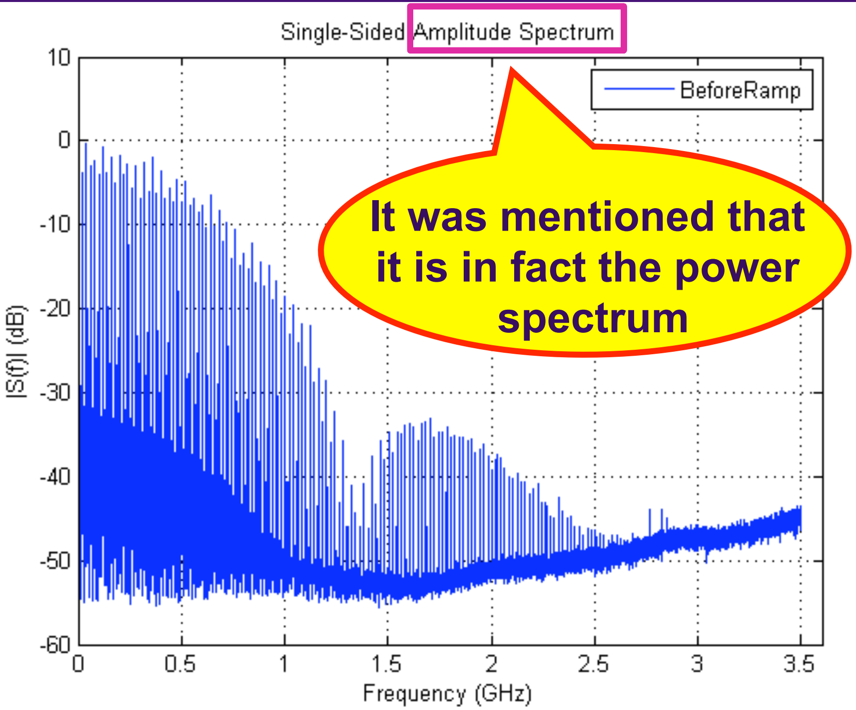
POWER SPECTRA COMPARISON BETWEEN DIFFERENT TYPES OF LONGITUDINAL BUNCH PROFILES FOR THE LHC

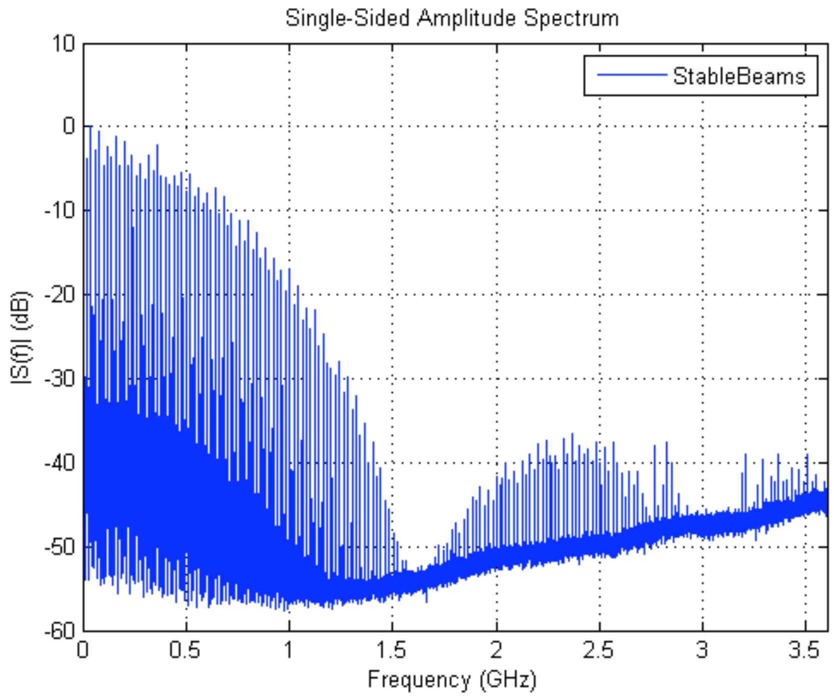
Elias Métral

- **Examples of measured bunch spectra**
- **Comparison of 4 very different longitudinal bunch profiles and corresponding power spectra**
- **Comparison of several longitudinal bunch profiles close to Gaussian ones (BUT with finite tails), and power spectra**
- **What is the (simple) distribution fitting best the 2 measurements: Before Ramp and Stable Beams**
- **Conclusion**
- **Appendix: some formulae**

EXAMPLES OF MEASURED BUNCH SPECTRA

Measurements on B1 by Themis and Philippe on fill # 2261





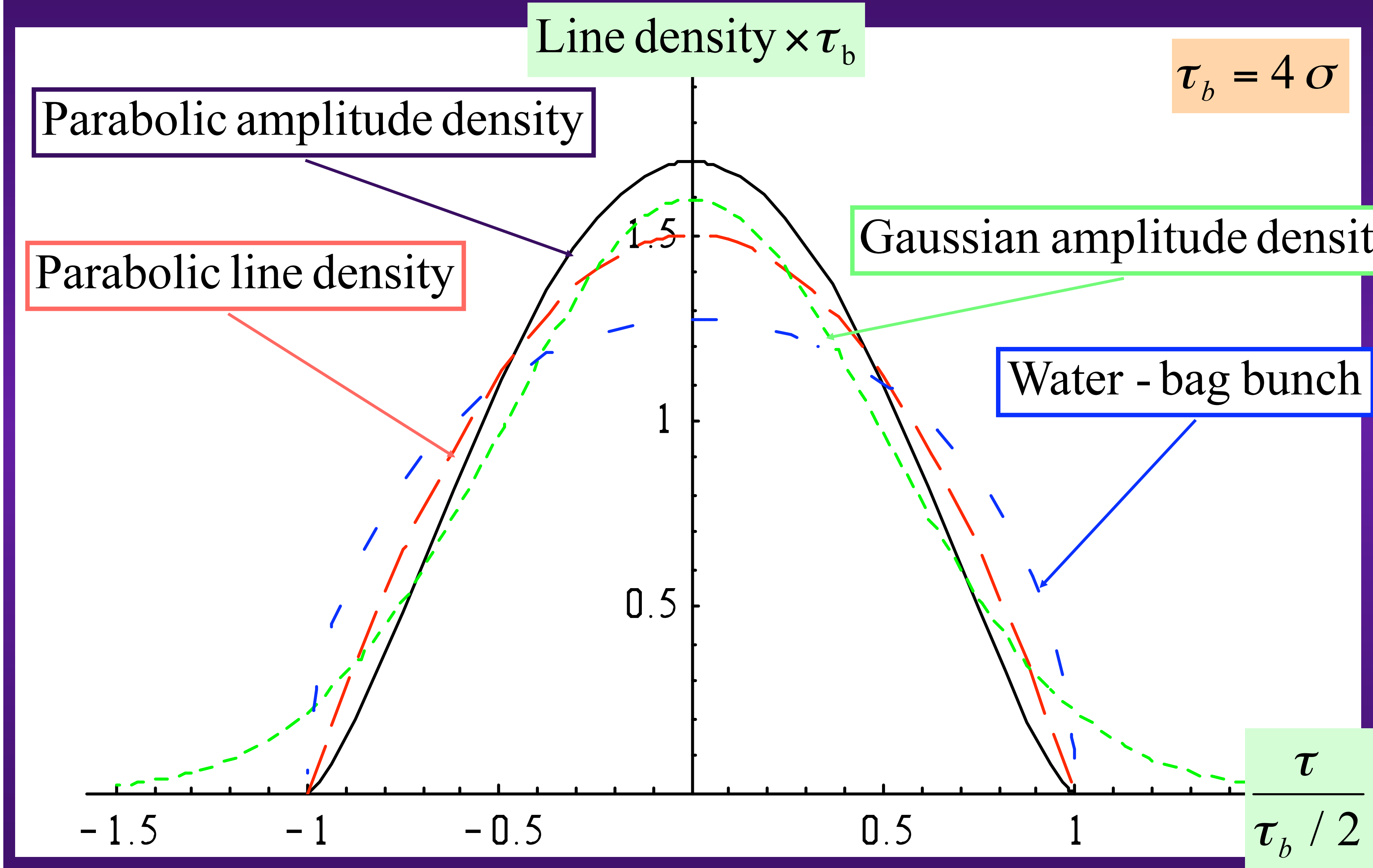
Reminder on the power loss/deposited [W]

$$P_{loss} = M \, I_b^2 \, Z_{loss}$$

$$Z_{loss} = 2 \, M \sum_{p=1}^{\infty} \mathrm{Re}\left[Z_l \left(p \, M \, \omega_0 \right) \right] \times \mathrm{PowerSpectrum}\left[p \, M \, \omega_0 \right]$$

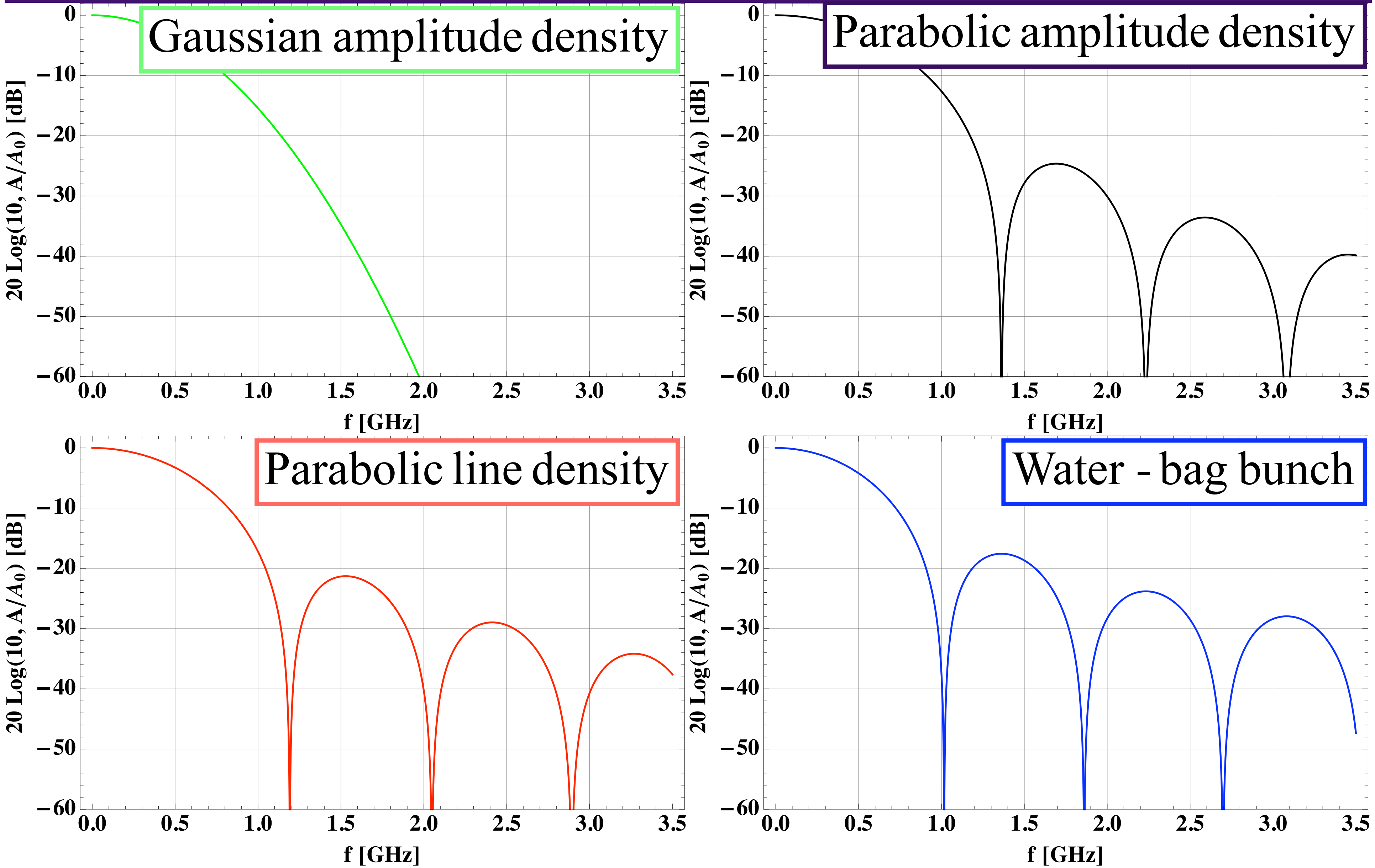
$$I_b = N_b \, e \, f_0$$

4 THEORETICAL LONGITUDINAL BUNCH PROFILES



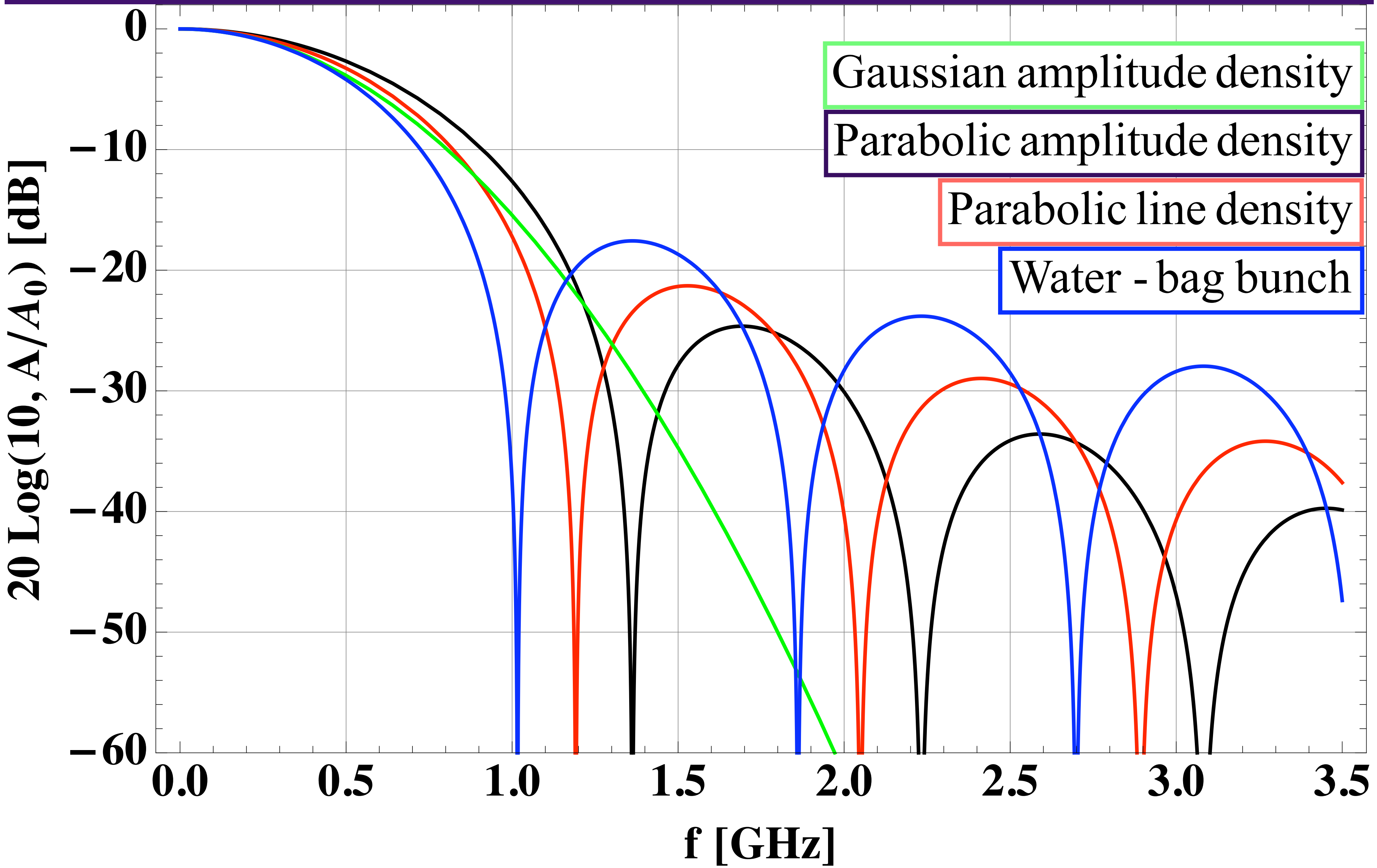
CORRESPONDING POWER SPECTRA (1/2)

$\tau_b = 1.2$ ns

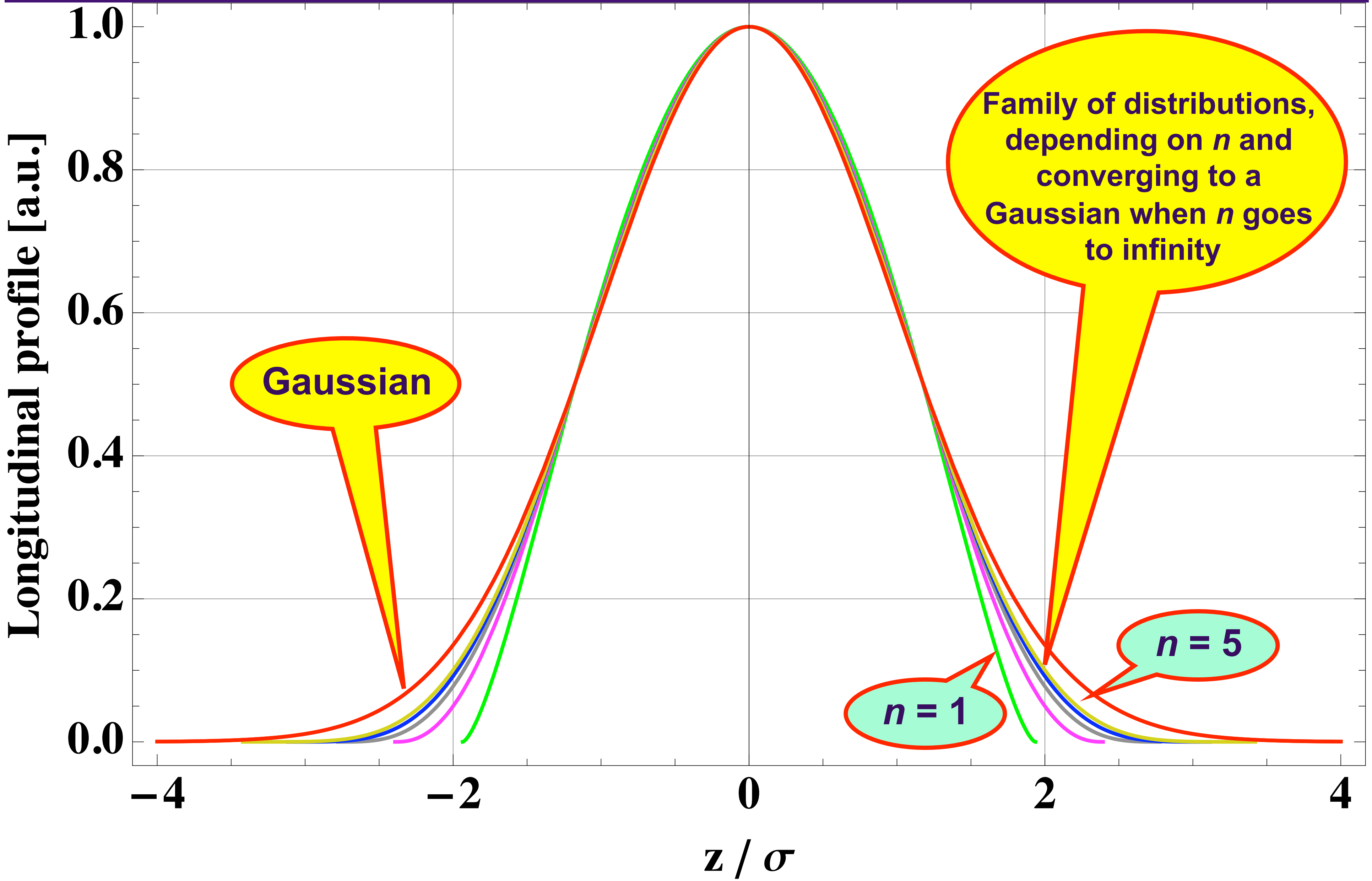


CORRESPONDING POWER SPECTRA (2/2)

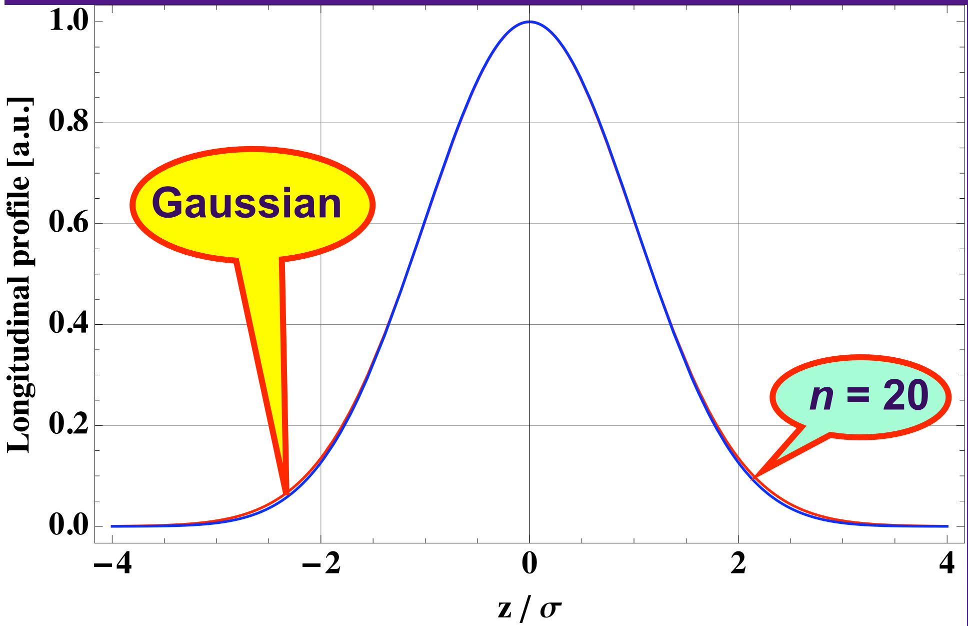
$\tau_b = 1.2$ ns

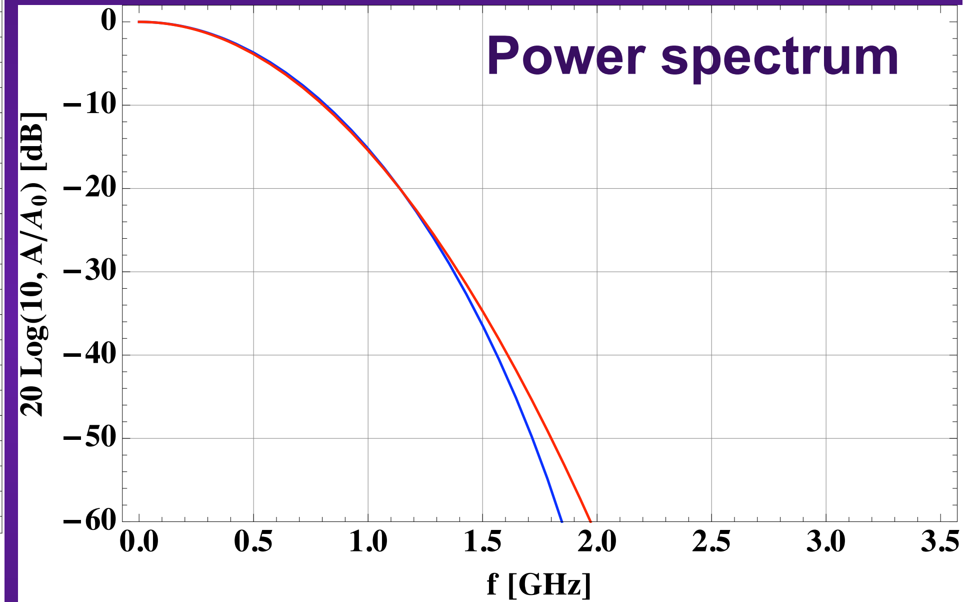


COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (1/7)

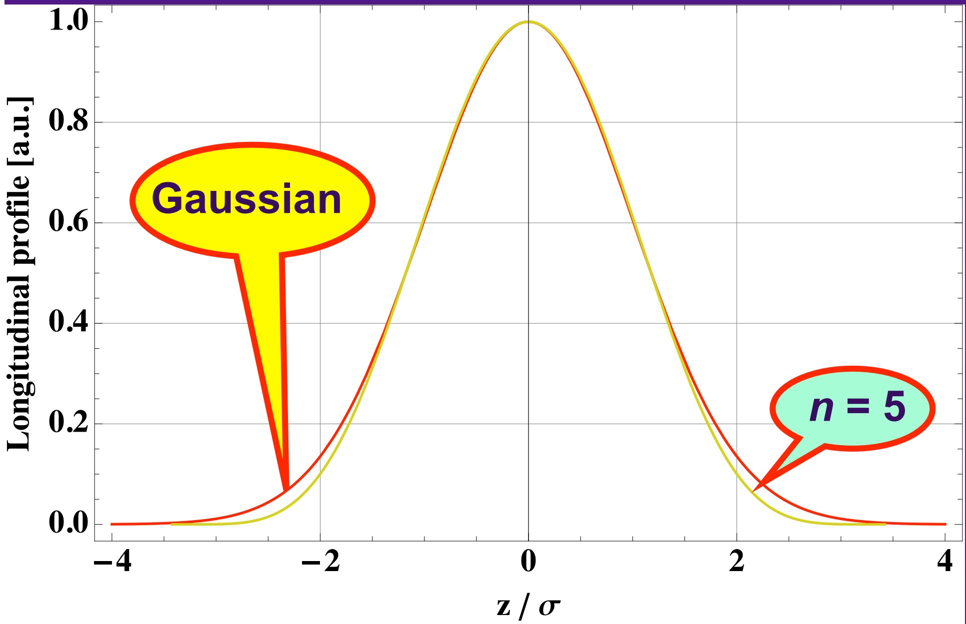


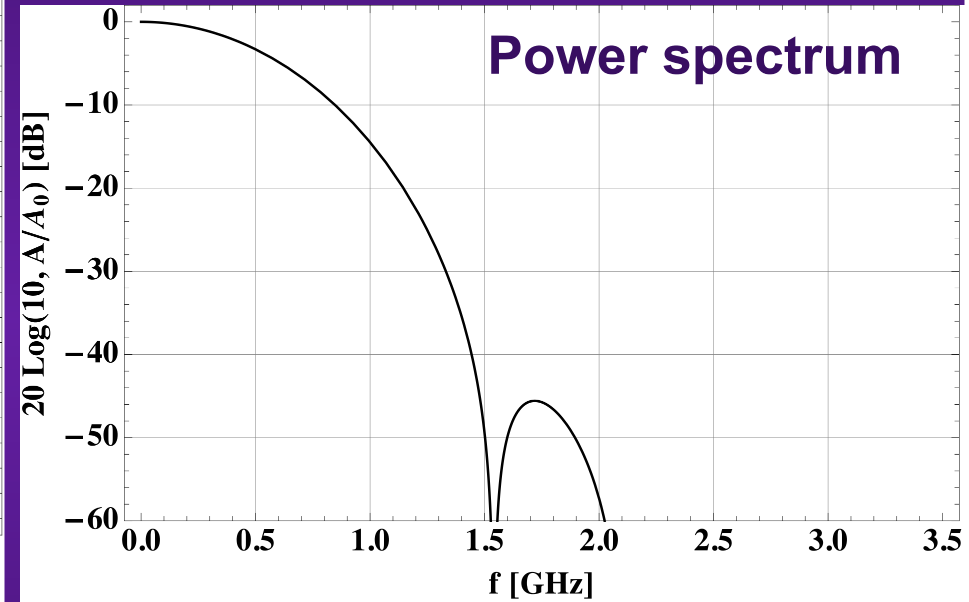
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (2/7)



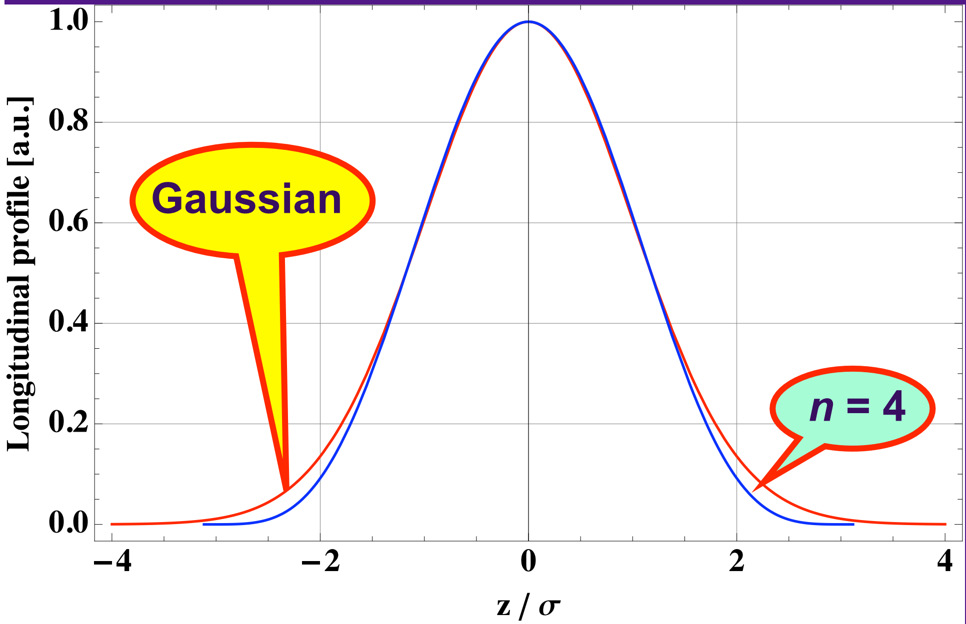


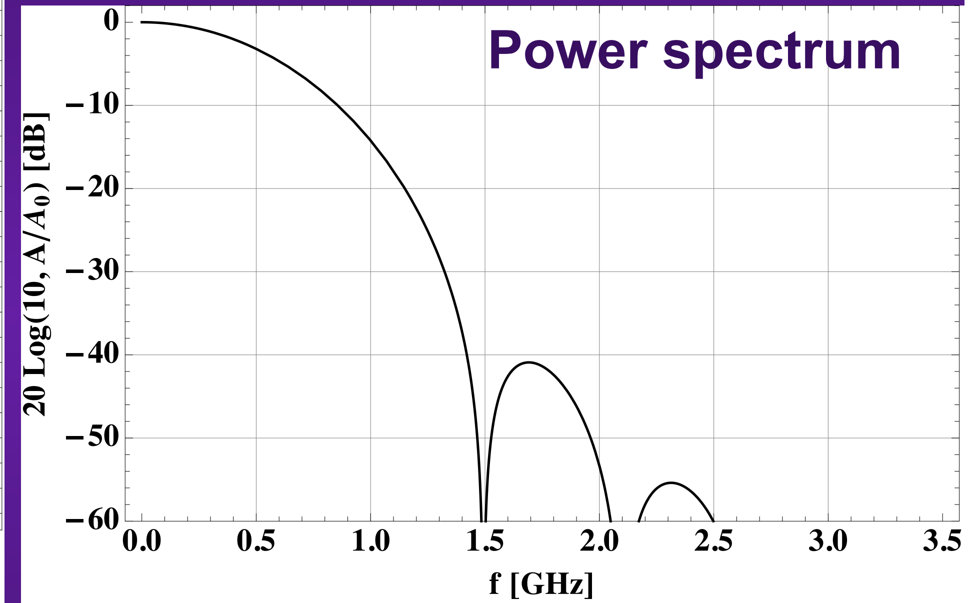
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (3/7)



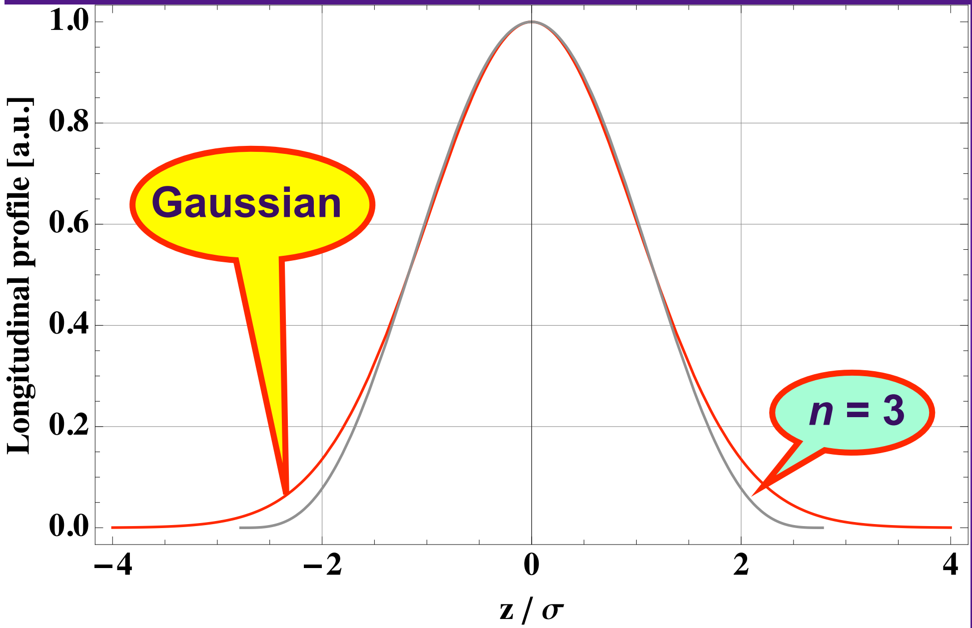


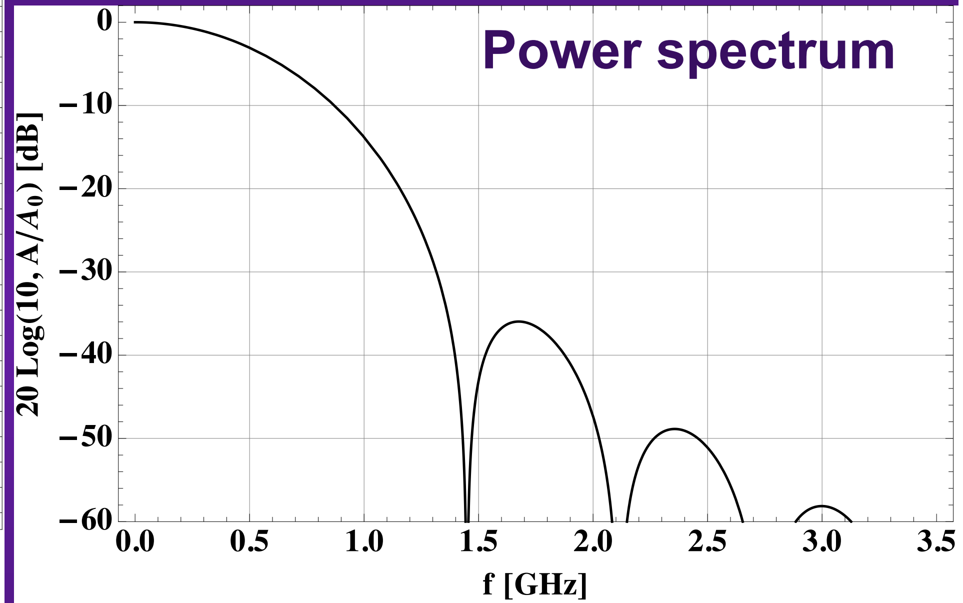
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (4/7)



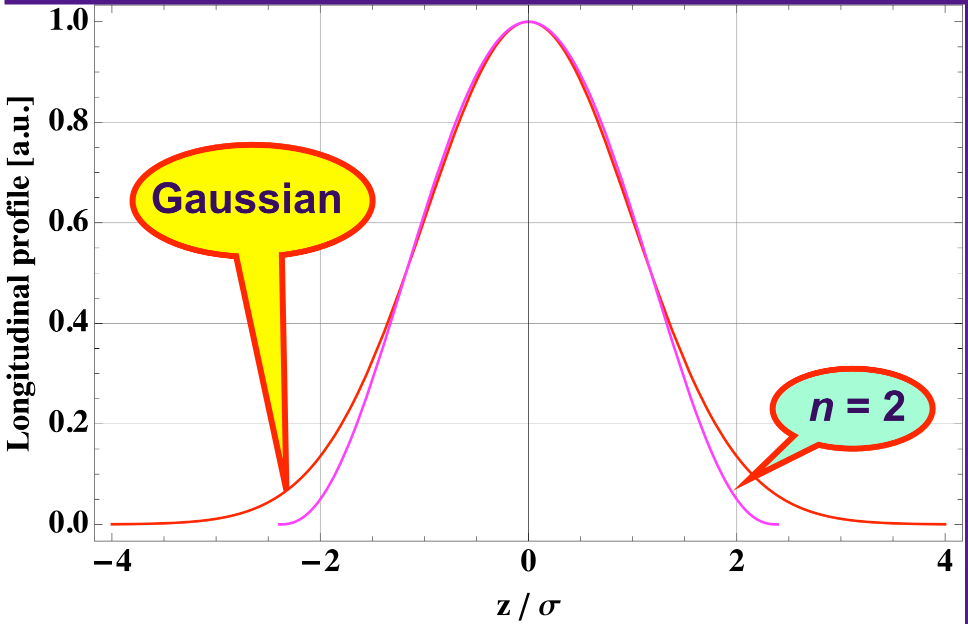


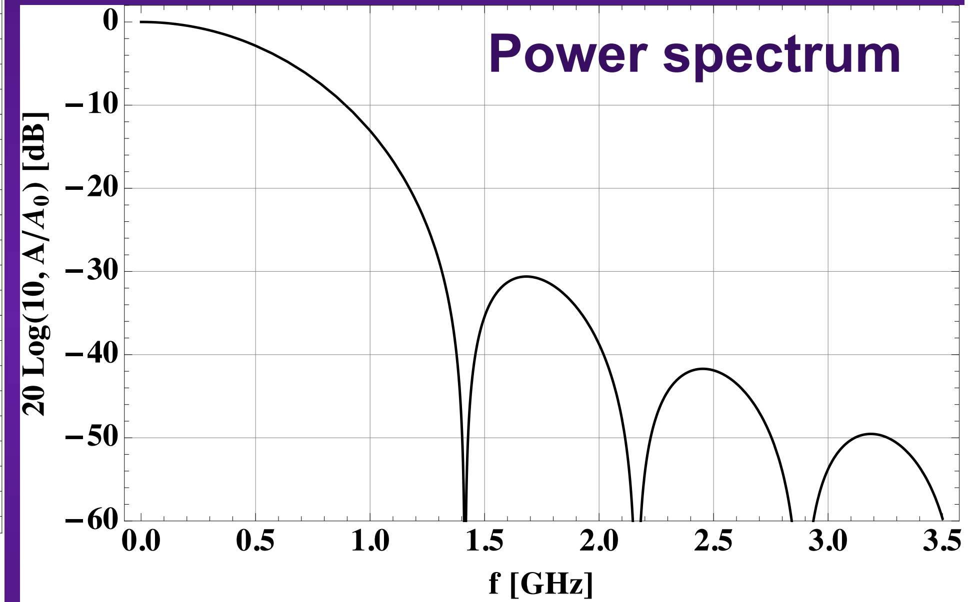
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (5/7)



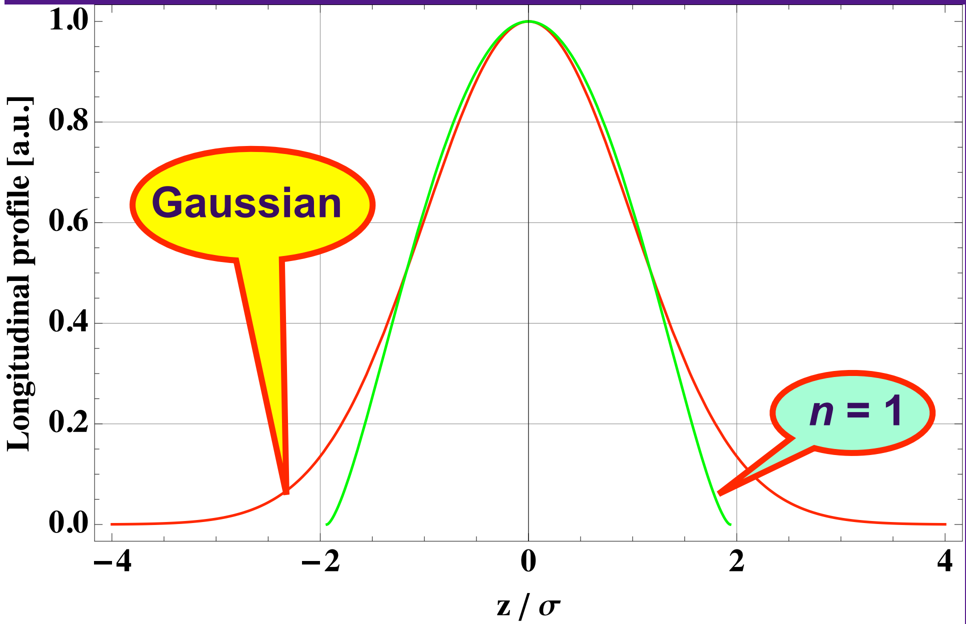


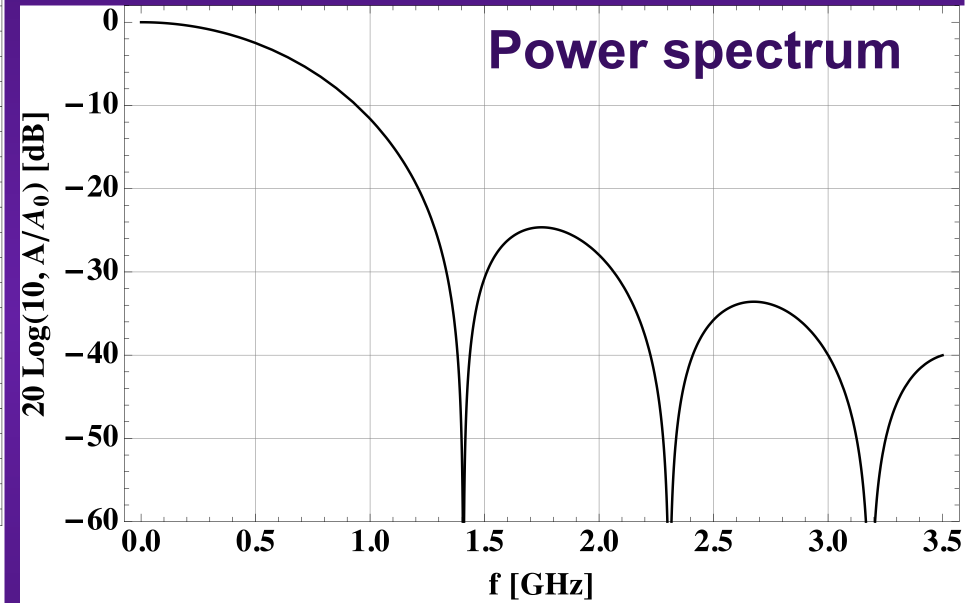
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (6/7)



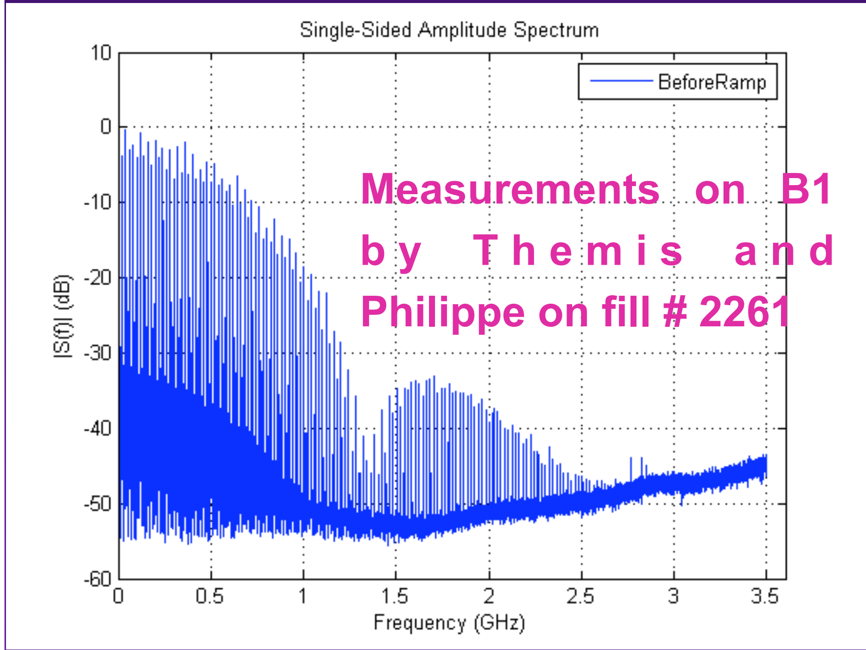


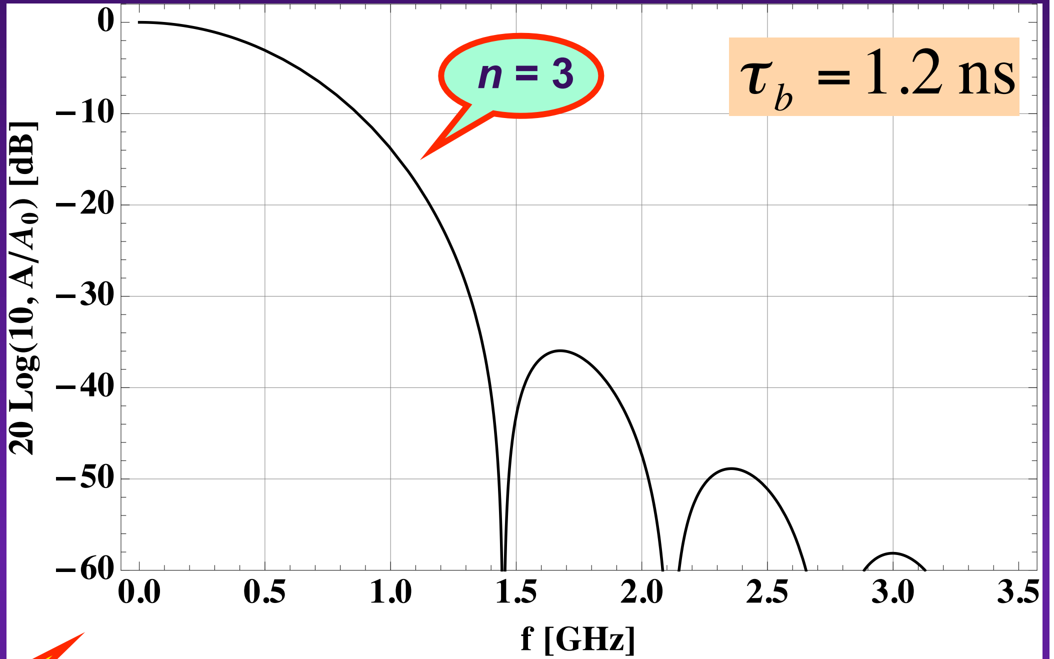
COMPARING LONGITUDINAL BUNCH PROFILES CLOSE TO GAUSSIAN BUT WITH FINITE TAILS (7/7)





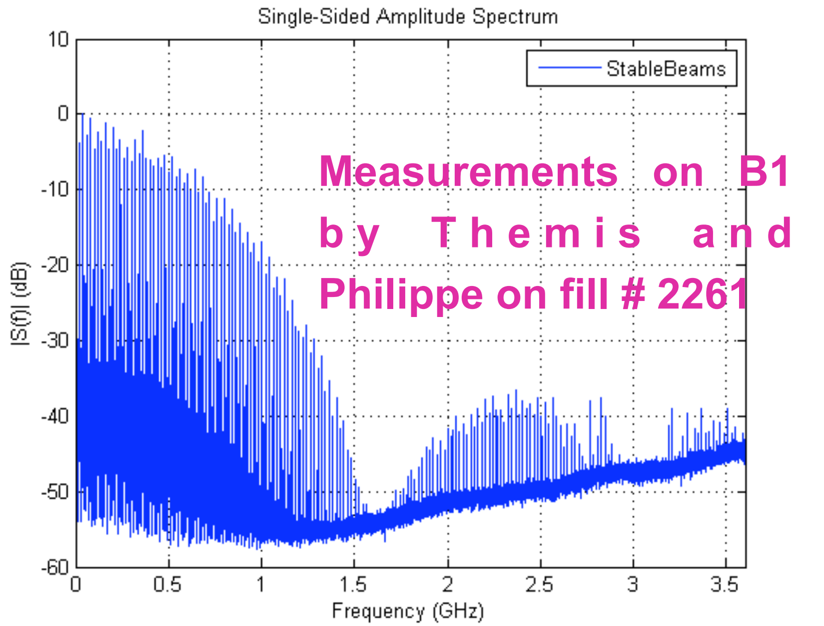
WHAT IS THE (SIMPLE) DISTRIBUTION FITTING BEST THE MEASUREMENT BEFORE RAMP?

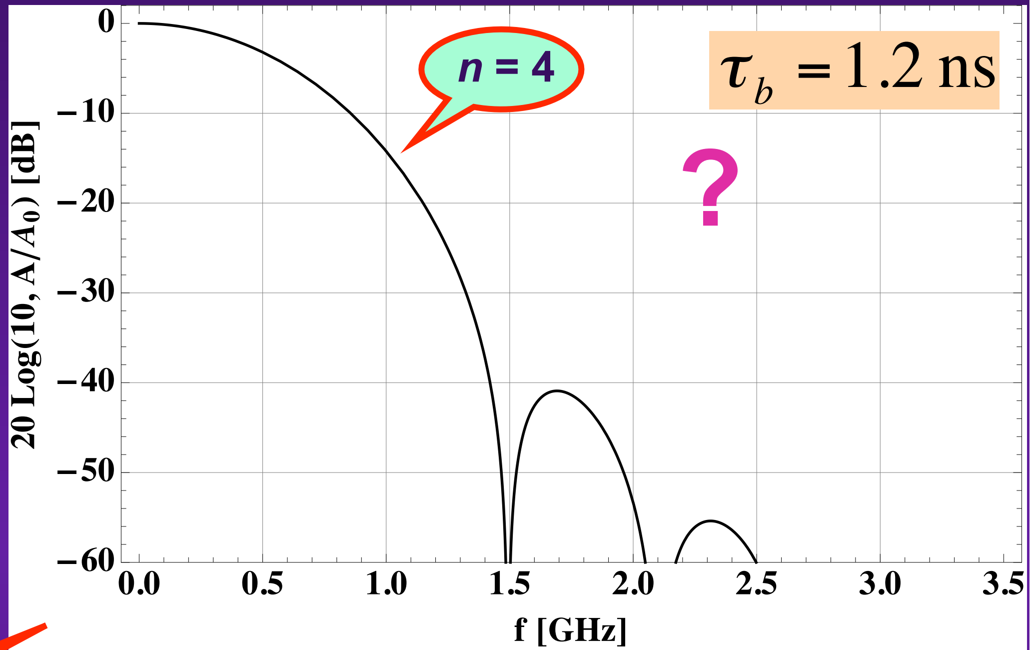


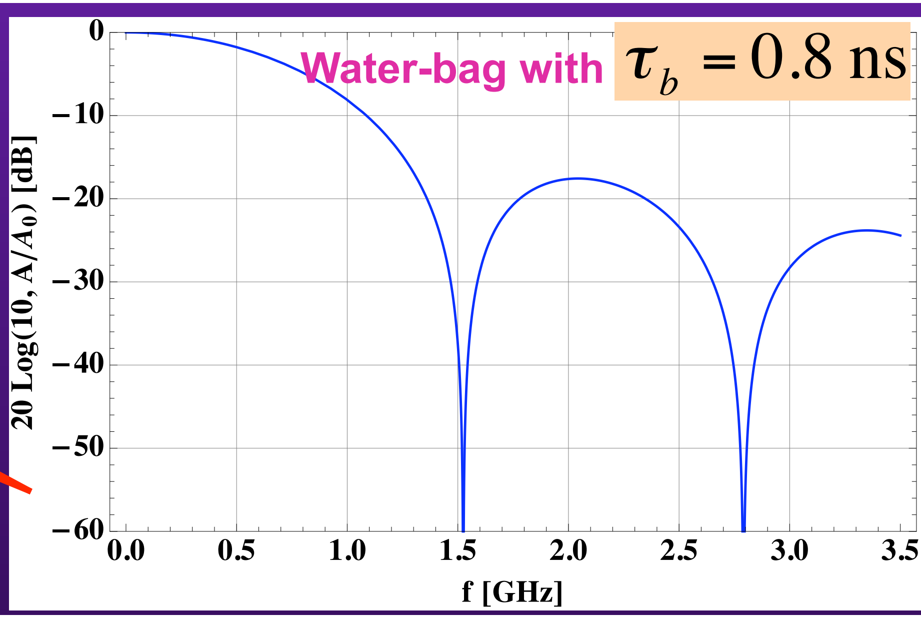


Maybe not too bad
(with the 2nd dip hidden for some reason…)

WHAT IS THE (SIMPLE) DISTRIBUTION FITTING BEST THE MEASUREMENT IN STABLE BEAMS?







Not very satisfactory!!!

CONCLUSION

- I made an error in some previous estimates and thought that the LHC longitudinal profile was close to a water-bag one (as the agreement was so good I did not check everything!…)
  => See https://indico.cern.ch/getFile.py/access?contribId=65&sessionId=5&resId=0&materialId=slides&confId=150474
- I checked (or at least tried to…) my computations (still to be checked by others! Thanks in advance => I gave the procedure in the Appendix)
- It seems now that the LHC longitudinal profile is maybe not too far from a Gaussian-like distribution with finite tails (n=3) before the ramp
- However, in stable beams I cannot fit it reasonably with the simple distributions used in these slides => Effect of the longitudinal blow-up to be followed up…

APPENDIX: SOME FORMULAE (1/3)

Plot of the analytical spectra

- Several distributions considered to compute the power spectra => See Laclare, CAS, CERN 87-03, page 268, Eqs. (25) to (28) + a family of distributions close to Gaussian one but with finite tails (similar to what was done in the past for the transverse plane: http://cdsweb.cern.ch/record/733611/files/ab-2004-019.pdf, assuming the same Half-Width at Half-Maximum)
- Amplitude A of the spectrum for a given frequency => Page 267, Eq. (23)
- Normalize the amplitude spectrum by the spectrum at 0 frequency => A / A_0
- The power spectrum (in dB) is obtained by taking 20 Log[10, A / A_0]

APPENDIX: SOME FORMULAE (2/3)

(Simple) computation of the power loss for the case of a (sharp) resonance

- **Let's assume a longitudinal resonance defined by (f_r, R_l, Q) with a high Q**

- **The power loss can be written** $$P_{loss} = \left(M \, I_b \right)^2 \times R_l \times 10^{\frac{P_{dB}\left(f_r \right)}{10}}$$

  where P_{dB} (f_r) is the power in dB read from a power spectrum (computed or measured) at the frequency f_r

- **Note that in the case of a Gaussian bunch, the power loss is written** $$P_{loss}^{Gaussian} = \left(M \, I_b \right)^2 \times R_l \times e^{-\left(2 \pi f_r \sigma_\tau \right)^2}$$

$$I_b = N_b \, e \, f_0$$

APPENDIX: SOME FORMULAE (3/3)

Why write the power loss as in page 2 (see for instance: Furman, Lee, Zotter, Energy Loss of Bunched Beams in SSC RF Cavities)?

- **Because in this case we see clearly that**
  - **For a broad-band impedance, the sum can be replaced by an integral and the *M* in front disappears => Power loss proportional to *M* (i.e. it is *M* times the single-bunch case)**
  - **For a narrow band impedance, the sum is only 1 term (see previous page) => Power loss proportional to M^2 (i.e. it is NOT *M* times the single-bunch case)**

ACKNOWLEDGEMENTS

- Many thanks to Alexej Grudiev, Alexey Burov, Benoit Salvant, Carlo Zannini, Elena Shaposhnikova, Hannes Bartosik, Hugo Alistair Day, Nicolo Biancacci, Olav Ejner Berrig, Philippe Baudrenghien, Themistoklis Mastoridis, etc. for very interesting discussions => To be followed up