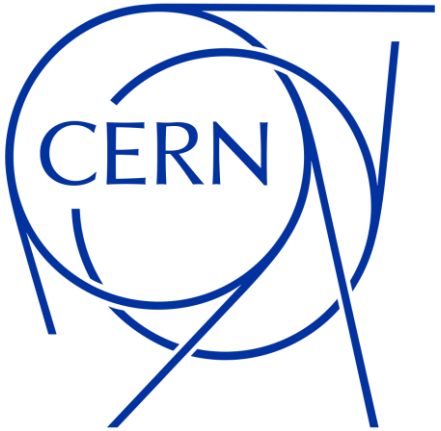

Injector Controller Studies
Continual optimisation of injection in the PSB

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2025/02/05

Common problem

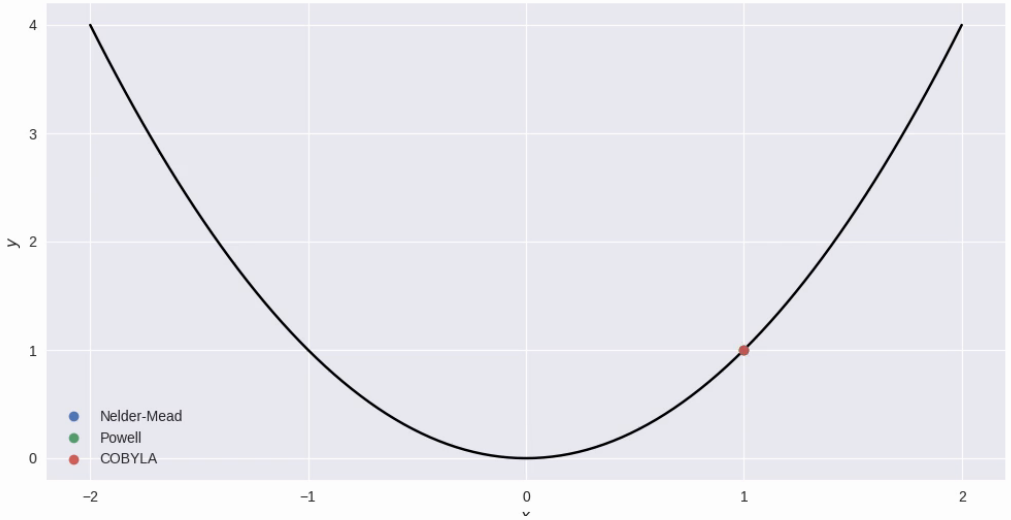
- Minimise some quantity *f*, dependent on:
  - **p**, parameters, i.e. things we can change

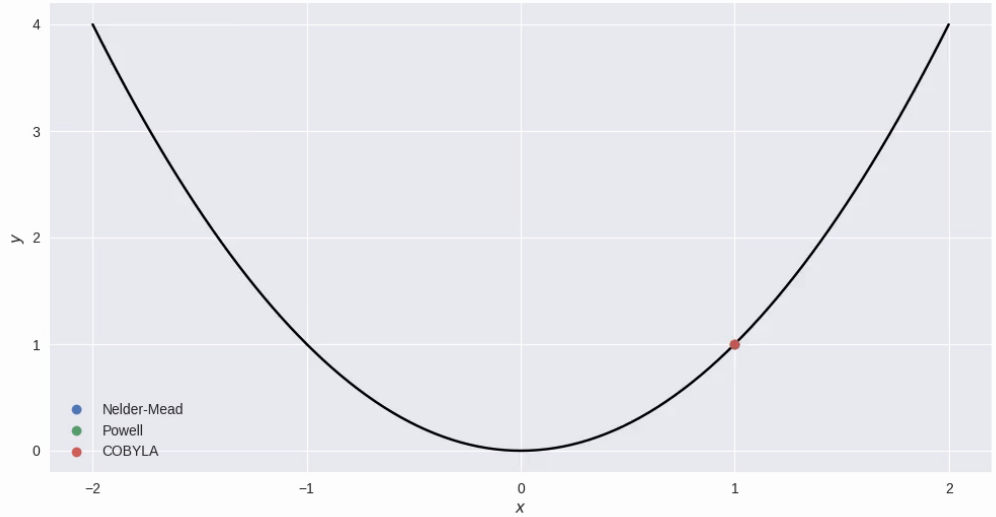
    optimiser ⇨ $\mathbf{p}_{\text{opt}}$
  - **s**, state variables, i.e. things we can't change
    - e.g.: machine drifts, stray fields

$$\min_{\mathbf{p}_t} f_t(\mathbf{p}_t) = f(\mathbf{p}_t; \mathbf{s}(t))$$

- Classical optimisers only handle **s** = {} or $\mathbf{s}_0$

  ⇒ **Time-varying Bayesian optimisation**[1]





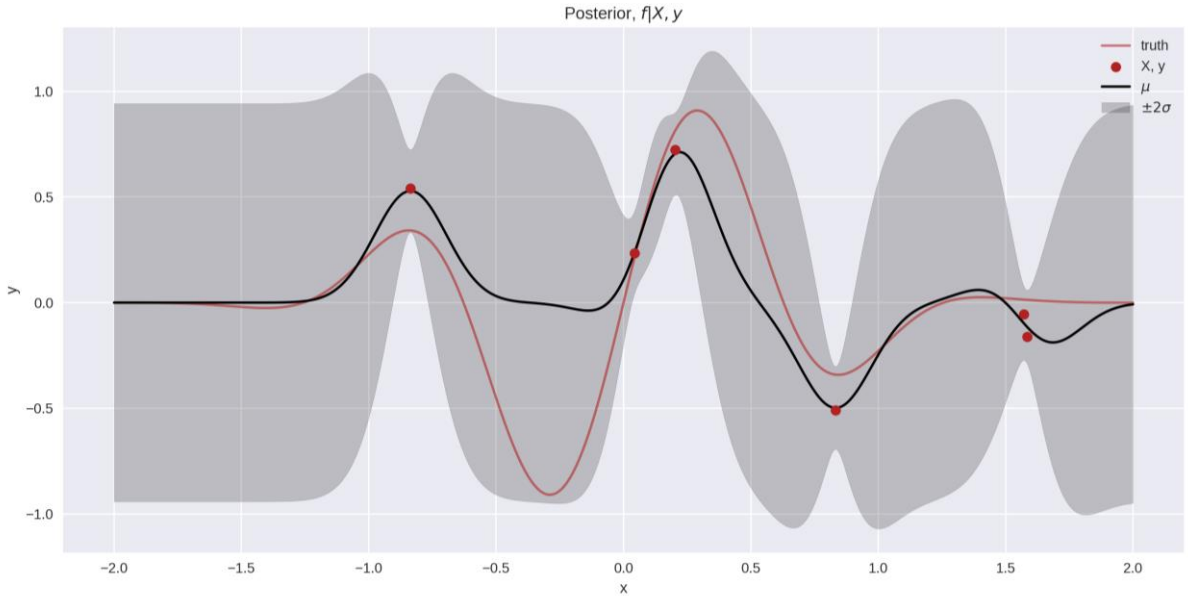
[1] Bogunovic et al, 2016 -- https://arxiv.org/abs/1601.06650

Gaussian process

- Probabilistic model:

$$f(\mathbf{x})|\mathbf{X},\mathbf{y} \sim \mathrm{Gaussian}(\mu(\mathbf{x}),\sigma(\mathbf{x}))$$

- For any **x**, we have a mean estimate μ, and uncertainty σ.



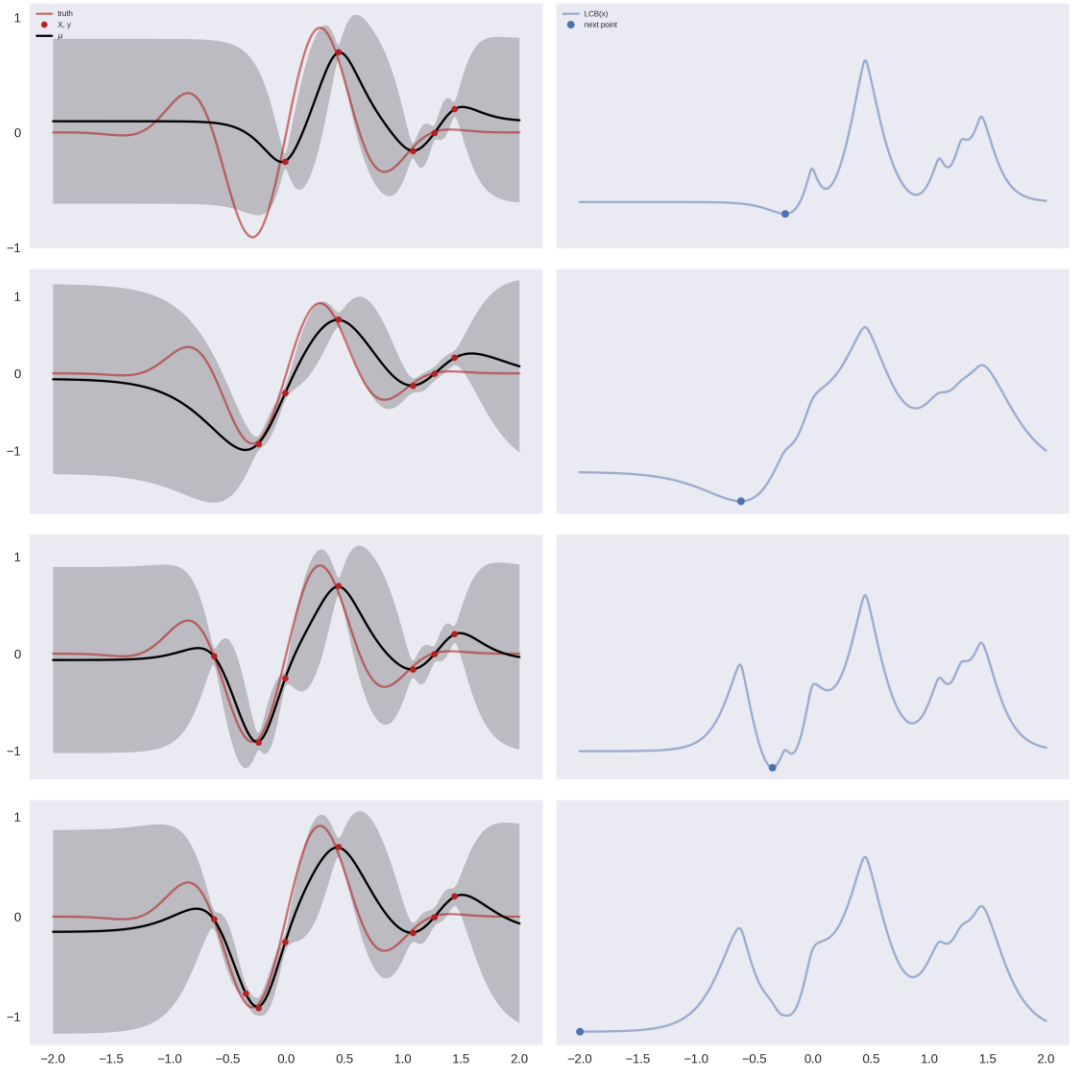
Bayesian optimisation

Procedure

1. Pick next point to observe: **x**
2. Get observation: *y*
3. Update posterior: μ, σ

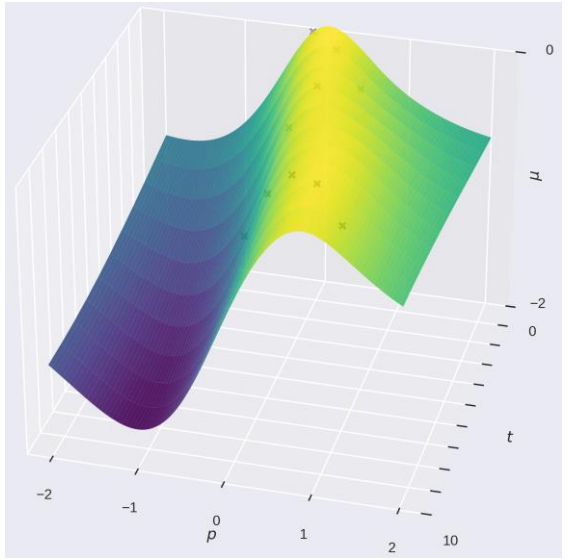
Picking next point

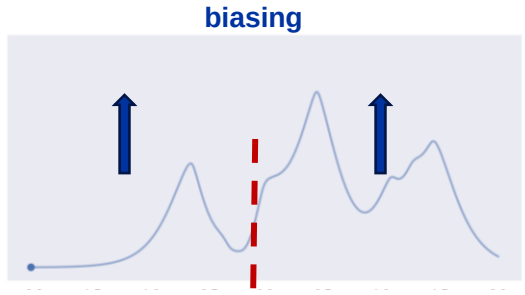
- Acquisition function:
  combine μ (exploitation) and σ (exploration)
  - e.g. LCB(**x**) = μ(**x**) - β σ(**x**)
- Minimum of acquisition function = next point



Time-varying Bayesian optimisation

- In addition to the parameters **p**, we add time, *t*, as a variable of the GP.
  - *t* is a proxy for the state **s**.
- Choose next point with *t* fixed to the next time (e.g. cycle timestamp).
- Avoiding large changes in parameters:
  - Proximal biasing
  - Proximal constraining

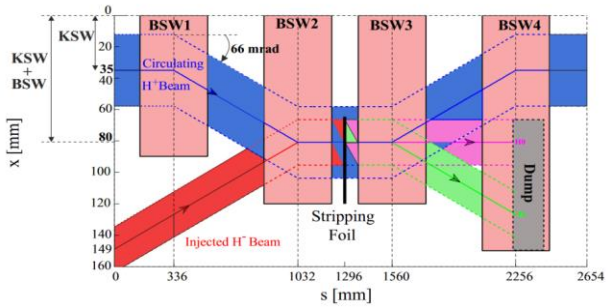


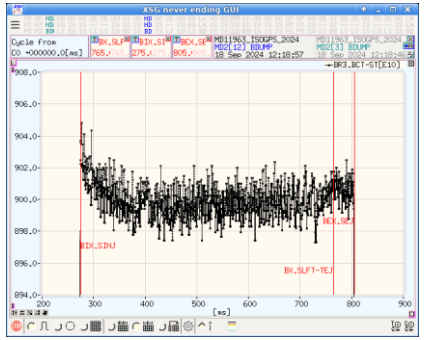


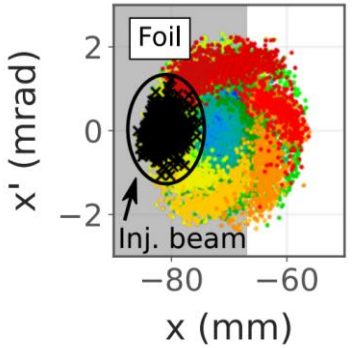
PSB Transverse Painting

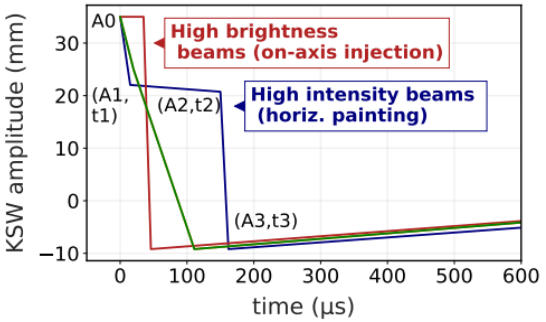
[2] Renner, 2022 https://cds.cern.ch/record/2843059m

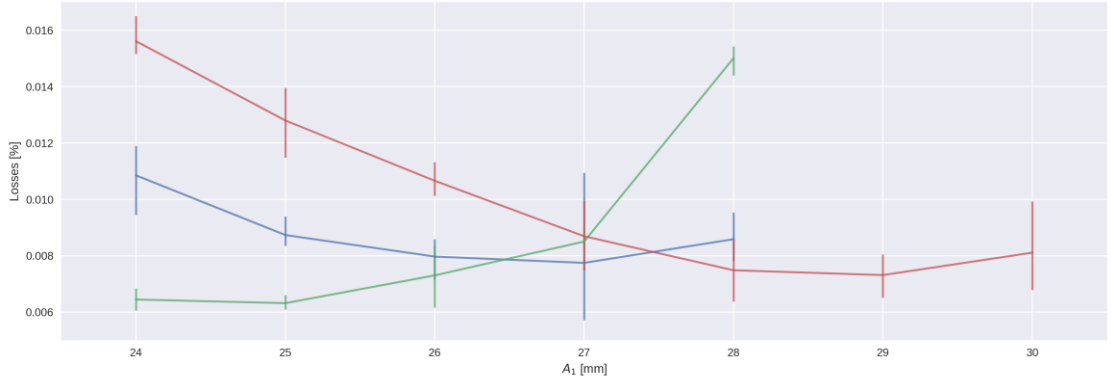
- LN4 injects H^-, which pass through a stripping foil, resulting in H^+, H^0, H^-.
- Space-charge losses
  - Minimise by sweeping the injected beam horizontally (painting) with the KSW.
- Match injection location with closed orbit (orthogonal steering vs KSW bump)



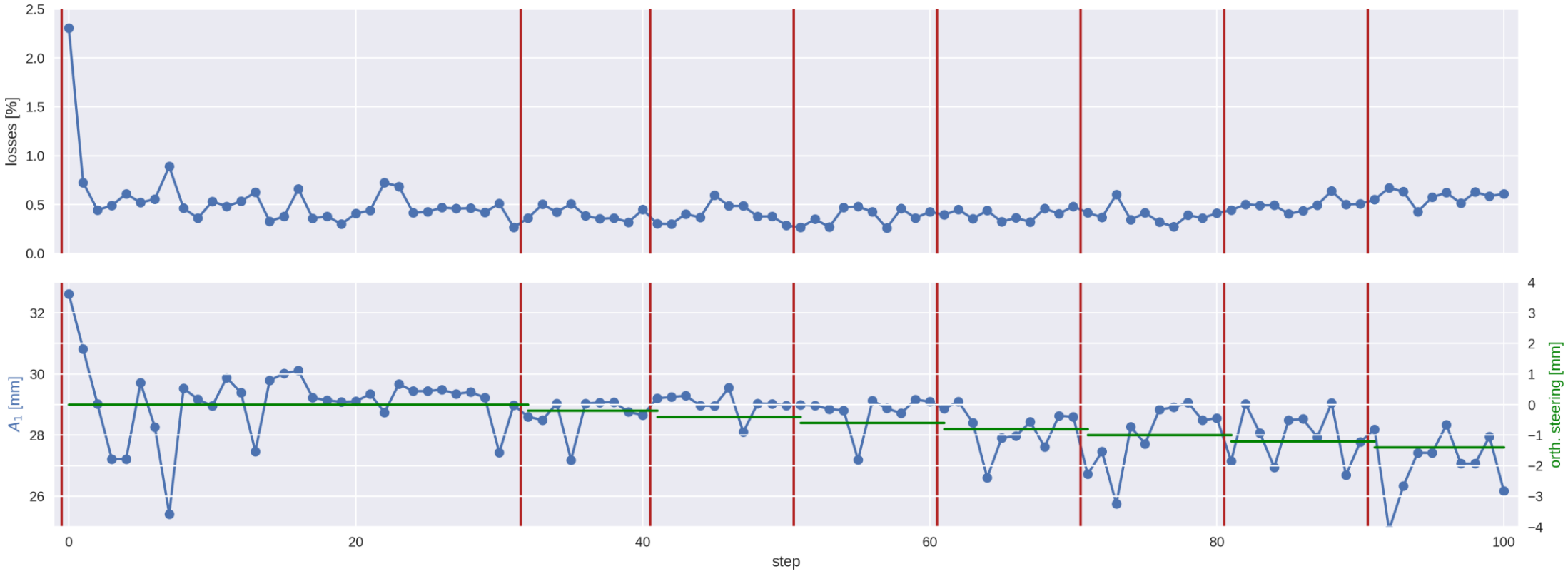




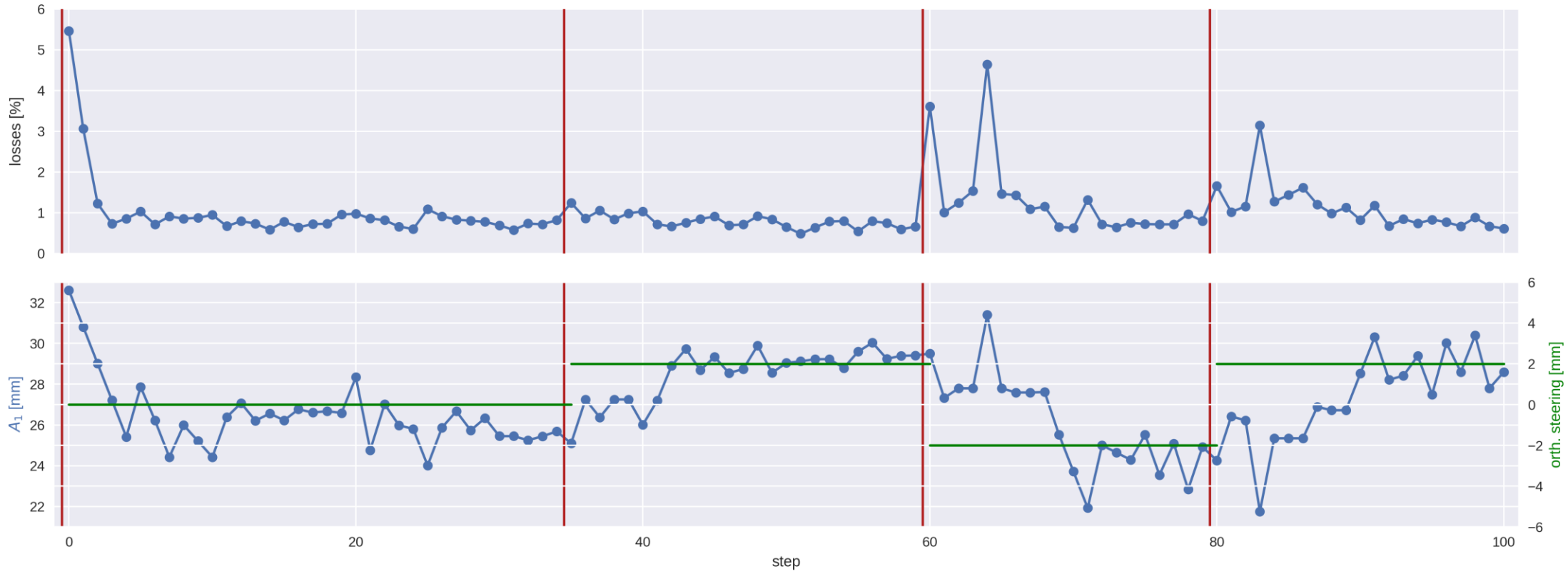




Results – drift



Results – jumps



Conclusion & Future

Conclusion

- TVBO successfully optimises objective vs slow and fast time-variations in state
- UCAP device and acc-geoff4ucap agent developed
- TVBO available as another optimiser that can be readily used by others

Future

- TVBO running continually via acc-geoff4ucap
- Fully configurable and supervised by OP/experts, e.g. via LSA settings
- Test acc-geoff4ucap on long MD (days, perhaps weeks)


CERN

Results – multiple parameters