Beams from the injectors

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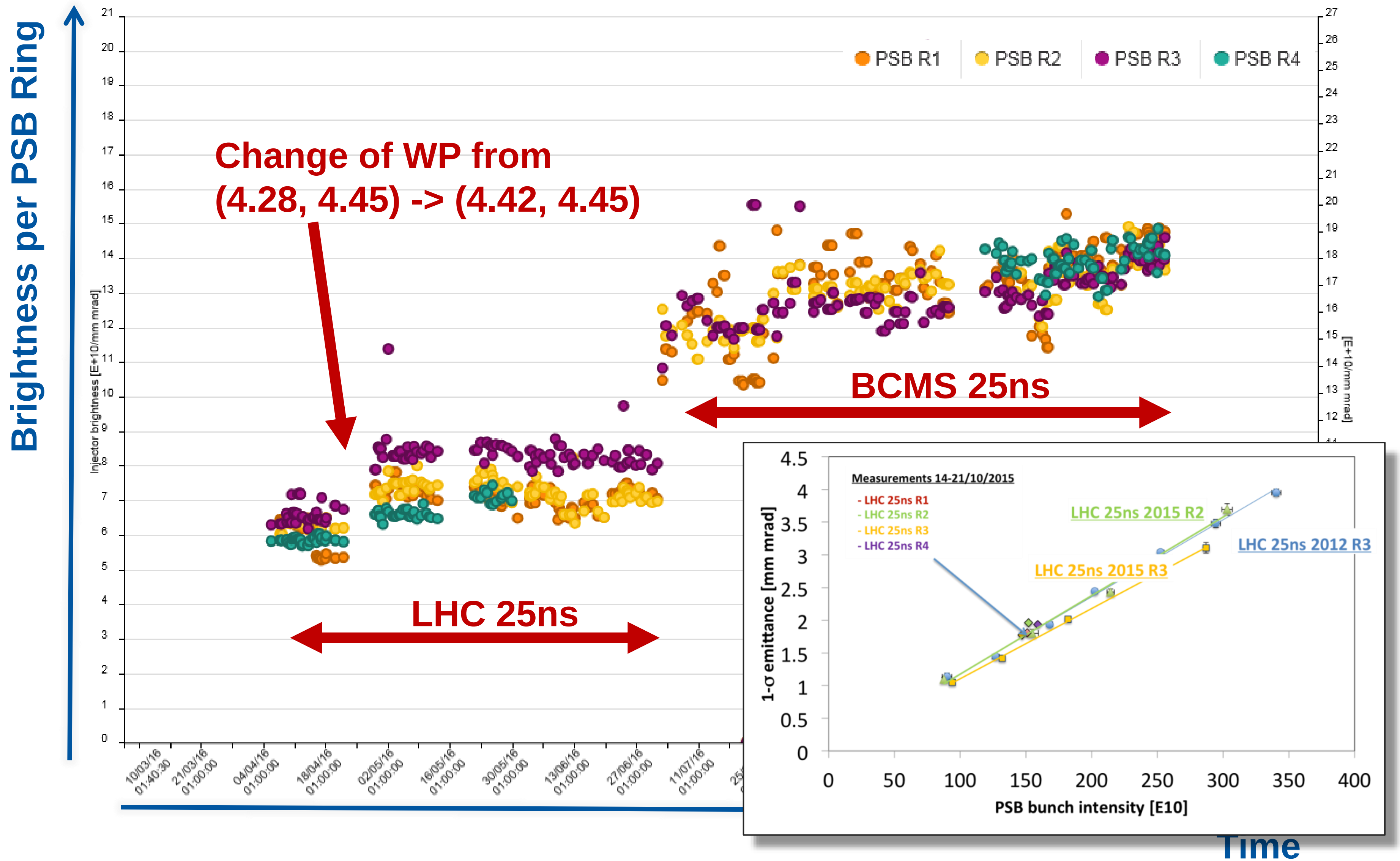
Evian workshop, December 2016

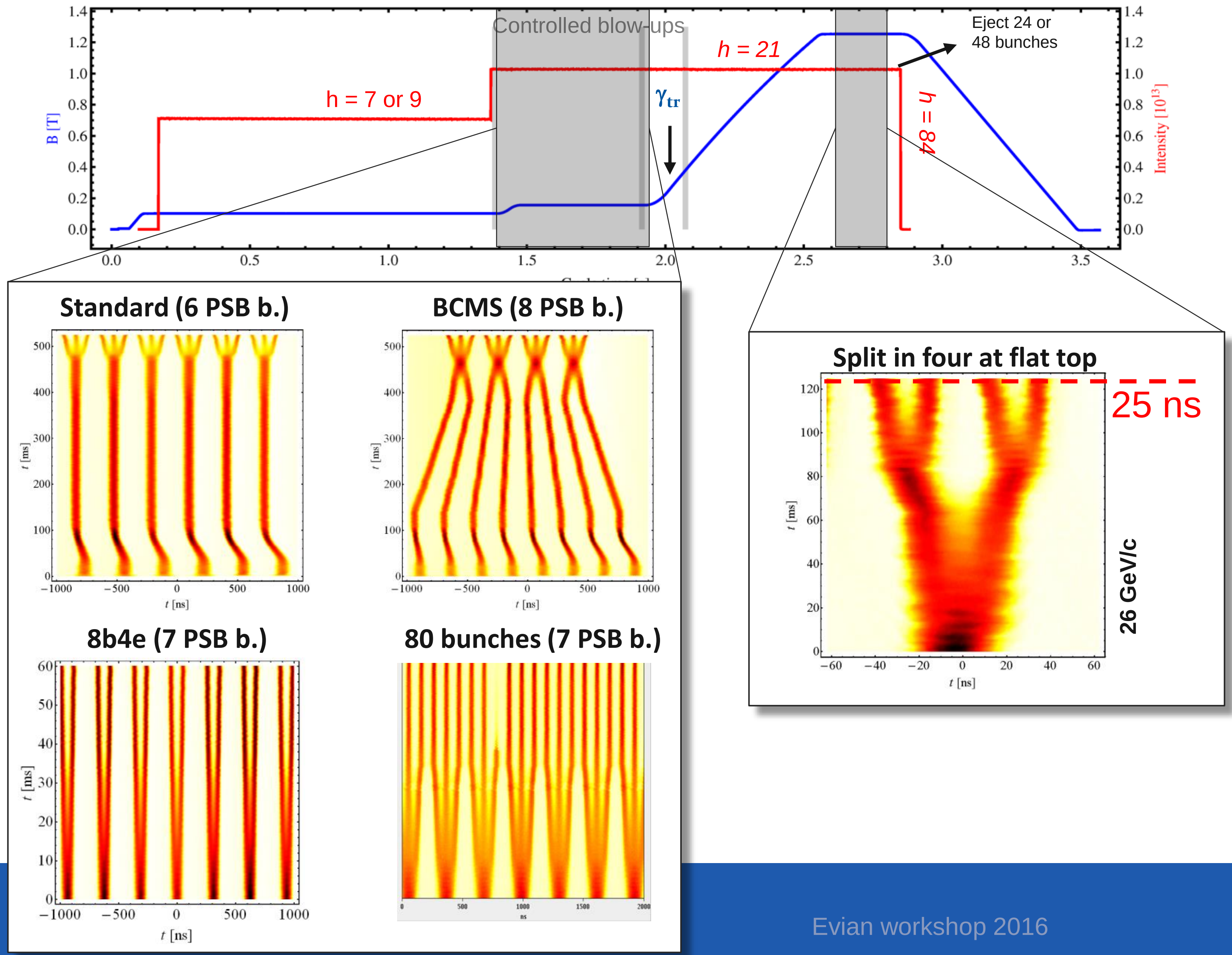
Outline

- 25 ns standard
- 25 ns BCMS
- Special beams (80 bunches, 8b4e, doublet beam)
- Miscellaneous
- Summary table of beam parameters

LHC beam brightness in the PSB

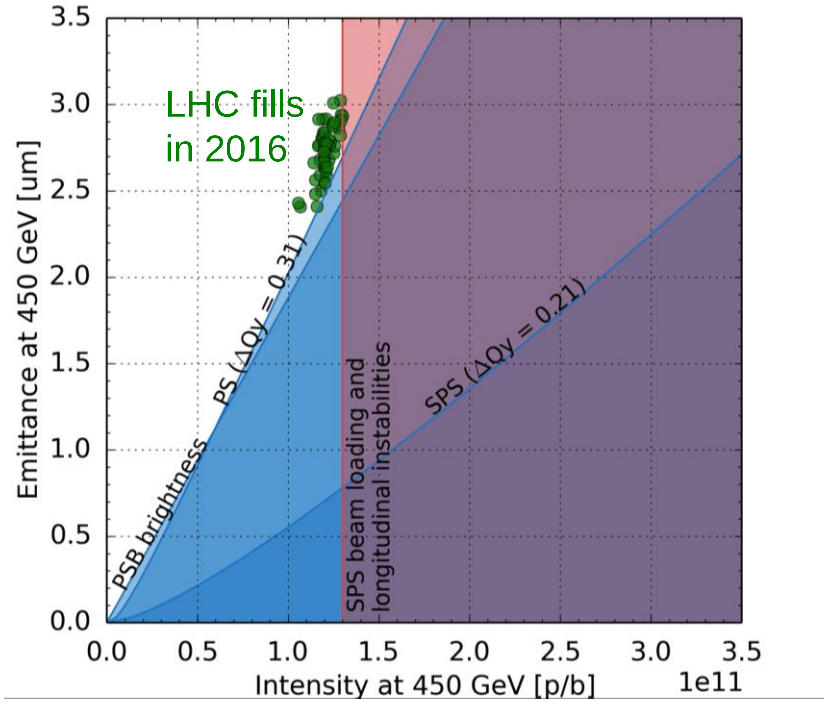


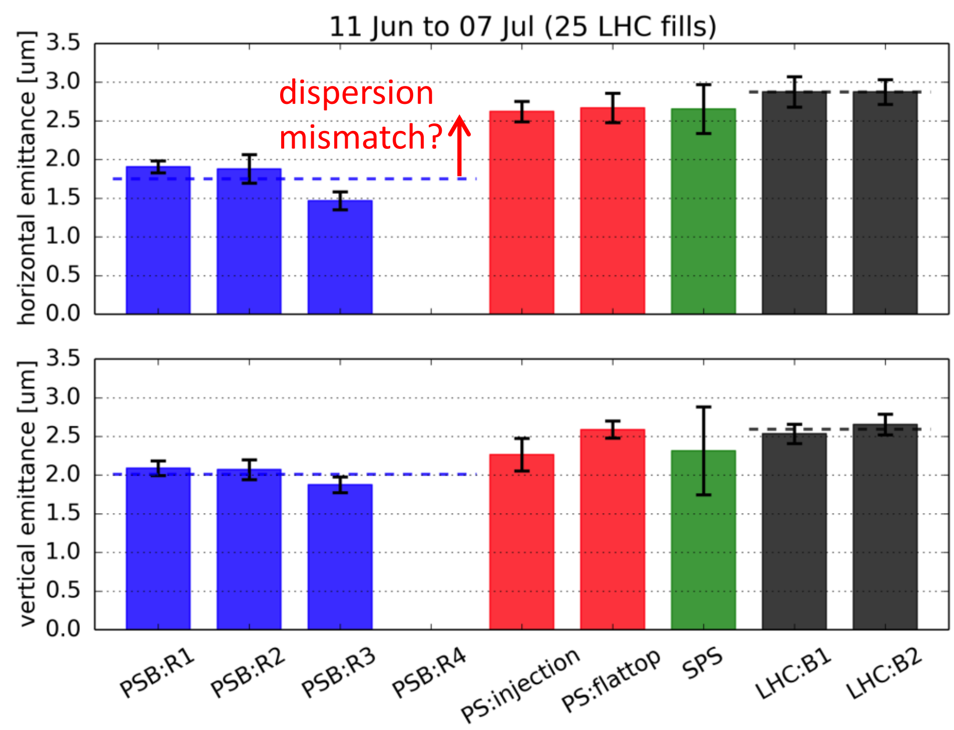
LHC beam production in the PS



25 ns standard beam in 2016

- Operated close to optimum brightness (in 2016 one batch only…)
  - Some horizontal blow-up at PS injection (from PSB-to-PS dispersion mismatch?) but in the shadow of PS space charge limitation
- Intensity limited by beam loading and available RF power during SPS ramp!

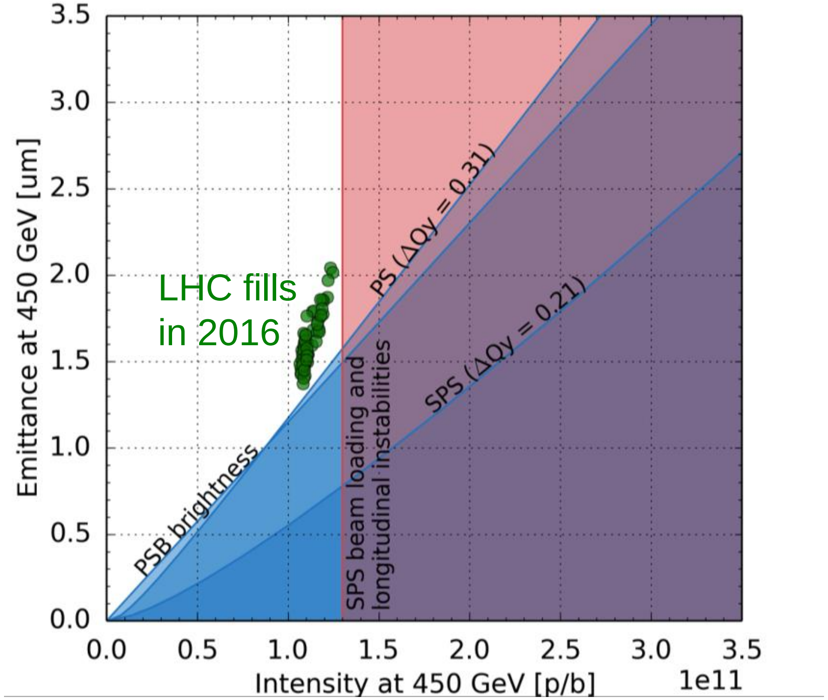


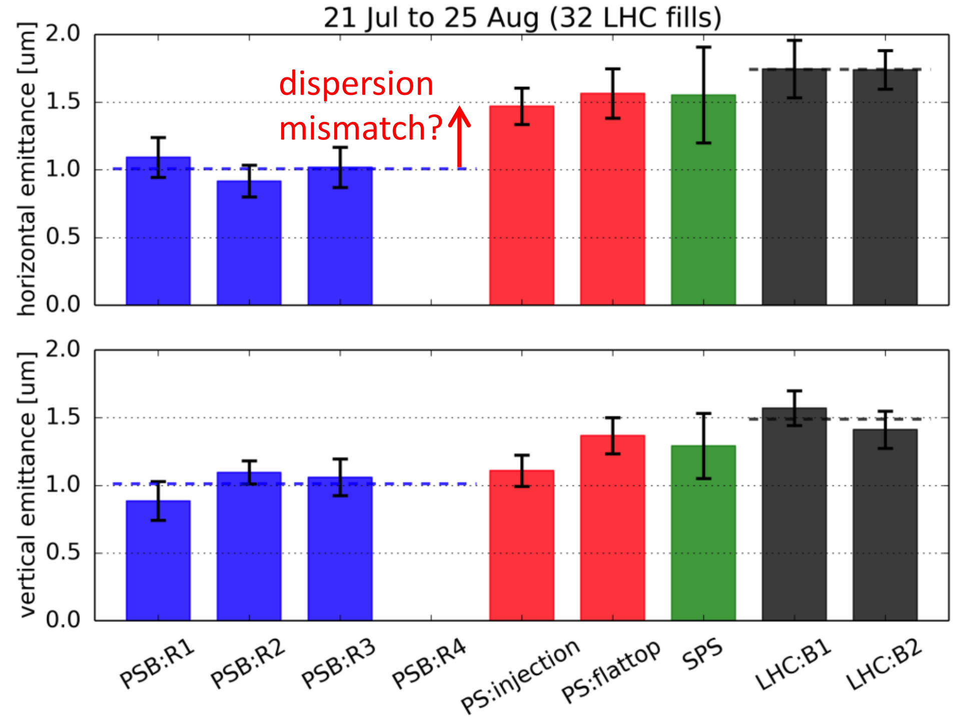


25 ns BCMS beam in 2016

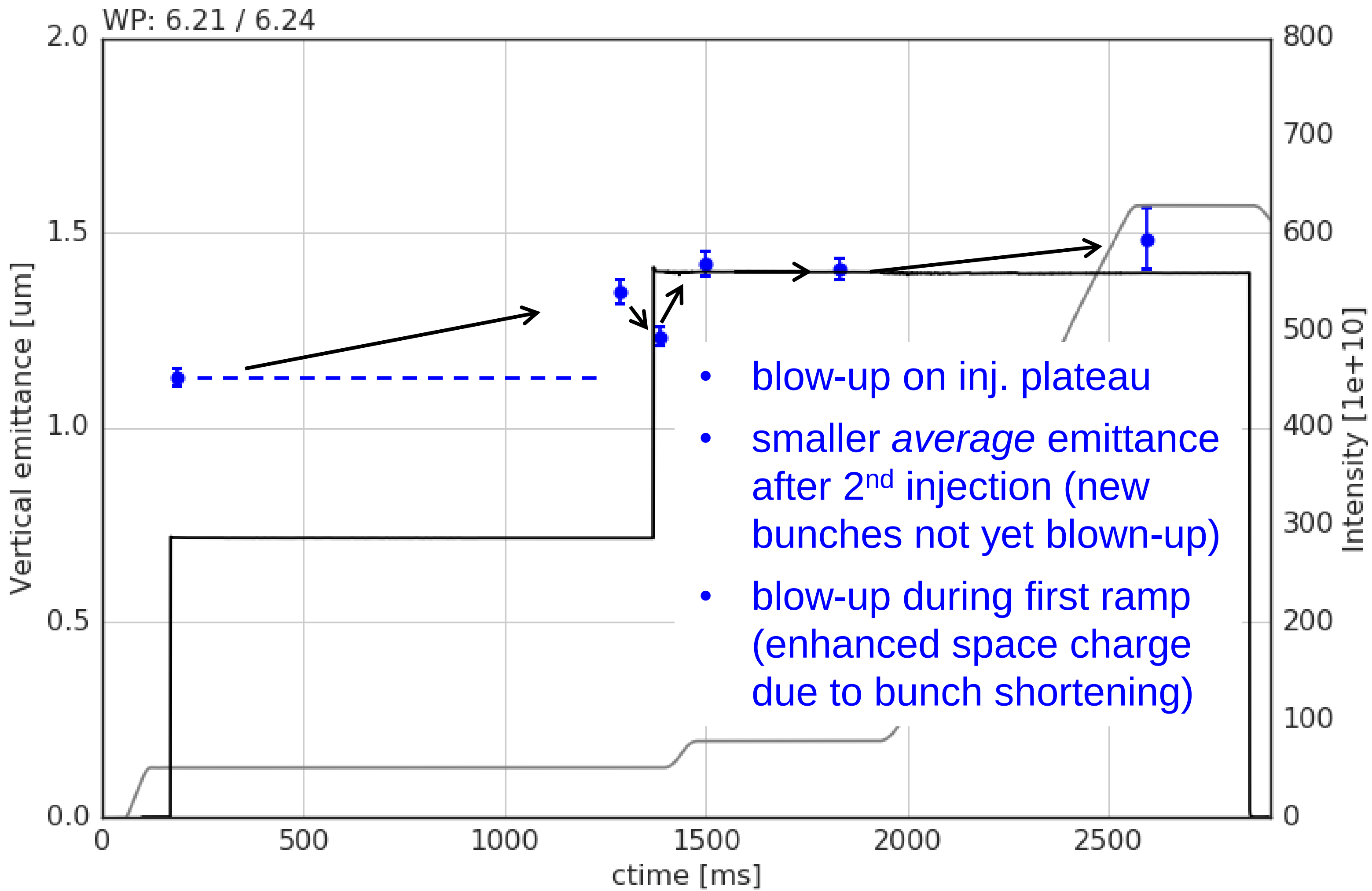
- Not yet at optimum brightness due to emittance blow-up
  - Horizontal mainly at PS injection (due to PSB-to-PS dispersion mismatch?)
  - Vertical mainly along PS cycle (see next slides)

- Margin to increase intensity to 1.3e11 p/b at SPS extraction



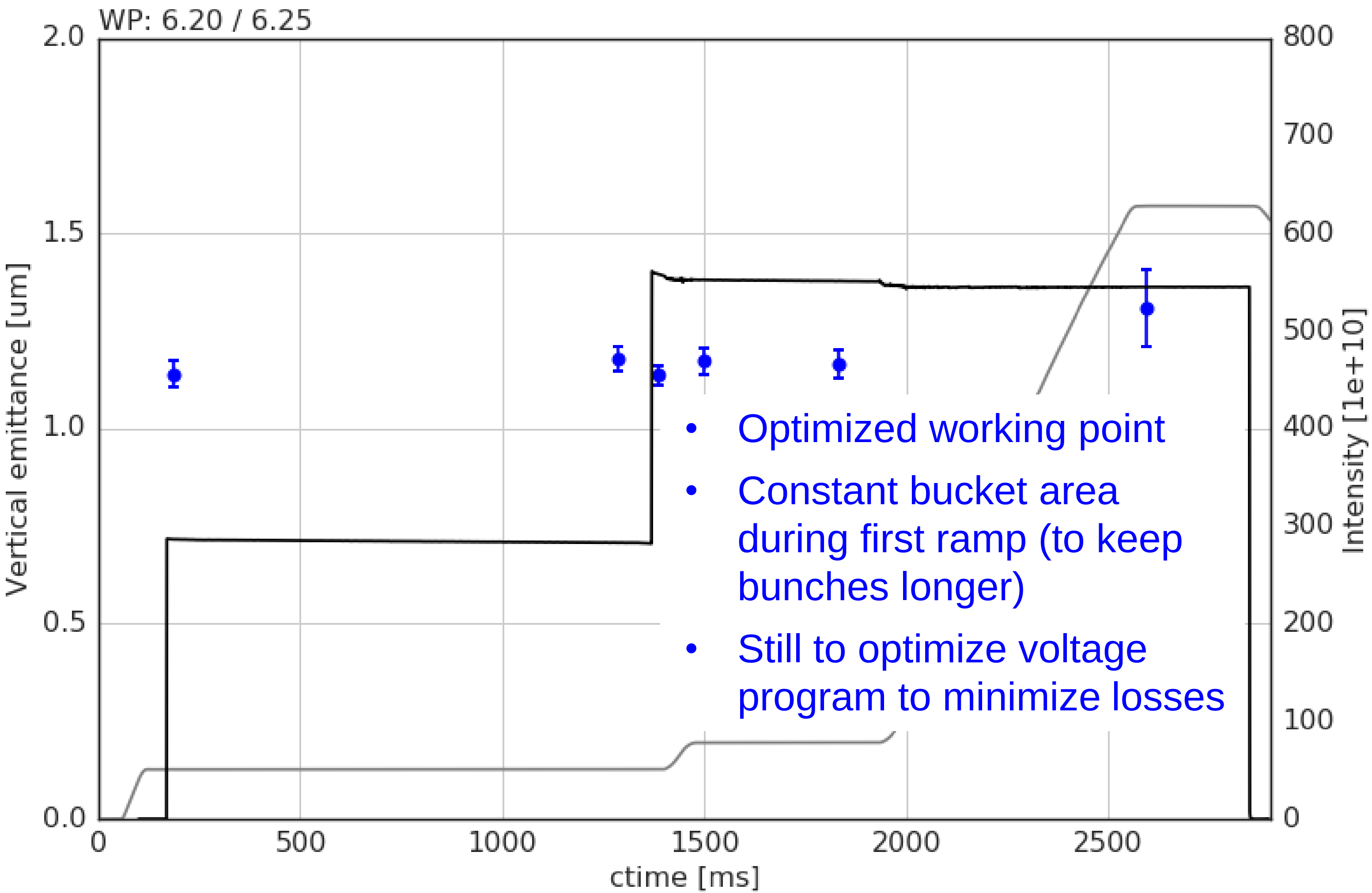


MD on vertical blow-up in PS (I)



- blow-up on inj. plateau
- smaller *average* emittance after 2nd injection (new bunches not yet blown-up)
- blow-up during first ramp (enhanced space charge due to bunch shortening)

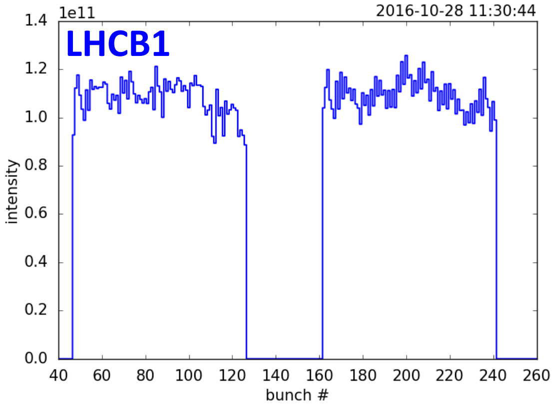
MD on vertical blow-up in PS (II)



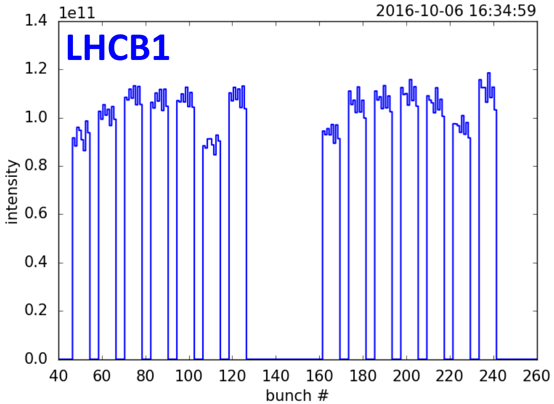
- Optimized working point
- Constant bucket area during first ramp (to keep bunches longer)
- Still to optimize voltage program to minimize losses

Special beams (I)

- 80 bunches
  - 7 PSB injected into PS → triple splitting → one of 21 bunches eliminated → splitting into 80
  - Tested in LHC MD (1.15e11 p/b in 2.6 um)
  - Increased losses at LHC injection (scraper settings?) - optimization needed
  - Used PS extraction kicker for eliminating bunch … further MDs needed for using transverse damper
  - Potential for larger number of bunches in LHC (320b per injection after LS2), or for mitigating total current limits in SPS for same LHC performance (240b per LHC injection)



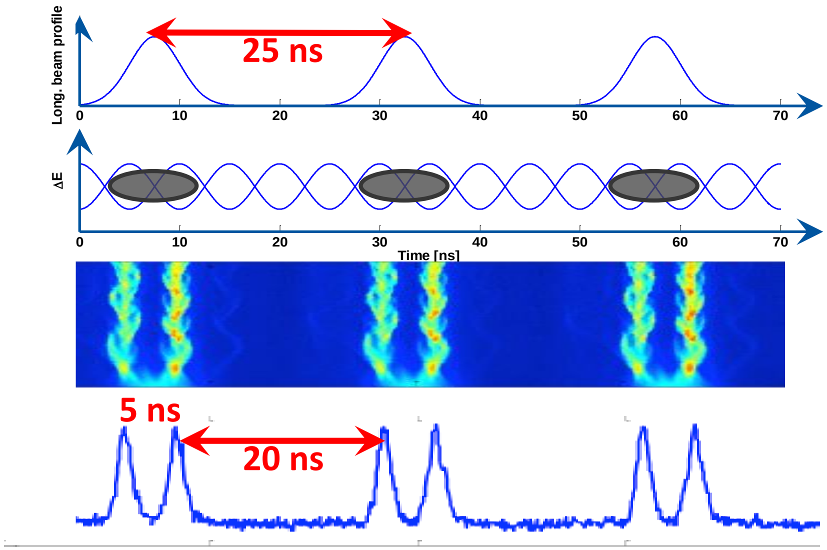
- 8b4e
  - 7 PSB injected into PS → double instead of triple splitting → flat top splitting into 56
  - Tested in LHC MD (1.15e11 p/b in 1.8 um)
  - Potential for higher intensity per bunch compared to other bunch trains due to reduced beam loading, but similar total current (also limited by SPS beam loading)



Special beams (II)

- Doublet beam
  - Based on LHC 25 ns standard beam
  - With final bunch rotation, using 40 MHz, but no 80 MHz cavities
  - SPS injection on unstable phase to split bunches into doublets
  - Not an easy beam for the SPS (beam stability and losses are critical)
  - Could be made available again for LHC tests by mid 2017

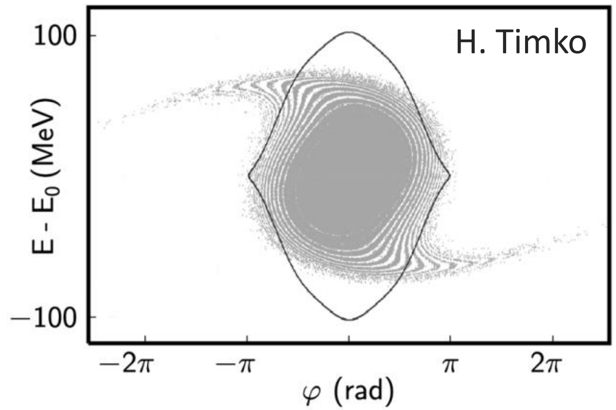
Non adiabatic splitting at SPS injection



Miscellaneous

- SPS will get a new TIDVG internal dump
  - Needs conditioning with beam (graphite outgassing) … “SPS scrubbing run”?
  - New beam dump limit OK for 2017 beams (1h dumping once per super-cycle)
- Limitation of number of bunches into LHC due to transfer line collimators
  - Standard beam OK with 4x72, BCMS limited to 3x48
- Reduction of losses in SPS (and LHC)
  - Losses in SPS (even on flat bottom!) mostly due to un-captured beam as result from PS bunch rotation
  - Longitudinal tails and therefore losses reduced using additional 40 MHz cavity in PS – now operational
  - Also reduces losses at LHC injection (less ghosts)
  - This will be an issue for LIU beams if not solved

Simulated distribution at SPS injection



- SPS Q22 optics with intermediate transition energy to be tested in 2017
  - Hoping to increase intensity out of SPS due to less required RF power

LHC physics beams in 2017

	Intensity [1e11 p/b]	Emittance [um]	pattern
25 ns standard (like 2016)	1.15	2.5 (2.4)	1-4 x 72 → 288
25 ns standard (max. intensity)	1.30	2.8 (2.7)	1-4 x 72 → 288
25 ns BCMS (like 2016)	1.15	1.7 (1.4)	1-3 x 48 → 144
25 ns BCMS (max. intensity)	1.30	1.9 (1.6)	1-3 x 48 → 144
25 ns 80 bunches (like 2016)	1.15	2.6 (2.4)	1-3(4) x 80 → 240
25 ns 80 bunches (max. intensity)	1.30	2.8 (2.7)	1-3(4) x 80 → 240
8b4e (like 2016)	1.20	1.8 (1.6)	1-3 x 56 → 168
8b4e (max. intensity)	1.60	2.4 (2.1)	1-3 x 56 → 168

minimum batch spacing in 2017: 200 ns (see presentation of W. Bartmann)

emittances in parentheses should be achievable, to be demonstrated operationally

Thank you for your attention

Robustness simulations: Transfer Line Collimators

- Note: Transfer line collimators still at locations with smaller beta functions after LS1
  - ➔ Similar energy deposition for run 2 BCMS as for LIU BCMS.

Beam status	Emittance [Pi.mm.mrad]	Spot Size (βx*βy) [m^2]	Bunch Intensity	Material	Number of Bunches	Max. Temperature [°C]	Tens. Strength /Max Tens. Stress	Comp. Strength /Max Comp. Stress	Mohr-Coulomb S.F.	Status
Run2 BCMS	1.39	1238.8	1.3e11	Graphite	**288**	1400	30/32	118/81	**0.9**	✗
					240	1250	30/24	118/75	**1.44**	✓
					192	1043	30/18	118/58	**1.75**	✓
Run2 Standard	2.6	1238.8	1.2e11		**288**	862	30/15	118/42.5	**2**	✓

Sufficient attenuation only for ≤ 144 bunches. Similar to 50 ns particle density in 2012.

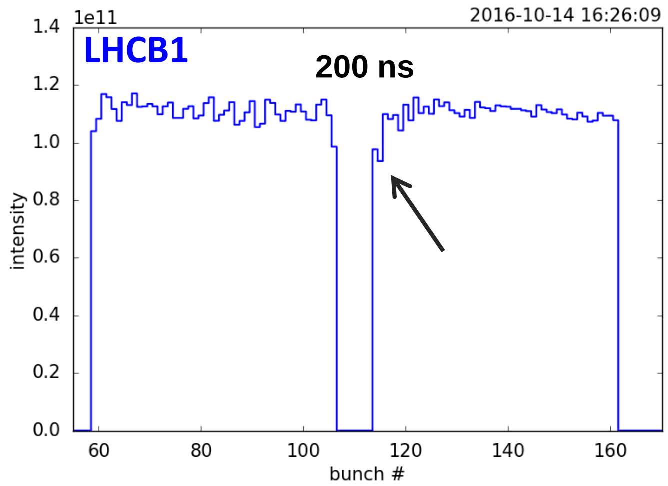
Robustness simulations: TDI

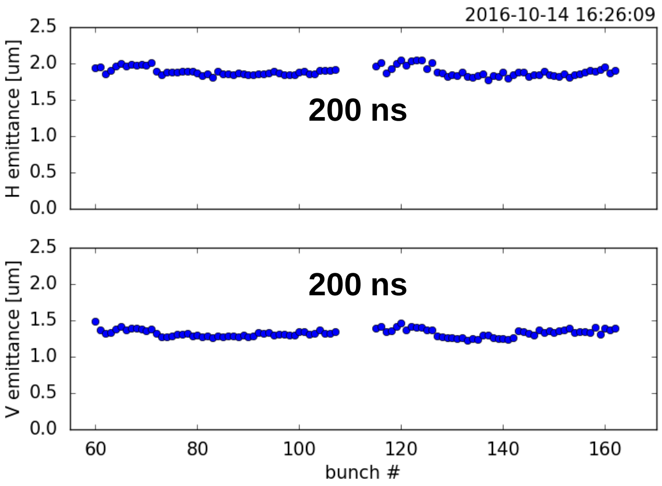
Results for TDI injection stopper

Beam status	Emittance [Pi.mm.mrad]	Spot Size (βx*βy) [m^2]	Bunch Intensity	Material	Number of Bunches	Max. Temperature [°C]	Tens. Strength /Max Tens. Stress	Comp. Strength / Max Comp. Stress	Mohr-Coulomb S.F.	Status
Run2 BCMS	1.39	4423.8	1.3e11	h-BN5000	**288**	902,8	7/12	59/37	**0.53**	✗
					240	788,9	22/13	59/32	**1.10**	✓ ✗
					192	667,4	27/12	59/26	**1.28**	✓
Run2 Standard	2.6	4423.8	1.2e11		**288**	572,2	39/12	74/25	**1.88**	✓

Sufficient attenuation for all cases

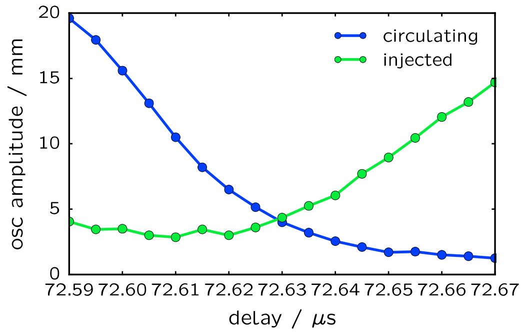
200 ns MKP kicker gap





- Tested with 25 ns beam (LHC MDs) and operationally used for p-Pb run
  - Slight impact on intensity for bunches at beginning of PS batch
  - Hardly any effect on transverse emittance (thanks to SPS damper)

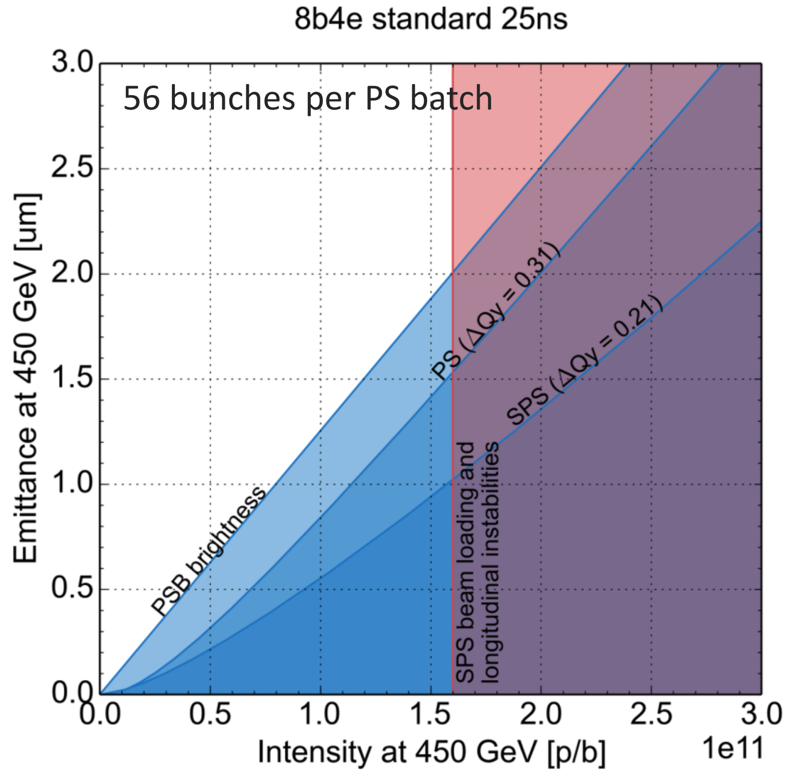
F. Velotti

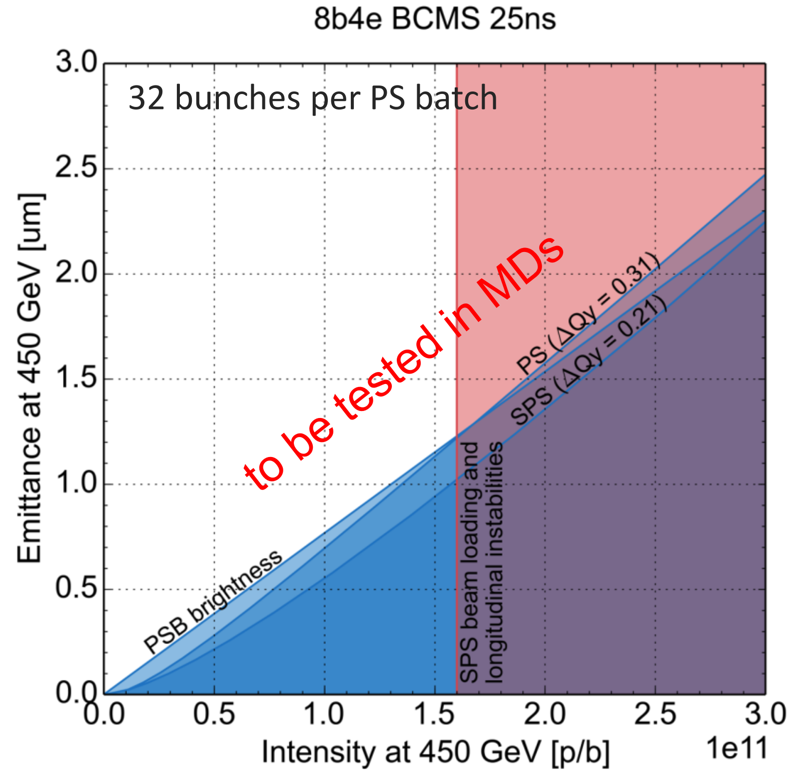


- Relies on optimal synchronization of MKP switches
  - Increased sensitivity to drifts
  - operational stability?
  - Need to foresee regular checks

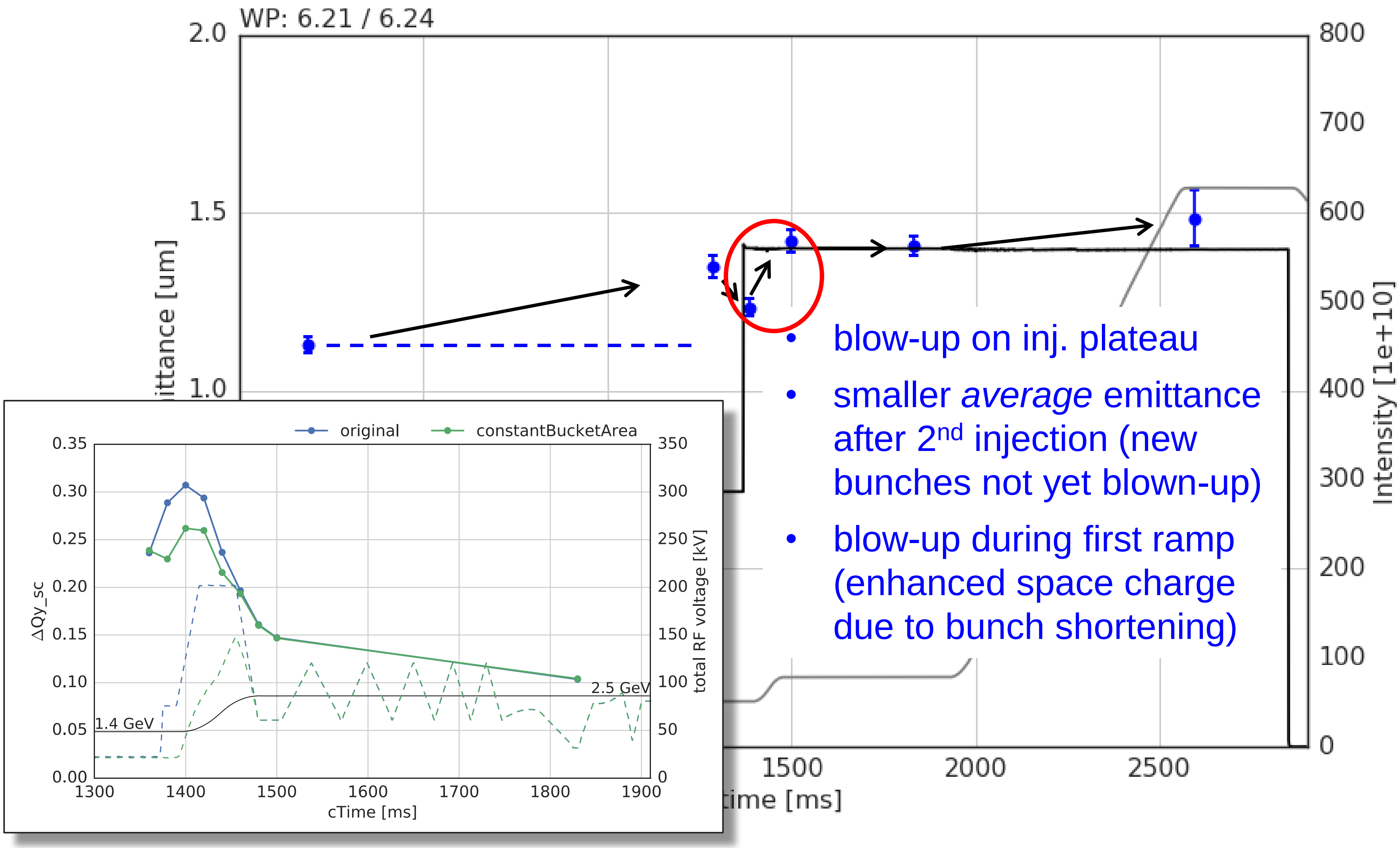
8b4e scheme

- Expected to be limited to 1.6 x 10^{11} p/b because of beam loading and limited RF power during SPS ramp
- Brightness limit from PSB for standard scheme



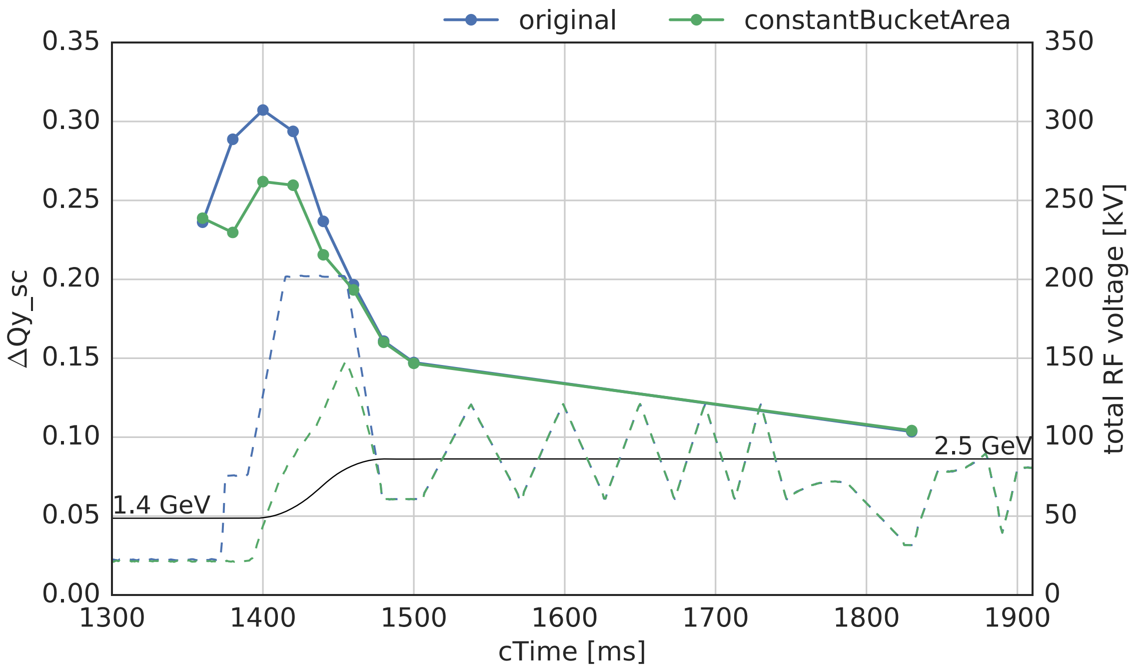


MD on vertical blow-up in PS (I)



- blow-up on inj. plateau
- smaller *average* emittance after 2nd injection (new bunches not yet blown-up)
- blow-up during first ramp (enhanced space charge due to bunch shortening)

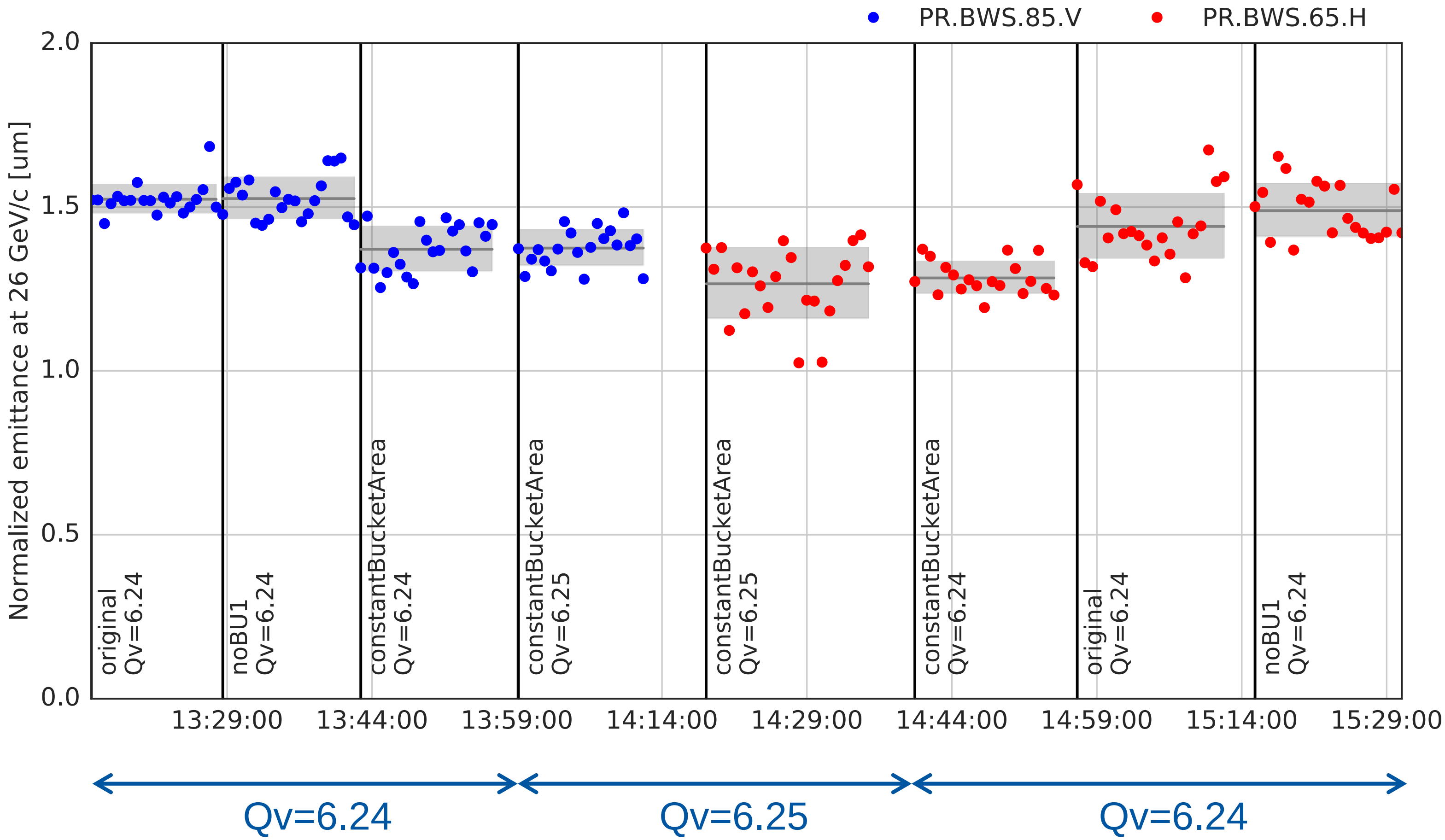
Blow-up at first ramp (BCMS)



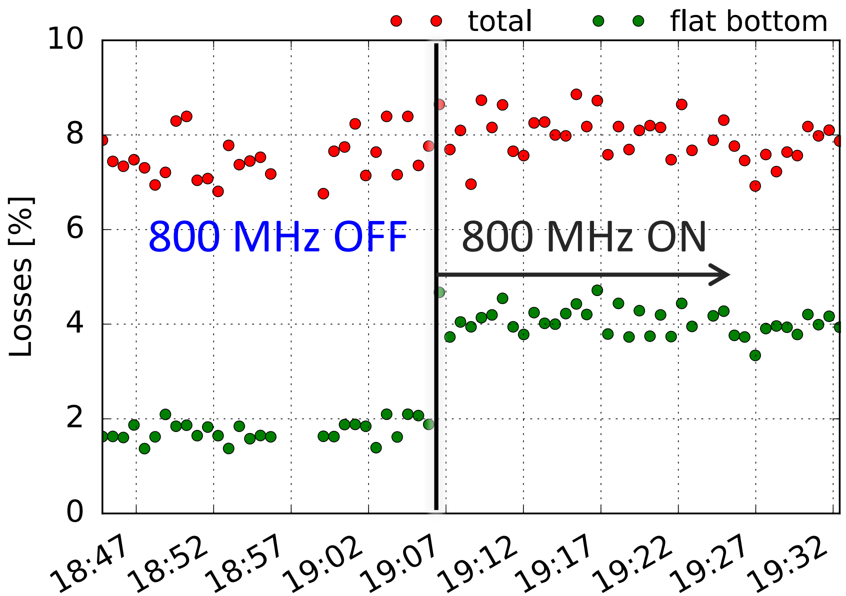
- Calculated space charge tune spread during acceleration to 2.5 GeV
  - Based on measured bunching factor and momentum spread
- Comparison of voltage programs
  - Enhanced tune spread with operational voltage program (first voltage step for BU1, voltage increase during ramp for larger bucket area)
  - Modified voltage program with constant bucket area for minimizing tune spread

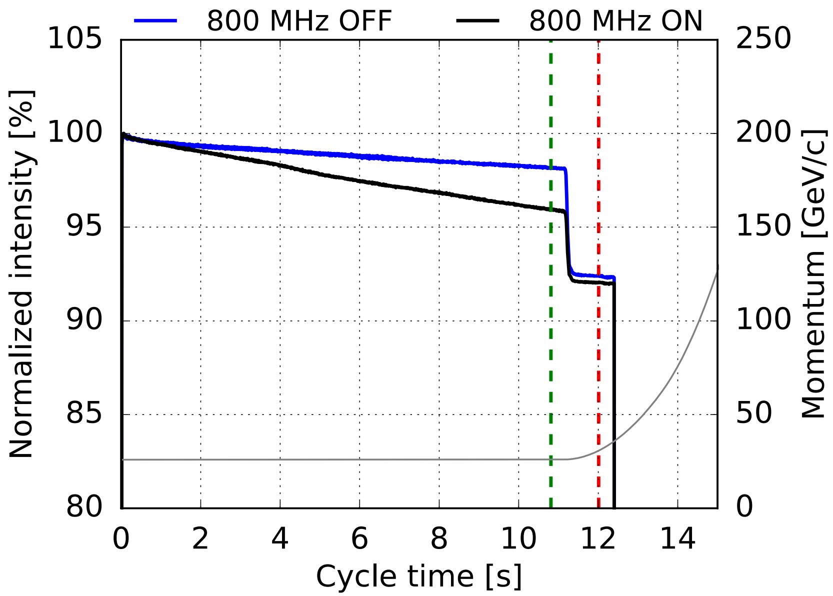
Emittance measurements at PS at flat top (BCMS)

- Clearly reduced emittances for voltage program with constant bucket area
- No effect of increased flat bottom working point



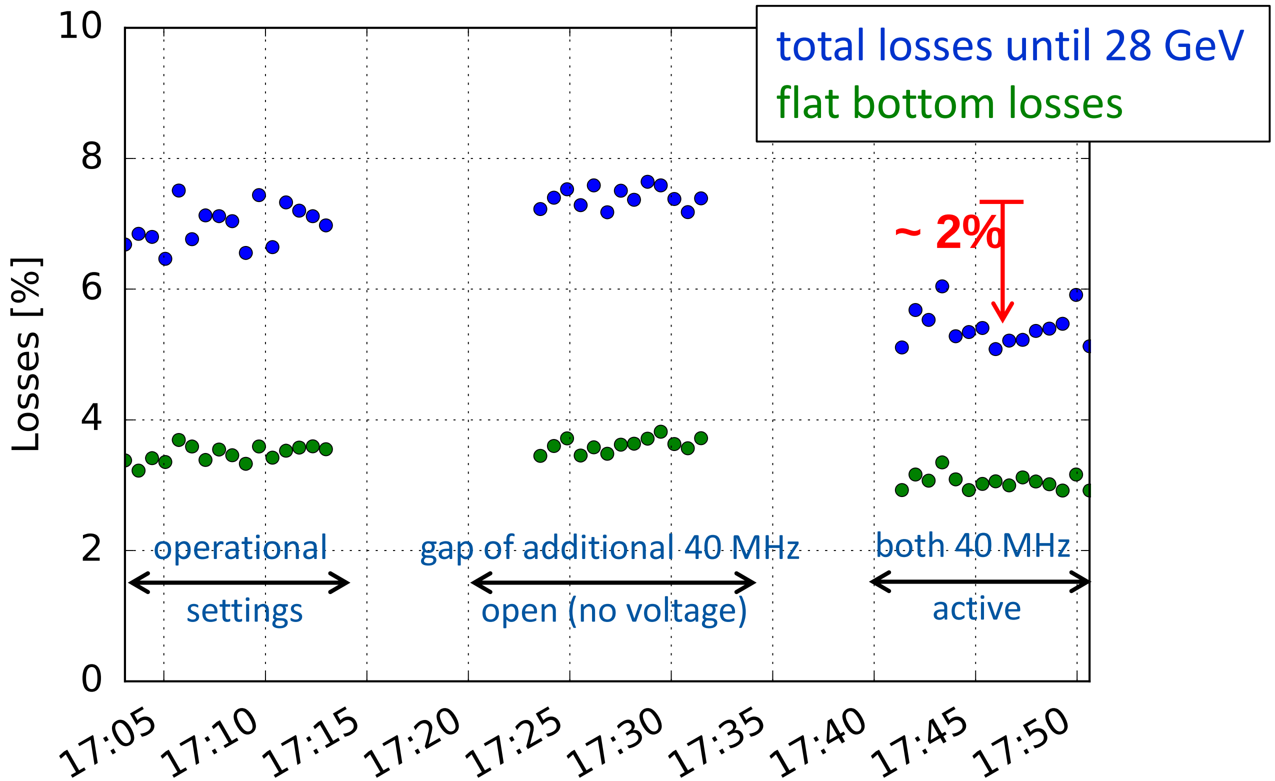
SPS incoherent losses





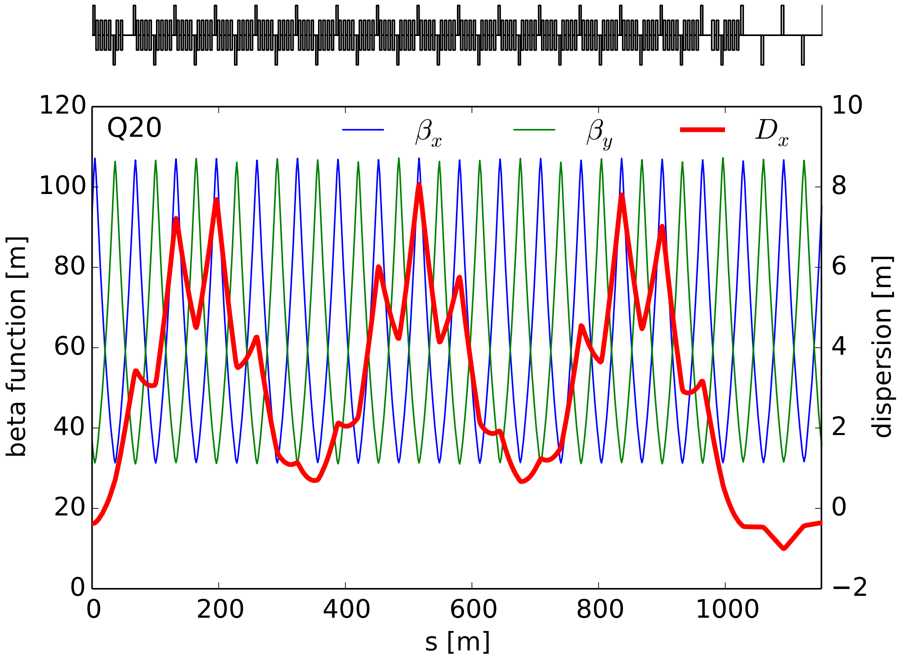
- Studies with 25 ns BCMS beam (1 batch with 1.4e11 p/b)
- **Incoherent losses dominated by uncaptured beam:**
  - flat bottom losses enhanced with 800 MHz ON (loss mechanism under study)
  - same total losses until 30 GeV with or without 800 MHz
  - mitigation on LHC filling cycle by operational deployment of additional 40 MHz cavity in PS (improved bunch rotation)

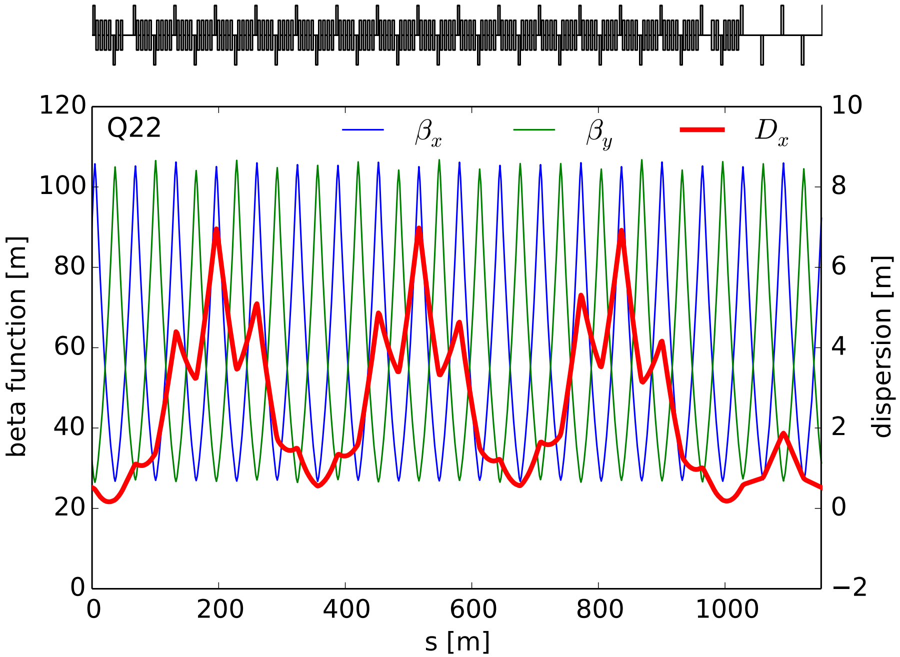
Test with both 40 MHz cavities



- LHC25ns nominal beam on special MD cycle
  - Operational intensity with 72 bunches
  - Loss reduction by about **2%** with both 40 MHz cavity used for PS bunch rotation (with optimal settings of 2015, Heiko)

SPS Q22 vs. Q20



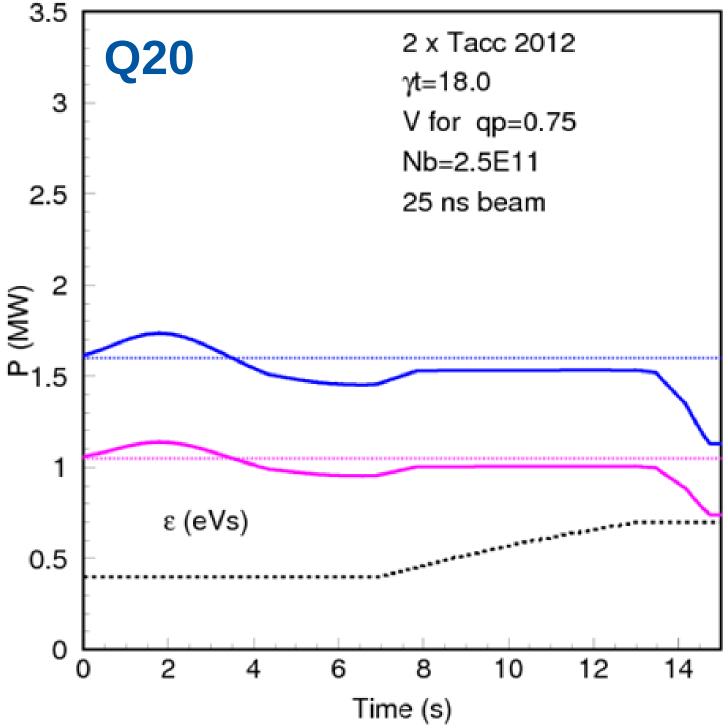


- **Slightly smaller dispersion peaks (bigger momentum acceptance)**
- Dispersion in straight sections up to 2 m (and sign flip!) in Q22
- Smaller normalized dispersion at the momentum scraper in Q22

SPS RF power

- Acceleration cycle (twice longer compared to present) with 2.5×10^{11} p/b
  - **First part: Q22 requires less RF voltage and RF power**
  - Second part: same RF power in both optics (beam stability requires larger longitudinal emittance in Q22 and thus similar RF voltage as in Q20)

Power/cavity for 2.5×10^{11} – Longer cycle



Power/cavity for 2.5×10^{11} – Longer cycle