TECHNOLOGY AND FIRST BEAM TEST OF THE NEW CERN-SPS BEAM POSITION SYSTEM

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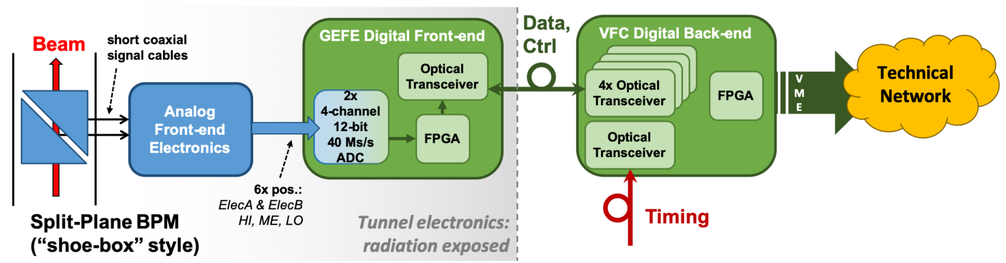
IBIC MALMÖ, SWEDEN International Beam Instrumentation Conference 8-12 SEPTEMBER 2019

A Logarithmic Position System (ALPS) for the CERN Super Proton Synchrotron (SPS)



Simplified layout of the ALPS BPM read-out electronics – one channel shown

- **CERN SPS BPMs**
  - 215 BPM pickups: 102 horizontal, 94 vertical split-plane ("shoe-box") and 19 stripline types, will stay unchanged.
  - Present MOPOS BPM electronics suffer from radiation damage in long (up to 700 m) coaxial signal cables and other aging effects.
- **New ALPS BPM electronics**
  - Based on logarithmic amplifiers for the analog signal conditioning at a frequency of 200 MHz

$$\text{beam position} = \frac{1}{S_{dB}k}20\log_{10}\left(\frac{A}{B}\right) = \frac{1}{S_{dB}}\left[\frac{1}{k_A^{rg}}20\log_{10}(A) - \frac{1}{k_B^{rg}}20\log_{10}(B)\right] \quad \text{with range: } rg \in (\text{HI, ME, LO})$$

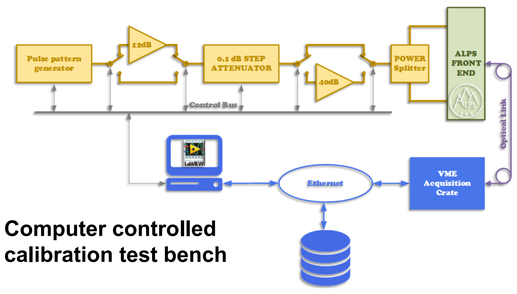
  - Radiation tolerant analog and digital front-end electronics located in the SPS tunnel near each BPM pickup (tested to a integrated radiation dose of 750 Gy, compatible with 10 years of operation)
  - Point-to-point optical fiber links between the front-end electronics and the back-end VME electronics for transfer of the raw BPM data, controls and timing synchronization

Typical beam conditions at the SPS

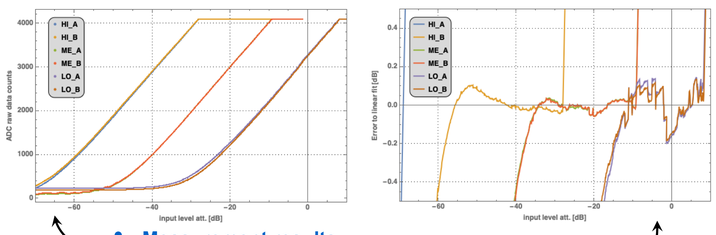
	protons	ions
Bunch intensity (# of particles per bunch)	>2e9 (minimum, single bunch) 1.5e10 (maximum, 5 ns multibunch) 2.6e11 (maximum, 25 ns multibunch) 3.5e11 (maximum, 50 ns multibunch)	>2e9 (minimum) 5e9 (typical) 2e10 (maximum)
Typical beam formats	Single bunch Multibunch batches: 5 ns: 6…2000 bunches 25 ns: 1…12 batches (each max. 288 bunches) 50 ns: 1…6 batches (each max. 144 bunches)	50 ns & 100 ns 1…12 batches (each max. 60 bunches)
Bunch length (4σ)	1.65 ns (400 GeV/c* or 450 GeV/c, extraction) 4 ns (26 GeV/c, proton injection) 5 ns (14 GeC/c*, ion injection)	
f_{RF}	199.95 MHz (injection) 200.40 MHz (extraction)	197.02 MHz (injection) 200.39 MHz (extraction)

* Beam momentum given for protons,
For ions: 5 GeV/c/u (injection), 177 GeV/c/u (extraction)

Calibration System



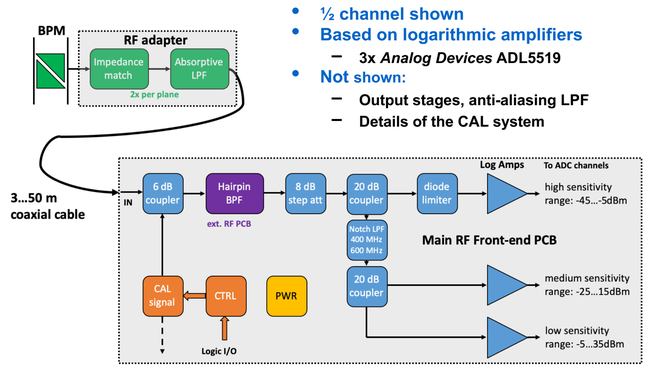
Computer controlled calibration test bench



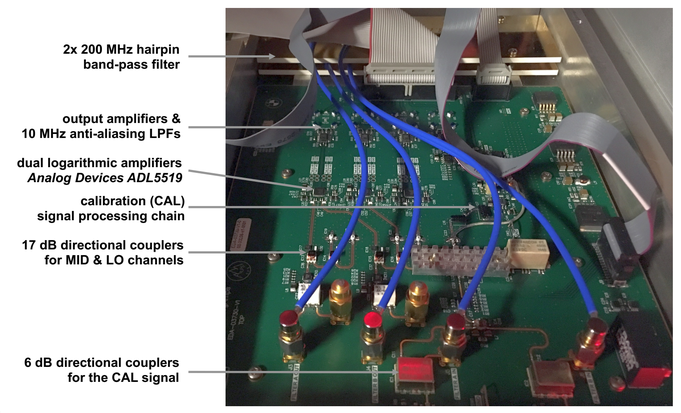
- **Measurement results**
  - Logarithmic characteristic $ADC_{out} = f(V_{in})$
    - Simulated multi-bunch batch, 5 ns bunch spacing
  - Linear fit $\rightarrow k_{(A,B)}^{rg}, rg \in (\text{HI, ME, LO})$
    - Error between $ADC_{out} = f(V_{in})$ and $k_{(A,B)}^{rg}$

RF Front-end Electronics

Simplified block schematics

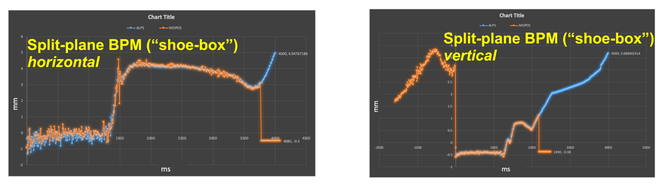


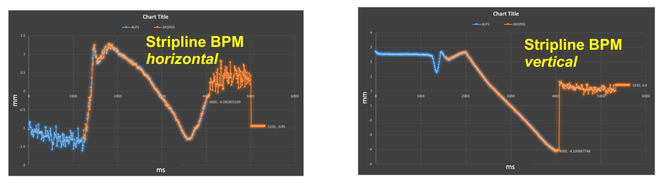
- ½ channel shown
- Based on logarithmic amplifiers
  - 3x *Analog Devices* ADL5519
- Not shown:
  - Output stages, anti-aliasing LPF
  - Details of the CAL system



Beam Tests

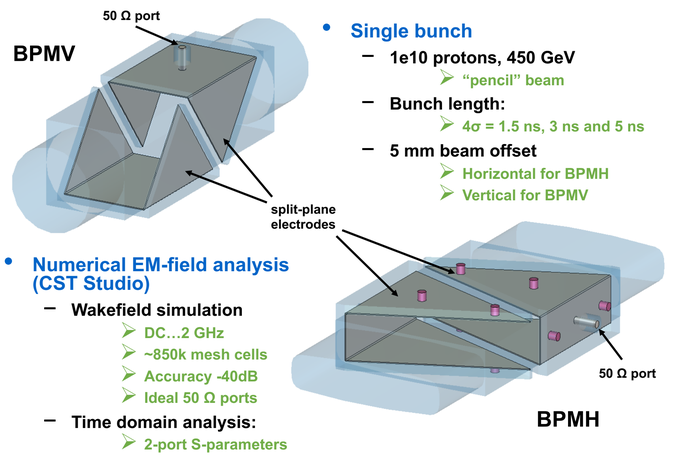
on a pre-series of 12 ALPS units installed in the SPS





- MOPOS (old BPMs) vs. ALPS (new BPMs)
  - Beam offset differences within $\pm 0.5\ mm$
  - Gain difference within ~5 %
  - LO and MID channels show same slope, the offset needs to be corrected
- ALPS resolution
  - Turn-by-turn, single acquisition: $0.2 \ldots 0.6\ mm$
  - Orbit mode, $BW \approx 1\ kHz$: $\sim 30\ \mu m$ (SB), $\sim 100\ \mu m$ (MB)

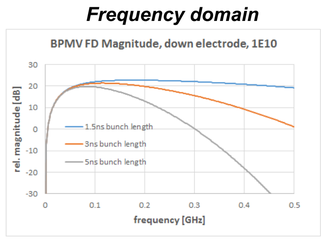
"Shoe-box" Pickup Analysis



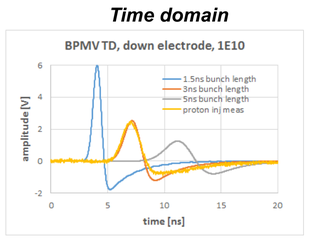
- Single bunch
  - 1e10 protons, 450 GeV
    - "pencil" beam
  - Bunch length:
    - 4σ = 1.5 ns, 3 ns and 5 ns
  - 5 mm beam offset
    - Horizontal for BPMH
    - Vertical for BPMV
- Numerical EM-field analysis (CST Studio)
  - Wakefield simulation
    - DC…2 GHz
    - ~850k mesh cells
    - Accuracy -40dB
    - Ideal 50 Ω ports
  - Time domain analysis:
    - 2-port S-parameters

Wakefield Simulation Results

Frequency domain

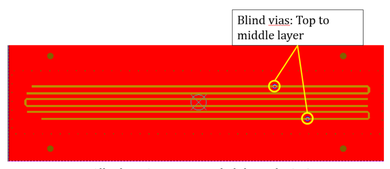


Time domain

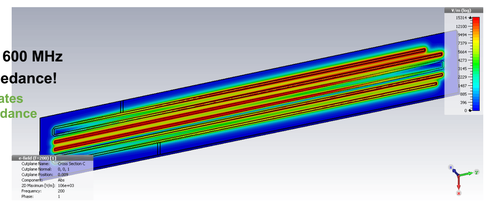


- BPM pickup position sensitivity
  - Horizontal (BPMH): ~0.2 dB/mm
  - Vertical (BPMV): ~0.4 dB/mm

"Fun" with RF Filters

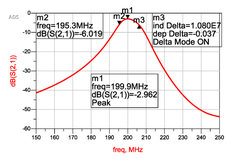


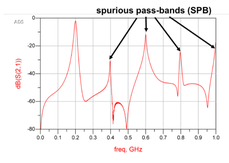
- 3rd order Gaussian band-pass
  - CF: 200 MHz, BW: 10 MHz
  - "hairpin" stripline design
  - *Rogers RO4360G2* (ε_r=6.15)
  - ~3dB insertion loss
  - ~100 ns impulse response
- Requires LPF with pole at 600 MHz
- Requires 50 Ω source impedance!
  - Dual network to compensates the pickup electrode impedance (RF adapter)



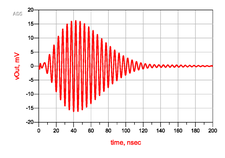
- Typical characteristics

Frequency domain

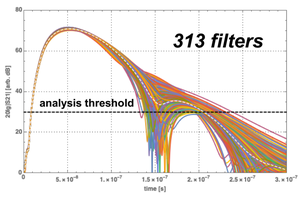




Time domain

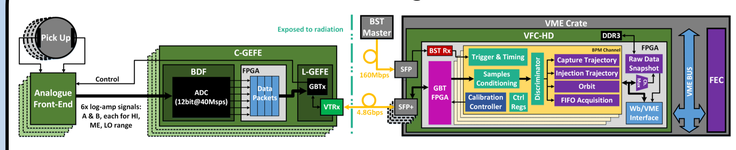


- Filter matching procedure
  - VNA TD data: $|S21|_{dB}(t)$
    - From all filters
  - Set the analysis threshold
    - Here: +30 dB
  - Compare all filters
    - *Anderson-Darling* test
  - Sort out the best pairs

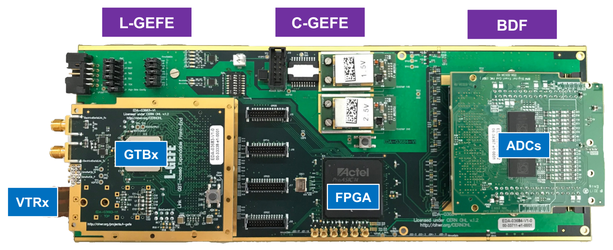


Digital Signal Processing

Block diagram



GEFE Digital Front-end (located in the SPS tunnel)



- Utilizes 2 radiation tolerant ADCs
  - Each 4-ch., 12-bit, 40 MSPS
  - Located on BDF FMC board
- GEFE: Giga-bit transceiver (GBT) expandable front-end
  - Carrier GEFE holds a radiation tolerant *Microsemi ProAsic3L* FPGA
  - L-GEFE link board holds the radiation tolerant GBT components
    - GBTx and VTRx
    - 4.8 GBPS full-duplex optical link
- VFC-HD: VME FMC carrier
  - *Altera Arria V GX* FPGA
  - 2 GB DDR3
  - BPM acquisition modes:
    - Injection trajectory (64 turns)
    - Capture trajectory (selectable TbT data)
    - Orbit (average of *n* turns)
    - FIFO acquisition (self-triggered)

VFC-HD Digital Back-end