Longitudinal Beam Loss Studies of the CERN PS-to-SPS Transfer

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Outline

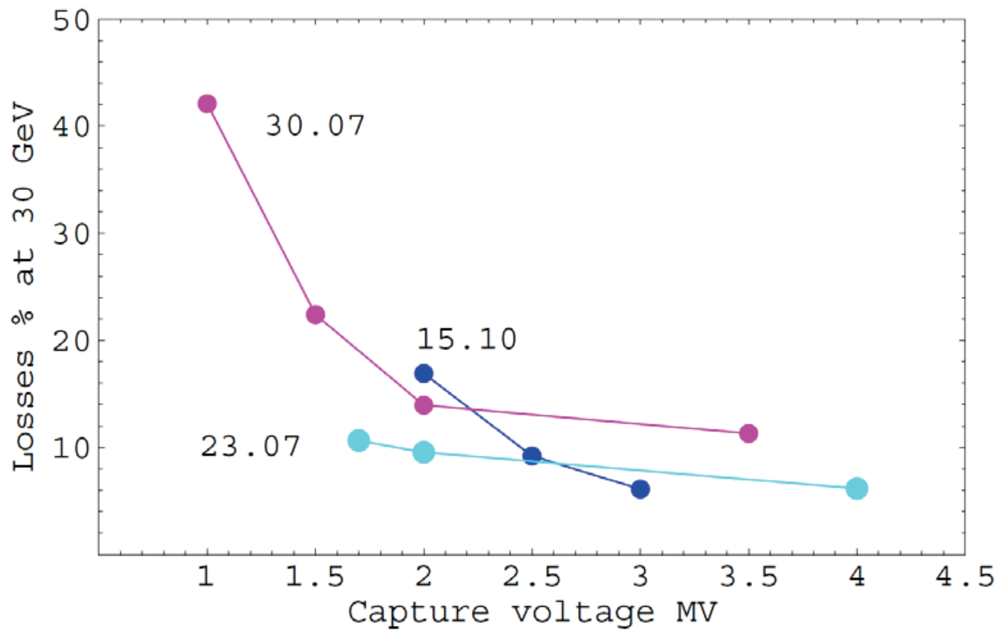
- Introduction and motivation
  - Studies in the past and now
- Methods
  - Simulations and measurements
- Optimisation of the PS bunch rotation
  - Using spare cavities
- Emittance and intensity dependence
- Implications and conclusions

Introduction & motivation

- Continuous efforts to optimise the PS-SPS transfer for several years
- *<u>In the past:</u>* the aim was to reduce losses
  - For low SPS capture voltages, losses were unacceptable, up to 20-40 % (2004)

Nominal LHC intensity
(~1.2×10^{11} ppb), 25 ns

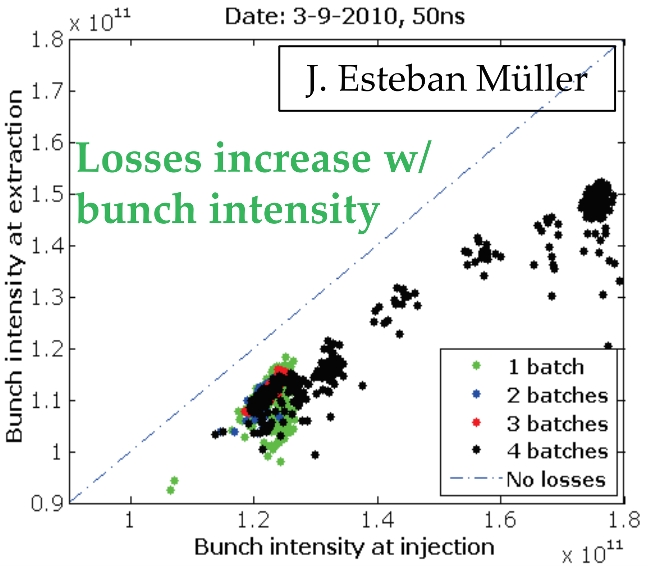
E. Shaposhnikova et al.:
Capture loss of the LHC beam in the CERN SPS



Motivation (2)

- *Now:* only ~5 % losses for the nominal intensity (due to long optimisation and less e-cloud)
  - However, relative losses increase with intensity ⇒ will be an issue
    - Higher intensity → ε_l → more losses
    - Beam loading → deformation of bucket → more losses
  - Using a larger ε_l is desirable also for stability in the PS & SPS

- *In measurements till 2011* no loss reduction could be achieved by changing the PS bunch rotation settings
  - Idea: shorter τ using higher voltage for the PS bunch rotation
  - Result: even though τ got significantly shorter, loss remained the same
  - This scheme didn't work and it wasn't understood why…



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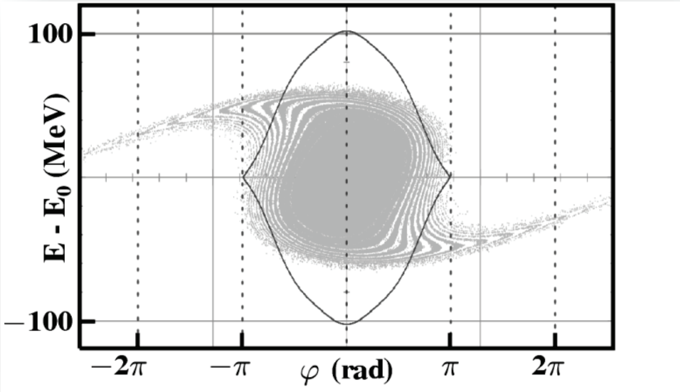
Simulations

- The LHC-type 50 ns and 25 ns beam has been modelled with ESME
  - Single bunch simulations, without intensity effects
  - Using averaged, real bunch distributions, measured at PS FT (with the tomoscope)
  - Full tracking of PS & SPS RF manipulations
    - PS: adiabatic voltage reduction, double splitting(s), bunch rotation;
    - SPS: FB, in some cases also ramp

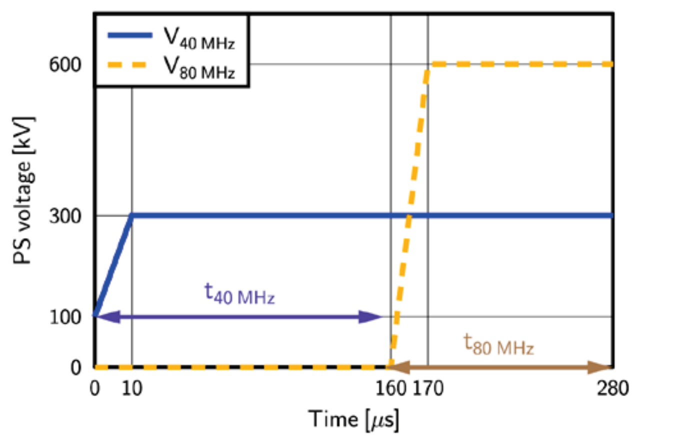
- Capture losses dominated by losses from the bunch tails
  - *Shorter bunches do not necessarily result in the best transmission*
- Need to optimise the particle distribution in phase space – *not visible from bunch profiles, sims. needed!*

Operational bunch-to-bucket transfer



Measurements

- First measurements started in 2011, several sessions in 2012
- *Dedicated cycle* for measurements in parallel with operation
  - 36 bunches of 50 ns spaced LHC-type beam
  - Intensity: ~1.6× 10^{11} ppb (except for intensity studies)
  - Varying the PS rotation timings $t_{40\ MHz}$ and $t_{80\ MHz}$ to optimise the distrib.
  - Using the spare 40 MHz or the spare 80 MHz cavity in the PS to increase the rotation voltage
    - Operational: 1×40 MHz, 2×80 MHz cavities
- *Bunch length:*
  - at PS ejection
- *Transmission:*
  - (intensity at 30 GeV) / (injected intensity)
  - In the simulations:
    - only capture + FB losses



Operational PS voltage at bunch rotation

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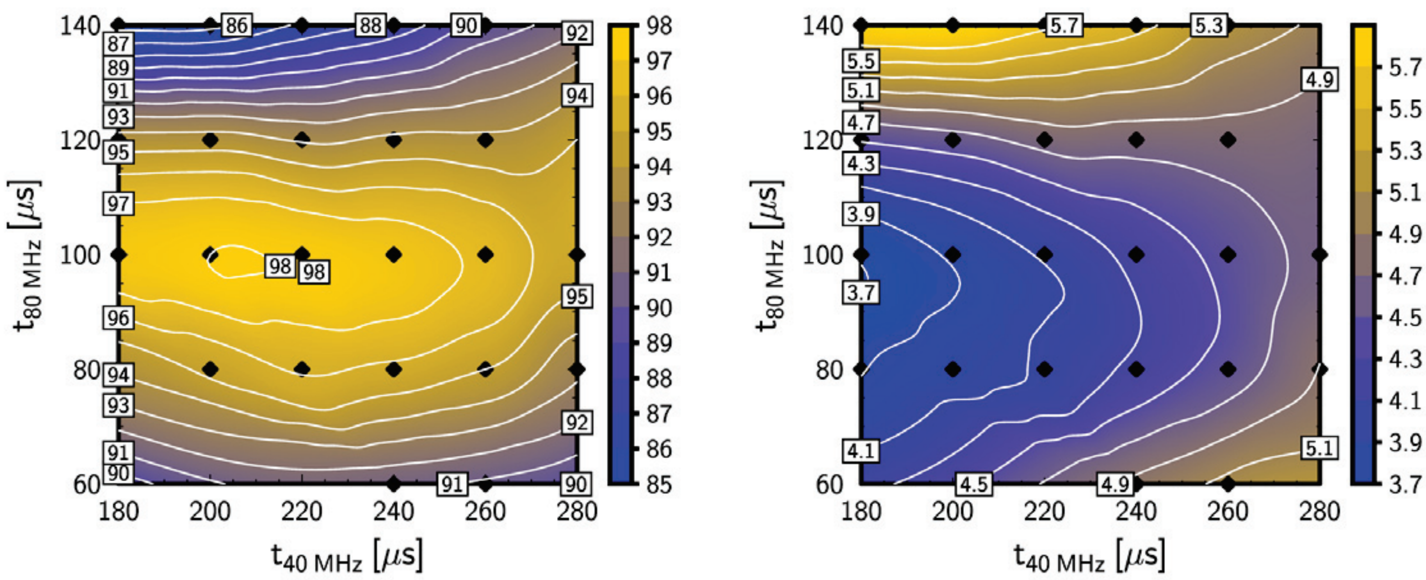
Option 1: Use the spare 80 MHz cavity

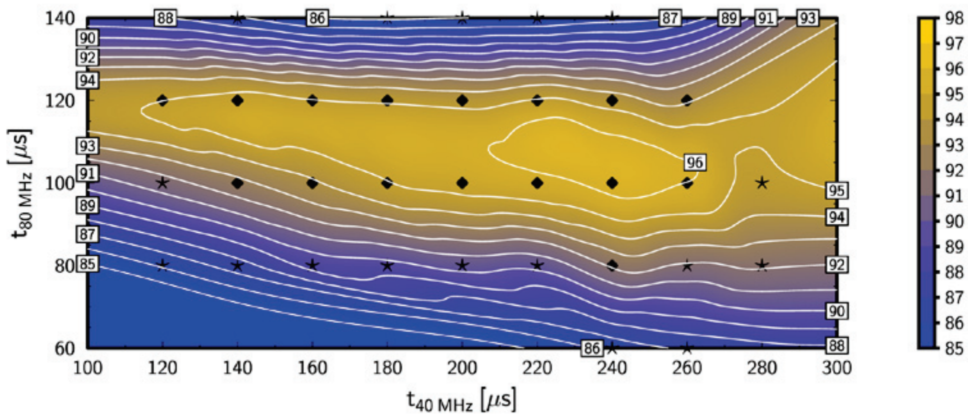
- Simulations predict: optimum at t_{40MHz} = 200-220 μs, t_{80MHz} = 100 μs
- Gain compared to operational settings:
  - T = 95.6 % → 97.9 %; L = 4.4 % → 2.1 %



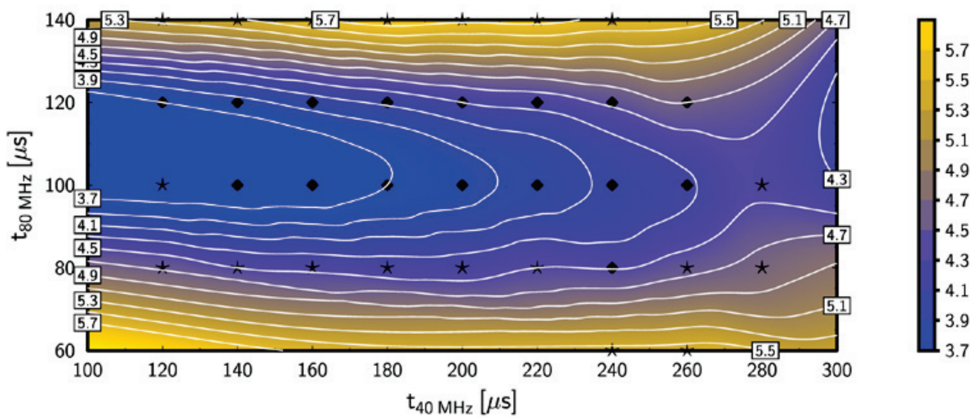
(a) Transmission [%], end of FB

(b) Bunch length [ns] at PS extraction

Option 1: Measurement results



(a) Transmission [%] at 30 GeV/c



(b) Bunch length [ns] at PS extraction

- Optimal settings for

  V_{40MHz} = 300 kV,
  V_{80MHz} = 900 kV:

  t_{40MHz} = 240 μs,
  t_{80MHz} = 100 μs

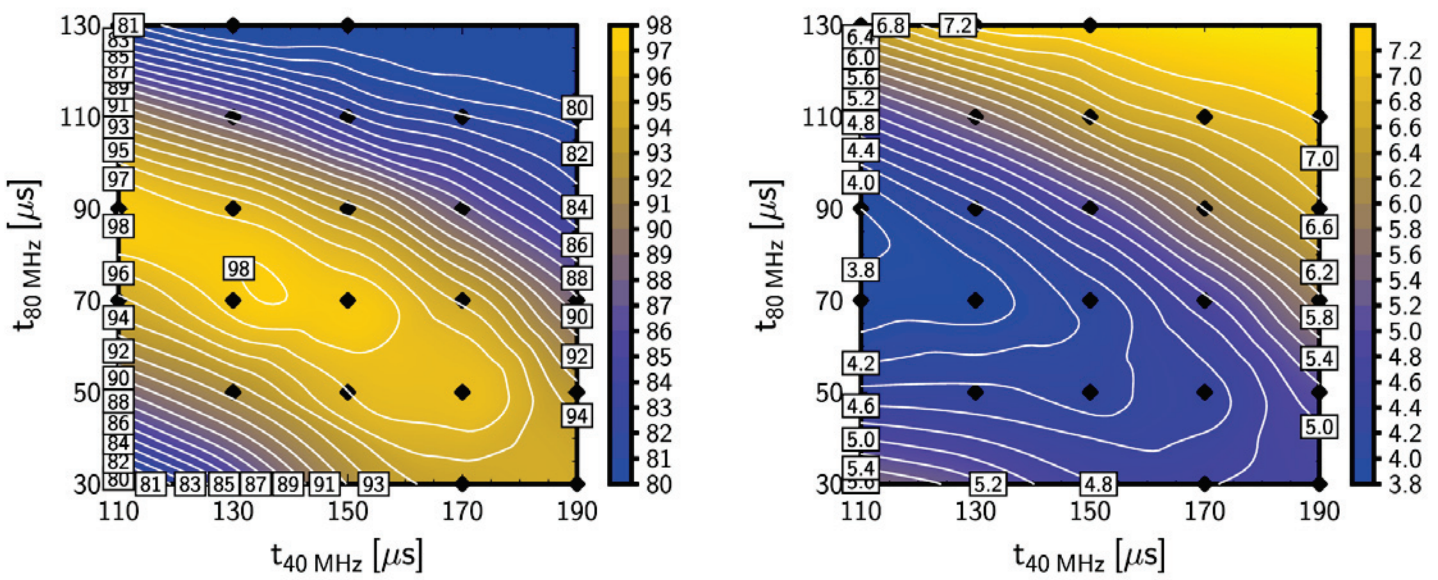
- Gain compared to operational settings

  T = 95.4 % → 96.3 %
  L = 4.6 % → 3.7 %

- N.B. constant offset of transverse losses

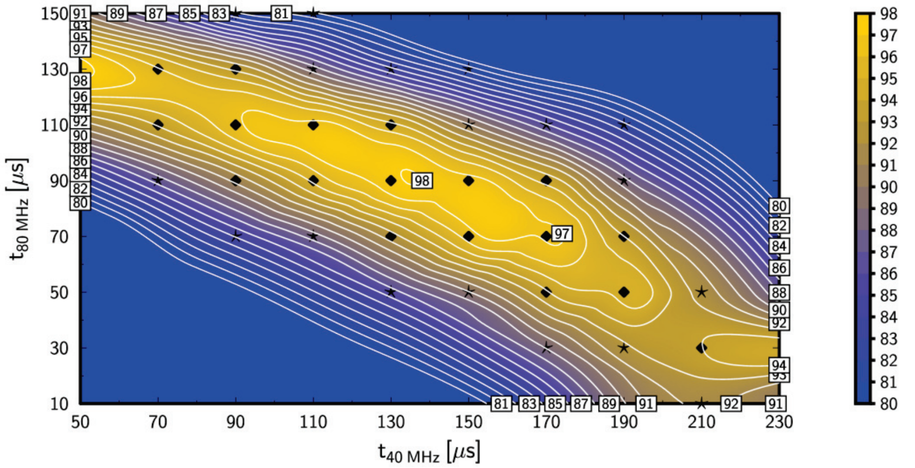
Option 2: Use the spare 40 MHz cavity

- Simulations predict: optimum at $t_{40MHz} = 130\ \mu s$, $t_{80MHz} = 80\ \mu s$
- Gain compared to operational settings:
  - $T = 95.6\ \% \rightarrow 98.1\ \%$; $L = 4.4\ \% \rightarrow 1.9\ \%$

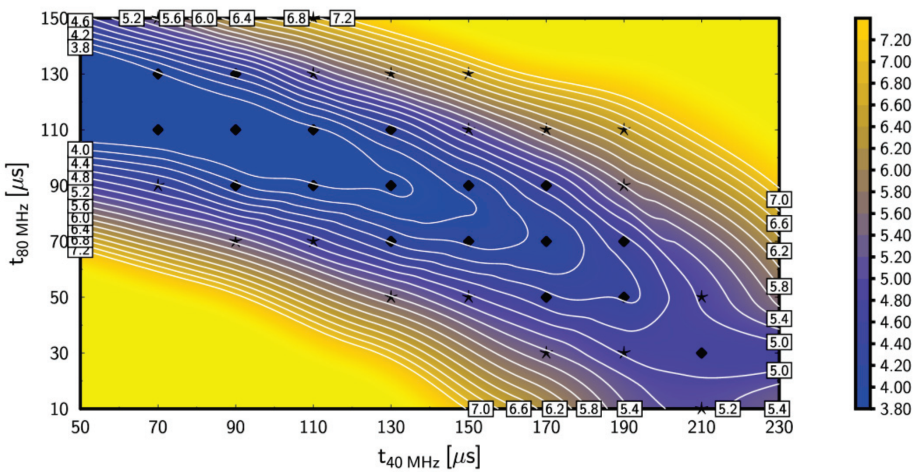


(a) Transmission [%], end of FB (b) Bunch length [ns] at PS extraction

Option 2: Measurement results



(a) Transmission [%] at 30 GeV/c



(b) Bunch length [ns] at PS extraction

- Optimal settings for

  V_{40MHz} = 600 kV,
  V_{80MHz} = 600 kV:

  t_{40MHz} = 130 μs,
  t_{80MHz} = 90 μs

- Gain compared to operational settings

  T = 94.8 % → 97.7 %
  L = 5.2 % → 2.3 %

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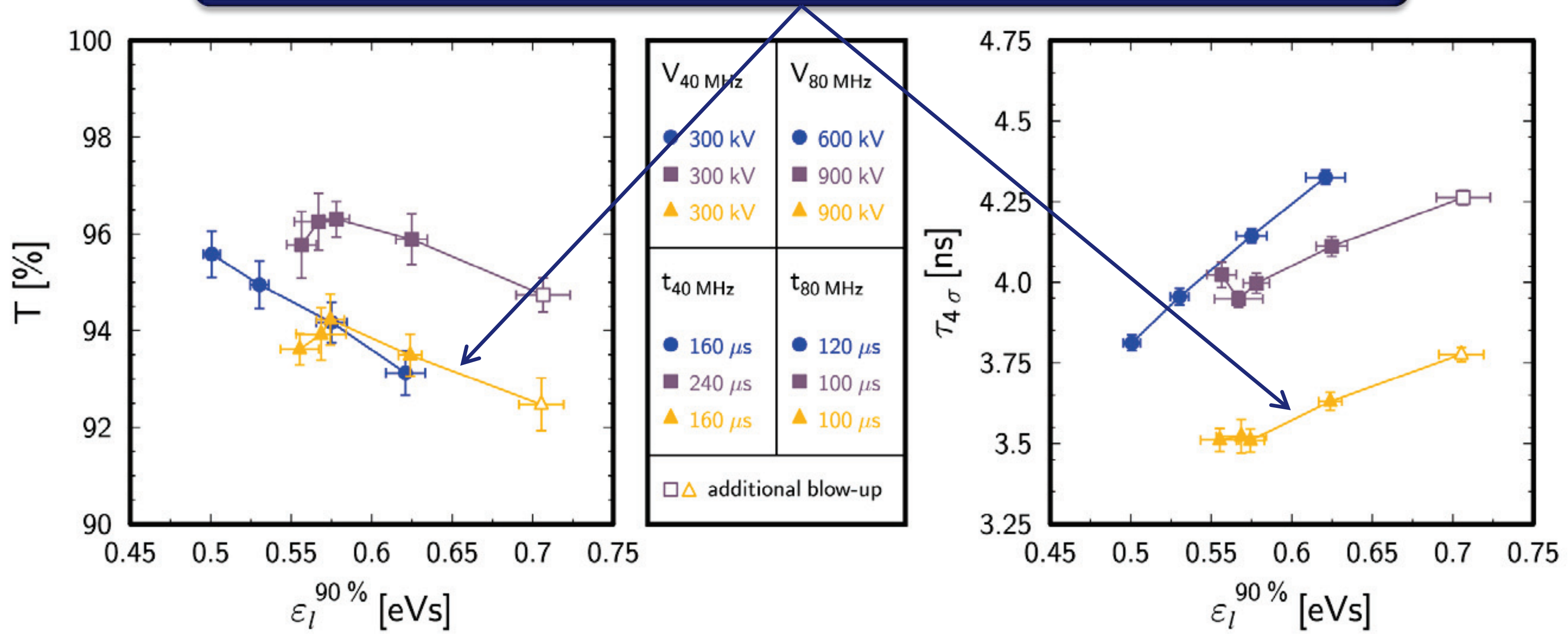
Spare 80 MHz cavity: Emittance dependence

- Now we understand the results of previous years…

Earlier MDs with spare 80 MHz cavity optimised only τ



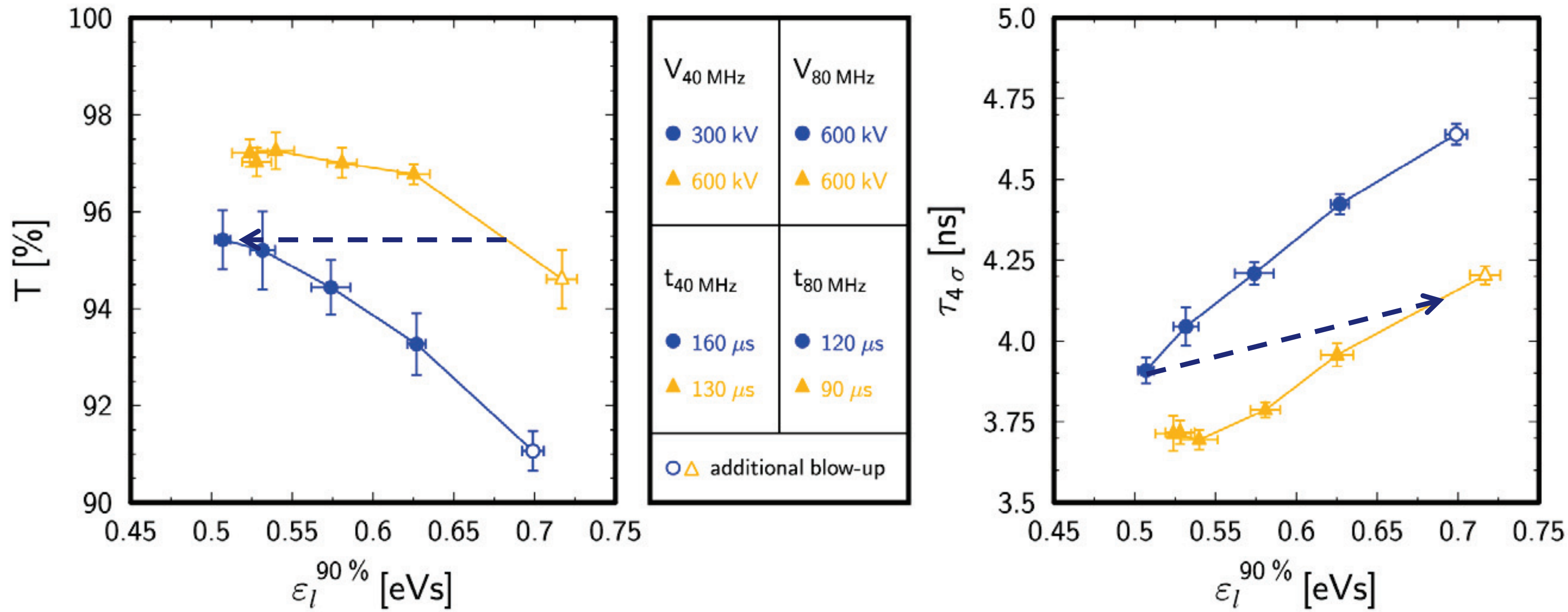
(a) Transmission

(b) Bunch length

Spare 40 MHz cavity: Emittance dependence

- Gives a better transmission *and* shorter bunches!

Operational transmission even with ~40 % larger ε_l!



(a) Transmission (b) Bunch length

Spare 40 MHz cavity: Intensity dependence

- About ~ 15 % higher intensity with the same transmission

Operational

W/ spare 40 MHz cavity

$V_{\text{blow-up}}$	$t_{40\text{ MHz}}$	$t_{80\text{ MHz}}$	$\varepsilon_l^{90\ \%}$	T	$\tau_{4\sigma}$
1.58×10^{11} ppb, $V_{40\text{ MHz}} = 300$ kV, $V_{80\text{ MHz}} = 600$ kV					
2×5.5 kV	160 µs	120 µs	(0.539 ± 0.006) eVs	(94.9 ± 0.5) %	(4.00 ± 0.04) ns
2×5.5 kV	200 µs	120 µs	(0.546 ± 0.005) eVs	(95.2 ± 0.5) %	(4.23 ± 0.03) ns
1.81×10^{11} ppb, $V_{40\text{ MHz}} = 300$ kV, $V_{80\text{ MHz}} = 600$ kV					
2×5.5 kV	160 µs	120 µs	(0.567 ± 0.010) eVs	(93.4 ± 0.3) %	(4.02 ± 0.03) ns
2×5.5 kV	200 µs	120 µs	(0.611 ± 0.008) eVs	(93.4 ± 0.9) %	(4.23 ± 0.03) ns
1.58×10^{11} ppb, $V_{40\text{ MHz}} = 600$ kV, $V_{80\text{ MHz}} = 600$ kV					
2×5.5 kV	130 µs	90 µs	(0.550 ± 0.012) eVs	(97.0 ± 0.4) %	(3.63 ± 0.03) ns
2×8.5 kV	130 µs	90 µs	(0.612 ± 0.012) eVs	(96.8 ± 0.3) %	(3.84 ± 0.02) ns
1.81×10^{11} ppb, $V_{40\text{ MHz}} = 600$ kV, $V_{80\text{ MHz}} = 600$ kV					
2×5.5 kV	130 µs	90 µs	(0.551 ± 0.007) eVs	(94.6 ± 0.9) %	(3.71 ± 0.04) ns
2×8.5 kV	130 µs	90 µs	(0.550 ± 0.007) eVs	(95.1 ± 0.7) %	(3.83 ± 0.02) ns

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Balance

- *Using the spare 40 MHz cavity* has some clear advantages over the 80 MHz cavity:
  - Better transmission
  - Shorter bunch length
  - Emittance margin: 40 % (!)
  - Intensity margin: 15 %
  - Spare 40 MHz cavity not needed for ions (unlike the spare 80 MHz)
- *The new scheme still needs to be tested in an operational cycle*
- Even if beam losses currently don't cause concerns, *stability is a key issue* at the present intensity, both in the PS & SPS
  - Maybe the spare 40 MHz cavity could be a solution?
    - Empirical longitudinal stability scaling in the PS (at low intensities): N_b/ε_l = const. ⇒ in theory, could gain up to 40 % in intensity

PS hardware requirements

- Using a spare 40 MHz cavity requires only minimal low-level hardware modifications
  - Low-cost solution
  - Improved operational availability of the 40 MHz cavities is important (e.g. new power supplies)
- Do we need to have a spare cavity?
  - If a cavity fails, we still can go back to the currently operational settings
- Adding a 3rd 40 MHz cavity to the PS is an option, too
  - But: at significant cost and manpower effort

Conclusions

- Simulations determined the loss mechanism of the PS-SPS transfer and agree very well with previous and present measurement results
- The *optimum phase space particle distribution* at PS extraction has been obtained by simulations, and confirmed by experiments
  - Can significantly improve the transmission
  - Or provide a ~40 % emittance margin while keeping the same transmission
- Has the potential to *improve beam stability* in the PS and, hence, allows for higher-intensity beams with good quality, which is important for the LHC
- Once the spare 40 MHz cavity is available again, the new scheme still needs to be tested under operational conditions

Thank you!