BI Day 2012

The Beam Position System for LINAC4

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Linac4 BPM, 06.12.2012

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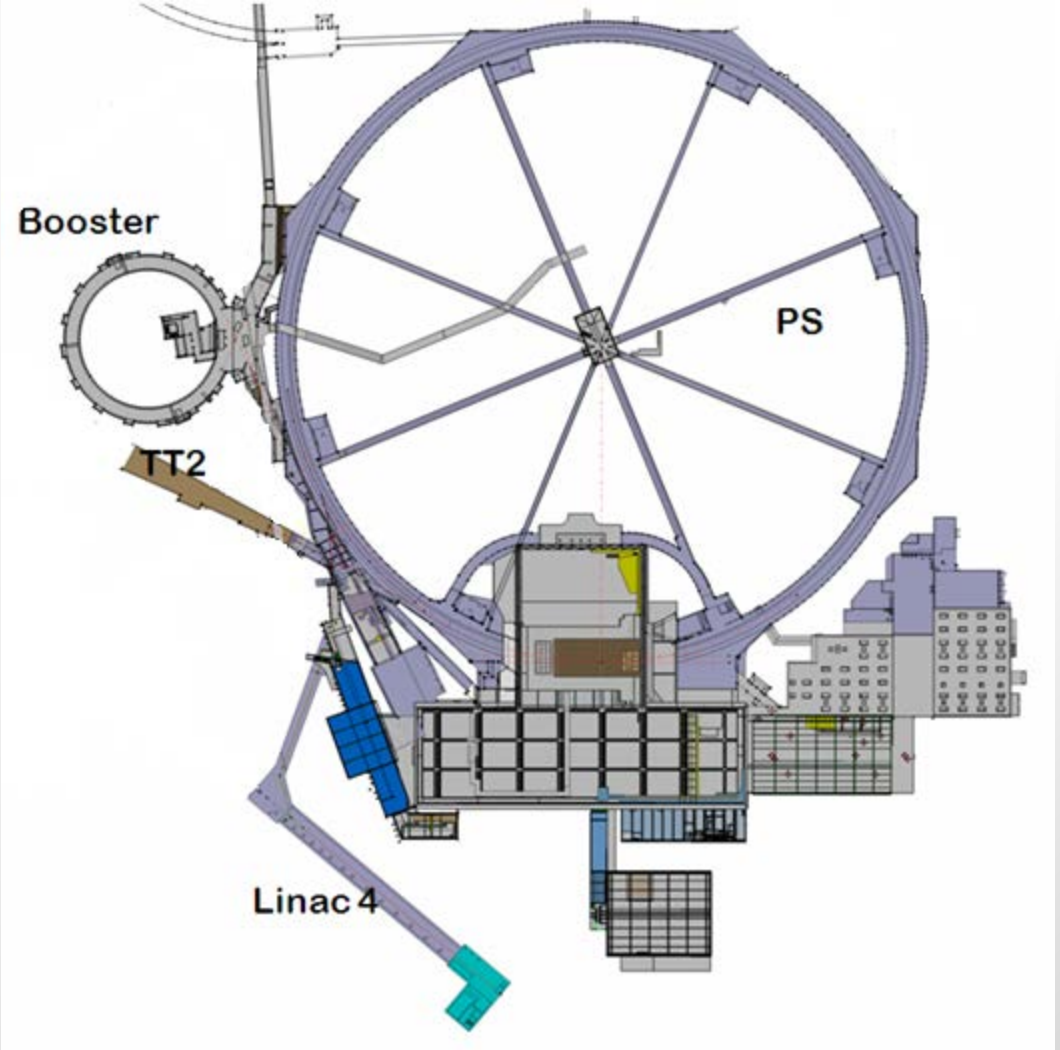
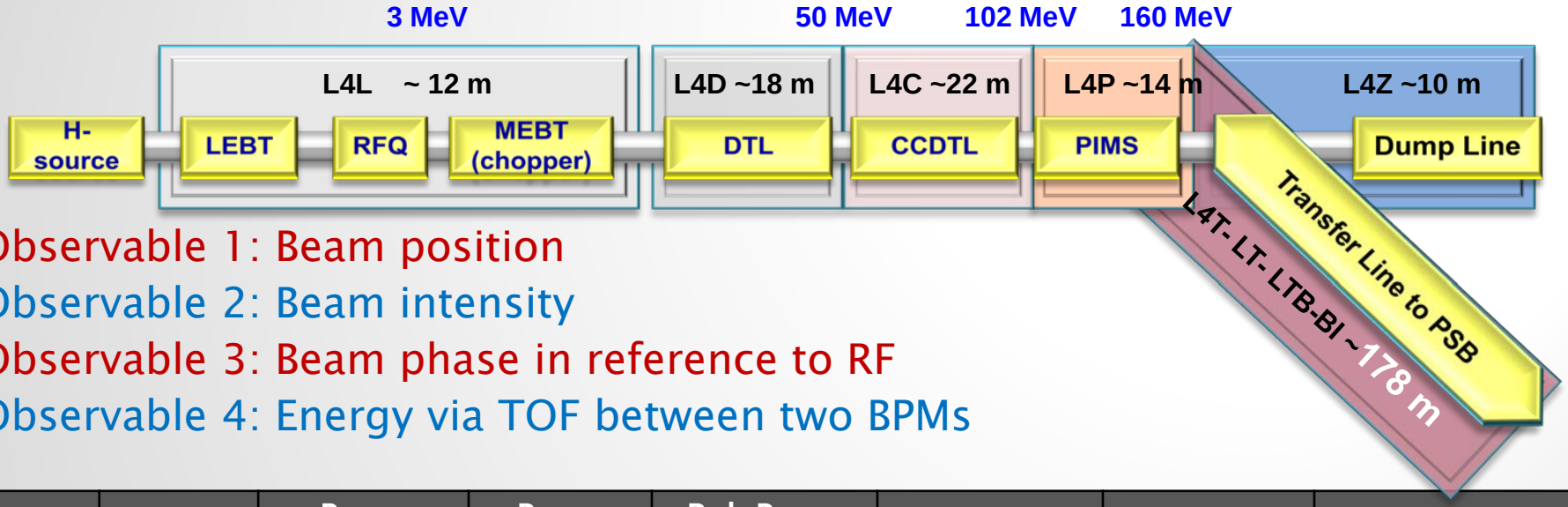
Linac4 accelerator

- Ion species H^-
- Output energy 160MeV
- Bunch frequency 352.2MHz
- Max. repetition rate 2Hz
- Beam pulse length 400µs
- Mean pulse current 40mA
- Number of particles per bunch $1.14 \cdot 10^9$



BPM layout and specs for Linac4



Observable 1: Beam position

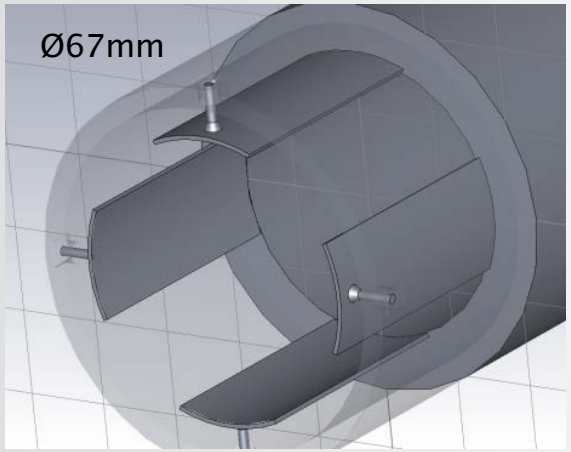
Observable 2: Beam intensity

Observable 3: Beam phase in reference to RF

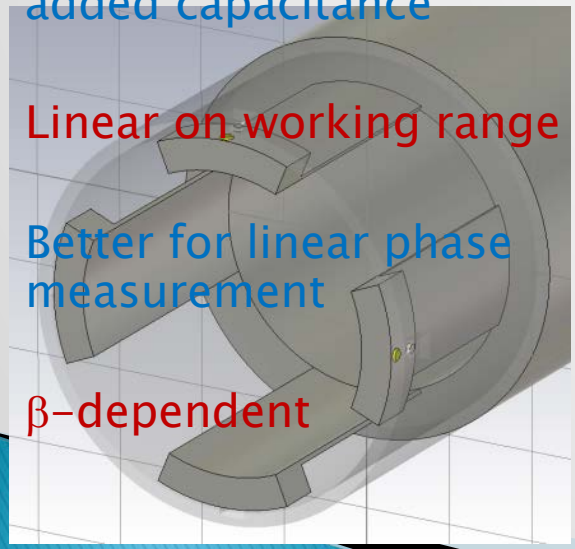
Observable 4: Energy via TOF between two BPMs

Line	# of Monitors	Beam position Resolution	Beam position Accuracy	Rel. Beam Intensity Resolution	Beam phase Resolution	TOF Resolution	Comments
L4D	2	0.1mm	0.3mm	1% of peak current	0.5°	1 per thousand	Ø34mm
L4C	7						Ø39mm
L4P	6						Ø39mm
L4T to PSB	10+17						Ø100 + 140mm

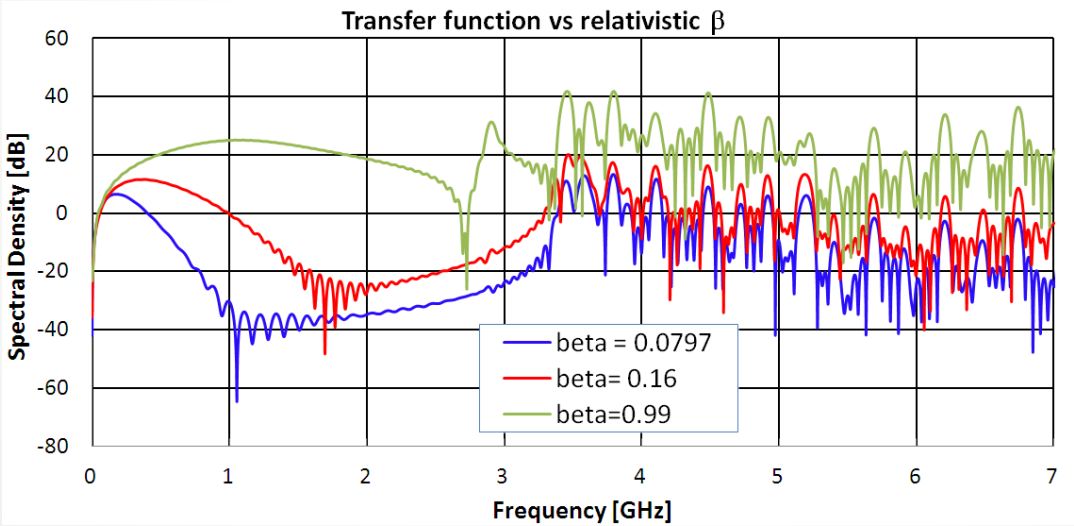
Transfer function of the test stand BPM

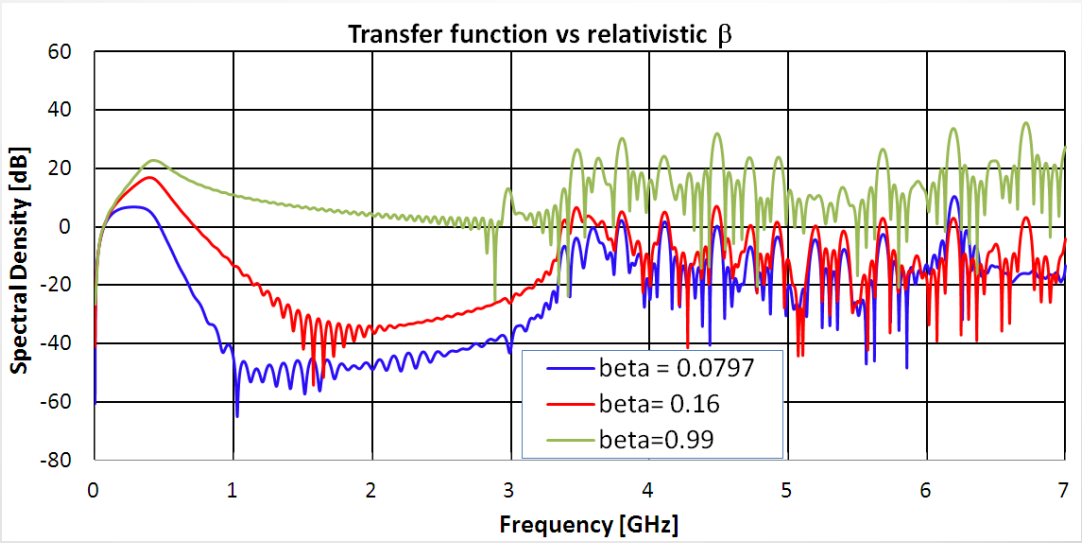


- Shorted stripline with added capacitance



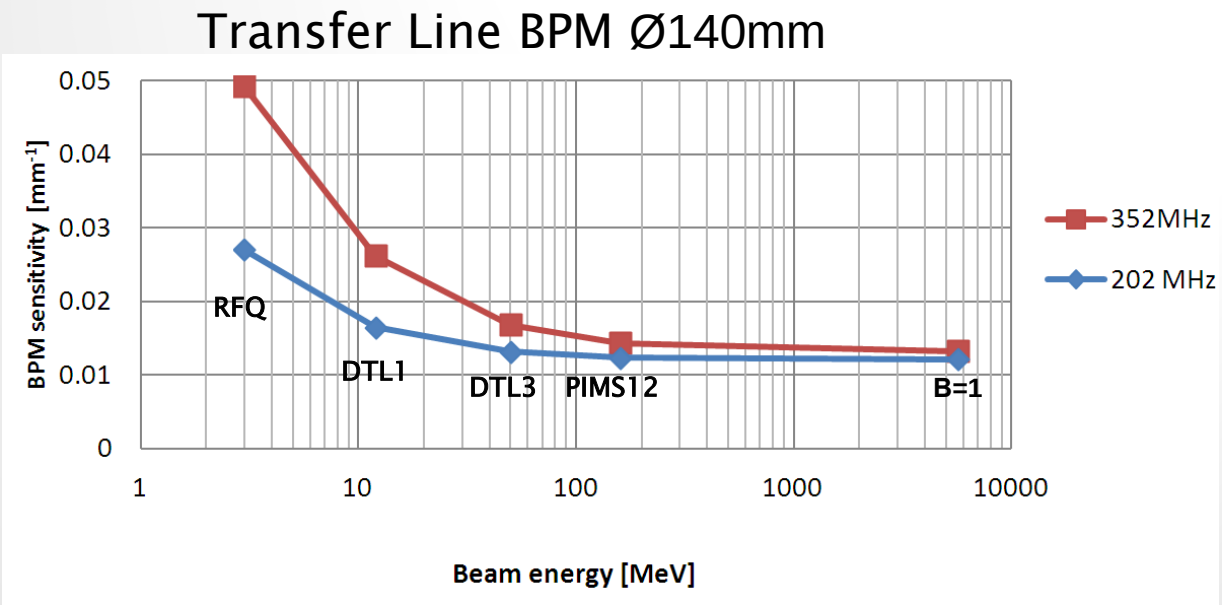
- Linear on working range
- Better for linear phase measurement
- β-dependent





Dealing with low-β beams

- PU sensitivity changes with β
- These simulations confirm Shafer's theorem (1994)
- The values obtained from the simulations will be implemented in the software

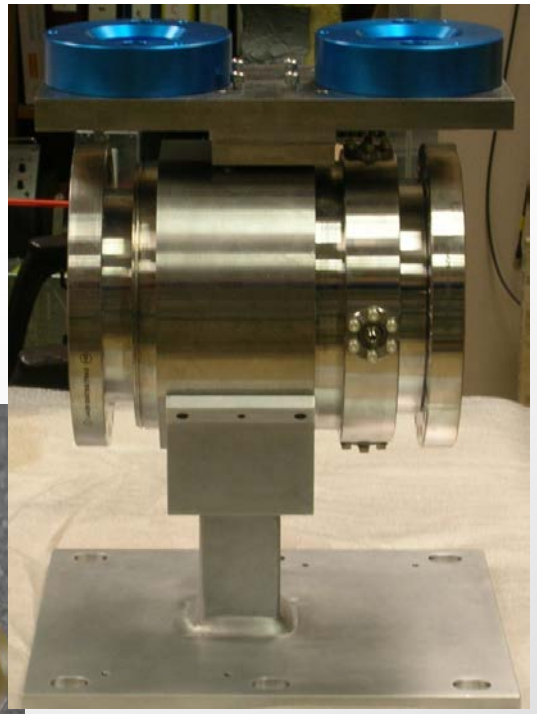


Many different BPM variants

DTL
- Beam aperture: 34 mm
- Electrode length: 117 mm

3MeV
- Beam aperture: 60mm
- Electrode length: 67mm

TRANSFER LINE
- Beam aperture: 100 mm
- Electrode length: 140 mm

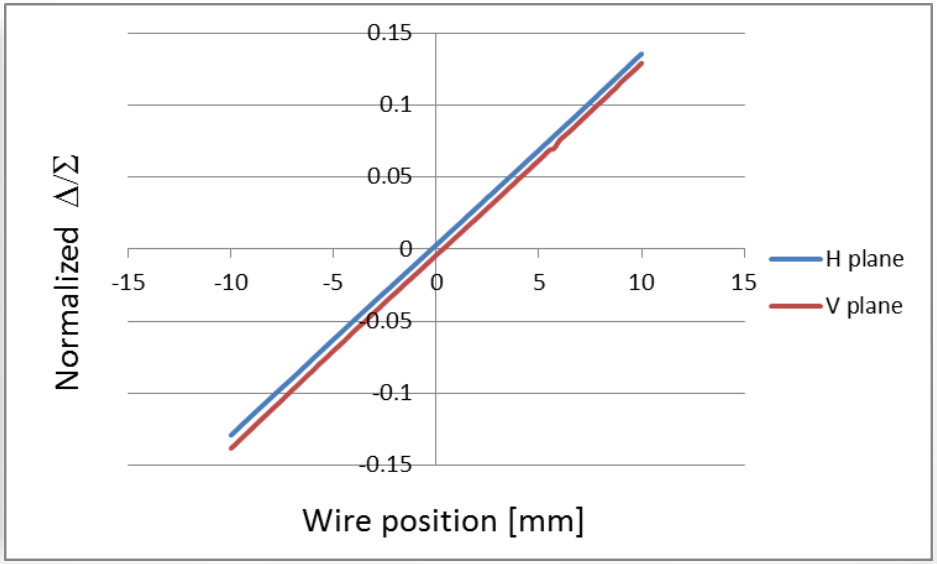


Lab test bench

- Wire technique with standing waves
- Optical sensor for mechanical centering : ±0.01mm
- 352MHz sine wave with a N.A.
- Data acquisition with steps of 0.1mm
- Gives sensitivity and electrical offset

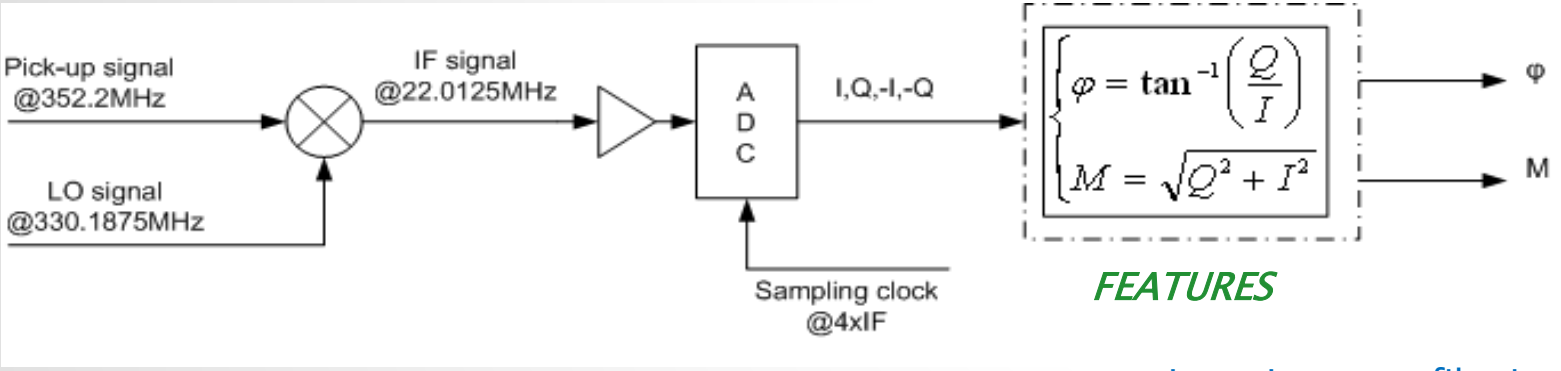
BPM sensitivity at 352MHz

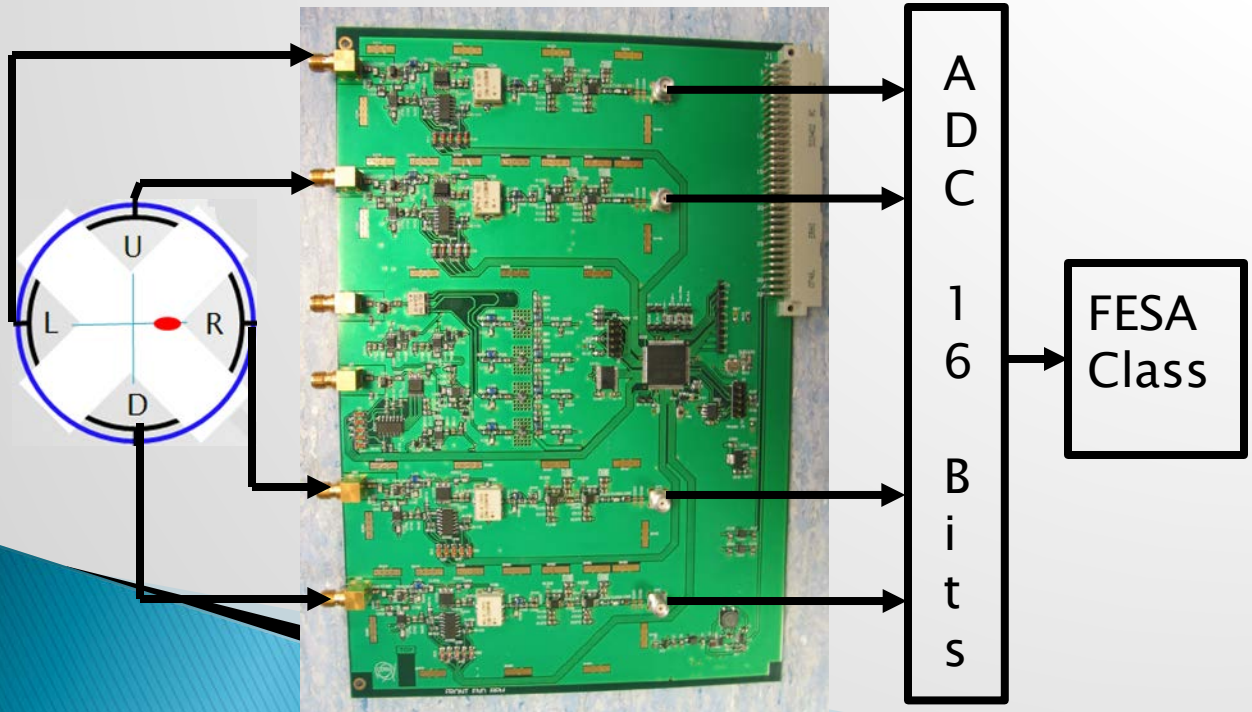
Transfer Line BPM Ø140mm



@352MHz	Simulations	H plane	V plane
Sensitivity[mm]	75.4	75.88	75.24
Elec. Offset [mm]	-	-0.31	0.34

Acquisition chain





FEATURES

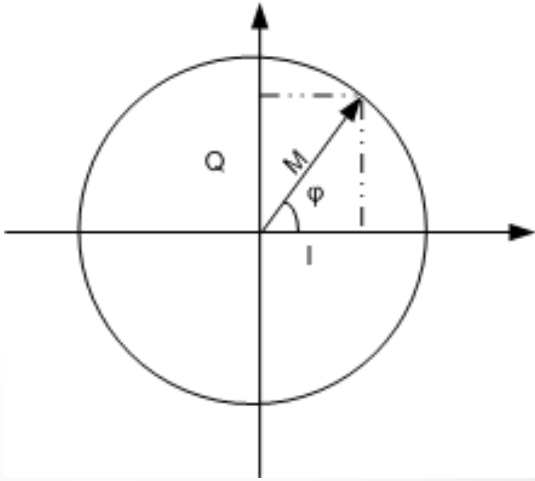
- Input Low pass filtering @1GHz
- Down-mixing with LO
- Variable gain selection
- Band-pass filtering @22MHz
- FPGA for calibration and gain control
- Sampling frequency = 4x IF
- ENOB ADC 13.4 bits
- LSB ADC 76µV

Signal processing

- Phase and intensity calculation with I/Q sample per channel

$$M_1 = \frac{1}{A_1} \cdot \sqrt{I_1^2 + Q_1^2}$$

$$\varphi_1 = \tan^{-1}\left(\frac{Q_1}{I_1}\right) + P_1$$



- Calculation for each PU
  - Position
  - Phase
  - Intensity

$$\Delta H = S_h \cdot \frac{M_1 - M_2}{\sum M_i} + offset_h$$

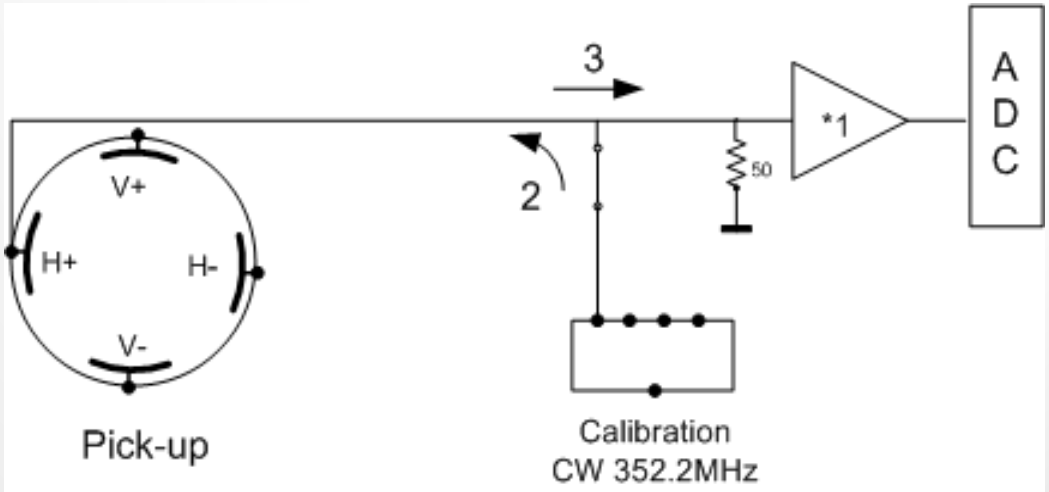
$$\varphi_{tot} = \frac{\varphi_1 + \varphi_2 + \varphi_3 + \varphi_4}{4}$$

$$I = \frac{\sum M_i}{Zt}$$

Zt : transfer impedance

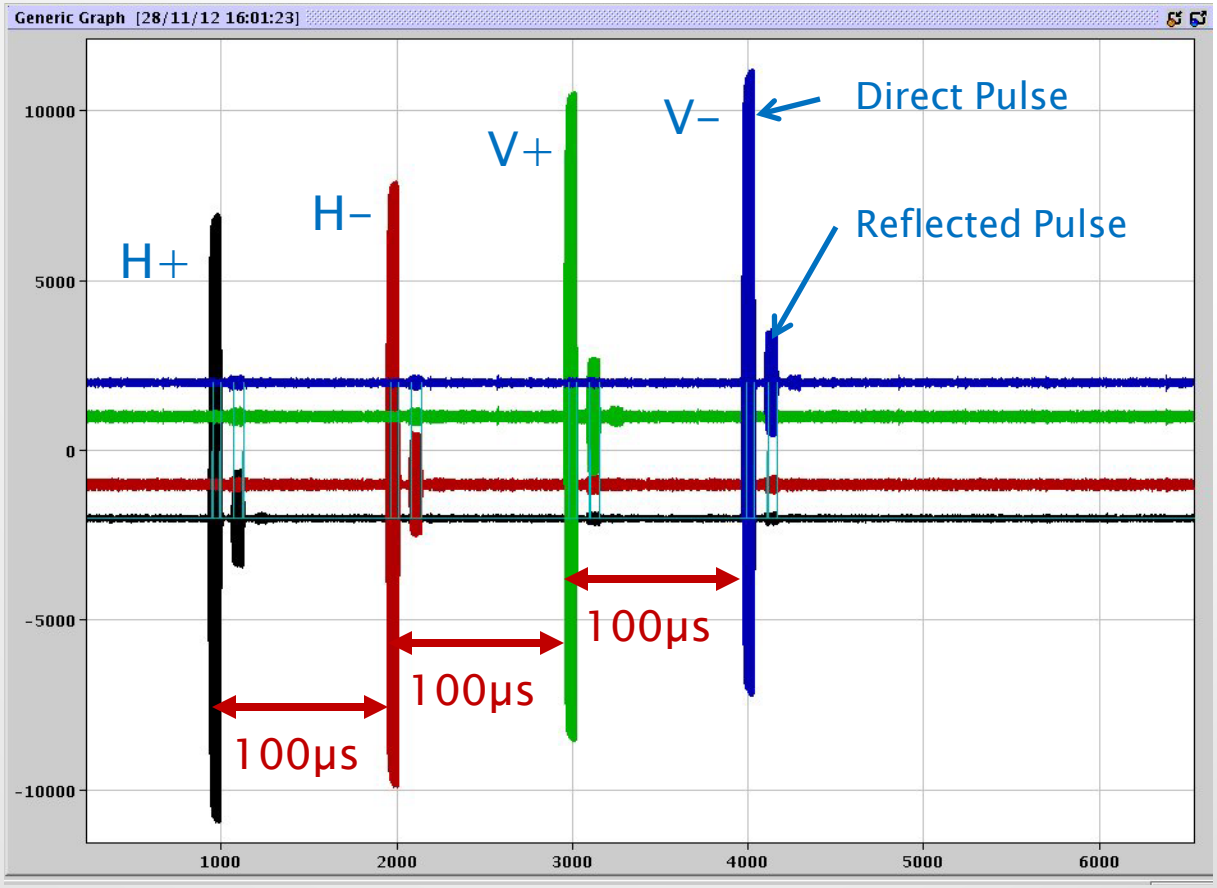
Calibration procedure

- Set the phase and the gain per channel
  - Inject sine wave into the direct channel(1)
  - Numerical gain and phase correction
- Set the length of cables per PU
  - Inject sine wave into the cable(2)
  - Signal back after reflection on the PU(3)
  - Numerical gain and phase correction



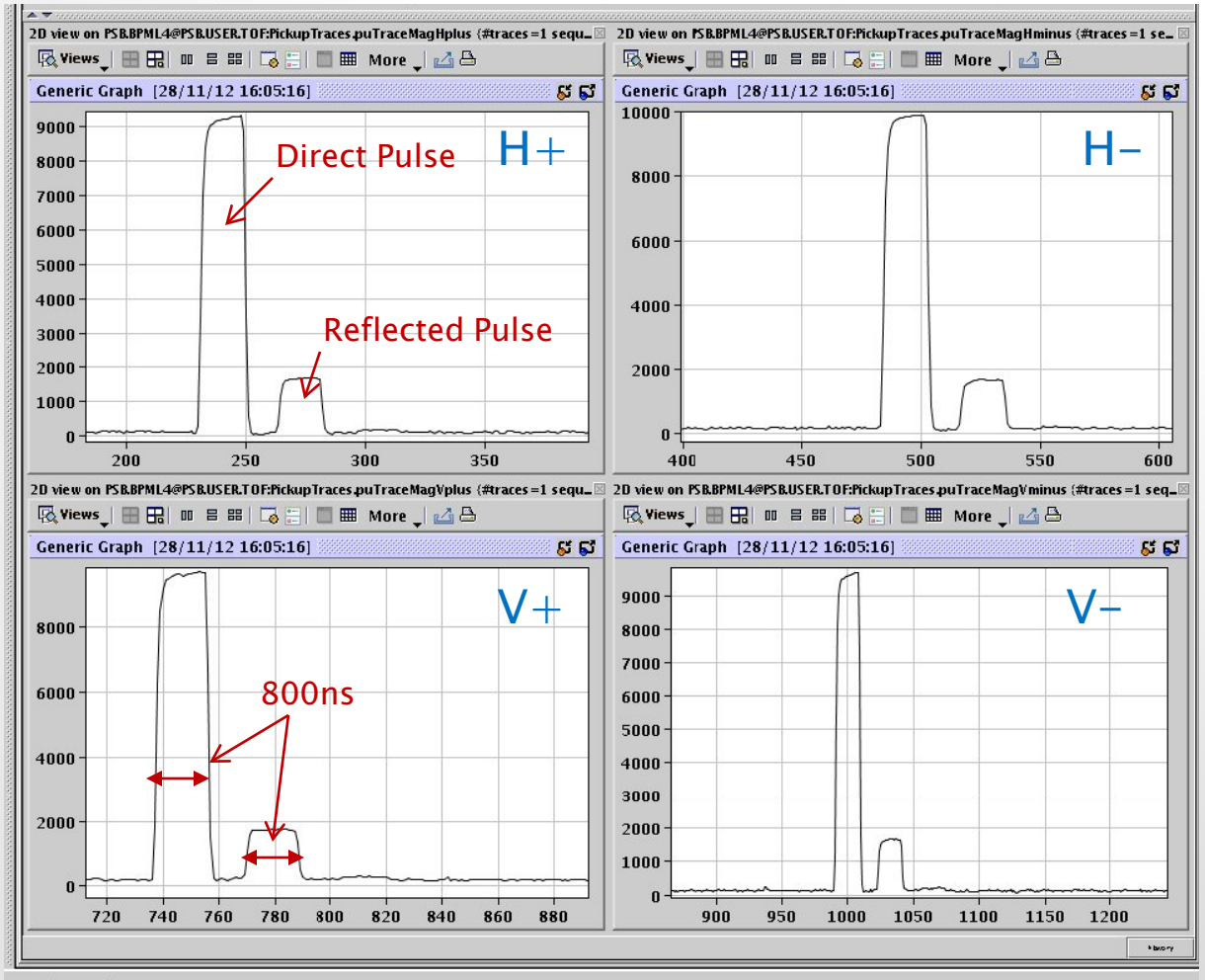
Calibration : raw data

- 4 electrode-calibration
- Each channel space with 100µs
- Direct and reflected sine wave pulse
- I/Q sample series
- With artificial offset

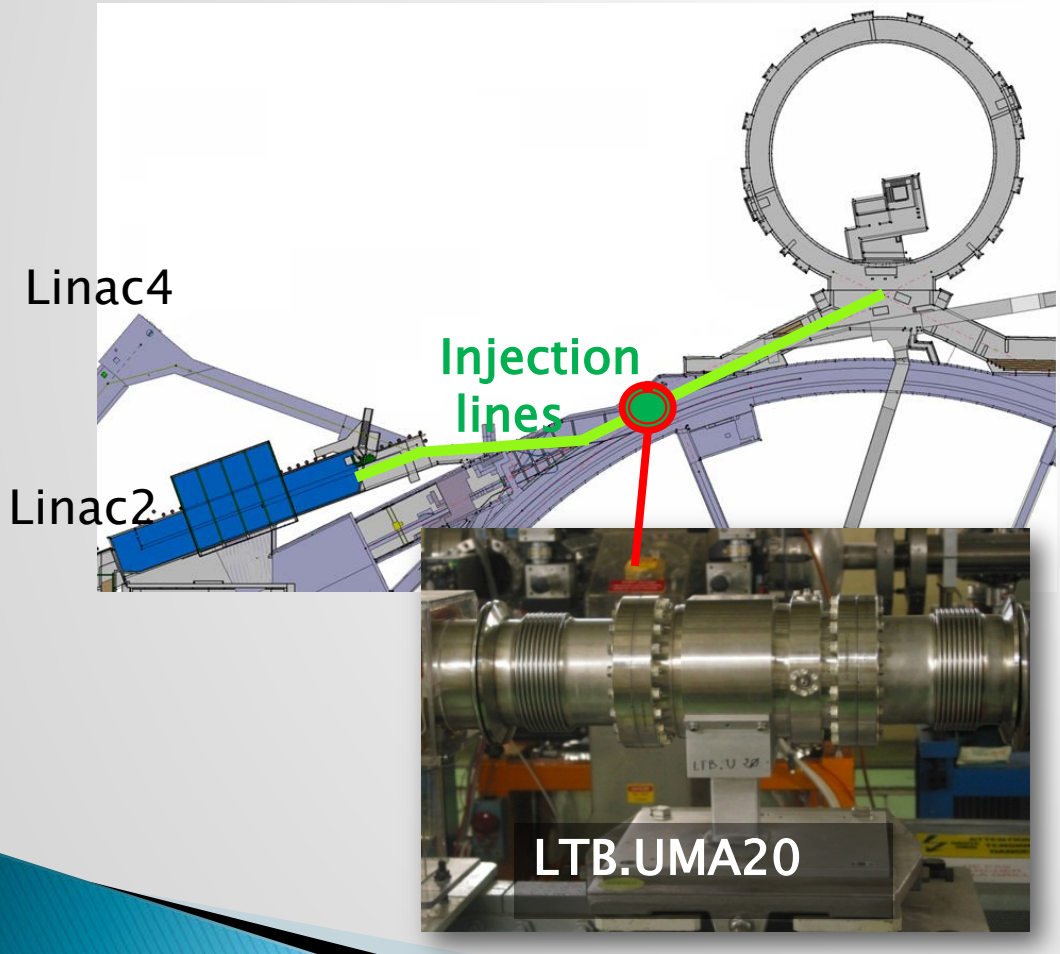


Calibration : processed data

- 4 electrode-calibration
- Direct and reflected sine wave train
- One magnitude point for one quadruplet (I,Q,-I,-Q)
- Gives a set of scaling factors per electrode: [Amplitude, Phase] $[A_{1..4}, P_{1..4}]$



Commissioning with proton beam



- Transfer lines from Linac-2 to Booster
- Upgrade with Linac4 type BPM : shorted stripline(present BPMs are 40 years old)
- Status : commissioning of one monitor with protons since Sept. 2012
- Bunching frequency 202MHz

First raw beam data

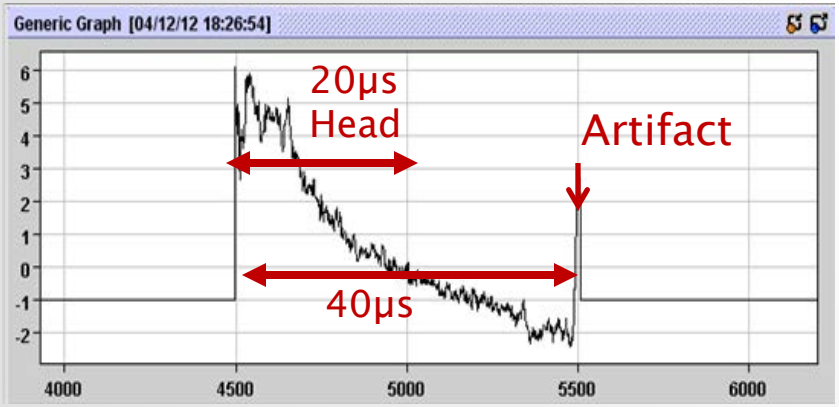
- TOF beam
- 4 channels
- Electronics card output
- Difference between simulation and real life : Amplitude is 45% less than expected

Position measurement

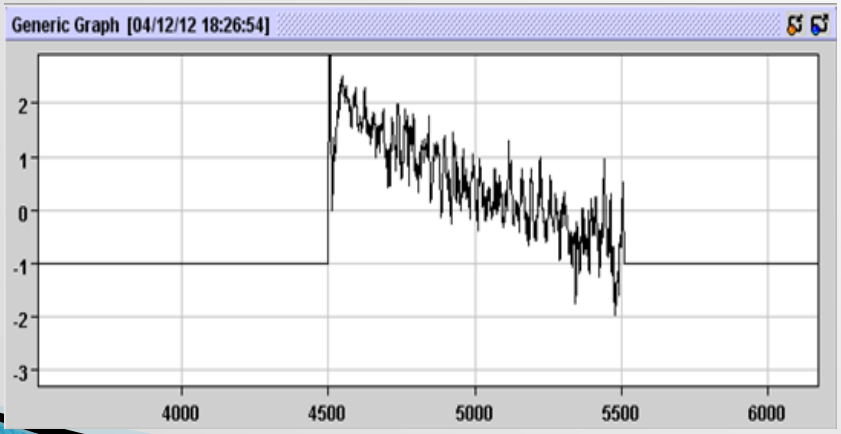
TOF beam

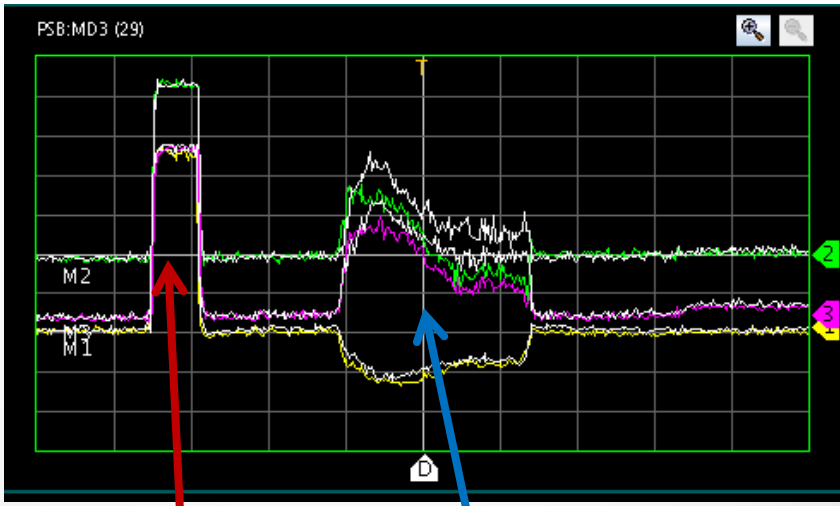
- New BPM measurement
- Old BPM measurement

- Horizontal position



- Vertical position

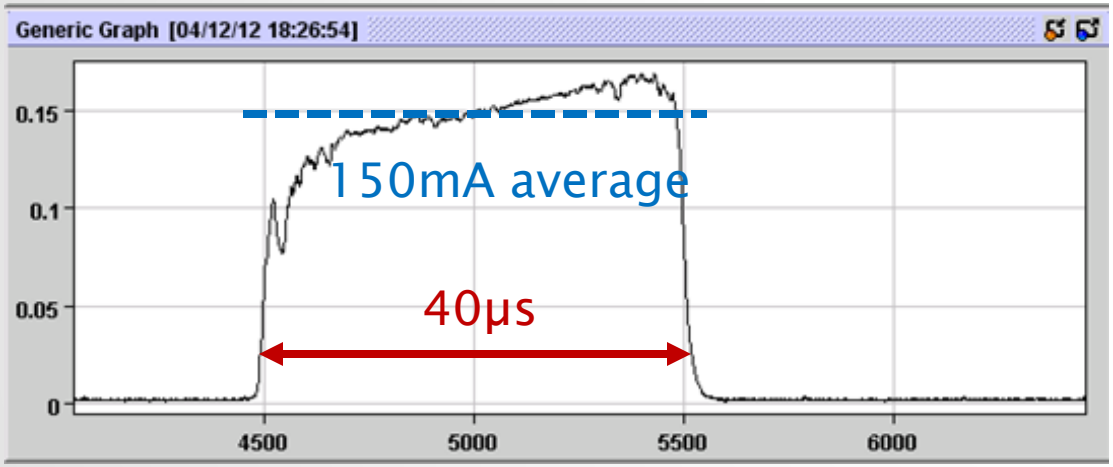




Calibration pulse

Beam

Intensity measurement



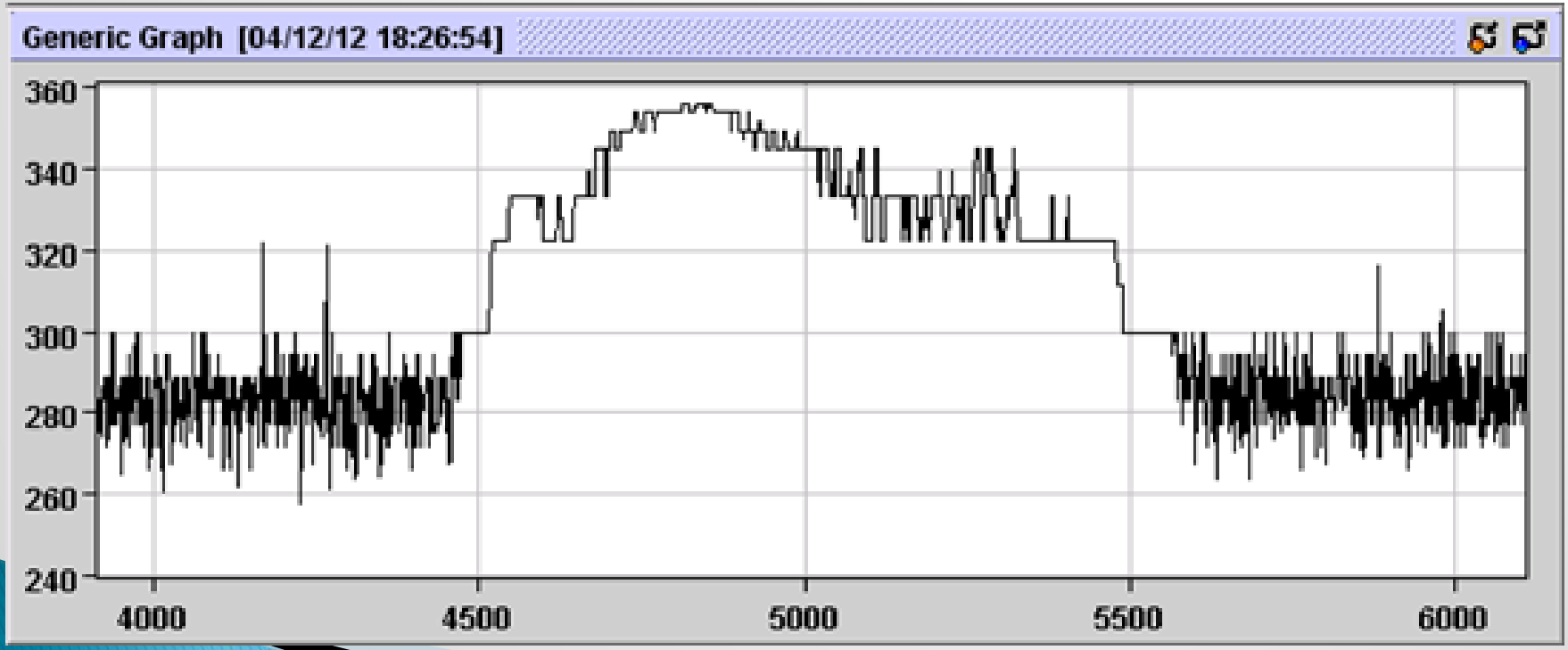
- BPM measurement

- TOF beam
- Beam current [A]
- Calibrate with BCT

- BCT measurement

Phase measurement

- First phase measurement
- 5° phase jump
- Phase between one BPM and the RF reference



To-do list

- Finish commissioning test with the LTB-UMA-20
- Be ready for H^- beam in the 3MeV test stand in January 2013
- LS1change all the old L2 BPM and install new acquisition system
- Be ready for H^- beam test in L4 tunnel in September 2013

Summary and conclusion

- Encouraging first results with beam
- Very useful test with Linac2 for the future commissioning of the Linac4
- Not expected position measurement excursion, we need to do a MD to test that
- Intensity measurement with 45% less signal at the output of the BPM
- 5° phase jump for phase measurement to be understood and corrected

Acknowledgements

- Project leader Jocelyn Tan
- Michael Ludwig for the software
- Delphine Gerard for the mechanics
- RF group
- All the BI-PI section
- Drawing office EN/MME

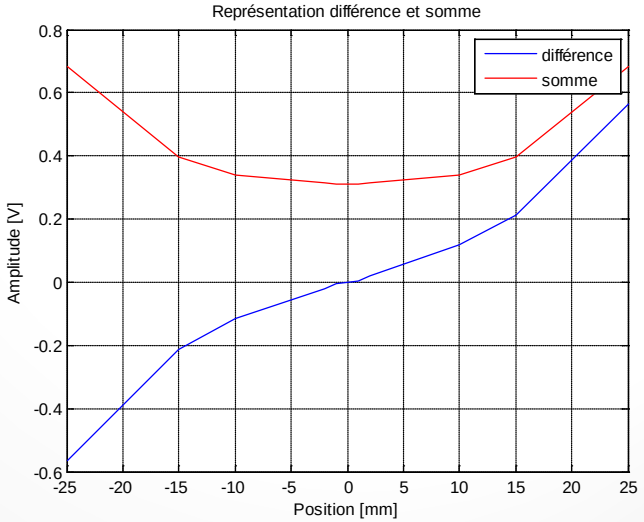
Thank you for your attention

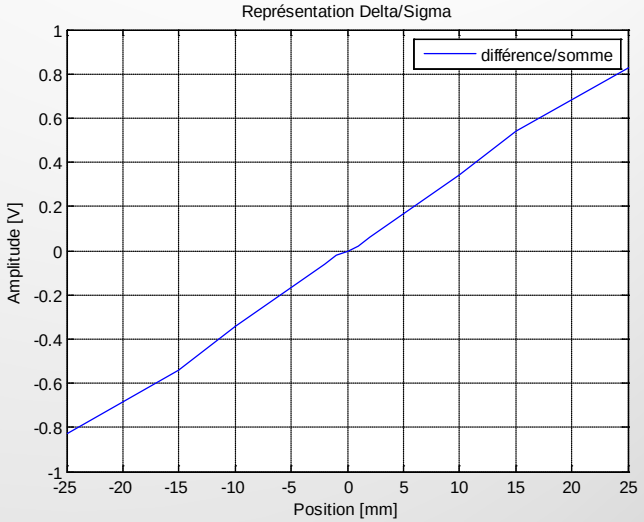
QUESTIONS ???

Extra Slide

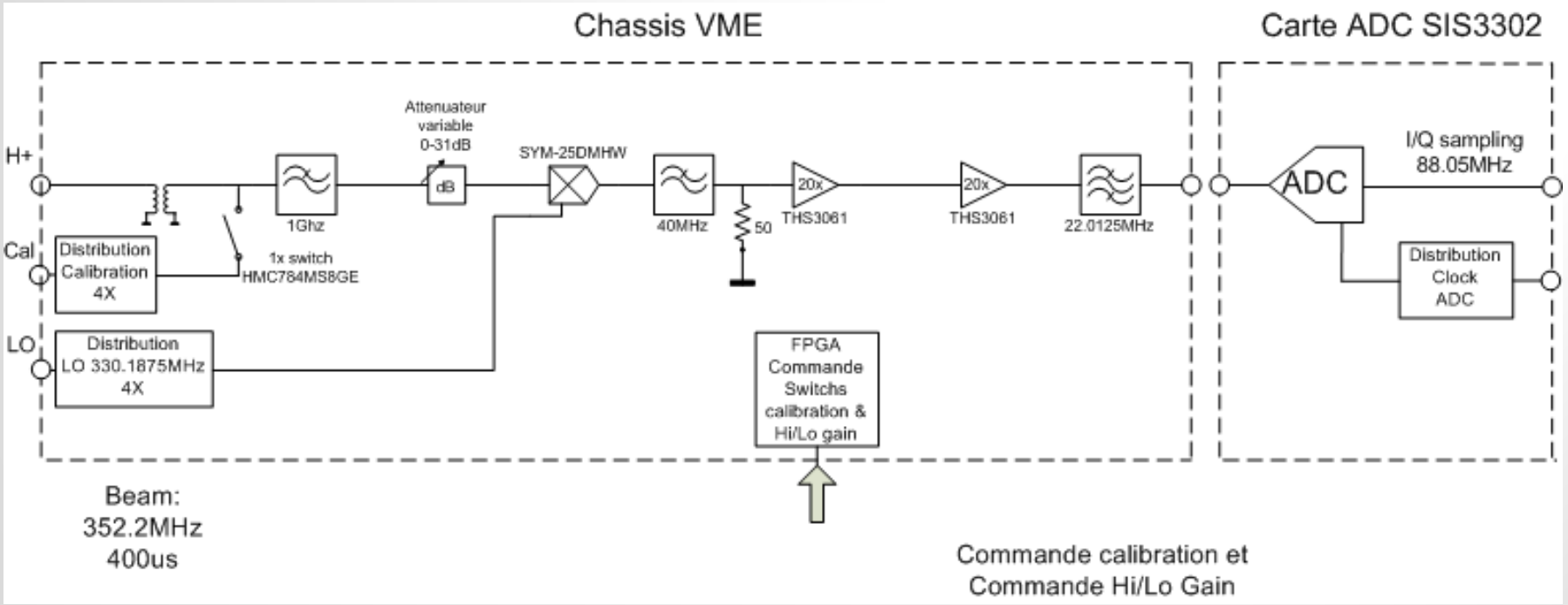
Sensibility measurement

- Constant sum between ±15mm
- Linear difference between ±15mm
- Linear electrodes between ±15mm
- The PU is linear on the desired range



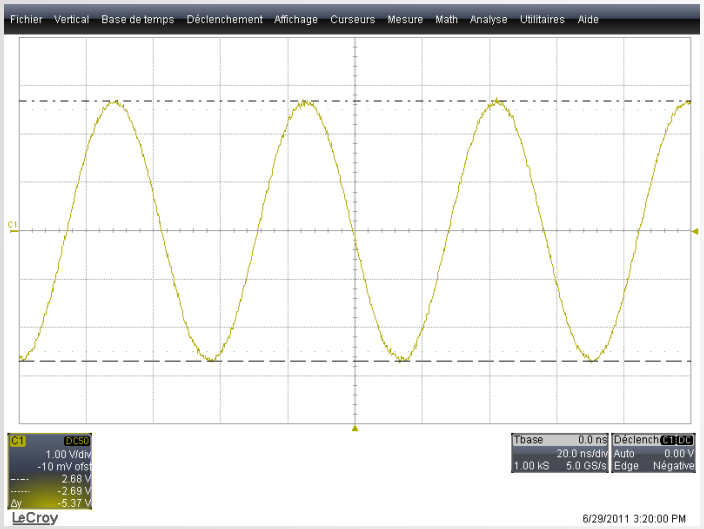


Analog card block diagram

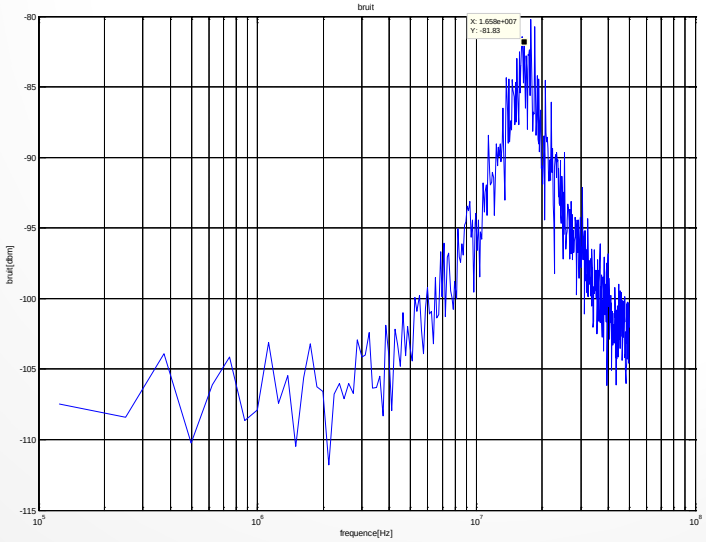


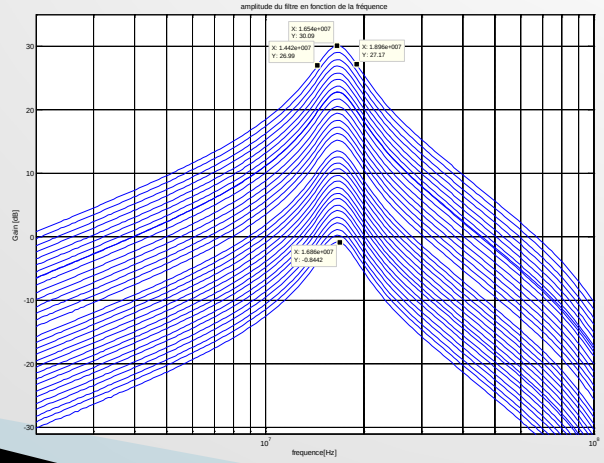
Lab measurement

Dynamic range



Noise measure



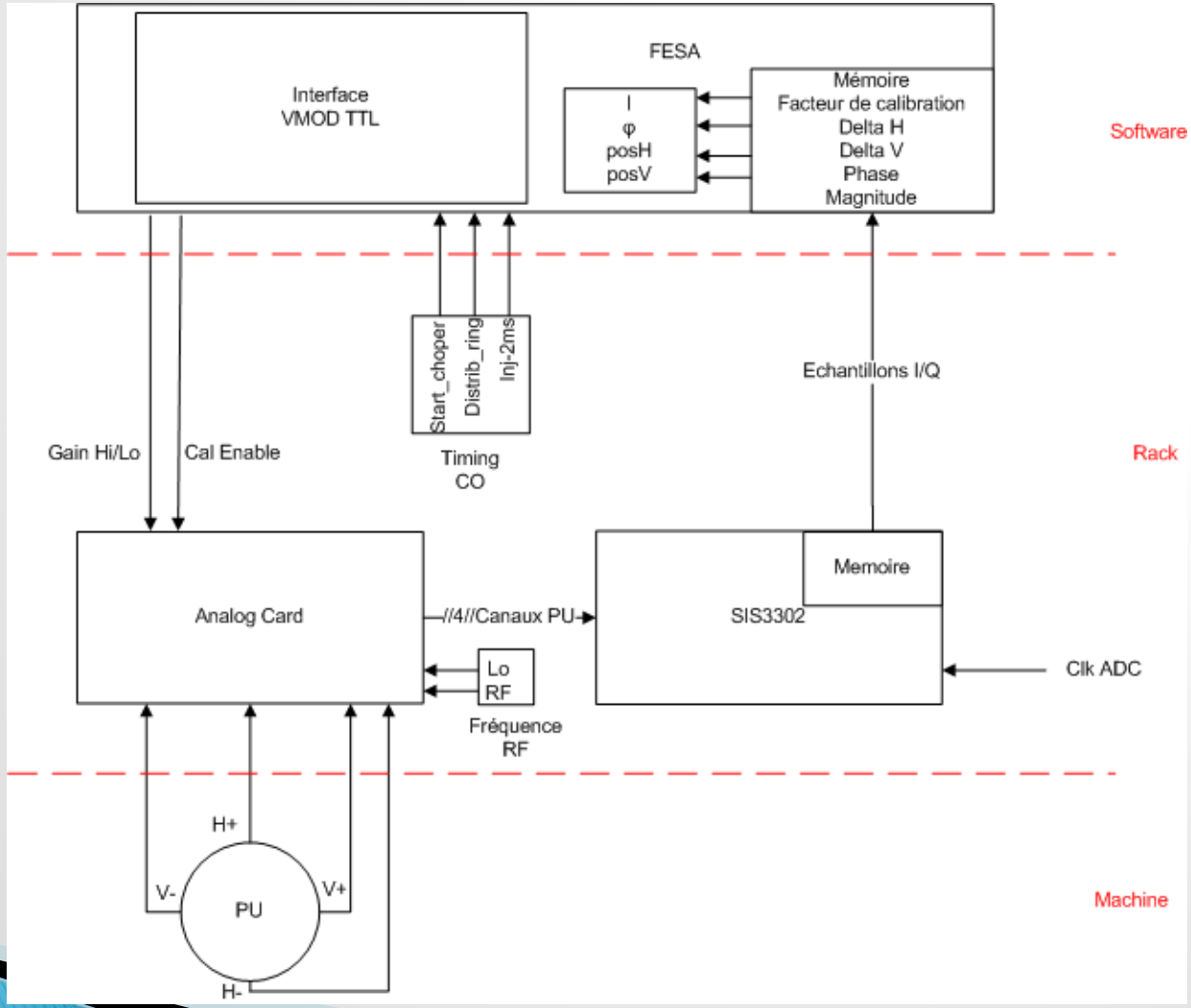


Gain & Bandwidth

Analog board characteristics

	Measure
Gain	0dB to 30.8 dB
Central frequency	22.01 MHz
Bandwidth	10 MHz
Output range	±2.68 V
Output thermal noise	700 µV
Crosstalk Signal Cal to IF 22 MHz	-50.4 dBm/0.7mV
Crosstalk LO 330 MHz	-57.2 dBm/0.3mV

Acquisition chain



Dealing with low-β beams

- Transfer impedance changes with β and bunch length
- PU sensitivity changes with β
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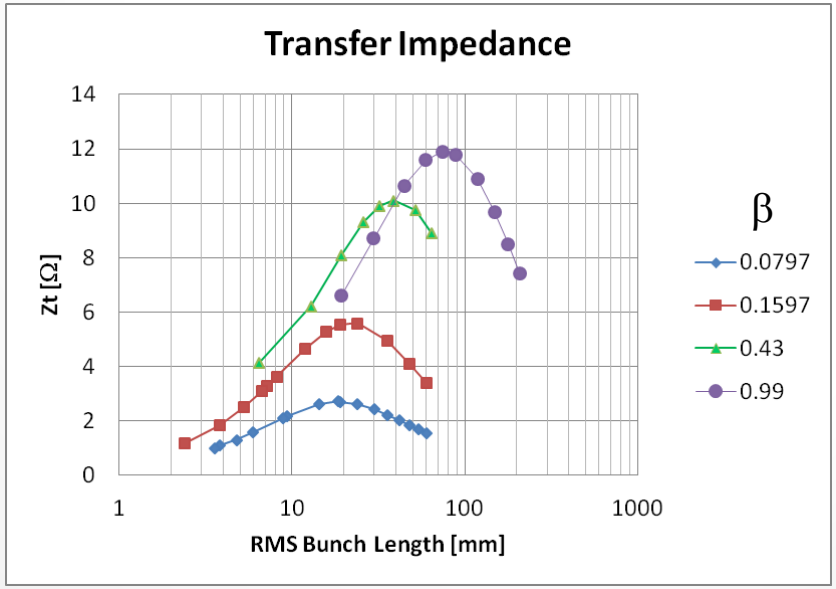

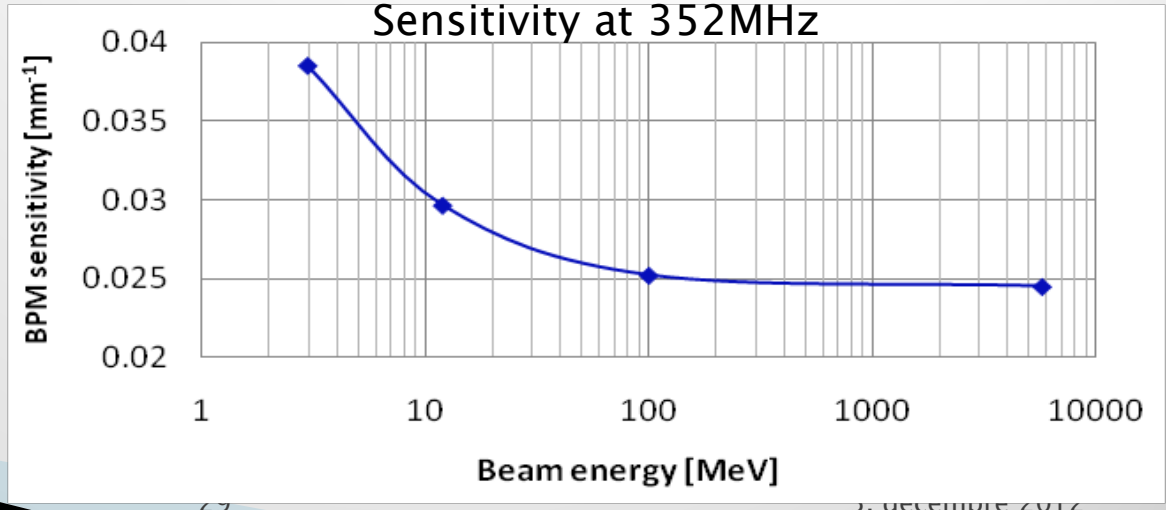

Intensity and position measurement