Beam instrumentation for machine protection

Evian workshop
2-4 June 2014

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For the BE-BI group

Outline

- Interlocked BPMs
  - Changes
  - Status at startup
  - Scrubbing with doublets
- FBCCM (dI/dt)
  - Changes
  - Status at startup
- Abort gap monitor
  - Changes
  - Status at startup

Interlocked BPMs

- Strip line pick-ups installed in IR6 just after Q4 (BPMSX was BPMSA) and just before the TCDQ (BPMSI was BPMSB)
- Prevent beam on TCDS
- Acquisition is based on the LHC BPM design with dedicated firmware
- Two operational ranges used (high and low sensitivity modes)

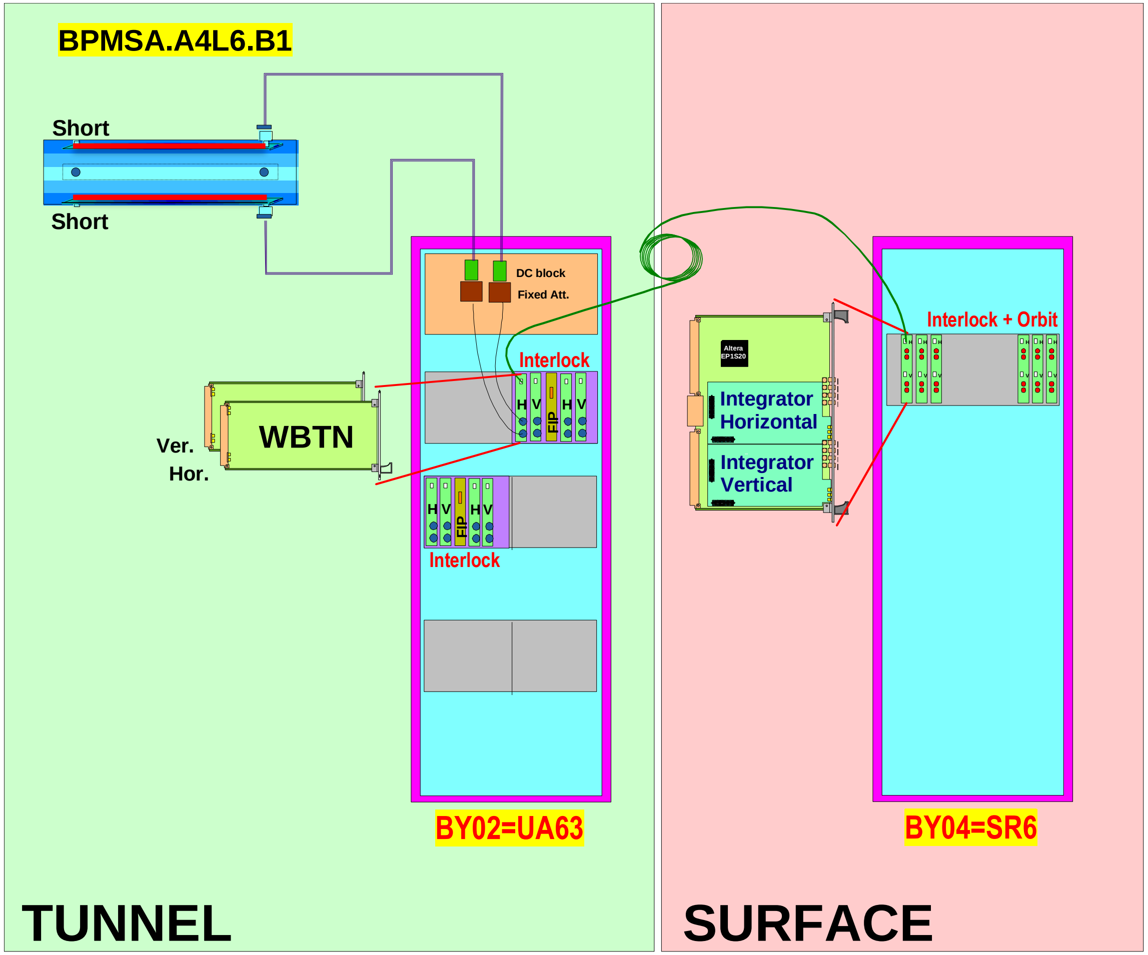
Issues in run 1

- Interlock fires for bunches near the detection threshold
- Reflections from intense bunches cause false triggers (seen as weak bunches)
- Detection threshold adjusted (by changing attenuators) between signal and reflections
- Insufficient diagnostics for the PM analysis

Actions during LS1

- Replaced shorted strip-lines with 50 Ω terminated s.l.
- Added absorptive filter at strip-line output (100 MHz)
- Separated orbit and interlock functions (2 DABs)
- Improved HW & firmware: bunch-by-bunch interlock post-mortem data (3564 slots x 294 turns)
- Installed thermal controlled racks (stability)
- FESA adapted to new firmware (and new CPUs)
- New GUI for the interlock post-mortem t.b.d. (BI/OP)

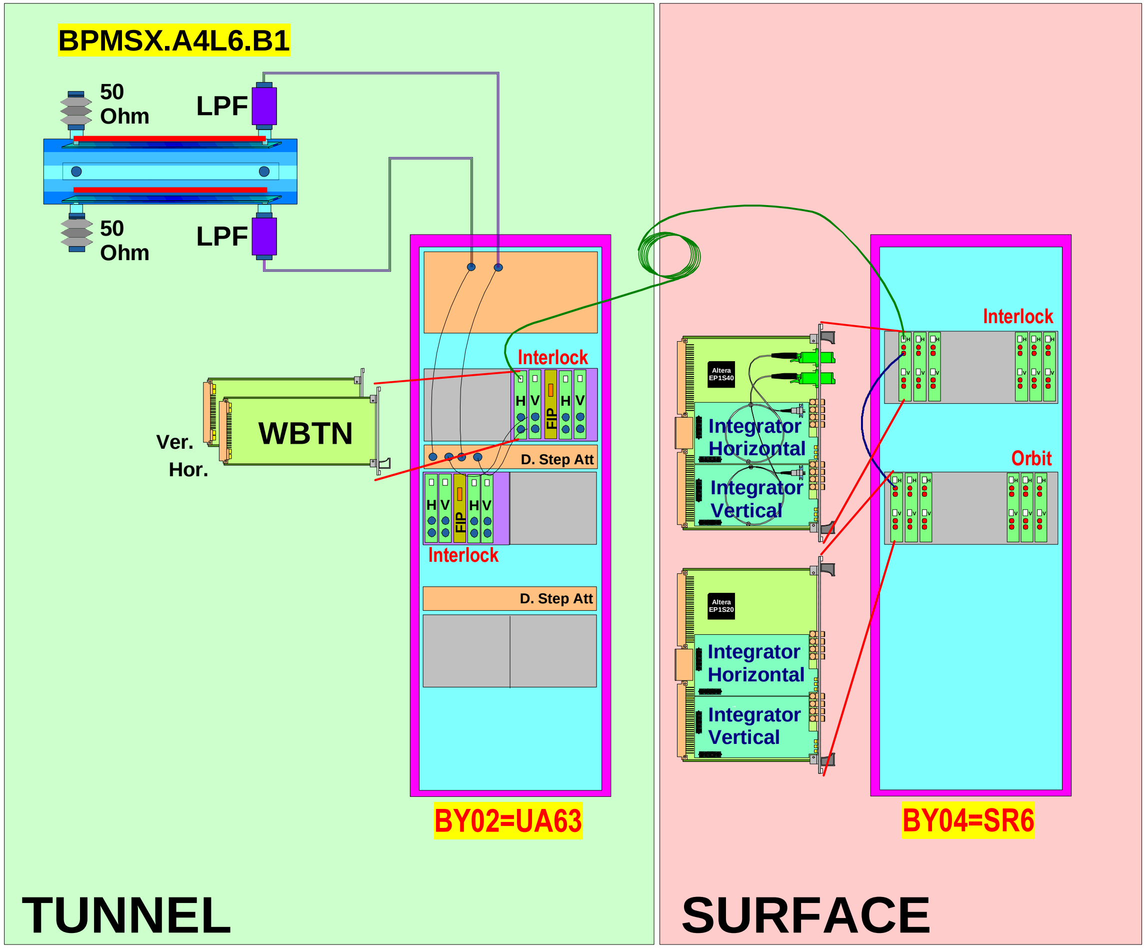
Old BPM setup



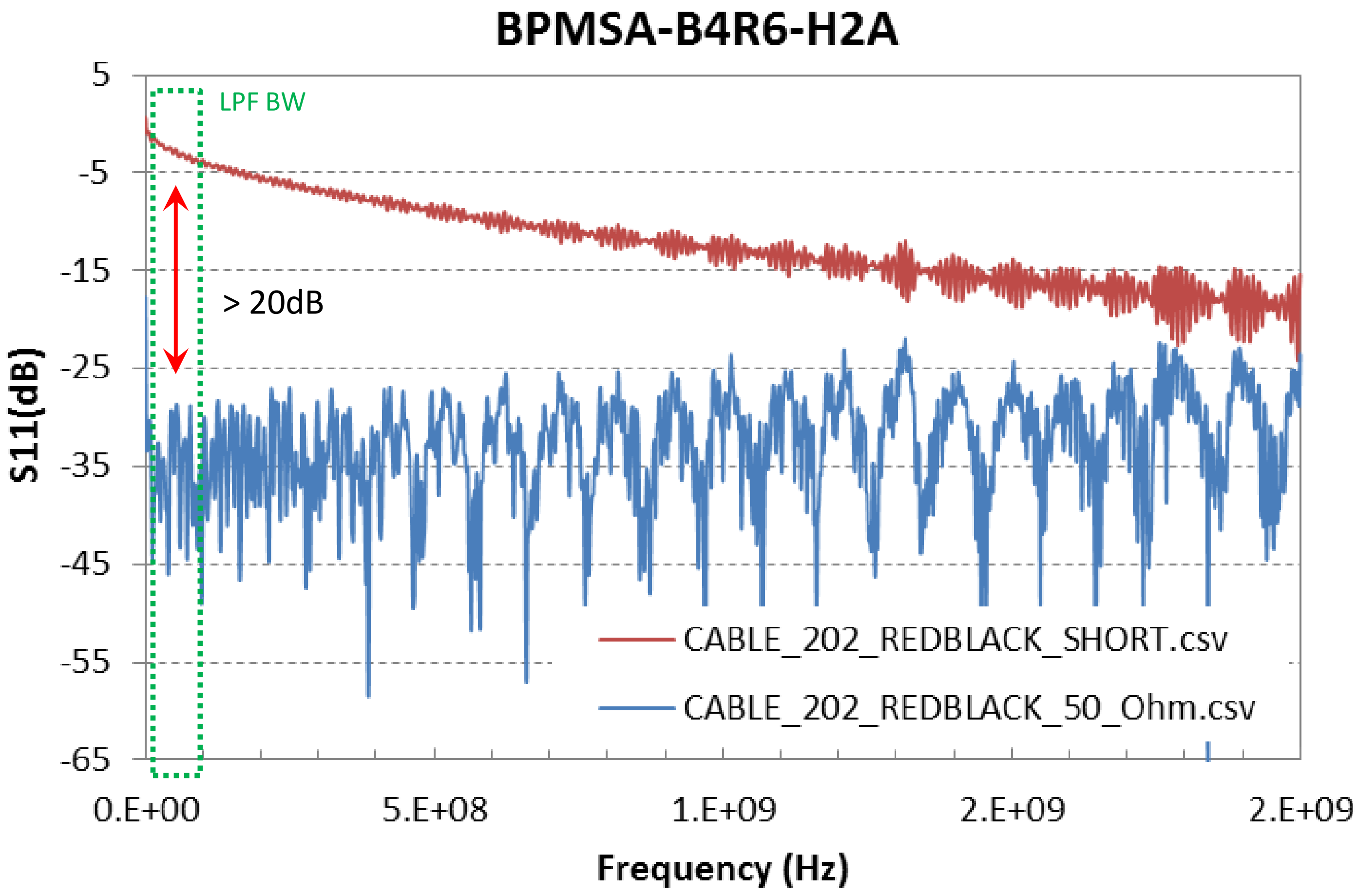
New BPM setup

The BPMs have been renamed (LHC-BP-EC-0002)

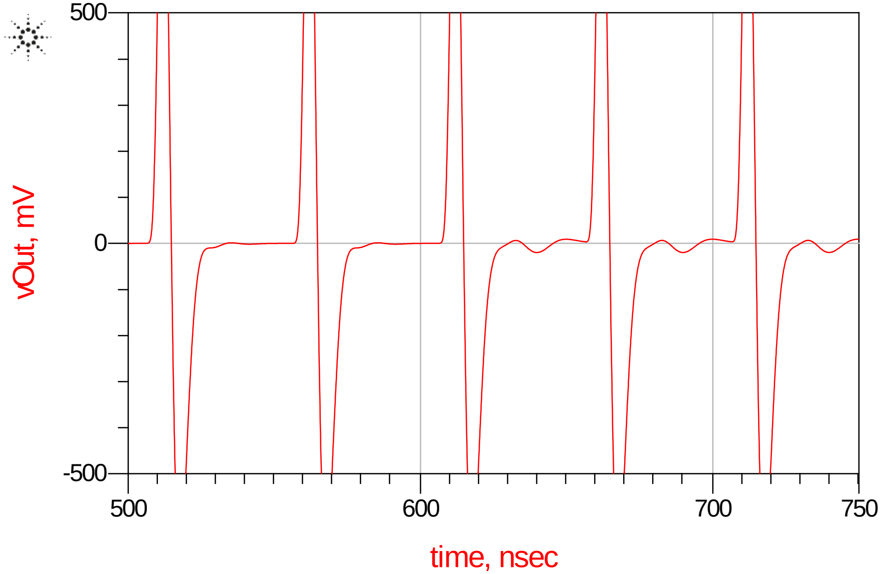
The Interlock and orbit systems have been separated

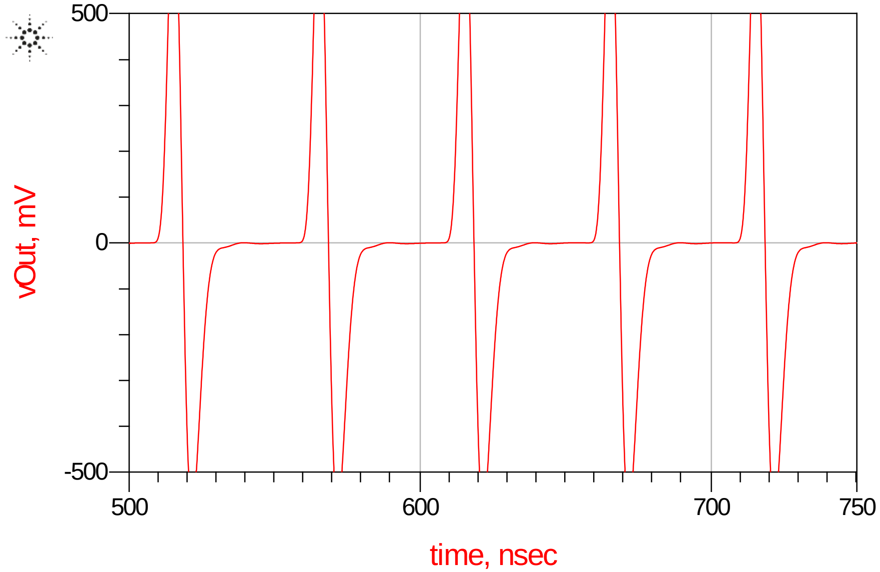


BPMs Reflections



Reflections in time domain

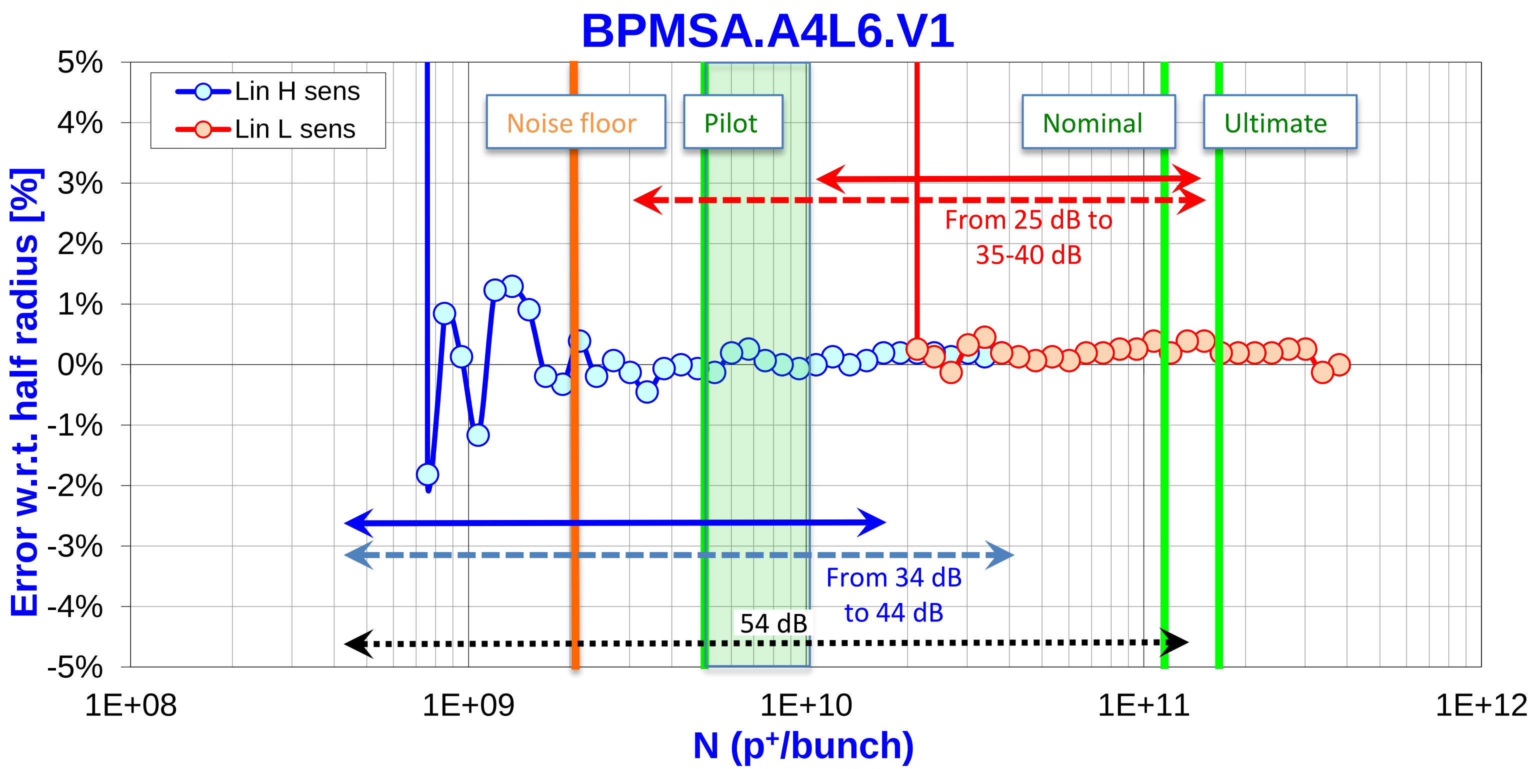




Shorted strip-lines reflections
Measurement: -27 dB
Simulation: -34 dB

Terminated strip-lines with LPF:
Simulations: <-46 dB

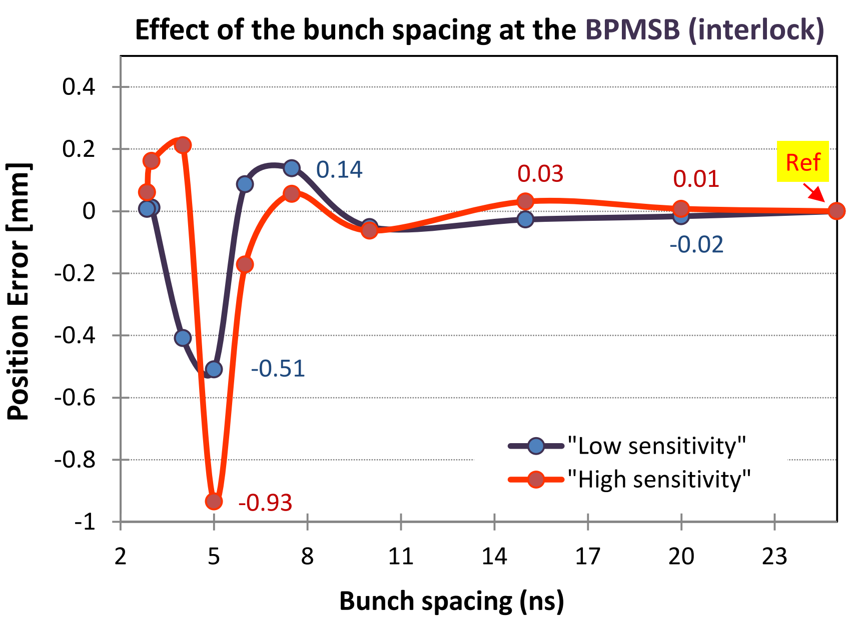
Interlock thresholds

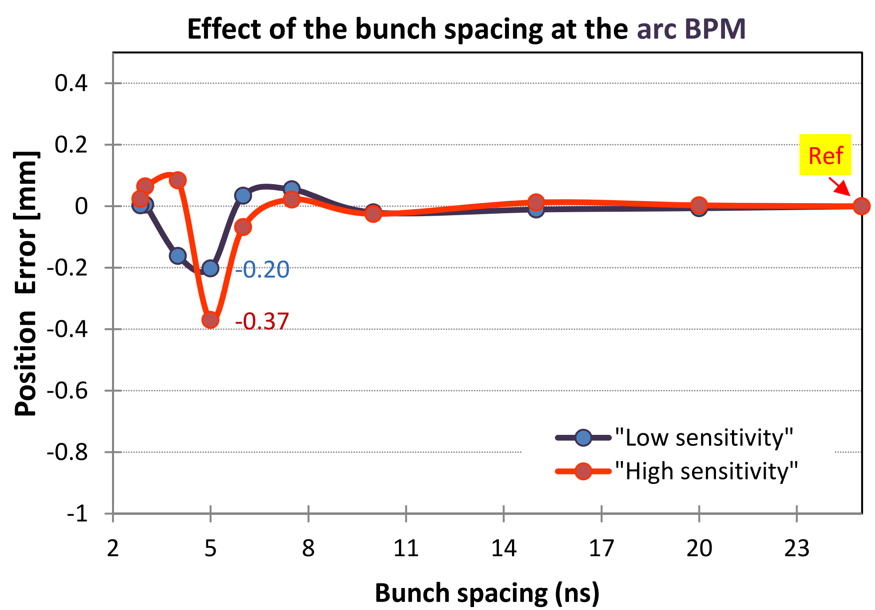


- Thresholds to be defined
- Verifications with beam required

Scrubbing doublets

Beam “simulator” tests (beam signal replaced by pulse generator)
May be possible to test on SPS with beam

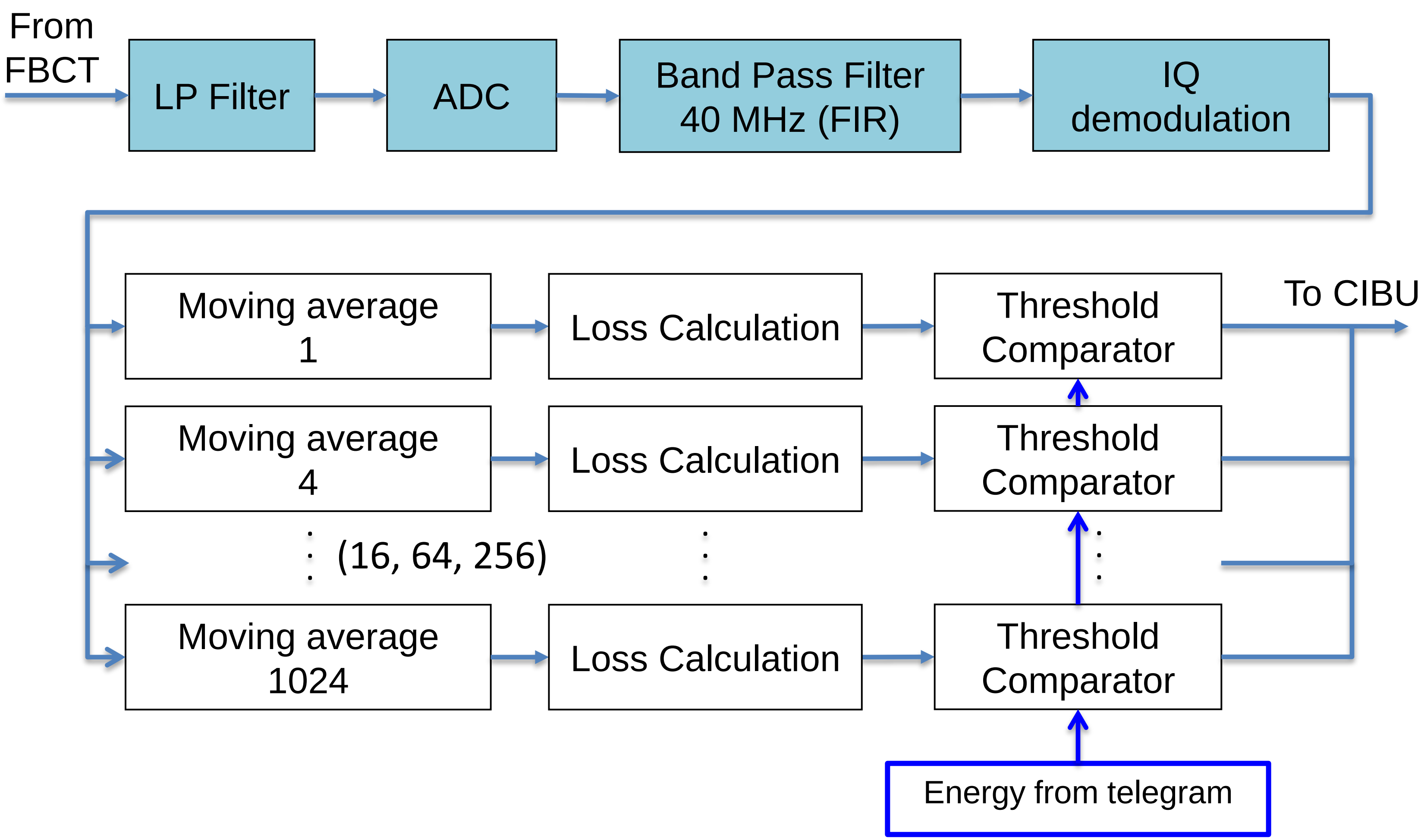




FBCCM (dI/dt)

- Interlock system based on the reading of the fast beam current transformers
- Detects rapid changes of beam currents i.e. losses or debunching (of one or more bunches)
- Six different time integration windows
  - 1, 4, 16, 64, 256 and 1024 turns
- 32 energy thresholds
- Prototypes tested in 2012

FBCCM Signal Processing



FBCCM units

- 6 Units produced based on prototype
  – Reduced noise
  – One beam per box
- 4 Will be installed in July (2 oper. B1/B2 + 2 dev. B1/B2)

FBCCM for 2015

- Two systems per beam running in parallel
  - One will be operational (System A) (stable HW and FW)
  - One will be used for debugging/development (system B)
- New fast current transformers (to address position sensitivity)
  - System A remains old FBCT (position and σ_z sensitivity)
  - System B will be CERN/BERGOZ BCTI on Beam 1 and CERN BCTW on Beam 2
  - Switch to BCTIs or BCTWs on both beams (without breaking vacuum) later on depending on results with beam
- FESA class 90% ready, expert GUI almost ready, Post mortem analysis tool to be defined (BI/OP)
- Connected to the BIS but initially masked (allowing to collect statistics)

FBCCM commissioning

- Need dedicated beam time for repeating the lab measurement (controlled losses, scraping)
- Lot of learning, debugging and setting-up can be done in parallel with the normal operation of the machine
- Possibility to carry out realistic beam simulations in the lab?

Abort Gap Monitor

- Monitors the particles population inside the 3μs abort gap (needed by the dump kickers)
- It is based on the detection of synchrotron light by a gated photomultiplier and is integrated in the BSRT telescope

Issues during run 1

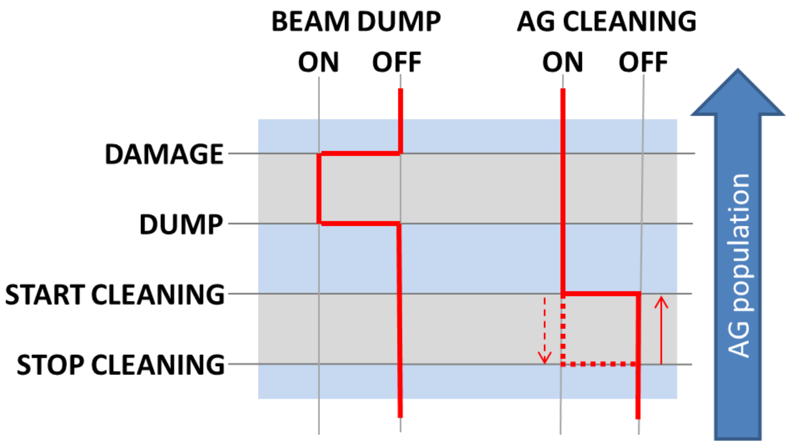
- Interference between BSRT and AGM
- Extraction mirror heating
- Software issue affecting reliability
- Lots of manual actions for calibration and verification (expert only)

Changes during LS1

- New extraction mirror [LHC-BSRTM-EC-0002]
  - No more heating problem (TBC with beam)
- New layout of optical table (optimized)
- New readout electronic (not deployed at start up)
- New automated software procedures for calibration and diagnostics [EDMS 1337184]
  - Actions to be included in the sequencer

AGM and SIS

- AGM will eventually be connected to SIS
- SIS also used for triggering AG cleaning
- AGM-FESA to handle cleaning and dump logic
- Thresholds need to be finalized (based on new quench limits)



Conclusions

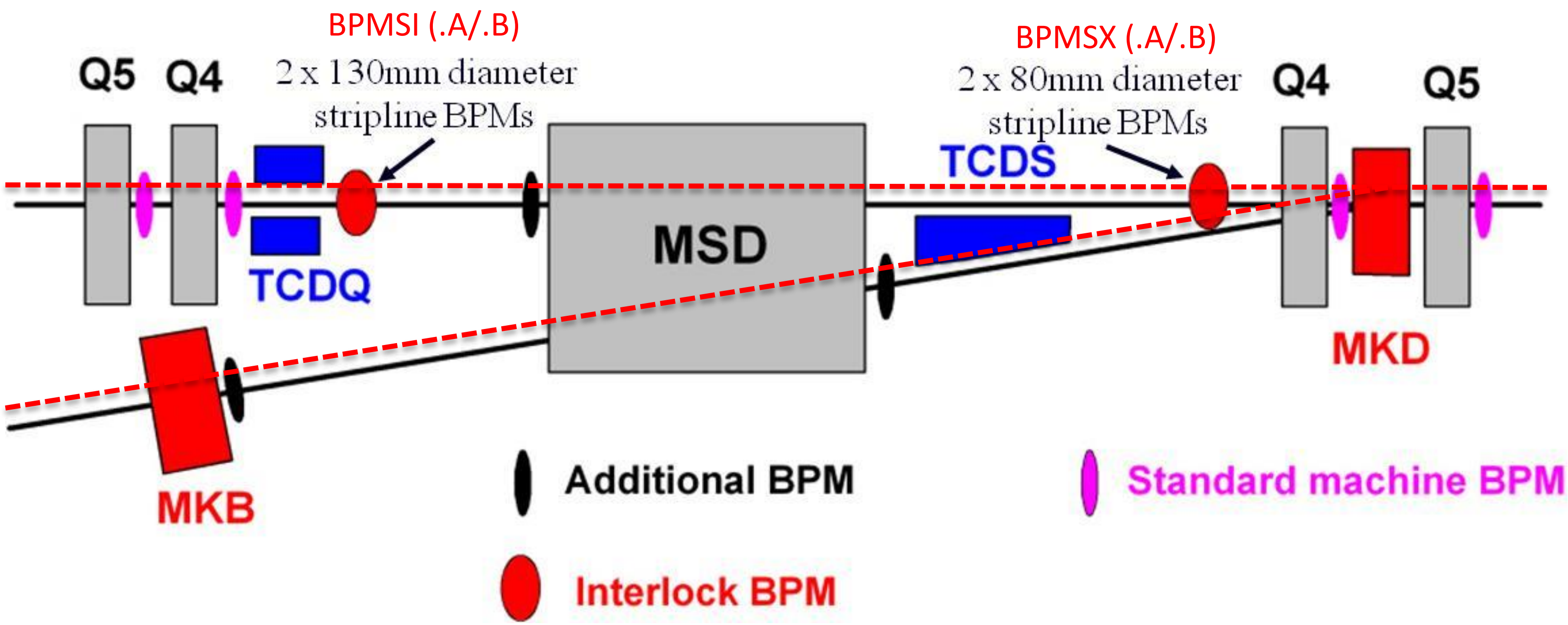
- The impact of the interlocked BPMs on the length of fills should be minimized (surely for ions)
  - Thresholds levels to be defined
- 4 FBCCM will be available at startup
  - Prototype and lab test give encouraging results, some debugging and fine tuning required when beam comes back
- Reliability of AGM improved
  - No significant changes in performances (better if any)
  - System should become much more reliable and self-diagnosing

Thanks!

The End

Support slides

Dump Channel

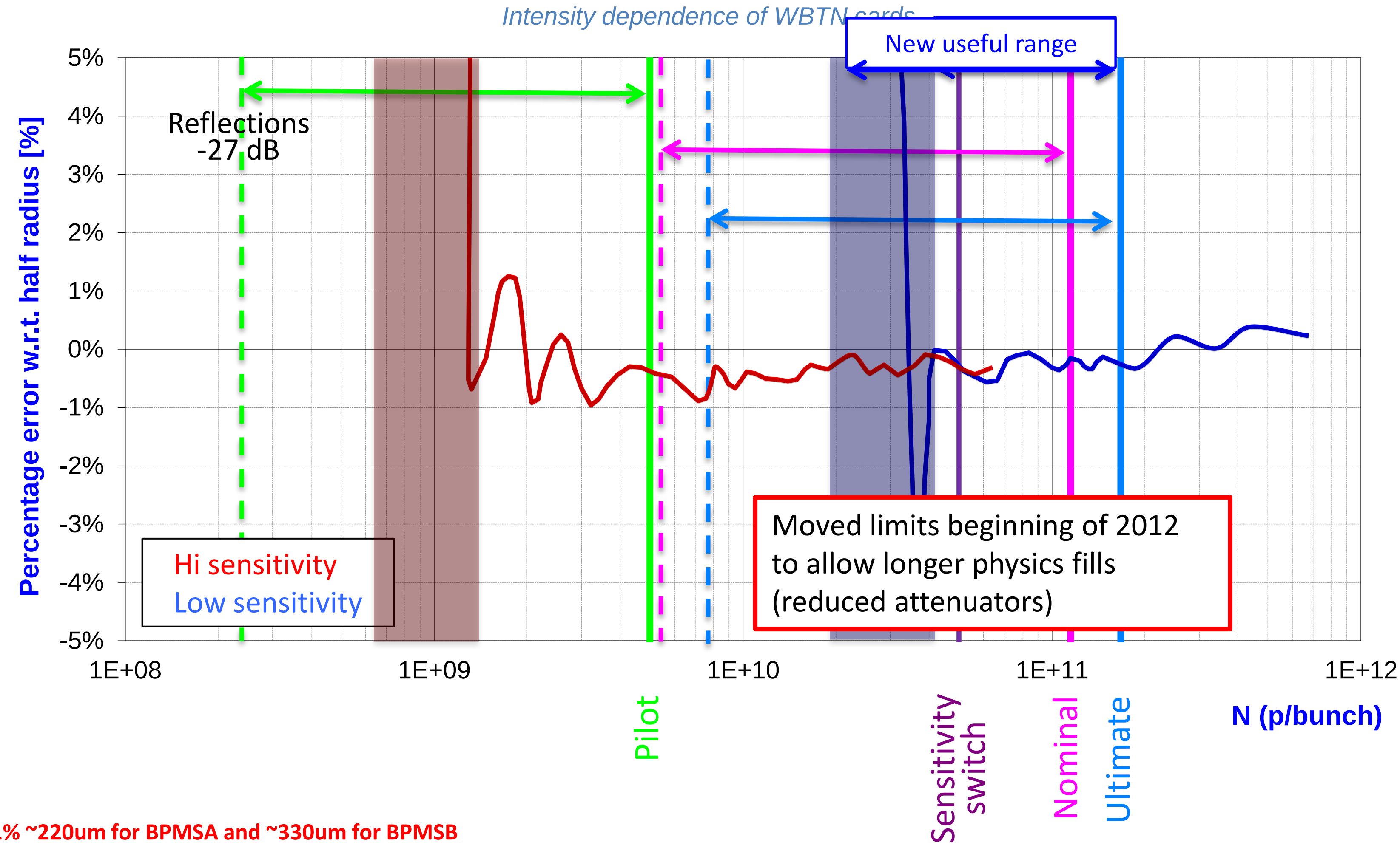


The main aim of these BPMs is to avoid large orbit offsets leading to high losses on the septum protection during a dump

Interlock Mechanism

- Two separate trigger logics
  - 70 reading in the last 100 turns out of limits (a single bunch can trigger the dump)
  - 250 reading in the last 10 turns out of limits (response to fast orbit changes)
- Limits set to ~±3mm
- The whole chain from readout to beam dump trigger is in hardware (and firmware)
- Interlock signal connected to a maskable channel of the BIS

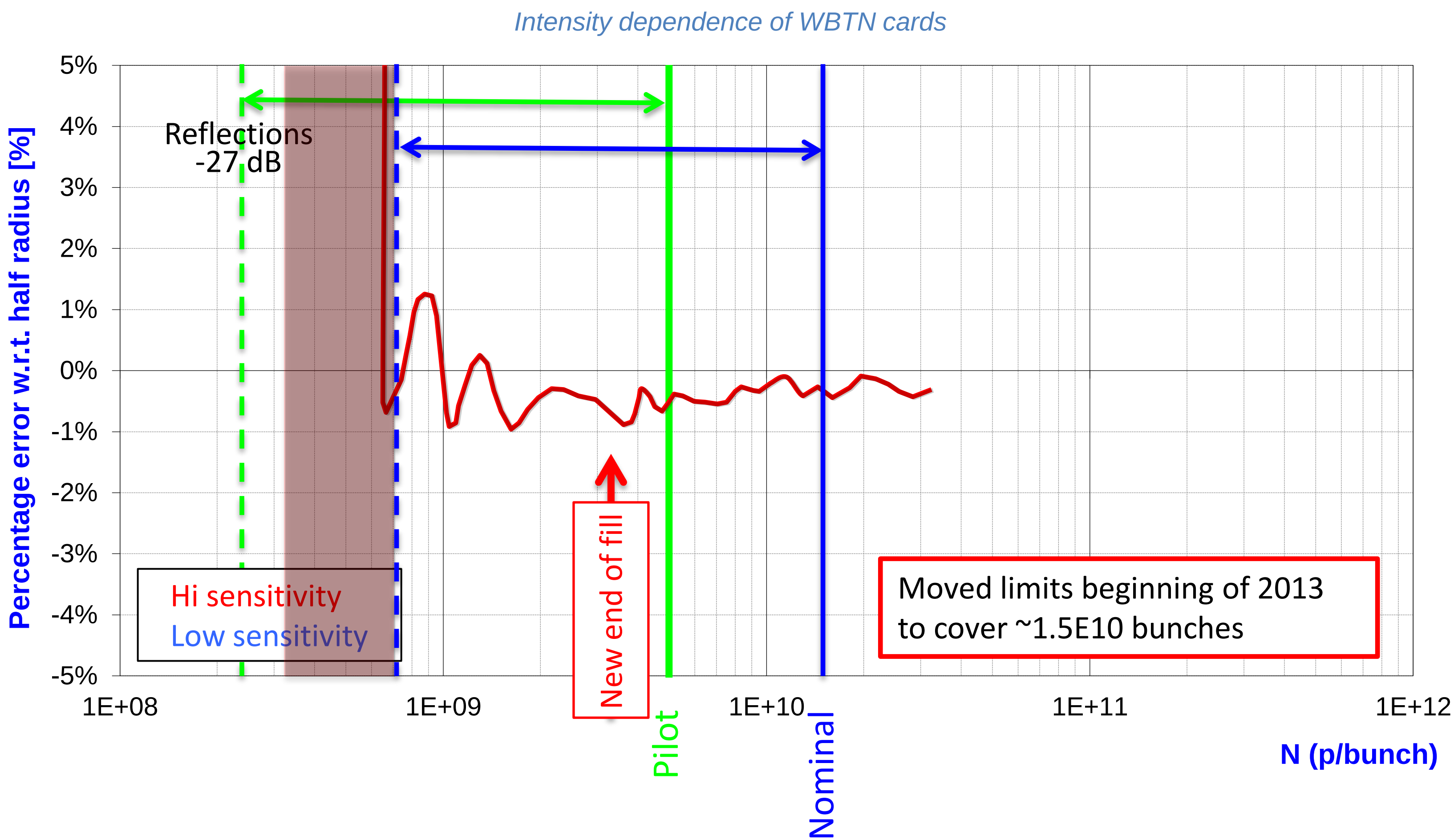
BPMs Signals (Protons)



Note: 1% ~220um for BPMSA and ~330um for BPMSB

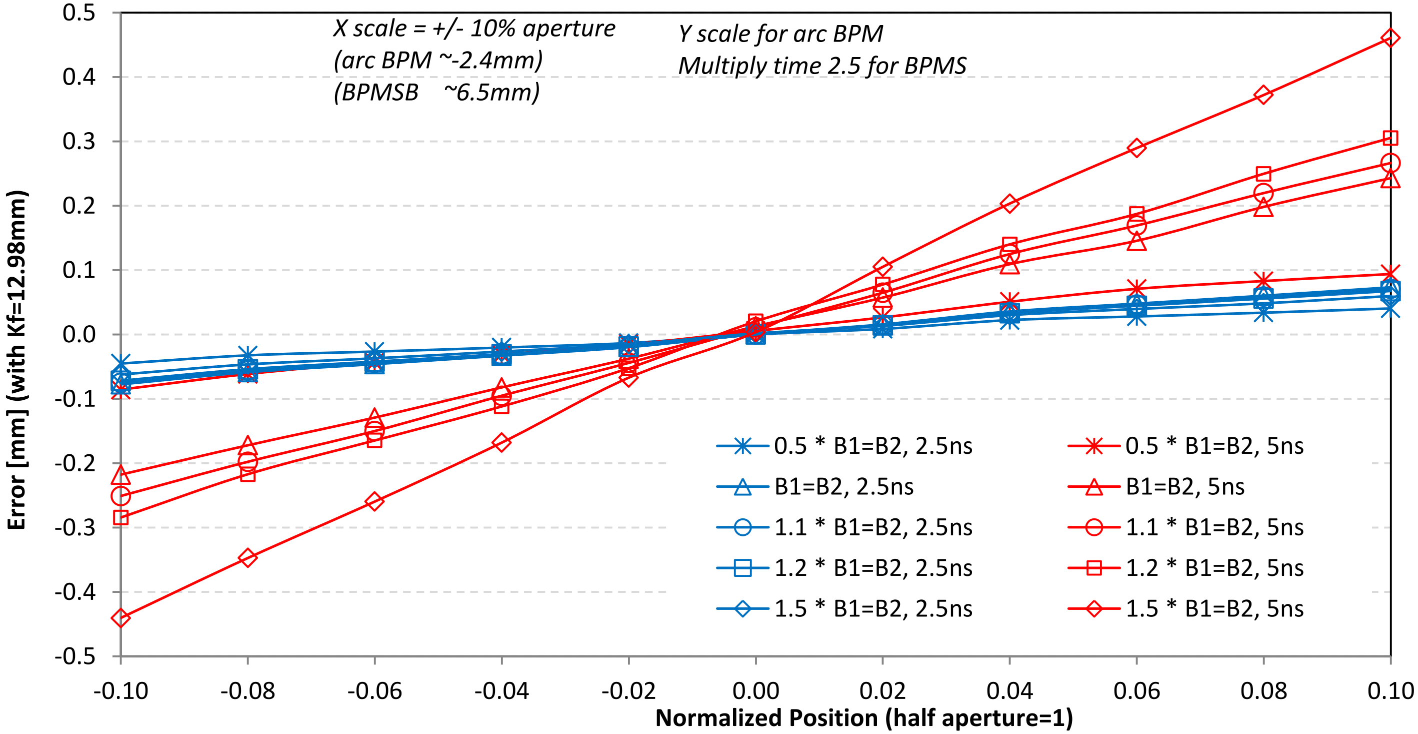
BPMs Signals (Ions)

- With p-Pb only use Hi Sensitivity mode (only 1.5 10^{10} charges / bunch)
- P-Pb MD showed that the satellites of the nominal beam triggered the interlock



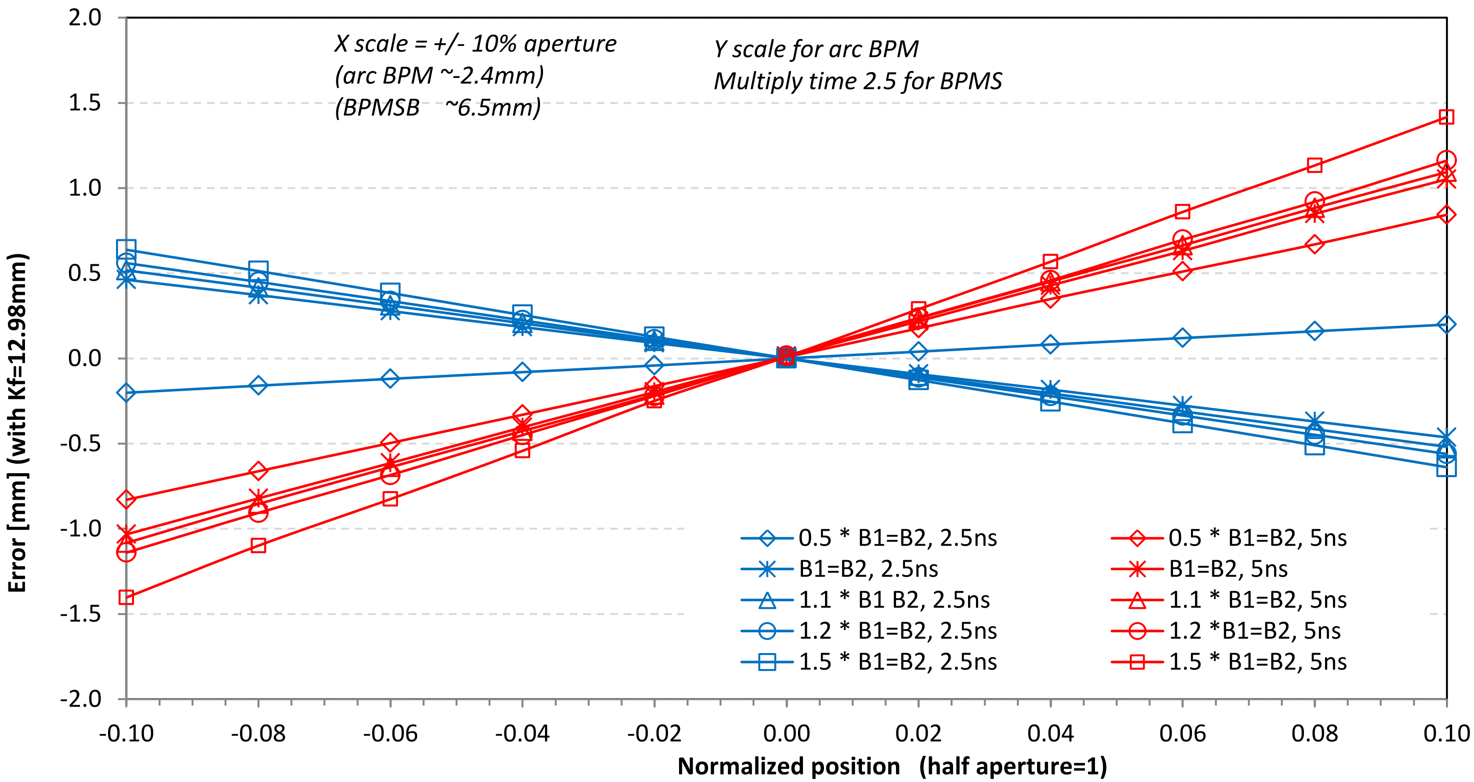
Doublets simulations 1

Bunch 1 and bunch 2 with same position

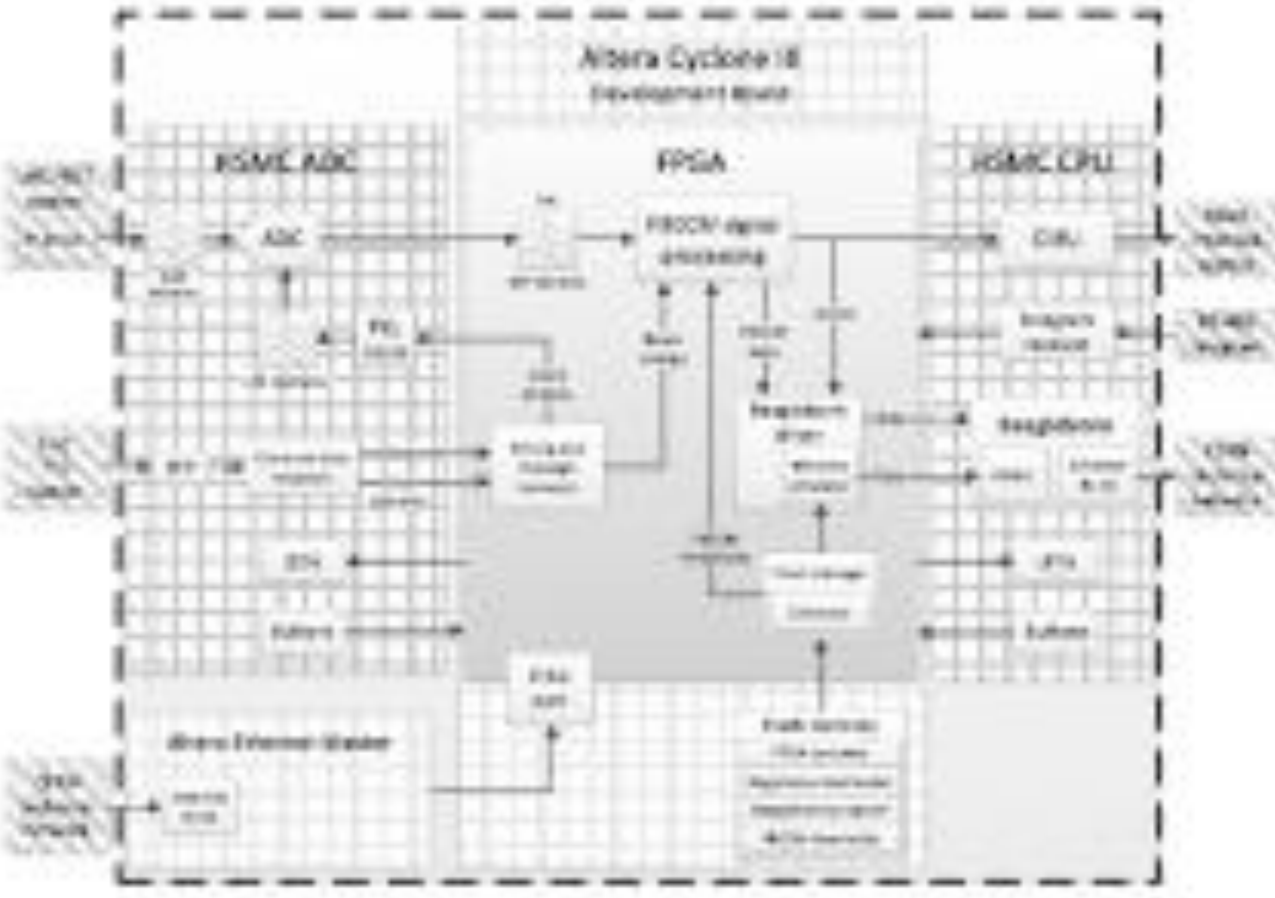


Doublets simulations 2

Bunch 2 always centred



Detail of Implementation



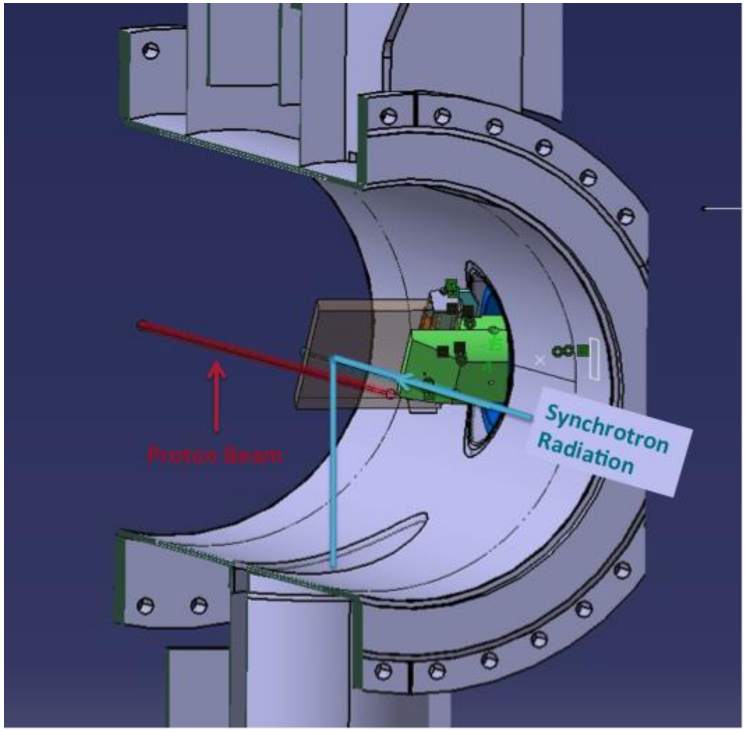
AGM Performance

- A-gap population published and logged at 1Hz
- Sensitivity and accuracy depends on the energy and the particle type
  - The higher the emission the more precise the measurement
- For protons the sensitivity is better than 10% of quench level (fulfilling the specs) for all Energies
- For Pb ions the AGM only fulfills the specs above 1.5 TeV
  - Would need a new undulator to solve this
- The error on the measurement is of the order of 50%

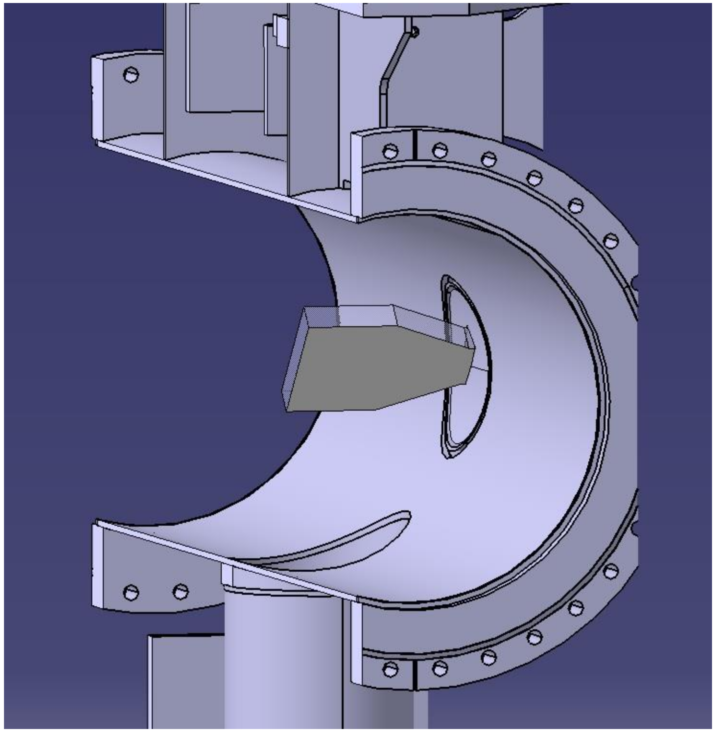
AGM Error Sources

- Alignment and steering
  - Light collection efficiency very sensitive to these
- Attenuation of light in optical components
  - Can change due to dust, radiation etc.
- PMT gain vs. voltage stability and HV control
- Photocathode ageing
- Electromagnetic noise in the signal

BSR extraction mirror

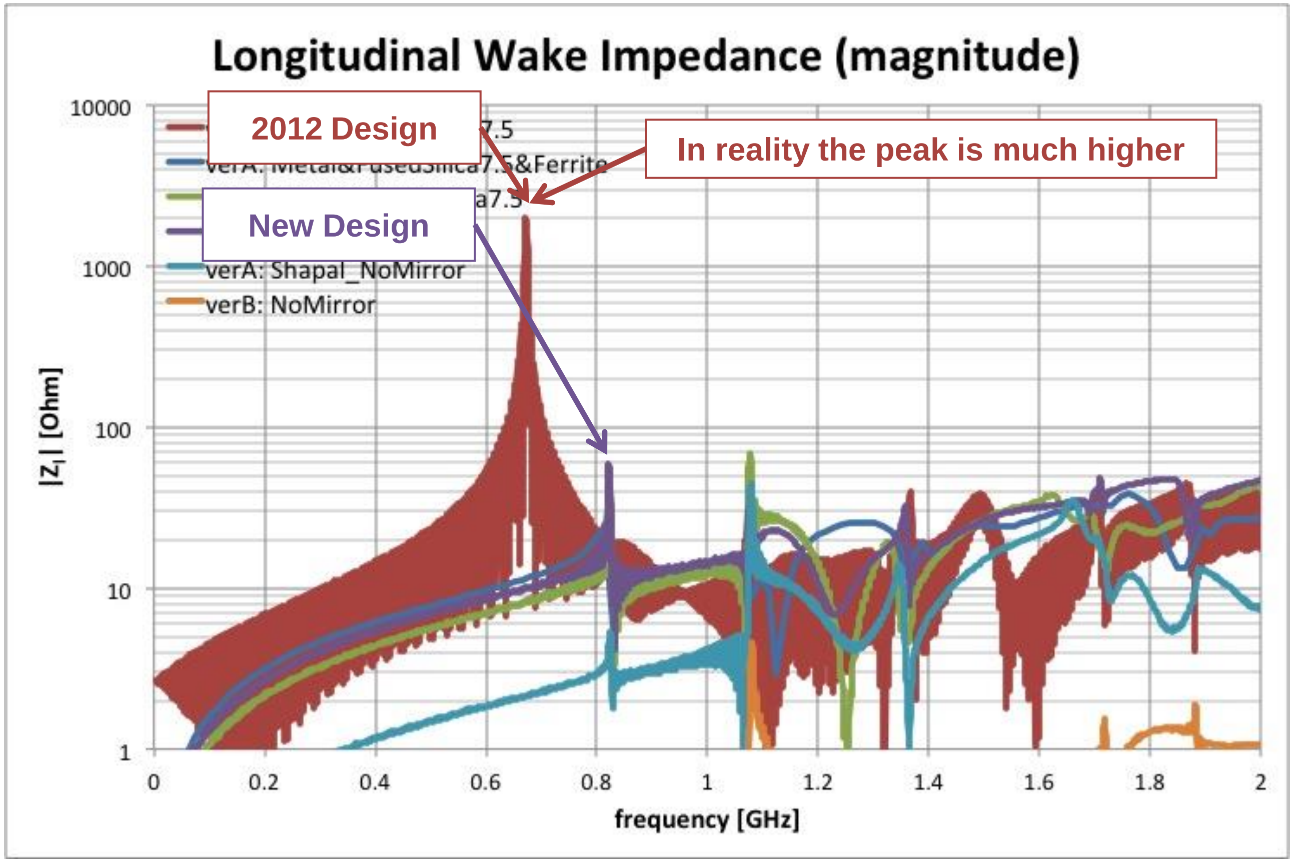


Old



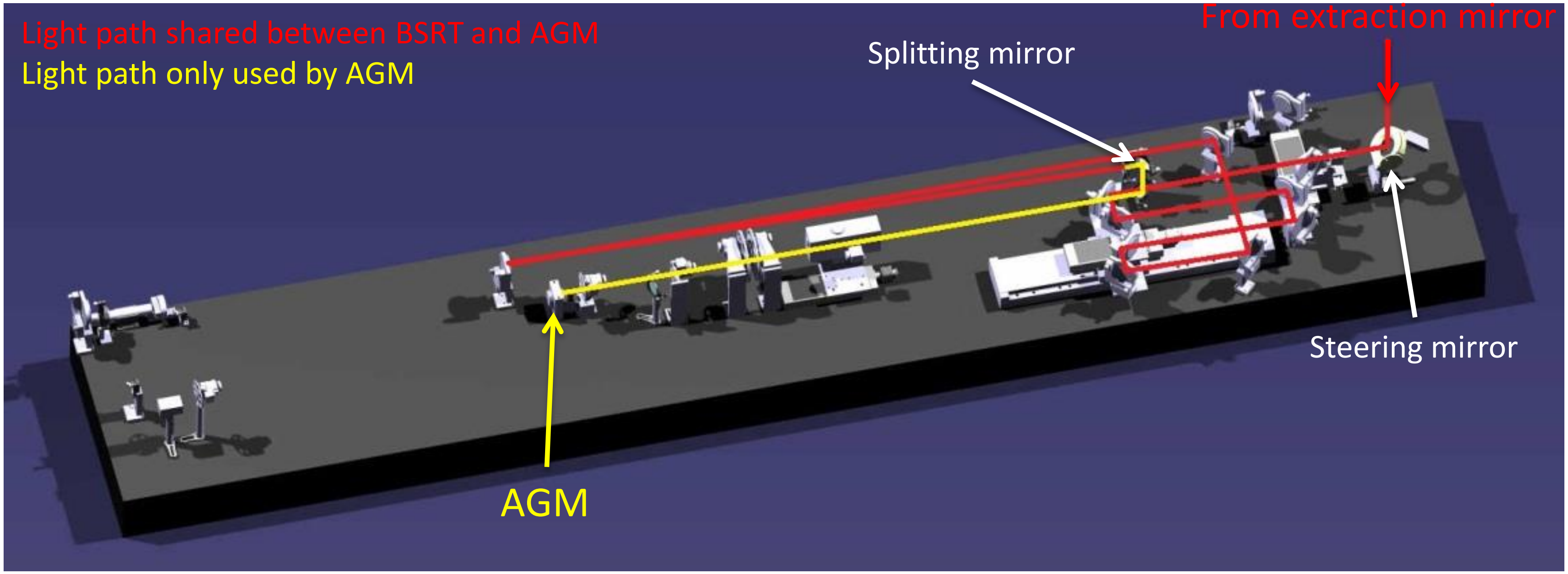
New

Frequency domain simulations



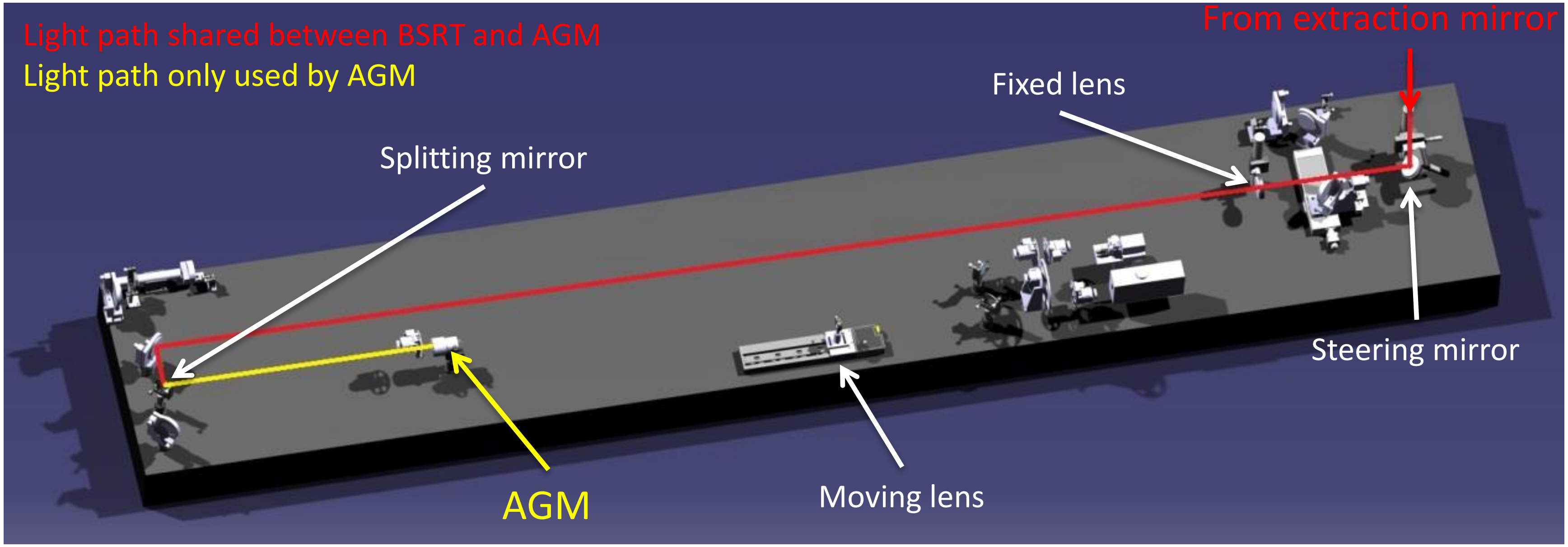
Power dissipated reduced ~100 times (~1w now)

Original BSRT Telescope Layout



- Telescope was based on spherical mirrors (hoping to use IR for ions at inj.)
- In order to cope with the different synchrotron light sources an optical delay line ("trombone") was used. This meant that the light had to go through many mirrors making alignment difficult
- Errors in the alignment resulted in large variation of light collection efficiency

New BSRT Layout



- Spherical mirrors replaced by lenses
- Since we can move the lenses, there is no need for the optical delay line anymore ("trombone")
- No moving parts before the AGM
- Alignment much simpler and light collection less influenced