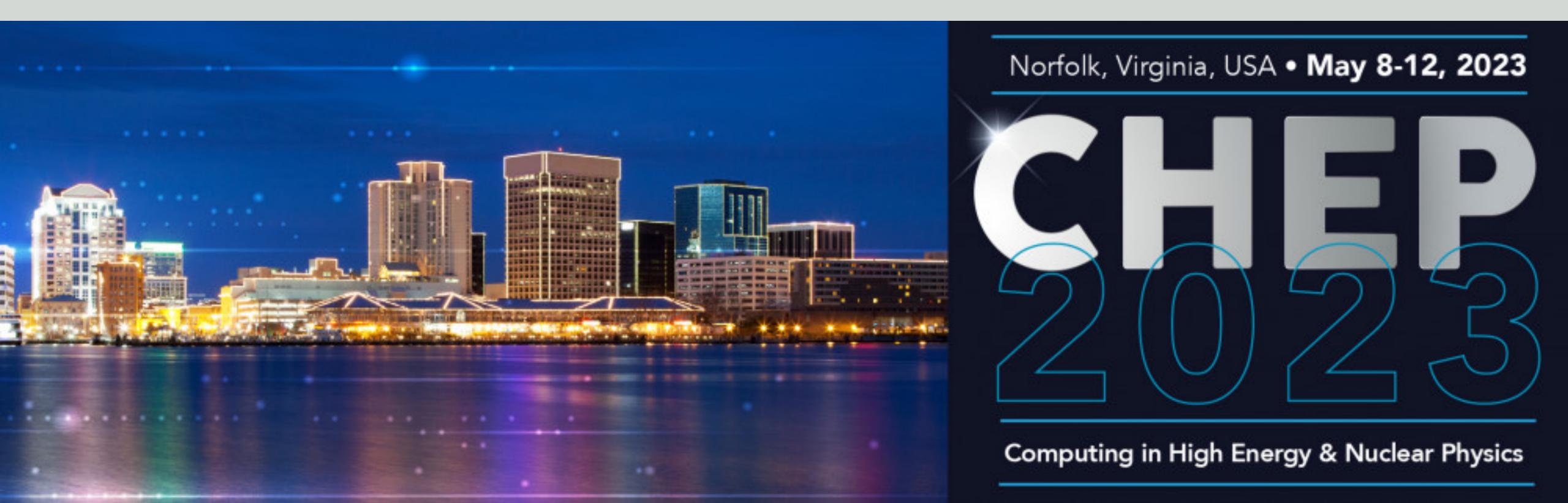
A parameter optimisation toolchain for Monte Carlo detector simulation - improving the recipe for full detector simulations -

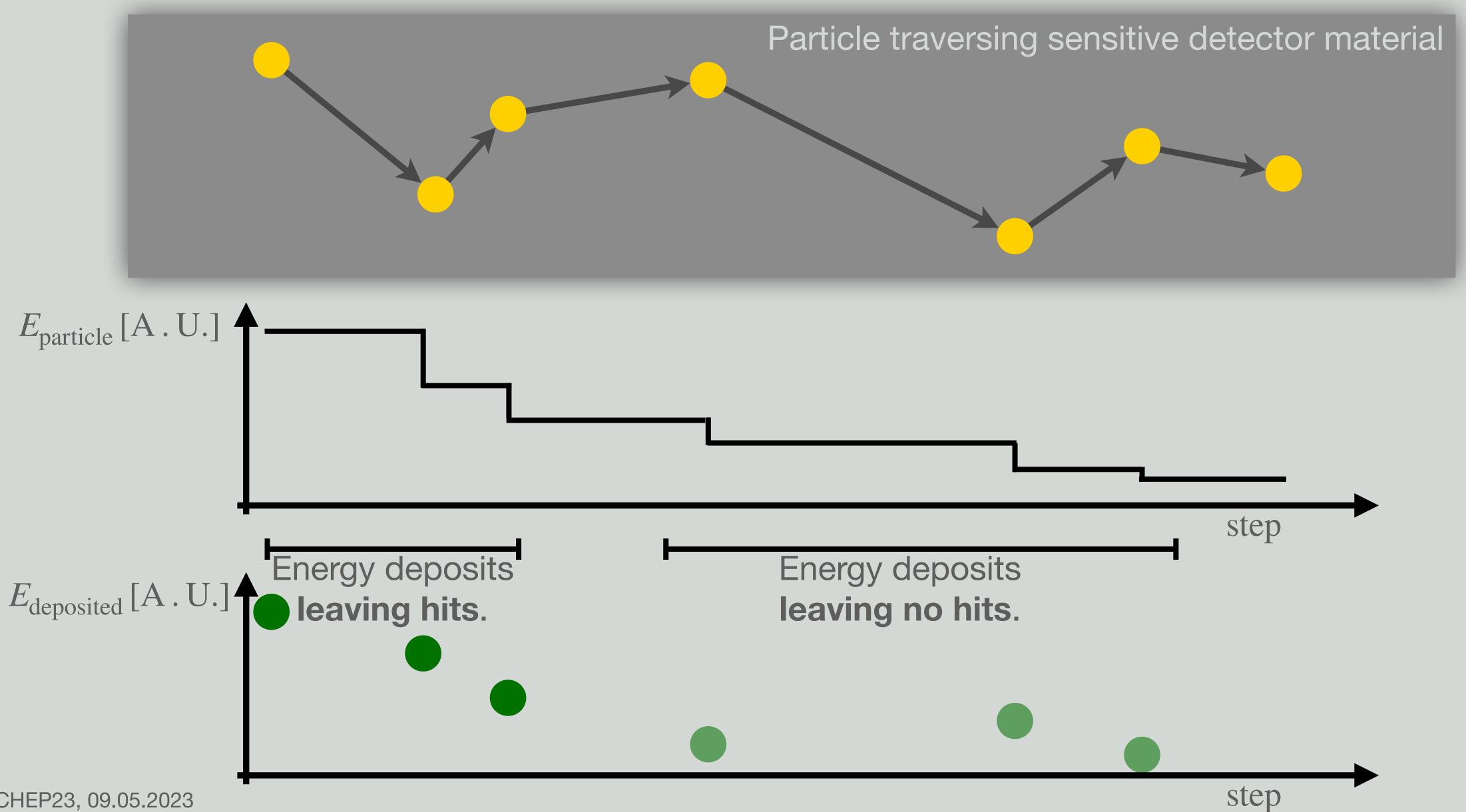
CHEP2023/Track 3 - 09.05.2023



<u>B. Volkel</u>



MC transport recipe



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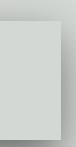


MC transport recipe



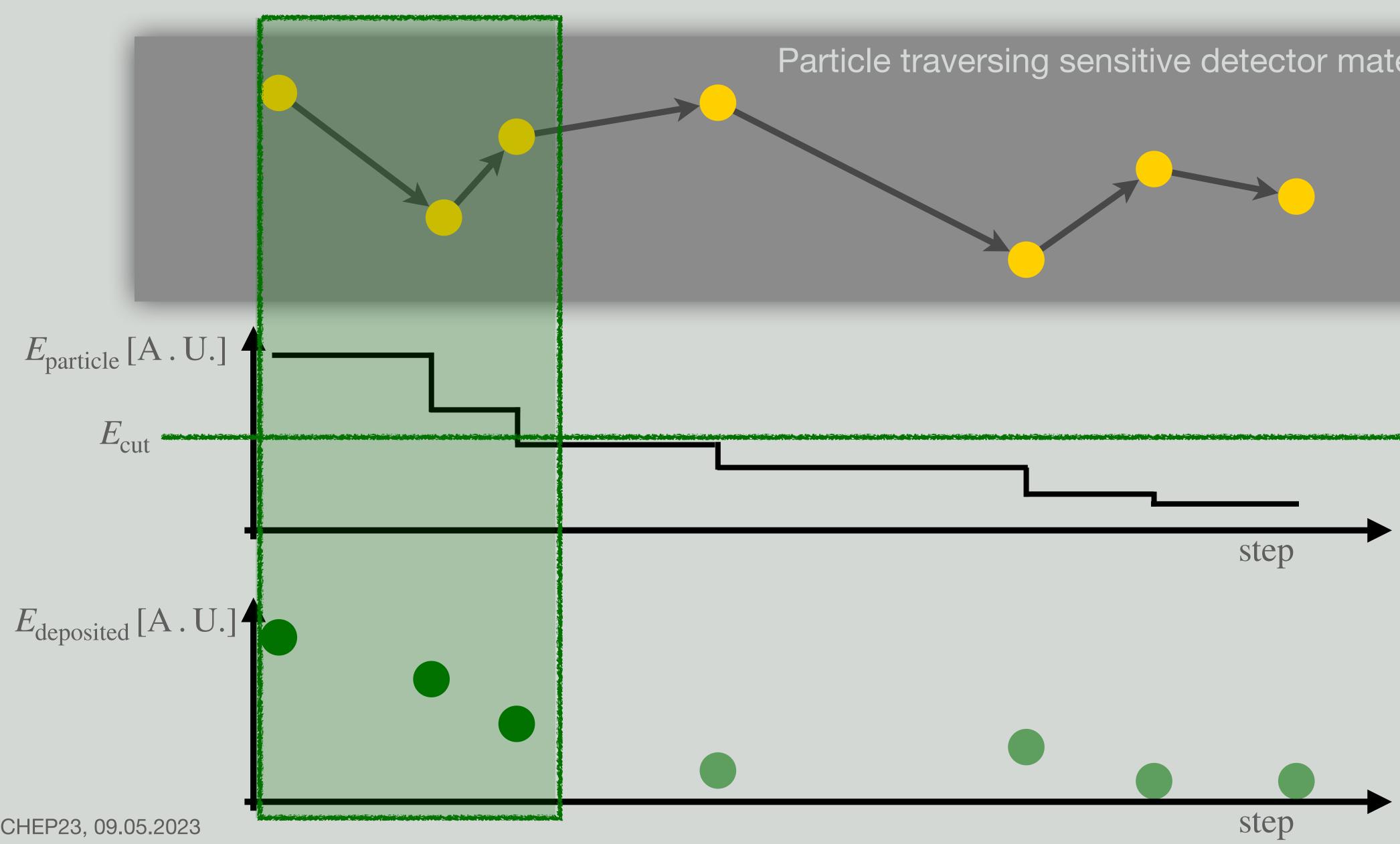
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Steps without hits don't add to the taste...

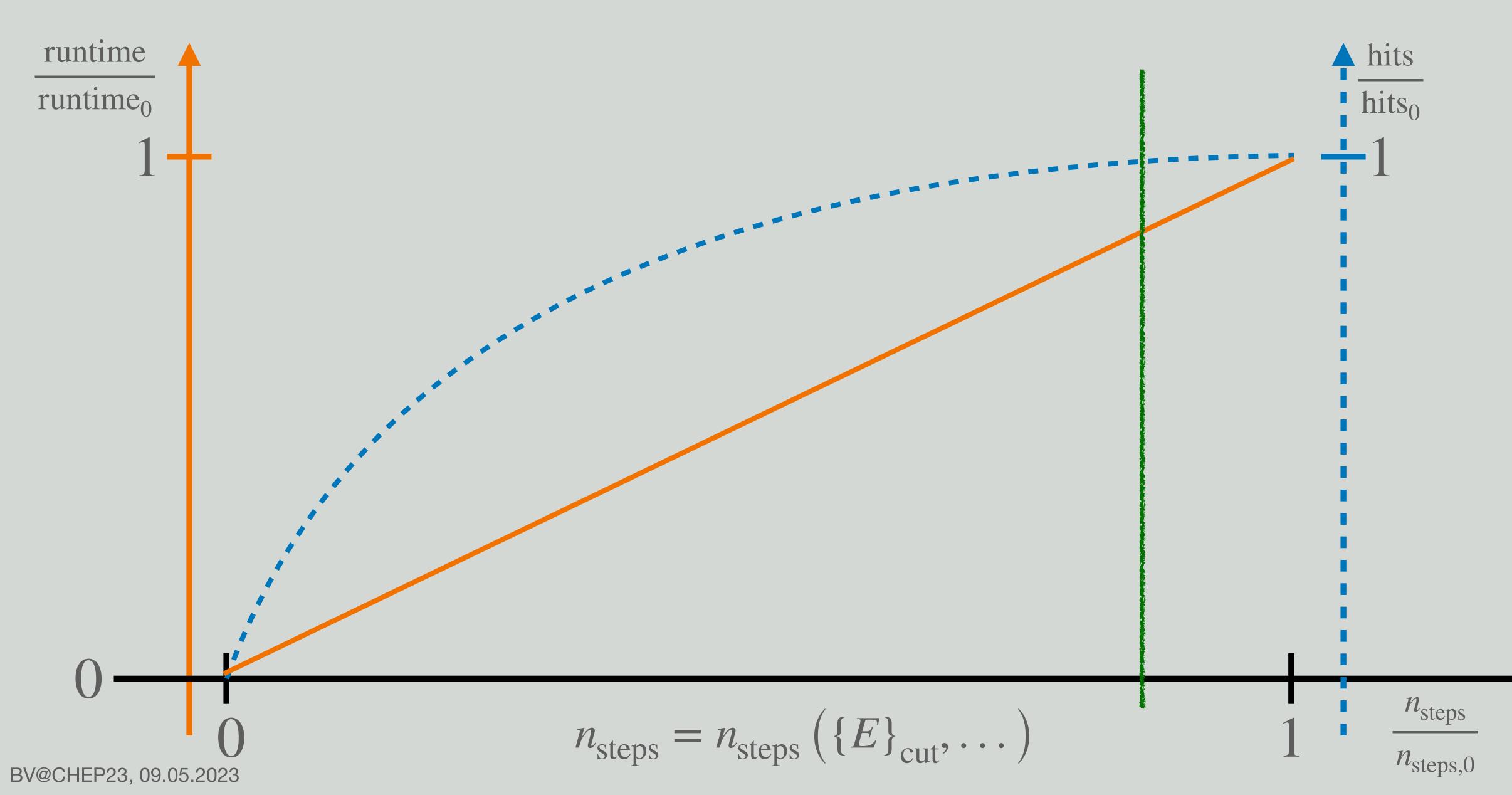


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Particle traversing sensitive detector material



... so we might speed up the preparation!





►



...so we might speed up the preparation!

runtime runtime₀

Can we find an optimal set for $\{E\}_{cut}$ for different particles and materials such that the impact on the hits is negligible while the resource needs can be decreased significantly?

This is an optimisation problem!

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nsteps

n_{steps,0}







Ingredients

100% reproducible simulations

Optimisation framework

Validation and closure

Specific definition and configuration of optimisation

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<u>MCStepLogger</u> <u>MCReplayEngine</u>

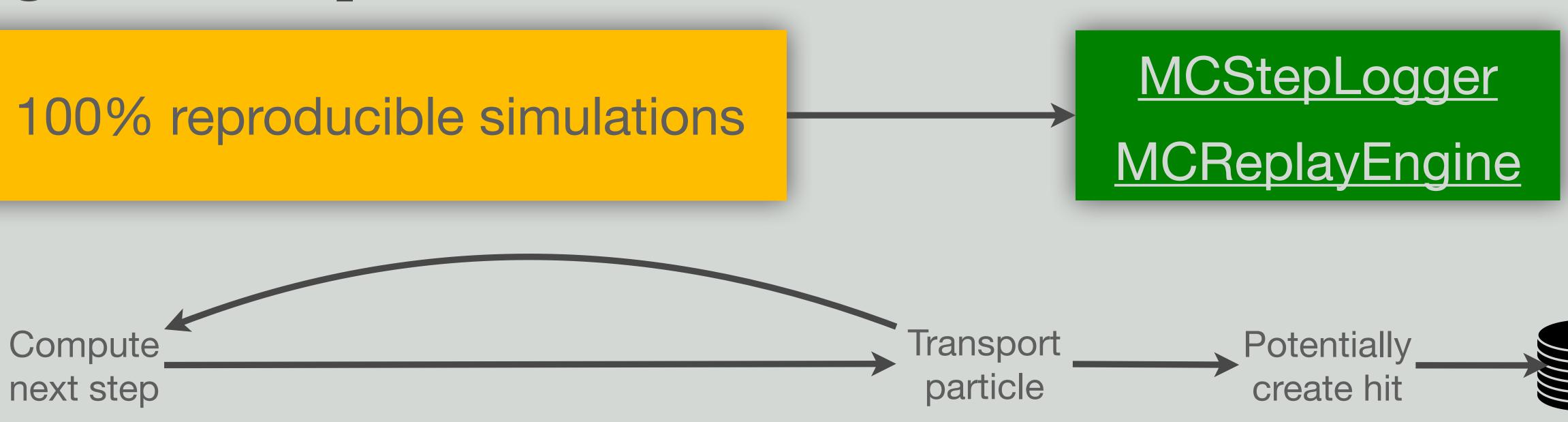


ReleaseValidation

o2tunerRecipes







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Hits

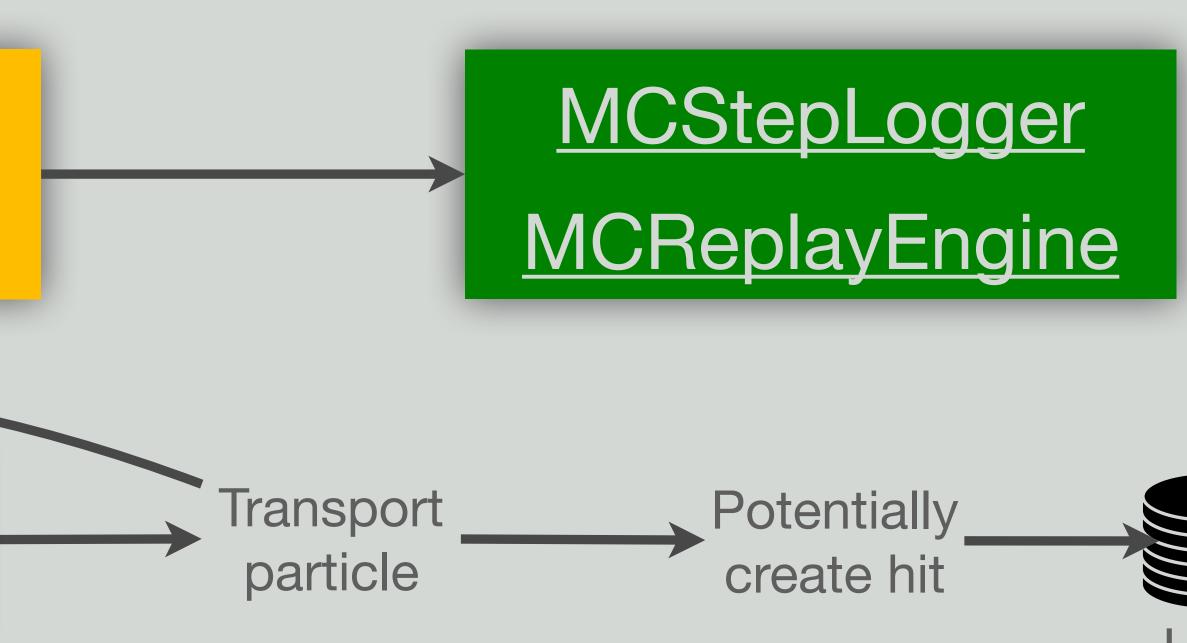
100% reproducible simulations



MCStepLogger overwrite symbols

and dispatch



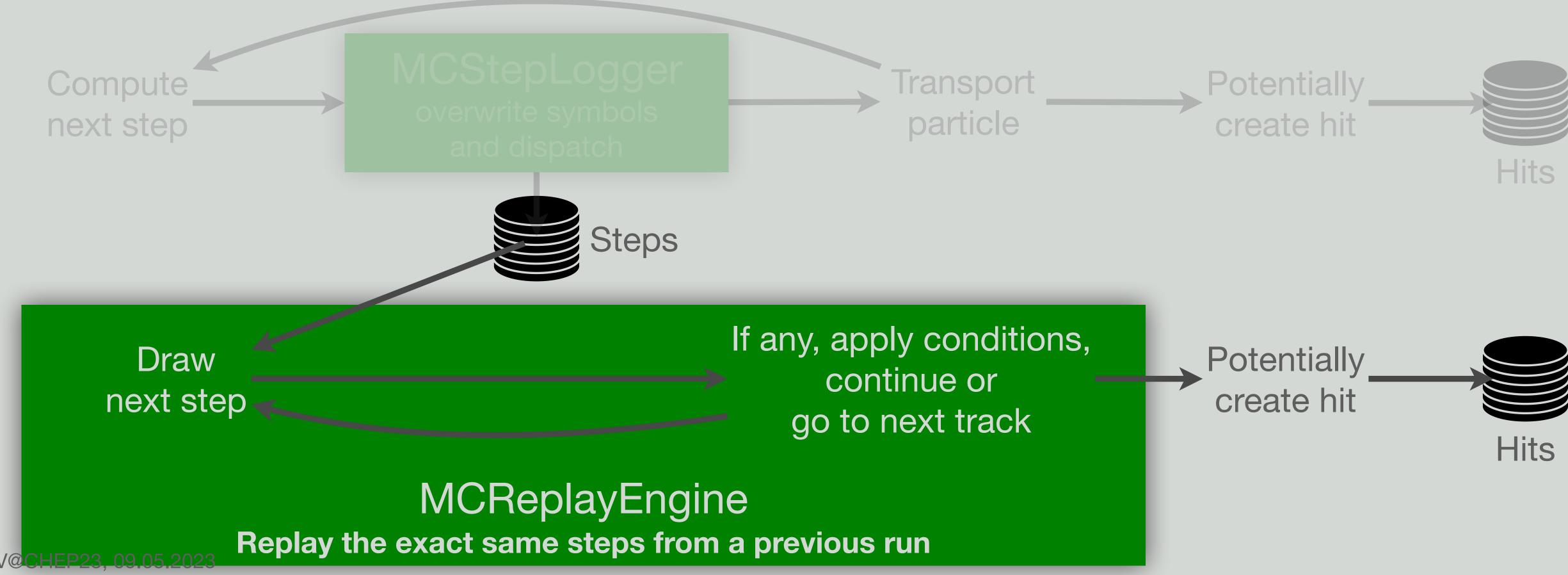




Hits



100% reproducible simulations







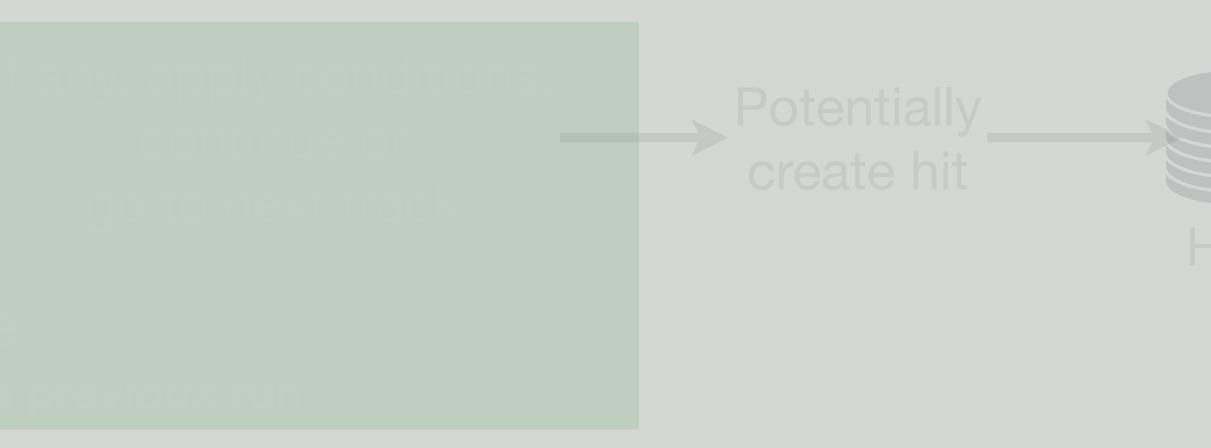


100% reproducible simulations

We can EXACTLY replay a previously recorded full simulation!

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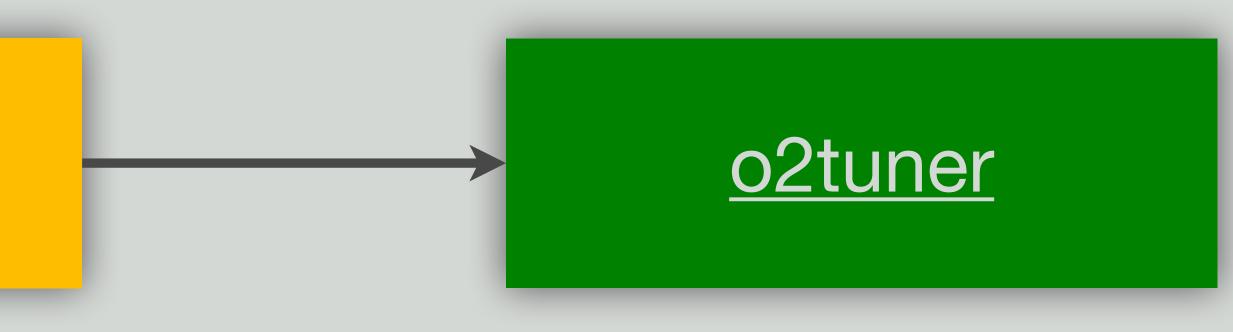


lits

Optimisation framework

- Execute user-defined recipe

 - Ensure reproducibility
 - Wrap parallelisation
 - **Optimise** various applications such as ML models or parameter-dependent executables and scripts



• Work through necessary steps (e.g. data preparation, optimisation, evaluation)





Validation and closure

- Automatically
 - Compare various different observables
 - Compute various different metrics
 - Plot and report summaries

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ReleaseValidation



Ingredients - prepared by the user

Specific definition and configuration of optimisation

- Toolchain definition
 - Objective function and loss [required]
 - Functions for (reference) data creation [optional]
 - User-defined evaluation and closure tests [optional]
 - Optimisation configuration [optional] [number of trials, jobs, parameter sampling etc.]

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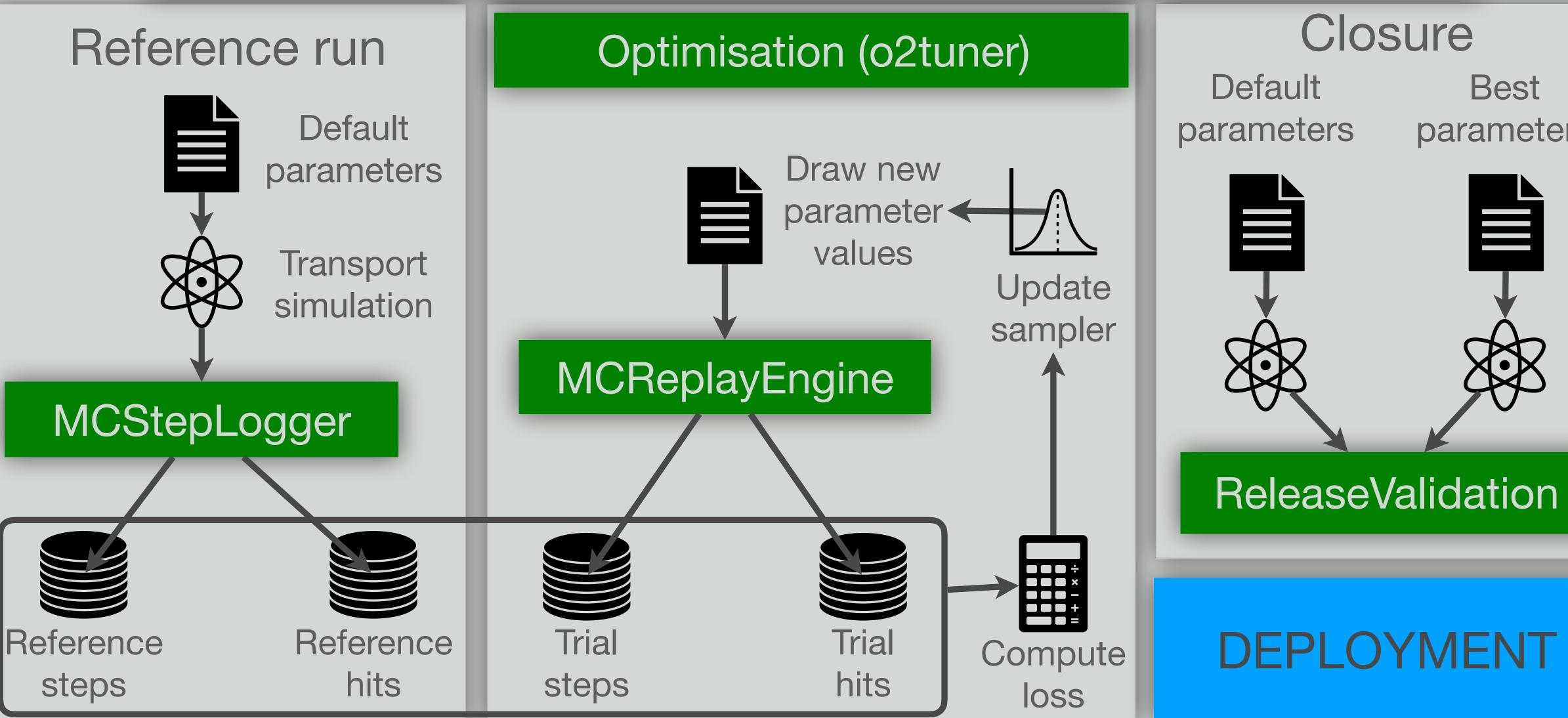
o2tunerRecipes





Preparation

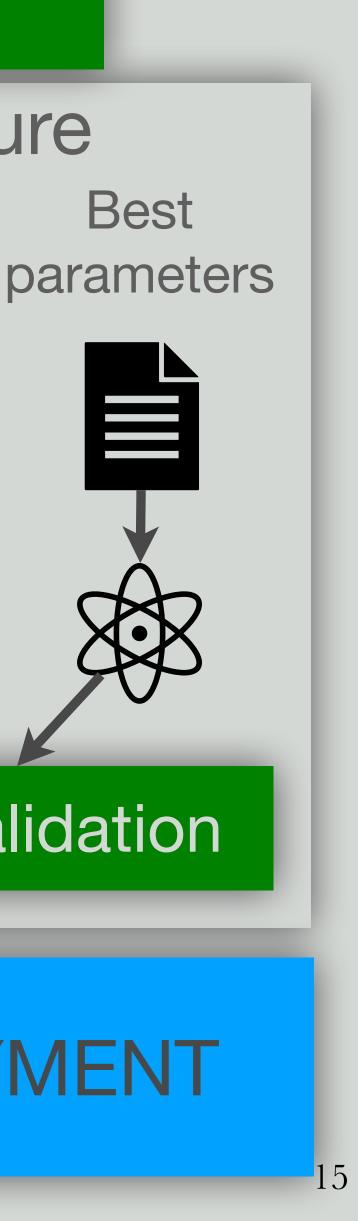
Toolchain definition (o2tunerRecipes)



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Best



Pre-cook the loss

Steps

Steps themselves are **invisible** to the detectors. They are the results of MC calculations.

Keep hits while dropping steps! Defining the loss.

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→Hits

Hits are the physical energy deposits a detector **can see**. This is what we need to keep.



Pre-cook the loss

$$\frac{\partial L}{\partial s_{t}} > 0$$

 $L_{t}(s_{ref}, \{h\}_{ref}^{d}, s_{t}, \{h\}_{t}^{d}) =$

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► Hits $\frac{\partial L}{\partial h_{\rm t}^{\rm d}} < 0$

Define a metric to be evaluated for each chosen set of drawn values.

Optimisation trial t, Number of steps S, Detector d, Hits h^{d} in detector, detector-specific penalty α^{d} .



Pre-cook the loss

$$\frac{\partial L}{\partial s_{t}} > 0$$

Define a metric to be evaluated for each chosen set of drawn values.

$$L_{t}\left(s_{\text{ref}}, \{h\}_{\text{ref}}^{d}, s_{t}, \{h\}_{t}^{d}\right) = \frac{s_{t}}{s_{\text{ref}}} + \frac{1}{N^{\text{det}}} \sum_{d \in \text{det}} \alpha^{d}\left(h_{t}^{d}, h_{\text{ref}}^{d}\right) \cdot \left[1 - \frac{h_{t}^{d}}{h_{\text{ref}}^{d}}\right]$$

Optimisation trial **t**, Number of steps S, Detector d, Hits h^{d} in detector, detector-specific penalty α^{d} .

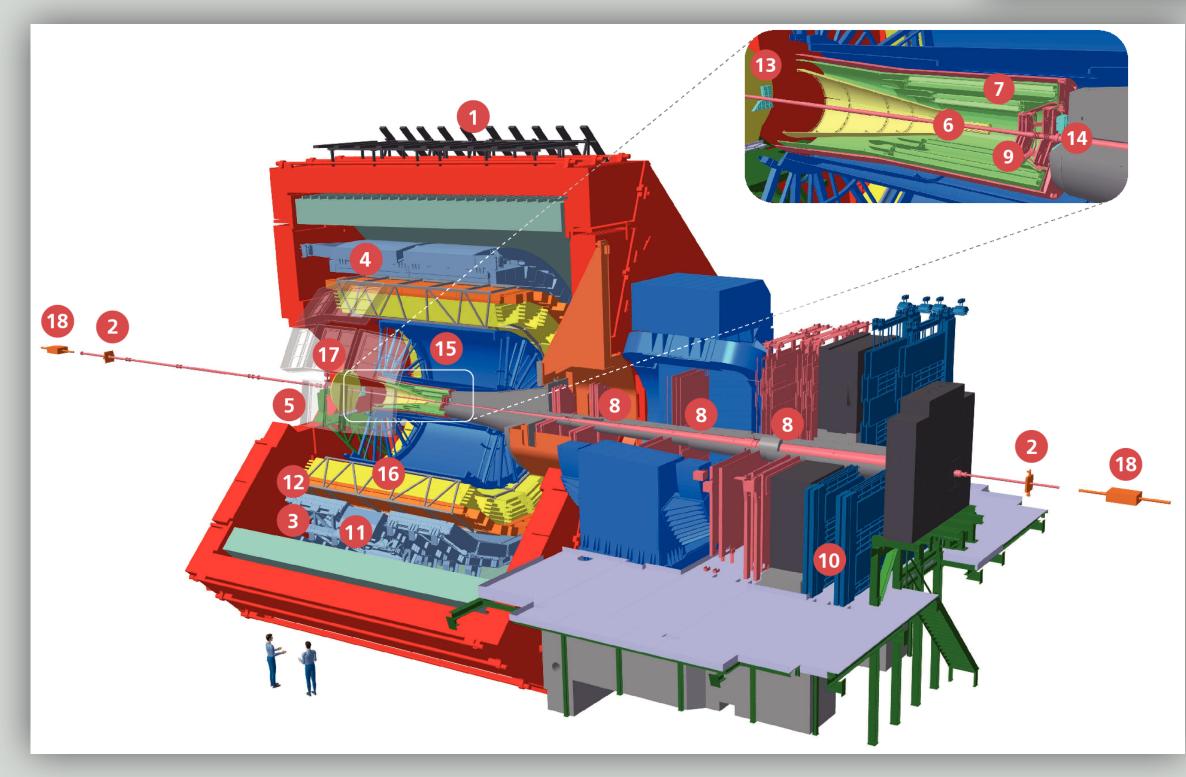
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$$Hits \frac{\partial L}{\partial h_{\rm f}^{\rm d}} < 0$$



Final thoughts before optimising



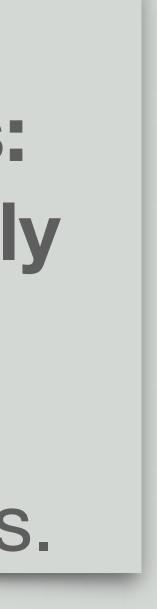


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We first target the reduction of steps in passive modules: only leave what will eventually be seen by detectors. Show results for beam pipe. Account for hits in all detectors.







Optimisation... boiling, waiting, stirring... Tasting!



Optimised values of electromagnetic cut parameters

		L				
		PIPE_BE (ID 43)				
		PIPE_CU (ID 44)	-			
		PIPE_INS_C0 (ID 51)	-			
		PIPE_AIR (ID 48)				
		PIPE_VACUUM (ID 52)	-			
		PIPE_INOX (ID 56)				
		PIPE_TITANIUM (ID 65)	-			
		PIPE_CU_NF (ID 45)				
		PIPE_AIR_HIGH (ID 49)	-			
	ЭС	PIPE_VACUUM_NF (ID 53)				
	name	PIPE_INOX_NF (ID 57)	-			
	medium I	PIPE_CU_HC (ID 46)				
		PIPE_AIR_NF (ID 50)	-			
		PIPE_VACUUM_HC (ID 54)	-			
		PIPE_INOX_HC (ID 58)	-			
		PIPE_AA5083 (ID 60)	-			
		PIPE_AA2219 (ID 61)	-			
		PIPE_POLYIMIDE (ID 62)	-			
		PIPE_M55J6K (ID 63)	_			
		PIPE_ROHACELL (ID 64)	_			
		PIPE_CU_NFHC (ID 47)				
	F	PIPE_VACUUM_NFHC (ID 55)				
		PIPE_INOX_NFHC (ID 59)	_			
			TELE			x GAM
			CO.			ري
E	8V@	CHEP23, 09.05.2023		cut par	ameter	

Many parameters changed by 1-3 orders of magnitude.

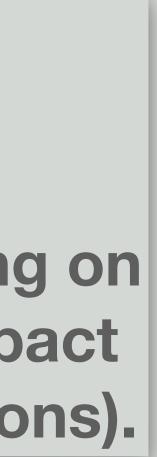
In this case (electromagnetic), cutting on electrons(photons) has a strong impact on the abundance of photons(electrons).

ratio opt / ref

10²

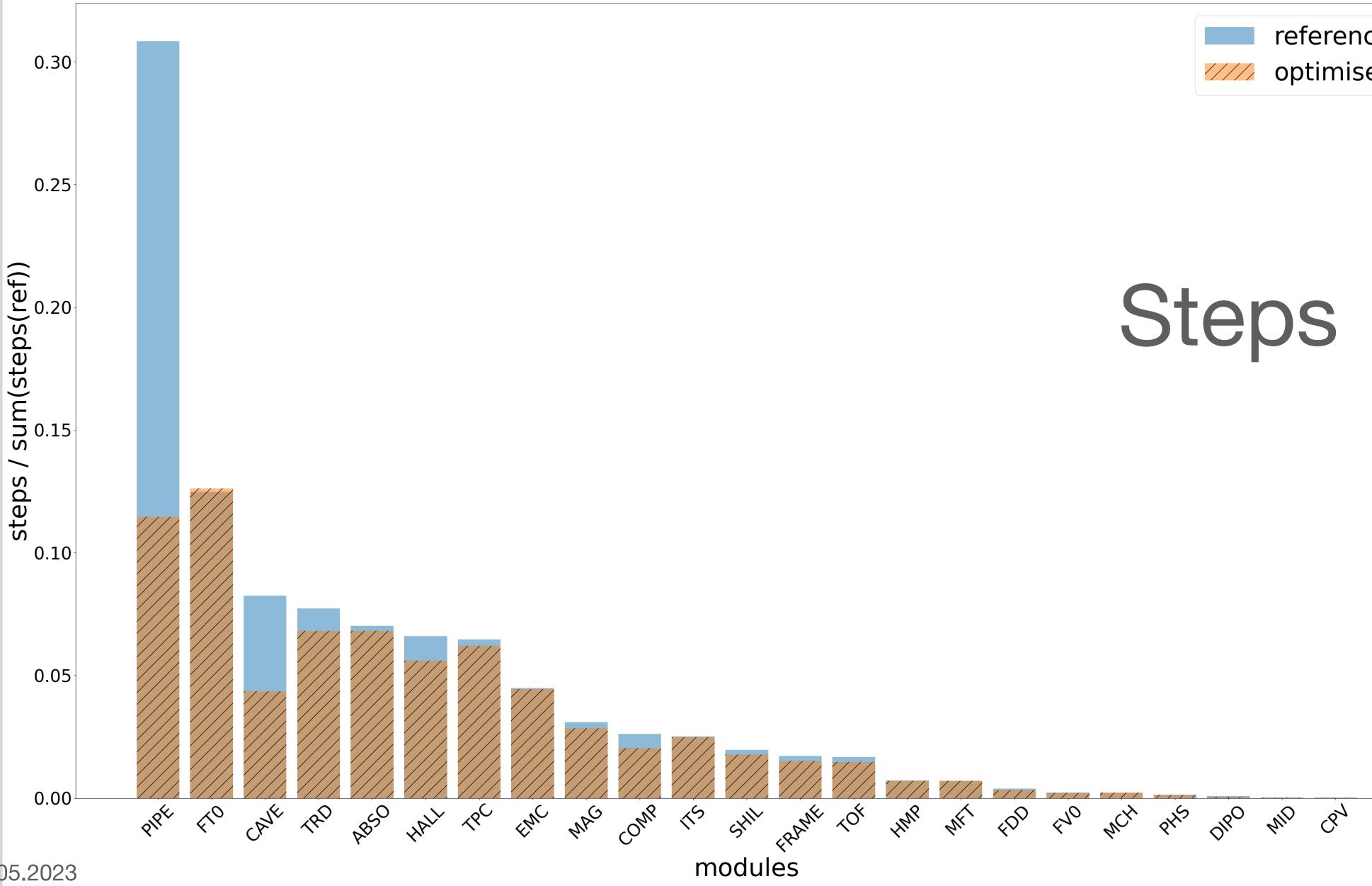
·10¹



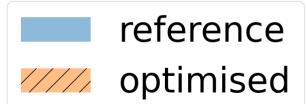




Removed more than 20% of all steps...

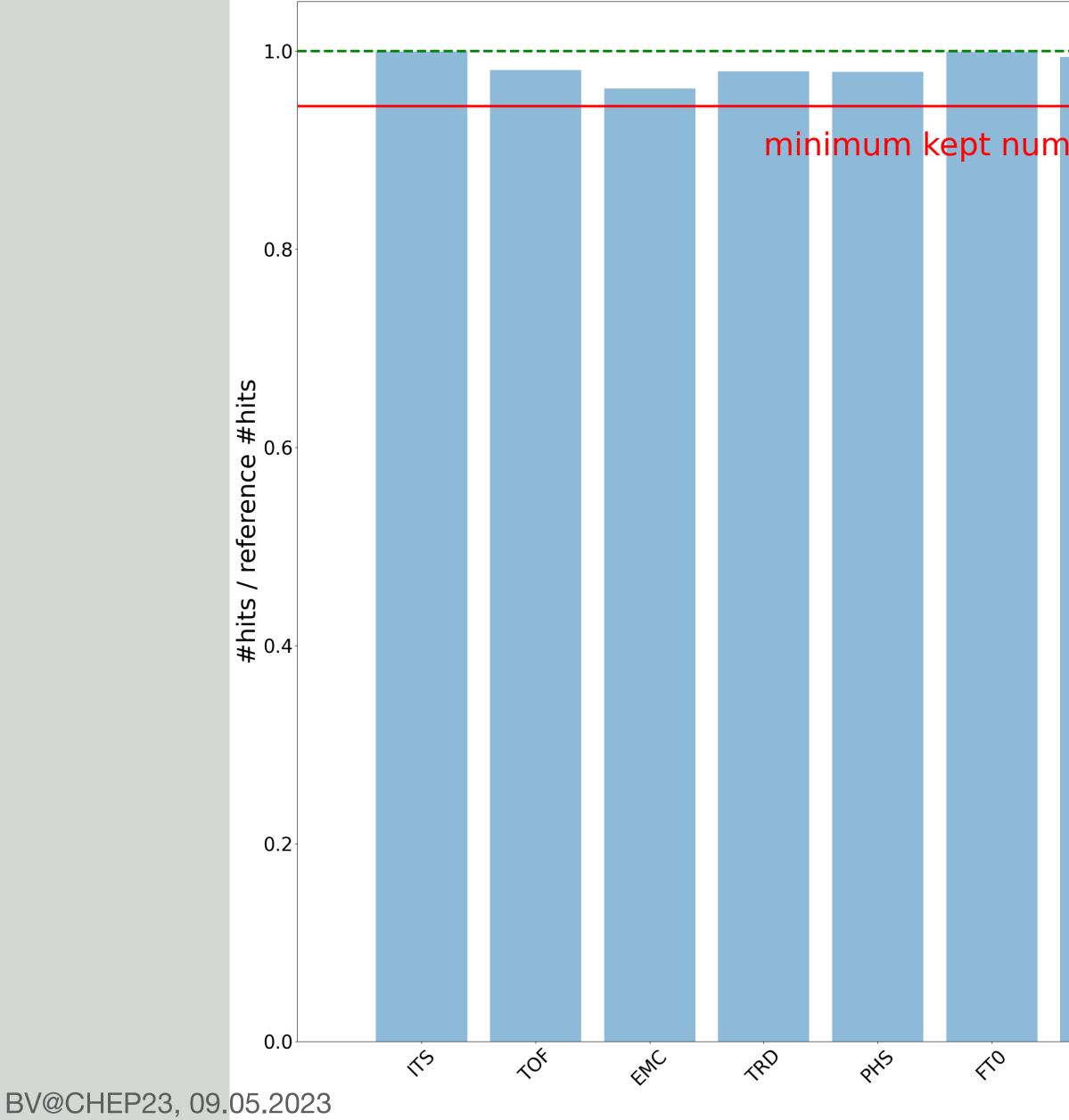


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...while keeping almost all hits



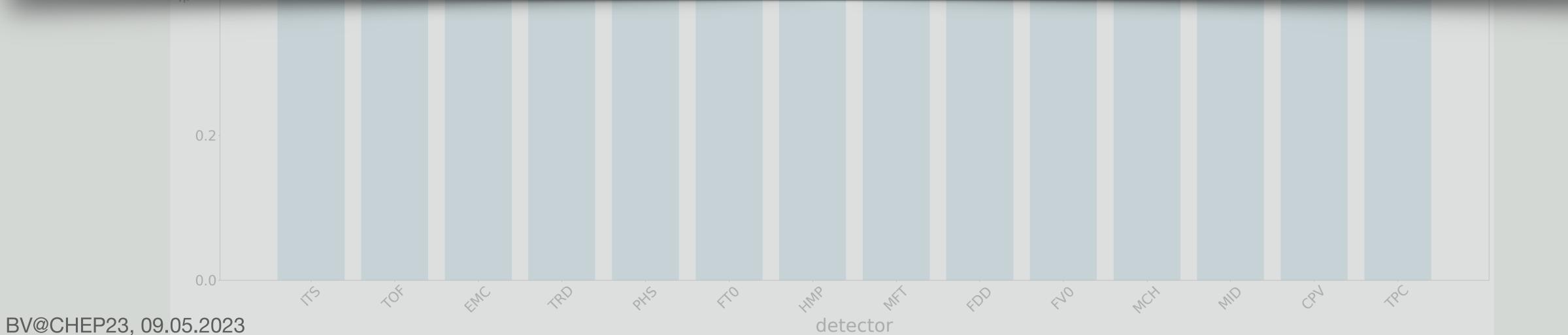
nber of hits 0.	9445						
				- H.	1:1-		
					lits	5	
			.>		~	()	
unt detector	400	ENO	MCH	MID	CEN	RC	



...while keeping almost all hits



Good agreement between old and new parameter settings, compared more than 1,000 observables using various metrics for comparison.









Bon Appetit!

- Gain 20% speed-up of full-simulation (only beam pipe).
- We will target other geometry or phase-space related parameters in such optimisations.
 - Now, the focus lies on further passive modules.
 - After that, we target additional parameters.
- Not only applicable to transport simulation but also to other parts of the simulation chain. [Digitisation, reconstruction, tracking...]
- Our studies teach us more about our detector as well as our simulation algorithms. [Provide valuable insight towards potential fast-simulation approaches.]







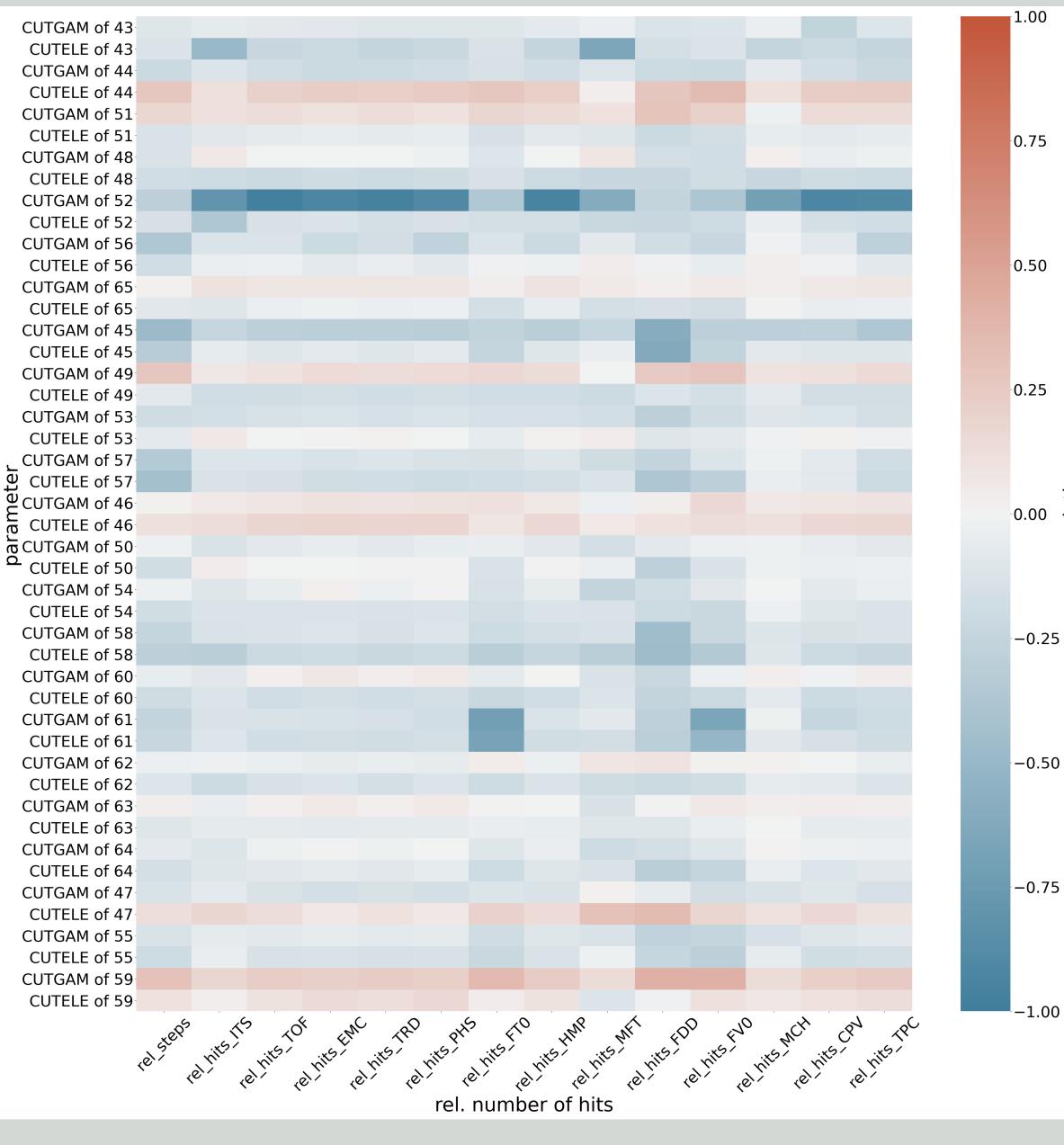
Thank you very much, enjoy dinner, and have a great conference!



BACKUP



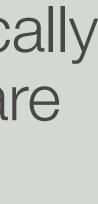
Parameters and hits go well together



Correlation of number of kept hits with chosen cut value across all optimisation trials.

- A negative correlation basically means higher/lower cut ~ less/more hits.
- Intuitively, a positive correlation physically does not make sense. However, we are only looking at a "first order" relation between the hits and cuts. The choice of cut values is more complex!

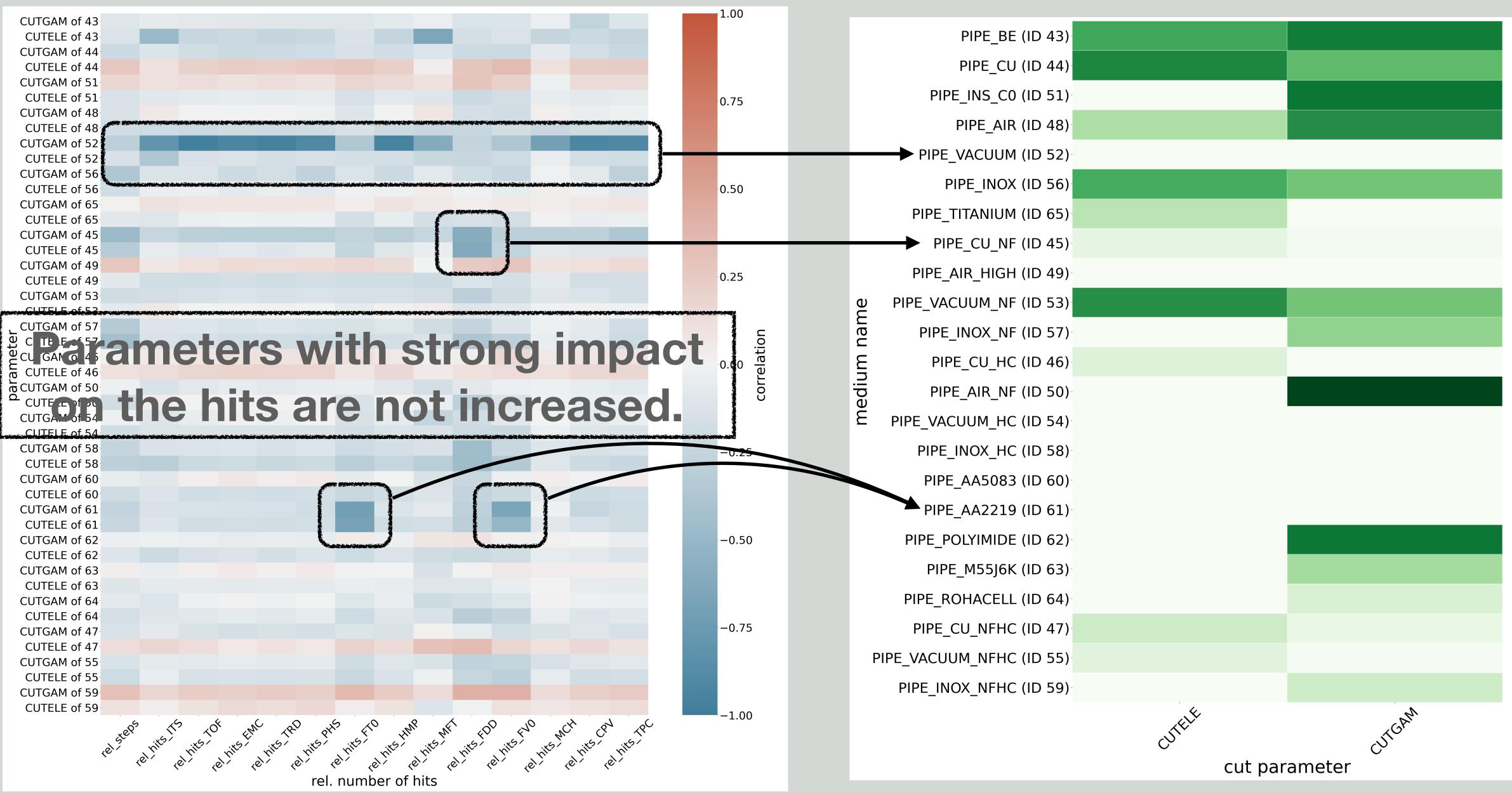








Parameters and hits go really well together

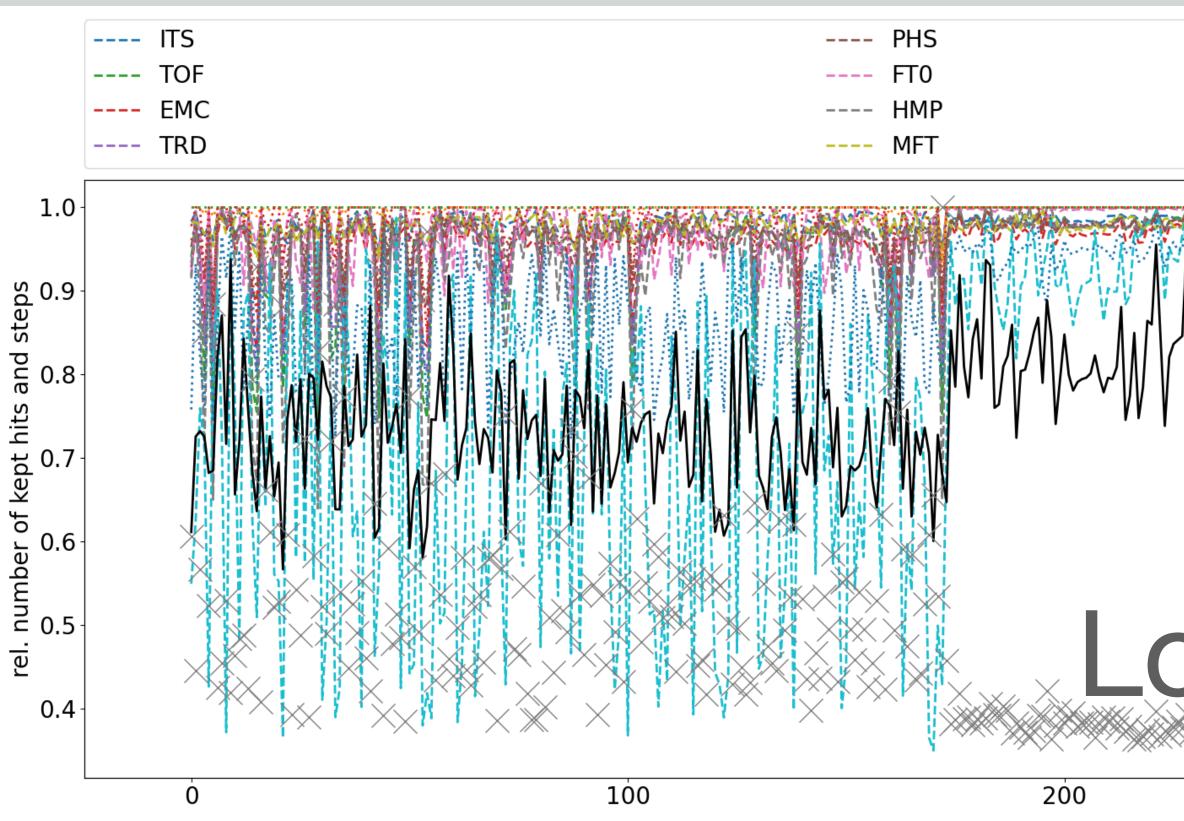








Evolution of steps and hits



"Warm-up" (drawing random parameters) for 150 trials.

during optimisation		ALICE
FDD FV0		CPV TPC
MCH MID		STEPS
		2.2
MMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMMM		-2.0
	MIMMAN NYW	-1.8
'Steps		-1.6 SSOT
	\times \times $ $	1.4
DSS ×	$\langle \langle \rangle \rangle $	1.2
		1.0
300 400 trial		500 0.8

triai

Optimising



