


Impressions of the CERN North Area – 1977/1978

Experimental Requirements on Spill Quality
Slow Extraction Workshop CERN, 10.11.2017

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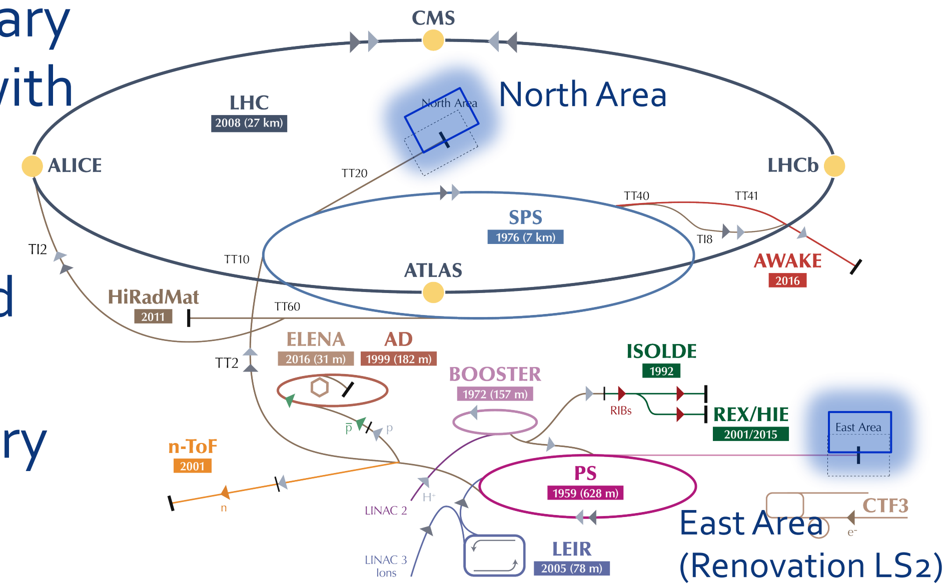
Our Users and their Requirements

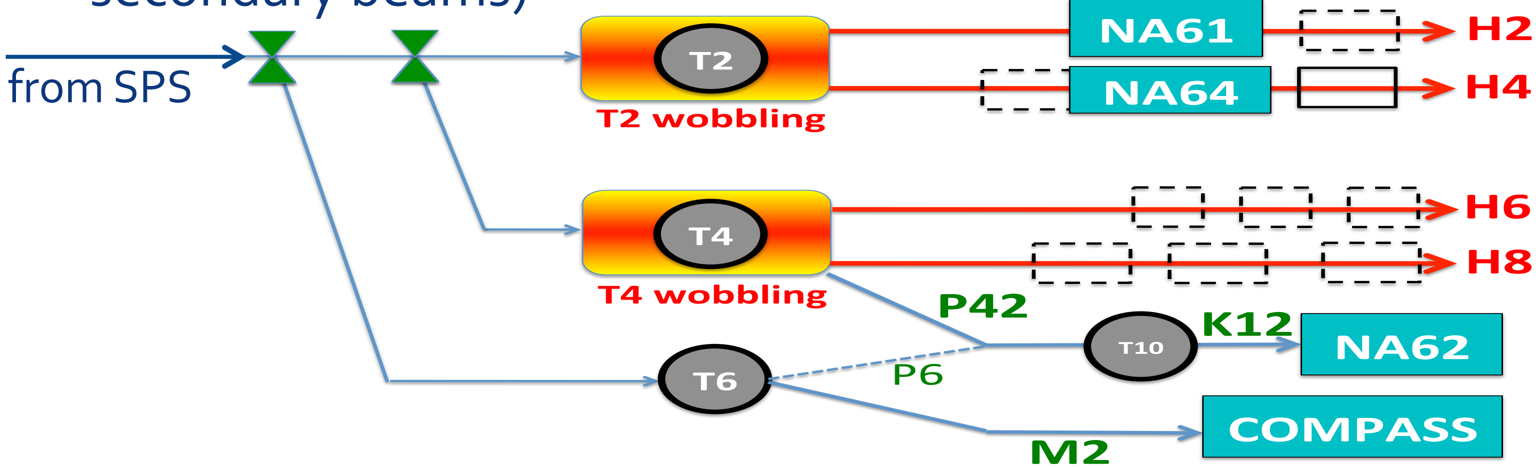
- Fixed target experiments
  - Precision studies (QCD, standard model, BSM physics)
  - Constant running in the order of 150-200 days/year
  - High intensity beams with slow extraction, sometimes limited by RP
  - Typically only limited by instantaneous rate and integrated intensity per spill
- Test beams
  - Campaigns for detector R&D and calibrations, typically 1-2 weeks/year
  - 'Volatile' environment with a wide range of demands on particles types and intensities
  - Nowadays more and more requests for medium to high intensity beams for test of LHC experiment upgrades
- Irradiation facilities
- Outreach

Secondary Beams at CERN with slow extraction

CERN provides high intensity secondary beams in a wide range of momenta with largely selectable particle species

- East Area / PS (primary 24 GeV/c protons and ions for irradiation and 0.5 – 12 GeV/c secondary beams)
- North Area / SPS (400 GeV/c primary protons / ions and 5 – 380 GeV/c secondary beams)

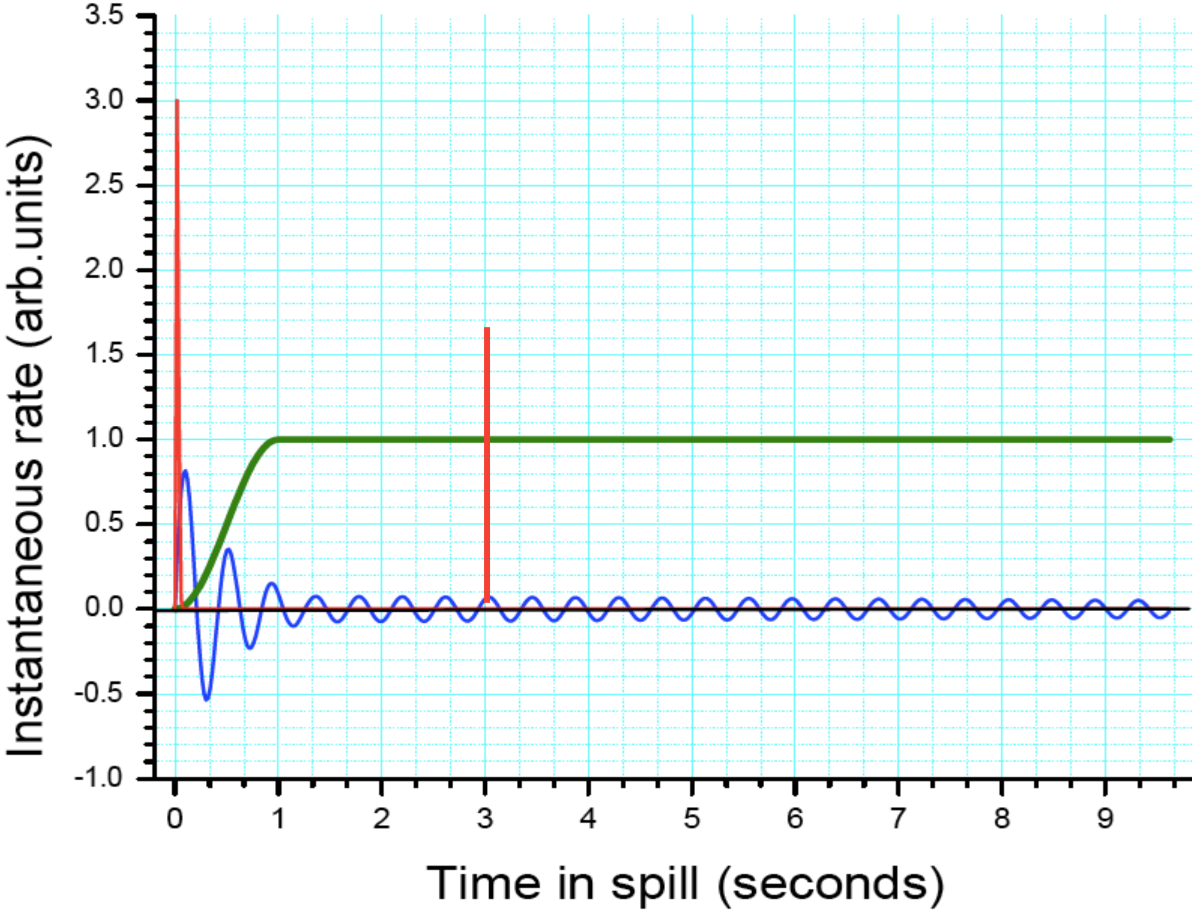




Experiments in the CERN North Area

- The NA experiments all rely critically on **slow extraction.**
- They are rate limited, mainly during the flat top.
  Their instantaneous rate is given in events per seconds, their integrated luminosity is proportional to integrated **time on flat top**.
  This assumes that they get enough flux to saturate their data-taking rate.
- Integrated time on flat top = **Duty-cycle** x Length of run (x efficiency)
- The number of events per second is limited by dead-time (signal length, event size, etc) and by **pile-up** (proportional to at least the square of the instantaneous rate).
- For a given flux and flat top length the optimum instantaneous rate is achieved for a spill structure **as flat as possible** (from low frequency to RF).

Typical spill structures – North Area

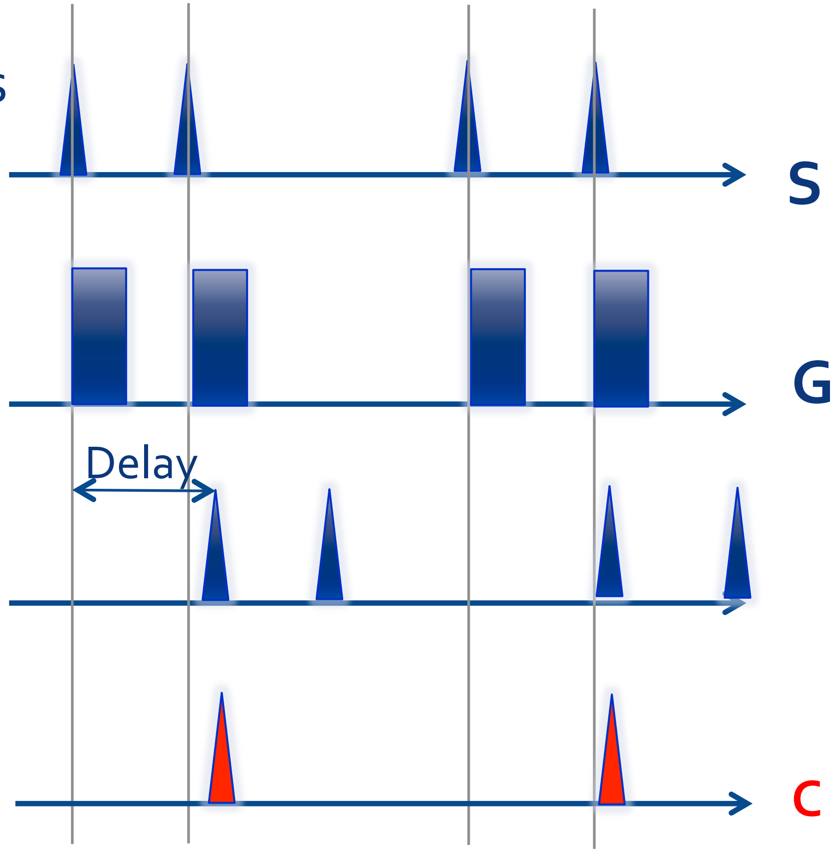


- The high frequency time structure (RF, f_{rev}) is still very present in the first 500 to 1000 milliseconds. Also: Low frequencies (e.g. 50Hz) from power converters.
- High-intensity spikes may occur at the beginning of the spill, in particular if the intensity is ramped up (too) quickly. A magnet glitch (e.g. QF) can produce a spike at any time.
- The slow ramping up is thus favored by the experiments, but together with the remnant structure it leads to a reduced **effective spill**.

Measurements of spill quality – I

Effective spill length a.k.a. 'Lifetime'

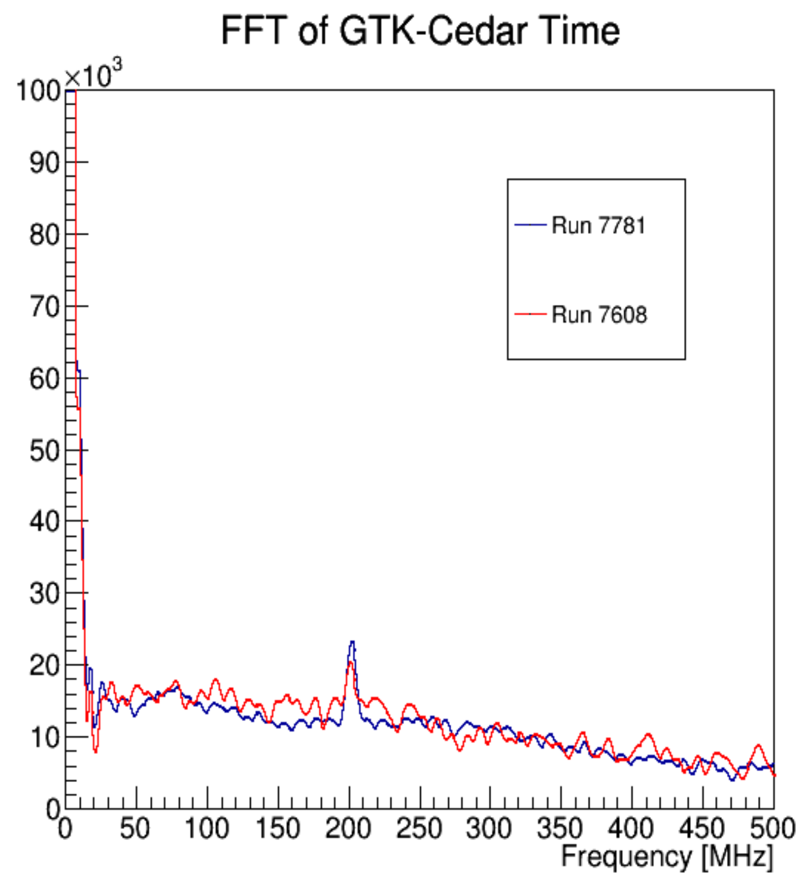
- Measured by a delayed coincidence of a rate signal with itself:
  Lifetime = Gate * Singles² / Delayed Coincidence
- Lifetime per cycle length is a measure of the availability for physics
- Useful for monitoring the spill quality over the whole frequency range, only limited by bandwidth of scaler electronics
- Shorter effective spill lengths are normally not taken into account for proposals, so a number of users in fact define this as the 'SPS efficiency' as it often has more impact than the SPS up-time thanks to the very good SPS availability.



Measurements of spill quality – II

FFT analysis of frequency spectrum

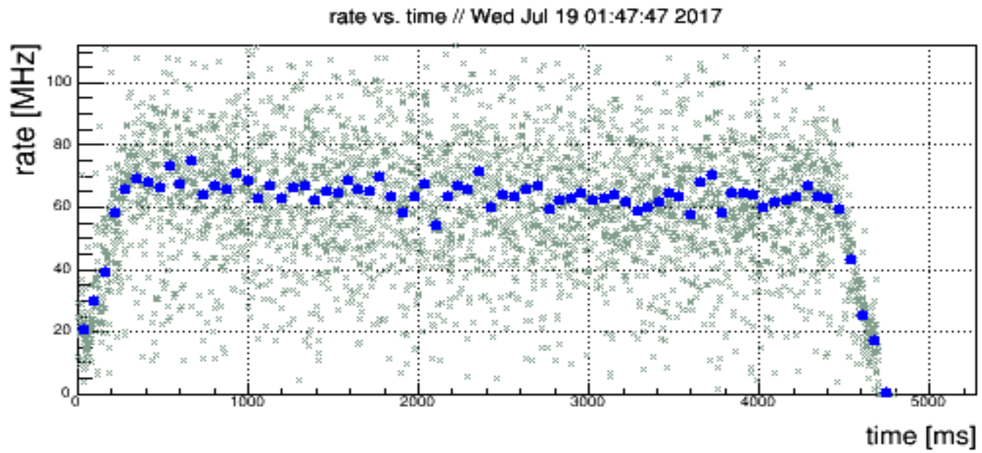
- Measured within a frequency band that is defined by the sample length and time resolution of the detector used
- Several MHz to GHz frequencies (sampling within typically 1 'event', order of 25ns) and frequencies up to a few hundred Hz can be identified (sampling over triggered events per spill)
- Useful for a direct feedback to operation

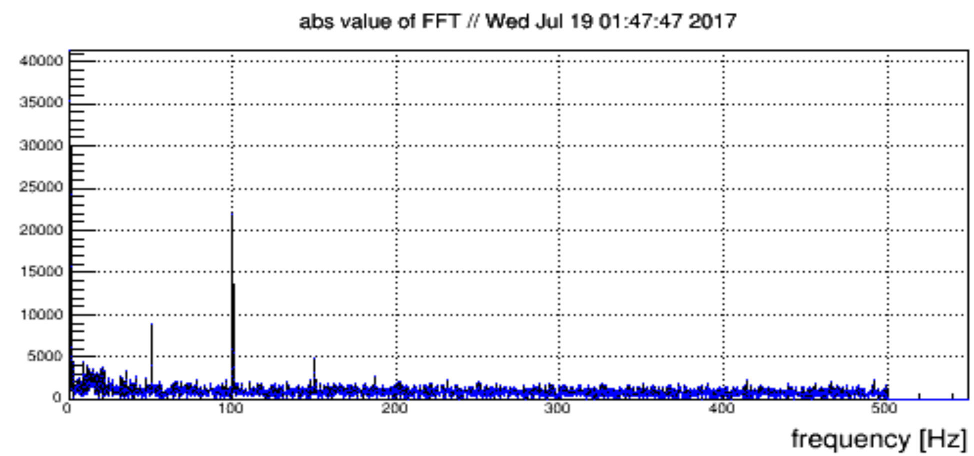


Example: High frequency spectrum measured with NA62 GTK and CEDAR
blue: standard 4.8s cycle, red: SHiP cycle

Example: COMPASS

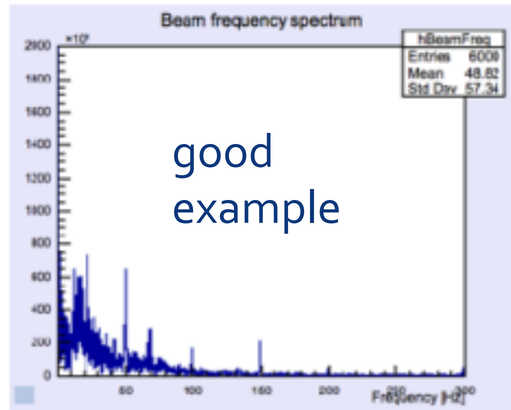
- Method: Scintillating fibre station with dedicated readout to compute FFT spectrum
- Mostly interested in low frequency online monitoring up to 500Hz
- Monitored by COMPASS shift crews and used as feedback to operators
- Includes automatic check of symmetry and intensity with audible alarm
- Offline analysis of frequencies of a few hundred MHz

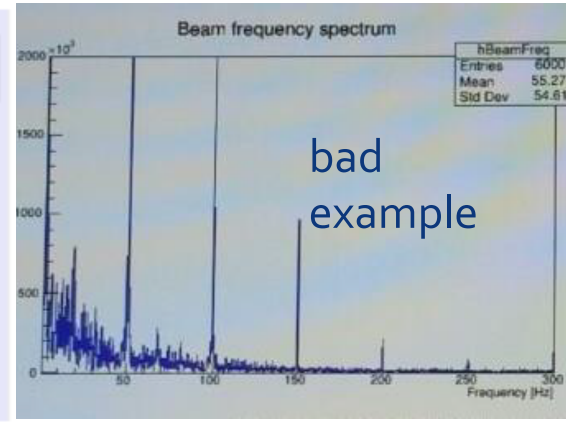


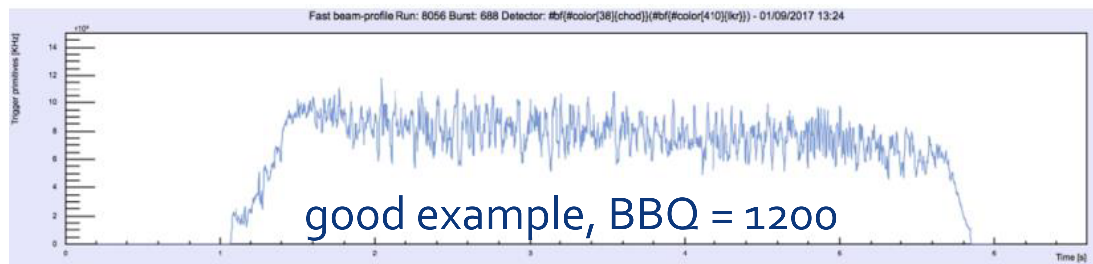


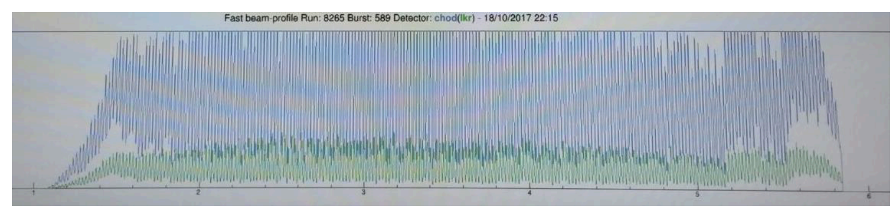
Example: NA62

- Method: 'Instantaneous' hit rate captured by the CHOD detector in windows of 1 ms
- First and last second are discarded (measure only flat top)
- Standard deviation of the resulting distribution is taken as the measure of the beam burst quality (referred to as the "BBQ")
- Direct feedback to operators for too high BBQ values









bad example, BBQ = 4400
blue = CHOD, green = LKr calorimeter

Impact on experiments – High Frequencies

- Most experiments introduce a 'Begin-of-spill veto' to inhibit the data taking or trigger system for the first 200ms - 500ms due to the surviving RF frequency.
- The result is a shorter effective spill length, hence a lower data taking efficiency.
- Higher amplitudes of RF frequencies lead usually to pile-up as most experiments have a natural time definition of an event, e.g. 25 ns.
- Pile-up can lead to a complex event topology, so a number of experiments discard such events (again loss of efficiency).

Impact on experiments – Spikes

- Most experiments run at the limit of their data taking capability, but also on very high gains and/or rate limits of some detectors
- Spikes can trip certain detectors (usually with high gain and HV supply) or even destroy them if the instantaneous intensity is very high. Recovery can take minutes to hours or even days.
- Medium intensity spikes can cause errors in front-end electronics and DAQ that cannot be recovered without manual intervention (e.g. reloading of firmware), usually takes some minutes.
- Frequent low intensity spikes can degrade the gain for a part of the spill ('intra-spill stability') and can stay unnoticed until the data are processed.

Impact on experiments – Low Frequencies

- Low frequencies can lead to gain fluctuations within the spill
- This is particularly dangerous for high gain detectors and detectors that need good stability on the gain, e.g. calorimeters / PMTs
- Gain fluctuations are normally seen after a physics run and cannot be recovered.
- Nowadays many detectors have a gain monitoring that works intra- and interspill.
- Intraspill monitors need an artificial deadtime, e.g. to pulse a laser (again lower effective spill length)

Possible Improvements

- Recent improvements on experimental side
  - Self-recovering DAQ: In case of a intensity related crash, the DAQ resets itself and continues running without manual intervention
  - Spill monitoring and FFT analysis with dedicated detectors and direct feedback to the operators

- Possible improvements for the accelerator side
  - Display the effective spill length on Page1
  - Active monitoring / alarms ?
  - Raise awareness (gain of 1% effective spill length = 1.5 days of operation per year!)
  - Additional instrumentation for a low frequency compensation with ion beams?

Conclusion

- The high-rate experiments in the North Area rely critically on the highest sustainable instantaneous rates and on maximum duty cycle for maximum precision and/or sensitivity.
- Recently main perturbations were 50 (and 30 or 65) Hz, RF residuals, spikes (at the beginning of the spill or from QF), and slow variations.
- Regular monitoring has proven crucial for improving the spill structure. Part of the input must come from the experiments, e.g. by providing effective spill on Page1 and by making more detailed plots permanently available in the CCC.
- A lot of work has been done by SLAWG and SPS-OP and the impressive progress is acknowledged and highly appreciated by the experiments. Any further improvement will increase the physics output even more (e.g. NA62 is still spill limited).
- A last thought: Reconsidering the flat top to slightly longer times could further improve the duty cycle.

Thank you for your attention!

... and a big thank you to BE-OP and SLAWG for all improvements plus TE-EPC for solving the QF ripple!

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Backup: East Area / PS Slow Extraction

- The slow extraction to the East Area has a spill length of about 400ms.
- So far, the East Area experiments have no particular demand for a well-tuned spill profile, but this might change in the future
- Current example of a spill profile at T10 (courtesy Y.Shitov, Imperial College London):