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PSB longitudinal painting: concept and control

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Acknowledgements: B. Mikulec, C. Carli, E. Benedetto, J. Sanchez

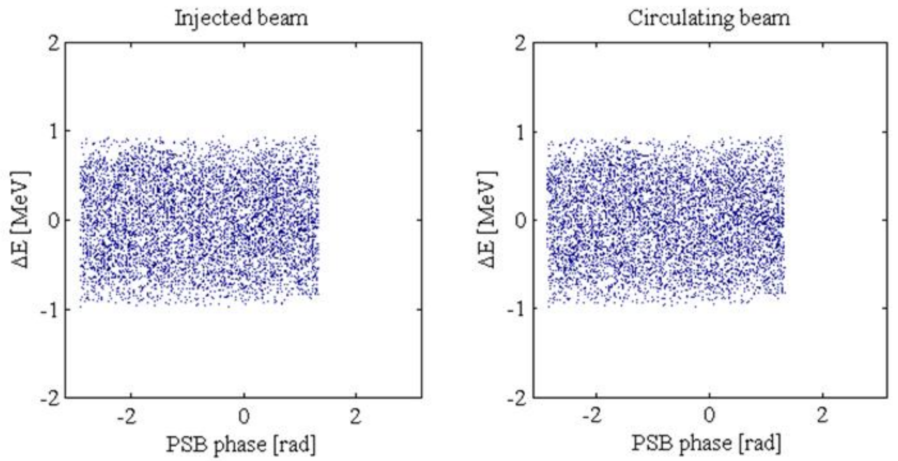
Outline

- Longitudinal painting concept
  - The process
  - Physical parameters
  - Present hardware limitations
- A longitudinal painting control algorithm
- Summary and next steps

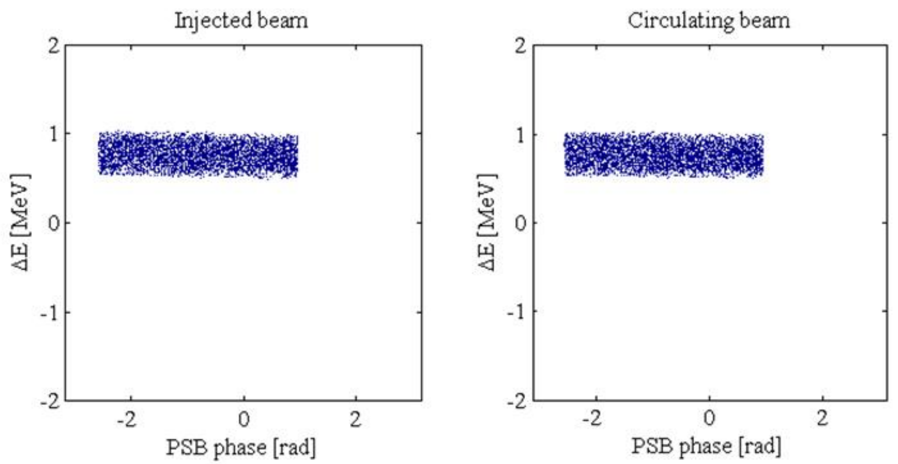
The process

- Multi-turn **un-modulated energy** injection
  - The L4 bunch trains arrive to the PSB with **the same central energy E_0 = 160 MeV**
  - The **rms energy spread δE is** usually **large (~400-450 keV)** to compensate peaks of line density

    → bad for space charge
  - The **chopping factor is fixed (~60%)**



- Multi-turn **longitudinal painting**
  - The **L4 bunch trains** arrive to the PSB **with different (turn-by-turn) central energy arou E_0 = 160 MeV**
  - The **rms energy spread δE is fixed (120-250 keV)**
  - The **chopping factor is varying** to follow the longitudinal iso-Hamiltonian contours for a give longitudinal emittance.



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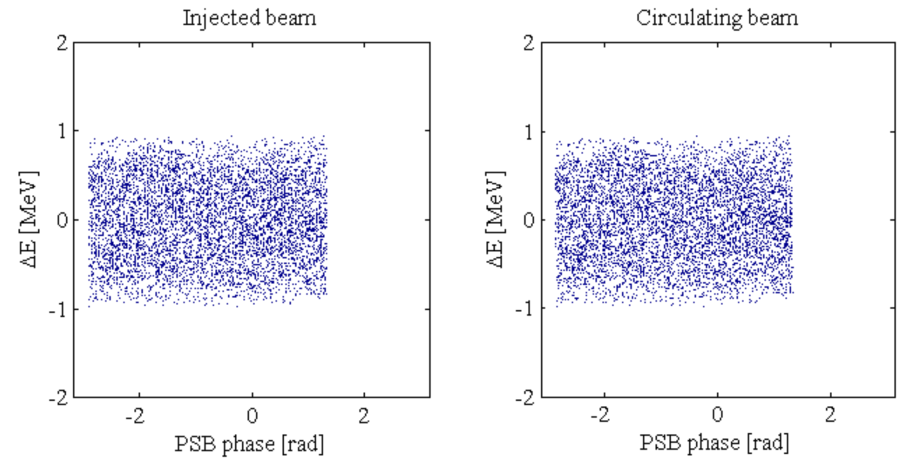

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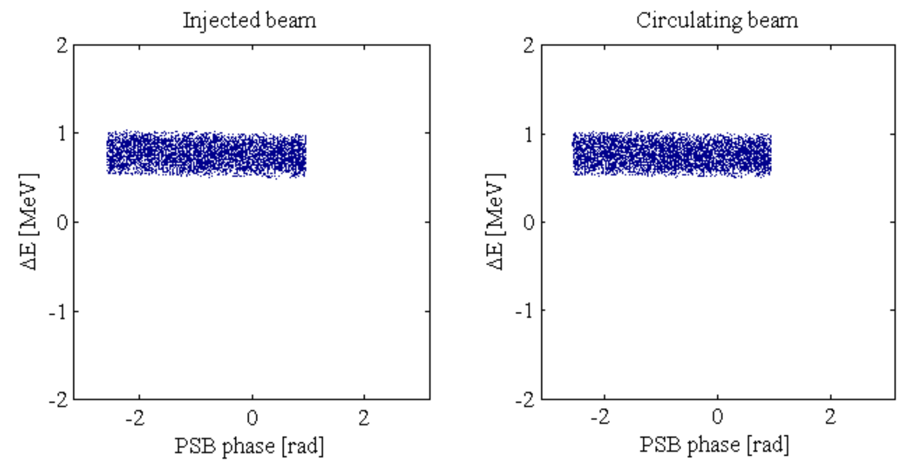
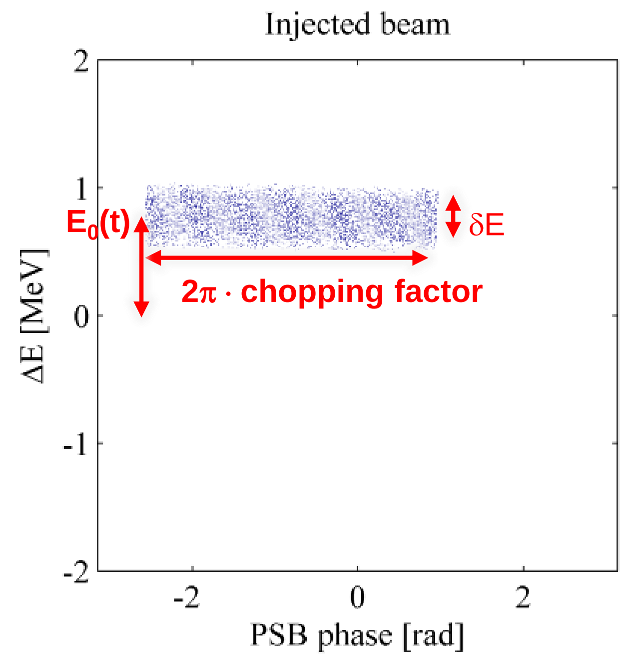
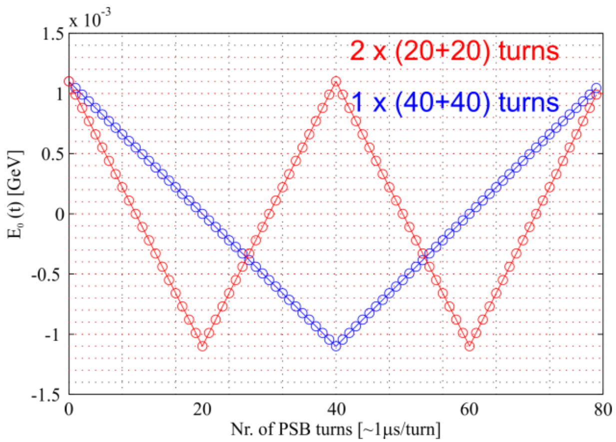


Physical parameters

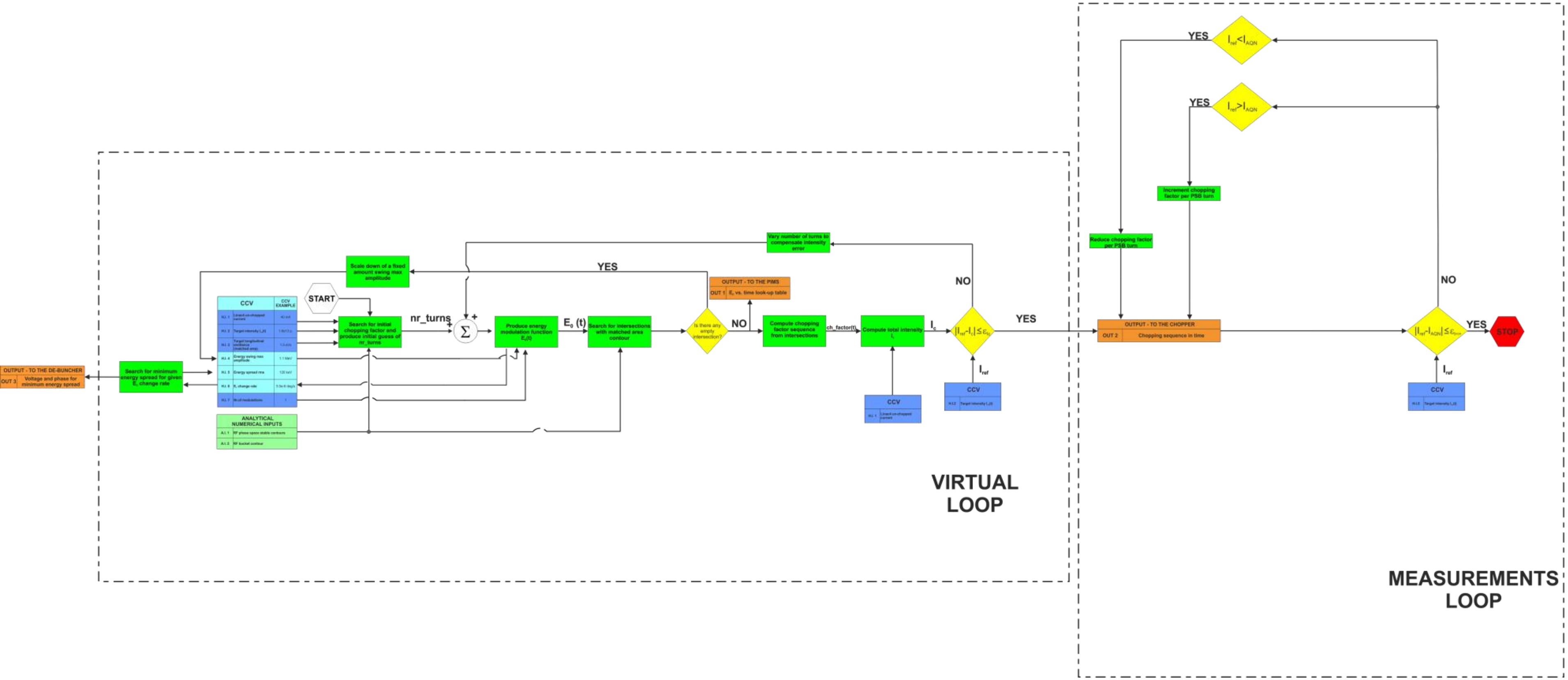
- **The rms energy spread δE**
  - Imposed **by the de-buncher**
  - **Fixed** during the injection process
- **The central energy $E_0(t)$**
  - Imposed **by the last two PIMS**
  - **Can be swept turn-by-turn** at injection
- **The central energy sweeping rate $dE_0(t)/dt$**
  - Imposed by the last two PIMS → **change of phase and, thus, power requested to the de-buncher**
- **The chopping factor (≤1)**
  - Imposed **by the chopper**
  - **Rations the effective current/turn** at the PSB entrance
    - **$I_{eff}(t)$ = chop. factor × unchopped current = chop. factor × 40 mA**
  - **Can be modulated** turn-by-turn at injection
  - **Determines the number of turns to be injected** for any given target intensity
- **The number of injectable turns**
  - **Is limited** by the BI.DIS **at <150 per PSB ring**





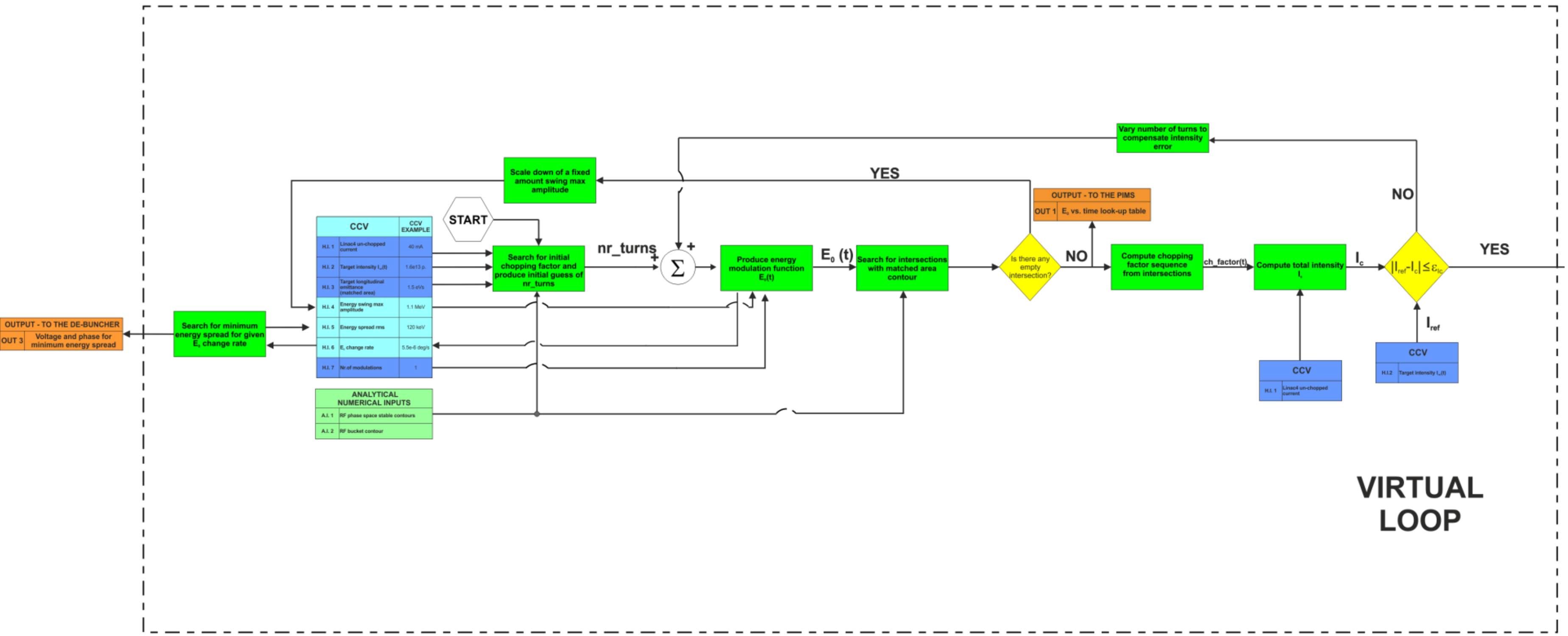
A possible energy sweep through the PIMS

A longitudinal painting control algorithm



Virtual loop

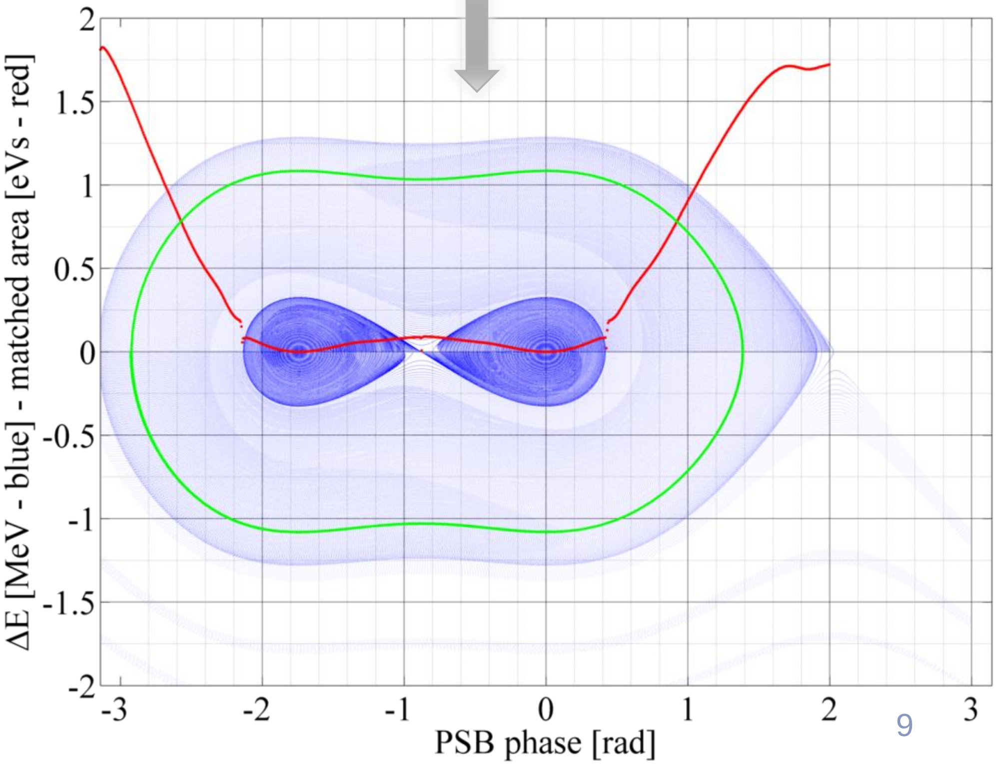
- The virtual loop, from the inputs, is an algorithm to set the HW through:
  - Chopping factor sequence (chopper)
  - Energy swing function (PIMS)
  - Energy-spread (de-buncher)



Inputs

CCV		CCV EXAMPLE
H.I. 1	Linac4 un-chopped current	40 mA
H.I. 2	Target intensity $I_{ref}(t)$	1.6e13 p.
H.I. 3	Target longitudinal emittance (matched area)	1.5 eVs
H.I. 4	Energy swing max amplitude	1.1 MeV
H.I. 5	Energy spread rms	120 keV
H.I. 6	E_0 change rate	5.5e-6 deg/s
H.I. 7	Nr.of modulations	1

ANALYTICAL NUMERICAL INPUTS	
A.I. 1	RF phase space stable contours
A.I. 2	RF bucket contour



Fixed inputs

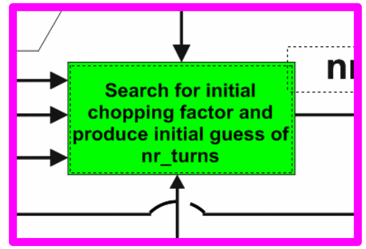
Variable inputs

HW outputs

OUTPUT - TO THE DE-BUNCHER	
OUT 3	Voltage and phase for minimum energy spread

OUTPUT - TO THE PIMS	
OUT 1	E_0 vs. time look-up table

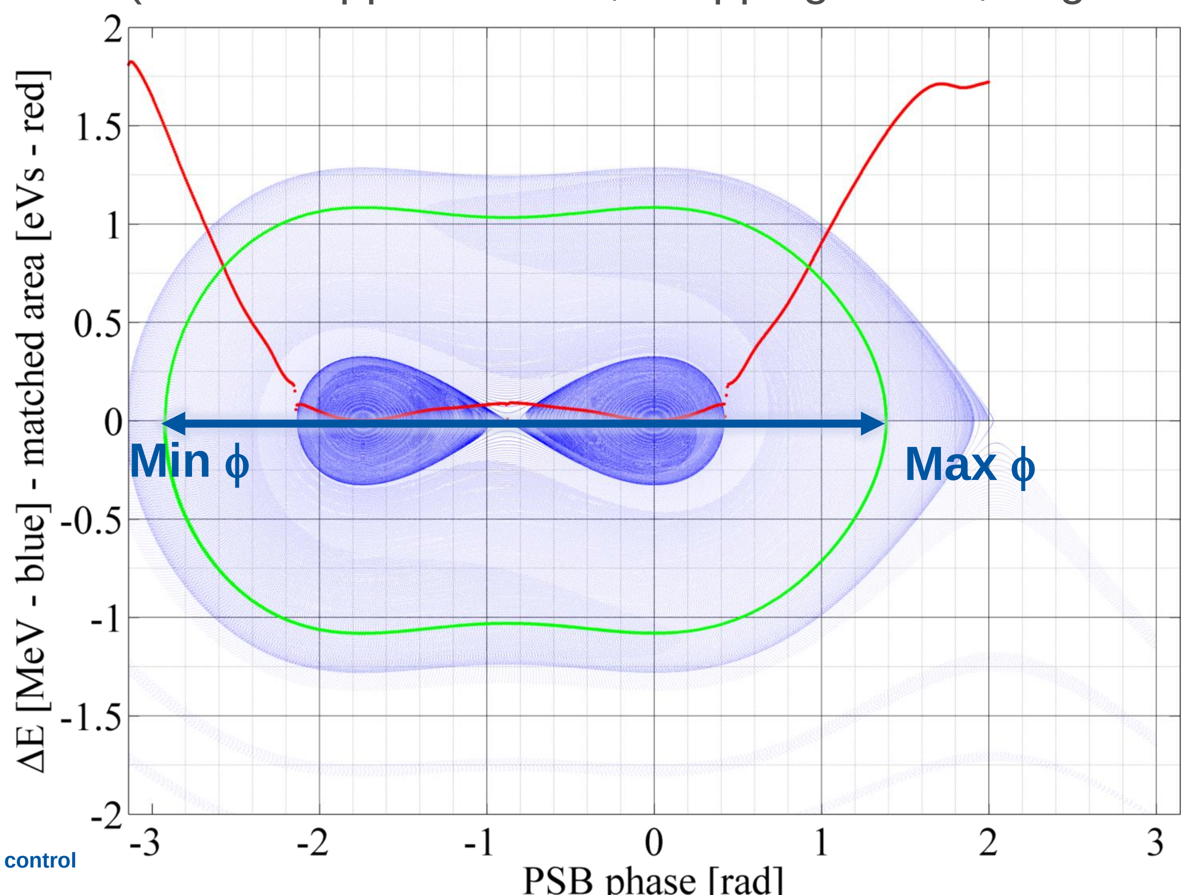
OUTPUT - TO THE CHOPPER	
OUT 2	Chopping sequence in time

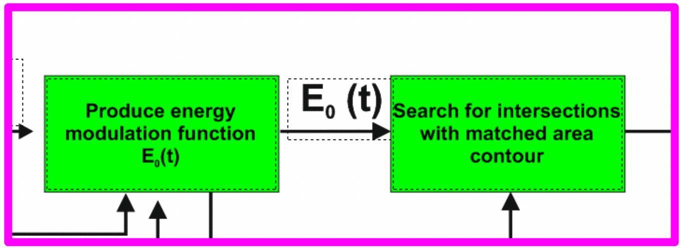


➢ **First guess of the chopping factor → initial nr. of turns (<u>under-estimated!</u>)**

Initial chopping factor = (Max ϕ – Min ϕ)/2π

nr. of turns = f (L4 unchopped current, chopping factor , target intensity)

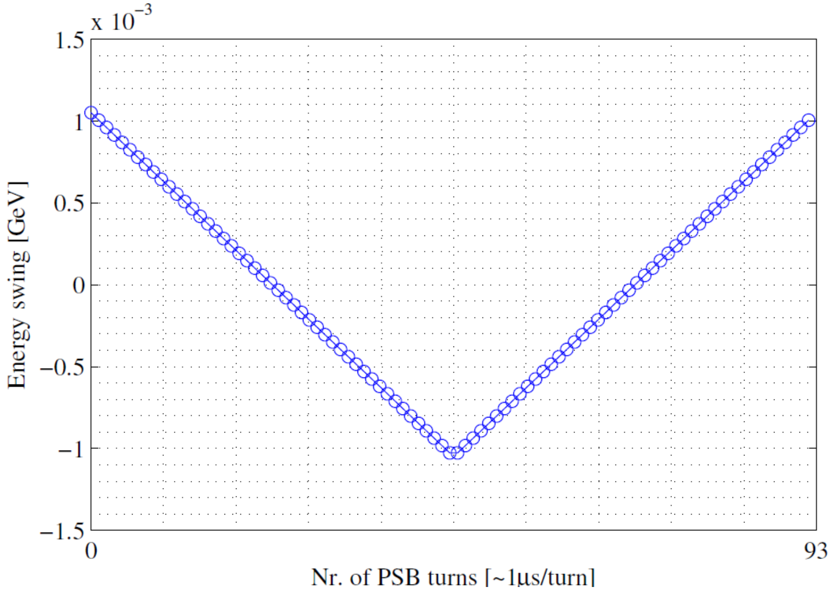


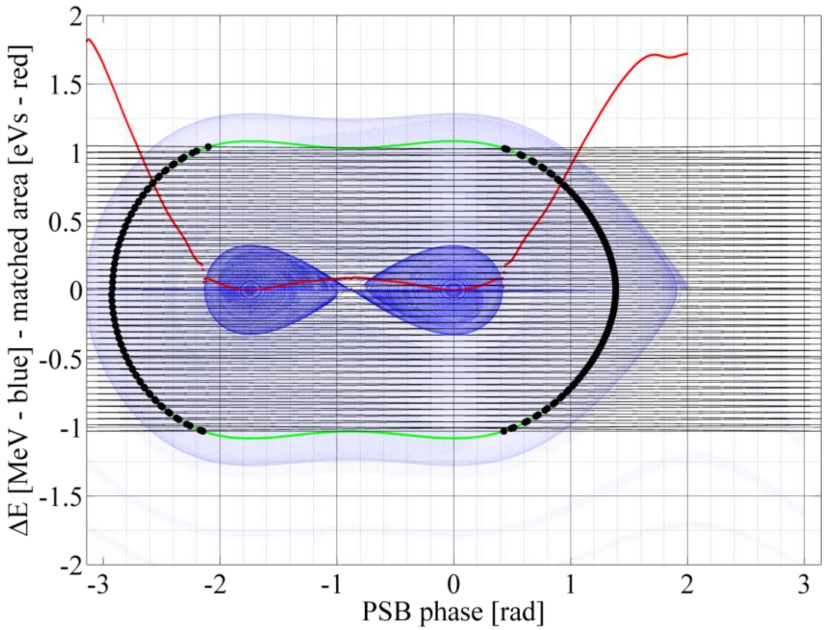


- Estimation of the energy modulation function for the PIMS (e.g. triangular waveform)

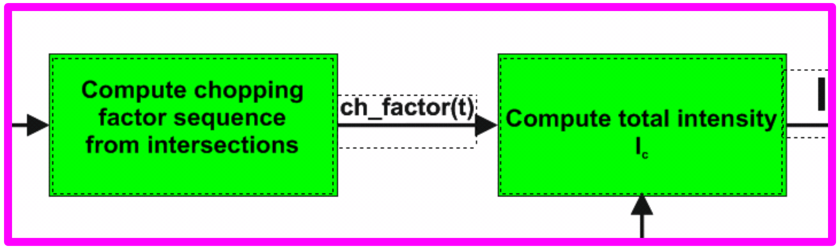
energy_modulation= f(nr turns, nr of modulations, amplitude)

- **The intersections of the energy swing** function **with the target contour** determines the portion of the L4 pulse that has to be retained at every PSB turn
  → **the chopping factor**

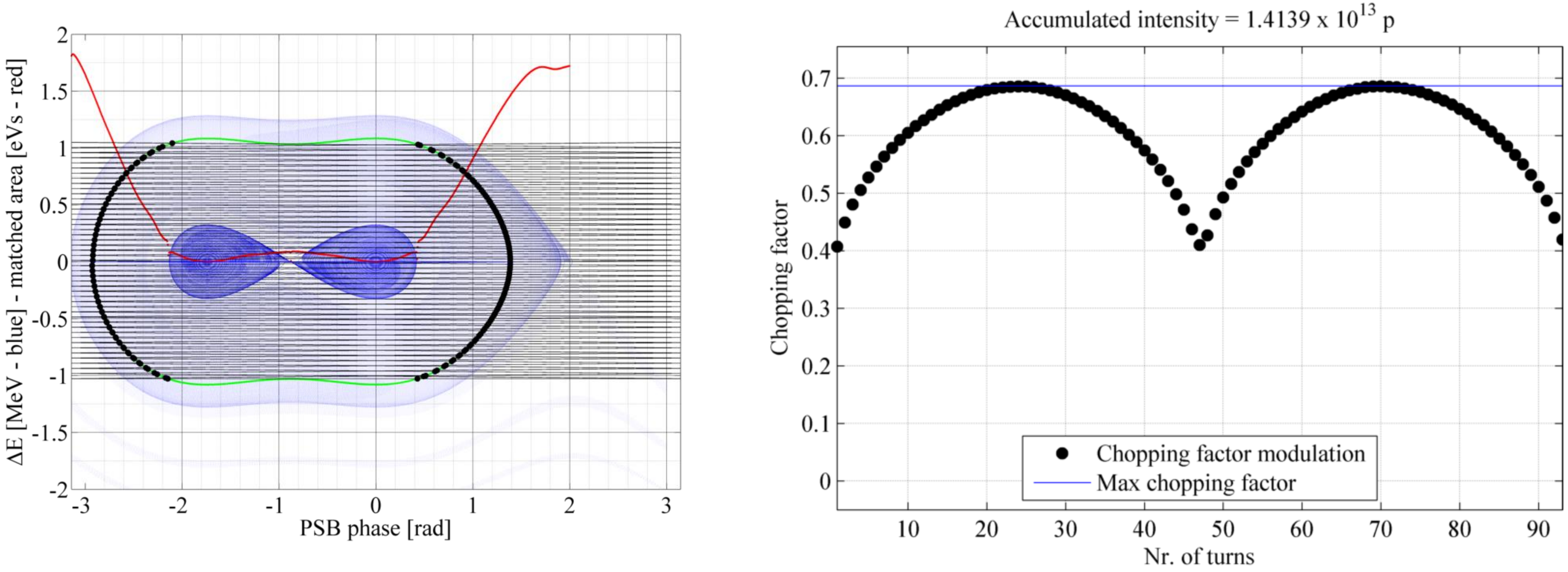


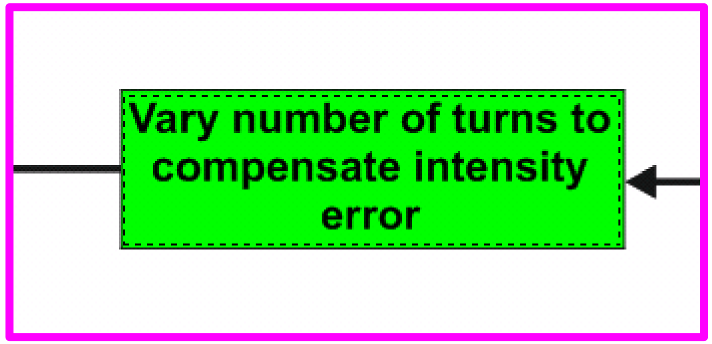


- **NOTA BENE! Empty intersections are un-useful and un-wanted →** if present, one has to **scale down the PIMS amplitude in feed-back** by a small amount

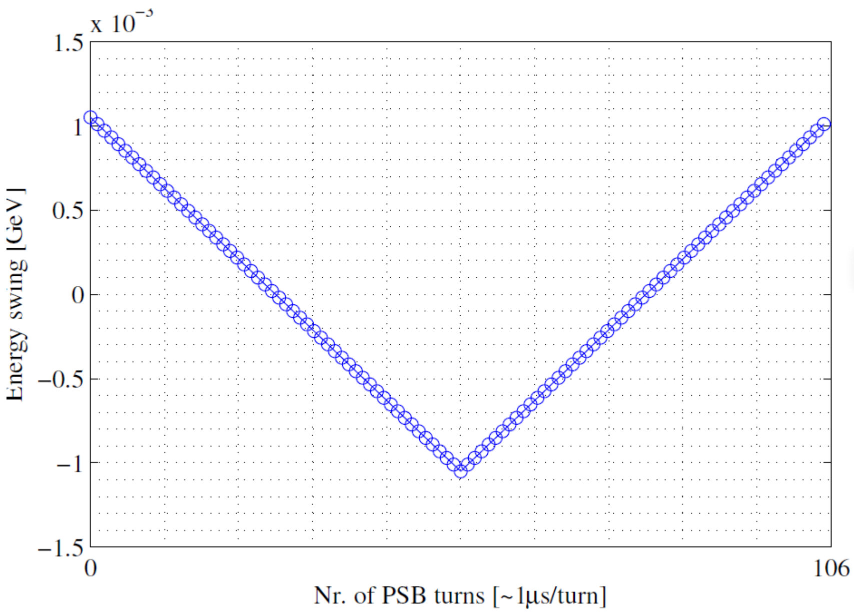


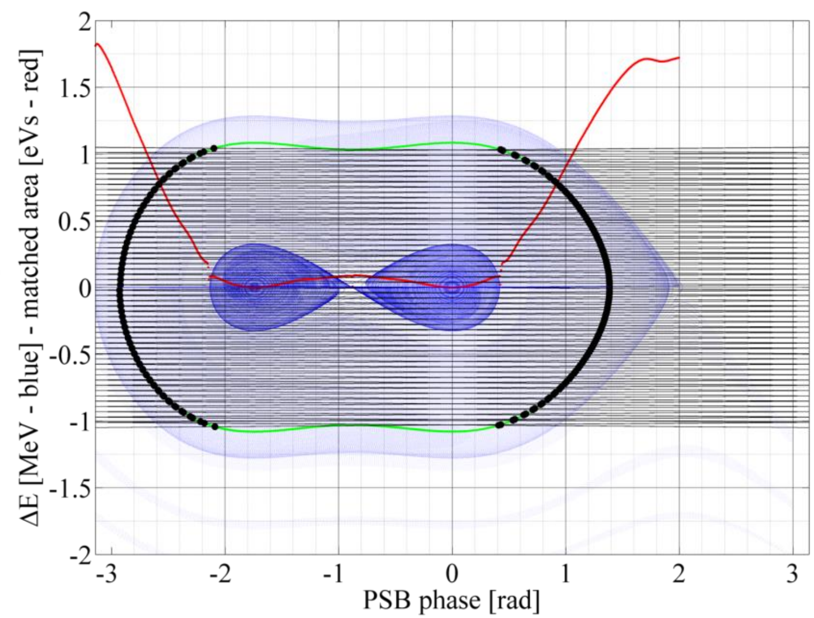
➢ **For convexity of the phase edges of the longitudinal iso-Hamiltonian contours, the chopping factor modulation causes the accumulated intensity to be lower** than the reference intensity (**1.4139e13 < 1.6e13 p.)**

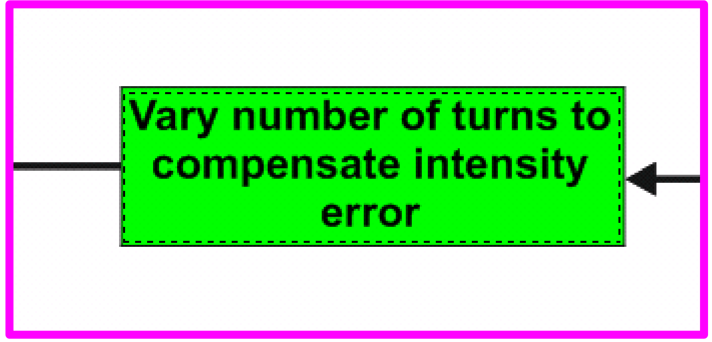




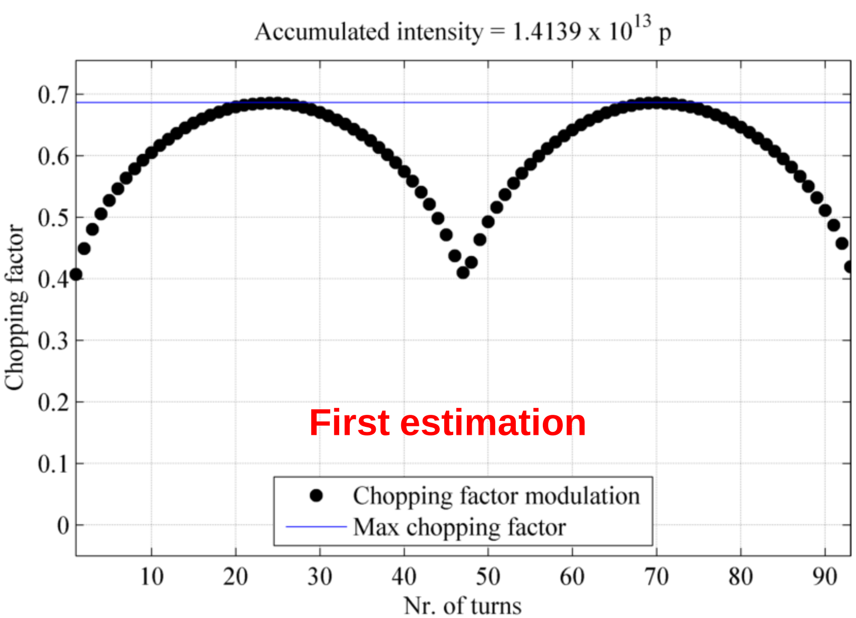
➢ **An iteration (feed-back) is needed to compensate the intensity difference → More turns are needed (from 93 to 106!) → <u>Slower</u> <u>energy modulation</u>**

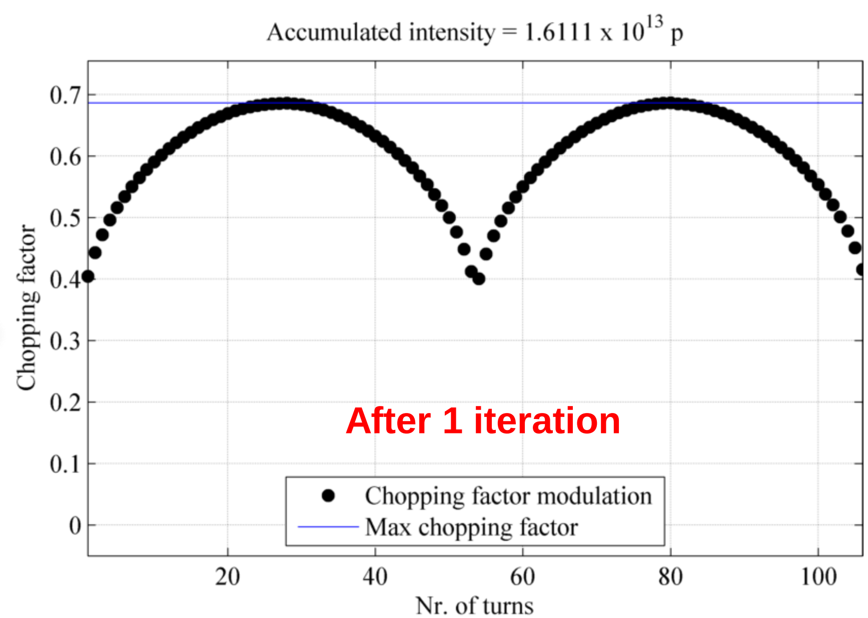






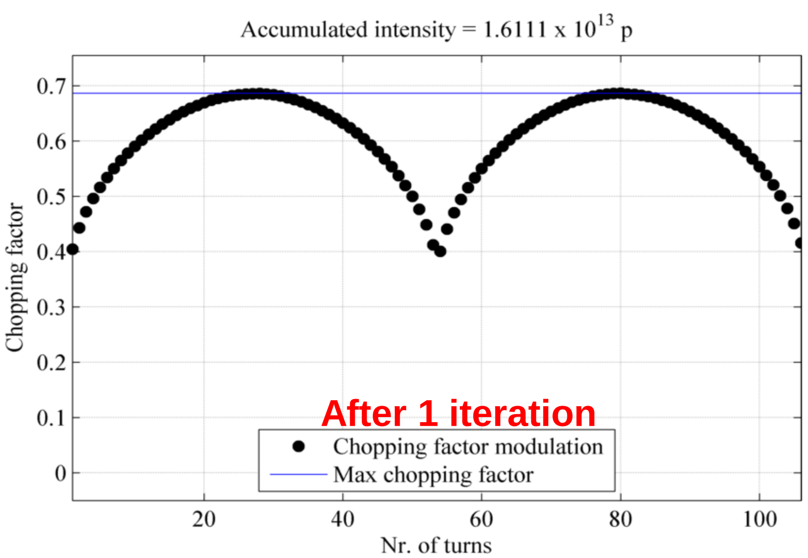
- After 1 iteration the estimated intensity is reasonably close to the target value (1.6111e13 ~ 1.6e13 p.)
  → The chopping factor pattern period becomes <u>slower</u>

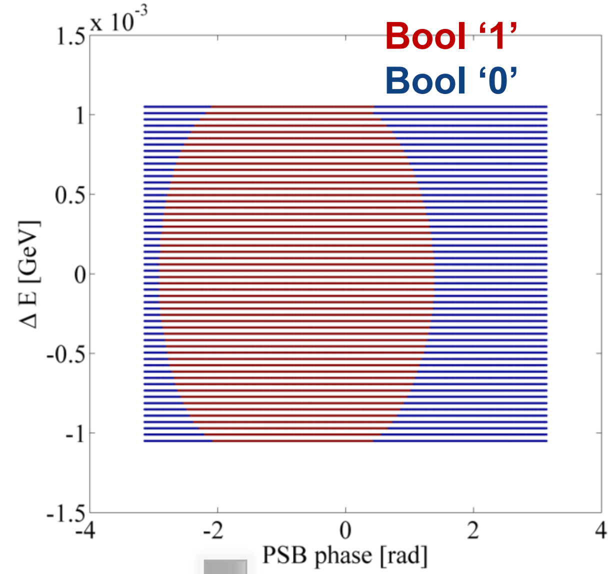


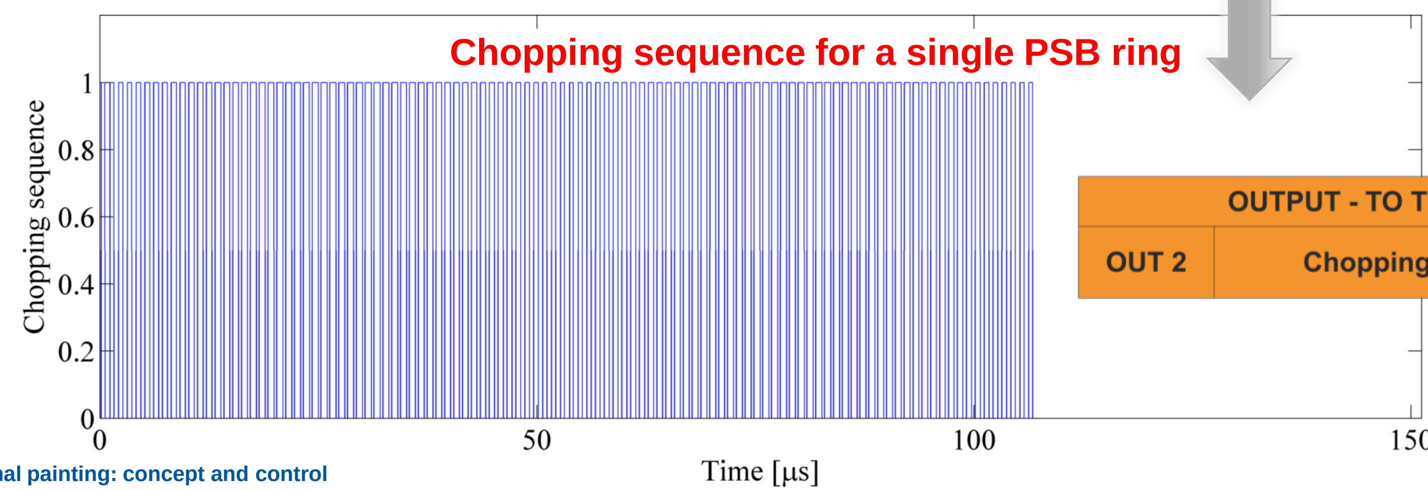


Output to the hardware: the chopping

- The chopping pattern must be translated in information for the chopper hardware: e.g. a binary sequence (0/1) of L4 microbunches





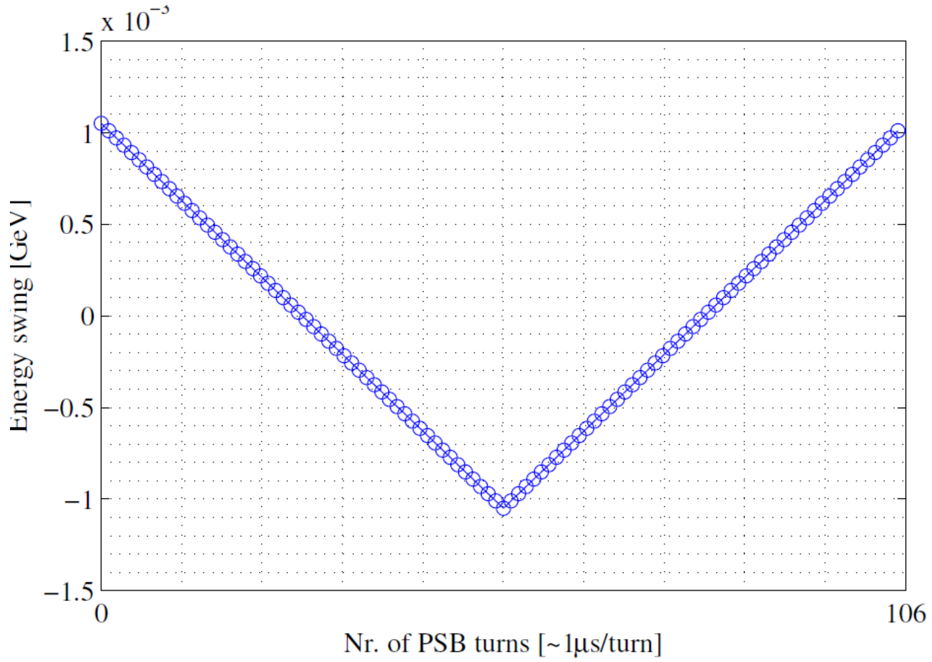


OUTPUT - TO THE CHOPPER	
OUT 2	Chopping sequence in time

Output to the hardware: the PIMS E_0 modulation

OUTPUT - TO THE PIMS	
OUT 1	E_0 vs. time look-up table

- The E_0 swing function could be **translated in form of GFA** (look-up table) for the PIMS cavities (11+12) regulations.



- **The swing rate (dE_0/dt) depends on the wanted energy spread by the de-buncher and by the power (available) at the de-buncher cavity.**

Output to the hardware: the de-buncher

OUTPUT - TO THE DE-BUNCHER	
OUT 3	Voltage and phase for minimum energy spread

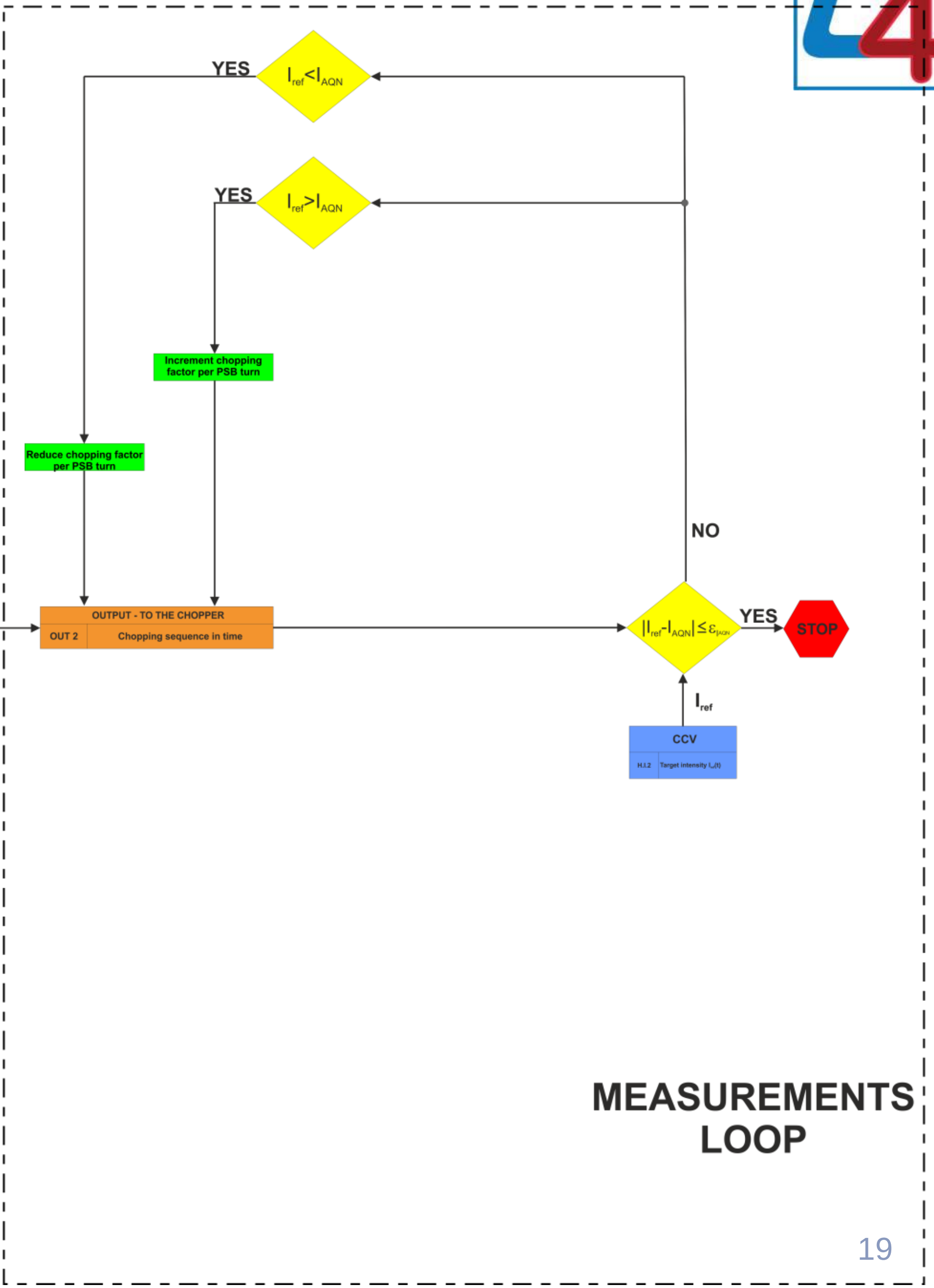
- The de-buncher is needed to generate different energy spreads at the entrance of the PSB.
- The voltage and the phase must be defined once, respecting the present hardware limitation constraints.
- The minimum energy spread achievable strictly depends on the E_0 sweep rate (imposed by the PIMS)
- **NOTA BENE!** For a finest painting, **the smaller the energy spread, the better**! → We aim to use ~100 keV rms at the entrance of the PSB
  → max E_0 sweep rate of 5.5 deg/s (limits the number of PSB turns to achieve given intensity)
- The correlation between de-buncher phase and energy spread at given voltage is foreseen during the commissioning in the LBS line.

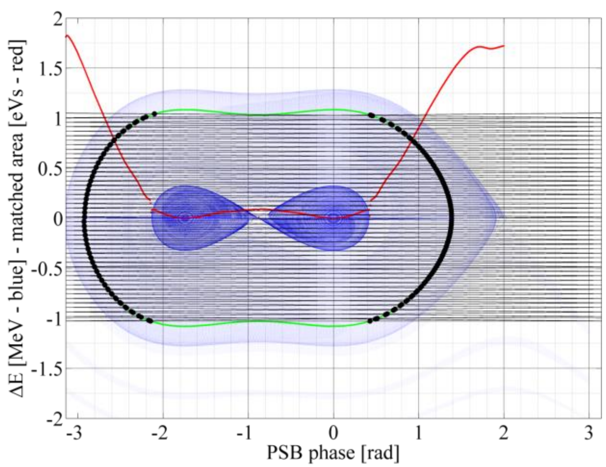
The measurements loop

- The measurements loop acts in **a smart way** on the **chopping factor** sequence in case the **measured intensity at a certain time marker soon after injection** differs from the desired one

- **E.g. 'Smart' way**: **random reduction or increment** of the chopping factor per turn **to minimize the mismatch with target contour**.

From virtual loop





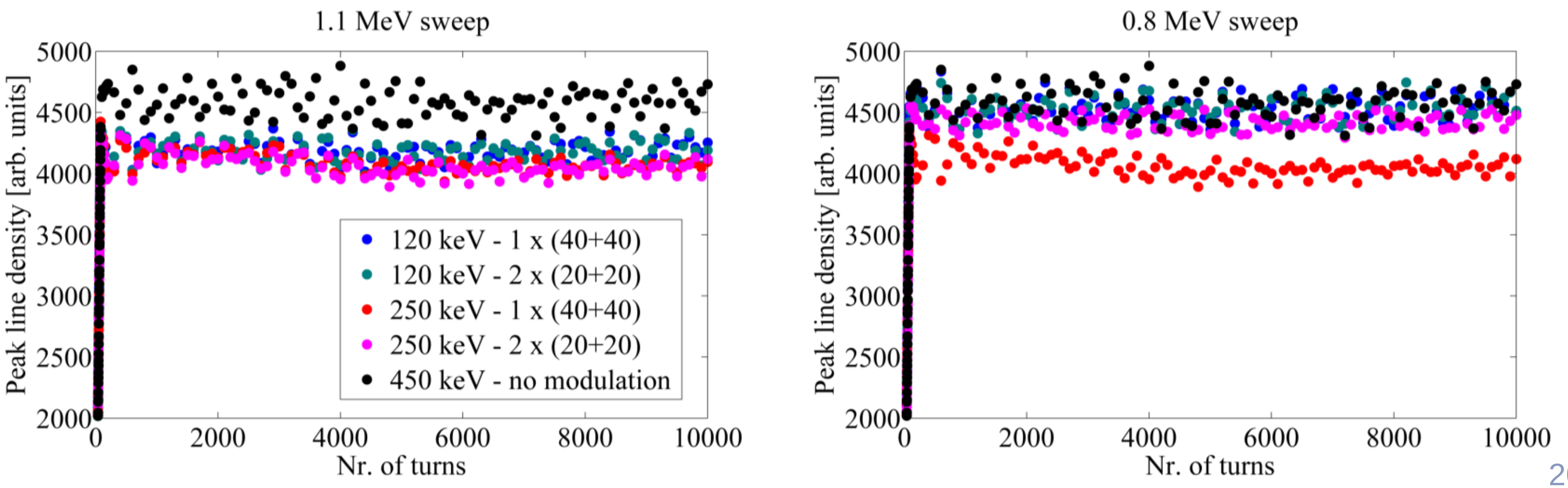
Next: longitudinal painting quality figures of merit

- The historical reasons for the painting in the PSB with L4 have always been related to space charge reduction.
- We might need another loop to control a specific figure of merit.
- **Suggestion: instead of pointing at target longitudinal emittance, shall we point to the contour with lowest peak line density amplitude and beating in time?**

- **Peak line density**
  - An **advantage of the longitudinal painting** is to **lead to a SMALLER peak line density (10%)**, compared to the un-modulated energy case.

$$\Delta Q_y = -\frac{r_0 \lambda}{2\pi e \beta^2 \gamma^3} \oint \frac{\beta_y(s)}{\sigma_y(s)\left[\sigma_x(s)+\sigma_y(s)\right]} ds$$

Simulations for future ISOLDE beams



Summary and next steps

- The longitudinal painting technique for the new L4 to PSB injection has been initially proposed by C. Carli and R. Garoby, as an **elegant and efficient way to reduce longitudinal filamentation , thus bunch shape (bunching factor) beating** from the very beginning.

- An introduction to the longitudinal painting process and control has been given.

- The longitudinal painting has the advantage to control the longitudinal plane with **high flexibility**, as we will do with the painting in the transverse plane.

- **It gives the possibility to implement in a very controlled way different longitudinal** (and also exotic, e.g. hollow bunches) **beam phase spaces**.

- **A 'simple' control algorithm, totally generic (for any given RF bucket shape) has been proposed**

- **<u>This algorithm could work also for the un-modulated injection</u>**, as this last is a particular case of injection with $E_0(t)=0$

- **The longitudinal painting is foreseen only at a late stage of the commissioning**, so **this is the moment to make brain storming and propose ideas** for its realization.

Next steps

- Missing implementative details:
  - Timing
  - Control
  - ….
- Control tolerances and quality indexes
- Interlocks
- Suggestions?

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