Beam Diagnostic Challenges for High Energy Hadron Colliders

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*CERN, Geneva, Switzerland*

HB2014
East Lansing
Michigan

Special thanks to Rhodri Jones, Thibaut Lefevre, Michiko Minty, and Manfred Wendt for their input
<table>
<thead>
<tr>
<th></th>
<th>Physics start date</th>
<th>Max. beam energy [TeV/n]</th>
<th>av. Beam current [mA]</th>
<th>Peak Luminosity [cm$^{-2}$s$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>RHIC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Brookhaven, 3.8 km circum.</td>
<td>pp polarized</td>
<td>2001</td>
<td>0.255</td>
<td>257</td>
</tr>
<tr>
<td></td>
<td>AuAu</td>
<td>2000</td>
<td>0.1</td>
<td>145</td>
</tr>
<tr>
<td></td>
<td>dAu, CuCu, UU, CuAu, He$^3$Au</td>
<td>2002, 2004, 2012, 2014</td>
<td>up to 159 (depending on ion)</td>
<td>0.9 – 270 × 10$^{27}$</td>
</tr>
<tr>
<td><strong>LHC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CERN, 26.7 km circum.</td>
<td>pp</td>
<td>2009</td>
<td>3.5 - 4</td>
<td>400</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2015</td>
<td>6.5 - 7</td>
<td>580</td>
</tr>
<tr>
<td></td>
<td>HL-LHC upgrade pp</td>
<td>2025+</td>
<td>7</td>
<td>1200</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 × 10$^{34}$ (levelled)</td>
</tr>
<tr>
<td></td>
<td>PbPb (pPb in 2012)</td>
<td>2010</td>
<td>1.38</td>
<td>6.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2015</td>
<td>2.76</td>
<td>7.4</td>
</tr>
<tr>
<td></td>
<td>PbPb high lumi upgrade</td>
<td>2020</td>
<td>2.76</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>up to 7 × 10$^{27}$</td>
</tr>
</tbody>
</table>
### The next 10 Years

**LHC Injector Upgrade:**
- Connection new LINAC4
- Major upgrades many systems: RF, BI, inj./ext. …

**High Luminosity Pb Experimental Upgrade:**
- ALICE and LHCb

**High Luminosity p:**
- Peak luminosity $5 \times 10^{34}$ cm$^{-2}$s$^{-1}$
- 3000 fb$^{-1}$ in 10 years
- Replacement Triplet Quads
- Addition of crab cavities
- Cryogenic upgrade
- Major Experimental Upgrade

---

<table>
<thead>
<tr>
<th>Year</th>
<th>Experiment</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015-16</td>
<td>p pol., ions</td>
</tr>
<tr>
<td>2017</td>
<td>--</td>
</tr>
<tr>
<td>2018-19</td>
<td>Au</td>
</tr>
<tr>
<td>2020</td>
<td>p pol., Au</td>
</tr>
<tr>
<td>2021-22</td>
<td>--</td>
</tr>
<tr>
<td>2023-24</td>
<td>Transition to eRHIC</td>
</tr>
</tbody>
</table>

Based on a slide by B. Mueller presented at the RHIC Science and Technology Review (Sept., 2014).
Parameters under consideration for
- Future Circulating Collider (FCC)
- Super Proton Proton Collider (SppC)

<table>
<thead>
<tr>
<th></th>
<th>Circumference [km]</th>
<th>Physics start date</th>
<th>Max. beam energy [TeV/n]</th>
<th>av. Beam current</th>
<th>Peak Luminosity [cm(^{-2})s(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FCC-hh</strong> pp</td>
<td>100 (80)</td>
<td>2035-2040+</td>
<td>50</td>
<td>0.5 A</td>
<td>5 × 10(^{34}) (lev.)</td>
</tr>
<tr>
<td></td>
<td>PbPb</td>
<td></td>
<td>19.7</td>
<td>3 mA</td>
<td>12.7 × 10(^{27})</td>
</tr>
<tr>
<td></td>
<td>pPb</td>
<td></td>
<td></td>
<td></td>
<td>3-5 × 10(^{30})</td>
</tr>
<tr>
<td><strong>FCC-ee</strong> (e+e-)</td>
<td>26.7</td>
<td></td>
<td>16.5</td>
<td>0.4 A</td>
<td>5 × 10(^{34}) (levelled)</td>
</tr>
<tr>
<td><strong>HE-LHC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SppC</strong> (pp)</td>
<td>50-70</td>
<td>2042+</td>
<td>25 – 45</td>
<td>0.4 – 0.5 A</td>
<td>2-3 × 10(^{35})</td>
</tr>
<tr>
<td><strong>CEPC</strong> (e+e-)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Challenges related to Beam Diagnostics I

- Stored energy (beam and superconducting magnets), high brightness beams
  - Avoid uncontrolled losses
    - Machine protection
      - BI systems part of machine protection require high dependability
        - Loss monitoring, certain BPMs, fast current change monitors
    - Collimation and related monitoring
    - Halo Monitoring
  - Avoid intercepting measurement devices
    - Quench magnets
    - Get destroyed by the beam
    - → Non-invasive monitoring of all relevant machine parameters!
  - Small beam sizes
    - Systematic effects dominate the measurement
Energy stored in the Magnets – release of 600 MJ

- LHC 2008 incident **without beam**
  - Electrical arc provoked a He pressure wave damaging ≈600 m of LHC
- LHC magnets at 7 TeV: 10 GJ

![Over-pressure](image1.png)

![Arcing in the interconnection](image2.png)

![Magnet displacement](image3.png)
Energy stored in the Beams – uncontrolled Losses

- LHC at 7 TeV 360 MJ:
  - Pilot bunch of $5 \times 10^9$ close to damage level
  - Loss of $3 \times 10^{-7}$ of nominal beam over 10ms can create a quench

- SPS incident in June 2008
  400 GeV beam with 2 MJ
  (J. Wenninger, CERN-BE-2009-003-OP)

1MJ can heat and melt 1.5 kg of Copper

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1MJ can heat and melt 1.5 kg of Copper
- LHC 7 TeV: 360 MJ
- HL-LHC: 694 MJ
- FCC-hh: 8 GJ
- HE-LHC: 0.7 GJ

World record @ LHC: 140 MJ @ 4 TeV
**Dependability** (colloquially: reliability) **analysis**

- Machine protection system must be integrated in the machine design
- Dependability *(reliability, availability, maintainability and safety)* analysis → Budgets for
  - Probability of component damage due to malfunctioning
  - Downtime due to false alarms
  - Downtime due to maintenance

**Reliability**
- Hazard rates ($\lambda$)?
- Failure modes?

**Maintainability**
- Repair rates ($\mu$)?
- Inspection periods ($\tau$)?

**Consequences**
- >30 days downtime to change a magnet
- ≈3 h downtime to recover from a false alarm.

**Safety**
- Probability to loose a magnet: < 0.1/y.
- Number of false alarms per year: < 20/y.
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  - Avoid uncontrolled losses
    - Machine protection
      - BI systems part of machine protection require high dependability
        - Loss monitoring, certain BPMs, fast current change monitors
  - Collimation and related monitoring
  - Halo Monitoring

- Avoid intercepting measurement devices
  - Quench magnets
  - Get destroyed by the beam
    - Non-invasive monitoring of all relevant machine parameters!

- Small beam sizes
  - Systematic effects dominate the measurement
New LHC Collimators with Embedded BPMs

- 18 collimators now equipped with BPM buttons
- Readout via compensated diode peak detectors (Diode Orbit electronics)
  - Resolution <100nm for centered beams
- Fast, parallel alignment:
  - <20 s for all BPM collimators without touching the beam
  - 2 orders of magnitude faster than BLM method
- Constant monitoring of beam position → tighter collimator settings → smaller $\beta^*$
Halo Monitoring

- See overview presentation of K. Wittenburg on Tuesday and other contributions in this workshop

- Proceedings of HB workshops
Challenges related to Beam Diagnostics I

- Stored energy (beam and superconducting magnets), high brightness beams
  - Avoid uncontrolled losses
    - Machine protection
      - BI systems part of machine protection require high dependability
        - Loss monitoring, certain BPMs, fast current change monitors
    - Collimation and related monitoring
    - Halo Monitoring
  - Avoid intercepting measurement devices
    - Quench magnets
    - Get destroyed by the beam
      → Non-invasive monitoring of all relevant machine parameters
  - Small beam sizes
    - Systematic effects dominate the measurement
LHC Wire Scanner

- Needed to calibrate all other LHC beam size measurements
- At 450 GeV limit at $2.7 \times 10^{13}$ protons by wire breakage
  - One injected batch of 144 bunches @ 50ns OK
  - One injected batch of 288 bunches @ 25ns NOT OK
- At 6.5 TeV limit at $2.7 \times 10^{12}$ protons by the quench limit of cold magnet
  - $\approx 20$ bunches
- Aging due to wire sublimation

Wire breakage experiment 2011 with Pb ions

34 um

16 um

Courtesy M. Sapinski
RHIC Ionization Profile Monitors (IPM)

- $e^-$ from beam-rest gas interaction accelerated towards readout by E-field
- Guiding B-field
- Amplification by Multichannel plate (MCP)
- 64 strip anode readout
- Fast signal gating to reduce aging of the MCP
- Readout inside a Faraday cage to shield it from the beam’s image current
- single bunch and single turn

R. Connolly et al, PAC 2010
RHIC IPM – recent Improvements

Beam based offset and gain calibration

Absolute emittance measurement by using measured beta function:

- Convergence of horizontal and vertical emittances of both beams under optimized 3D stochastic cooling
- Agreement within 15% with the emittances measured by the experiments STAR and PHENIX

M. Minty et al. IBIC 2014
LHC Ionization Profile Monitor

- Gas injection (Ne)
- Electron collection with 0.2 T guide magnets and MCP signal amplification
- Optical readout from phosphor screen with Radiation-hard camera
- Worked well for Pb ions (what it was designed for)
LHC Ionization Profile Monitor for Protons

- Measured emittance at injection agrees with wire scanner
- When charge density increases → space-charge leads to profile distortion → signal non-gaussian and dominated by systematic effect at 7 TeV
- Increase of magnetic field to 1 T would allow direct measurement
- Try to find and algorithm to disentangle the beam size

poster by M. Sapinski
At 7 TeV even using UV (250nm) the imaging will be **diffraction dominated** ($\approx 250\text{mm} > \text{beam size of 180mm}$) → adding an optical line for interferometry (collaboration with KEK, SLAC and CELLS-ALBA)

- Non-diffraction limited and widely used in $e^{-}$ machines for very small beam sizes

\[
\text{Visibility} = \frac{I_{\text{max}} - I_{\text{min}}}{I_{\text{max}} + I_{\text{min}}}
\]

Simulated interference fringes at 7 TeV

Interference fringes for different emittances and predicted visibility as function of emittance
**RHIC Schottky transvers Emittance Measurement**

- High frequency cavity operated at 2.07 GHz
- **Absolute transvers emittance** measurement demonstrated
  

- Moving the cavity transversally to the beam and recording the spectrum at each position
- Power in the band of the revolution harmonics is proportional to the square of the distance of the orbit from the center of the cavity
- Sum of the power in the two betatron side-bands is proportional to the square of the rms beam size

→ 20% uncertainty in transverse emittance in 2008 measurement
- Slotted waveguide pick-up operated at 4.8GHz
  - High enough to have small coherent signals
  - Low enough not to have band overlap
- Triple down-mixing
- 25ns gating for individual bunch measurement
- Aim: on-line chromaticity and bunch by bunch tune
- Run1: successful for ion beams
- Currently: Design changes to improve performance for protons

LHC transvers Schottky Measurements
Beam Gas Vertex Monitor (BGV) – Novel Design

- Non-invasive and absolute transvers profile measurement
- Reconstruct the location of inelastic beam-gas interactions (vertex) with particle tracks
- Accumulate vertices to measure beam position, angle, width and relative bunch populations. Require:
  - Sufficient beam-gas rate → controlled pressure bump
  - Good vertex resolution → precise detectors; optimized geometry; LHCb reconstruction and monte-carlo framework
BVG Demonstrator

- **Prototype** BGV system on one beam at the LHC
- Commissioning planned for 2015
- Collaboration with: LHCb (CERN), EPFL (CH), Aachen (DE)

Detector
- Scintillating fibres read out with SiPMs
- Same technology as for the LHCb upgrade

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Accuracy</th>
<th>Time interval</th>
<th>Key factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative bunch width</td>
<td>5% / 5%</td>
<td>&lt;1 min / 5 min</td>
<td>vertex resolution stability</td>
</tr>
<tr>
<td>Absolute average beam width</td>
<td>2% / 10%</td>
<td>&lt;1 min / 1 min</td>
<td>$\sigma_{\text{beam}}$, $\sigma_{\text{MS}}$, $\sigma_{\text{extrap}}$ ($\sigma_{\text{hit}}$)</td>
</tr>
</tbody>
</table>

Aim for the **final instrument** (HL-LHC) / prototype

Courtesy of Plamen Hopchev
Challenges related to Beam Diagnostics II

- Large size of the colliders
  - Number of components
    - Cost
    - Maintainability
    - Data handling, monitoring, logging, analysis
- Readout electronics
  - either close to instrument → radiation hard
  - Or long cables → noise, losses
    → prefer optical diagnostics and optical signal transmission
- High radiation levels (IPs, collimation, …)
  - Radiation hard equipment
  - Interfere with los measurements
Challenges related to Beam Diagnostics III

- Instruments in cryogenic temperatures (BPMs, BLMs)
  - New regime (BLMs)
  - High dependability (feedthroughs etc.)
- Monitoring of beam instabilities
  - Bunch-by-bunch and intra-bunch measurements
  - Improved performance required e.g. for reliable feed-back systems
    - **RHIC**: orbit, tune and coupling feedback was a key to higher luminosities, polarization and integrated luminosity/uptime
    - **LHC**: orbit feed-back, tune feed-back only at selected periods during the cycle
- Wakefields and RF heating
  - Very strict impedance budget
    - Particularly for devices which are numerous (BPMs)
  - Damage due to RF heating
Beam Loss Monitoring at Cryogenic Temperatures

- Loss monitor closer to loss location → avoid that the signal is dominated by other radiation sources (e.g. physics debris)
  - Investigated: LHe, silicon, diamonds
  - First tests in the LHC in 2015
ELECTRON BACKSCATTERING DETECTOR (eBSD)

- **Aim of the RHIC electron lens**
  - Partially compensate the beam-beam effect $\rightarrow$ higher polarized proton luminosities
  - Non-linear focusing by low energy ($\approx 6$ keV), high intensity ($\approx 1$ A) electron beam
  - 2 m interaction region in the $\approx 6$ T solenoid, the centers of these $\approx 300$ μm rms wide beams need to be aligned to less than 50 μm

P. Thieberger et al., IBIC 2014
ELECTRON BACKSCATTERING DETECTOR (eBSD)

- New tool for the precise alignment of electron with ion beam
- Small plastic scintillator installed close to the e-gun
  - Measures back-scattered electrons
- Automatic procedure for beam alignment by maximizing eBSD counting rates

- Might also be used for hollow electron lens considered as option for HL-LHC (CERN_LARP collaboration), based on Tevatron lens design

P. Thieberger et al., IBIC 2014
Intra-bunch Measurements LHC

- Head-Tail monitor
  - Resolution limited to ≈100 μm
- Multiband Instability Monitor – currently being developed
  - Monitors 16 frequency bands individually ($\Delta f_b = 400$ MHz)
  - Trigger high rate acquisition of other systems; potential to reconstruct mode of oscillation

![Graph showing HT signal and amplitude over time](image)
Intra-bunch Measurements LHC

- **Head-Tail monitor**
  - Resolution limited to \( \approx 100 \, \mu m \)
- **Multiband Instability Monitor** – currently being developed
  - Monitors 16 frequency bands individually (\( \Delta f_b = 400 \, MHz \))
  - Trigger high rate acquisition of other systems; potential to reconstruct mode of oscillation

---

![Graph 1](image1)

- **Graph 1**: Frequency response of the system with different parameters.

![Graph 2](image2)

- **Graph 2**: Time-domain oscillation with varying parameters.
Intra-bunch Measurements LHC

- Head-Tail monitor
  - Resolution limited to \( \approx 100 \mu m \)
- Multiband Instability Monitor – currently being developed
  - Monitors 16 frequency bands individually (\( \Delta f_b = 400 \text{ MHz} \))
  - Trigger high rate acquisition of other systems; potential to reconstruct mode of oscillation

![Graph showing frequency vs. magnitude and time vs. amplitude for different q values.]
Challenges related to Beam Diagnostics III

- Instruments in cryogenic temperatures (BPMs, BLMs)
  - New regime (BLMs)
  - High dependability (feedthroughs etc.)
- Monitoring of beam instabilities
  - Bunch-by-bunch and intra-bunch measurements
  - Improved performance required e.g. for reliable feed-back systems
    - RHIC: orbit, tune and coupling feedback was a key to higher luminosities, polarization and integrated luminosity/uptime
    - LHC: orbit feed-back, tune-feed-back only at selected periods during the cycle
- Wakefields and RF heating
  - Very strict impedance budget
    - Particularly for devices which are numerous (BPMs)
  - Damage due to RF heating
RHIC p-Carbon Polarimeter Target

- Thin carbon ribbons (25-100 nm thick, 1-10 μm wide, 2.5 cm long)
- Scanned through the p beam to measure beam polarization profiles
- Frequent target breakage (also without beam contact, even in park position)
  - installation of cameras
  - RF heating at the wire ends without touching the beam

→ Add “fins” to deviate the EM field from the wire ends reduces significantly the heating

H. Huang et al., IBIC 2014
Video 2

http://www.youtube.com/watch?v=hQsOAyQ7Kck

Courtesy M. Minty
Beams induced RF heating – LHC run1

Overheating → pressure rise

- Injection Kicker
- ATLAS ALFA Detector

Material deformation

- Beam screen around injection protection jaw
- RF contact fingers at magnet interconnects
Synchrotron Light Extraction Mirror

Mirror heating correlated to:
- Beam intensity
- Bunch length
- Beam spectrum

Failure of mirror holder + blistering of mirror coating

Overheated and broken ferrite absorbers (BSRT)
- EM simulations and lab tests are essential for all equipment which is installed on the beam
- Mitigation by e.g.:
  - Design changes to reduce the build-up of wake fields – or deviate from the sensitive location
  - Adding ferrites to absorb the RF power given there is sufficient cooling for the ferrites
  - Multi-mode couplers to extract the power and dissipate it outside of the vacuum
Summary

- Challenges:
  - Dependability (availability, reliability, maintainability, safety)
  - Instabilities
    - Bunch / intra-bunch measurements
    - Measurement stability, precision, resolution → feedback
  - Non-invasive measurements
  - Wakefields / RF heating
Thank you for your Attention
Wall Current Transformer for Intensity Measurement

- New device developed at CERN for the LHC – combination of a Wall Current Monitor and a Beam Current Transformer
  - Insensitive to beam position
  - Installation without breaking the vacuum
  - Small magnetic cores (no worries with material homogeneity)
  - Capable of resolving the LHC bunch

Image

Beam

Courtesy Marek Gasior, Michał Krupa
LHC Schottky System 2010

Triple down-mixing scheme to Base Band
- Successive filtering from bandwidth of 100MHz to 11kHz
- Capable of Bunch by Bunch Measurement thanks to the 25ns Gate.
- Gate reduces noise theoretically about 30dB.

Measurements are made using a 2x25ns = 50ns Gate to be sure we get all the signal from one bunch with the current 50ns spacing used for proton physics.

Slotted waveguide Structure
- High Sensitivity Pickup Structures operating at 4.8GHz
- Amplification of the signal for single bunch
- Pickup transverse sensitivity ~ 200MHz

Beam pipe 60x60mm

270 coupling slots in 0.2mm thick CuBe-foil (~20x2mm, 4mm pitch)

TE₁₀ mode waveguides type WR187 (WG12)
Motivation for Schottky Signal Monitoring: Beam Parameter Characterization

- The Schottky signals allow to characterize some transverse beam parameters in a non-invasive way:
  - Incoherent Tune
    \[ q = \frac{1}{2} + \frac{f_2}{2f_{\text{rev}}} - \frac{f_1}{2f_{\text{rev}}} \]
  - Momentum spread
    \[ p = \frac{1}{2} \left( \frac{W_1 + W_2}{2h_f_{\text{rev}}} \right) \]
  - Chromaticity
    \[ \mu = \frac{W_1}{W_1 + W_2} \]
  - Emittance
    \[ \mu = A_1 W_1 + A_2 W_2 \]

Zoom of the LHC proton Schottky signals (B1H, stable beam)
Diamond Detectors

- Fast and sensitive
- Small and radiation hard
- Used in LHC to distinguish bunch by bunch losses
- Dynamic range of monitor: $10^9$
- Temporal resolution: few ns
Diamond: arrival time histogram during ramp

- 50 ns bunch spacing
- Loss signal at 25 ns is from opposite beam ("cross talk")
  → sub 25 ns resolution required to resolve

**Figure 12: Losses during ramp.**

Courtesy B. Dehning
### Transverse Profile Measurements – Wire Scanners

<table>
<thead>
<tr>
<th></th>
<th>Wire speed</th>
<th>Number of equipment</th>
<th>Dynamic range</th>
<th>Absolute accuracy on emittance</th>
<th>Spatial resolution</th>
<th>Meas. range in $\Delta x$ and $\Delta y$</th>
<th>Bunch selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>PSB</td>
<td>rotational 15 m/s</td>
<td>1 H / ring 1 V / ring</td>
<td>100</td>
<td>20%</td>
<td>200μm</td>
<td>calibrated to +/- 5 cm</td>
<td>Could be made b-p-b ?</td>
</tr>
<tr>
<td>PS</td>
<td>rotational 15 m/s</td>
<td>3 H 2 V</td>
<td>100</td>
<td>20%</td>
<td>200μm</td>
<td>calibrated to +/- 5 cm</td>
<td>Could be made b-p-b ?</td>
</tr>
<tr>
<td>SPS</td>
<td>rotational 6 m/s</td>
<td>3 H 3 V</td>
<td>100</td>
<td>20%</td>
<td>200μm</td>
<td>+/- 5 cm</td>
<td>Bunch-per-bunch</td>
</tr>
<tr>
<td>Linear</td>
<td>1/0.6 m/s</td>
<td>2 H 2 V</td>
<td>100</td>
<td>20%</td>
<td>50μm</td>
<td>~ +/- 4 cm</td>
<td>Bunch-per-bunch</td>
</tr>
<tr>
<td>Future SPS 2014</td>
<td>rot. 20 m/s</td>
<td>1 V</td>
<td>$10^4$ (spec)</td>
<td>&lt; 10%</td>
<td>&lt;10 μm</td>
<td>+/- 4 cm (full aperture)</td>
<td>Bunch-per-bunch</td>
</tr>
<tr>
<td>LHC</td>
<td>linear 1 m/s</td>
<td>1 H / ring 1 V / ring + 2 dev./ring</td>
<td>100</td>
<td>2013: 10-50% 2014: 10%</td>
<td>50μm</td>
<td>Full aperture</td>
<td>Bunch-per-bunch</td>
</tr>
</tbody>
</table>

- It typically takes a few 100 turns for one profile (e.g. PSB ~600 turns)
- LS1: systematic simulation study to improve WS accuracy
# Transverse Profile Measurements - others

- Relative measurements, they need to be calibrated against the wire scanners

<table>
<thead>
<tr>
<th></th>
<th>Number of equipment</th>
<th>Dynamic range</th>
<th>Absolute accuracy on beam size measurement (after cross calibration)</th>
<th>relative accuracy emittance / beam size</th>
<th>Spatial resolution</th>
<th>Measurement rate</th>
<th>Bunch selection</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS Synch. 2014</td>
<td>Only above 300GeV</td>
<td>1</td>
<td>200 or $10^5$ by changing attenuation</td>
<td>30% on emittance – hope to improve</td>
<td>~50μm (expected)</td>
<td>10Hz (flexible gating time width)</td>
<td>72 bunches – 1 PS batch</td>
</tr>
<tr>
<td>(refurbished)</td>
<td></td>
<td></td>
<td></td>
<td>10%/5% (same setting, 2 bunches in the machine for example)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LHC Synchrotron Light</td>
<td>BSRT</td>
<td>1 / beam</td>
<td>200 or $10^5$ by changing attenuation</td>
<td>30% on emittance – hope to improve</td>
<td>10%/5%</td>
<td>50μm</td>
<td>10Hz (flexible gating time width)</td>
</tr>
<tr>
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<td>SPS 2015</td>
<td>IPM</td>
<td>2: H,V</td>
<td>$10^3$</td>
<td>20%</td>
<td>5% / 2.5%</td>
<td>100μm</td>
<td>10 bunches in 0.1 s</td>
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<tr>
<td>LHC 2015</td>
<td>IPM</td>
<td>2 / beam</td>
<td>$10^3$</td>
<td>20%</td>
<td>5% / 2.5%</td>
<td>100μm</td>
<td>10 bunches in 0.1 s</td>
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Beam Halo Mitigation: Hollow E-Lens

- Halo cleaning by electron lens demonstrated at Tevatron.
  - Soft scrapper
  - No material damage
  - Tunable strength – diffusion speed

- Such a lens is considered as option for HL-LHC (CERN_LARP collaboration)

Stancari et al., Phys. Rev. Let. 107, 084802
Set-up and validation of collimation performance

- Find the beam center with each collimator jaw by stepping the jaw towards the beam and observing the BLM signal.

'loss map': losses along the ring normalized to the losses at the primary collimator: performance verification.
New CERN Wire Scanner Development

Design Goals:

- Spatial resolution of few µm (using high resolution angular position sensor)
- Dynamic range: $10^4$
- Minimize fork and wire deformations
- Solution to be found for impedance and RF heating
  - tank and fork geometry
  - **damping by loading with ferrite**
  - extracting power with **multi-mode coupler**
- Current Wire Scanners at CERN: Dynamic range 100; accuracy 5-10%; spatial resolution 50 µm (linear type) and 200 µm (rotational)