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Systematization of accelerator layout design using Monte Carlo simulations

Michał Jarosz
oPAC Fellow,
ESS Beam Instrumentation Group

March 12, 2015
CAoPAC, Darmstadt GSI

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Systematization of accelerator layout design using Monte Carlo simulations or: An ESS flight to MARS and back

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Outline

- Why Monte-Carlo? Why MARS?
- Setting up the simulation
- Post-simulation data analysis
- What can we achieve
- Summary

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Talk full of obvious statements that are nevertheless very often forgotten

Why Monte Carlo?

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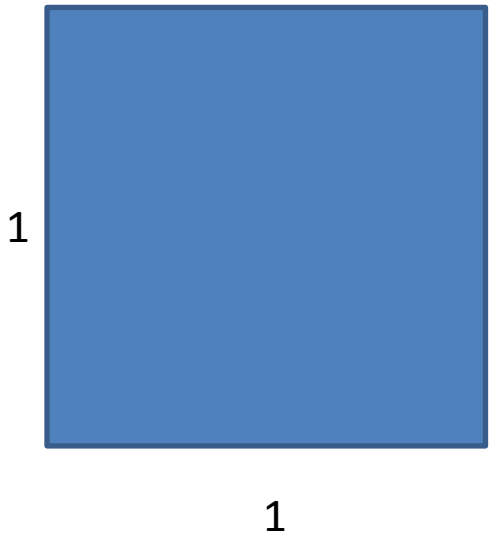
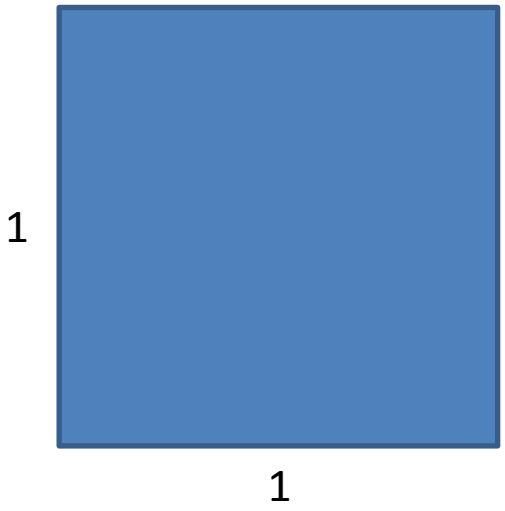
Why Monte Carlo?

What is the surface of figure below?

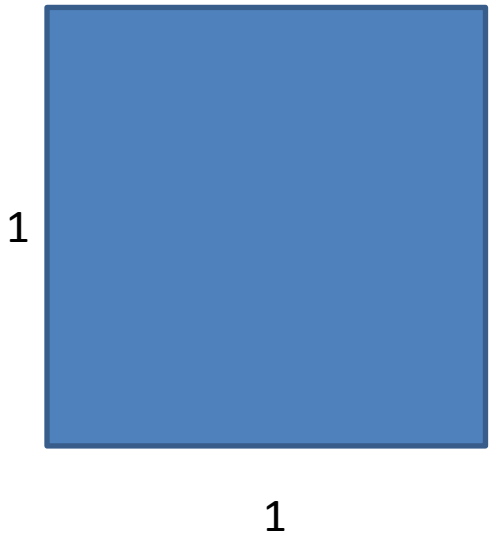




Why Monte Carlo?

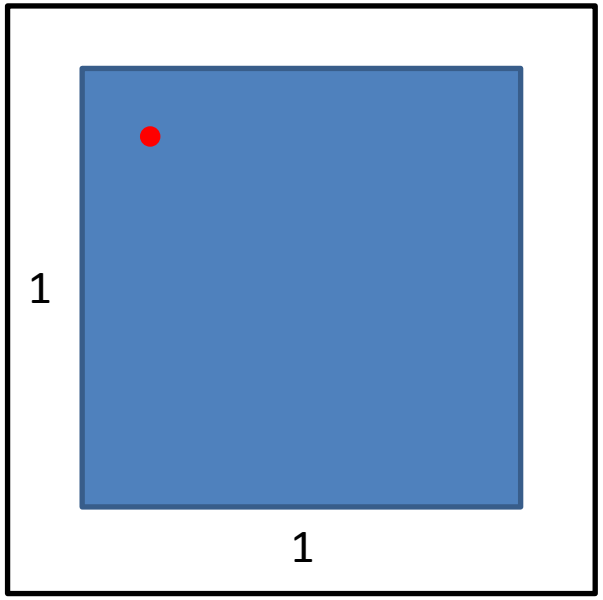
What is the surface of figure below?

Analytical approach



Time required for the answer: 1 slide

Monte Carlo approach



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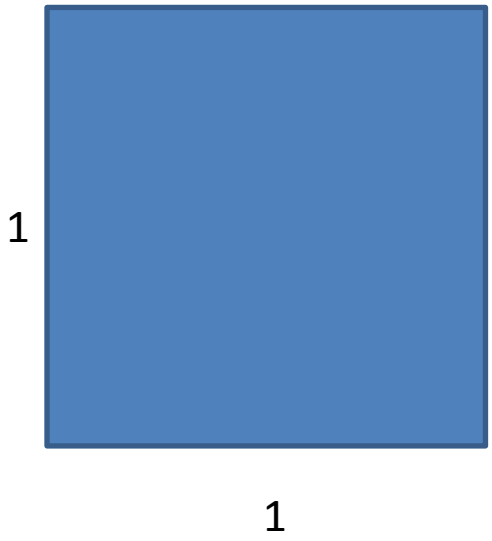
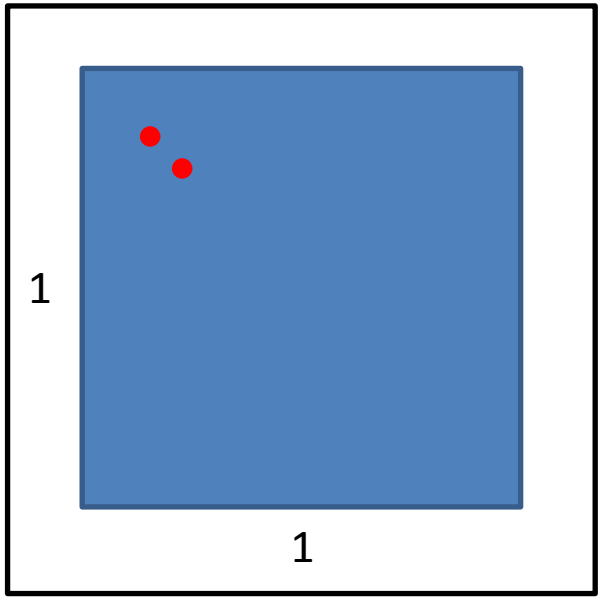


S = a^2 = 1*1 = **1.0 [unit^2]**

Time required for the answer: 2 slides

Monte Carlo approach



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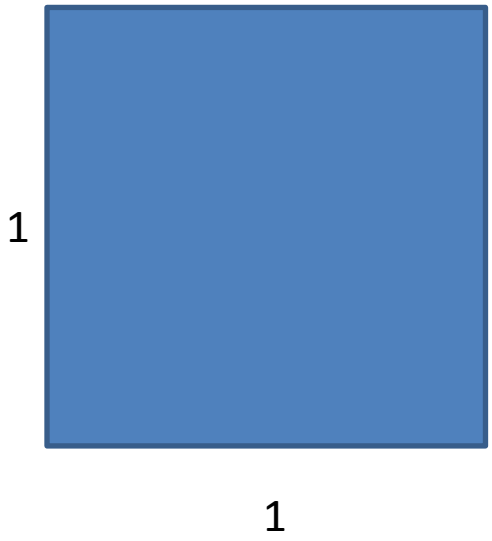

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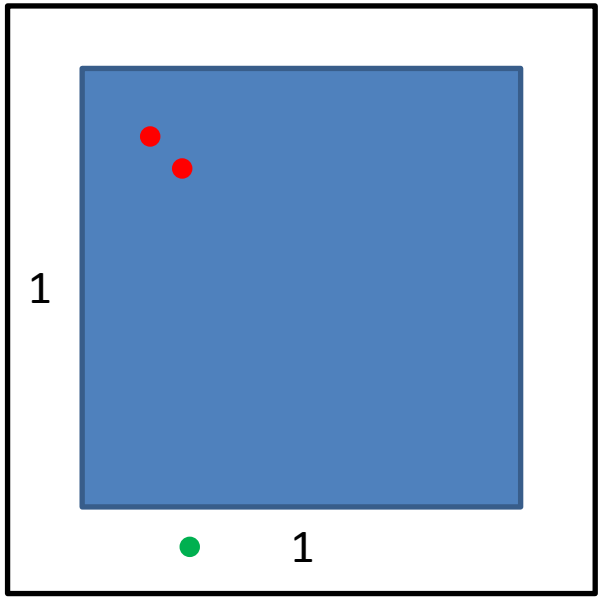
Time required for the answer: **2 slides**

Monte Carlo approach



Time required for the answer: 3 slides

Why Monte Carlo?

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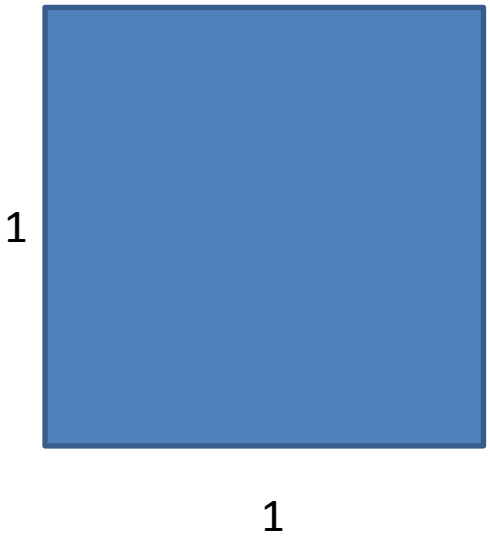
Let’s skip 9996 slides...

Why Monte Carlo?

What is the surface of figure below?

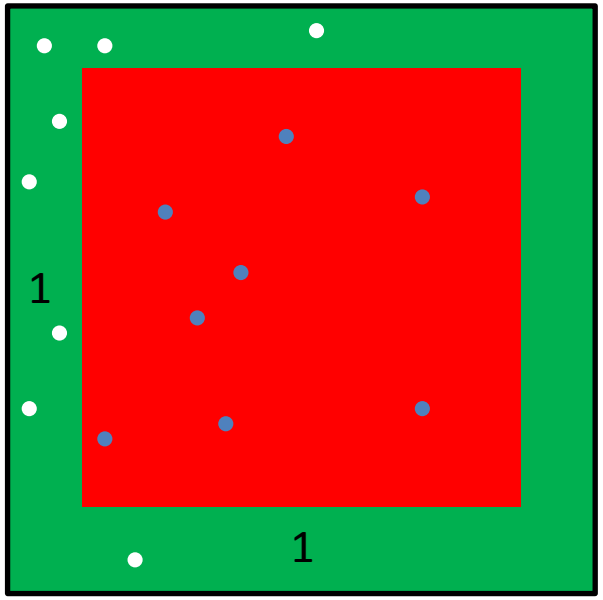
Analytical approach



S = a^2 = 1*1 = **1.0 [unit^2]**

Time required for the answer: **2 slides**

Monte Carlo approach



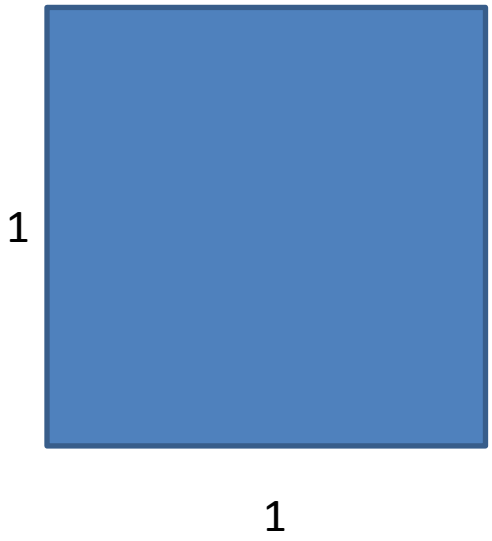
S = HITS / (HITS+MISSES) * big square surface

Time required for the answer: 10000 slides

Why Monte Carlo?

What is the surface of figure below?

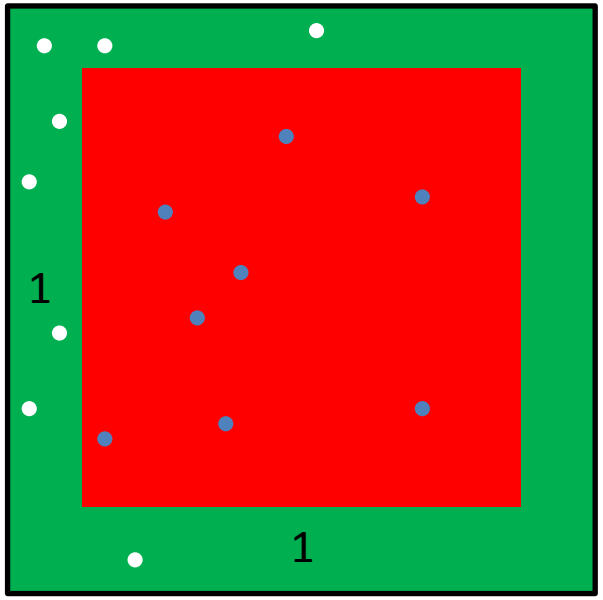
Analytical approach



S = a^2 = 1*1 = **1.0 [unit^2]**

Time required for the answer: **2 slides**

Monte Carlo approach



S = HITS / (HITS+MISSES) * big square surface

S = 0.99996 [unit^2] +- 0.0001

Time required for the answer: **10001 slides**

Why Monte Carlo?

What is the surface of figure below?

Analytical approach

Monte Carlo approach

Monte Carlo method:
A great tool to waste everybody's time !

S = a^2 = 1* **1.0 [unit^2]**

S = HITS / (HITS+MISSES) * big square surface

S = 0.99996 [unit^2] +- 0.0001

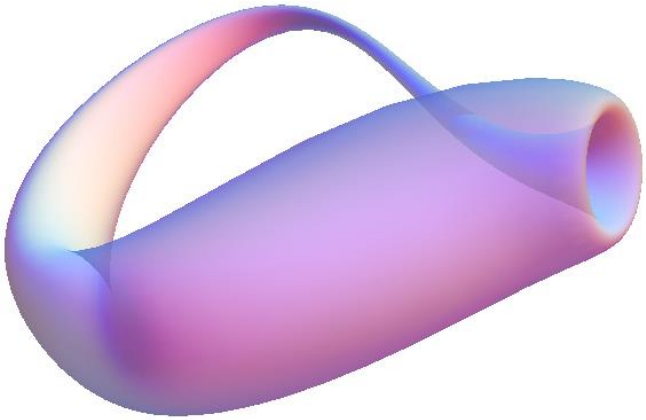
Time required for the answer: **2 slides**

Time required for the answer: **10001 slides**

Why Monte Carlo?

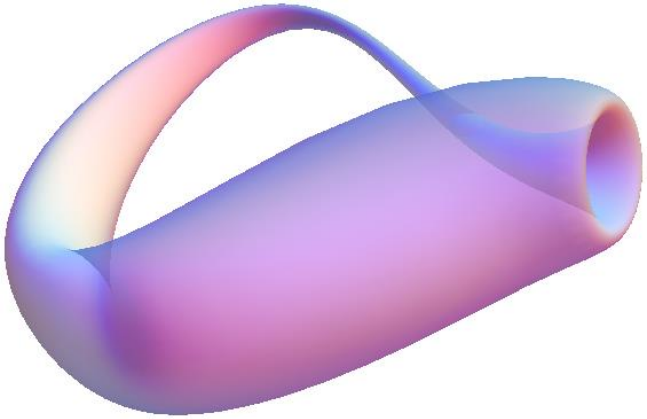
What is the volume of figure below?

Analytical approach



Time required for the answer:

Monte Carlo approach



Time required for the answer:

Why Monte Carlo?

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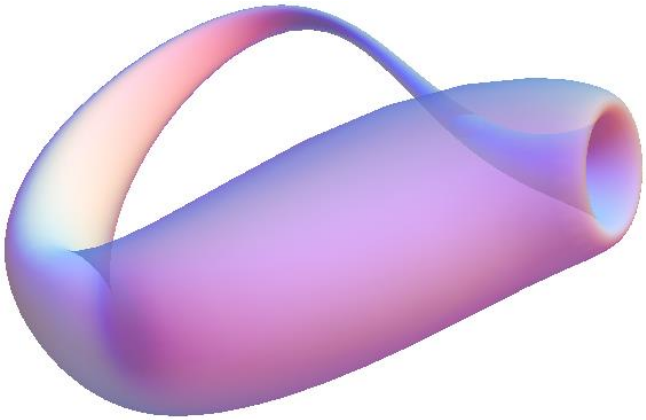
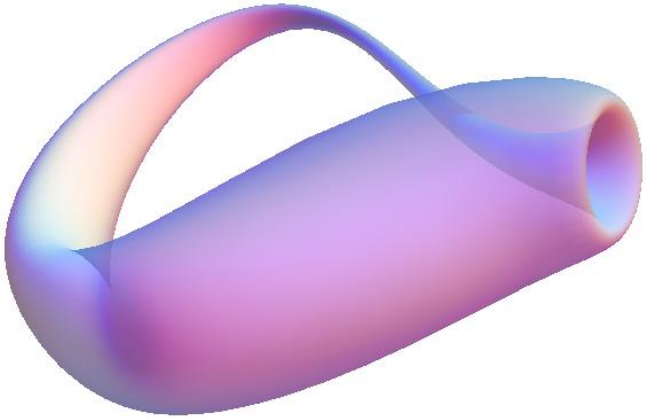
Analytical approach



Time required for the answer: **NaN (or close to that)**

Monte Carlo approach



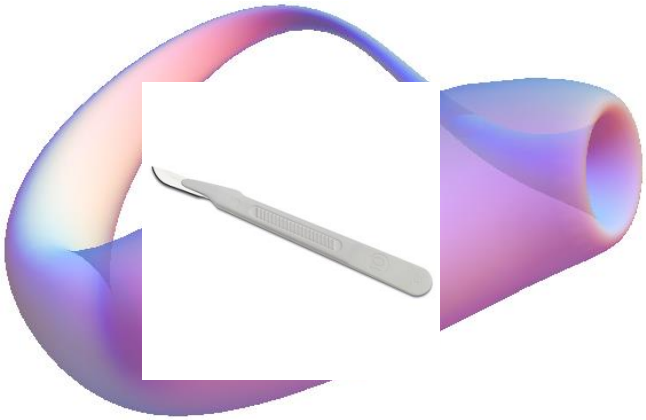
0.43556 [units^2]

Time required for the answer: 10000 slides

Why Monte Carlo?

What is the volume of figure below?

Analytical approach



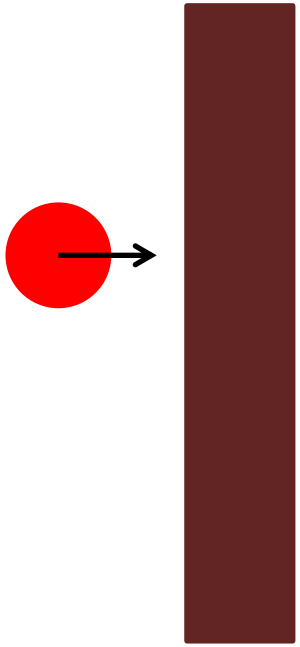
Monte Carlo approach

Time required for the answer: **NaN (or close to that)**

Time required for the answer: 10000 slides

Why Monte Carlo?

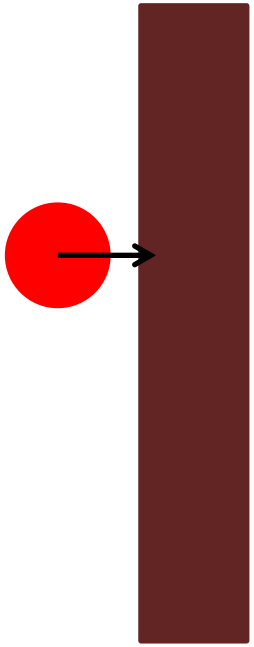
The particle journey



Step: 0

Why Monte Carlo?

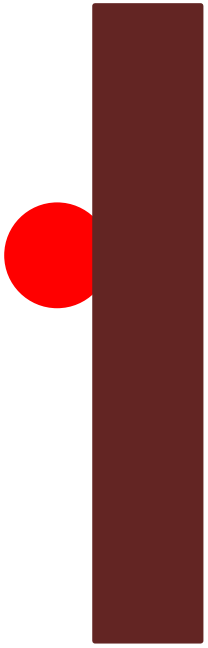
The particle journey



Step: 1

Why Monte Carlo?

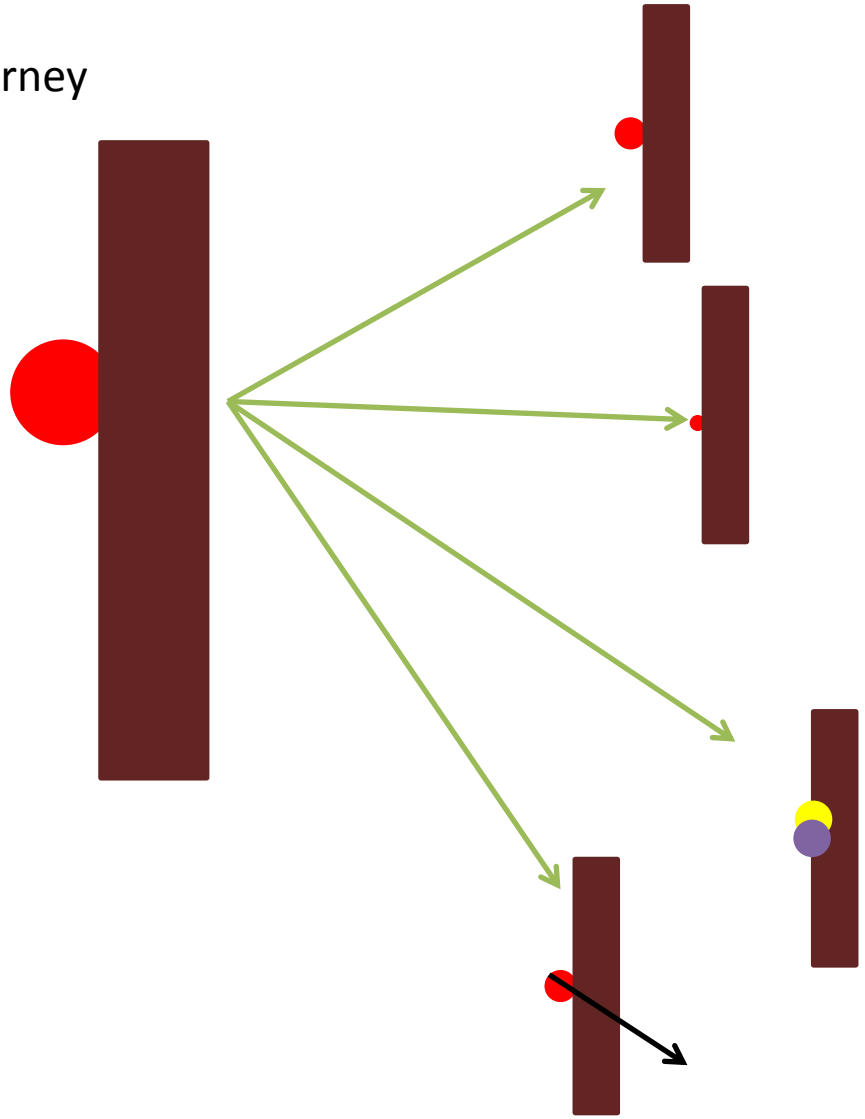
The particle journey



Step: 2

Why Monte Carlo?

The particle journey



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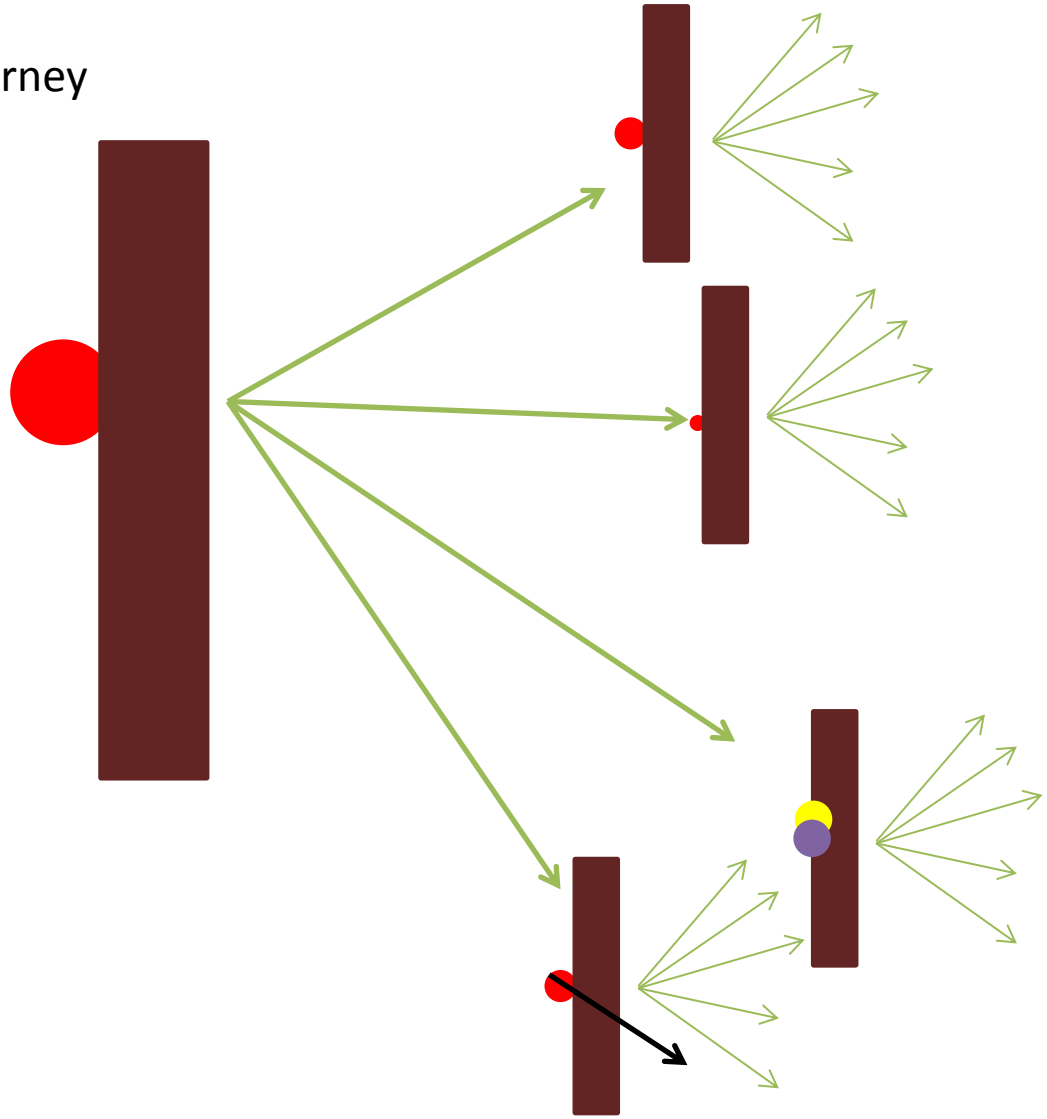

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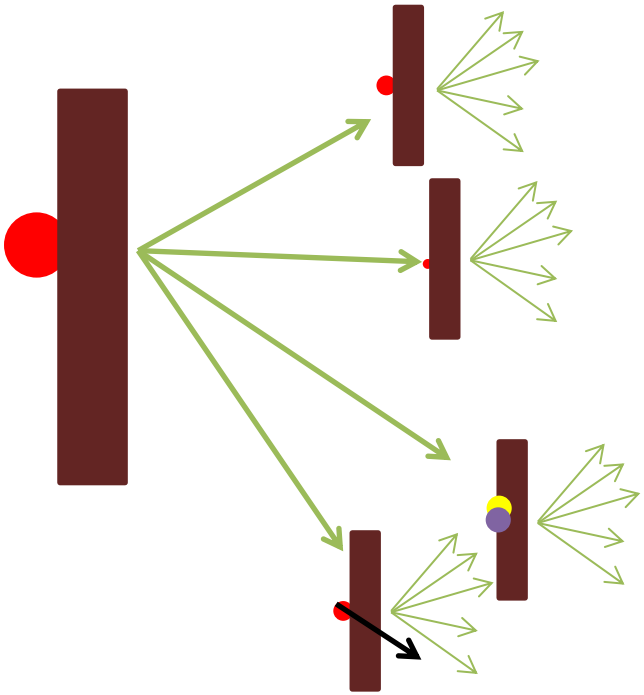
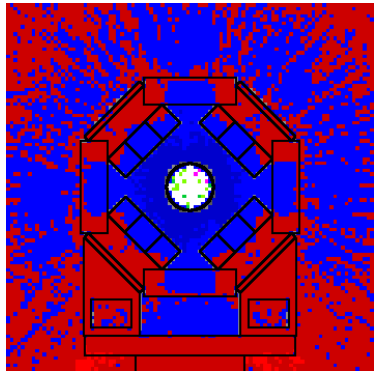


Many additional techniques:

- Biasing
- Thresholds
- Varying step size
- Scoring rules

But the principle remains the same



Why Monte Carlo?

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- Makes complicated, random processes solvable in finite time
- Works when analytical formulae approach fails
- Nowadays „cheap” in terms of computational efforts (parallel computing)

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- Makes complicated, random processes solvable in finite time
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Monte Carlo method: Flawless tool !

Why MARS?

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MARS Code System

EUROPEAN SPALLATION SOURCE

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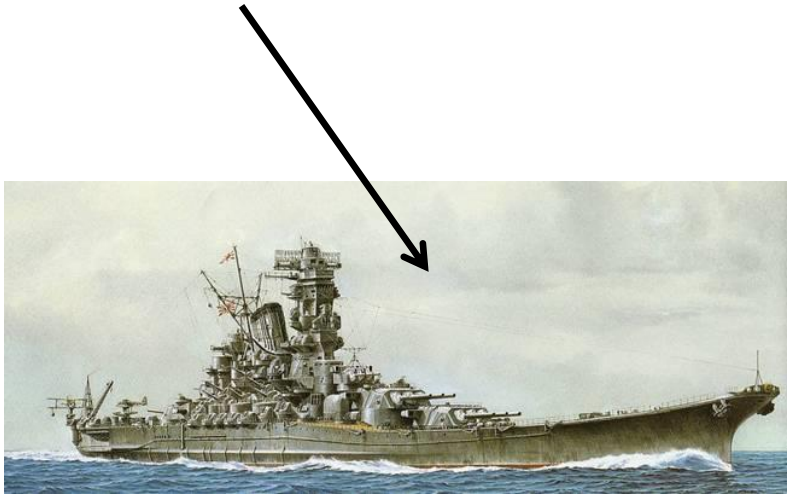

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All are comparable in terms of results, efficiency.

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All originated in 3rd century BC therefore are basing on Fortran programming language, founded by Archimedes.

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All are comparable in terms of results, efficiency.

Reasoning at ESS:

- Staff coming from FERMILAB, easy access to code and designers
- Cross-check required - many FLUKA experts available, need for second code
- Easy access to the source code and many tuning possibilities

Why MARS?

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- Staff coming from FERMILAB, ... ners
- Cross-check requir... ...ble, need for second ...
- Easy acce... ...de and many tuning possibilities

MARS:
Probably as good as everything else

Pre-simulation process

Planning the spaceship launch

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Pre-simulation process

Preparation phase:

- Creating the model
- Defining the beam environment (loss, production, collision + parameters)
- Deciding what to score

Spend a lot of time on those three topics, because

Pre-simulation process

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- Creating the model
- Defining the beam environment (loss, production, collision + parameters)
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Pre-simulation process

Monte Carlo particle transport tools will calculate everything with only the numerical error

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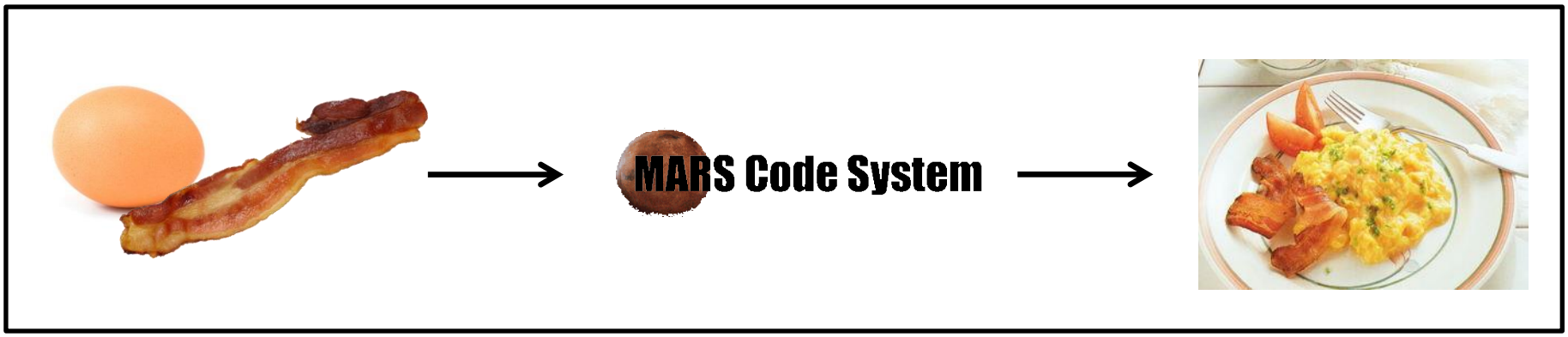

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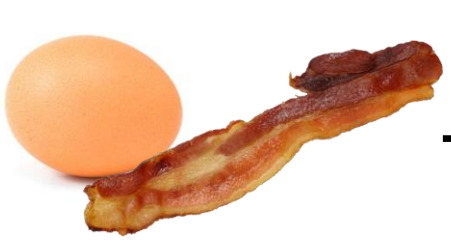

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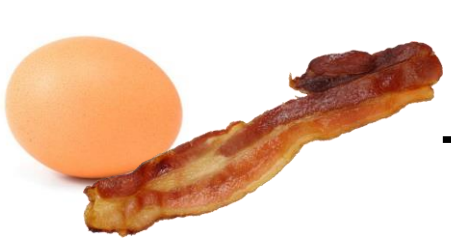

MARS Code System

GARBAGE IN – GARBAGE OUT

MARS Code System

Pre-simulation process
Modelling

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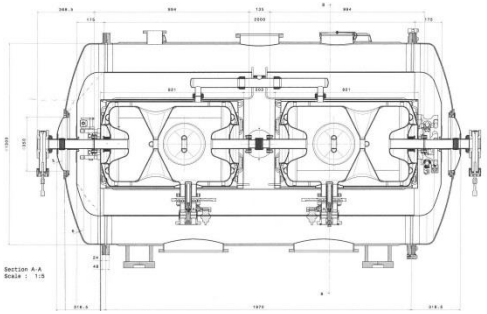
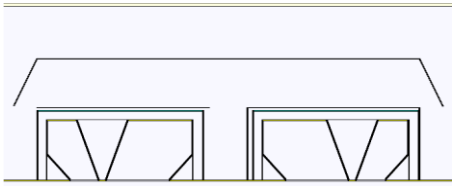
Pre-simulation process
Modelling

- Most time consuming stage of simulation preparation
- Involves translation of the accelerator's components technical drawings into the Monte Carlo machine code
- Lowest level designing must be done by hand





MARS

```
heltankm  2 0 2     0. 0. 19.6    20.9  21.4  92.6  !middle part of helium
tank
helcovl   2 0 2     0. 0. 19.6    9.1   21.4  0.5   !helium tank left cover
helcovr   2 0 2     0. 0. 111.7   9.1   21.4  0.5   !helium tank right cover

magshld   2 0 8     0. 0. 19.45   24.25 24.4  92.9 !magnetic shield over
cavities
magshll   2 0 8     0. 0. 19.45   9.1  24.25 0.15  !magnetic shield left cover
magshlr   2 0 8     0. 0. 112.2   9.1  24.25 0.15  !magnetic shield right
cover

termshld  2 0 9     0. 0. 0.      47.25 47.4  131.8 !thermal shield around
```

Pre-simulation process
Modelling

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- Most time consuming stage of simulation preparation
- Involves translation of the accelerator's components technical drawings into the Monte Carlo machine code
- Lowest level designing must be done by hand

You will need to help yourself – Monte Carlo codes will not do everything for you

Pre-simulation process
Modelling

- Most time consuming stage of simulation preparation
- Involves translation of the accelerator's components technical drawings into the Monte Carlo machine code
- Lowest level designing must be done by hand

Pre-simulation process
Modelling

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- The environment is too small – the codes and their interfaces cannot have tools for absolutely all of the applications

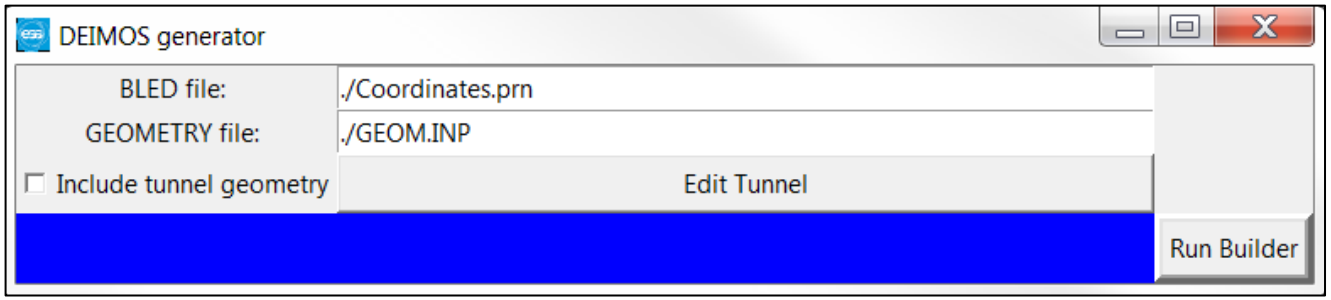
Pre-simulation process
Modelling

- The environment is too small – the codes and their interfaces cannot have tools for absolutely all of the applications
- If you see any possibility of replication, pattern, systematisation - use it; most likely you will need to redo many things so it might be useful to automatise the proccess

Pre-simulation process
Modelling

- The environment is too small – the codes and their interfaces cannot have tools for absolutely all of the applications
- If you see any possibility of replication, pattern, systematisation - use it;

- Create a link between your accelerator repository and your model – ideally you want to have a „one button model generator”



Pre-simulation process Modelling

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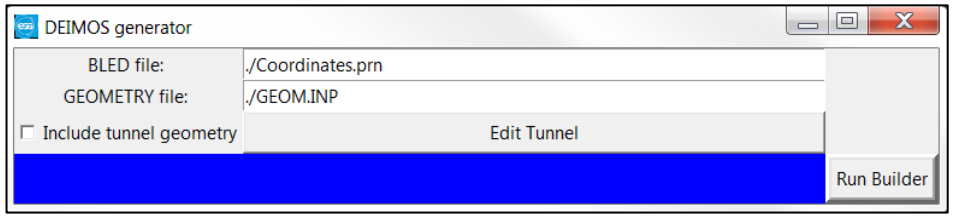
Info | PBS Layout | PBS Tree | XML Tree | Cell data | Slot data | BLE data | Monitor data | Cell Parts | Slot Parts | Beam-line Parts | Monitor Parts | Lego Sets

Source File

Section	Cell	Model	eVout	v/c	Length	Xend	Yend	Zend	Xsur	Ysur	Zsur
			(MeV)		(m)	(m)	(m)	(m)	(m)	(m)	(m)
FE	FE	FrontEndCell	3.6	0.087348	0	0	0	0	0	-4.5	-595.4308
MEBT	010	MebtCell01	3.6	0.087348	0.35	0	0	0.35	0	-4.5	-595.0808
MEBT	020	MebtQhpCav	3.6	0.087348	0.35	0	0	0.7	0	-4.5	-594.7308
MEBT	030	MebtCellQvp100Drift	3.6	0.087348	0.2	0	0	0.9	0	-4.5	-594.5308
MEBT	040	MebtCell04	3.6	0.087348	1.14	0	0	2.04	0	-4.5	-593.3908
MEBT	050	MebtCellQhp100Drift	3.6	0.087348	0.2	0	0	2.24	0	-4.5	-593.1908
MEBT	060	MebtCellQvp100Drift	3.6	0.087348	0.2	0	0	2.44	0	-4.5	-592.9908
MEBT	070	MebtCell07	3.6	0.087348	0.45	0	0	2.89	0	-4.5	-592.5408
MEBT	080	MebtQvpCav	3.6	0.087348	0.35	0	0	3.24	0	-4.5	-592.1908
MEBT	090	MebtCellQhp100Drift	3.6	0.087348	0.2	0	0	3.44	0	-4.5	-591.9908
MEBT	100	MebtCellQvp100Drift	3.6	0.087348	0.2	0	0	3.64	0	-4.5	-591.7908
MEBT	110	MebtCellQhp100Drift	3.6	0.087348	0.2	0	0	3.84	0	-4.5	-591.5908
DTL	010	DtlCell01	21.246552	0.209274	7.741788	0	0	11.581788	0	-4.5	-583.849012
DTL	020	DtlCell02	39.049829	0.279849	7.310466	0	0	18.892254	0	-4.5	-576.538546
DTL	030	DtlCell03	56.736474	0.332852	7.843558	0	0	26.735812	0	-4.5	-568.694988
DTL	040	DtlCell04	73.740534	0.374728	8.149519	0	0	34.885331	0	-4.5	-560.545469
DTL	050	DtlCell05	89.81105	0.408759	7.835414	0	0	42.720745	0	-4.5	-552.710055
SPK	010	SpokeLedpCell	96.24764	0.421208	4.74	0	0	47.460745	0	-4.5	-547.970055
SPK	020	SpokeCell	104.764415	0.436801	4.26	0	0	51.720745	0	-4.5	-543.710055
SPK	030	SpokeCell	114.691751	0.453852	4.26	0	0	55.980745	0	-4.5	-539.450055
SPK	040	SpokeCell	125.012326	0.470447	4.26	0	0	60.240745	0	-4.5	-535.190055
SPK	050	SpokeCell	135.546178	0.486336	4.26	0	0	64.500745	0	-4.5	-530.930055
SPK	060	SpokeCell	146.161101	0.501394	4.26	0	0	68.760745	0	-4.5	-526.670055
SPK	070	SpokeCell	156.765172	0.515582	4.26	0	0	73.020745	0	-4.5	-522.410055
SPK	080	SpokeCell	167.264015	0.528869	4.26	0	0	77.280745	0	-4.5	-518.150055
SPK	090	SpokeCell	177.61781	0.541302	4.26	0	0	81.540745	0	-4.5	-513.890055
SPK	100	SpokeCell	187.786116	0.552893	4.26	0	0	85.800745	0	-4.5	-509.630055
SPK	110	SpokeCell	197.585406	0.563601	4.26	0	0	90.060745	0	-4.5	-505.370055
SPK	120	SpokeCell	207.058132	0.573486	4.26	0	0	94.320745	0	-4.5	-501.110055
SPK	130	SpokeCell	216.413771	0.582853	4.26	0	0	98.580745	0	-4.5	-496.850055
MBL	010	MedBetaCell	230.621563	0.596382	8.52	0	0	107.100745	0	-4.5	-488.330055
MBL	020	MedBetaCell	249.583639	0.613252	8.52	0	0	115.620745	0	-4.5	-479.810055
MBL	030	MedBetaCell	276.433559	0.635103	8.52	0	0	124.140745	0	-4.5	-471.290055
MBL	040	MedBetaCell	312.523855	0.661279	8.52	0	0	132.660745	0	-4.5	-462.770055
MBL	050	MedBetaCell	358.016112	0.689995	8.52	0	0	141.180745	0	-4.5	-454.250055
MBL	060	MedBetaCell	413.375381	0.719812	8.52	0	0	149.700745	0	-4.5	-445.730055
MBL	070	MedBetaCell	467.807102	0.744792	8.52	0	0	158.220745	0	-4.5	-437.210055



Pre-simulation process
Environment

Need to know as much as possible about the simulated beam.

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ESS Beam Physics group asked about the nature of the beam losses along the machine (locations, magnitude, angles, etc.):

Pre-simulation process Environment

Need to know as much as possible about the simulated beam.

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„We don’t expect any beam losses”

EUROPEAN SPALLATION SOURCE

Thank you for attention.

Pre-simulation process
Environment

Need to know as much as possible about the simulated beam.

If there is no information available, make some assumptions.

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Pre-simulation process Environment

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Try to look for the data in similar machines, take into account some general rules.

When in doubt – go with the worst case scenario (to some extent)

Pre-simulation process
Environment

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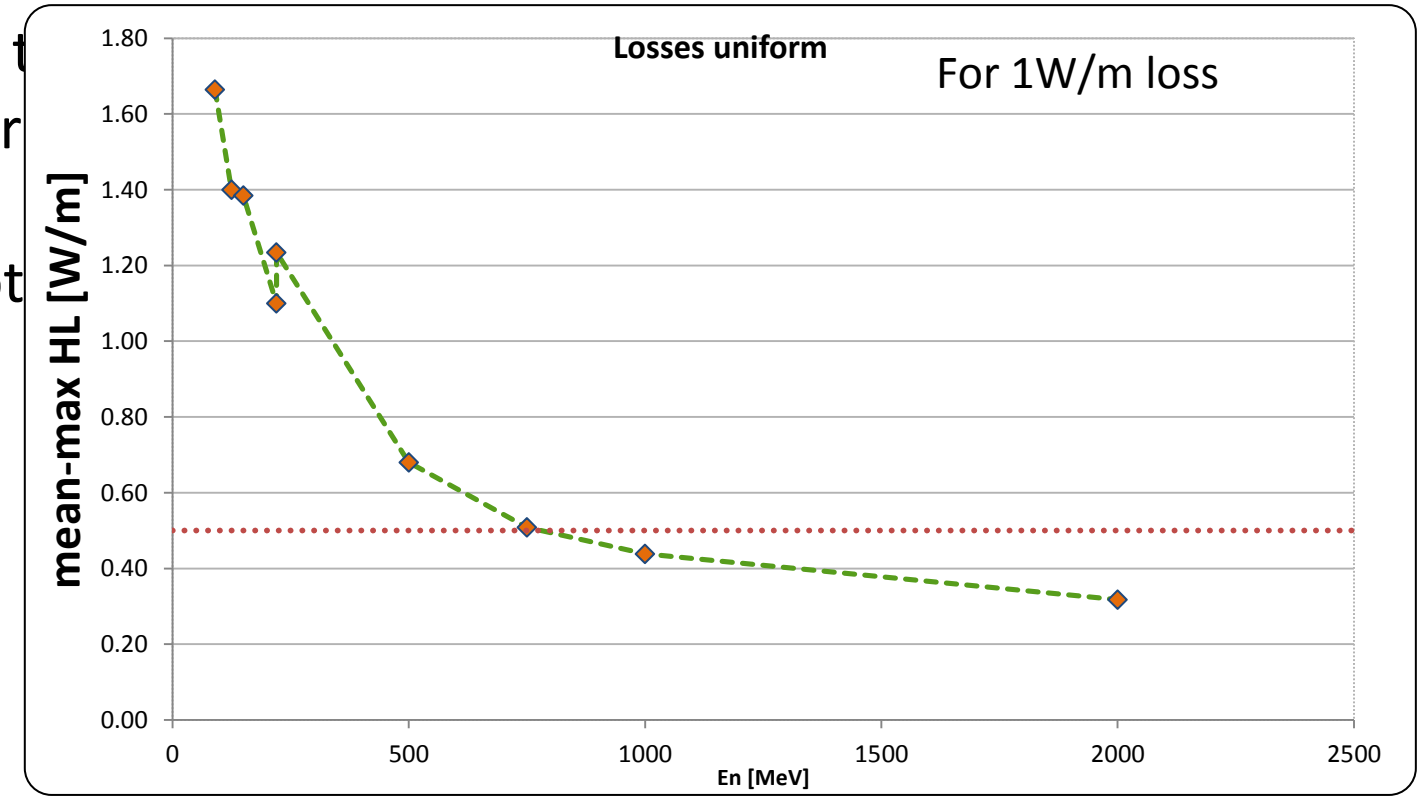
Try to look for t
some general r

When in doubt
extent)



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When in doubt
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Pre-simulation process
Scoring

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Pre-simulation process
Scoring

Ideally: score everything.

Reality: hard drives are not infinetely large

Pre-simulation process
Scoring

Answer two questions:

- Why did you started the simulation process in the first place?
- What can, apart from obvious quantities, improve your knowledge of the associated phenomena

Pre-simulation process
Scoring

Answer two questions:

- Why did you started the simulation process in the first place?
- What can, apart from obvious quantities, improve your knowledge of the associated phenomena

(is absorbed dose sufficient to evaluate something? maybe it could be useful to look on the contribution of different particle types? how about their energy distribution? to be honest, also their fluxes could be used somehow...)

Simulation itself

Lift-off

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Simulation itself

Sit down, enjoy, and relax – Monte Carlo code will do it for you...

Simulation itself

Sit down, enjoy, and relax – Monte Carlo code will do it for you...

... and give you a lot of time to think about the analysis of the obtained data!

Simulation data analysis

Is this a rock or a Martian?

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Simulation data analysis

Raw data from the simulations are close to useless

Simulation data analysis

EUROPEAN SPALLATION SOURCE

Raw data from the simulations are close to useless

DATA ANALYSIS IS (OTHER) KING

Simulation data analysis

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This is the moment to shine with creativity

Simulation data analysis

Data analysis involves everything from presentation of data (even the way you plot results might influence your evaluation) through some simple threshold algorithms (looking for limits) up to really complicated analysis harvester programs.

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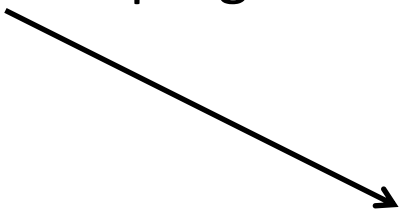

Once more – pure programming

Simulation data analysis

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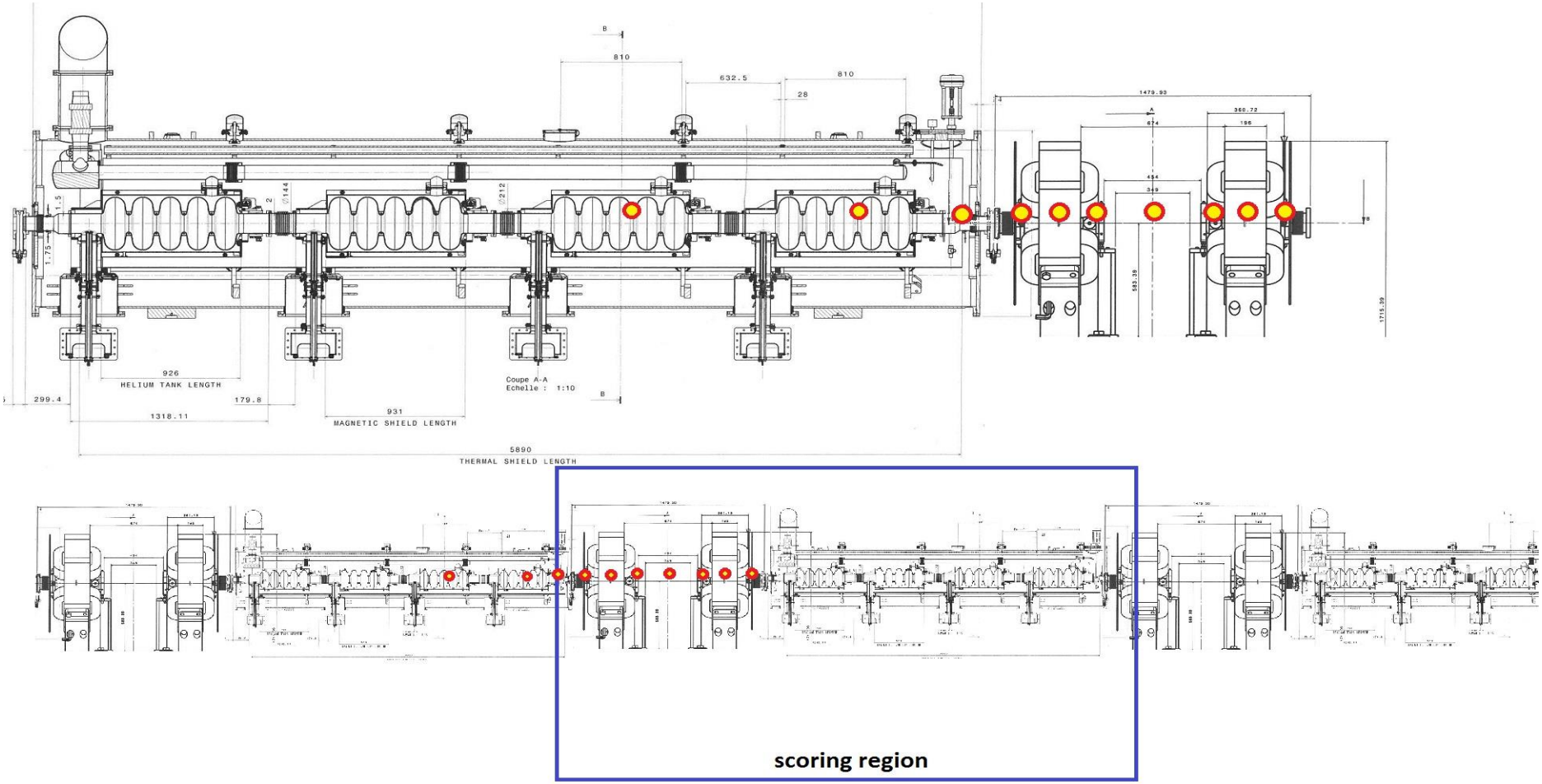
Example: loss pattern recognition for ESS superconducting linac

Simulation data analysis

EUROPEAN SPALLATION SOURCE

Example: loss pattern recognition for ESS superconducting linac



Simulation data analysis

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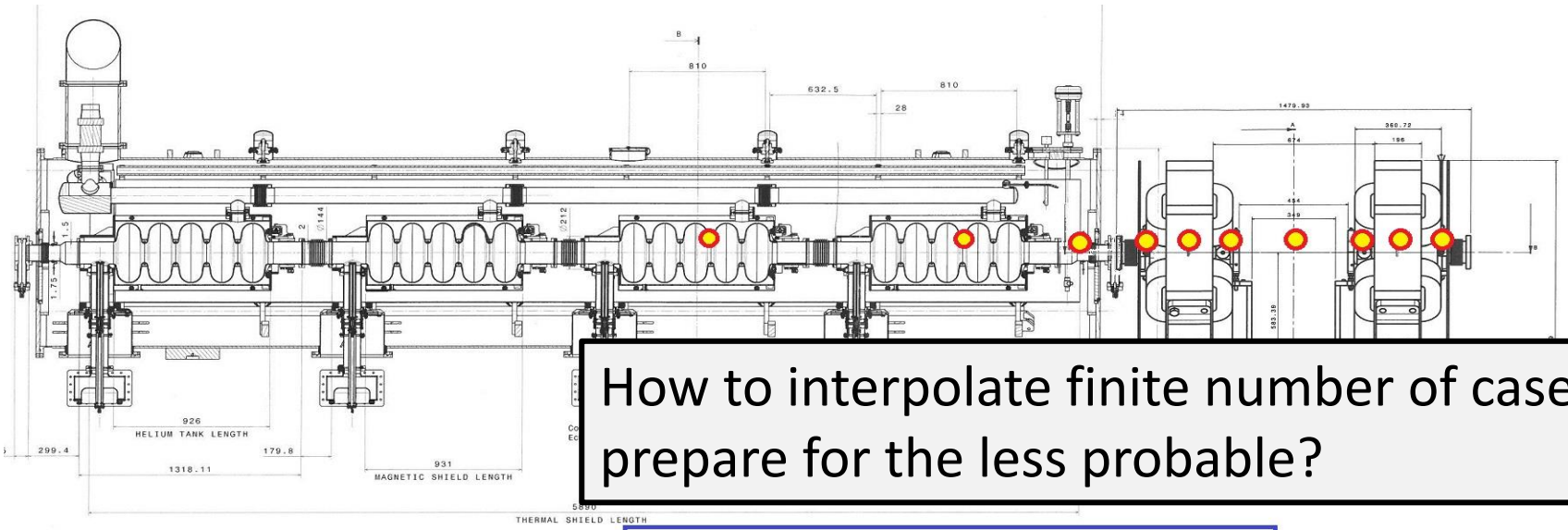
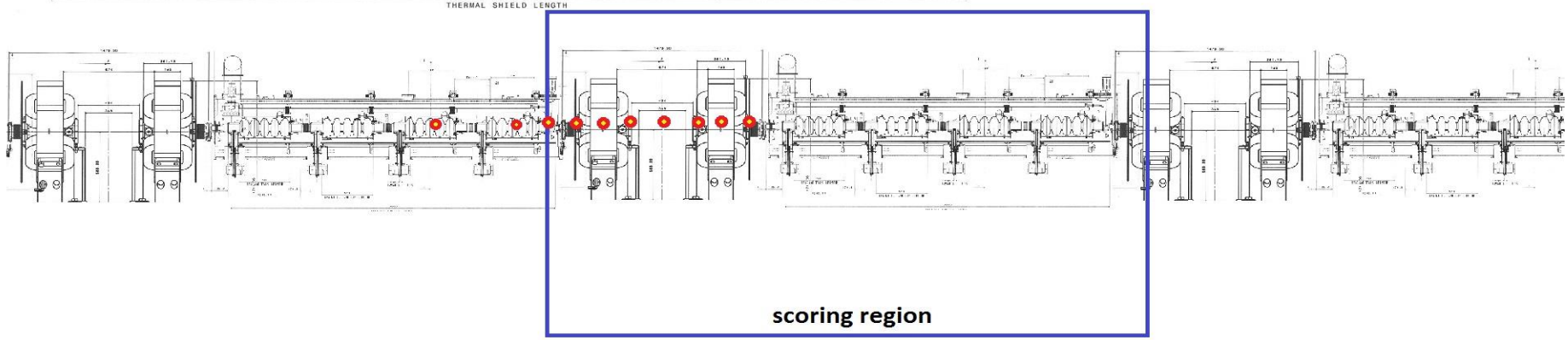
Example: loss pattern recognition for ESS superconducting linac



How to interpolate finite number of cases to prepare for the less probable?



Simulation data analysis

Possible solution for this multidimensional, non-linear, complicated problem: neural network based algorithm

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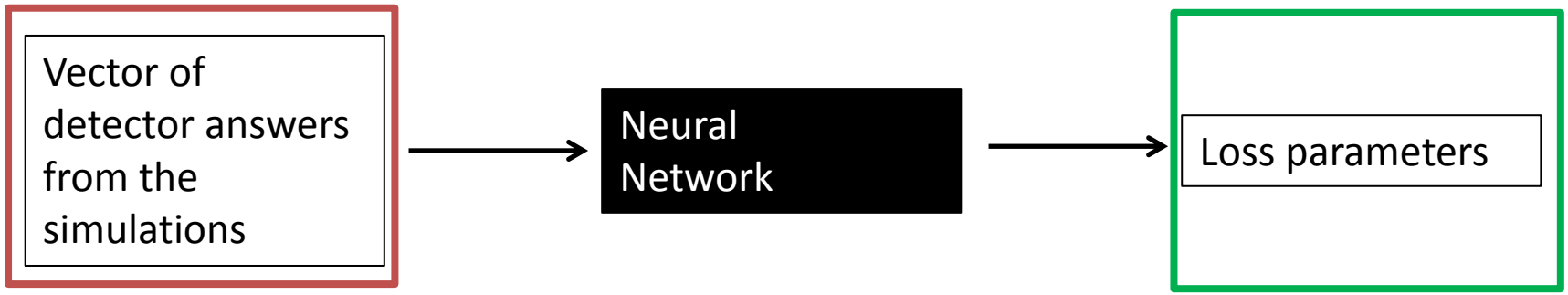
Possible solution for this multidimensional, non-linear, complicated problem: neural network based algorithm

Training sets: simulation assumptions and results



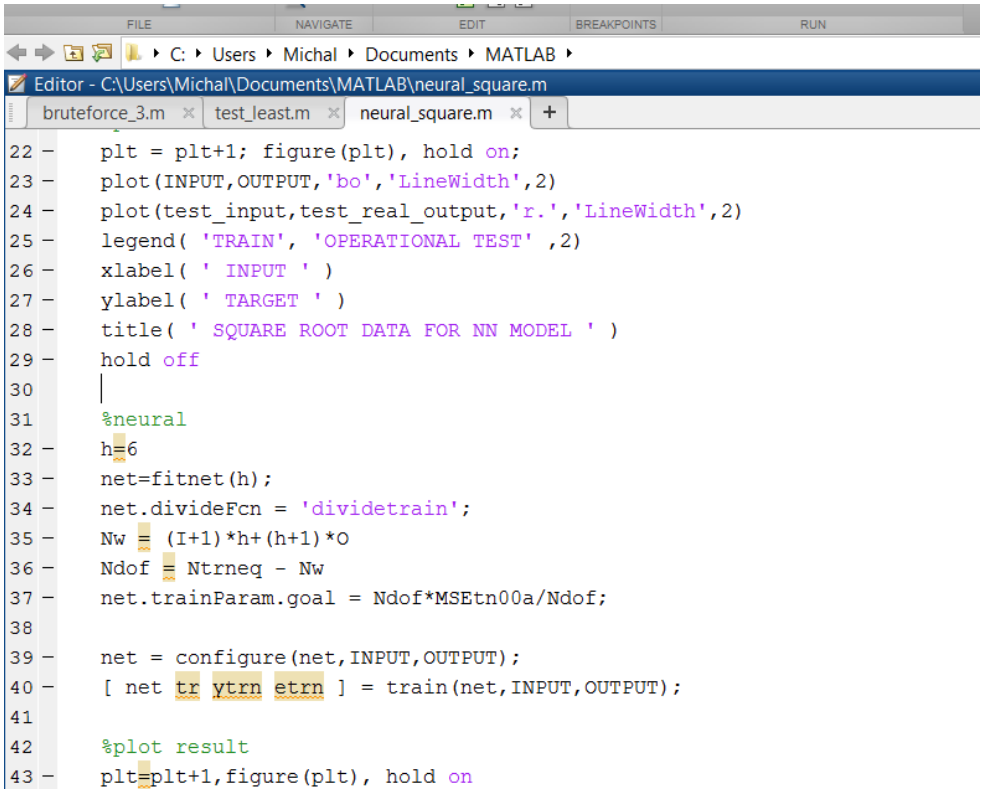
Simulation data analysis

EUROPEAN SPALLATION SOURCE

Possible solution for this multidimensional, non-linear, complicated problem: neural network based algorithm

Neural Network

First attempts done in Matlab, working on incomplete data sets



Simulation data analysis

EUROPEAN SPALLATION SOURCE

Possible solution for this multidimensional, non-linear, complicated problem: neural network based algorithm

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	
1	TYPE 1	TYPE 2	ENERGY	angle	pos. X	pos. Y	loss E2	loss E1	loss D	loss A1	loss A	loss A2	loss C	loss B1	loss B	loss B2	
2	ELLIPTICAL		220	3mrad	8.7mm	0	1	1	1	1	4	1	4	1	4	1	
3	ELLIPTICAL		500	3mrad	0	8.7 mm	1	1	1	4	3	3	1	2	1	1	
4	ELLIPTICAL		500	3mrad	-8.7mm	0	1	1	1	1	1	1	1	1	1	1	
5	ELLIPTICAL		500	3mrad	8.7mm	0	1	4	4	4	4	4	4	4	4	4	
6	ELLIPTICAL		1000	3mrad	8.7mm	0	1	1	4	1	4	1	4	1	4	1	
7	ELLIPTICAL		2000	3mrad	8.7mm	0	1	1	1	2	4	2	1	2	1	1	
8	ELLIPTICAL		220	1mrad	8.7mm	0	1	1	1	1	1	1	1	1	1	1	
9	ELLIPTICAL		500	1mrad	8.7mm	0	1	1	1	2	4	2	1	2	1	1	
10	ELLIPTICAL		1000	1mrad	8.7mm	0	1	1	1	1	1	1	1	2	1	1	
11	ELLIPTICAL		2000	1mrad	8.7mm	0	1	1	1	1	1	1	1	2	1	1	
12	ELLIPTICAL		220	1deg	8.7mm	0	1	1	1	1	1	1	1		1	1	
13	ELLIPTICAL		500	1deg	8.7mm	0	1	1	1	2	4	2	1	2	1	1	
14	ELLIPTICAL		1000	1deg	8.7mm	0	1	1	1	1	2	1	1	3	1	1	
15	ELLIPTICAL		2000	1deg	8.7mm	0	1	1	1	1	2	1	1	3	1	1	
16	UPGRADE	2mm beampipe	2000	3mrad	8.7mm	0					4						
17	UPGRADE	4mm beampipe	2000	3mrad	8.7mm	0					4						
18	SPOKE		90	3mrad	0	2.4 mm	1	1	1	1	4	1	1	1	1	1	right
19	SPOKE		90	3mrad	-2.4 mm	0	1	1	1	1	4	1	1	1	1	1	bottom
20	SPOKE		90	3mrad	2.4 mm	0	1	1	1	1	4	1	1	1	4	1	top
21	SPOKE		150	3mrad	0	2.4 mm	1	1	1	1	4	1	1	1	1	1	right
22	SPOKE		220	3mrad	-2.4 mm	0	1	1	1	1	4	1	1	1	1	1	bottom
23	SPOKE		220	3mrad	2.4 mm	0	1	1	1	1	4	1	1	1	4	1	top
24	SPOKE		220	3mrad	0	2.4 mm	1	1	1	1	4	1	1	1	1	1	right

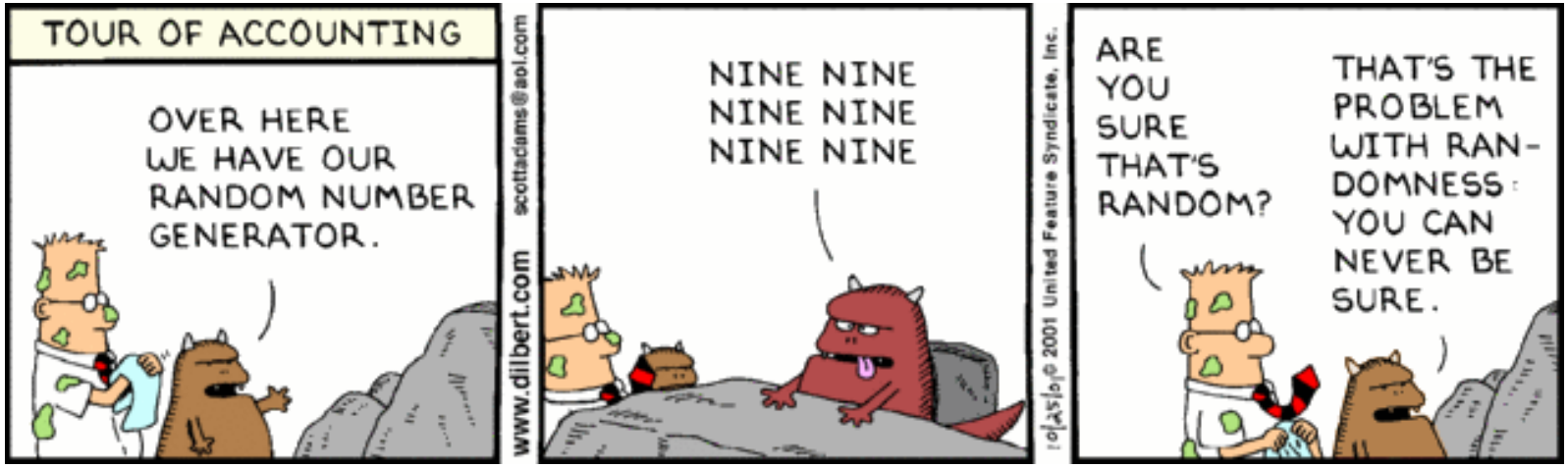
Dare to press the button?

Summary

Monte Carlo codes used in a right way are necessary tools in the design process of every accelerator machine

The more time you spend on pre-simulation chores the more accurate your results will be and the less white hair will be produced

You WILL need to program a lot to make your simulationist life easier, although the trend is to embed as much as possible into the code itself (also: SHARE YOUR WORK)


TOUR OF ACCOUNTING
OVER HERE WE HAVE OUR RANDOM NUMBER GENERATOR.
www.dilbert.com scottadams@aol.com
NINE NINE NINE NINE NINE NINE
ARE YOU SURE THAT'S RANDOM?
THAT'S THE PROBLEM WITH RANDOMNESS: YOU CAN NEVER BE SURE.
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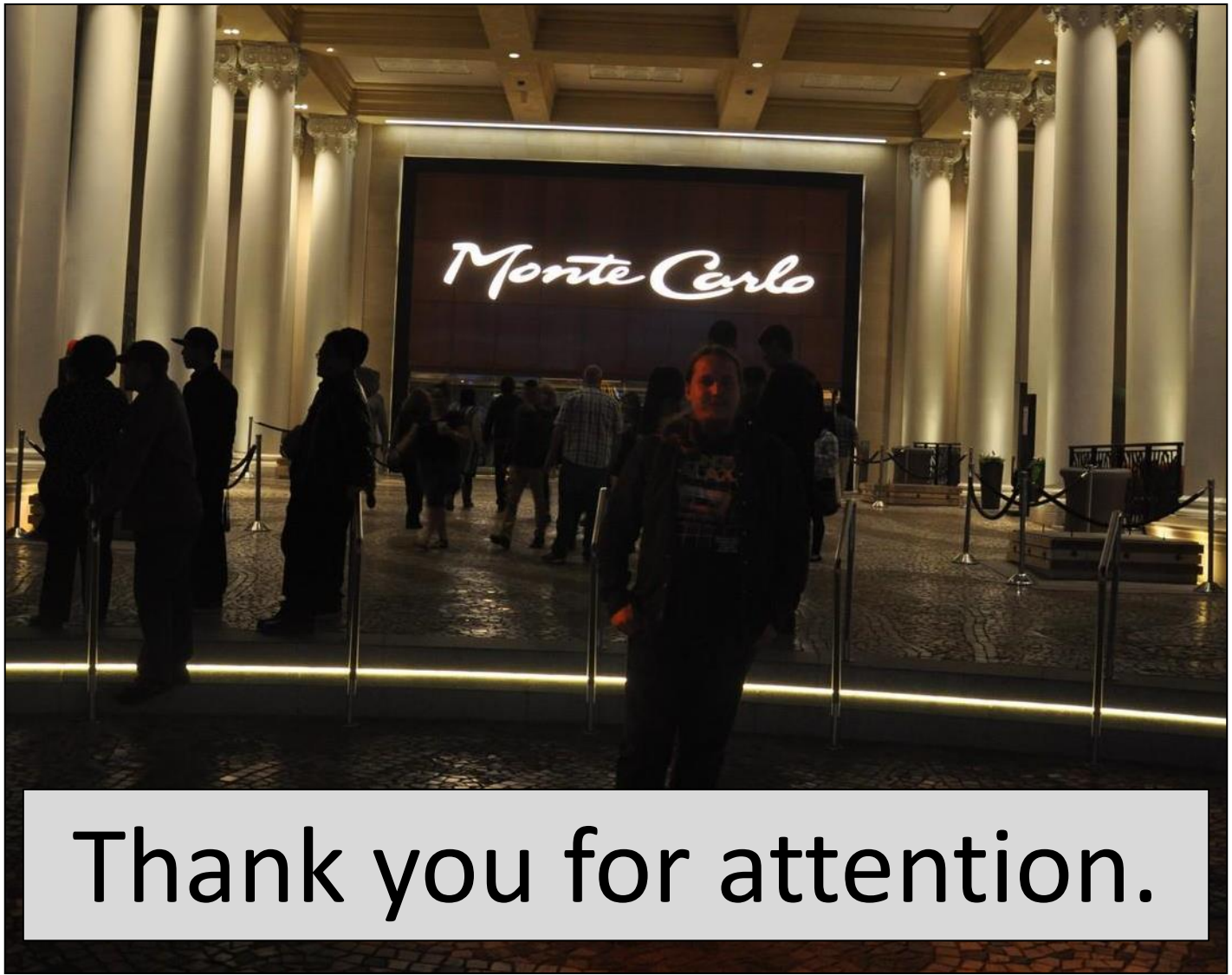

Thank you for attention.