MODEL AND MEASUREMENTS OF CERN-SPS SLOW EXTRACTION SPILL RE-SHAPING - THE BURST MODE SLOW EXTRACTION

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ENUBET (Enhanced NeUtrino BEams from kaon Tagging) [1,2,3]

- New-concept ν_e source based on tagging of large angle e^+ from $K^+ \rightarrow e^+ \pi^0 \nu_e$ decays in an **instrumented decay tunnel**.
- Reduction of the systematic uncertainties on the knowledge of the initial neutrino flux to O(1%) level.

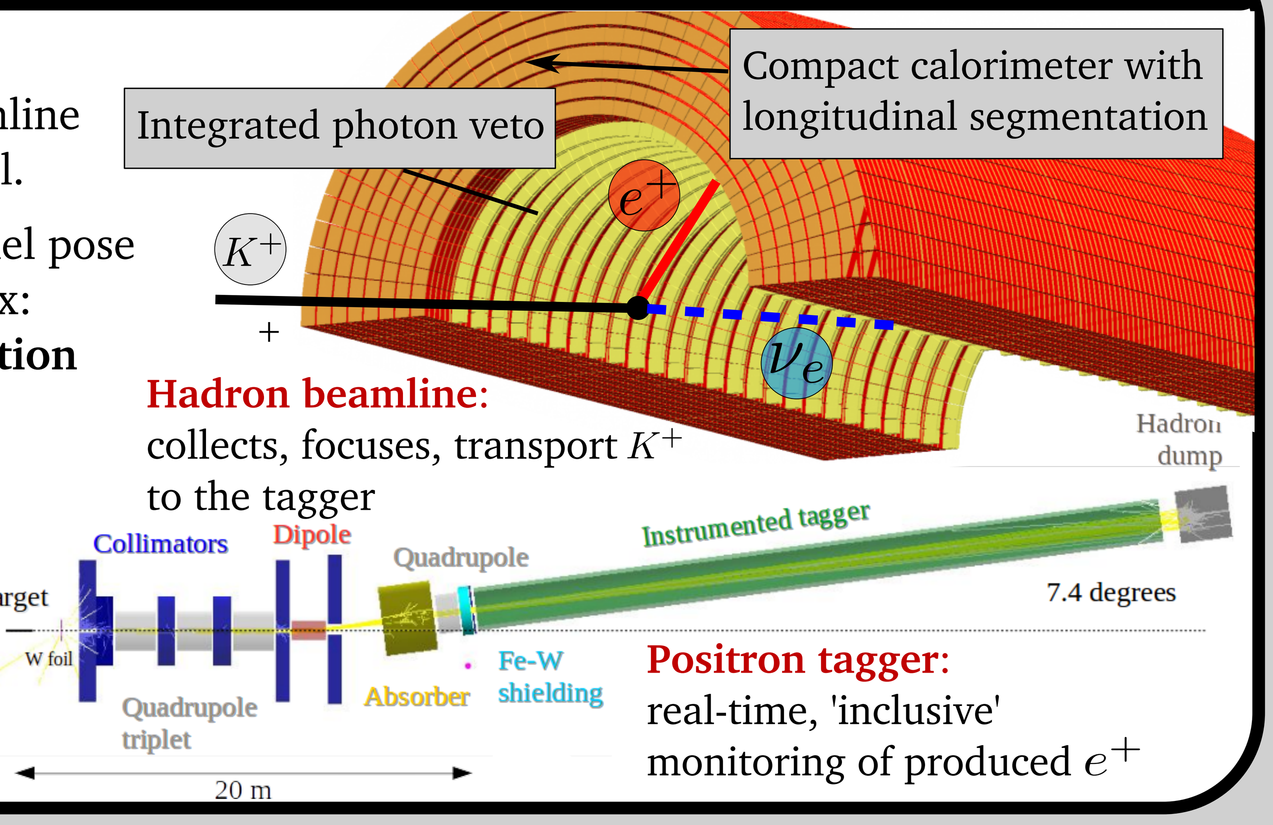
Physics implications

- Unprecedented high precision measurement of ν_e and $\bar{\nu}_e$ cross sections (short baseline neutrino experiments).
- Highly beneficial for tackling the main open neutrino-related problems: mass hierarchy, θ_{23} octant, leptonic CP violation.
- First step towards a time tagged neutrino beam: direct ν production/detection correlation.

Experiment design

- **Monitored neutrino beam**: hadron beamline followed by an instrumented decay tunnel.
- Pile-up levels in instrumented decay tunnel pose hard constraints on maximum hadron flux: **slow resonant extraction is the best option for the primary protons.**

Proposed new proton slow extraction scheme consisting of several 2-10 ms pulses repeated at 10 Hz [2]: burst mode slow extraction. It would open to strong focusing (magnetic horns) + advantages in int. meas. & cosmics.



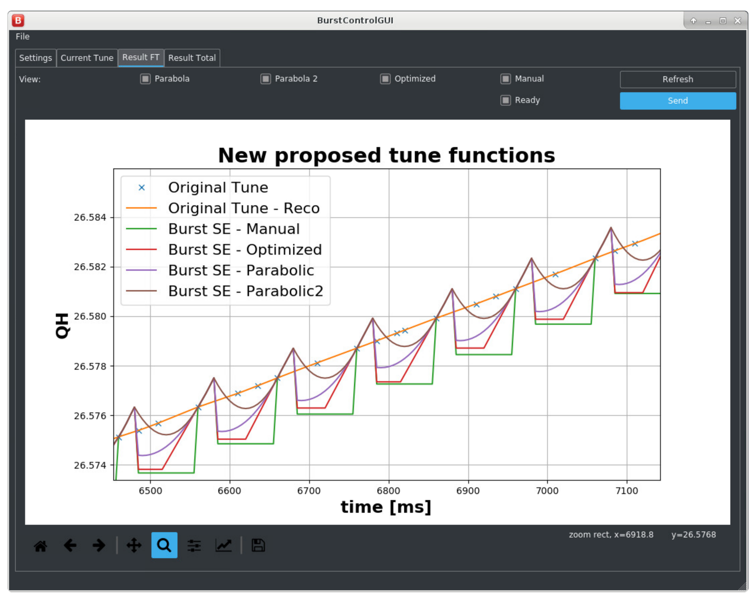
Burst Mode Slow Extraction: implementation and simulation at CERN-SPS

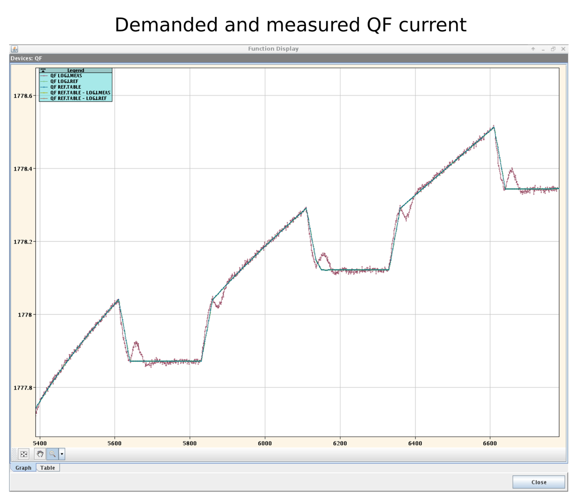
Implementation

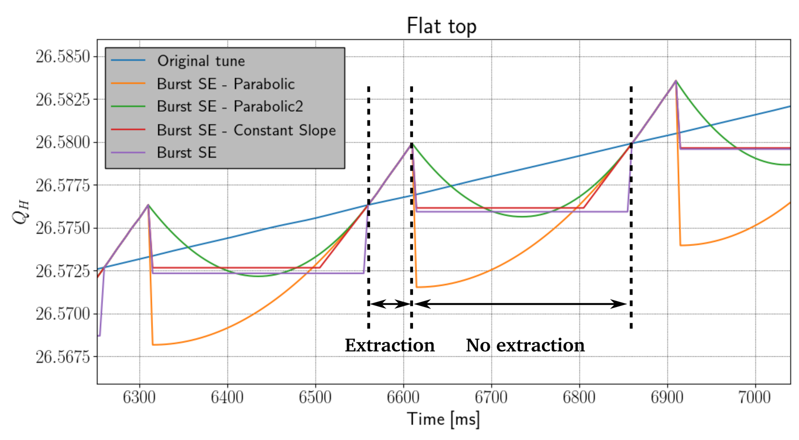
- Nominal slow extraction at CERN-SPS: chromatic-based third integer resonant. The horizontal tune is swept across a third integer resonance, extracting about 4x10^{13} protons in 4.8 s.
- The burst mode slow extraction is built on top of the nominal slow extraction horizontal tune Q_H^{nom}, with the following tune reshaping:

$$Q_H^{\text{nom}}(t+nT) \longrightarrow \begin{cases} Q_H^{\text{nom}}\left(\frac{T}{\lambda}t+nT\right) & t\in[0,\lambda] \\ f(t+nT) & t\in[\lambda,T] \end{cases} \quad (1)$$

- A graphical user interface has been developed based on the tune reshaping of Eq (1) and successfully used to implement the burst extraction at CERN-SPS:

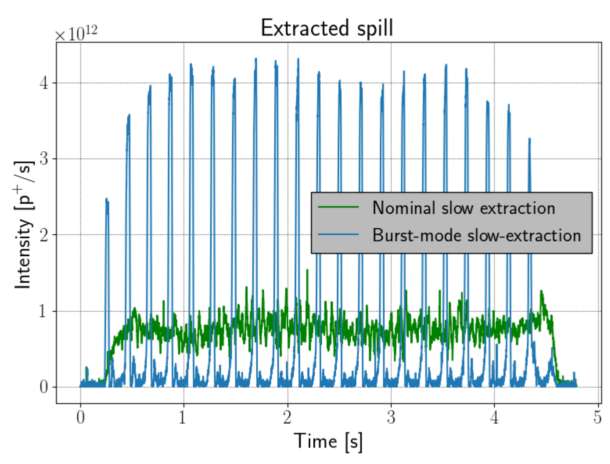


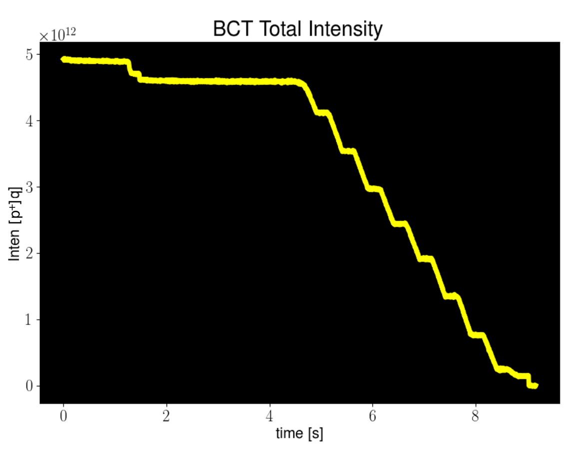




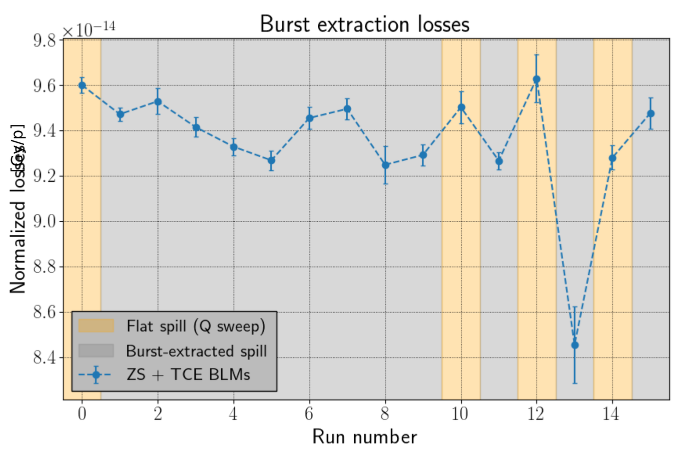
→ The difference in the proposed tune functions is only in the function f(t) of Eq. (1) in order to minimize the non-ideal power converter response.

Experimental results





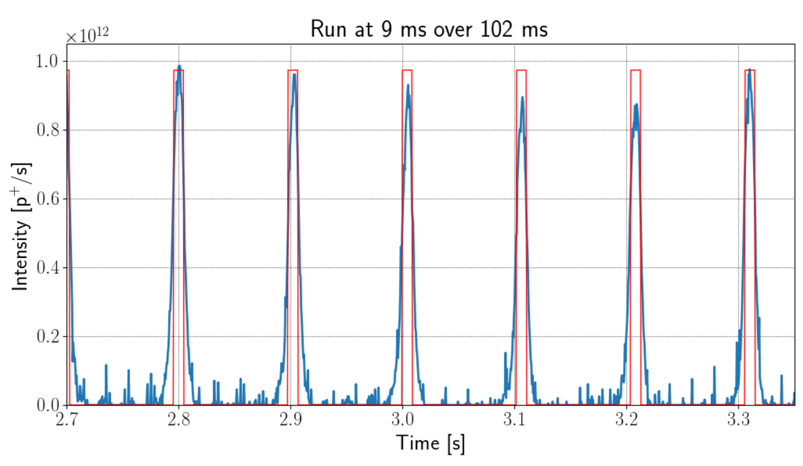
- No significant losses increase has been observed during operation:



The losses are monitored at the electrostatic septum (ZS) and downstream collimator (TCE).

- The burst mode extracted spill is characterized in terms of the "effective burst length", based on the "effective spill length" [4], and defined as:

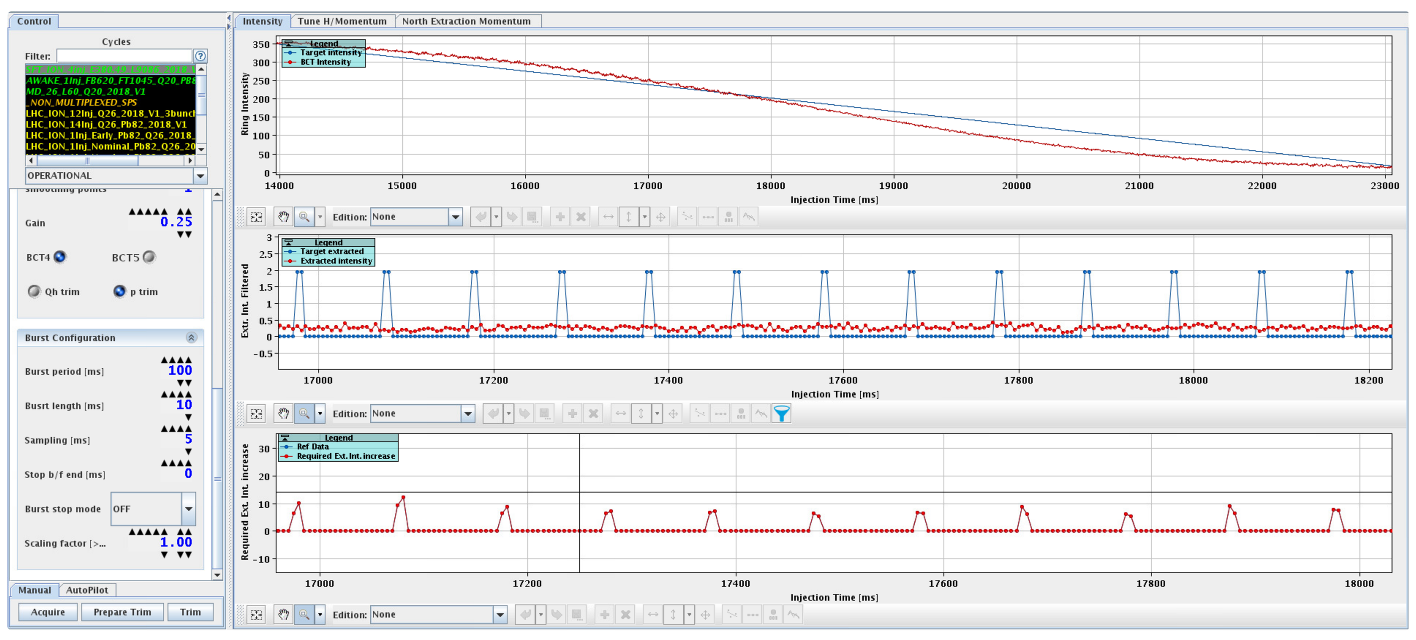
$$\lambda_{\text{eff}}^n = \frac{\left(\int_{-T/2}^{T/2} s(t+nT+t_0)\,dt\right)^2}{\int_{-T/2}^{T/2} s^2(t+nT+t_0)\,dt}$$



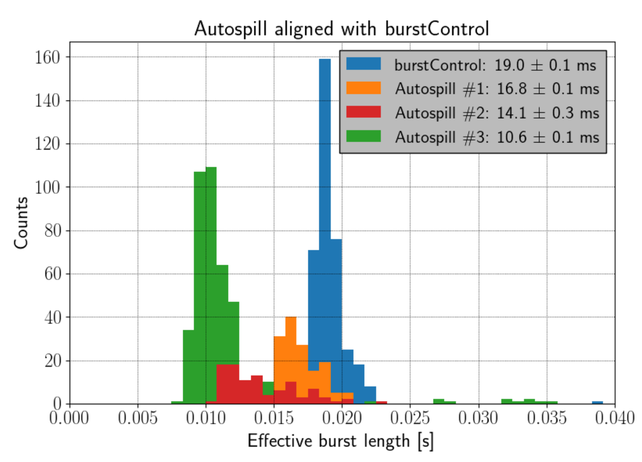
The effective burst length turns out to be systematically larger than the demanded one: this effect is given by the power converter non-ideal response and transit delays in phase space.

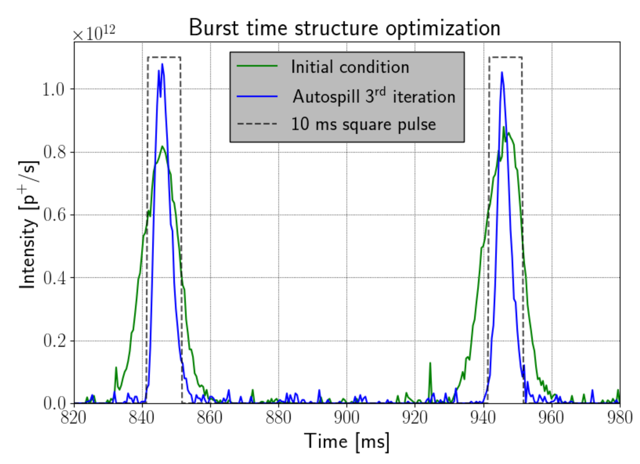
Optimization

- Upgraded the iterative feed-forward Autospill algorithm [5] for automatic convergence to the desired value of burst length during operation.



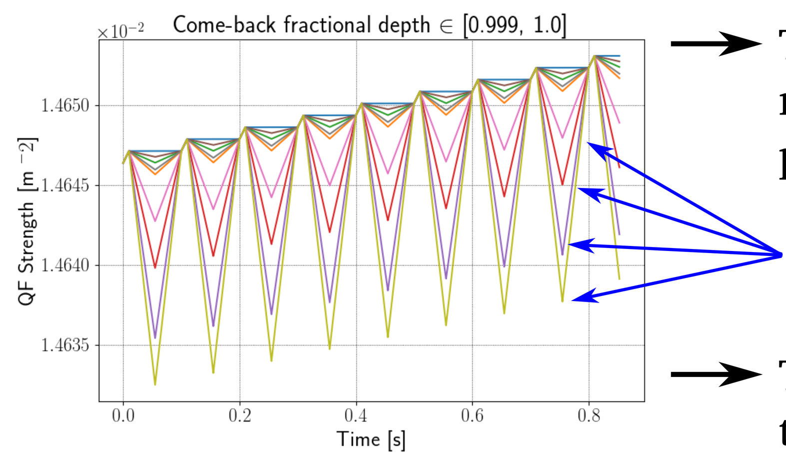
- Using Autospill, the spill is successfully optimized from an effective burst length of 19 ms to 10.6 ms in only three iterations, with a demanded burst length of 10 ms:





Simulation

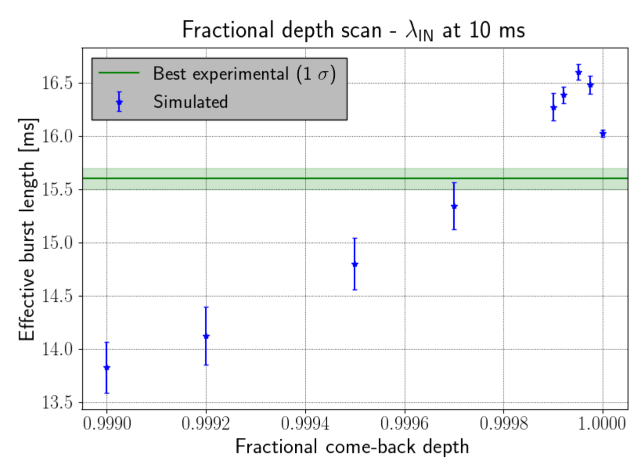
- The burst mode slow extraction has been implemented in MADX for comparison with the experimental results and to inspect possible ways of improvement not attempted in the machine developments.



→ The ramping of quadrupoles is simplified with respect to the experimental case. A single parameter characterizes the term f(t) of Eq (1):

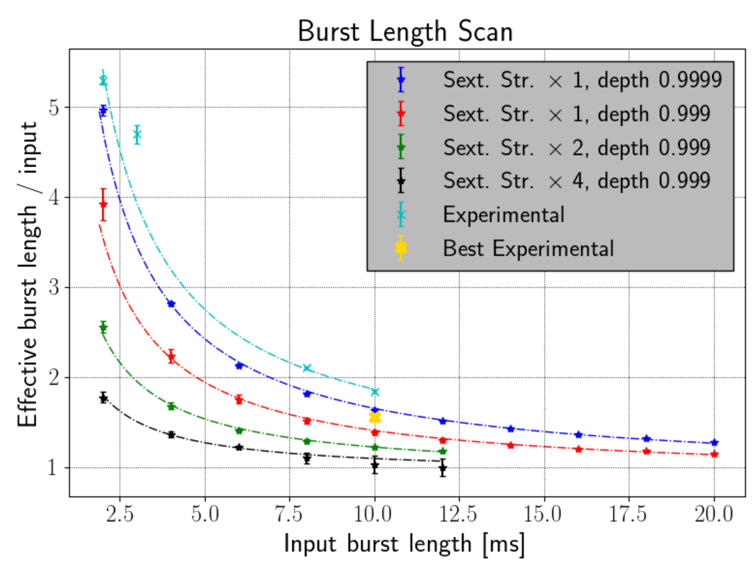
$$\text{fractional come-back depth} = \frac{\min f(t+nT)}{f(\lambda+nT)} \quad t\in[\lambda,T]$$

→ The effective burst length is consistently larger than the demanded one even in simulation: contribution of the phase space transit time distribution of the extracted particles.



→ A run at constant demanded burst length of 10 ms shows that the extraction of particles depends on the tune sweeping velocity, as detailed in [6].

- An increase of fractional effective burst length for smaller demanded burst lengths is observed both in simulation and experimental results:



→ The effect is thought to be linked to the low pass filter from tune to spill observed in the slow extraction process [7,8].

→ The experimental data points lie above the maximum found in simulation: the effect of power converters adds up to beam dynamics.

→ Increasing the sextupole strength increases the 3-turn amplitude growth in phase space: way to reduce effective burst length.

[1] Eur. Phys. J. C, vol. 75, no. 155, 2015
[2] CERN-SPSC-2016-036, Oct. 2016
[3] CERN-SPSC-2018-034, Oct. 2018
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[5] Proc. IPAC'16, doi:10.18429/JACoW-IPAC2016-TUPMR051
[6] LHC-PROJECT-NOTE-176, Dec. 1998.
[7] Proc. IPAC'18, doi:10.18429/JACoW-IPAC2018-TUPAF035
[8] Proc. IPAC'18, doi:10.18429/JACoW-IPAC2018-TUPAF050