Current situation with LHC transverse & longitudinal profile and bunch charge measurements

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Beam Gas Imaging Kick-off meeting

30-Oct-2012

Contents

- Transverse distribution monitors
  - ✓ Wire Scanners
  - ✓ Synchrotron Light monitor
  - ✓ Beam-Gas monitor

- Longitudinal Distribution and bunch charge
  - ✓ Longitudinal Density Monitor
  - ✓ Abort Gap Monitor
  - ✓ Wall Current Monitor
  - ✓ Fast Beam Current Transformer

Wire Scanners – Introduction

- Wire scanners are the LHC reference monitors for transverse profile measurements
  - ✓ 30um carbon wires flying at 1 m/s through the beam
  - ✓ At each proton beam revolution: downstream Scintillator+Photo-Multiplier measures secondary shower of particles to be correlated to wire position → profile
- Scan on demand
- Dynamic range controlled by PM gain and optical filters
- Can be used up to a maximum intensity that depends on beam energy
  - ✓ Above such maximum intensity: wire damage and/or quench downstream magnets (→ BLM thresholds to dump before reaching quench limit)
- Expected lifetime under normal operation (below intensity limits)
  - ✓ ~ 100.000 scans? (bellow, wire)

Wire Scanners – Operational Specifications

- Integration
  - ✓ 40 MHz sampling of PM integrator allows bunch per bunch measurements
    - 50 ns ok
    - 25 ns cross-talk being studied
- Repetition Rate
  - ✓ Ideally ~0.2 Hz, at cost of system lifetime (wire, bellows)
- Dynamic range
  - ✓ From pilot bunch to ultimate intensity per bunch, but:
    - Limits on total beam intensity

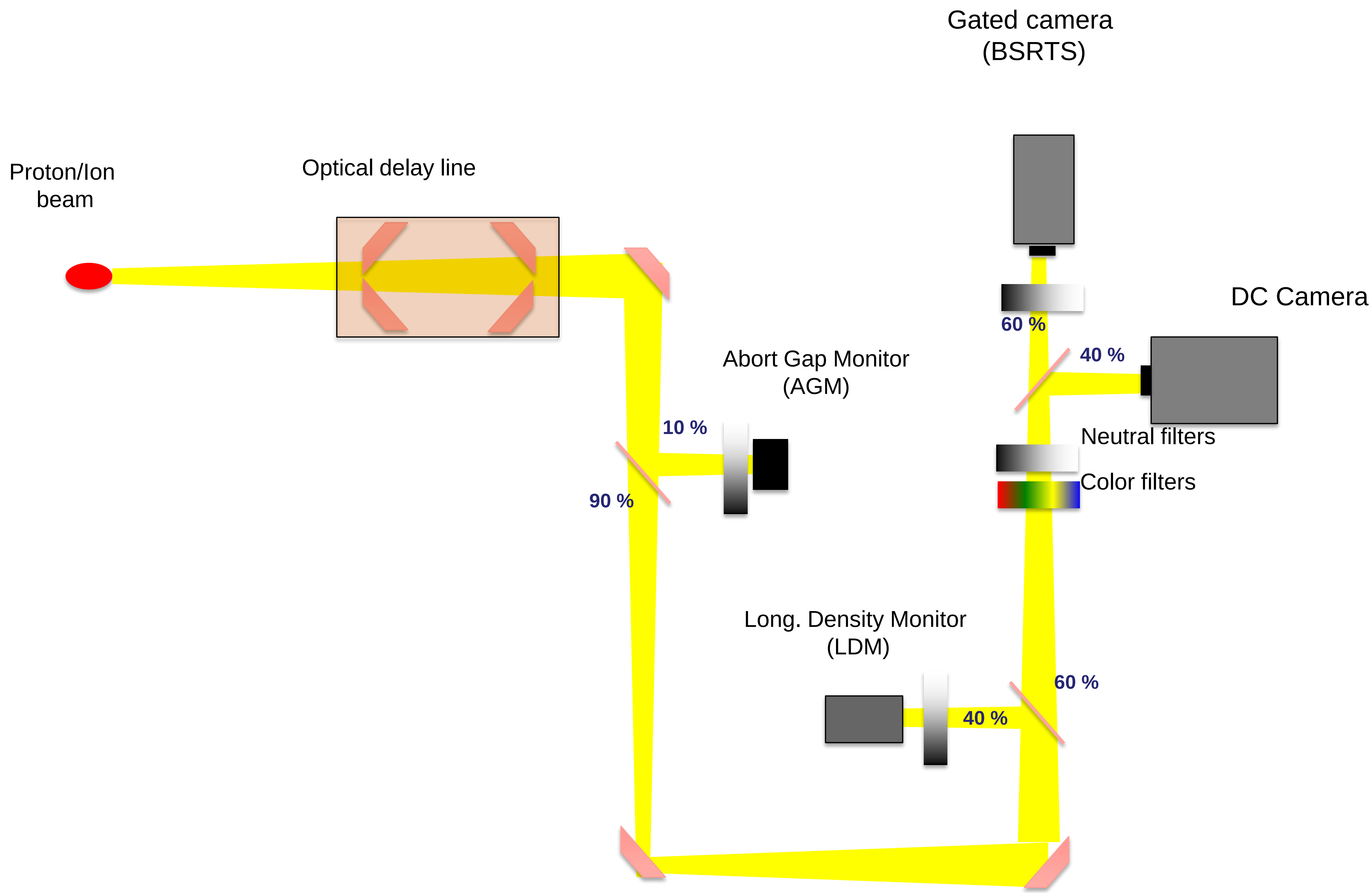
Energy	Limit	Reason
450 GeV	2.7e13p	Wire damage
4 TeV	3.6e12 p	BLM threshold
6.5 TeV	~1e12 p	BLM threshold

- Future: faster WS (20 m/s?)
  - ✓ can allow higher intensities at the cost of
    - multi-scans on a single bunch (go faster → few points/sigma) → need to overlap multi-scans with sampling position offsets
    - single scan, combine NN bunches to have enough points/sigma

Wire Scanners – Resolution/Accuracy

- Resolution
  - ✓ limited by minimum wire speed vs protons revolution frequency
    - 1 m/s → 89 um between two consecutive wire position acq. (→ profile points)
  - ✓ Can be improved overlapping multi-scans (or single scan combining NN bunches) with sampling position offset (as being tested now @ SPS)
  - ✓ Anyhow
    - Present wire position resolution limited by noise potentiometer noise (some 20um)
    - New WS: aiming for 2um resolution (independent of speed)
- Accuracy
  - ✓ With proper PM and filter settings, absolute accuracy proved to be 1% for the SPS linear WS
  - ✓ Accuracy of LHC WS under study
    - theoretically equal to SPS linear WS
    - At the moment: evidence of dependence on working point (PM gain + filter settings)
  - ✓ Plan for different secondary shower detector (diamond)
    - Improve dynamic range
    - Get rid of filters → avoid dependence on working point

BSRT - Layout


Gated camera
(BSRTS)
Proton/Ion
beam
Optical delay line
DC Camera
60 %
40 %
Abort Gap Monitor
(AGM)
10 %
Neutral filters
90 %
Color filters
Long. Density Monitor
(LDM)
60 %
40 %

BSRT -- Introduction

- Imaging of synchrotron radiation from SC undulator (for E<1.5TeV) and D3 dipole (for E>1.5TeV)
- Extraction mirror 30m downstream light source sends light to optical imaging system
- Continuous measurement
  - ✓ Far from being able to use images during the ramp (superimposition of undulator and D3 light)
- Dynamic range controlled by intensified camera gain + optical filters
- 2012 problems with high intensity beams, due to strong RF coupling → heating → extraction mirror distortion / mirror holding failure

BSRT – Operational Specifications

- Gating
  - ✓ Intensified camera gating down to 25ns with a 12.5ns gating resolution
- Repetition rate
  - ✓ Max 200 Hz (limited by intensifier trigger rate)
  - ✓ Present image digitalization (BTV) 50 Hz
  - ✓ Present control + acquisition SW ~12 Hz
  - → Can do bunch per bunch @ ~12Hz
  - → Can do single bunch single turn but not on consecutive turns
- Dynamic Range
  - ✓ Protons: From pilot at injection (single turn, every 220 turns) to average over all bunches at flat top
  - ✓ Ions: From ~30 bunches at injection to average over all bunches at flat top

BSRT – Resolution/Accuracy

- Resolution
  - ✓ Present optics 0.1 mm/pix, next: 0.05 mm/pix
- Relative bunch per bunch accuracy <= 5%
  - ✓ 5% on single shot, dominated by reproducibility affected by noise (airflow, optical elements vibration, fit accuracy, etc …)
  - ✓ 1% averaging on multi-shots
- Absolute accuracy:
  - ✓ Optics magnification validated to <= 5%
    - Calibration target
    - Beam orbit local bumps
  - ✓ Ultimate accuracy dominated by aberration / diffraction
    - Need cross calibration w.r.t. WS
    - → calibration factors → accuracy <=10% after calibration
  - ✓ Calibration factors not stable
    - Possible drifts due to mirror coating aging (heating)

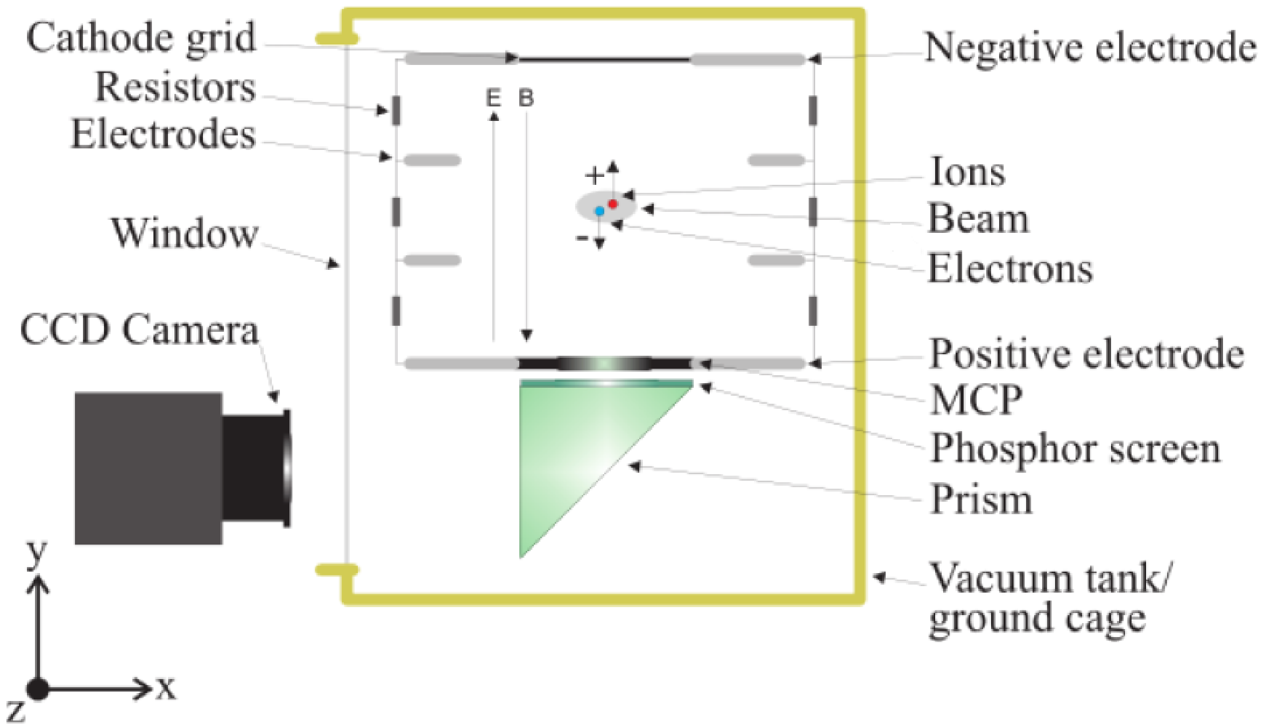
BSRT – LS1 Upgrades

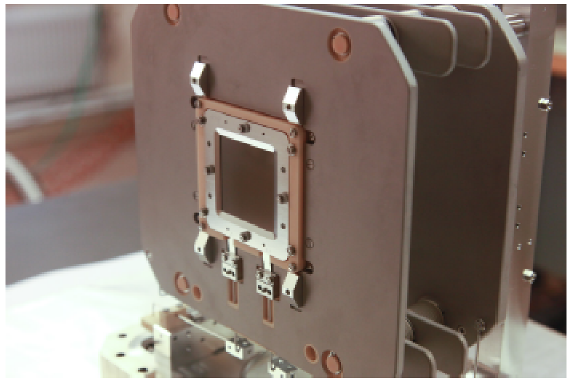
- Rethink mechanical design + mirror type to cope with RF heating with high intensity beams

- Change optics from focusing mirrors to focusing lenses
  - ✓ Simpler optics, less elements
    - Smaller effect of vibrations on reproducibility/noise
  - ✓ Decouple AGM and BSRT/LDM
  - ✓ Prototype optics installed on B1 during TS#3, will do the same on B2 during TS#4

BGI - Introduction

- Collect electrons form beam-gas ionization
  - ✓ Dipole B field to avoid drift from ionization location to MCP
  - ✓ MCP electron multiplication
  - ✓ Phosphor coupled to MCP output for electron→photon conversion
  - ✓ Imaging of phosphor output
- Designed for heavy ions
- Enough signal from protons by injecting local pressure bumps or high intensity
- Can monitor average relative beam size variation during the ramp





M.Patecki, M.Sapinski

BGI – Operational Specifications

- Gating/Integration
  - ✓ Gated camera
  - ✓ Need to gate over multi-bunches to have enough signal (see dynamic range)
- Repetition Rate
  - ✓ 50Hz, limited by image digitalization (BTV)
- Dynamic range
  - ✓ With a “fresh” MCP:
    - 10 proton bunches with gas injection 10-8mbar
    - Single Pb ion bunch with gas injection 10-8mbar
    - A bit better at 4TeV due to denser beam
  - ✓ MCP aging rather quick

BGI – Resolution/Accuracy

- Resolution
  - ✓ Present optics gives 0.115 mm/pixel
- Accuracy
  - ✓ Optics magnification validated to 1% by
    - Beam orbit local bumps
    - Reference wire-grid calibration
  - ✓ Needs cross calibration w.r.t WS and BSRT
  - ✓ For the moment not better than 20%, degrading with MCP aging
  - ✓ Many studies on going to understand ultimate resolution/accuracy
- LS1:
    - Replace MCPs
    - Second camera with better performances

Transverse Profile Monitors Summary

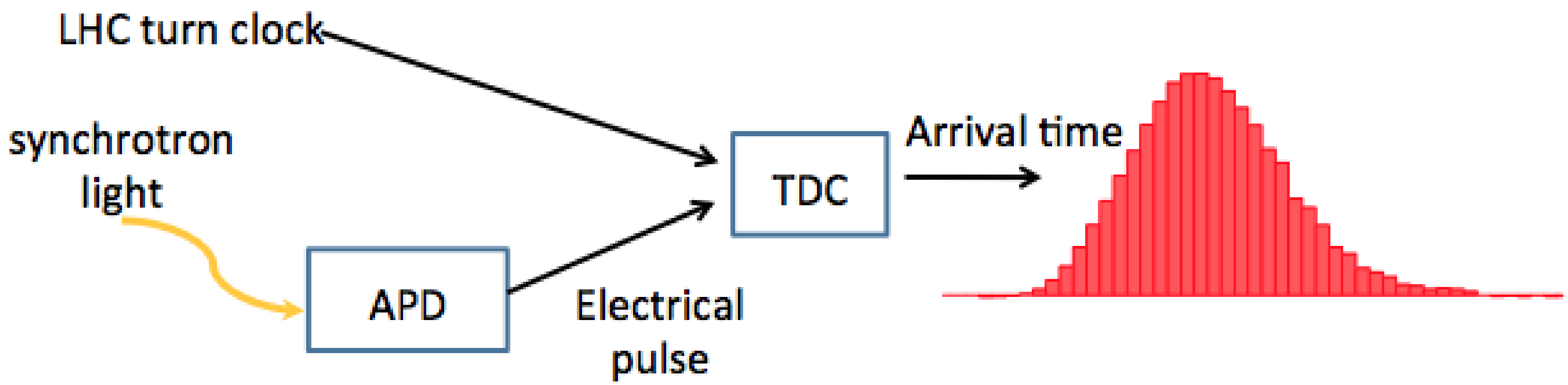
Monitor	Max Acq. rate	Minimum Gating/Sampling	Dynamic Range		Spatial Resolution	Accuracy	Remarks
			Prot.	Pb Ions			
WS	~ 0.2 Hz *	25 ns	>5e9 <2.7e13 (450 GeV) <3.6e12 (4TeV) <1e12 (6.5TeV)	Under study	89 um @ 1 m/s	On paper ~1 % absolute and relative	Dependence on operational point (PM+filters)
BSRT	12 Hz (SW overheads) 50 Hz (BTV)	25 ns	>5e9	>30 Pb ions bunches @ inj	0.1mm/pixel	1 % relative ~ 10 % absolute	Need frequent calibration w.r.t. WS RF heating
BGI	50 Hz (BTV) (but needs 100ms to see signal)	20 ns (but not enough signal) Operational :100ms	>1e12 (with 1e-8mbar)	1 Pb bunch (with 1e-8mbar)	0.1mm pixel	~20% after calibration w.r.t. WS/BSRT.	MCP aging

* **Would imply continuous scanning→ low wire, bellow lifetime + blow-up due (interceptive device)**

Abort Gap Monitor

- Photo Multiplier detecting synchrotron light
- 10 Hz acquisition
- ~1e6 dynamic range (without considering optical filters)
- 100ns resolution
- Better than 5 % accuracy after cross-calibration vs FBCT
  - ✓ Need calibration curve vs energy to cope with sync. light sources

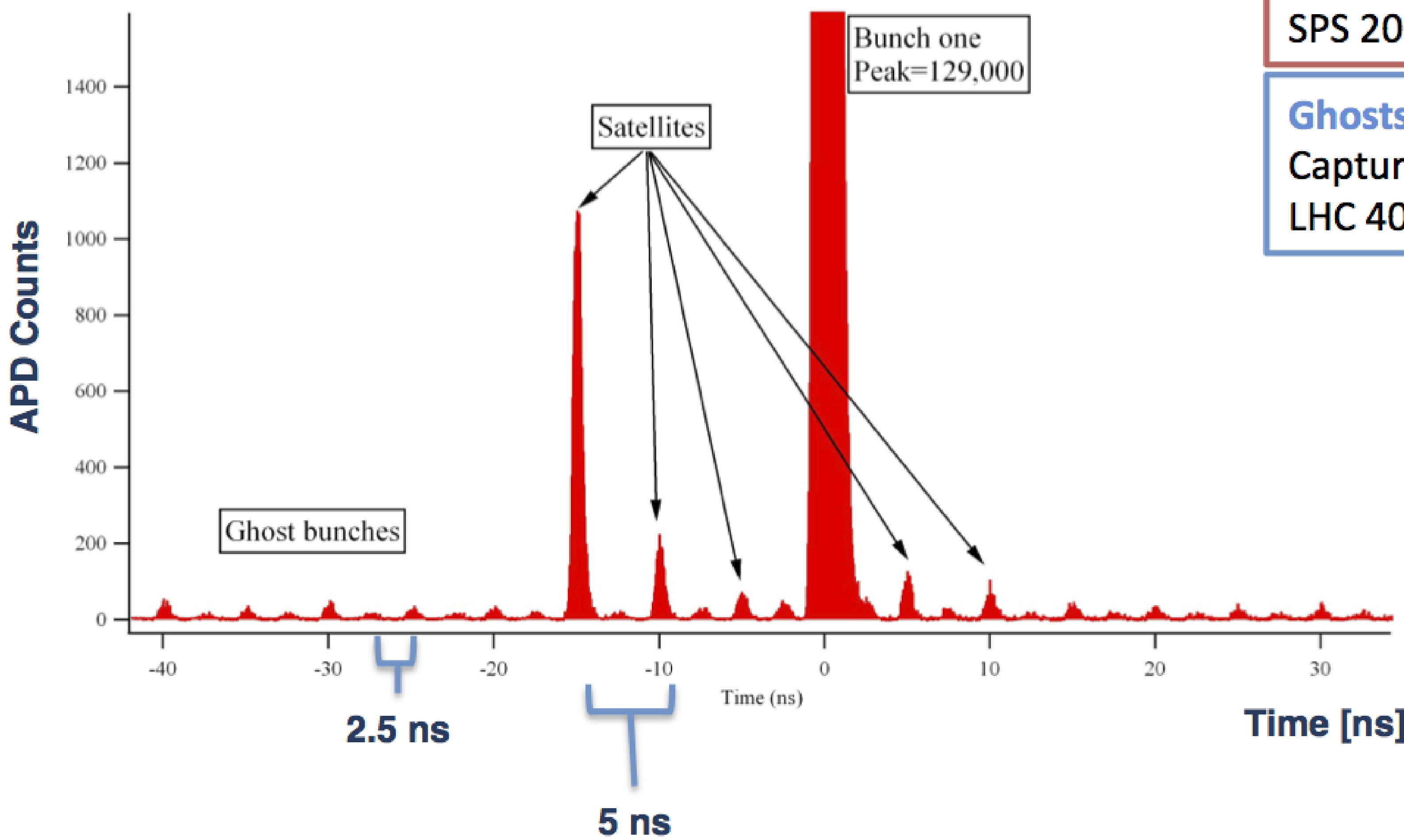
Longitudinal Density Monitor (LDM)



- Geiger mode Avalanche Photo-Diode, single photon counting
- 50ps resolution
- 10e5 dynamic range
- Need long integration time (10-15 minutes to achieve 10e5 dynamic range)
- Lots of data logged in 2012
- Ultimate accuracy/reliability affected by
  - ✓ BSRT system reliability
  - ✓ internal reflections
- Some ideas to improve system in LS1, resources manpower to be established

LDM meas. example

- Lead Ions beam
- Integration time ~ 10min



Satellites
Capture/splitting errors in the injectors
SPS 200 MHz → 5 ns

Ghosts
Capture/splitting errors in the LHC
LHC 400 MHz → 2.5 ns

LDM is the only LHC system able to see all structures from RF, with enough **dynamic range** and **time resolution** for monitoring satellites and ghosts

FBCT

- Fast Beam current transformer able to meas. bunch per bunch
- Needs cross calibration with DC BCT
- Dependence on bunch length reduced after modified electronics
- Dependence on beam position depends on detector itself
- Future: development of new detector that should be much less sensible to beam position
- Relative bunch per bunch charge 1%
- Absolute accuracy ~1% after calibration w.r.t. DC BCT
- Integration limited to 25ns (maybe better after LS1)

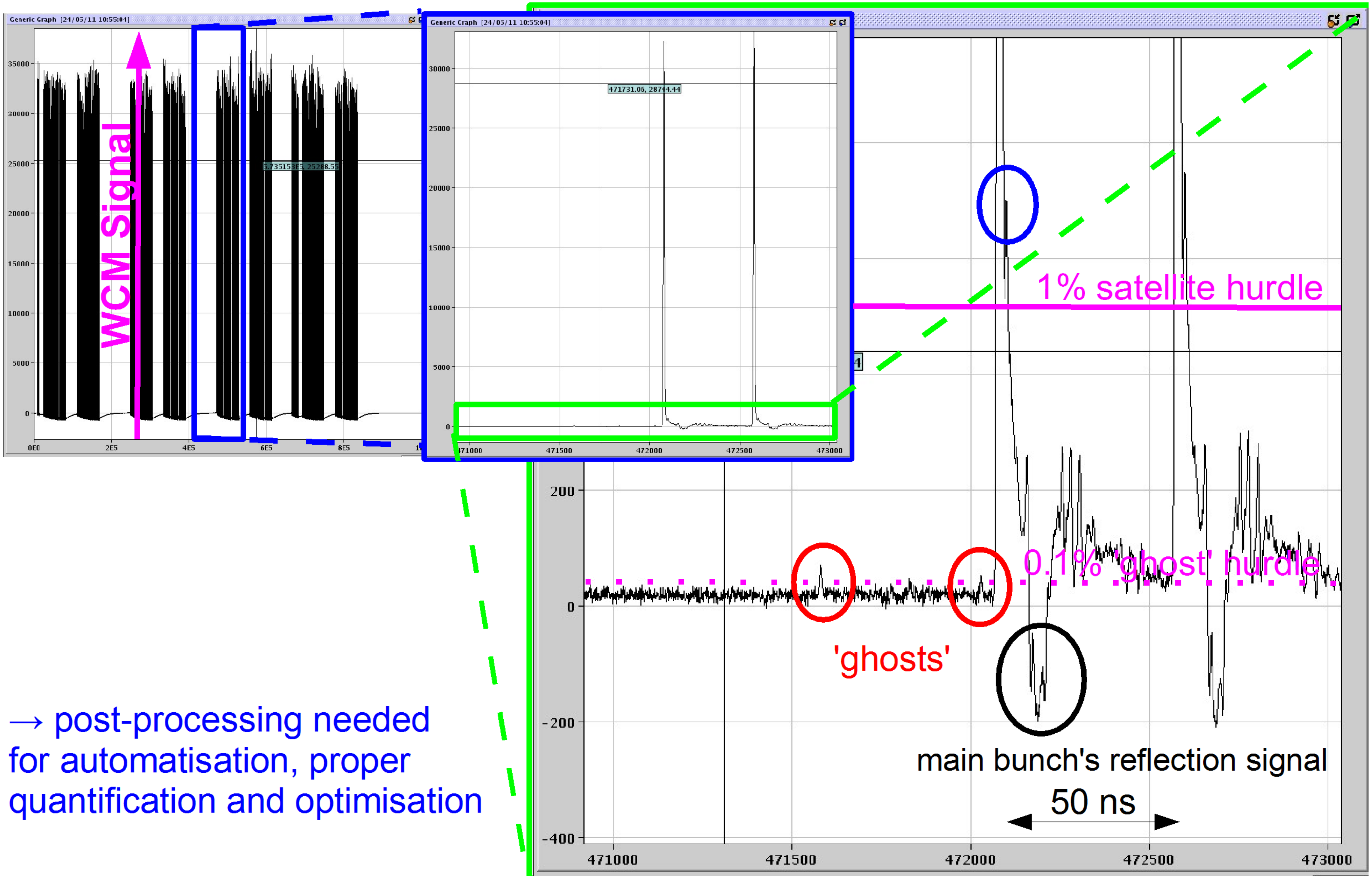
Wall Current Monitor

8 ports RF pickup capable of estimating bunch charges and bunch shape

- Bunch intensity:
  - ✓ Absolute accuracy: cross-calibration w.r.t. DC BCT
  - ✓ Relative bunch per bunch accuracy, 0.1% limited by ADC linearity, stable over weeks after calibration w.r.t. DC BCT
- Bunch length
  - ✓ Different fit functions (Gaus,Cos2,parabolic) + fit errors for identifying bunch shape variations
  - ✓ Compensated for cable length/dispersion up to 3 GHz → << 1% in defining bunch length/shape variations
- For both intensity and longitudinal distribution meas.
  - ✓ Ultimate accuracy is limited by systematics (reflection of main bunch)
  - ✓ Need Integration @ 0.1Hz
  - ✓ B1 operational, B2 need to sort out SW/HW issues
- After LS1:
  - ✓ Aim for 10-6 satellites/main bunch.

WCM example (R.Steinhagen)

- From a pure resolution point of view: “Can detect Ghosts by Eye”



→ post-processing needed for automatisation, proper quantification and optimisation

Summary

- Transverse Profile Monitors
  - ✓ WS are the most accurate system (dependence on working point under study), but
    - Can’t be used at all beam intensities
    - Can’t be used continuously
  - ✓ BGI and BSRT
    - provide a continuous and a higher repetition rate measurement, but ultimate relative and absolute accuracy is not established yet
  - ✓ WS, BGI, BSRT: Resolution for smaller beams at 6.5-7TeV (can go down to 100um or less with present beam optics) not necessarily achievable with present systems

- Bunch Charge and Longitudinal distribution monitors
  - ✓ FBCT relative bunch per bunch charge @ 1% after calibration w.r.t. DC BCT
  - ✓ LDM and WCM potentially very useful for longitudinal distribution, but still some work to achieve desired accuracy and reliability to consider them operaitonal

SPARE

WCM example (R.Steinhagen)

- Satellites have been deliberately produced for better proof-of-principle: