Beam Diagnostics for HEL

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Thanks to:

A.Rossi, G.Schneider, I.Papazoglou, J.Storey,

HEL Production Kick-off meeting, 13th April 2021

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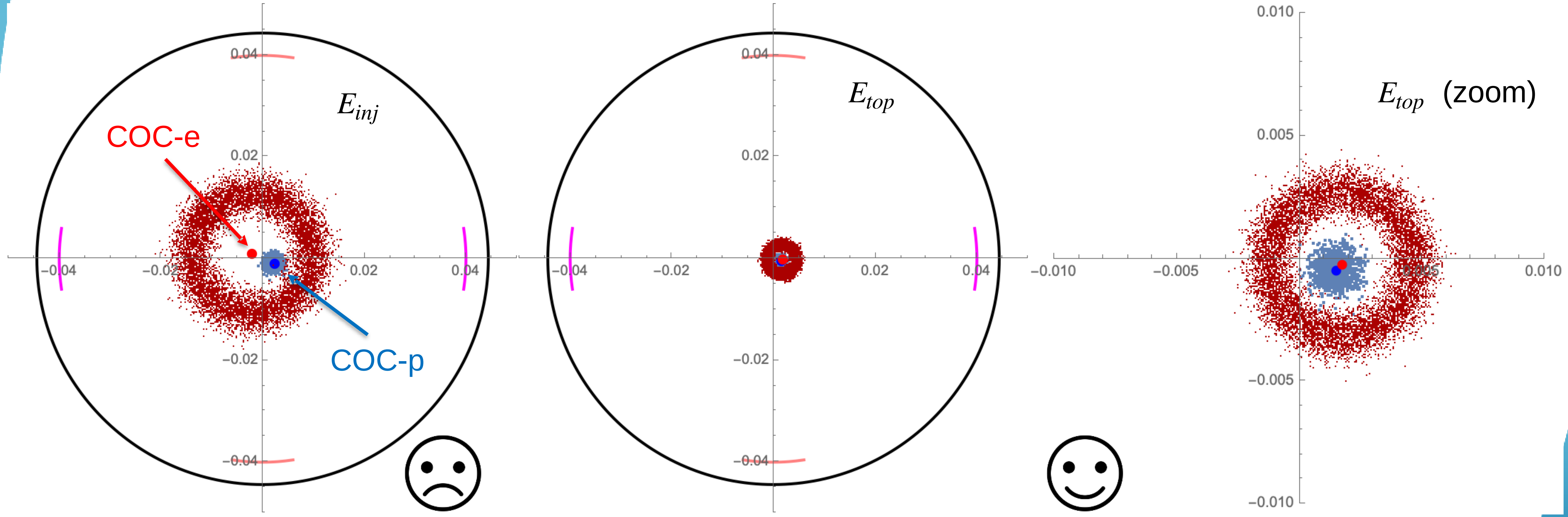
Contents

- Beam Position Monitors (BPMs)
  - BPM challenges for the HEL
  - Technical solutions
- Beam Gas Curtain Monitor (BGC)
  - BGC principle and collaboration structure
  - Project roadmap (including HEL test stand)
- Beam Loss Monitors (BLMs)
  - Installation of 8 standard LHC BLMs (no further technical details given)
- BI instrumentation manpower and material costs
- Summary, milestones and open issues

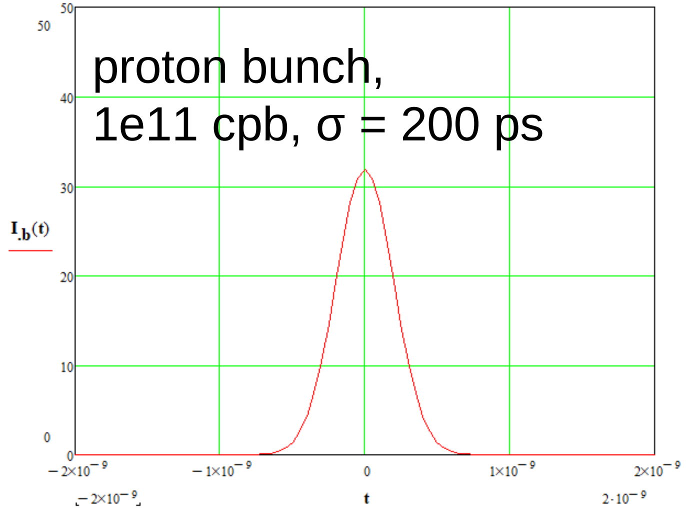
The HEL BPM Challenge

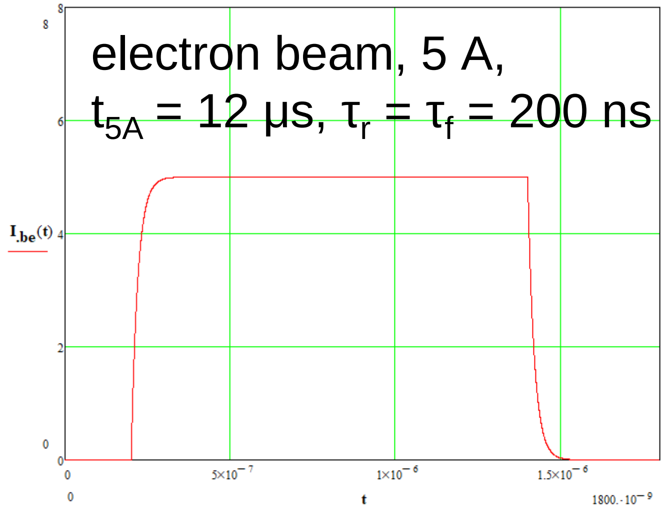
- Coaxial proton (center) and electron beam (hollow)
  - **Assuming round / circular co-propagating beams with Gaussian particle distribution**
- Measure the transverse position (x, y) of each beam
  - **In particular the relative position between both beams, e.g., their center-of-charge (COC)**



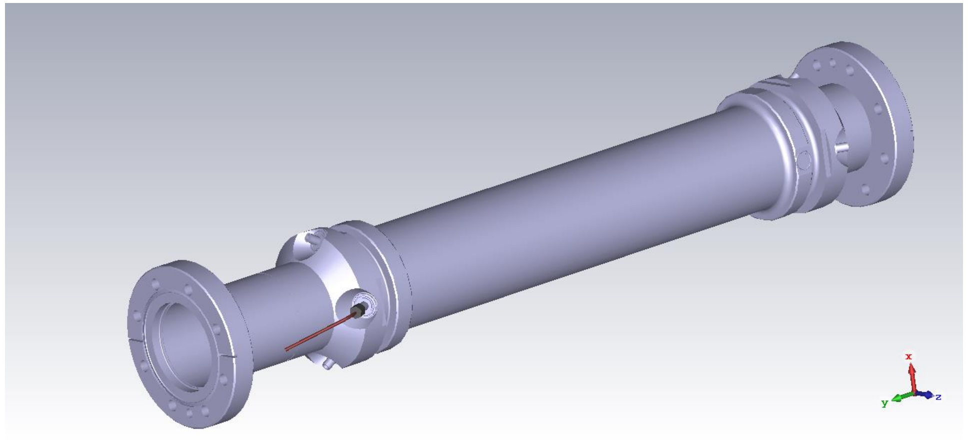
Beam conditions – beams of very different time structure

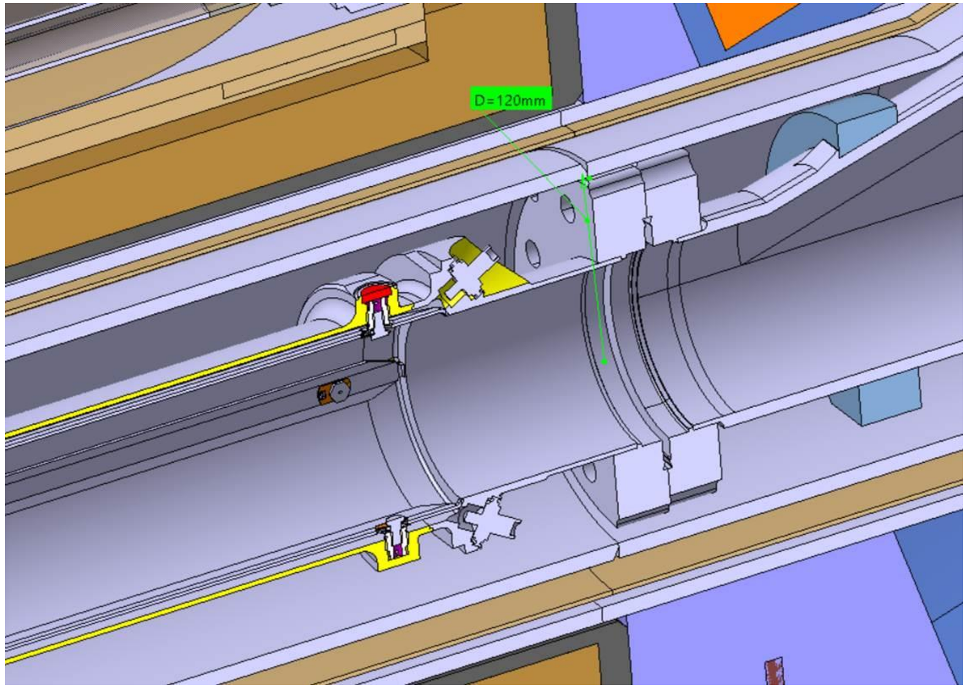
- **Proton beam**
  - **Bunched beam, up to 2760 bunches, 25 ns min. spacing, beam velocity: $\beta \approx 1$**
  - **Bunch charge: 1…2.3e11 cpb, 4σ bunch length: ~1 ns**
  - **Transverse beam size: ~0.5…1.0 mm ($\sigma_x \approx \sigma_y$)**
- **Hollow electron beam**
  - **"Quasi" DC beam, nominal beam current: 5 A**
    - ***(operation at lower beam current, 0.1 A, to be studied)***
  - **Abort gap injection, $t_{5A} \approx 86.4$ µs, $t_{0A} \approx 2.5$ µs, t_r, t_f (10-90%) ≈ 200 ns**
    - ***Other patterns to be expected with $t_{5A,min} \approx 1.2$ µs***
  - **Beam energy: 10…15 keV ($\beta \approx 0.2…0.24$)**
  - **Transverse beam size: ID ≈ 2…8 mm, OD ≈ 4…16 mm (OD-ID ≈ 8σ)**



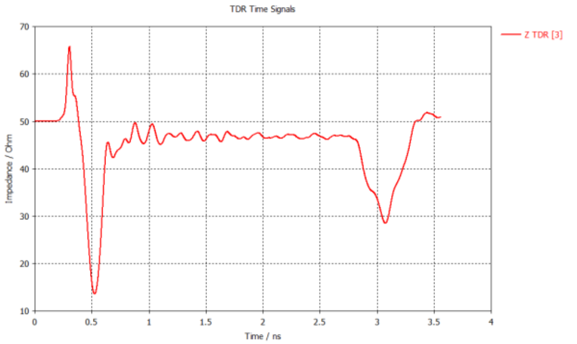


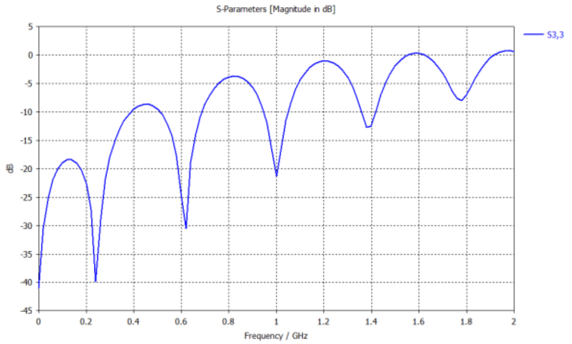
Stripline BPM





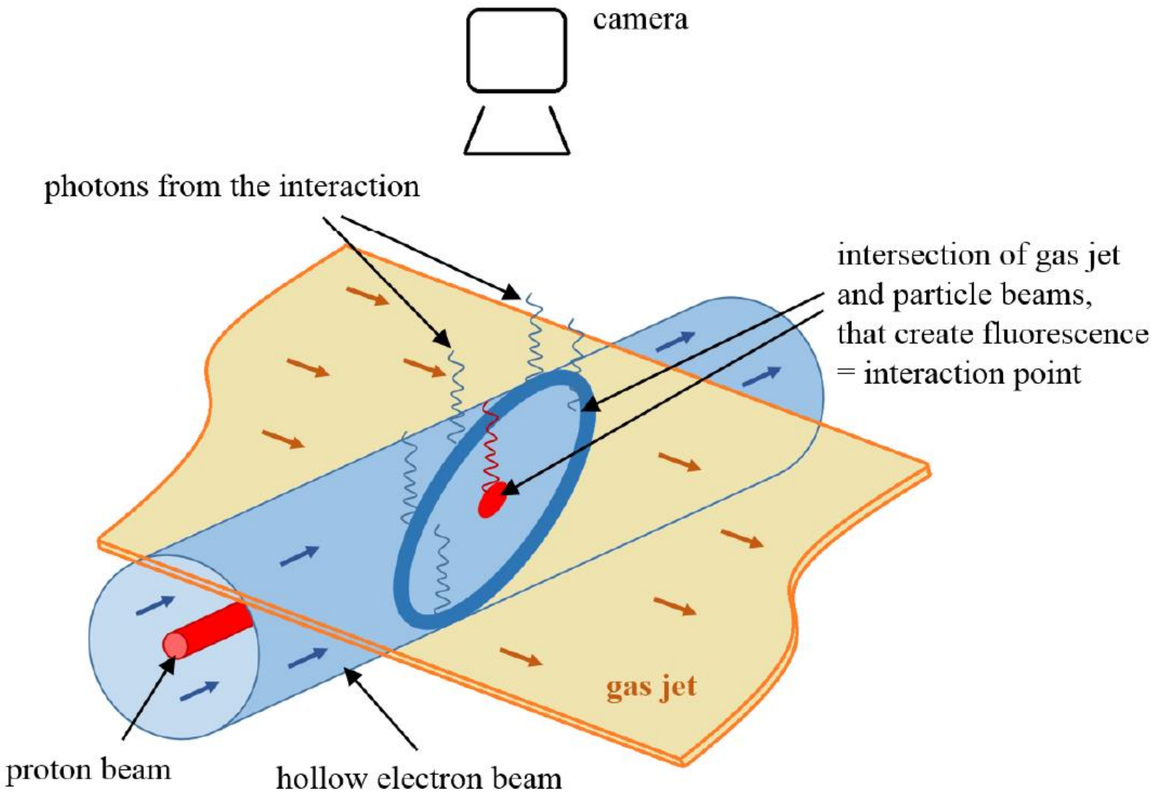
- 40 cm long electrodes, 60 mm aperture
  - For improved coupling to the e-beam
    - *Couples only during the e-beam switching time!*
- Difficult integration
  - Tight radial space, 120 mm diameter warm bore
  - Requires modifications of the flanges to pass signal cables
- Present draft design has some issues
  - Mechanical supports of the striplines causes strong signal reflections
  - Details of the feedthrough pin-to-electrode contact not worked out
  - Requires a design update!





BGC requirements and principle

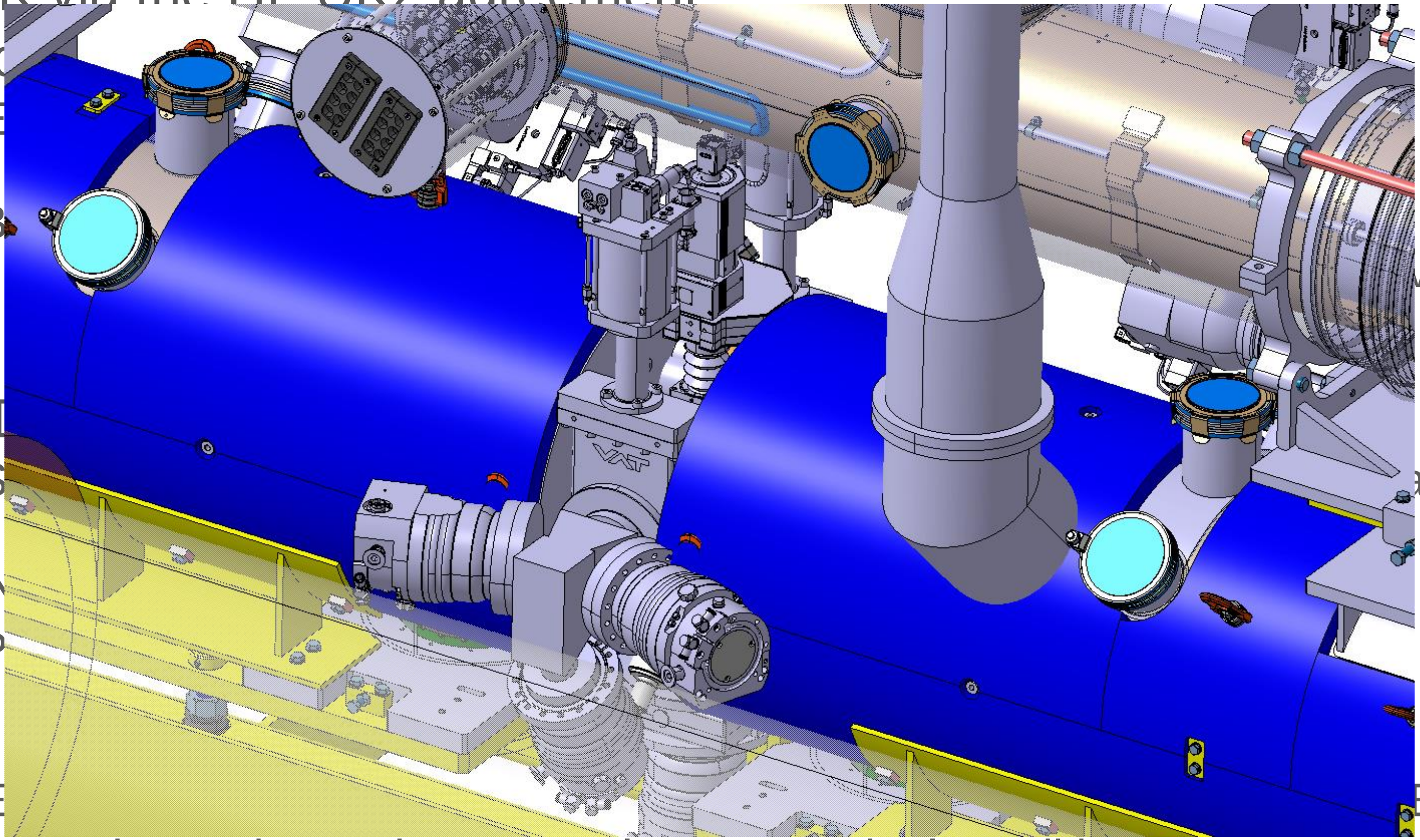
- Functional requirements
  - Determine the beam centroid of a nominal intensity and emittance HL-LHC proton beam at 7 TeV to better than 100 µm within a fixed, 2D image plane in less than 10 seconds
  - Simultaneously produce the 2D image of a hollow electron beam, with the nominal operating parameters of 15keV, 5A, in the same frame of reference as the proton beam image, within 1 second.
- Technical challenges
  - Different particles, energies, intensities
  - Operate in the HEL solenoid environment
    - Limited space for integration, strong magnetic field makes detection of ionized particles impractical
- Full functional specification in EDMS:
  - https://edms.cern.ch/document/2369616/1.0
  - The instrument is specified for nominal HEL operation.
    - Operation for pilot and test conditions is possible with detailed performance to be studied



The BGC collaboration structure

- The two *instruments* for the HEL are important in-kind contributions to HL-LHC from the UK via the HL-UK2 agreement*
- Cock
  - E
  - B

  v3 prototype



- GSI, D
  - S … agnostics
- CERN
  - P
  - E … E-VSC
  - Expertise and experiments at close to nominal conditions
    - HEL test stand with high-intensity 10 keV electrons (2021-22)
    - LHC background gas fluorescence measurements at 450 GeV and 7 TeV for p+ and ions (2022)
    - Prototype instrument tests in the LHC for p+ and ions (2023-4)

* https://edms.cern.ch/document/2234697/0.5

BGC Project roadmap (April 2021)

Surface

Assemble and commission v3 at CI

Test v3 proto on HEL stand

Integrate and test Final devices at CERN

2020	2021	2022	2023	2024	2025

Long shutdown 2 (for the LHC)

Y

YETS

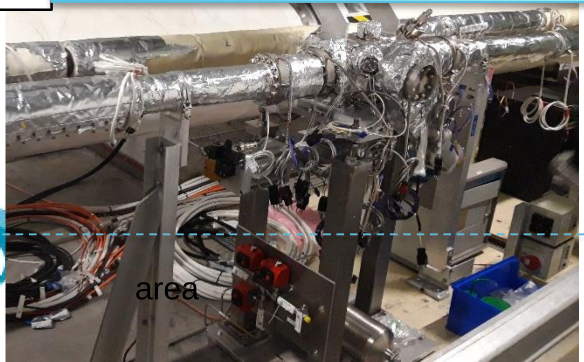
LS3

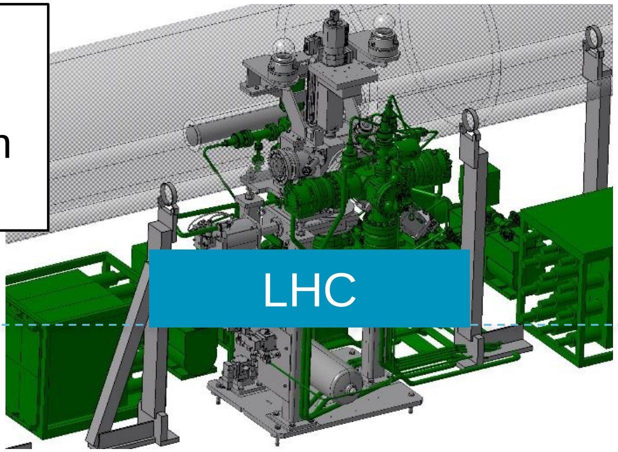
Install the v3 interaction chamber in the LHC

LHC Background gas test

v3 commissioning & experimental programme in the LHC

Install the complete v3 instrument in the LHC





LHC

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Summary, milestones and issues

- BI instrumentation requirements for nominal conditions are well understood
  - It is important for the ‘in-kind’ BGC to have clear acceptance test criteria that are not dependent on availability of LHC beams
  - Additional requirements for set-up and non-nominal conditions need to be studied and agreed
- BPM Key milestones and issues
  - Approval of Russian in-kind contribution (also for BLMs)
  - Electron beam tests on HEL test stand
- BGC Key outstanding milestones and issues
  - Prototype instrument test on HEL test stand
  - Background gas tests in LHC run 3
  - Prototype instrument tests in LHC run 3
  - Instrument integration in HEL (particularly LSS4R)
- Updated budget
  - Bottom-up review of material costs comes within 10% of the original budgets
    - Additional design work for integration of BPMs
    - CERN testing and installation costs for BGC
    - Need a review of required and available spares
  - BI additional MPA costs (VIA, PhD, PJAS)
  - Additional requests to VSC add costs for BGC (Study and design manpower, installation manpower, vacuum controls hardware and software)
    - Important that this LHC-operation-critical task stays with the CERN technical group

HiLumi
HL-LHC PROJECT

End

Backup slides follow

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Backup: Button BPM for the HEL?

- **Button BPM advantages**
  - **Simple, compact, lower costs**
  - **Can have more than 2 BPM per HEL**
  - **Different read-out system based on PLL lock-in technique**
    - ***Same analog signal path for e-beam and p-beam signals***
    - ***Improved long term reproducibility for the relative position measurement between both beams***
    - ***Measurement of the e-beam along the entire beam passage***
      - The stripline BPM measures only during the 200 ns switching transient, for $dI/dt \neq 0$
- **Button BPM disadvantage**
  - **Requires an intensity modulation of the e-beam, e.g., using the grid-electrode of the gun**
    - ***At a high frequency near a bunch harmonic, e.g.,*** $f_{mod} \approx 40, or\ 80, or\ 120\ MHz$
    - ***The modulation index can be low, a few*** 10^{-3} ***should be sufficient***
    - ***Feasibility to be tested at the HEL test stand***

Expected signal integration times for electron and proton beam profiles

Table 2: Average integration time <t_i>$_{MCP}$ for the detection of one emitted photon and total estimated integration time for the three working gases considered, using the parameters defined in Table 1.

Projectile	**Emitter**	**λ [nm]**	**σ [cm²]**	**I [A]**	**η_{pc}**	**Estimated Integration time [s]**	
						Single photon <t_i>$_{MCP}$	**Total** protons: 10^2 photons electrons: 10^4 photons
electron	N_2^+	391.4	$9.1\cdot10^{-19}$	5	0.19	$2.9\cdot10^{-7}$	0.003
proton	N_2^+	391.4	$3.7\cdot10^{-20}$	1	0.19	$3.6\cdot10^{-5}$	0.004
electron	Ne	585.4	$1.4\cdot10^{-20}$	5	0.09	$4.0\cdot10^{-5}$	0.4
proton	Ne	585.4	$4.7\cdot10^{-22}$	1	0.09	$5.9\cdot10^{-3}$	0.59
electron	Ar	750.4 & 751.5	$7.4\cdot10^{-20}$	5	0.02	$3.4\cdot10^{-5}$	0.34
proton	Ar	750.4 & 751.5	$3.3\cdot10^{-21}$	1	0.02	$3.8\cdot10^{-3}$	0.38
electron	Ar^+	454.5 & 476.5	$9.9\cdot10^{-21}$	5	0.20	$2.5\cdot10^{-5}$	0.25
proton	Ar^+	454.5 & 476.5	$1.7\cdot10^{-21}$	1	0.20	$7.4\cdot10^{-4}$	0.074

Table 1: Parameters for integration time estimation

curtain density n	$2.5\cdot10^{10}$ cm^{-3}
curtain thickness d	0.5 mm
optics transmission T	0.85
filter transmission T_f	0.8
solid angle Ω	$40\pi\cdot10^{-4}$ sr
photocathode efficiency η_{pc}	λ-dependent [6]
MCP efficiency η_{MCP}	0.75
average proton current I_p	1 A
DC electron current I_e	5 A

From: Development of a beam-gas curtain profile monitor for the high luminosity upgrade of the LHC. R.Veness et al. IBIC 2018