2010-06-23 Internal BI-QP Meeting on SPS BPM Renovation
First Iteration on Requirements and System Qualification

- Motivation – making SPS compatible as high-intensity injector for LHC
  - Timely renovation of ageing MOPOS system
  - Reduction of systematic e.g. fill-pattern dependences

- First iteration on SPS position measurement system requirements

- System qualification or 'what are the limits' of the existing infrastructure:
  - Shoe-box, buttons & strip-line pick-ups
  - (Super-long) signal cables
  - Low-level analogue electronic dependencies
  - Digital acquisition System

- What are our aims? What can we do?

LHC BPM Specification

- LHC-BPM-ES-0004 rev. 2.0, EDMS #327557, 2002, p. 25:

Measurement	P	Range	Accuracy	Scale error	Offset	Non-linearity	Resolution
			peak	*peak*	*peak*	*peak*	*rms*
Beam threading — TR2	*	R2	±2000µm	+	+	+	+
Close trajectory on itself — TR3	*	R1	±500µm	+	NR	+	+
Position error at injection — TR4	*	R1	±500µm	+	NR	+	+
		R1	±50µm	+	NR	+	+
Momentum mismatch detection at injection — TR5	*	R1	±1500µm	+	NR	+	+
		R1	±250µm	+	NR	+	+
Optics and local Q' checks — TR7/TR8	*	± 1 mm ⊂ R1	±400µm	+	NR	+	+
			±50µm	±4%	NR	+	+
TR11		R2		NR	NR	±500µm	50µm
Aperture optimisations — CO2	*	R1	±500µm	+	±250µm (±750µm)	+	+
LHC Collimation/Orbit FB — CO3		± 1 mm ⊂ R1	±20µm	NR	NR	NR	+
Orbit at injection elements — CO4		± 1 mm ⊂ R1	±30µm	+	+**	+	+
Position error at injection — CO7		R1			±100µm	±200µm over ±4mm	1000µm
Momentum FB (radial loop) — CO8		R1	±250µm	+	NR	+	+
Dispersion measurements — CO9 IP		± .1 mm ⊂ R1	±15µm	+	NR	+	+
CO9 other		± 1 mm ⊂ R1	±175µm	+	NR	+	+
b2/a2 to b4/a4 (~TOTEM) — CO14		± .1 mm ⊂ R1	±10µm	+	NR	+	5µm

Are we happy with this type of format? Other constraints? Open...?

Early SPS BPM Specification Draft (end-2008, J. Wenninger et al)

- Operational beam configurations used/envisaged (N_{batch} = 1-13)

Type	Bunch spacing	Bunch number	Bunch charge [10^{10}]	bunch length [4σ, ns]
FT / CNGS	5 ns	400-4000	0.1-2	1-4
LHC25NS	24.96 ns	N_{batch}x 72	1-20	1-4
LHC50NS	49.92 ns	N_{batch}x 36	1-20	1-4
LHC75NS	74.88 ns	N_{batch}x 24	1-20	1-4
LHC single bunch	524.4-2022.6 ns	1-16	0.2-20	1-4
LHC ion / Pb82+	100 ns	N_{batch}x 4	0.2-2	1-4

- Orbit@1kHz (40 turns) up to 60 seconds, 100 first turns & 10/100k turns total
- Resolution for large intensity beams (> $5 \cdot 10^{12}$ p):
  - orbit mode: 0.1 mm ↔ BPH: 0.1% (& 0.5%) BPV: 0.2%
  - trajectory: 0.4 mm ? ↔ BPH: 0.5% (& 1.8%) BPV: 1.0%
- Resolution for single bunches (LHC pilot):
  - orbit mode: 0.4 mm ↔ BPH: 0.5% (& 1.8%) BPV: 1.0%
  - trajectory: 1.0 mm ? ↔ BPH: 1.3% (& 4.5%) BPV: 2.4%
- Required accuracy: 0.5 mm (w/o alignment) ↔ BPH: 0.6% (& 2.3%) BPV: 1.2

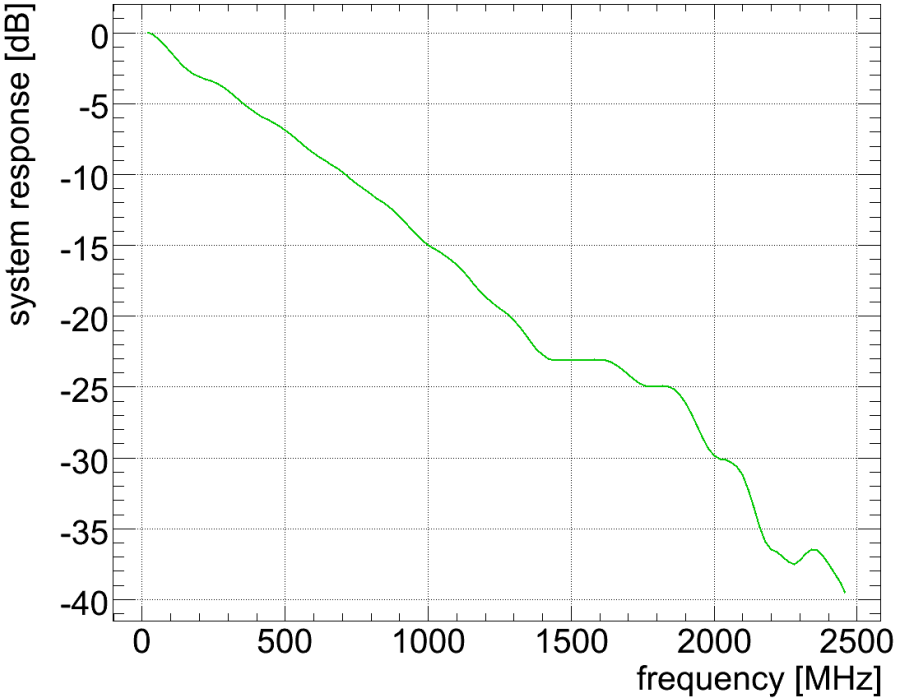
Future "Operational"/Physically Possible Beam Scenarios

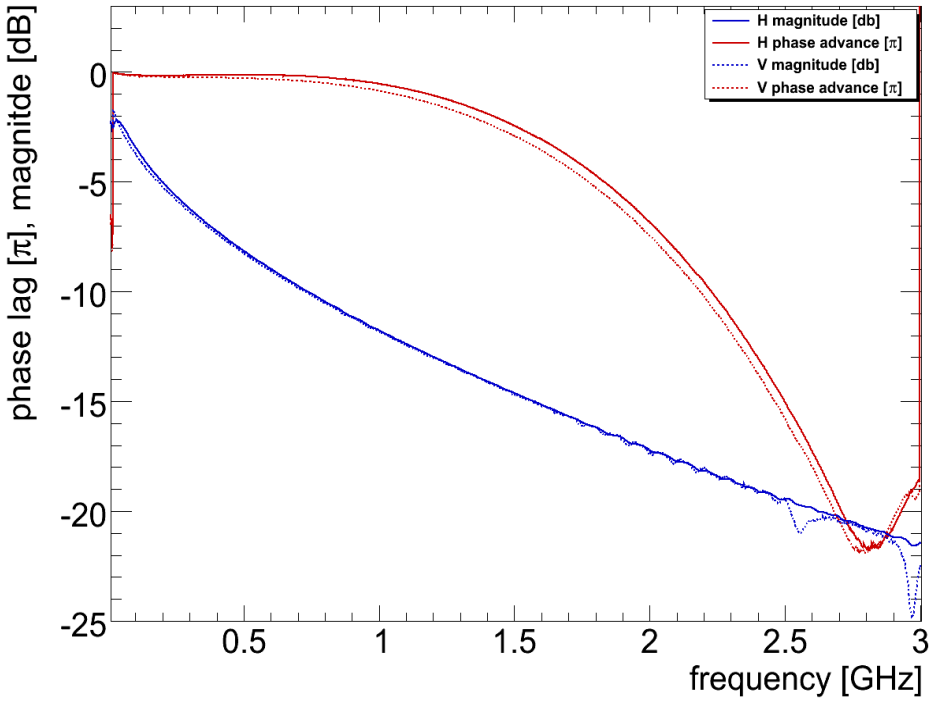
- Operational bunch charges: $1 \cdot 10^9 \rightarrow 2\text{-}3 \cdot 10^{11}$ protons/bunch
  - Minimum that can be still accelerated: ~10^8 protons/bunch
  - Maximum that can be still accelerated: ~$2\text{-}3 \cdot 10^{11}$ protons/bunch ???

- Time structure: 200 MHz or lower harmonics
  - Single bunch: 1-4 ns
  - Typical batch lengths:
    - SFTPRO/CNGS: ~10 μs (old) vs. ~ 4.4 μs (new)
    - LHC-type beam: down to 1 μs
      - » distinction 'batch vs. bunch' less obvious
  - Bunch-by-bunch measurement not strictly required
    - Exception: a few (3-4) pick-ups with LHC-type electronics

LSS5 ↔ ECA5 Cable Calibration
LSS4 ↔ ECA4 Cable Calibration

- Cable response via open and closed loop S12 setup (NA / pulse generator)

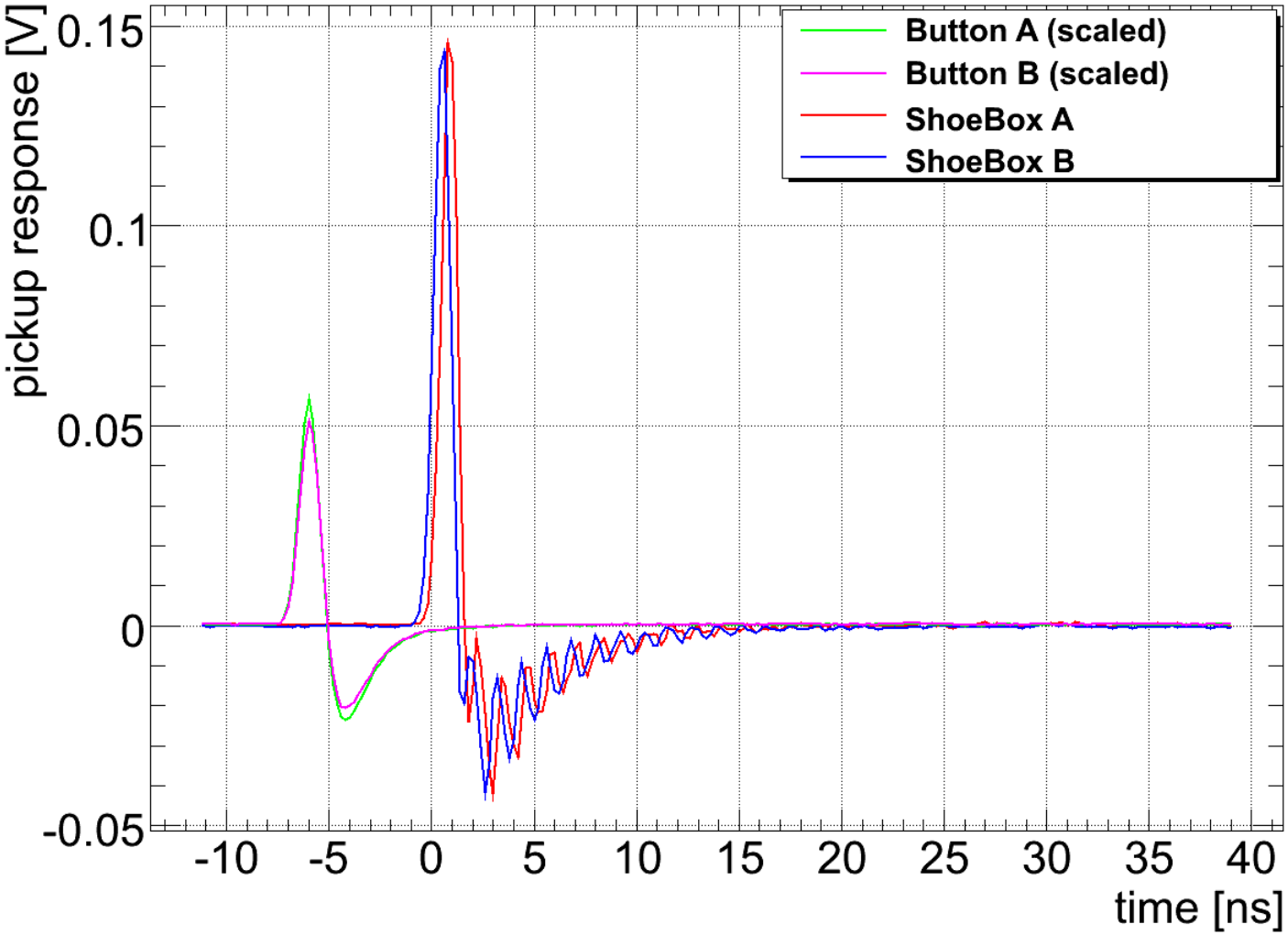




- LSS4 much better bandwidth → not surprising 130 m long 7/8” Heliax cable
- LSS5 more representative w.r.t. cables used by MOPOS: ~ 70 m long CMA50
  - Present MOPOS installation rely on cables that are several 100 m long!
    - Temperature effects, radiation degradation, (replacement) costs, ...

Example: ECA5 Measurement BPH vs. BPMB I/III

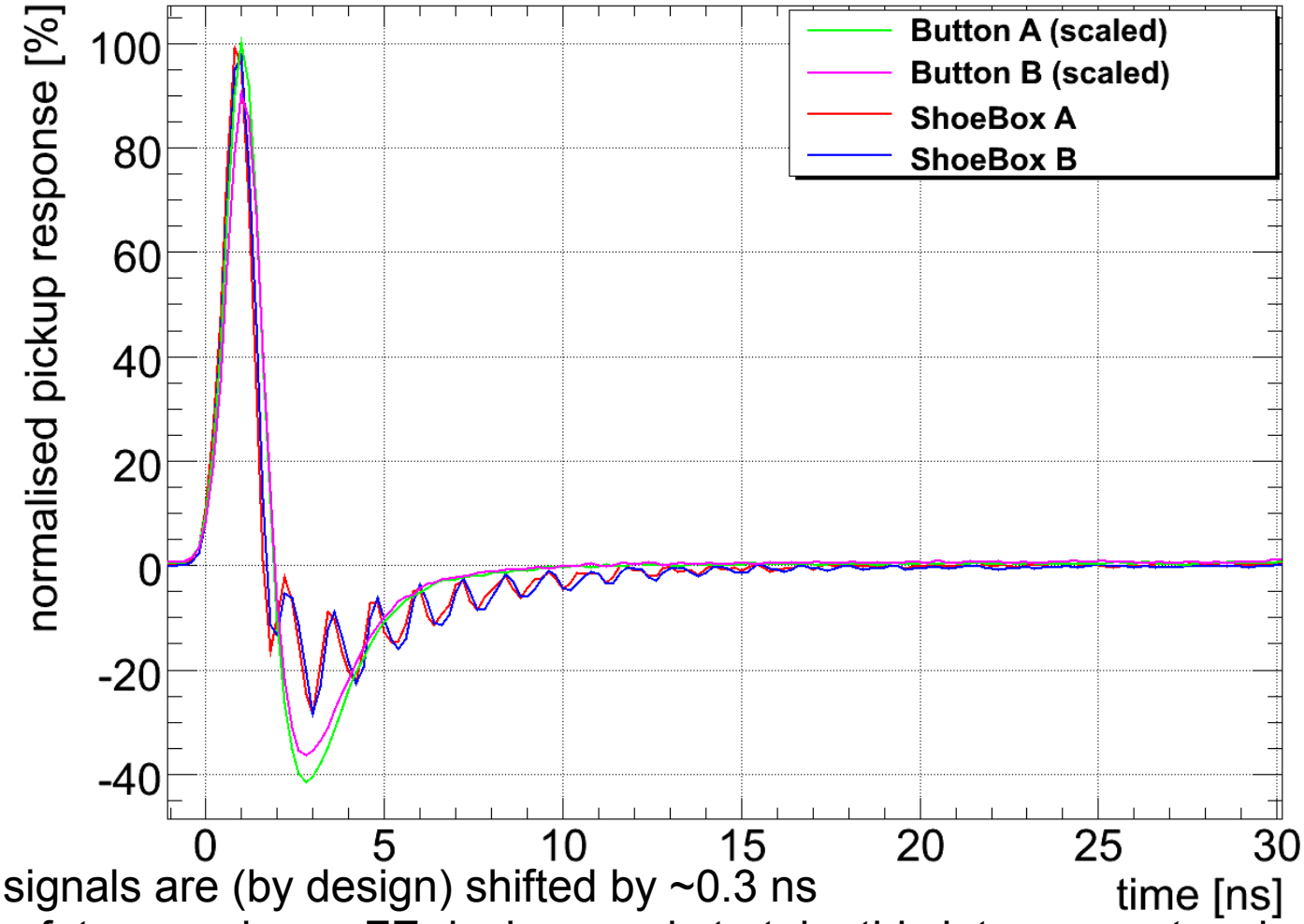
- Raw pick-up signals: BPH (77 mm) vs. BPMB (40 mm half-aperture)



- "Fat" LHC pilot bunch ~$2 \cdot 10^{10}$ p/bunch → BPH gives 10x more peak signal
  - N.B. 10dB attenuation for BPMB, 20 dB attenuation for BPH

Example: ECA5 Measurement BPH vs. BPMB II/III

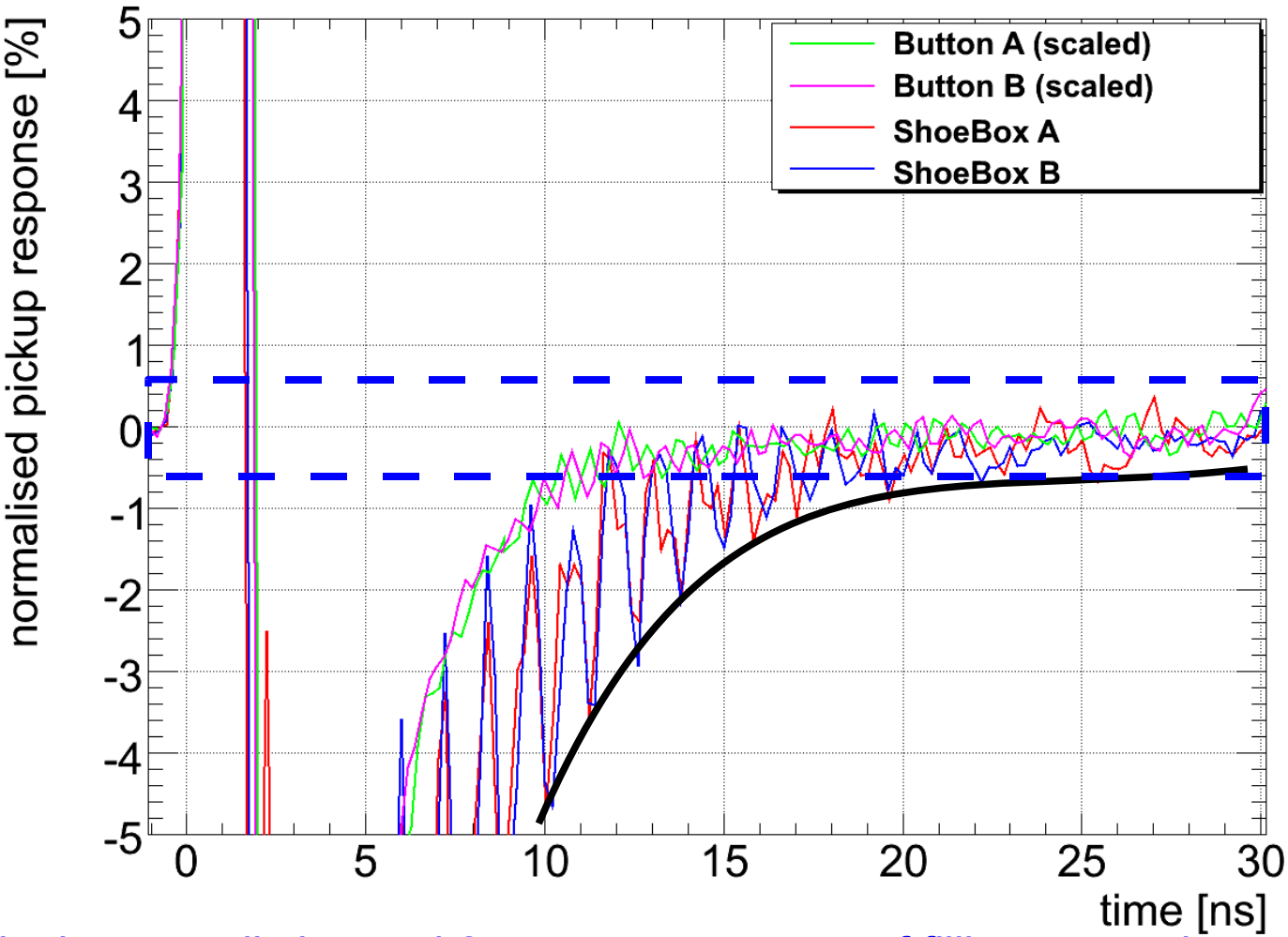
- Re-aligned and re-normalised signals:



- BPH signals are (by design) shifted by ~0.3 ns
  → any future analogue FE design needs to take this into account, unless re-using the existing (old) cables prior to the hybrid
- BPH has a much more pronounced ringing than the BPMB

Example: ECA5 Measurement BPH vs. BPMB III/III

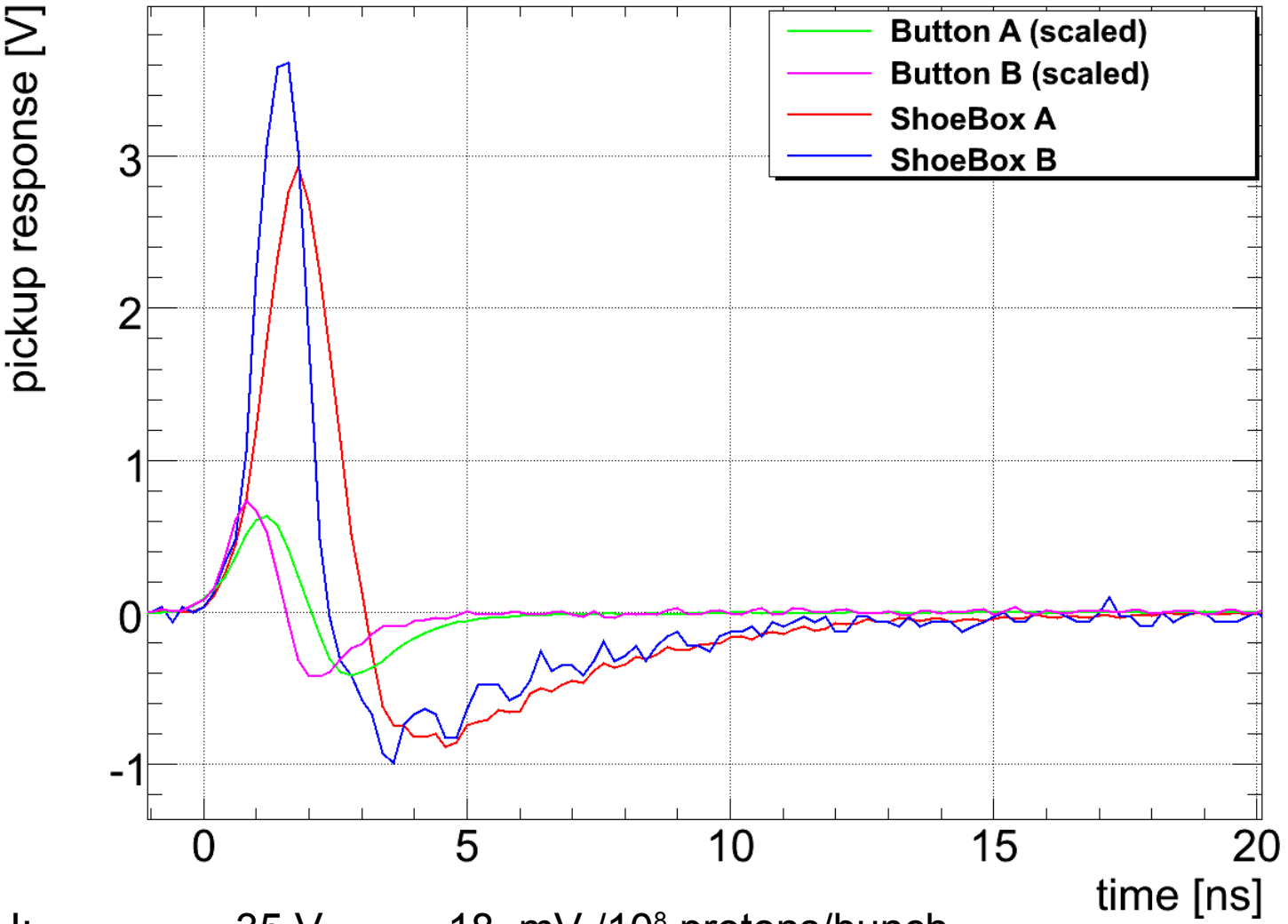
- Re-aligned, re-normalised and zoomed-in signals:



- BPH ringing prevails beyond 25 ns → one source of filling-patter dependence
  - worsened by long-cables (bandwidth limitation ↔ dispersion)
  - Transient length and frequency strongly dependent bunch length

Ultimate Intensities

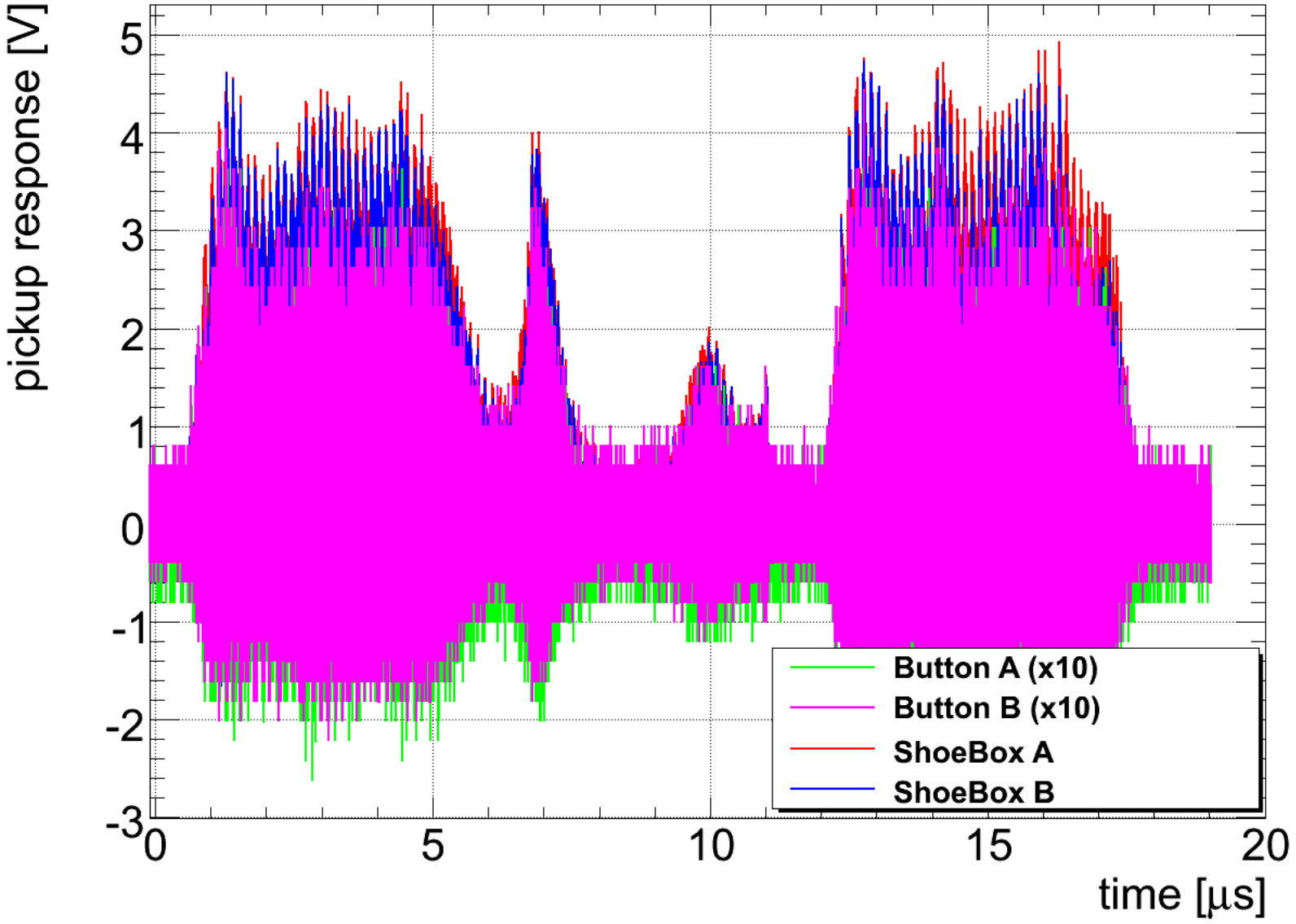
- Single LHC bunch at $2 \cdot 10^{11}$ p/bunch



- BPH: ~35 V → 18 mV /10^8 protons/bunch
- BPMB: ~ 2.5 V → 1.5 mV /10^8 protons/bunch

Typical SFTPRO structure

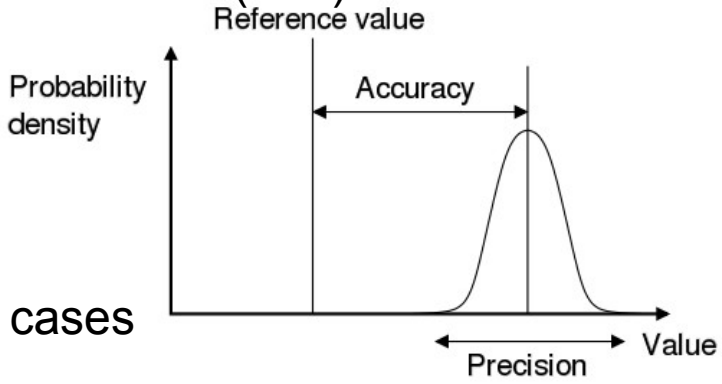
- … problems with second batch during the ramp



Terminology: Accuracy & Precision

Good summary: http://en.wikipedia.org/wiki/Accuracy_and_precision

- **Accuracy:**"[..] closeness of measurements [..] to its actual (true) value"
- **Precision** (also: reproducibility or repeatability): "[..] degree to which repeated measurements under unchanged conditions show the same results."
- Example: "Target analogy" and the two extreme cases



High **accuracy**, but low **precision**

High **precision**, but low **accuracy**

- Tentative OP specification excludes static alignment errors
  → measurement reference frame is de-facto the BPM body
  → remaining errors reducing the accuracy are drifts/dependences of:
  pick-up response, cables, analogue electronics, …