the beam core as a function of time. Simulated data in black, experimental data in blue.



Maximum wire temperature as inferred from the simulation during bench-marking experiments.

- This model has already been used at CERN LINAC4 and PSB to calculate beam power limits.

By: Araceli Navarro and Federico Roncarolo, CERN, 2021.

Summary and Next Steps

1. Collaborative support for development of **Cryogenic Current Comparators**

   GSI: Phd funding available for CCC optimization for FAIR, series production
   CERN: possibly participate in CCC series for SPS slow extraction

   → Participation of CERN in Verbundforschung workshops

2. GSI Support to CERN **e-lens** studies

   GSI: provides expert support, no short-term benefit (but long-term…)
   → Participation during commissioning of HEL teststand and LHC tests

3. Common developments on **FESA integration** of diagnostic devices

   → Define common topics (CCC, BSM) for FESA integration

4. Software and data analysis for **Ionization Profile Monitor**

   GSI, CERN: virtual IPM software, input for machine learning algorithms
   → Clarification of future software maintenance of virtual IPM (used by several teams worldwide!)

5. Control system integration of **Bunch Shape Monitor**

   GSI, CERN: development of reconstruction algorithms, DAQ transfer (CERN to GSI)

   → Important topic at GSI due to TK diagnostic upgrade

6. **SEM-Grid** developments for high-intensity beams

   GSI, CERN: common beam-based investigations during machine runs
   → Prepare amendment

Thank you…

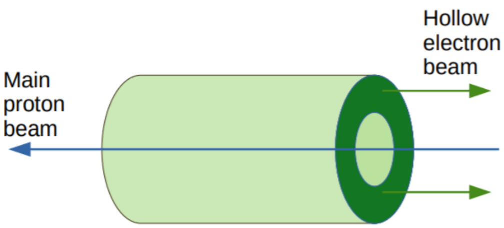
…for your attention !

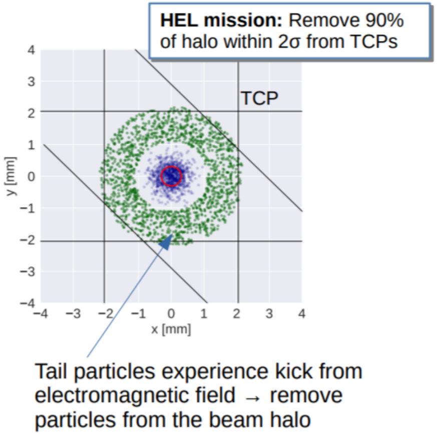
Spare Slides

Hollow Electron Lens Concept & BGC Monitor

Goal: Hollow Electron Lens (HEL) beam surrounds the proton beam:

- 10 keV electron energy, 1 A current guided by solenoid
- Separates halo protons to be caught by collimators
- Reduces background at physics detectors
- Reduces beam dump probability.

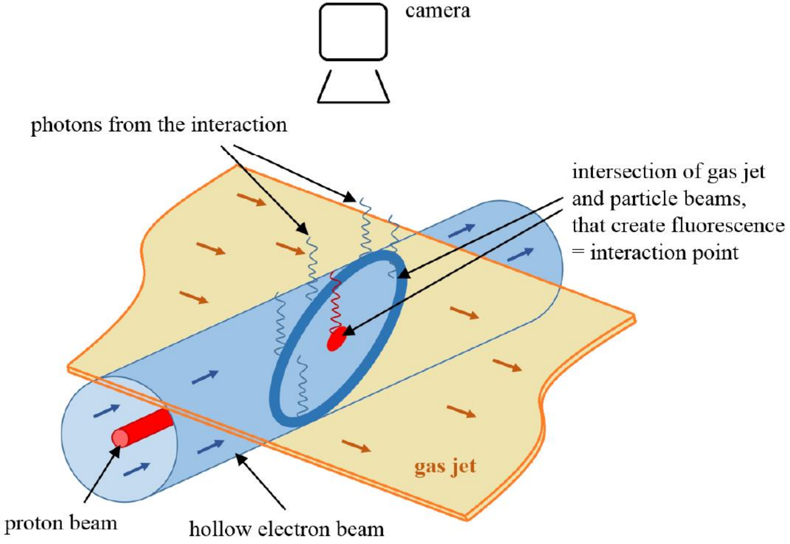




Courtesy P. Hermes

Diagnostics: Beam Gas Curtain Monitor (BGC):

- Gas jet of Ne or N_2 to increase gas density
- Observation of single photons
- Development by CERN, Cockcroft Inst. & GSI
- Part of HL-LHC WP13



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