LINAC 4 BPM

Michele Bozzolan (BI/PI)
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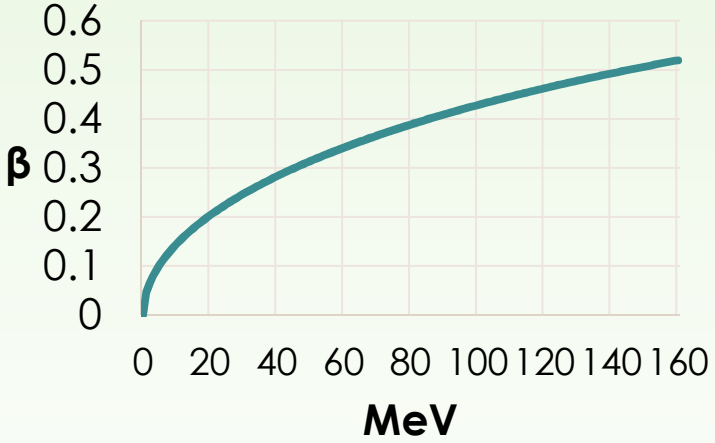
With contributions from J.Tan (BE/BI) & J.B. Lallement (BE/ABP)

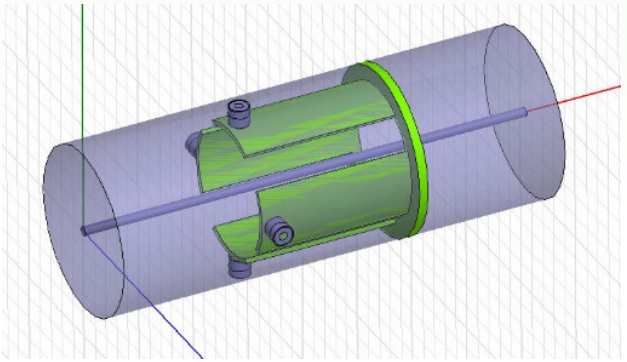
LINAC 4 Overview

- Normal conducting LINAC aimed to replace LINAC 2 after LS2
- H^- ions
- 80m long
- Macro-pulse lenght up to 600μs @ 30mA average current

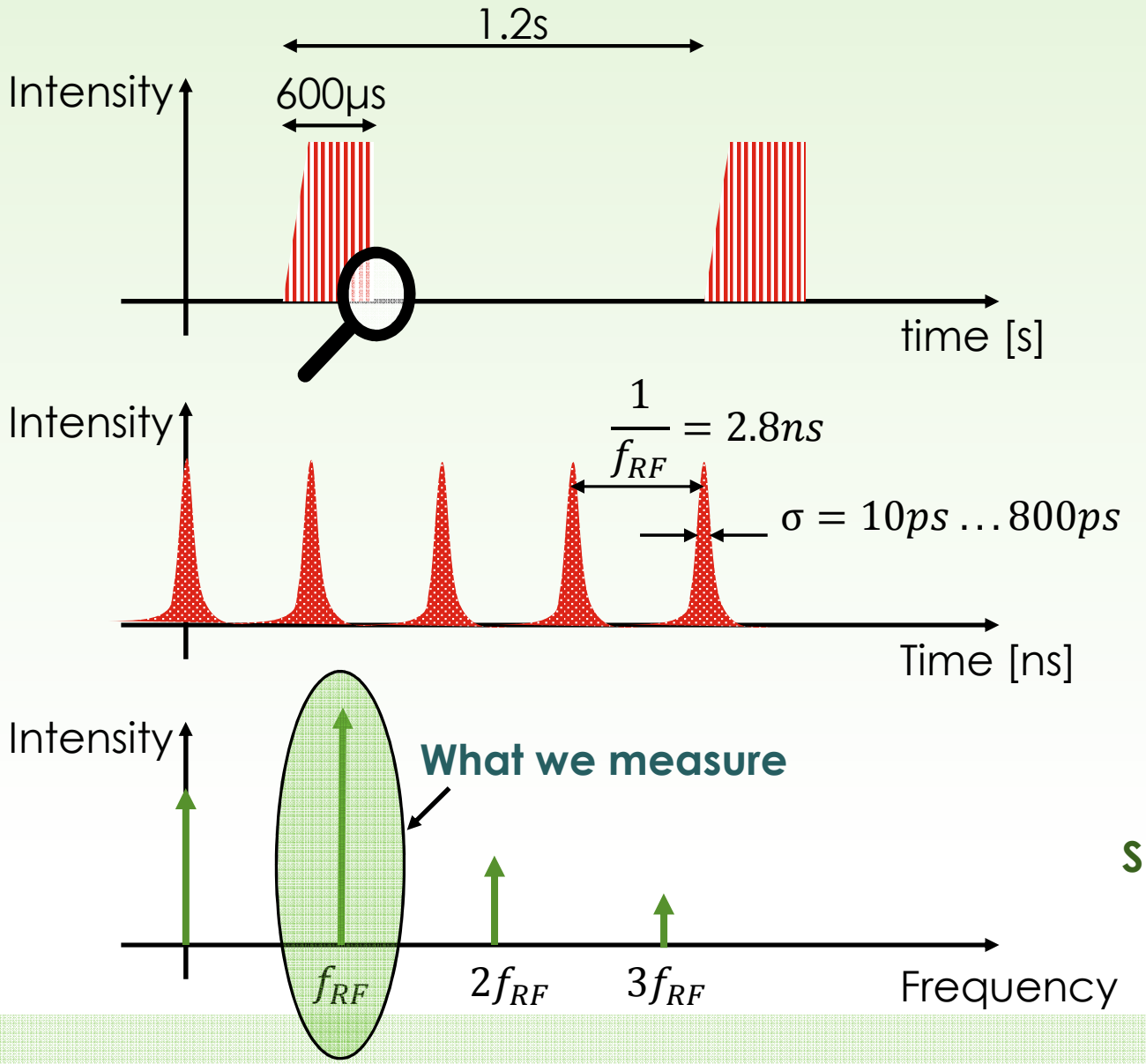


- 2 BPMs in DTL, 7 in CCDTL, 6 in PIMS, 10 in the transfer line

- BPM type: **Shorted stripline**
  - Compact size
  - Easy calibration of the coax cable



LINAC 4 beam



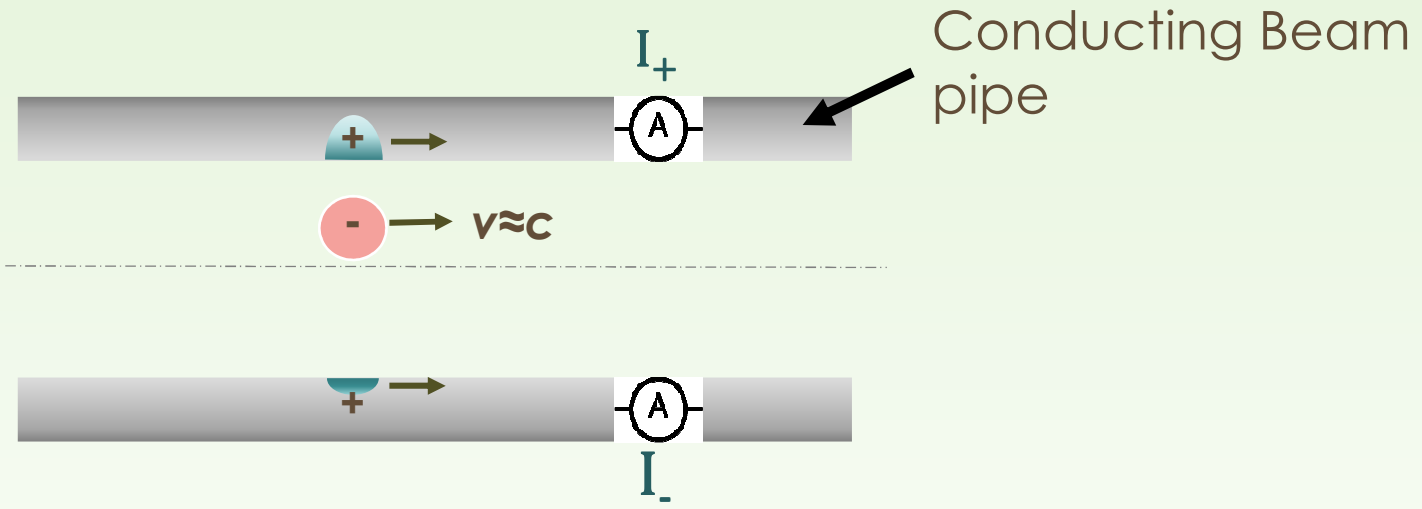
Macropulses

Bunches

(18 ... 222 injected into the PSB per turn)

Spectral components

Image current principle



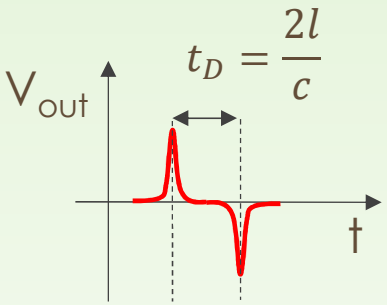
- Electric field is null inside (and outside) the pipe
- Relativistic charges produce TEM fields
- Free electrons of the metal compensate for the beam's field
- Measuring the image current in opposite location of the pipe allow us to estimate beam location and intensity.

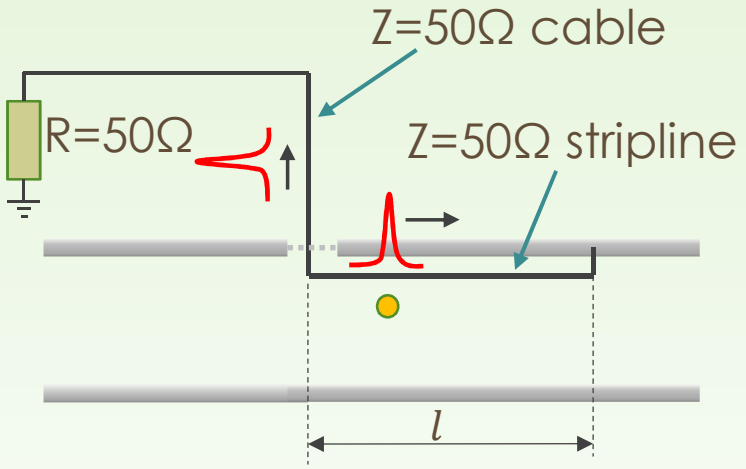
Intensity $\sim \Sigma = (I_+ + I_-)$

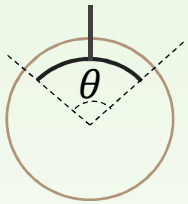
Position $= K \cdot \frac{\Delta}{\Sigma} = K \cdot \left(\frac{I_+ - I_-}{I_+ + I_-}\right)$

sensitivity

Shorted Stripline BPM (relativistic beam)





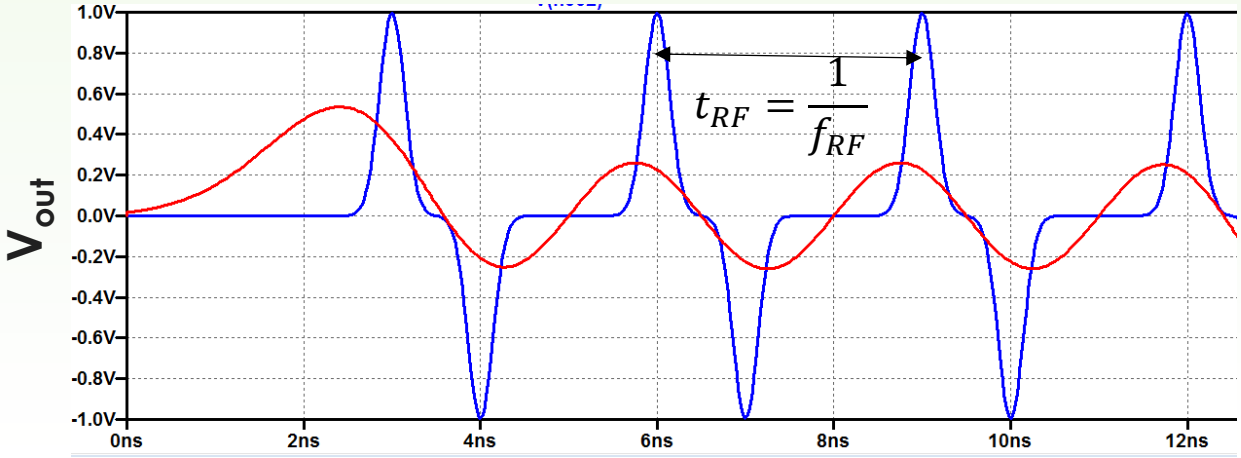


$$V_{OUT} = Z \cdot \left[I_b(t) - I_b(t - \frac{2l}{c}) \right] \cdot \frac{\theta}{4\pi}$$

Gaussian bunches response

$t_D = 1ns$
$t_{RF} = 2.8ns$

$\sigma = 0.2ns$
$\sigma = 1.5ns$

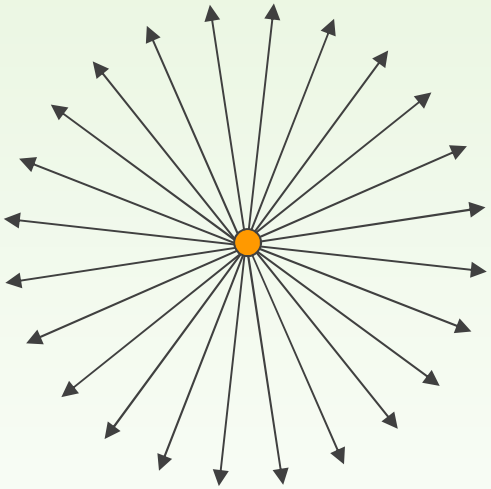


Signal strenght is bunch shape dependant: $V_{OUT} = f\{ I , \sigma , ... \}$

No absolute intensity measurement is possible (in general)

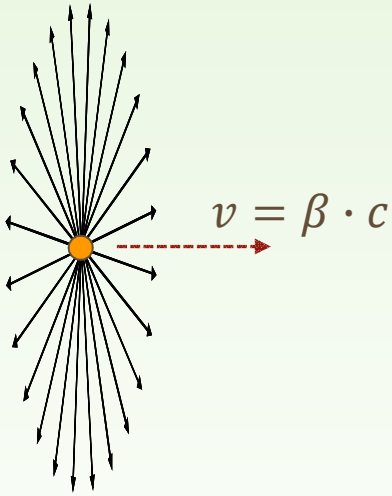
Electric field of a point charge

Static case



$$\boldsymbol{E} = \frac{q}{4\pi\varepsilon_0 r^2}\hat{\boldsymbol{r}}$$

Uniform motion

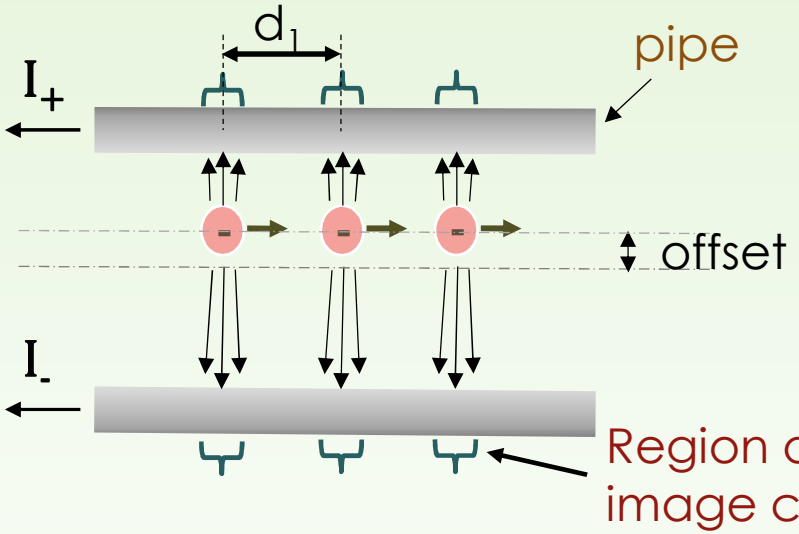


$$\boldsymbol{E} = \frac{q}{4\pi\epsilon_0}\frac{1-\beta^2}{(1-\beta^2 sin^2\theta)}\frac{\widehat{\boldsymbol{R}}}{r^2}$$

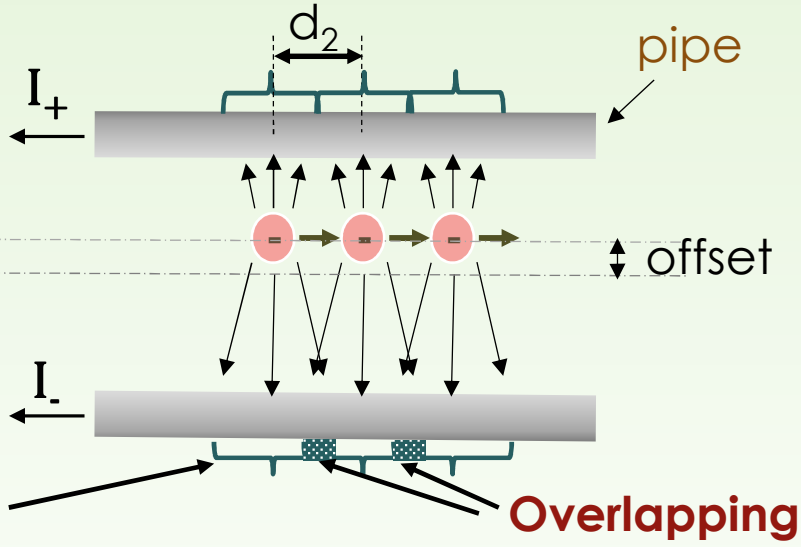
Field produced by the charge is the same but field lines get compressed by the lorentz factor when seen from an observer at rest (i.e. our instrument)

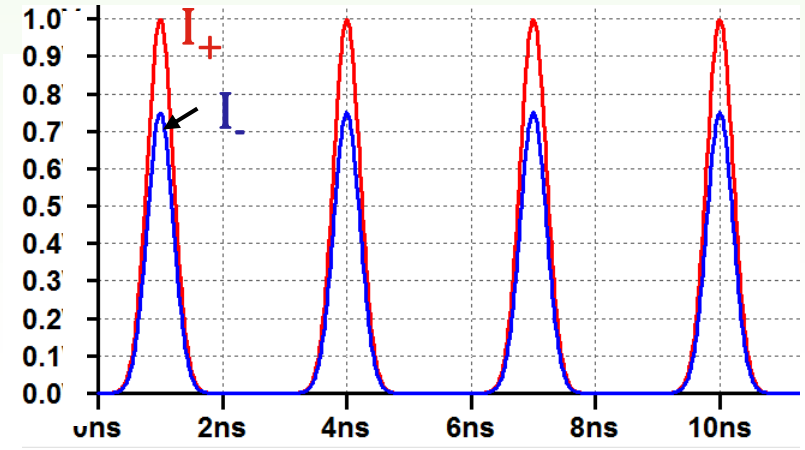
Low β effects

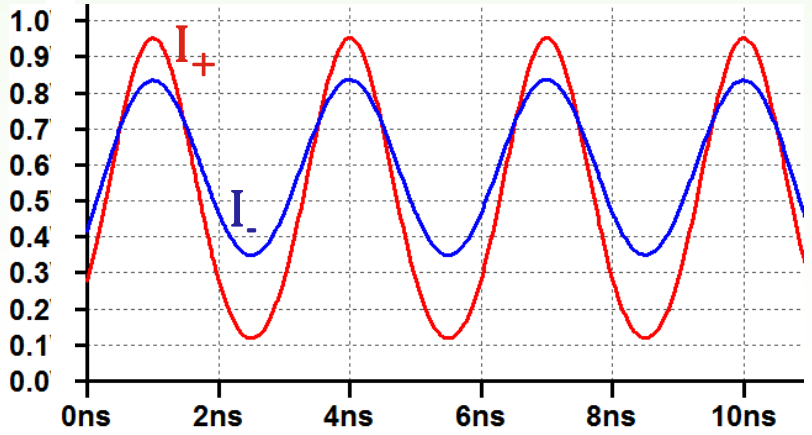
Relativistic beam: ***β≈1→ v≈c***



Low beta beam: ***β<1***

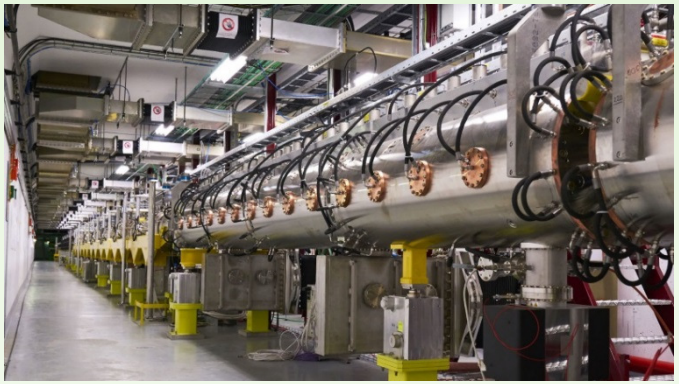


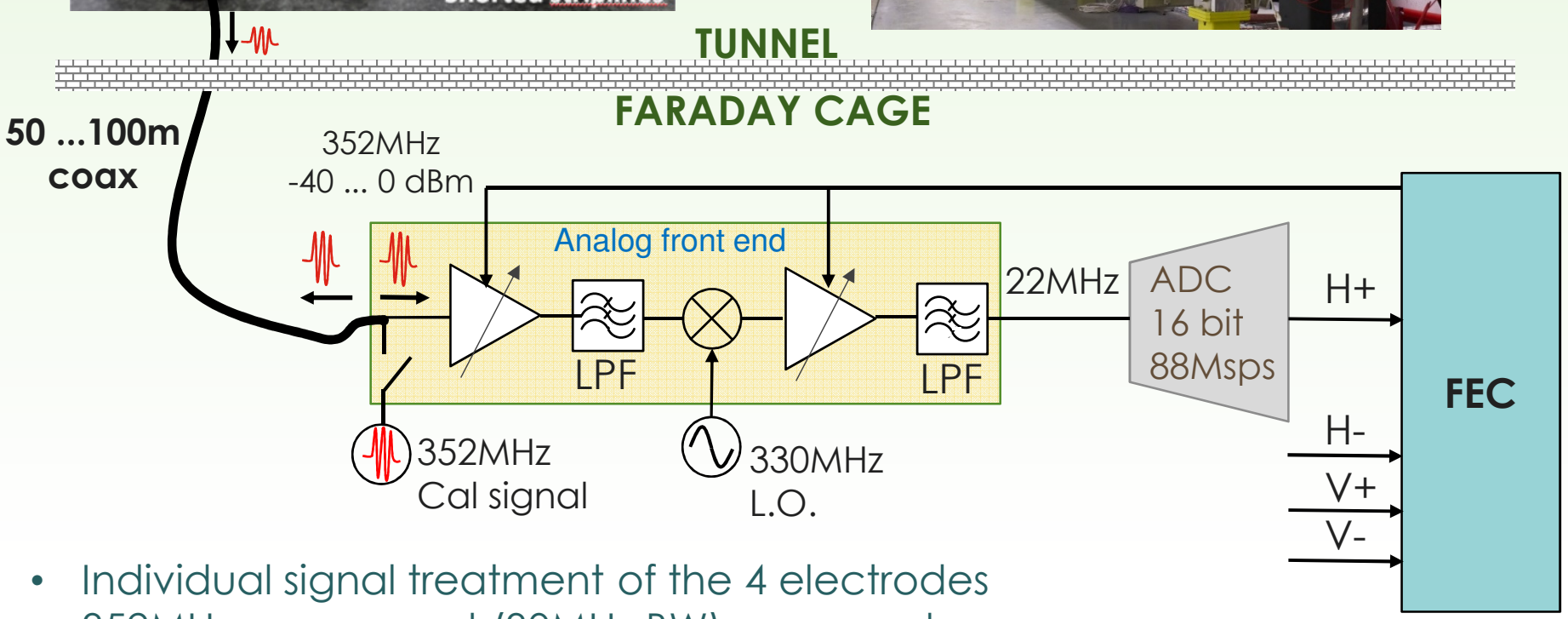




1) Lower β flatten the signals (i.e. less HF components) → **less amplitude**
2) The furthest image current is more affected → **higher position sensitivity**

BPM system overview



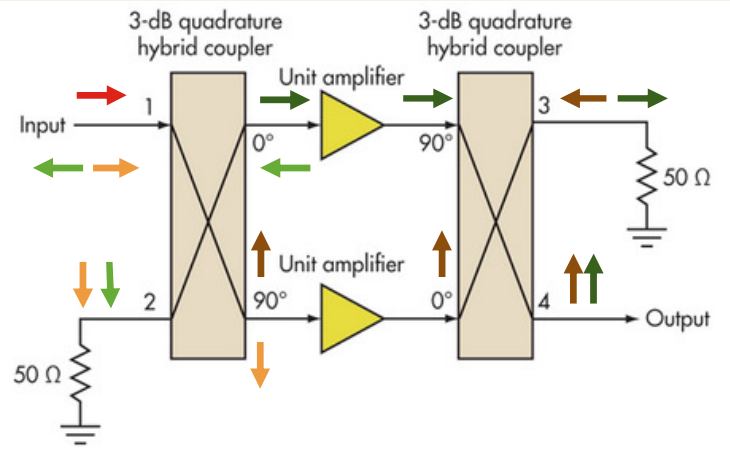


- Individual signal treatment of the 4 electrodes
- 352MHz component (30MHz BW) measured
- Compensation of cable and amplifier chain by calibration pulse injection

Analog Front End

- Linear over the signal dynamic range
- Good input match
- Low noise

} ~~attenuator~~

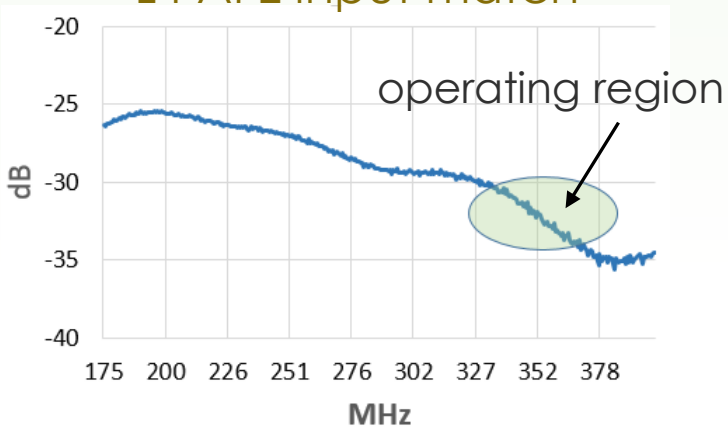


(Ideal) **Balanced amplifier** features:

1. 3dB higher dynamic range
2. Perfect input match
3. No noise degradation

Main limitation: hybrid coupler

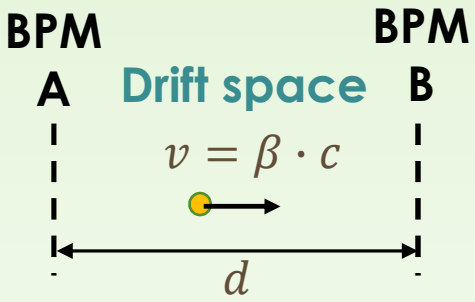
L4 AFE input match



L4 AFE main features:

Gain: 2 ... 48dB in 0.5db steps
P1dB: > 15dBm (input power)
N.F. : 12dB
Power: 8W

Energy measurement by time of flight

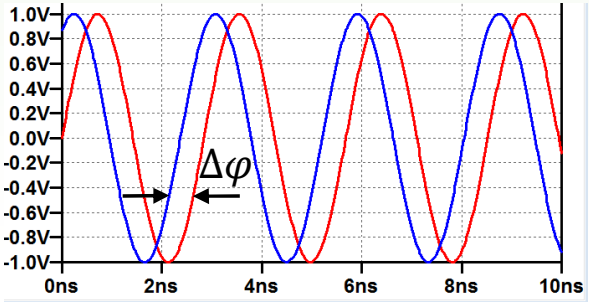


$$t = \frac{d}{\beta c} \rightarrow \beta = \frac{d}{ct}$$

$$\begin{cases} d=3m \\ E_{RESOLUTION} = 1MeV \end{cases} \rightarrow \text{Time resolution} \sim 1ns$$

Direct time delay measurement is not practical

$$\begin{cases} RF=352MHz \\ \varphi_{RESOLUTION}=5^\circ \end{cases} \rightarrow \text{Time resolution} = 40ps$$



$$-\pi < \Delta\varphi < +\pi$$

integer

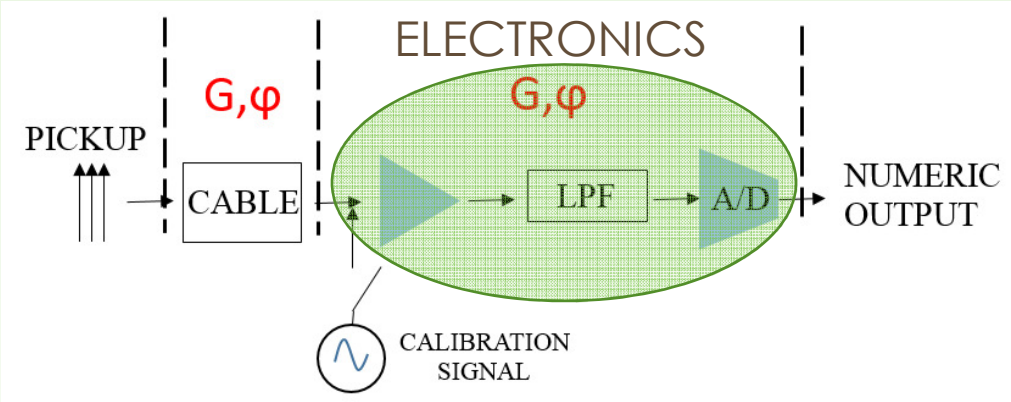
$$\Delta t = \left(\frac{K}{2} + \frac{\Delta\varphi}{2\pi}\right) \cdot \frac{1}{f_{RF}}$$

Phase delay give excellent time resolution but integer delay of half RF period (***K***) is unknown.

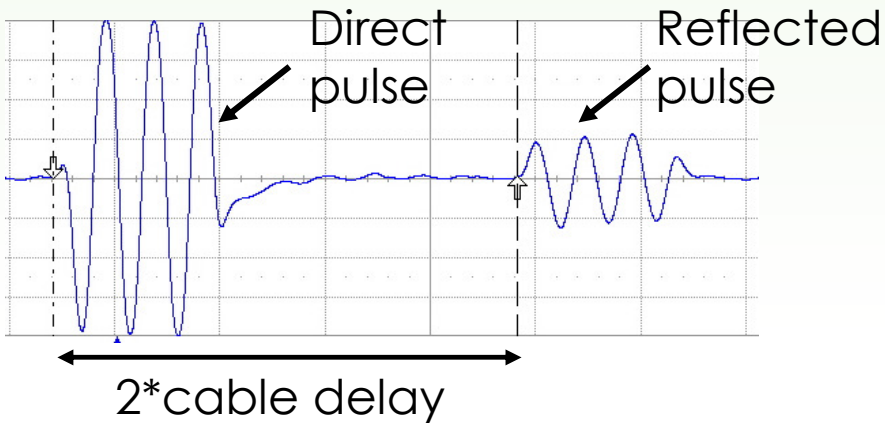
In L4: **~10<*K*<hundreds**

Calibration

1. Measure of amplitude asymmetries between + & - signal paths
2. Measure of phase delay between different PUs acquisition chain



Calibration signals



$$G_{CABLE} = \sqrt{\frac{A_{REFLECTED}}{A_{DIRECT}}}$$

$$\varphi_{CABLE} = \frac{\Phi_{REFLECTED} - \Phi_{DIRECT}}{2}$$

$$G'_{ELECTRONICS} = A_{DIRECT}$$
$$\Phi'_{ELECTRONICS} = \Phi_{DIRECT}$$

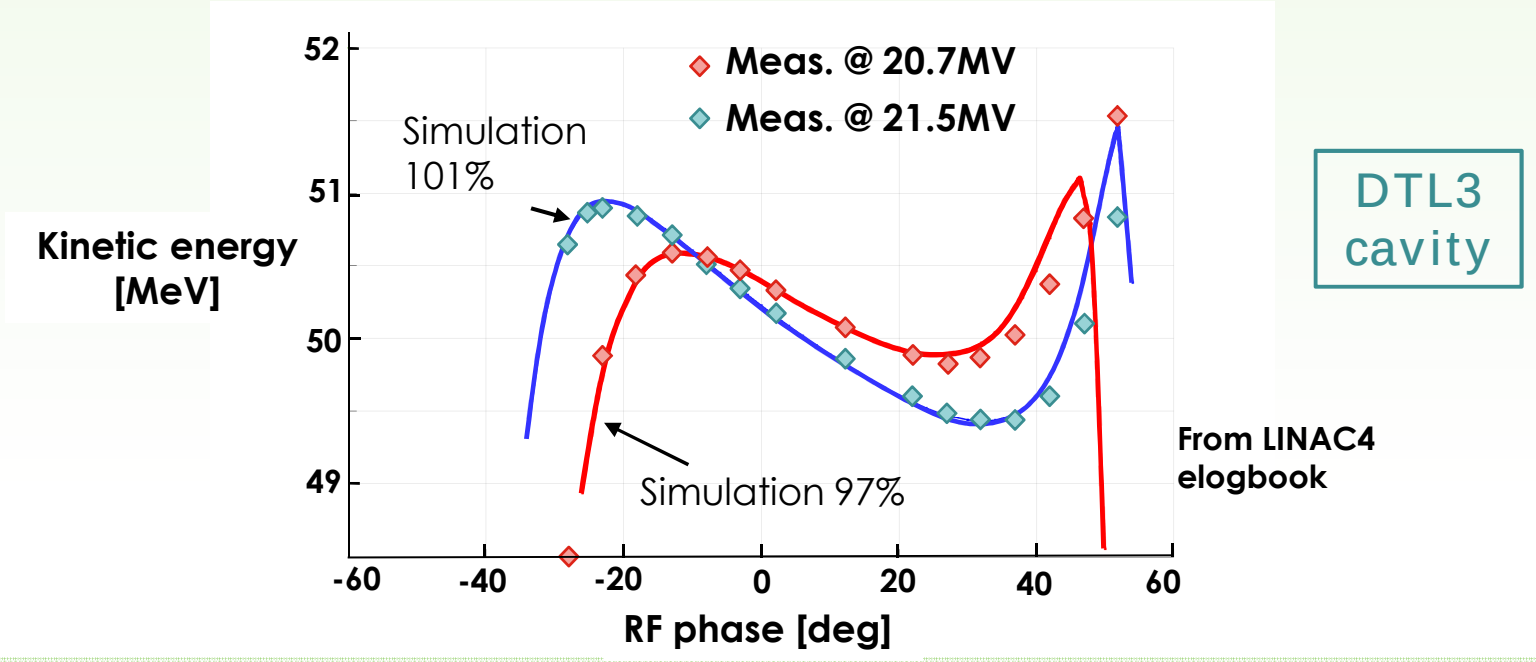
Relative measures

Calibration mismatch ~ 1/1000

Position error for 30mm sensitivity ~ 30um

LINAC 4 cavity tuning

- Each cavity must be setup (in terms of voltage and phase) to match the simulated beam dynamic conditions
- Following cavities are unpowered and detuned



Status and outlook

- BPMs have been installing during the L4 construction phases (2014 ... LS2)
- New FESA class developed (2017) to solve issues with server crashes
- New JAVA based expertGUI under development
- TOF still measured by a python scrypt.
  A BI server application and an OP GUI application are under development
- Algorithm for the estimation of TOF at the lowest energies to be improved