Experiment Simulation

CERN School of Computing 2006
Helsinki

Lecture 1

SWX SWISS EXCHANGE
Martin Liendl
SWX Swiss Exchange

Francois' programme:

Aatos' programme:

Experiment Simulation

- Motivation for experiment simulation
- Principles of the Monte Carlo Method for experiment simulation
- **GEANT4** tool kit – implementation of the Monte Carlo Method for experiment simulation
- **GEANT4** tool kit – user interaction / customization / output
- Introduction to exercises

Slides/Handouts Organisation

- Handouts don't always show the same thing as the slides
  - Some slides have been changed
  - Some slides have been added
- The presented version of the slides can be downloaded from the CSC web

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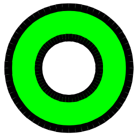
Whenever this symbol appears on the slide:



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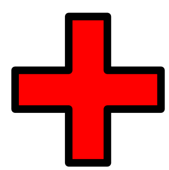
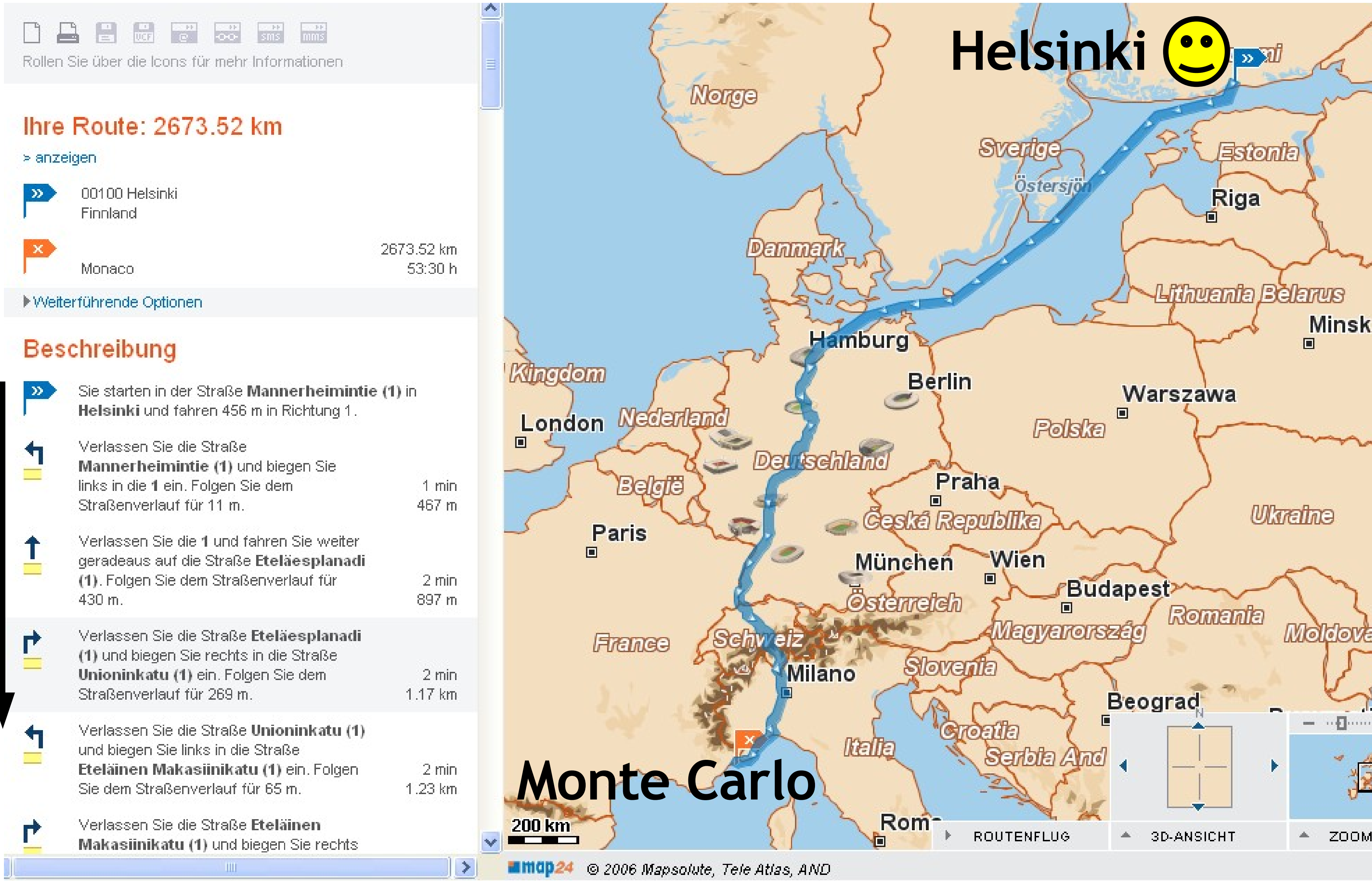
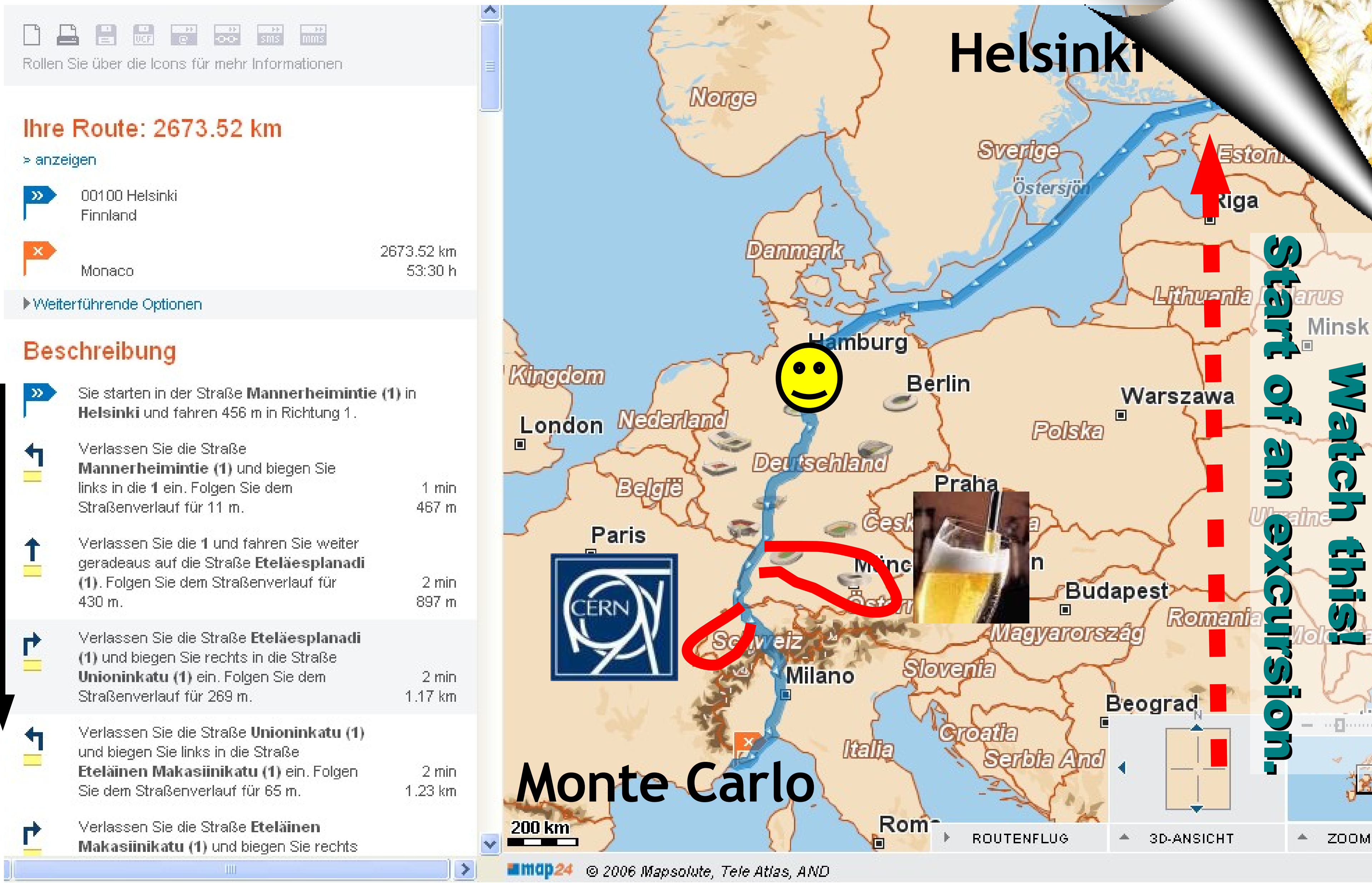


Lecture Organisation

long way to go ...



Free excursions included!



long way to go ...

Start of an excursion.

Watch this!

On an excursion ...

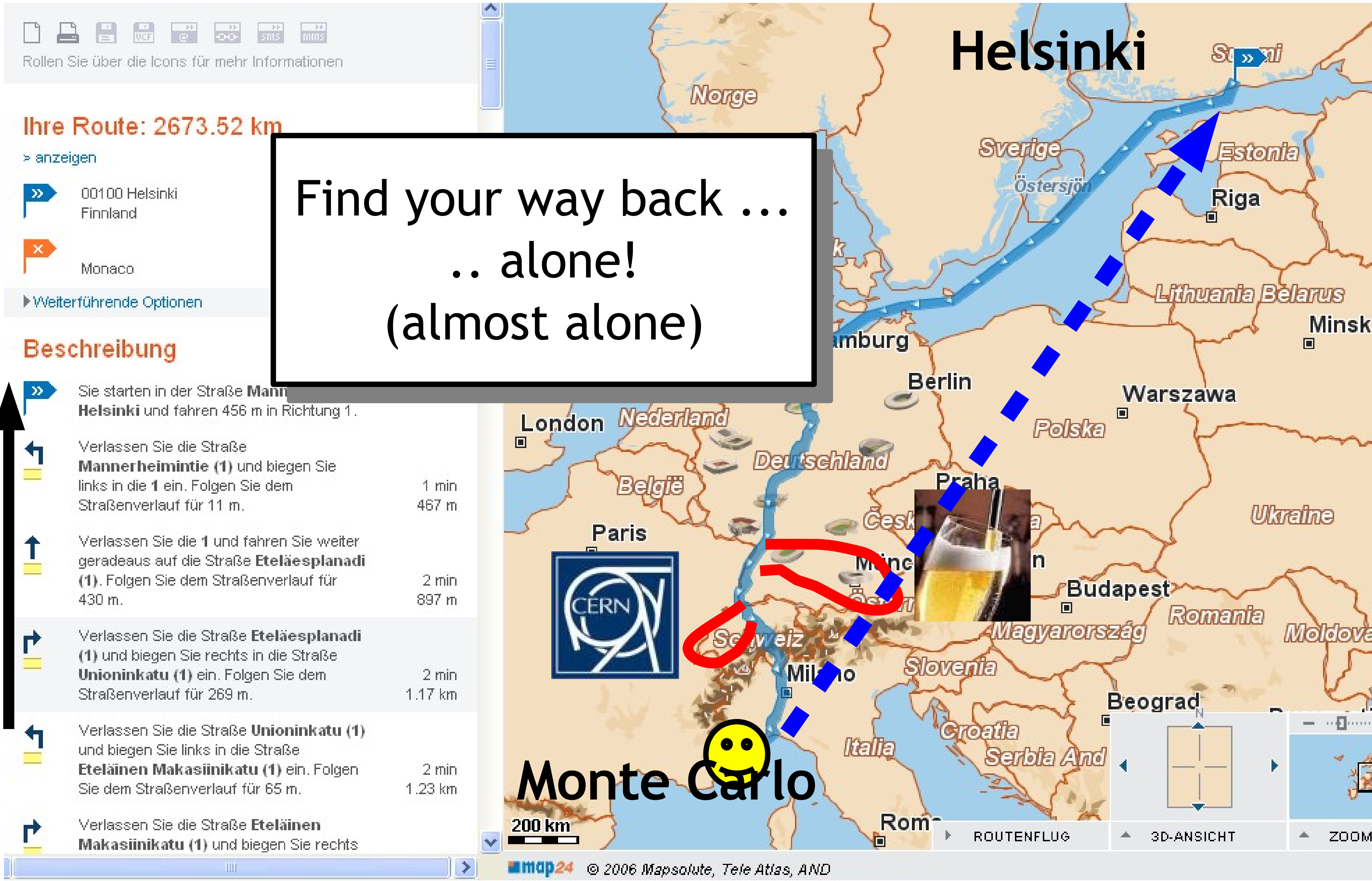
- ... we can relax!
- Excursions go into some details
  - related to the main track
  - but not required to follow the main track
- None of the examination questions are based on the material presented in excursions!

Marks the end of the excursion

Exercises!!!

Find your way back …
.. alone!
(almost alone)

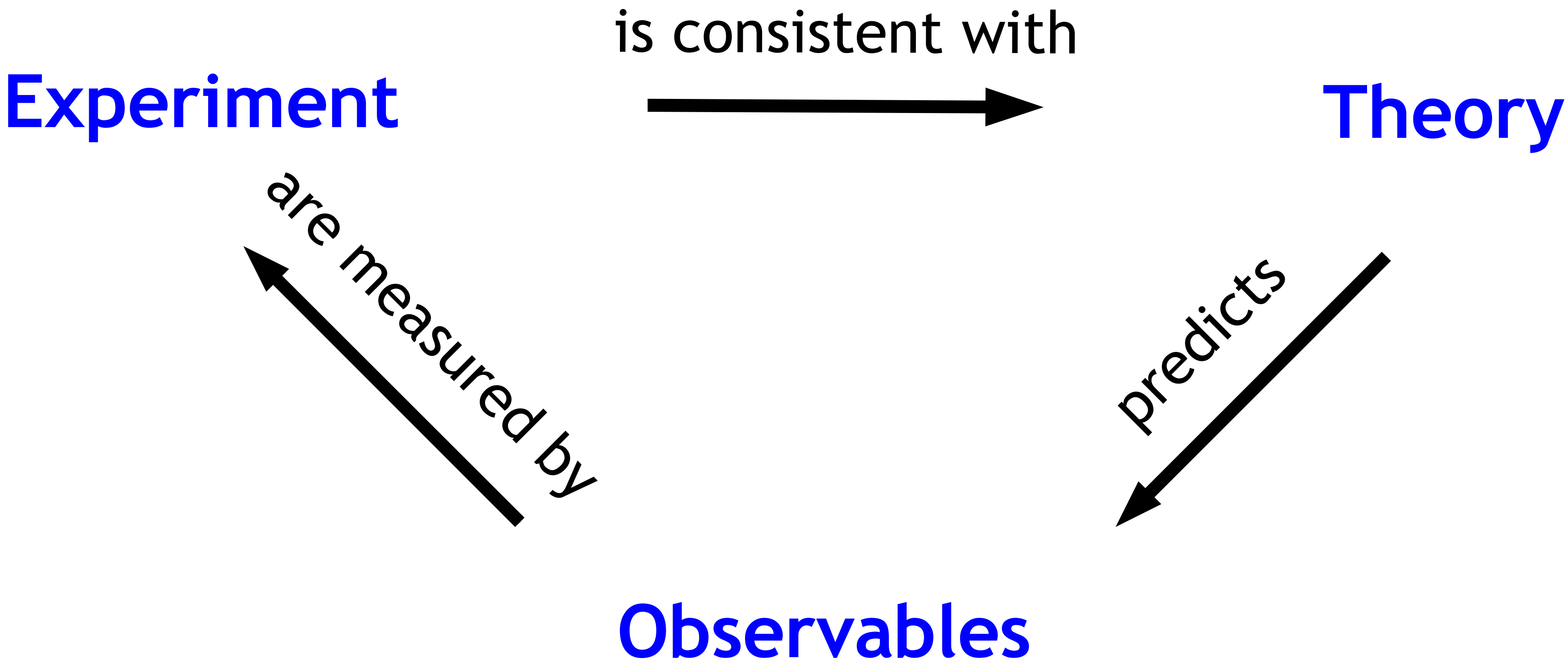
long way to go …



Why simulation?

- Some motivation:
  - from theory to experiment – in high energy physics
  - Where does simulation come in?
  - Where does simulation come in?
- “Case study”:
  - the Mickey Mouse theory and experiment
  - analogy to high energy physics
- Terminology and short explanation of terms
  - cross section, distributions

"Ideal" theory & experiment:

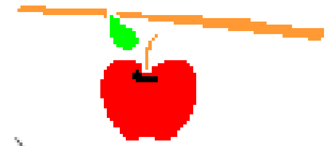


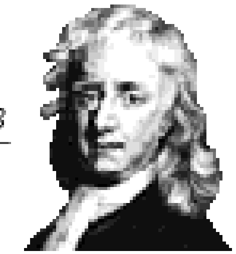
Experiment

is consistent with →

$$F = \frac{d}{dt}(mv)$$

$$|F| = \frac{G M_A M_B}{|r_{AB}|^2}$$



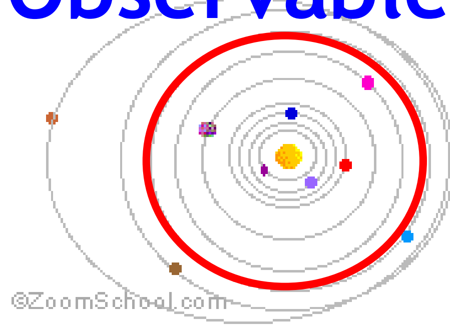


Theory

predicts

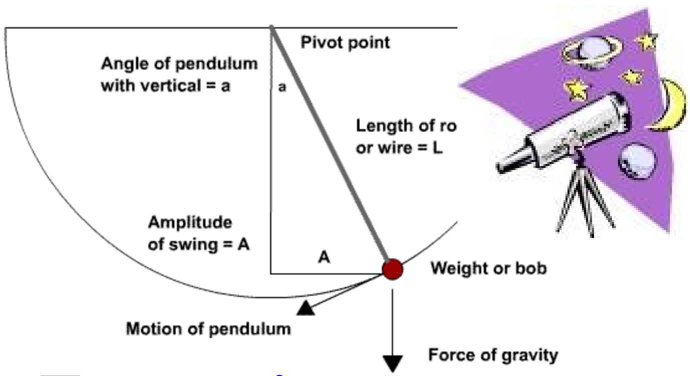
are measured by

Observables



undetermined parameter!

$$|F| = \frac{G M_A M_B}{|r_{AB}|^2}$$



Experiments

are consistent with

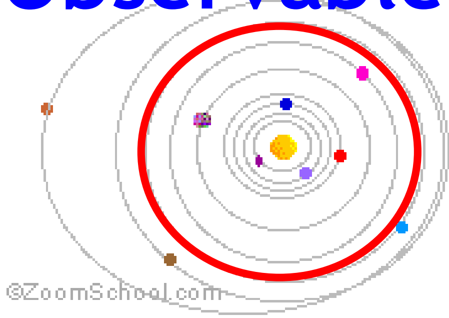
determine parameters

Theory

predicts

are measured by

Observables



Quantumtheory & experiment

(1) $H \mid \psi >= i\hbar\frac{\partial}{\partial t} \mid \psi >$

(2) $\frac{P^2}{2m} + V = -\frac{\hbar^2}{2m}\Delta + V$

(3) parameters

(4) $(i\gamma^\mu \partial_\mu - m)\psi = 0$

are consistent with

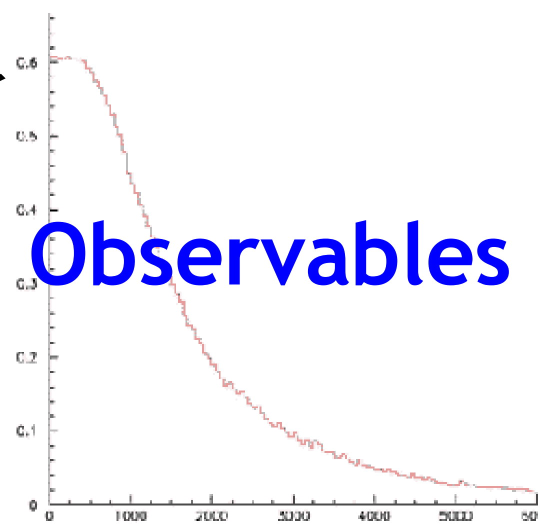
Experiments

Theory

determine parameters

are measured by

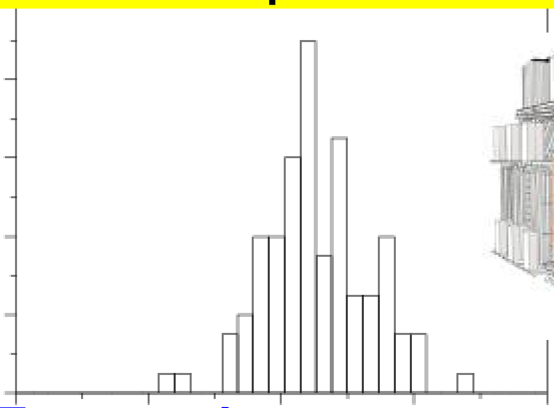
predicts

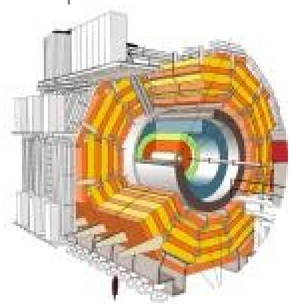


Observables

microscopic probability distributions

macroscopic distributions





Experiments

are consistent with

determine parameters

$$(1)\quad H \mid \psi >= i\hbar \frac{\partial}{\partial t} \mid \psi >$$

$$(2)\quad \frac{P^2}{2m} + V = -\frac{\hbar^2}{2m}\Delta + V$$

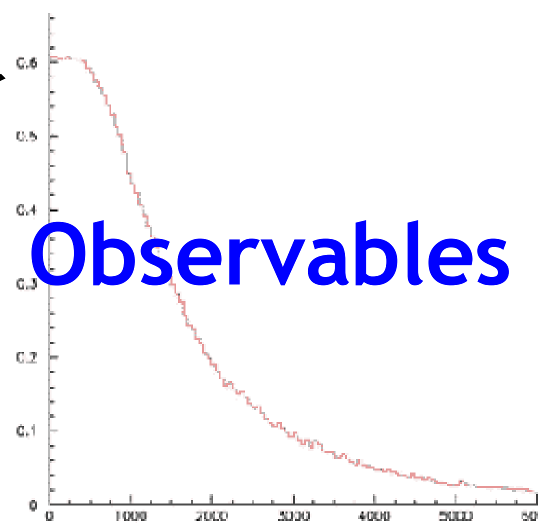
(3) parameters

$$(4)\quad (i\gamma^\mu \partial_\mu - m)\psi = 0$$

Theory

predicts

are measured by



Observables

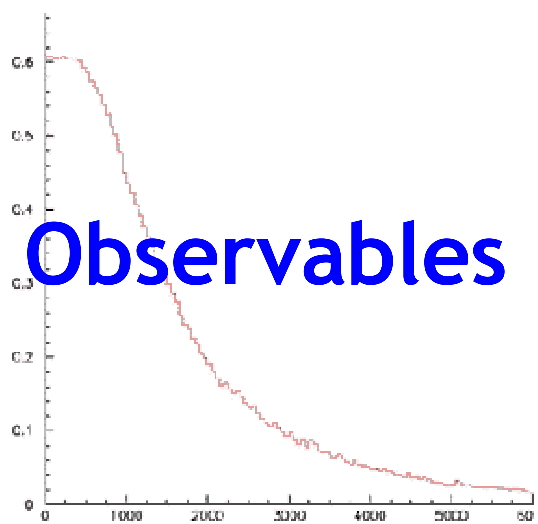
microscopic probability distributions

- We usually distinguish between **three levels** between theory and observables in HEP experiments:
  - fundamental interactions of not directly detectable particles predict distributions of detectable particles
  - theory of interactions of detectable particles with atoms/molecules of the detector
  - “digitization”

parameters

Theory

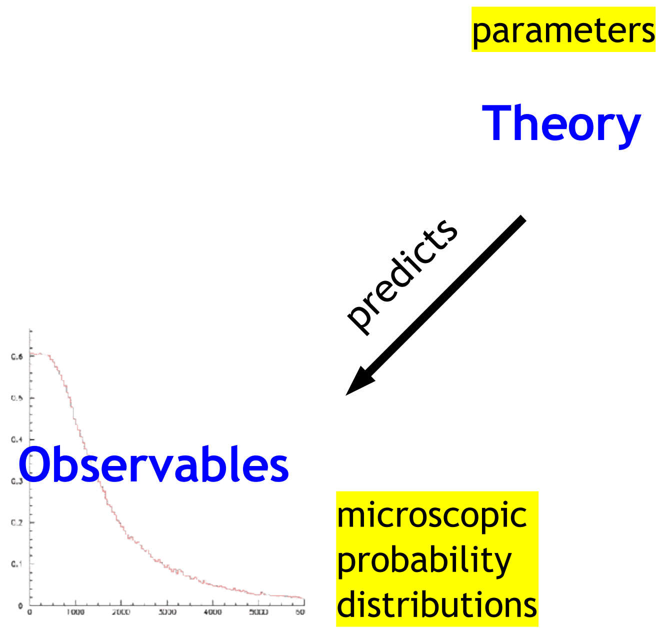
predicts



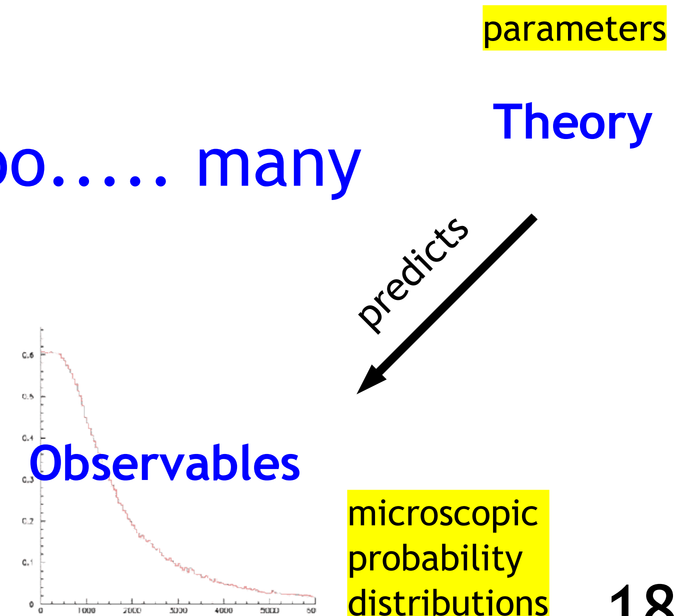
Observables

microscopic probability distributions

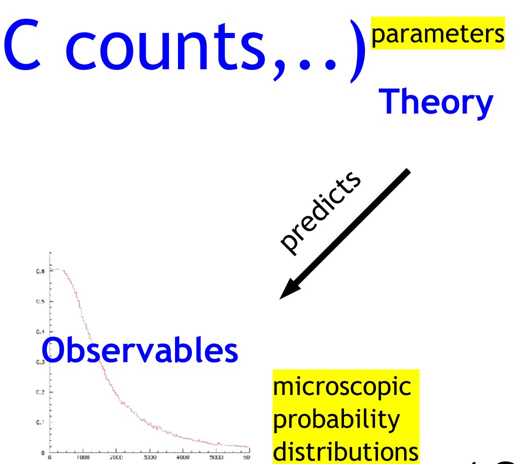
- Level one:
  - fundamental interactions of not directly detectable particles predict distributions of detectable particles
  - we have one or more theories which needs to be checked thoroughly before we can accept the one or the other
  - theories describe the isolated type(s) of interations which we still need to understand
  - fundamental parameters unknown



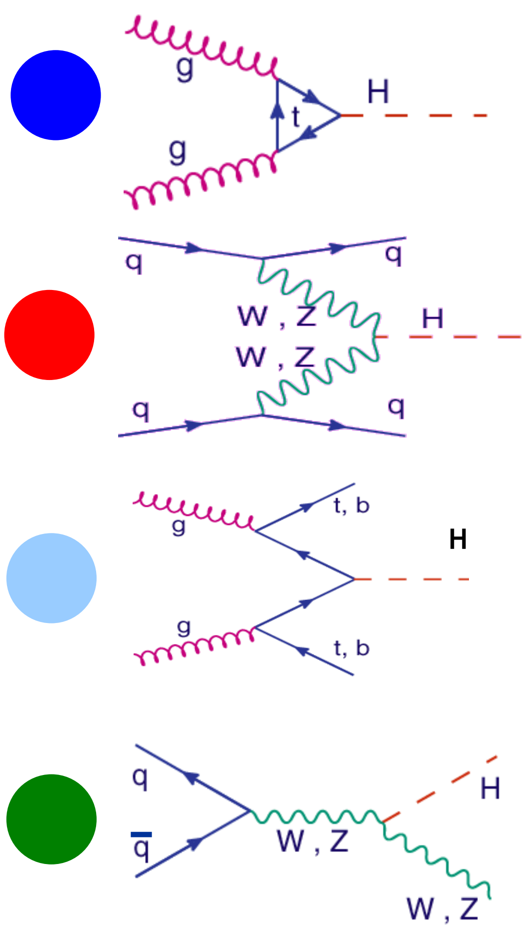
- Level one:
  - fundamental interactions of not directly detectable particles predict distributions of detectable particles
- Level two:
  - theory of interaction of detectable particles with atoms/molecules of the detector
  - we understand every type of interaction quite well
  - these interactions happen in the detector and thus induce the measurement signals
  - but, OH MY, there are SOOOOOoooooo..... many interactions!!!!
  - we have to understand this massive interaction-attack in order to under-stand our measurements!

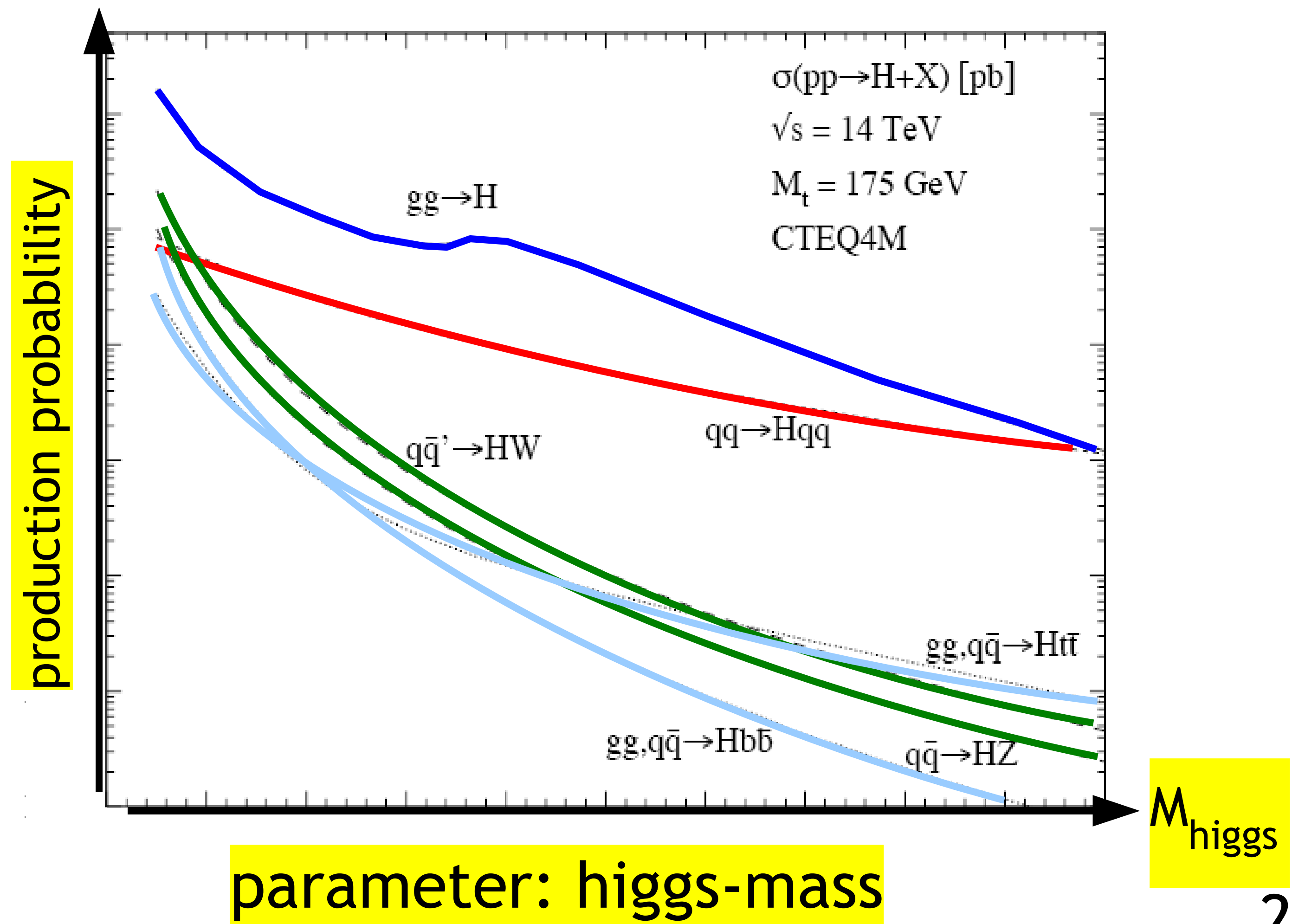


- Level one:
  - fundamental interactions of not directly detectable particles predict distributions of detectable particles
- Level two:
  - theory of interaction of detectable particles with atoms/molecules of the detector
- Level three:
  - known as “digitization”, detector response
  - conversion of many microscopic particle interactions in the detector to a measurement signal (ADC counts,..)
    - measured by specific electronics
    - depends on the type of detector
  - **NOT IN THIS LECTURES**

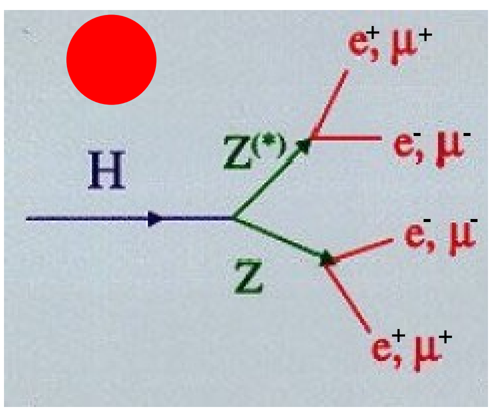


- Level **one:**
  - interactions of not directly detectable particles
- Example:
  - quark, gluon interactions in the standard model, production of a higgs particle

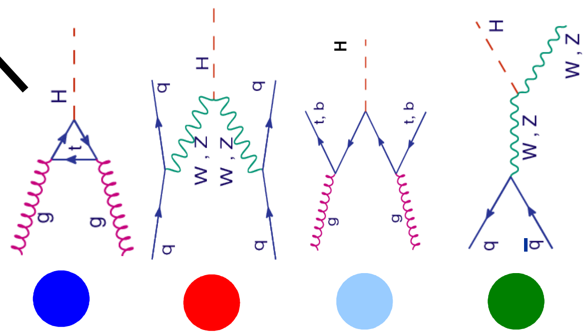


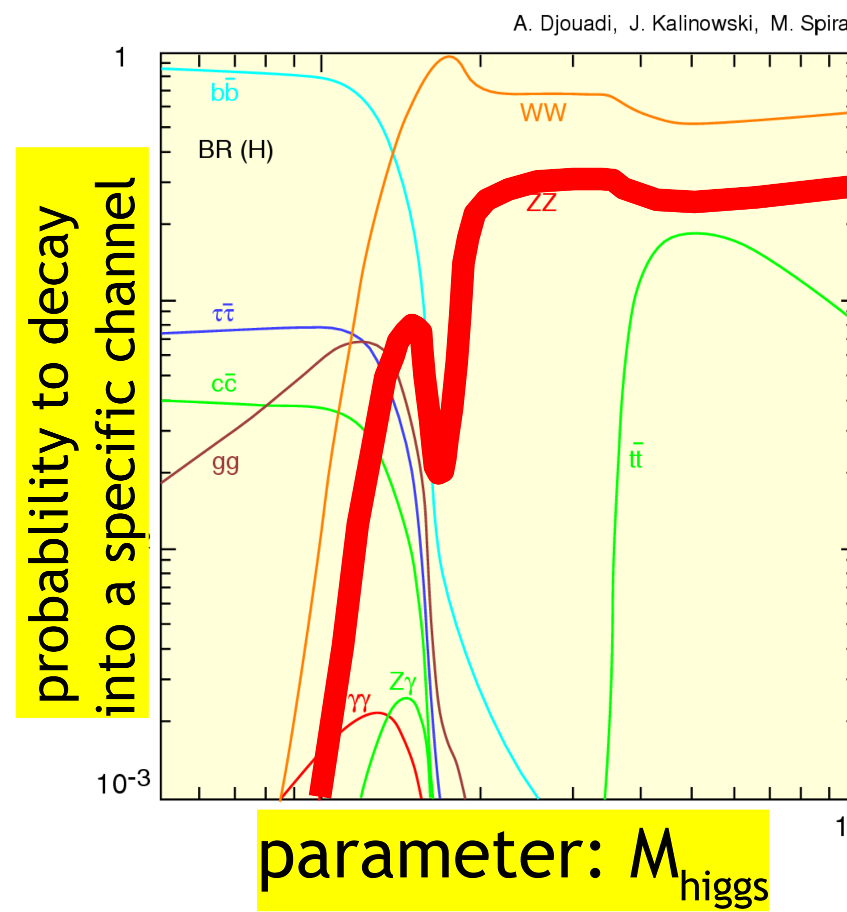


- Level **one:**
  - prediction of distributions of detectable particles
- Example:
  - higgs particle decays into different decay channels
  - each channel has its own distribution of the kinematical properties of the end-products



$e^{-,+}$, $\mu^{-,+}$ are detectable!





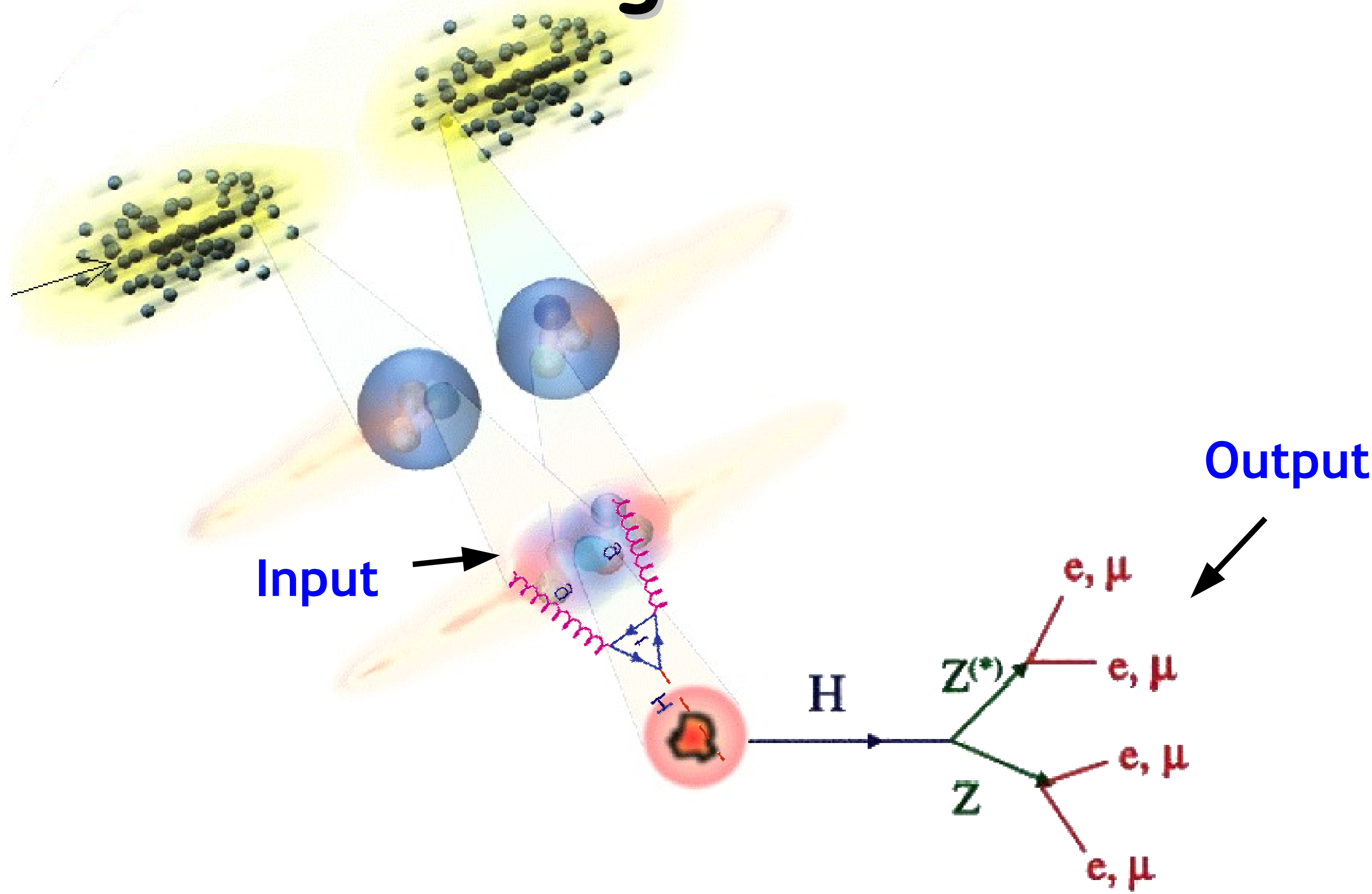
How to know what to look for?

- Standard Model
  - is one theory under test
  - there are others: supersymmetry, ...
- Higgs particle production & decay
  - is one (quite improbable) process out of many other processes in proton-proton collision
  - all other processes have their own probability distributions
- Higss mass is only one of the undetermined parameters ..
- **Its quite impossible to calculate all expected distributions in a deterministic, analytical manner**
  - use statistical sampling methods: **simulation!**
  - generation of "stable particles" from simulated collisions

Event generators

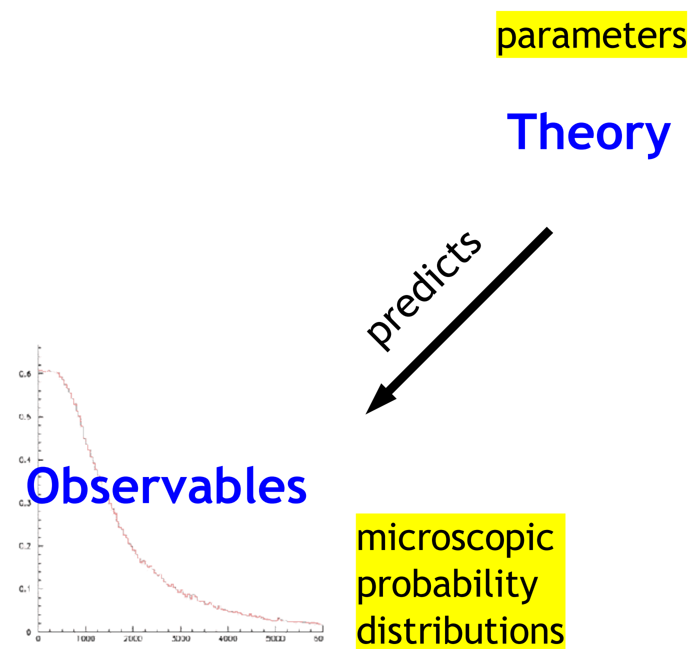
- Event generators are simulation programs
  - to simulate the interaction of fundamental particles
  - up to the “stable” particles resulting from the interaction
- Many different packages available for HEP
  - incorporate one or many fundamental theories
  - sample interactions according to the process distributions based on the quantumtheories
- Adjustable parameters
  - allow you to scan the parameter ranges of yet undetermined parameters of the theories
- **Good news: won't cover generators in these lectures!**

Event generators

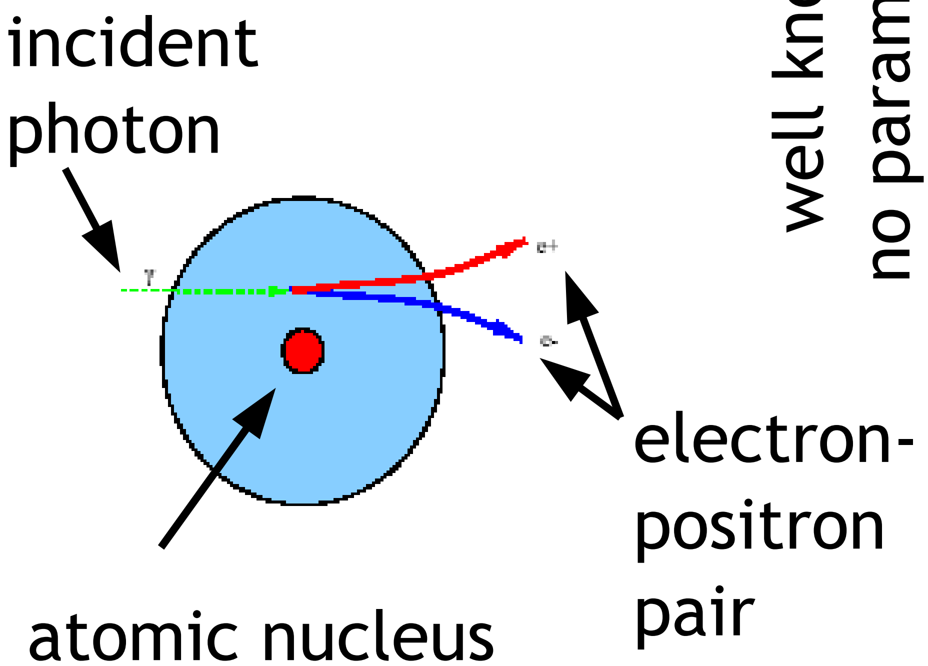


Remember?

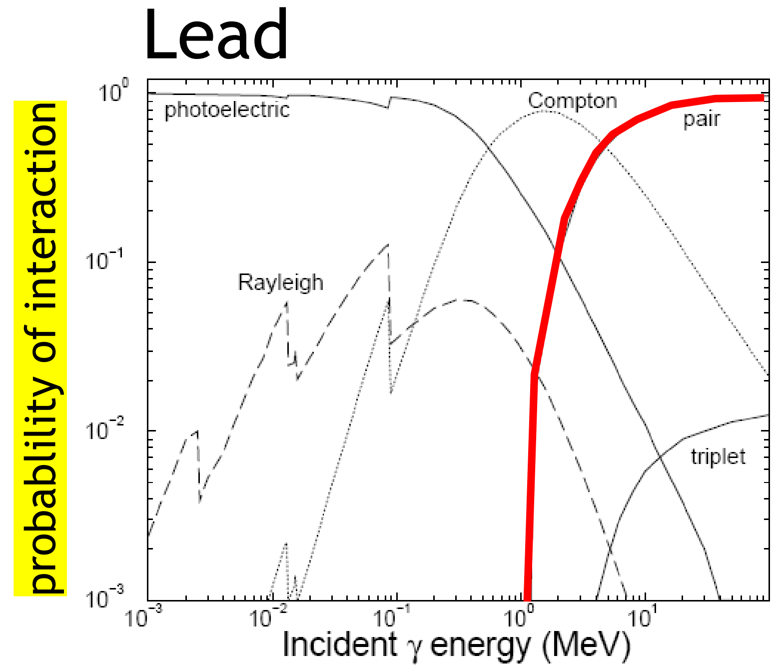
- Have **three levels** between theory and observables in high energy physics:
  - fundamental interactions of not directly detectable particles predict distributions of detectable particles
  - **theory of interactions of detectable particles with atoms/molecules of the detector**
  - "digitization"

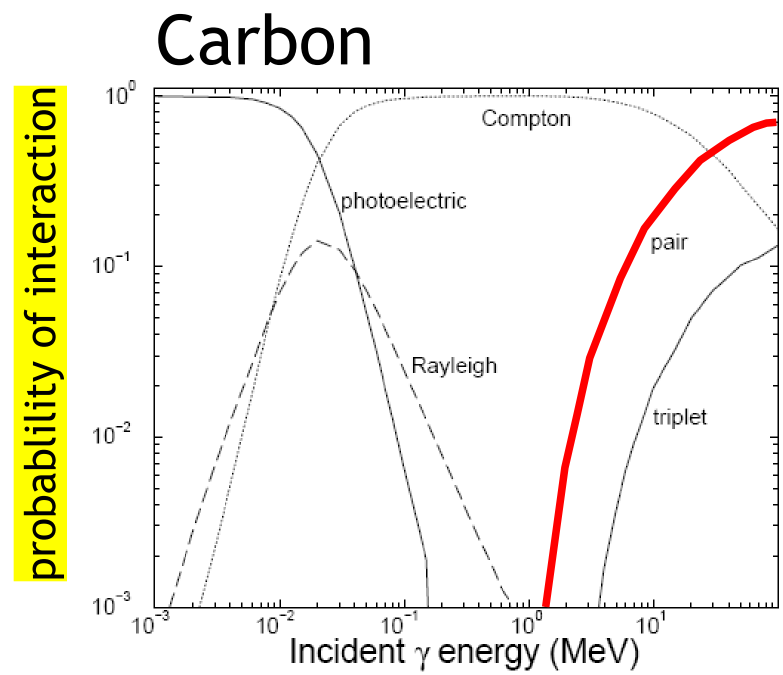


- Level **two**:
  - interactions of detectable particles
- Example:
  - pair creation

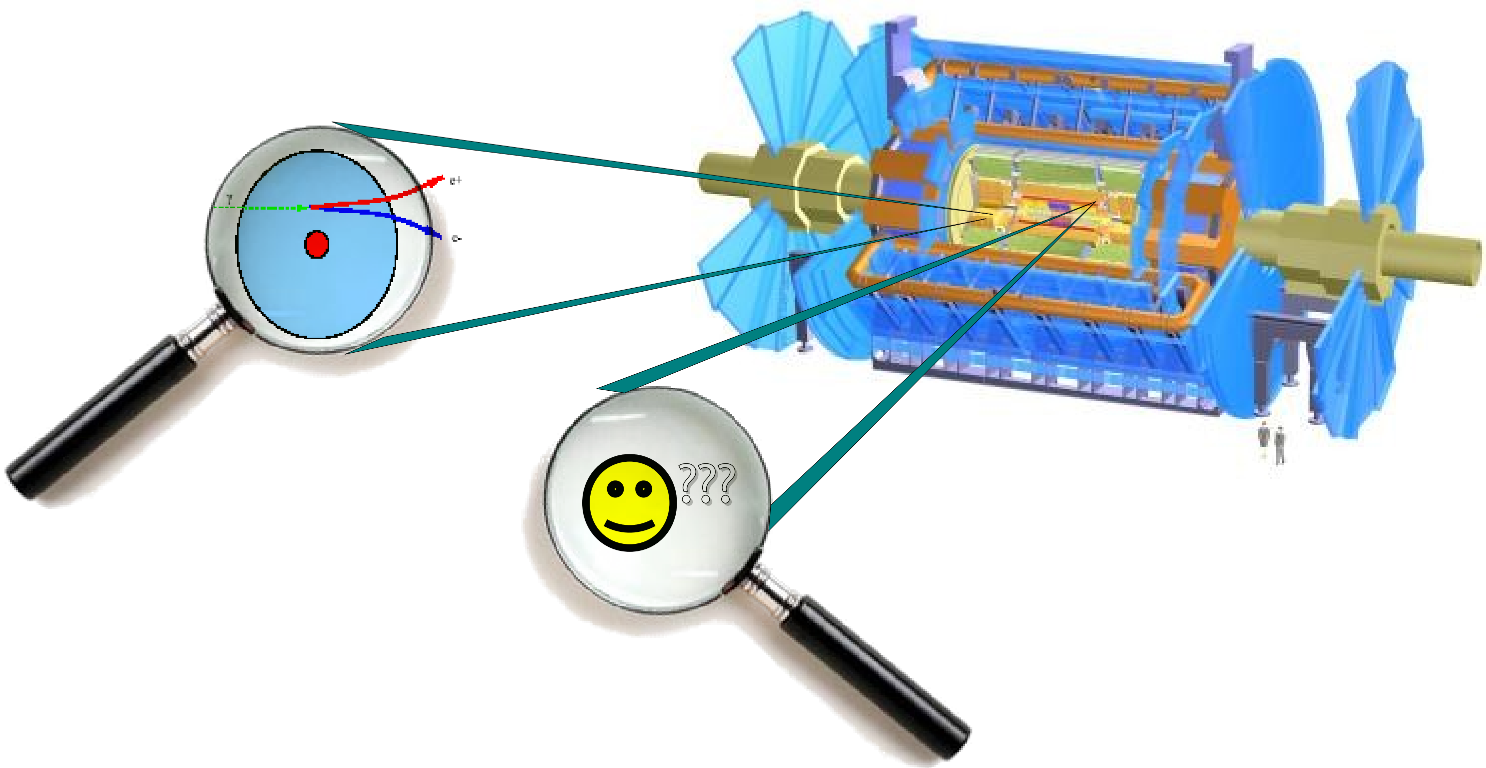


well known, no parameters!

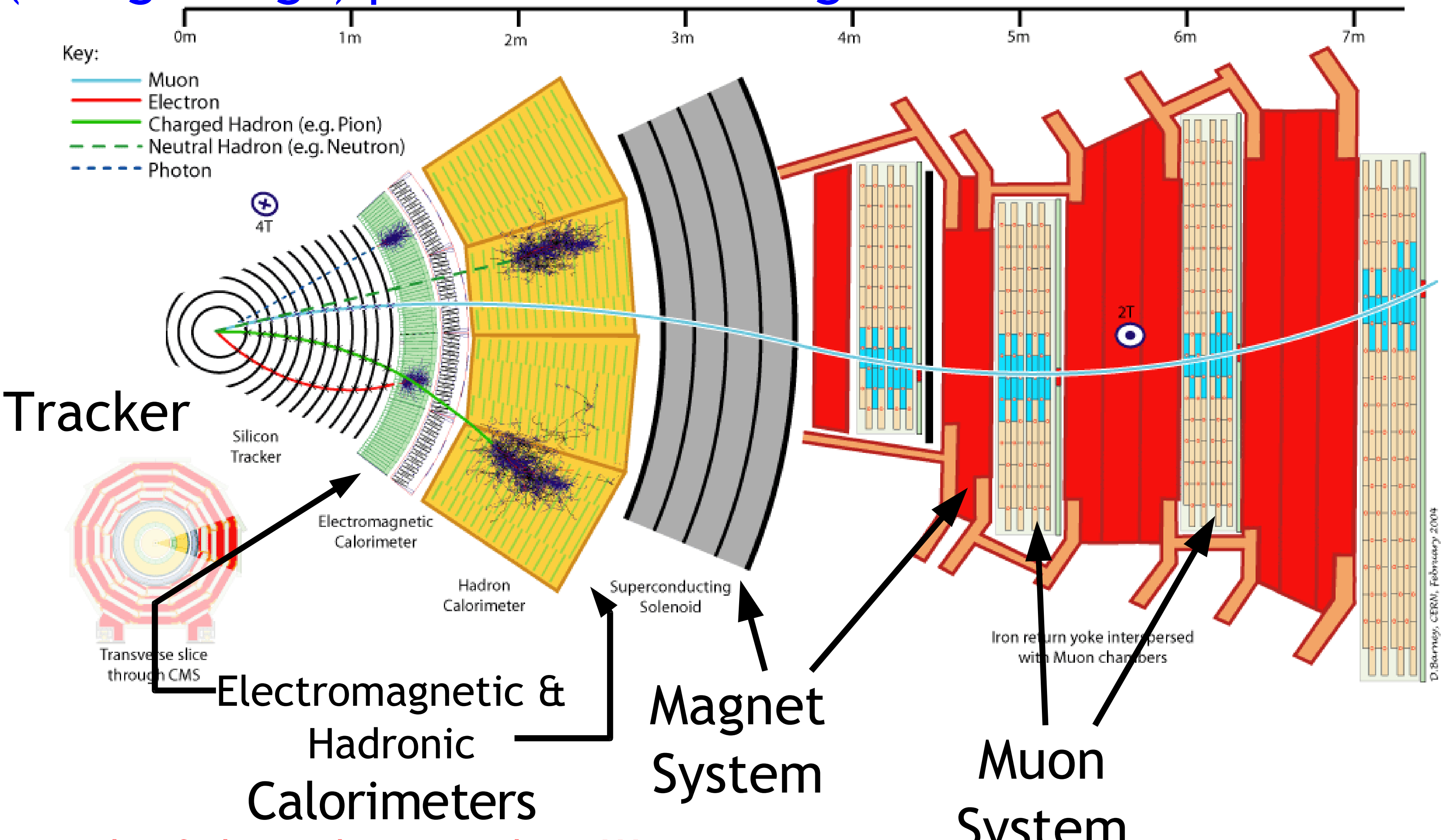




- Level **two**:
  - **the problem:** how do we get the probability distributions of our particles anywhere in our detector?
  - we need to know this distributions in order to understand what the detector has been measuring ...
  - especially when there is more than the pair-creation process affecting our particles ...



Onion shell design exploiting the physics processes of ("long living") particles traversing bulk matter



Thousands of channels everywhere!!!

Complex geometry ....

- Level **two**:
  - **the problem:** how do we get the probability distributions of our particles anywhere in our detector?
  - we need to know this distributions in order to understand what the detector has been measuring ...
  - especially when there is more than the pair-creation process affecting our particles ...
  - again: it's impossible to calculate these distributions in a analytical / deterministic way
  - **the solution:**
    - we simulate the fate of every single particle
    - faithfully according to the known theories
    - repeat the simulations often enough so that we get good estimates for the required distributions
    - => **EXPERIMENT SIMULATION, MONTE CARLO METHOD**

The Mickey Mouse Case Study

- Simplified view on the topics covered so far
  - to "induce" some feeling for physics for computing students
  - in order to have a common base for the chapter yet to come ...

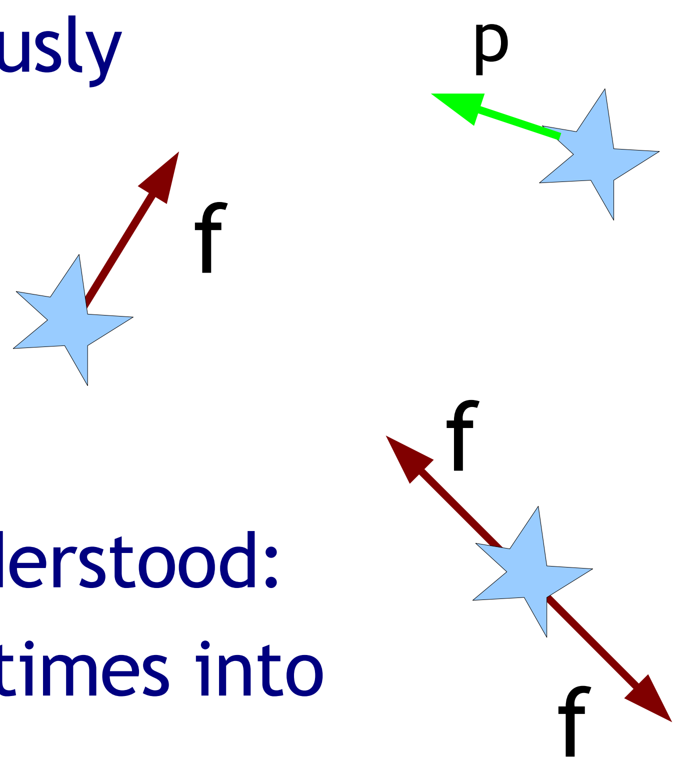
The Mickey Mouse Material

Somewhere in Disney World ...

... where everything is 2D, of course:

The M-material emits spontaneously

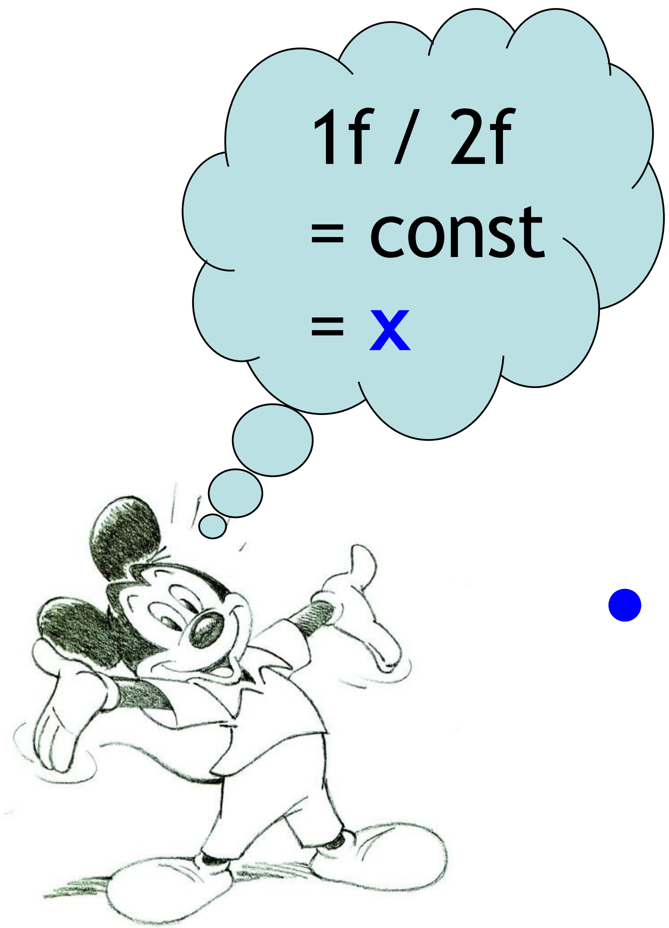
- at a time
- either one Pianissimo (p)
- or one Fortissimo (f)
- or two Fortissimos (f, f)



The physics of the p's is well understood: emission of p's occur at random times into random directions

The Mickey Mouse <u>Theory</u>

- Mickey had thought very hard and has a theory: M-Theory
- The M-theory states that
  - f's are emitted into random directions
  - in case of two f's, they go always into opposite directions
  - the fraction of single to double f emission is constant (**x**), but unknown: a **parameter** in the M-theory
- How big is **x**, provided the theory is OK?
  - equivalent with: what is the production ratio of single f-events vs. double f-events?



The Mickey Mouse Theory

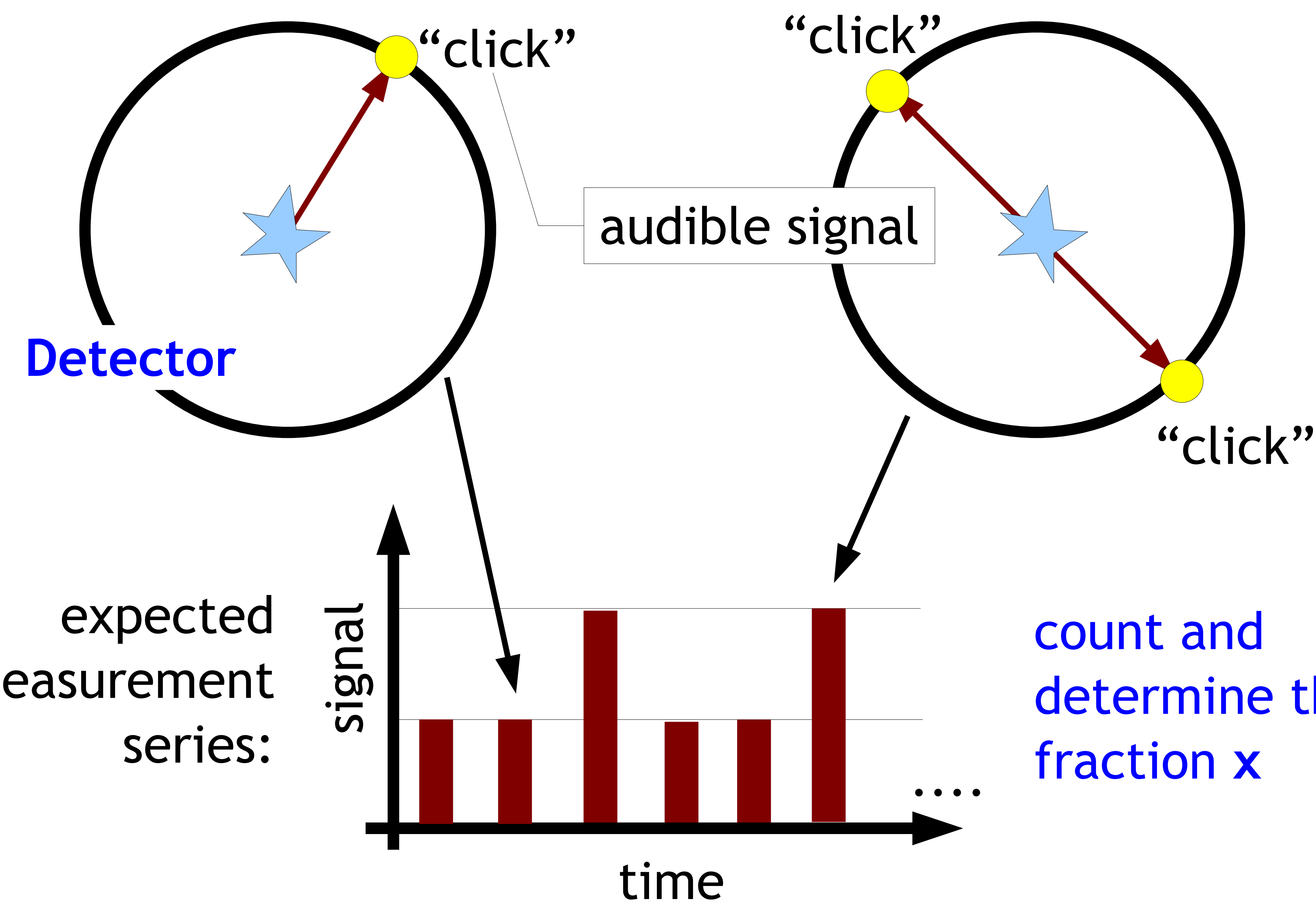
Remember?

- Mickey had thought very hard and has a theory: M-Theory
- The M-theory states that
  - f's are emitted into random directions
  - ...ys into
  - ... f
    emission is constant (**x**), but unknown: a **parameter** in the M-theory
- How big is **x**, provided the theory is OK?
  - equivalent with: what is the production ratio of single f-events vs. double f-events?

1f / 2f
= cons
= **x**

Level one: fundamental interactions, undeterminded parameters, e.g. higgs mass

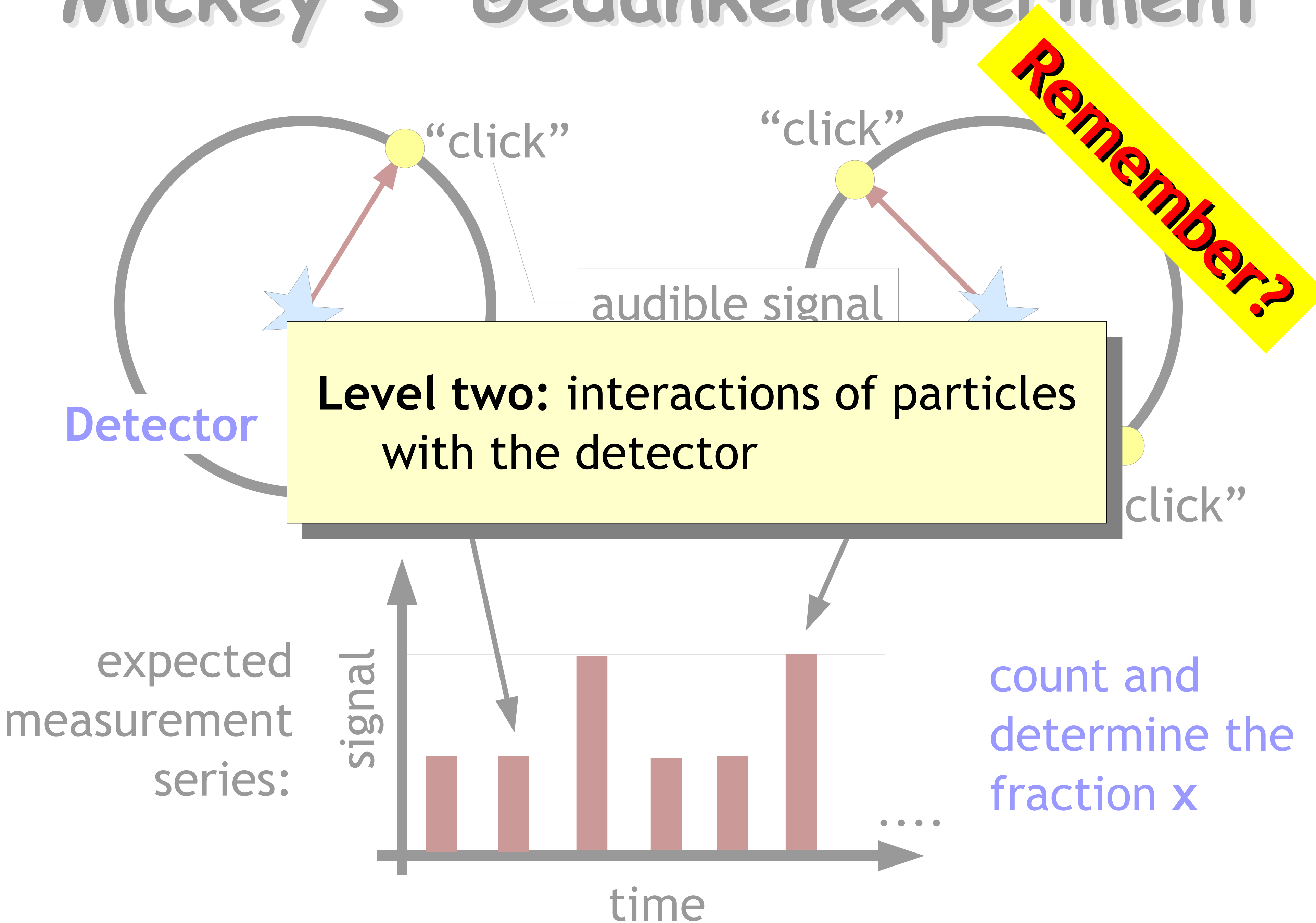
Mickey's "Gedankenexperiment"



expected measurement series:

count and determine the fraction **x**

Mickey's "Gedankenexperiment"



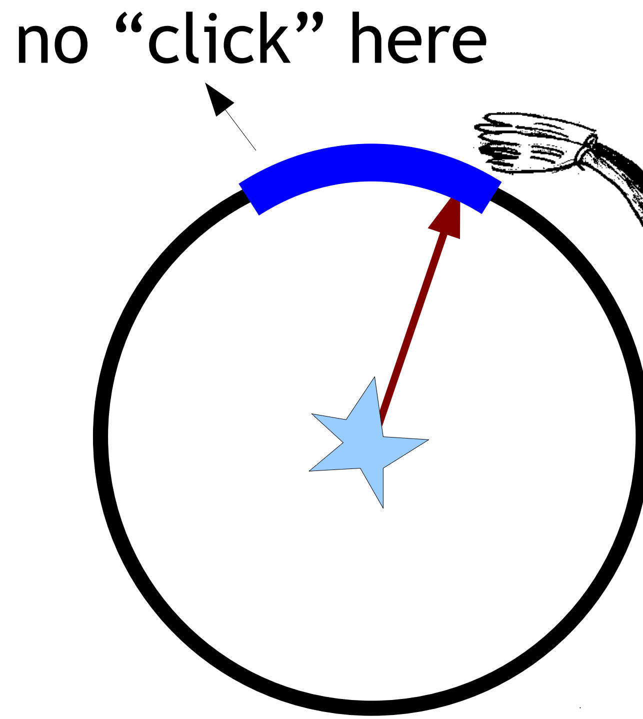
Level two: interactions of particles with the detector

Mickey's experiment

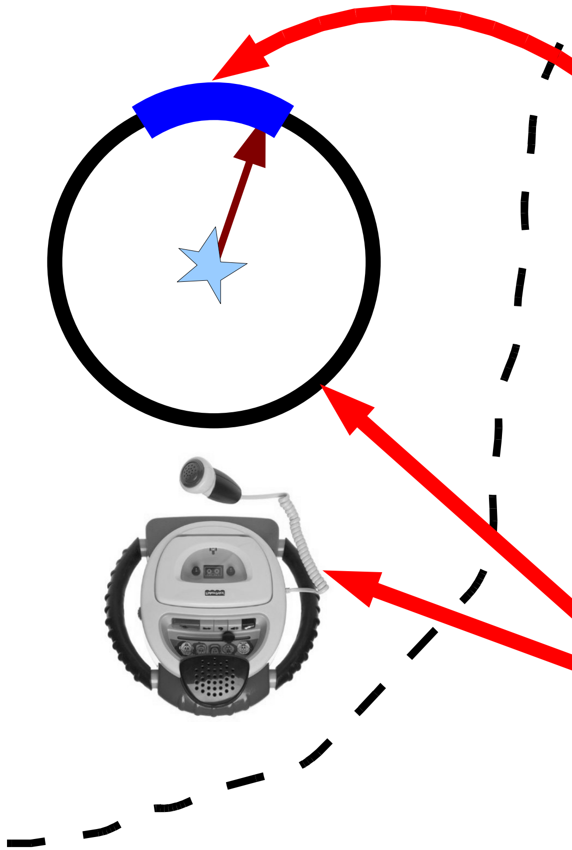
Goofy builds
the detector.

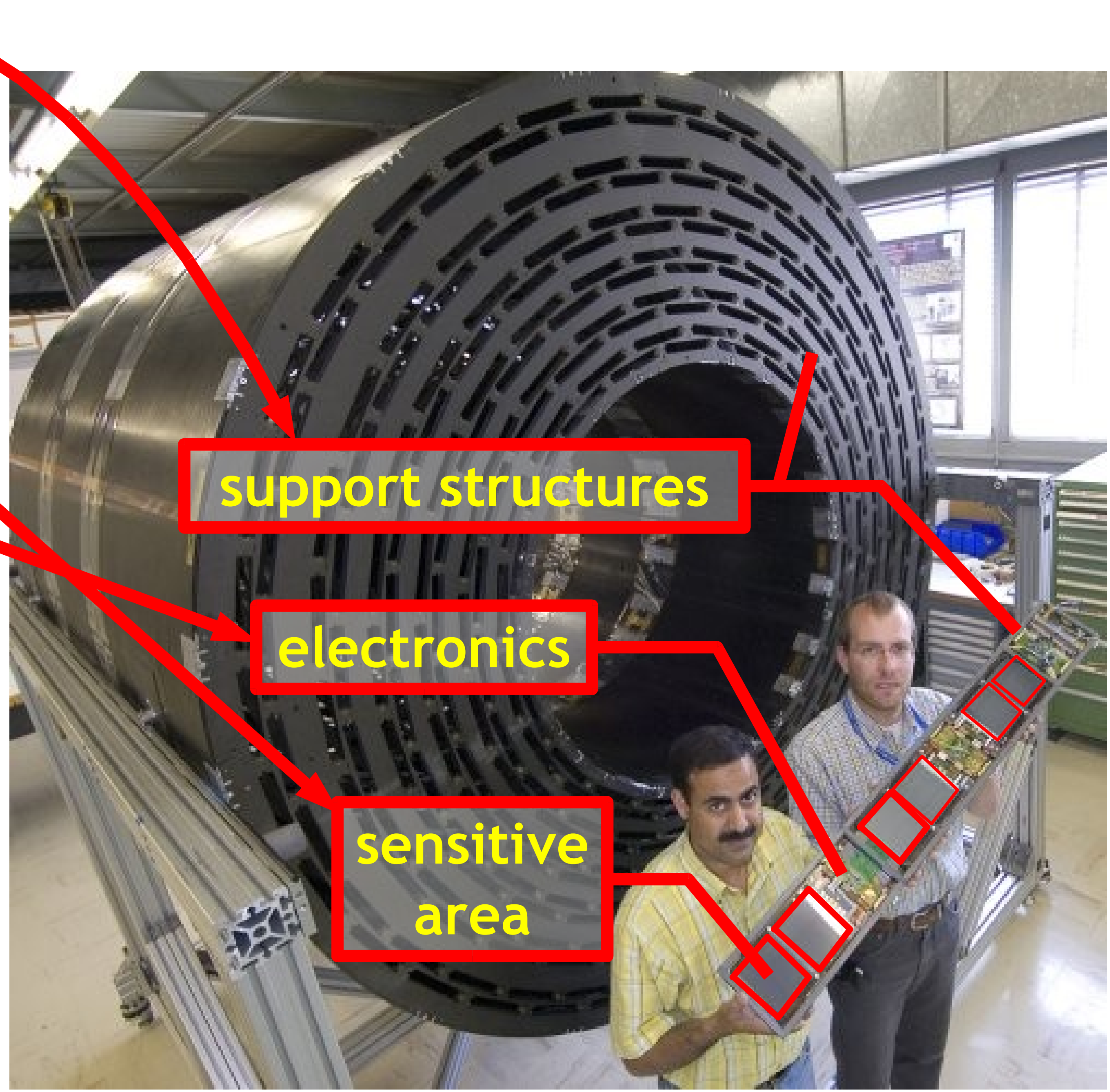
He has to use
a **cooling pipe**
taking **20%**
of the surface
of the detector´s
sensitive area

Technical Know How
and How To for
measuring observables



Click recorder

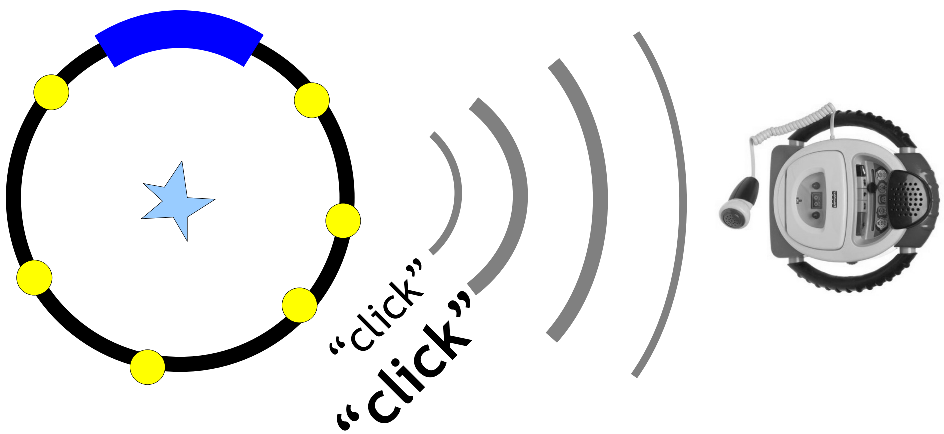


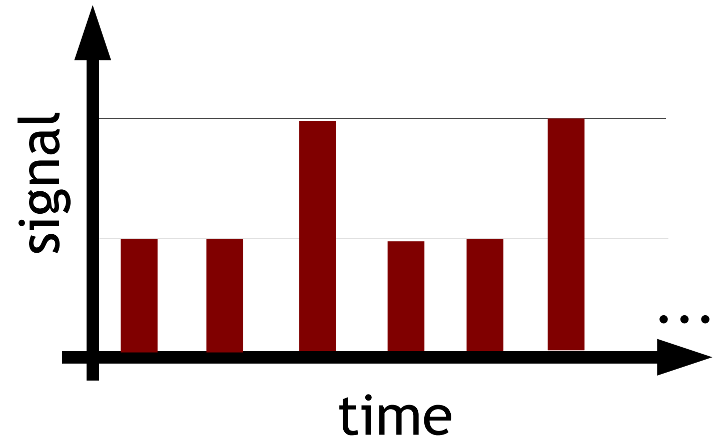


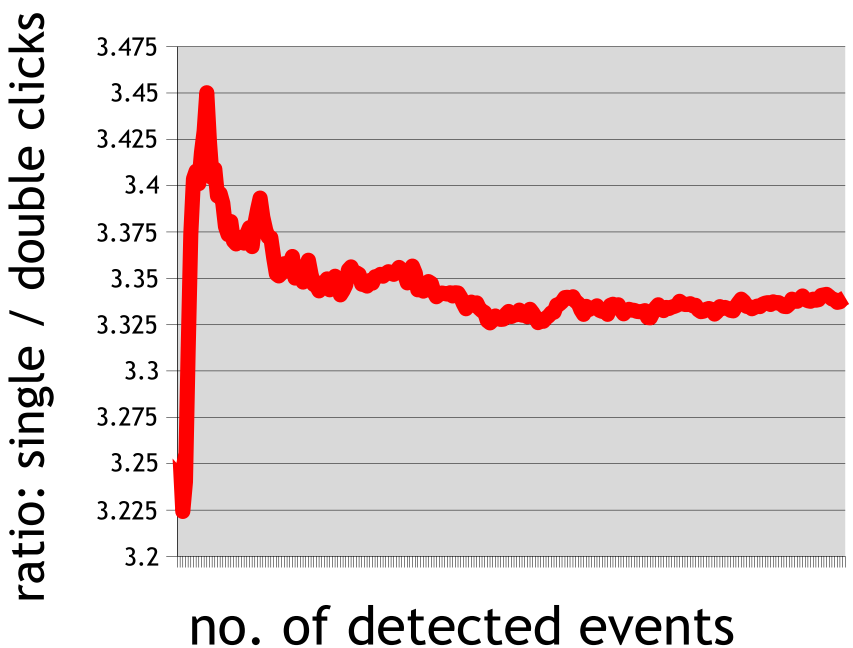
Not shown:
trigger electronics,
data storage, ...

And: it's “only” a part of the whole detector!

Doing the experiment



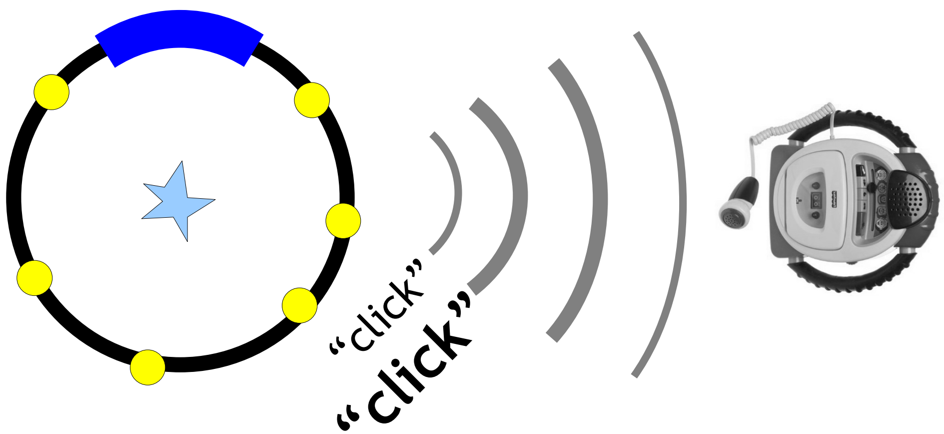




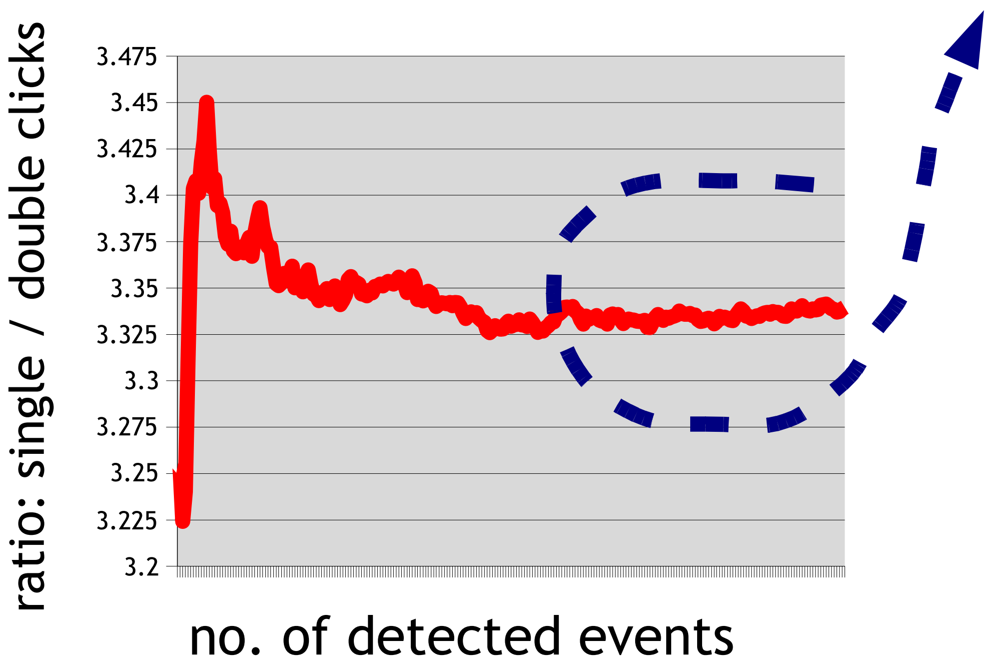
$$\frac{\text{single clicks}}{\text{double clicks}} \sim \text{const.} = x$$

x ~ 3,33

Analysis:



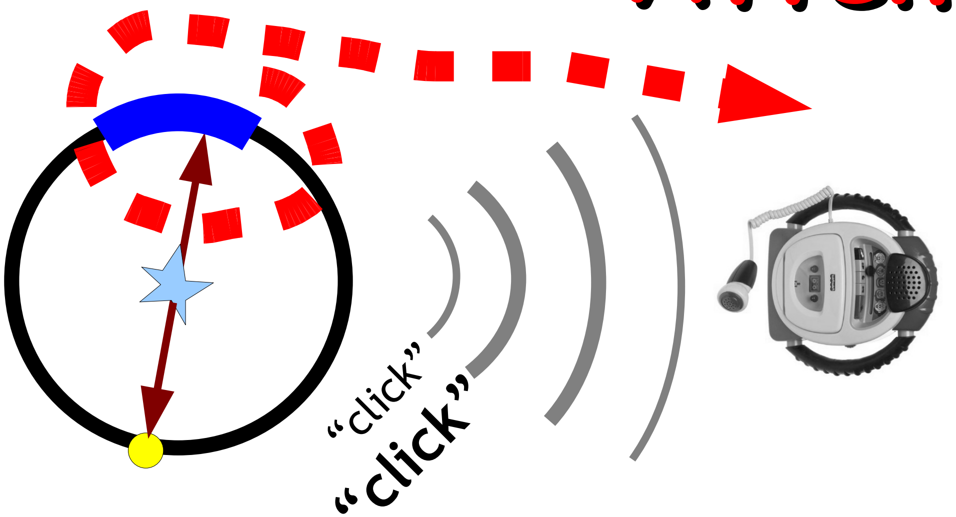
Ratio between single and double clicks is constant.
=> consistent with Mickey's theory.



$$\frac{\text{single clicks}}{\text{double clicks}} \sim \text{const.} = x$$

<u>**x ~ 3,33**</u>

Attention!!

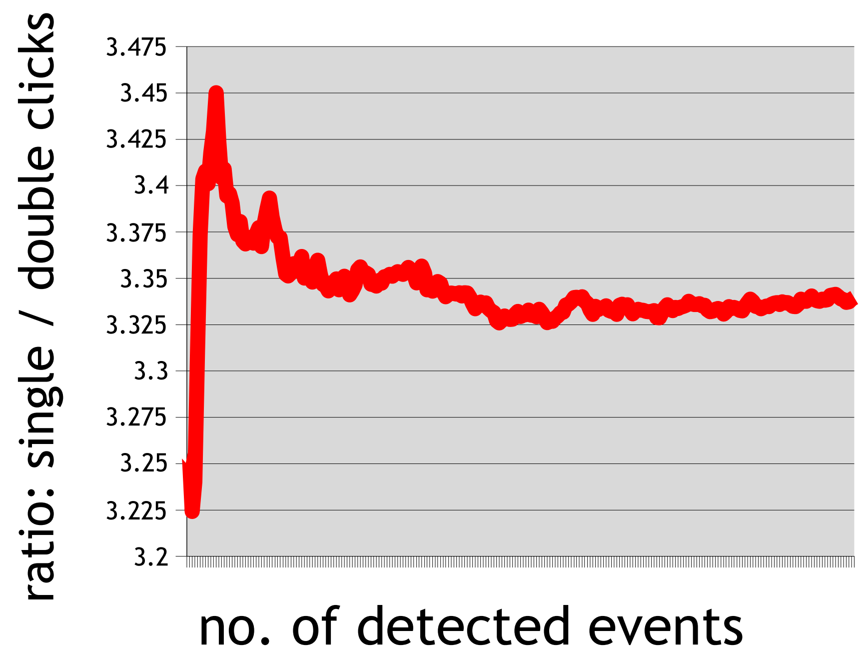


The measured ratio is biased!!

Count too many single click events!

$$\frac{\text{single clicks}}{\text{double clicks}} \sim \text{const.} = x$$

~~x = 3,33~~



Better analysis

- Our first excursion!!
- Take a closer look on
  - parameter in the M-Theory
  - indirect measurement of the parameter
- Analysis of the measurement
  - analytical method
  - simulation method

Analysis

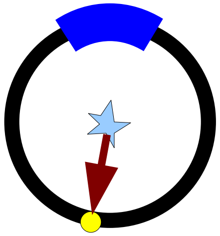
p .. probability for a single f-event
1-p .. probability for a double f-event

} $x = p/(1-p)$ .. ratio of single to double

s .. fraction of sensitive area (4/5 in our case)
1-s .. fraction of the cooling pipe (20% = 1/5 in our case)

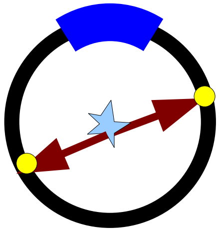
prob. of detecting a single click, in case of a single f-event:

$$P_S = p \cdot s$$



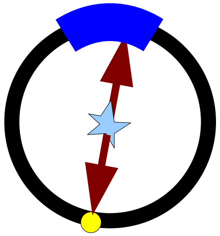
prob. of detecting a double click, in case of a double f-event:

$$P_D = (1-p) \cdot [s - (1-s)] = (1-p) \cdot (2s-1)$$



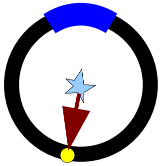
prob. of detecting a single click, in case of a double f-event:

$$P_F = (1-p) \cdot 2 \cdot (1-s)$$



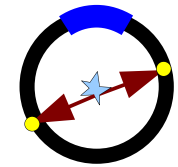
prob. of detecting a single click,
in case of a single f-event:

$$P_S = p \cdot s$$



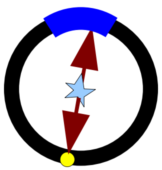
prob. of detecting a double click,
in case of a double f-event:

$$P_D = (1-p)\cdot[s - (1-s)] = (1-p)\cdot(2s-1)$$



prob. of detecting a single click,
in case of a double f-event:

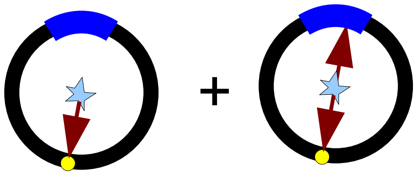
$$P_F = (1-p)\cdot 2\cdot(1-s)$$



But what we measure is:

prob. of detecting a single click,
in case of a single or double f-event:

$$\underline{P}_S = P_S + P_F$$



measured ratio single/double:

$$\underline{x} = \underline{P}_S \,/\, P_D = F(p), \quad p = F^{-1}(\underline{x})$$

$$p = \frac{\underline{x}\cdot(2s-1) - 2 + 2s}{\underline{x}\cdot(2s-1) - 2 + 3s} \rightarrow x = \frac{p}{1-p} = 1/s \cdot [\underline{x}\cdot(2s-1) - 2 + 2s]$$

→ $\underline{x} \sim 3.33$, $x \sim 2.$, $p \sim 0.66 \sim 2./3.$ for Mickey's setup

Simulation of Mickey's experiment

Analytical solution:

p .. probability for a single f-event
1-p .. probability for a double f-event
$\underline{x}$ .. ratio of measured single / double f-events
s .. fraction of sensitive detector
x .. ratio of single / double production rate, undetermined in the theory, i.e. p is undertermined.

$$x = \frac{p}{1 - p} = 1/s \cdot [\underline{x}\cdot(2s-1) - 2 + 2s]$$

Simulation

- p -> p_i in [0, 1/N, 2/N, ..., 1]
- for each p_i, generate M events: ~ p_i single f, $(1-p_i)$ double f
- for each event, sample a random direction
- for each event, check, if the direction hits the cooling or not, and count the “clicks” accordingly
- thus, for each p_i an $\underline{x}_i$ has been simulated
- correlate p_i and $\underline{x}_i$ to find the correction factor for the real experiment

Simulation of Mickey's experiment

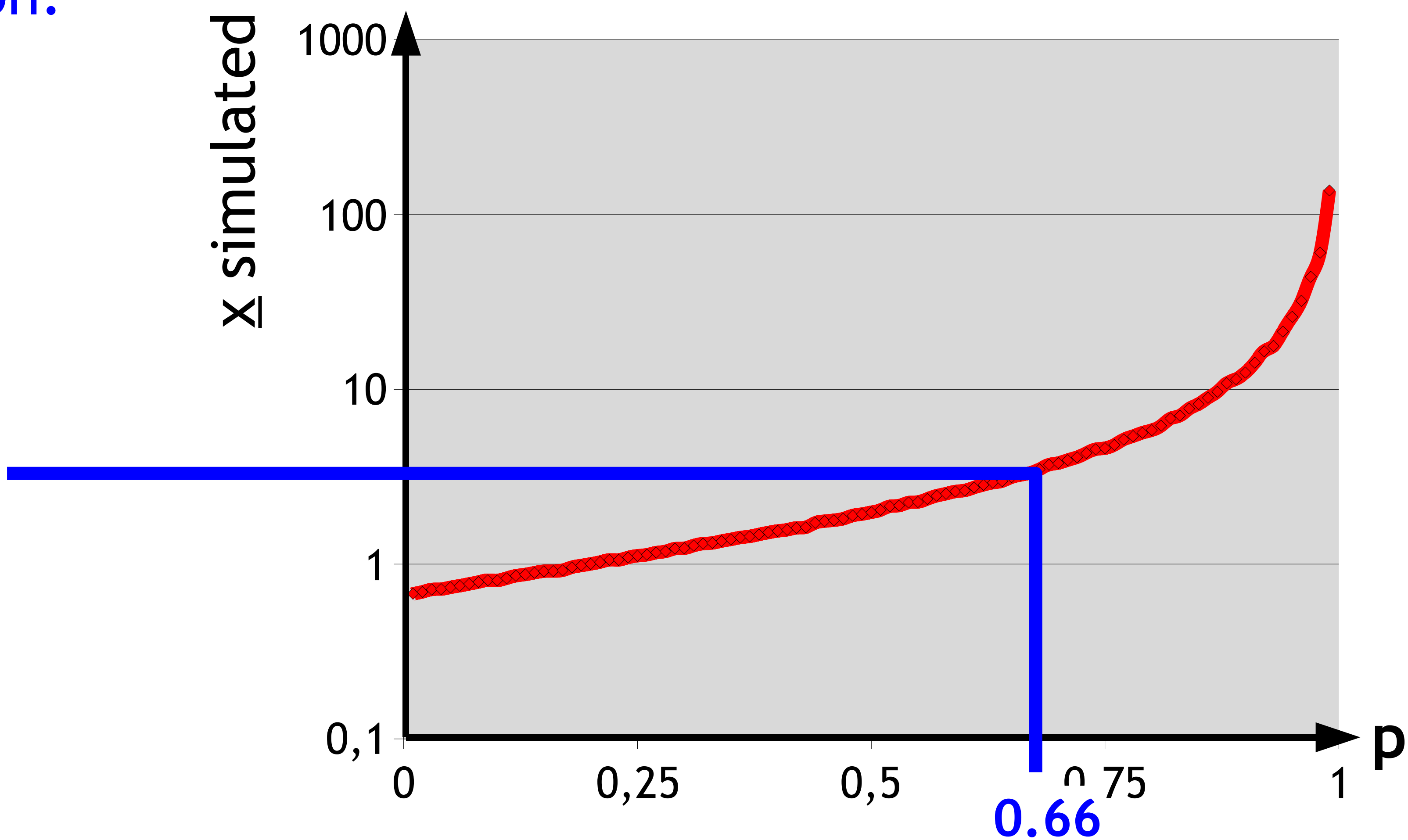
Analytical:

$$x = \frac{p}{1 - p} = 1/s \cdot [\underline{x}\cdot(2s-1) - 2 + 2s]$$

Simulation:

measured

$\underline{x}$ ~ 3.33



- Already very simple setups are difficult to treat in an analytic / deterministic way!
  - rather complex expression for the correction factor!
- In HEP, theories, detectors, and analysis procedures are A LOT MORE complex!!
  - we need to apply other methods to understand the measurements of our detector in order to draw conclusions concerning the underlying physics
  - the Monte Carlo method is a required tool, whenever the analytical solution can't be given easily

Example: acceptance, efficiency

Acceptance a:

N ... number of events of a given type (e.g. single f emission)

N_d .. number of detected events of the same type

$$\langle N_d \rangle = a \langle N \rangle$$

Acceptance relates the avarage number of detected events of a given type with the avarage occurance of this type.

Detection Efficiency ε(x) := probability of an event **x** to be detected if it has taken place

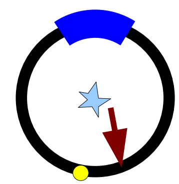
x .. physical variables (positions, momenta, ..)

f(**x**) .. distribution density of **x** (from physics-theory)

$$a = \int \varepsilon(\mathbf{x}) f(\mathbf{x}) d\mathbf{x}$$

Mickey's case

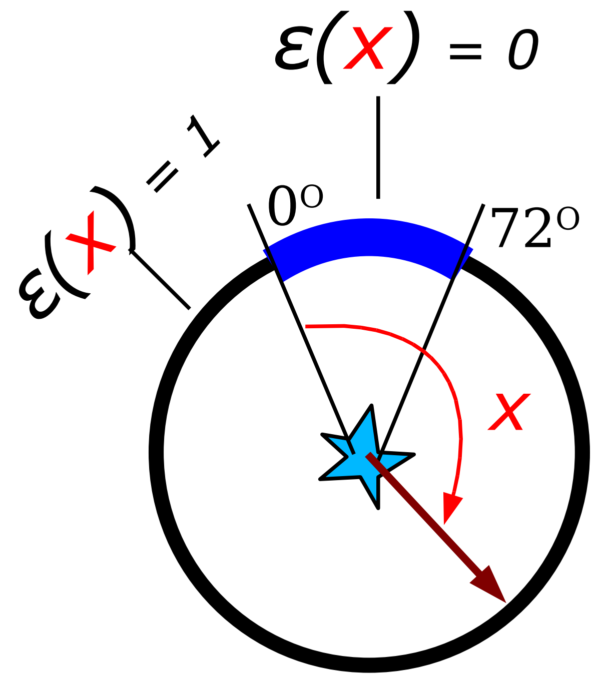
prob. of detecting a single click, in case of a single f-event:



p .. probability of emitting a single f-particle
s .. fraction of sensitive detector area

$$P_s = p \cdot s = p \cdot a = p \cdot \int \varepsilon(x) f(x) dx$$

x .. angle of emission of an f-particle
f(x) .. distribution of x: all directions are equally probable: $f(x) = 1/360^o$
ε(x) .. efficiency – here only determined by the geometry:



$$\varepsilon(x) = \begin{cases} 0 \text{ for } x \text{ in } [0^o, 72^o) \\ 1 \text{ for } x \text{ in } [72^o, 360^o) \end{cases}$$

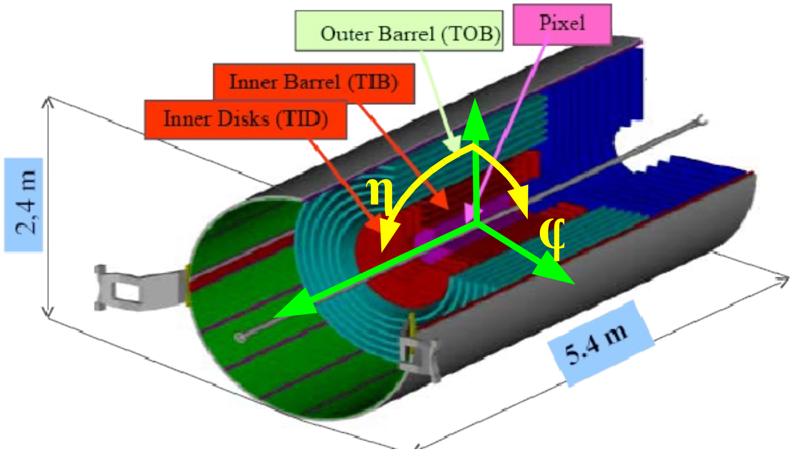
reconstruction algorithm

trigger

dead time of channels

$$\varepsilon(\mathbf{x}) \sim \varepsilon_1(\mathbf{x}) \cdot \varepsilon_2(\mathbf{x}) \cdot \varepsilon_3(\mathbf{x}) \ldots \cdot \varepsilon_g(\mathbf{x})$$

geometrical efficiency

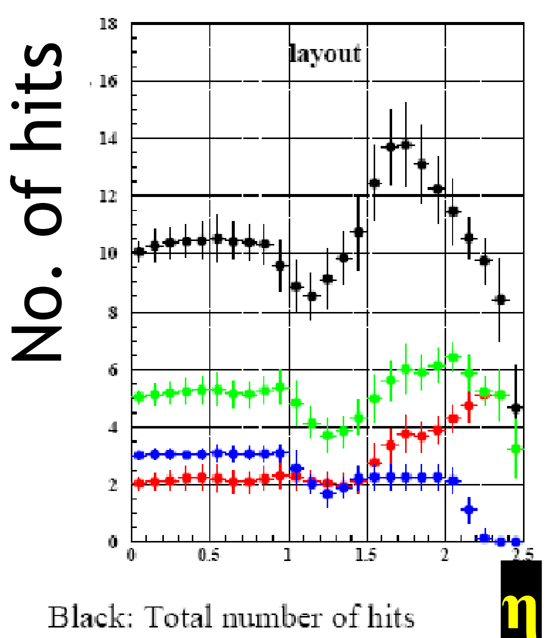


dead time of channels · trigger · reconstruction algorithm

$$\varepsilon(x) \sim \varepsilon_1(x) \cdot \varepsilon_2(x) \cdot \varepsilon_3(x) \ldots \cdot \varepsilon_g(x)$$

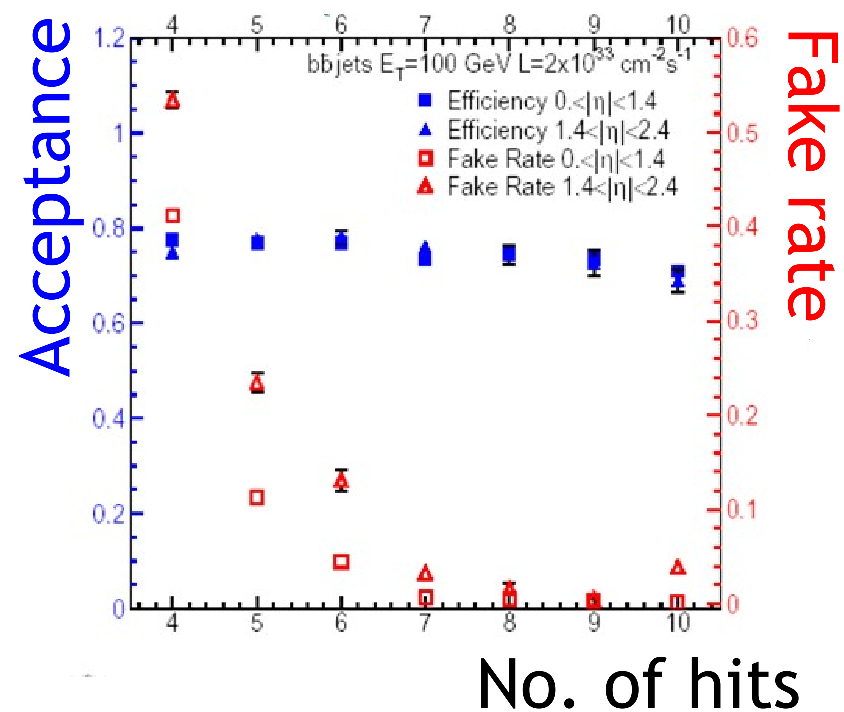
geometrical efficiency

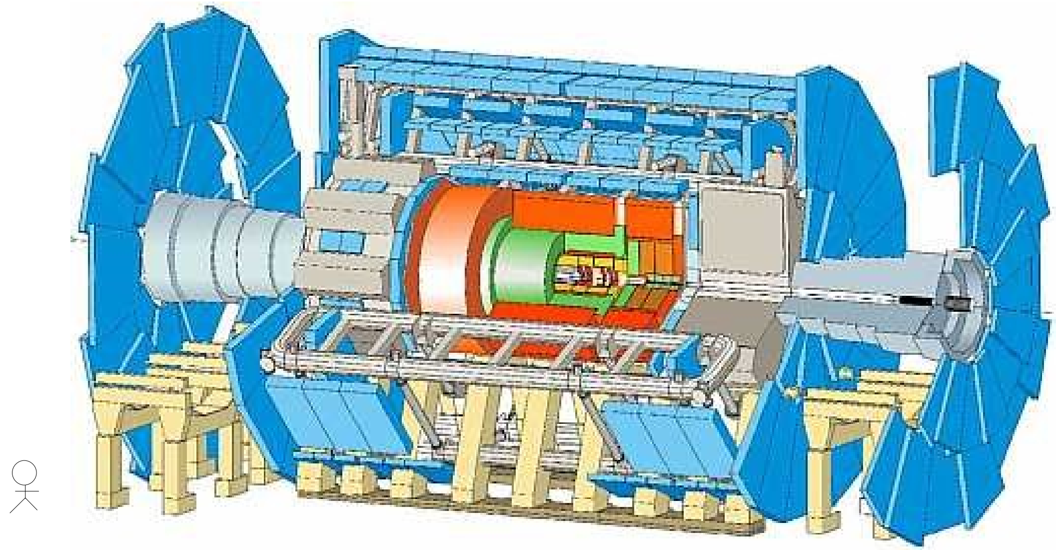
Number of SST hits by tracks:



Black: Total number of hits
Green: double−sided hits
Red: double−sided hits in thin detectors
Blue: double sided hits in thick detectors.

Jet detection:





Generally, **efficiency** depends on many things:

- money
- geometry
- choice of sub-detectors (physical properties, deterioration, ..)
- event type
- trigger efficiencies
- reconstruction & analysis algorithms / SW & computing

How can we design & built a detector "efficiently" enough to measure what we want to measure?

=> simulation studies contribute significantly to the taken decisions

There's more to understand ..

- Efficiency, acceptance described before cover
  - ony one aspect in an HEP experiment!!
  - only one type of event (e.g. emission of one f-particle)
  - don't tell you anything about other events
    - that you already understand very well
    - that you haven't thought of, yet ...
    - that you are not interested in measuring
    - that bias other measurements
- Some aspects, where **simulation** is extensively used to study and understand them
  - signal, background
  - noise, min. bias, ...

What we measure simultaneously

measured events
looking like events
of type E

from events of type E

$$\langle N_{measured} \rangle = a \langle N_{occured} \rangle + \langle N_{background} \rangle$$

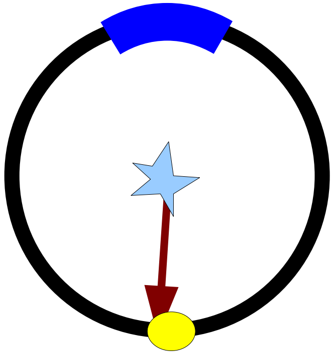
from similar
looking events

$$\langle N_{unwanted} \rangle = \langle N_{min.bias} \rangle + \langle N_{noise} \rangle$$

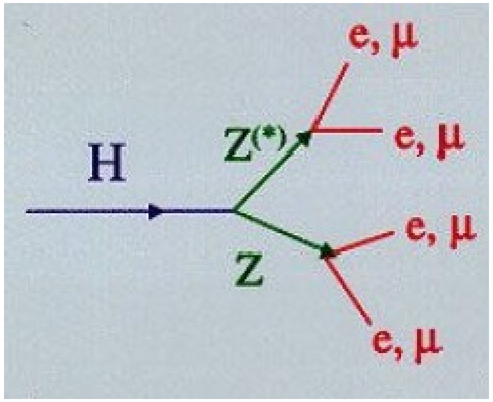
from other events

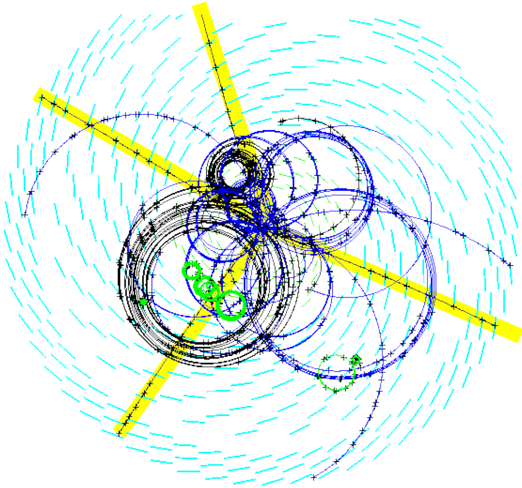
from somewhere else

simultaneously
detected
other events

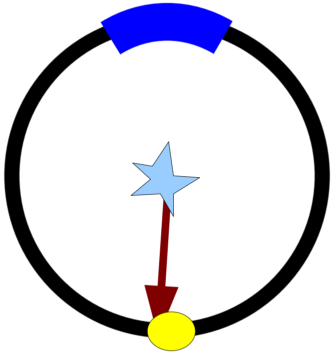


Signal



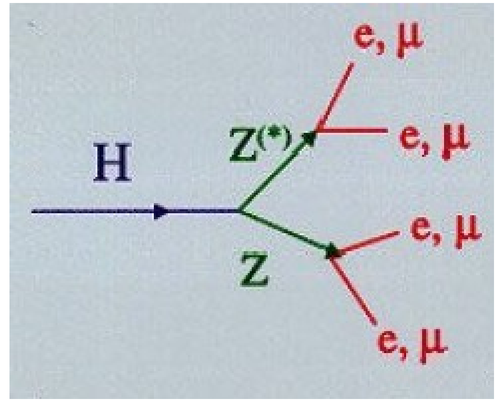


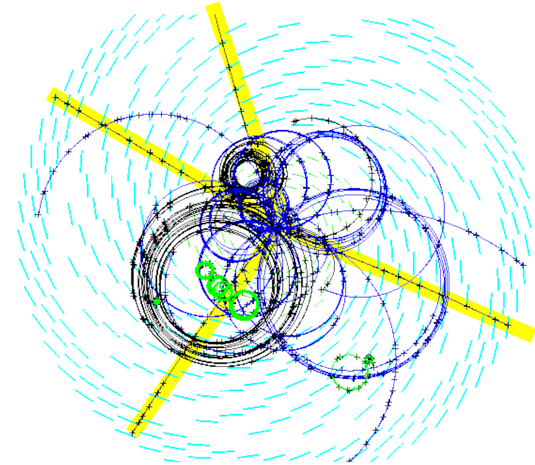
What we wish to measure!



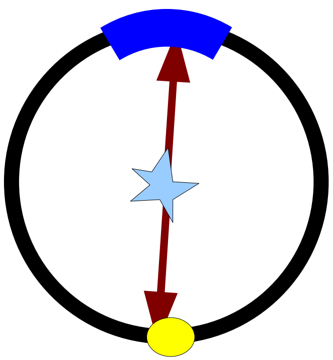
"click"

Signal



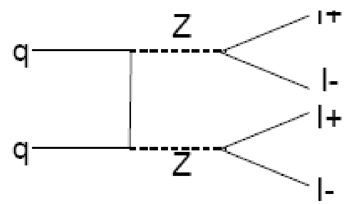


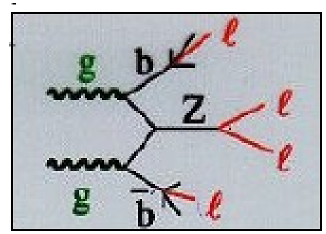
\+ **What we actually measure ...**

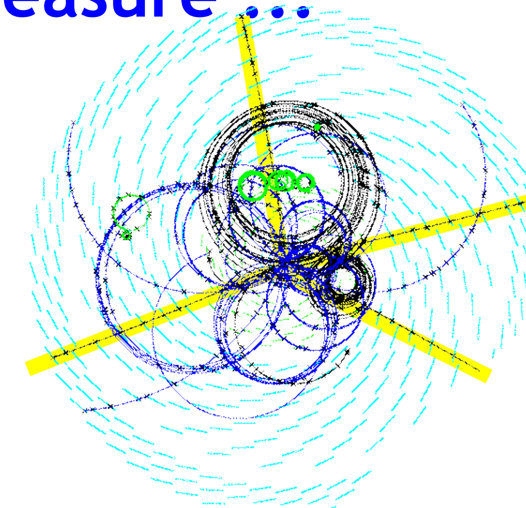


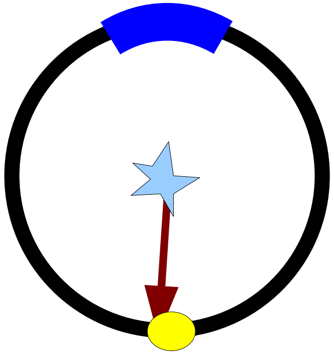
"click"

Back-
ground

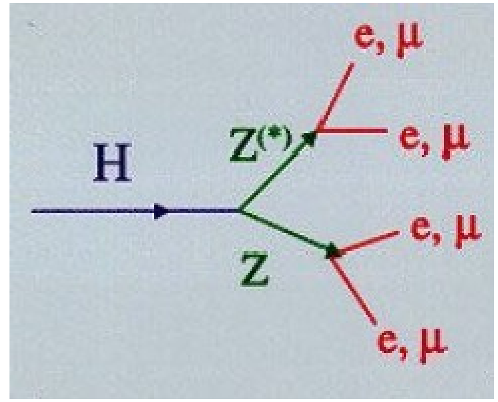




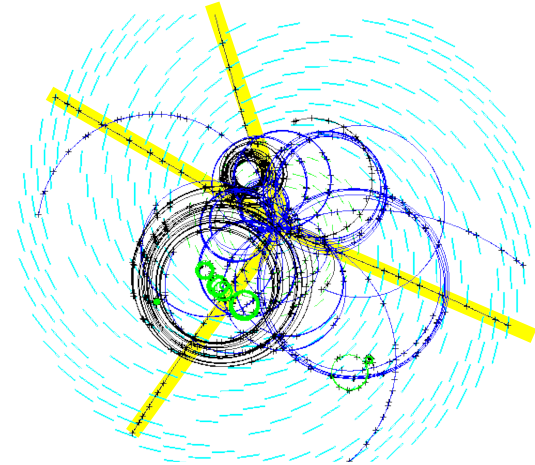




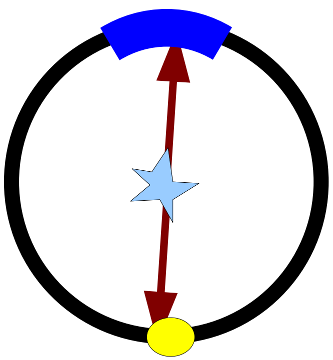
Signal



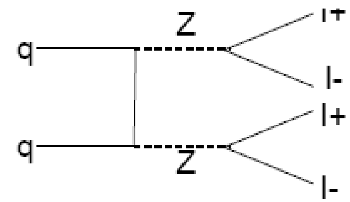
“click”

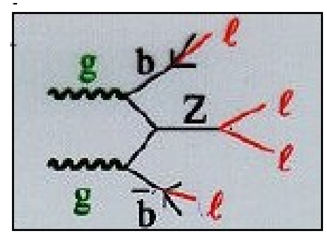


+ **What we actually measure ...**

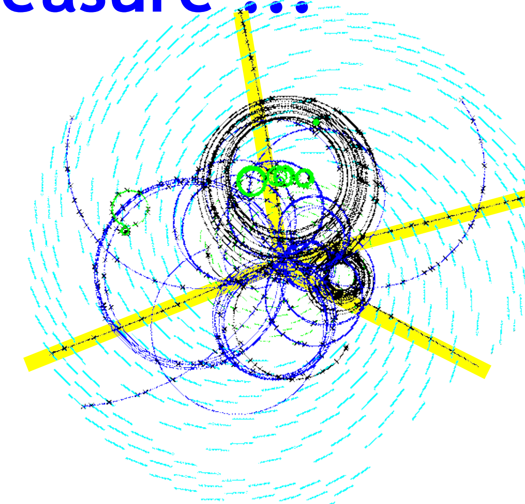


Back-
ground





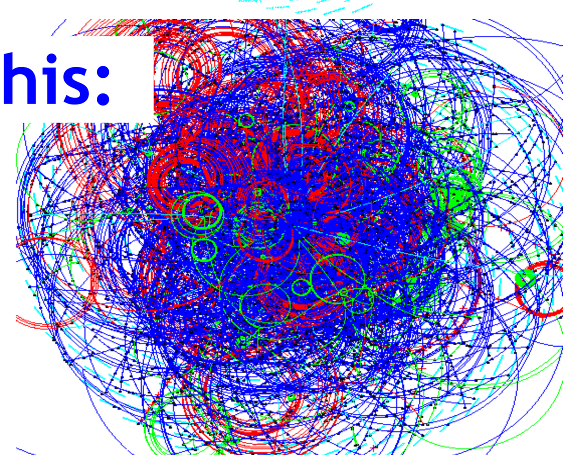
“click”



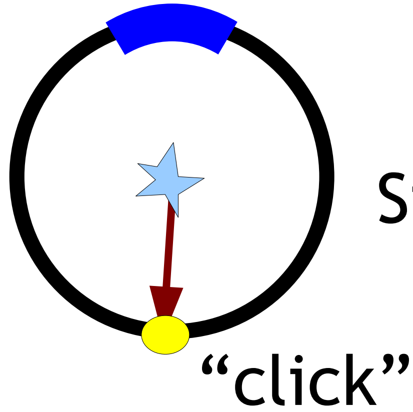
... if we manage to ignore this:

Mickey
was lucky!

= minimal bias events
and noise data

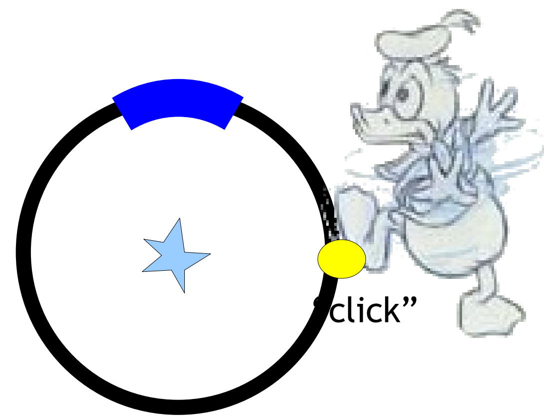


The four types of data

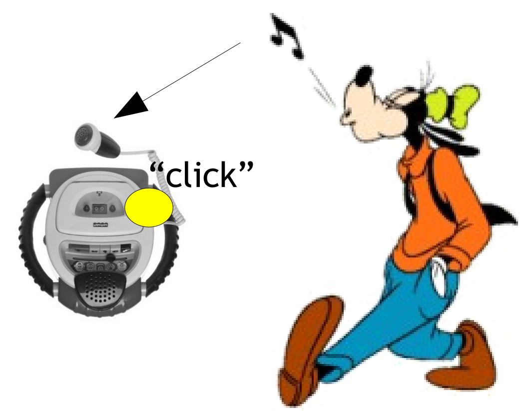


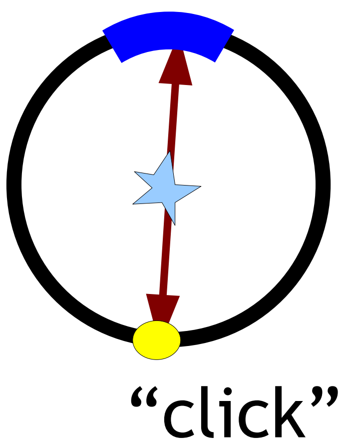
Signal

Noise

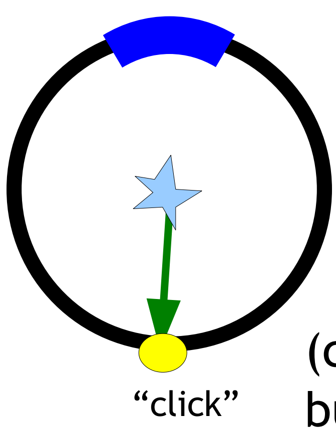


(comes from somewhere else)





Back-
ground

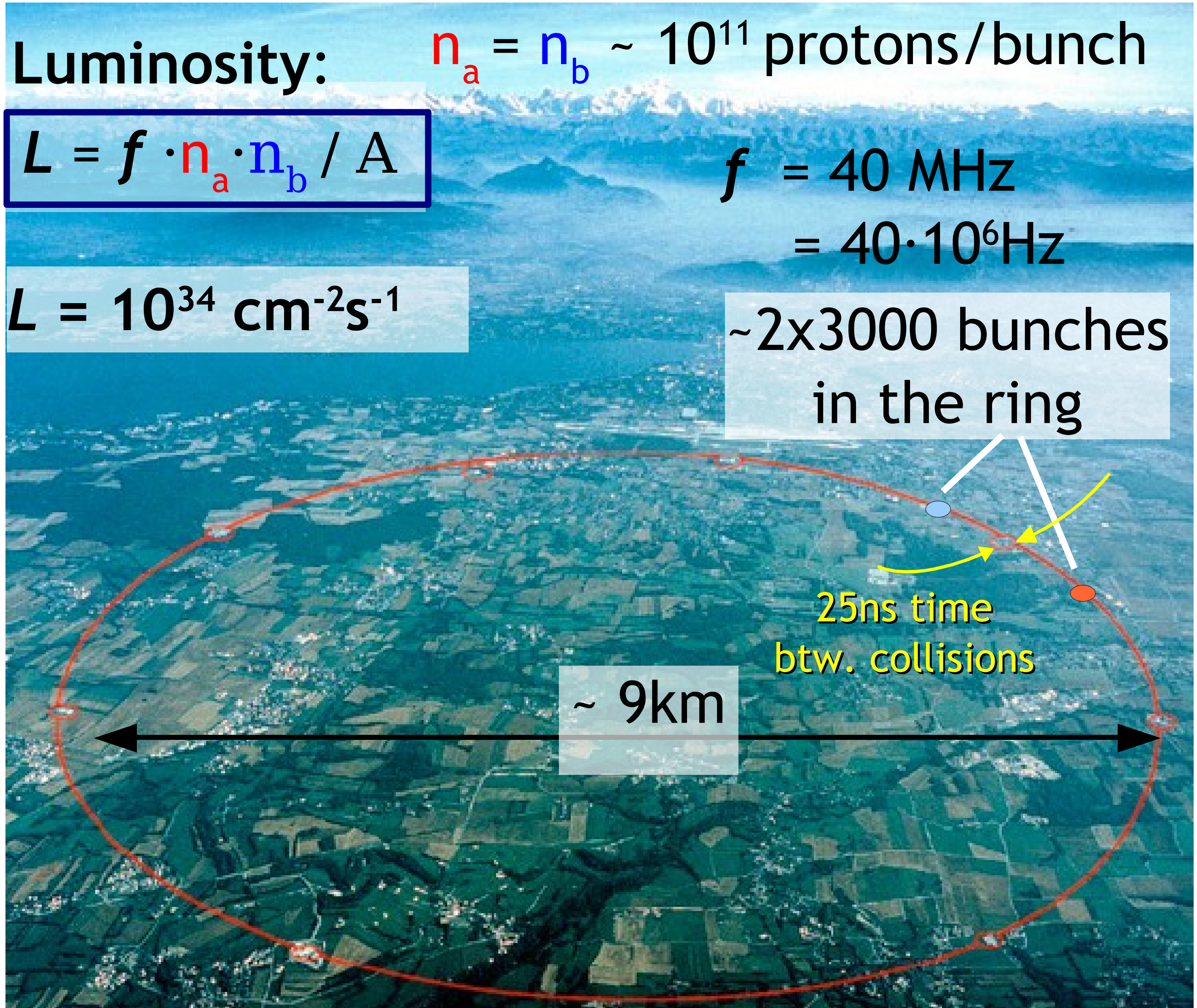


Minimal bias

emission of
a "Pianissimon"

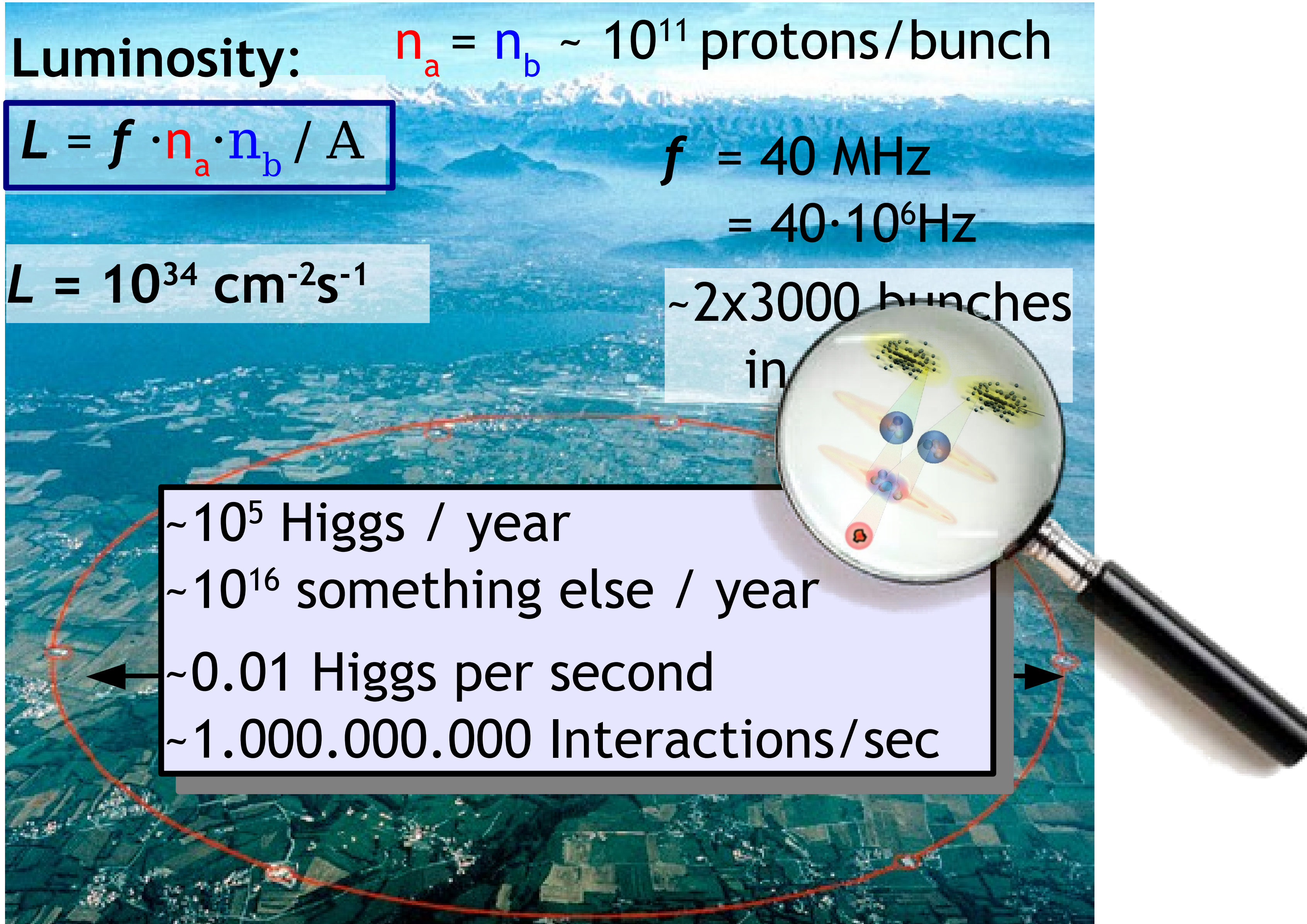
(comes from the interaction,
but is not signal nor background)

Signal to noise, higgs case



LHC@CERN

Signal to noise, higgs case



Luminosity: $n_a = n_b \sim 10^{11}$ protons/bunch

$L = f \cdot n_a \cdot n_b / A$

f = 40 MHz = $40 \cdot 10^6$ Hz

$L = 10^{34}\ cm^{-2}s^{-1}$

~2x3000 bunches in

~10^5 Higgs / year
~10^{16} something else / year

~0.01 Higgs per second
~1.000.000.000 Interactions/sec

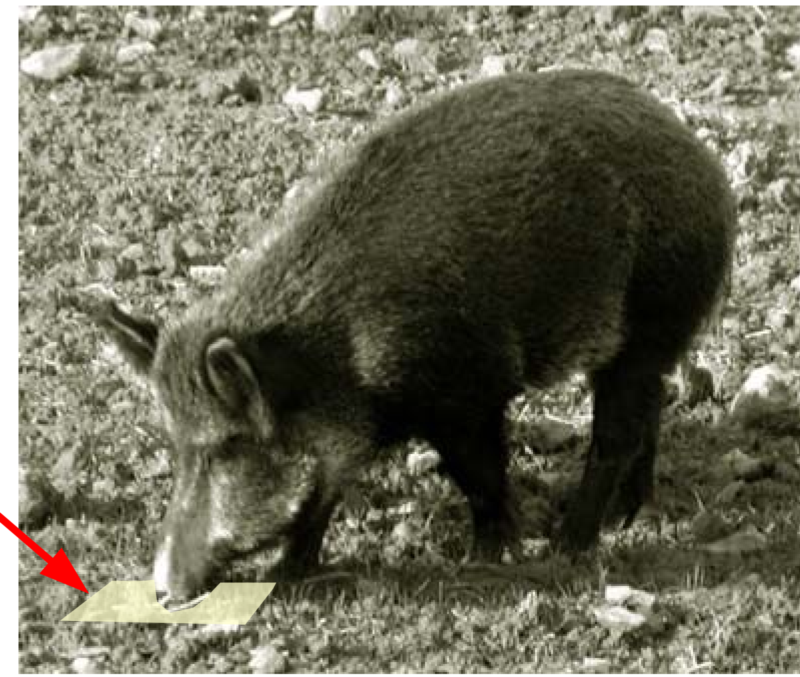
LHC@CERN

Experiment = truffles pig

~10^5 Higgs / year
~10^{16} something else / year → **1** Higgs event in **10^{11}** events

1 event .. $1 dm^2 = 10 \times 10\ cm^2$

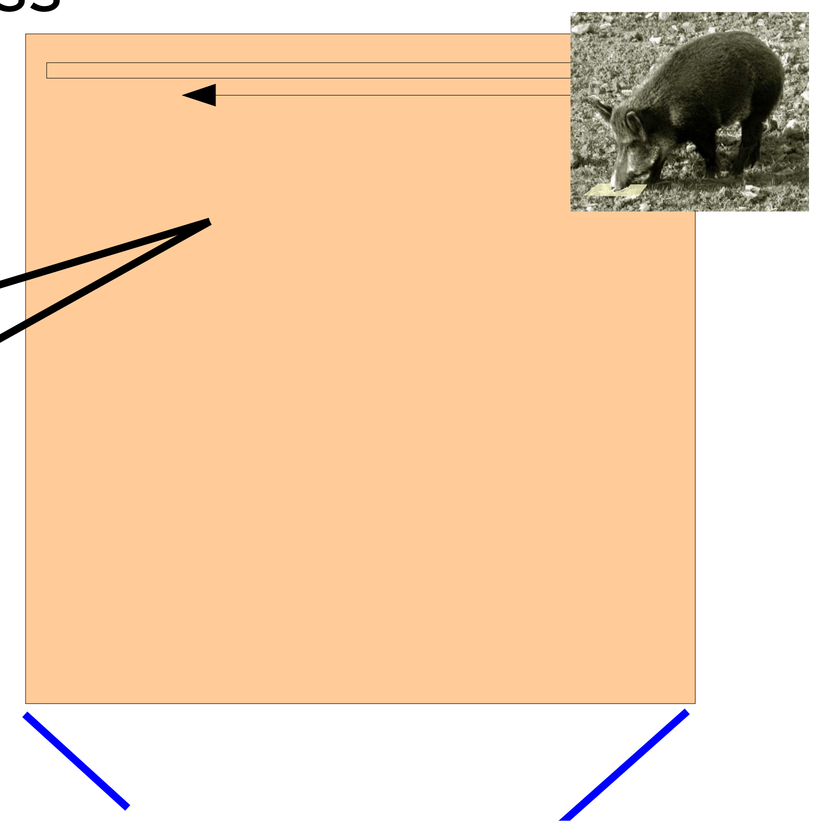
10^{11} events .. $10^{11} dm^2$ ~ $3 \cdot 10^5 \times 3 \cdot 10^5\ dm^2$



... just to visualize these numbers ...

Experiment = truffles pig

~10^5 Higgs / year
~10^{16} something else / year → 1 Higgs event in 10^{11} events



1 event .. $1 dm^2 = 10 \times 10\ cm^2$

10^{11} events .. $10^{11} dm^2$ ~
$3 \cdot 10^5 \times 3 \cdot 10^5\ dm^2$ =
30 km x 30 km

Find a 1 dm2 area in a field of 30 km x 30 km
in not more than 1.5 min!!

Experiment = truffles pig

~10^5 Higgs / year

~10^{16} some

events

1 event .

10^{11} ever

Numbers only for the standard model higgs!

Experiments need to be sensitive to discover events predicted by other theories, as well!

30 km x 30 km

Find a 1 dm2 area in a field of 30 km x 30 km in not more than 1.5 min!!

Let's summarize:

Theory

x

unknown
values for
parameters x
e.g. the mass of the Higgs

change in parameters,
change in prediction
of observables

Observable
$a(x)$

Theory
x

....

Observable
$b(x)$

unknown
values for
parameters x
e.g. the mass of the Higgs

change in parameters,
change in prediction
of observables

Theory
x

Observables
a(x)

....

Observables
b(x)

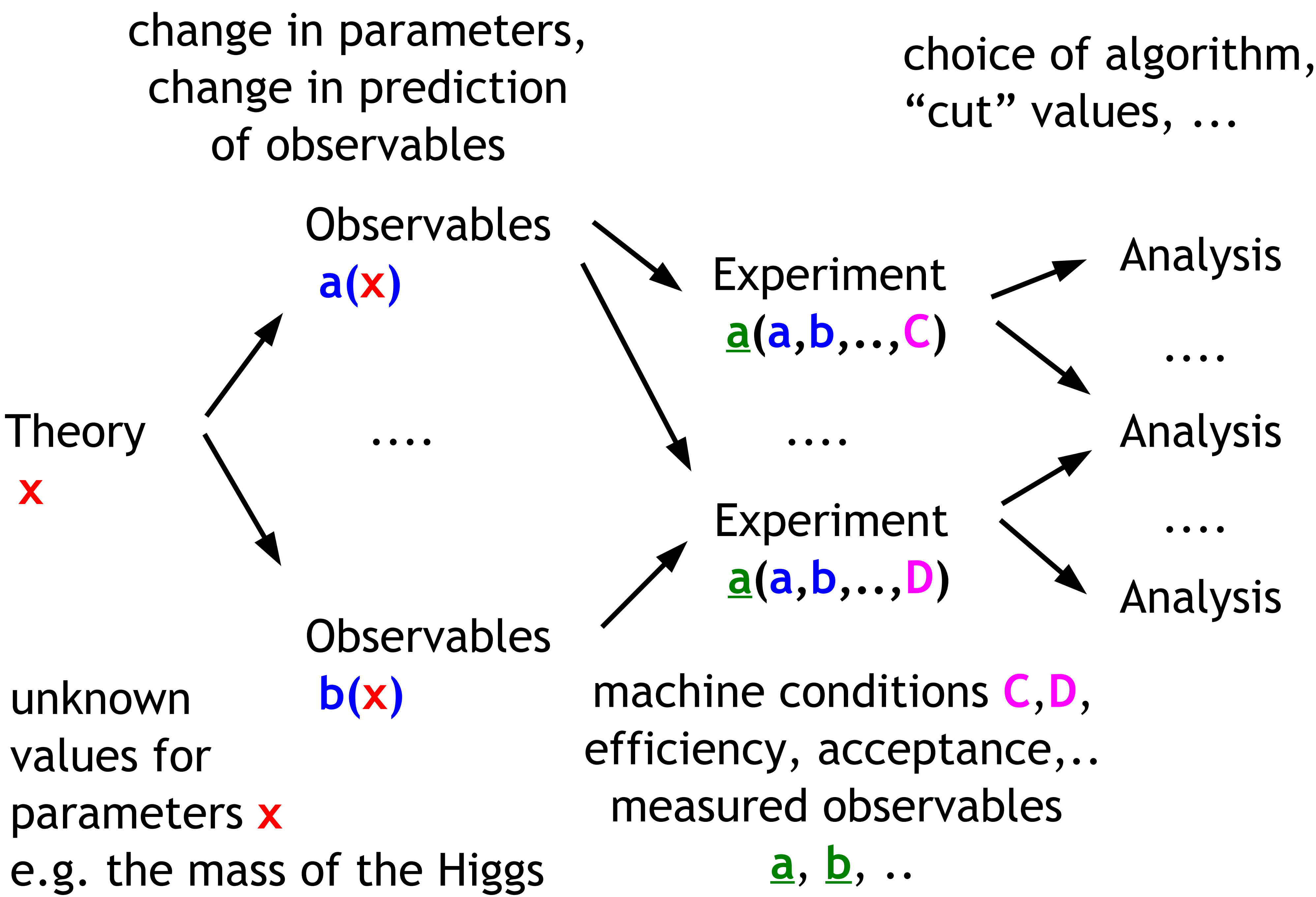
Experiment
a(a,b,..,C)

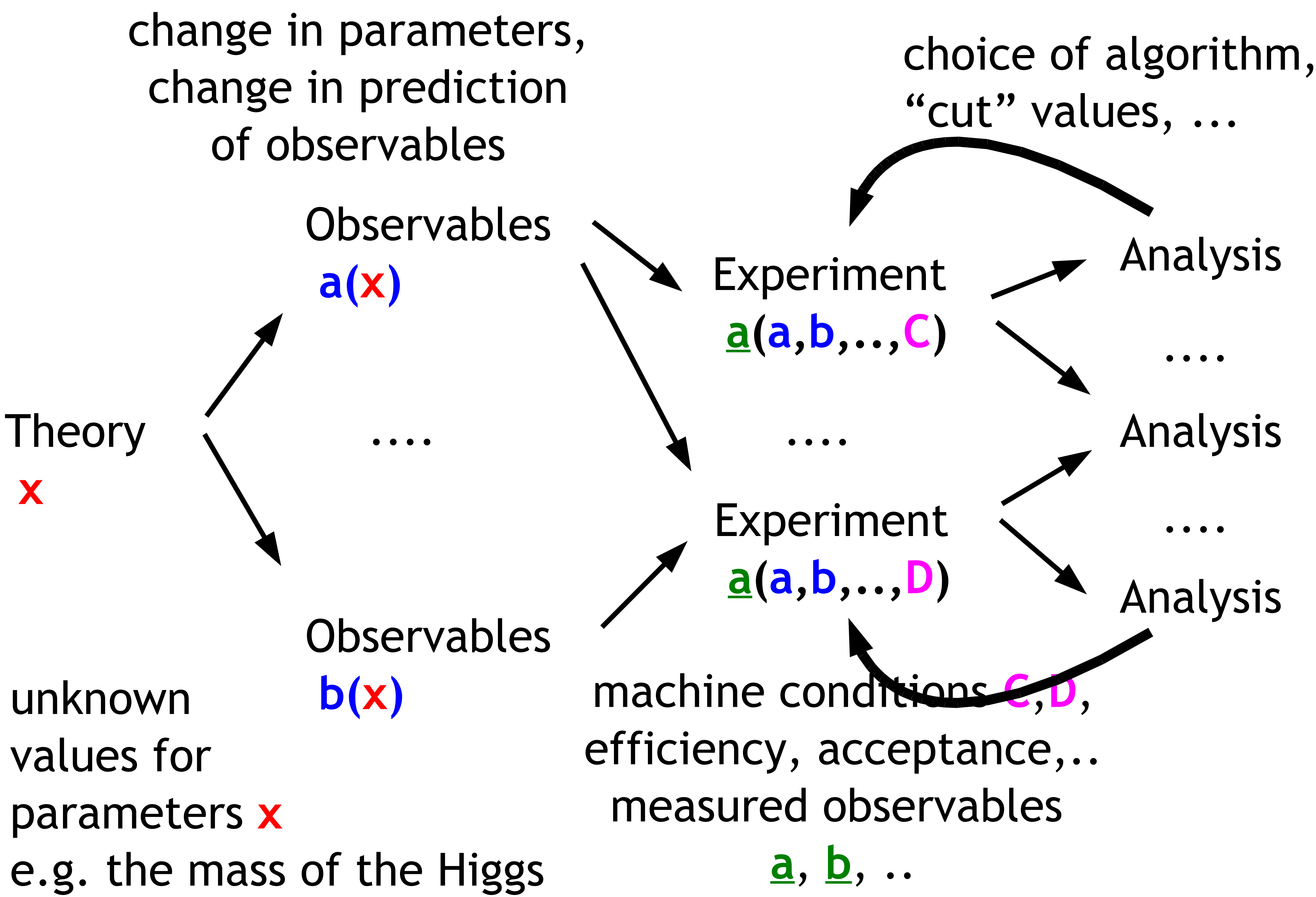
....

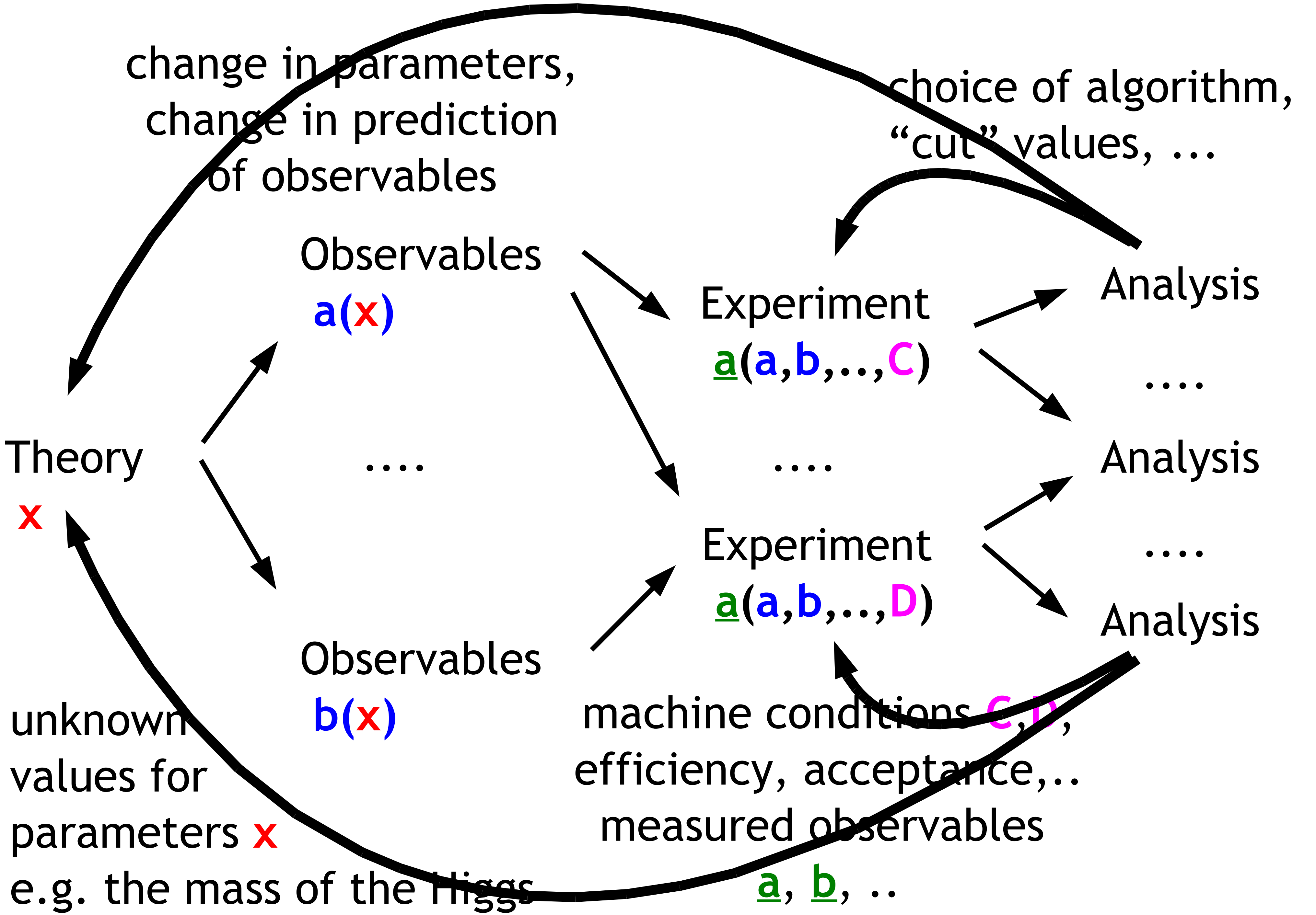
Experiment
a(a,b,..,D)

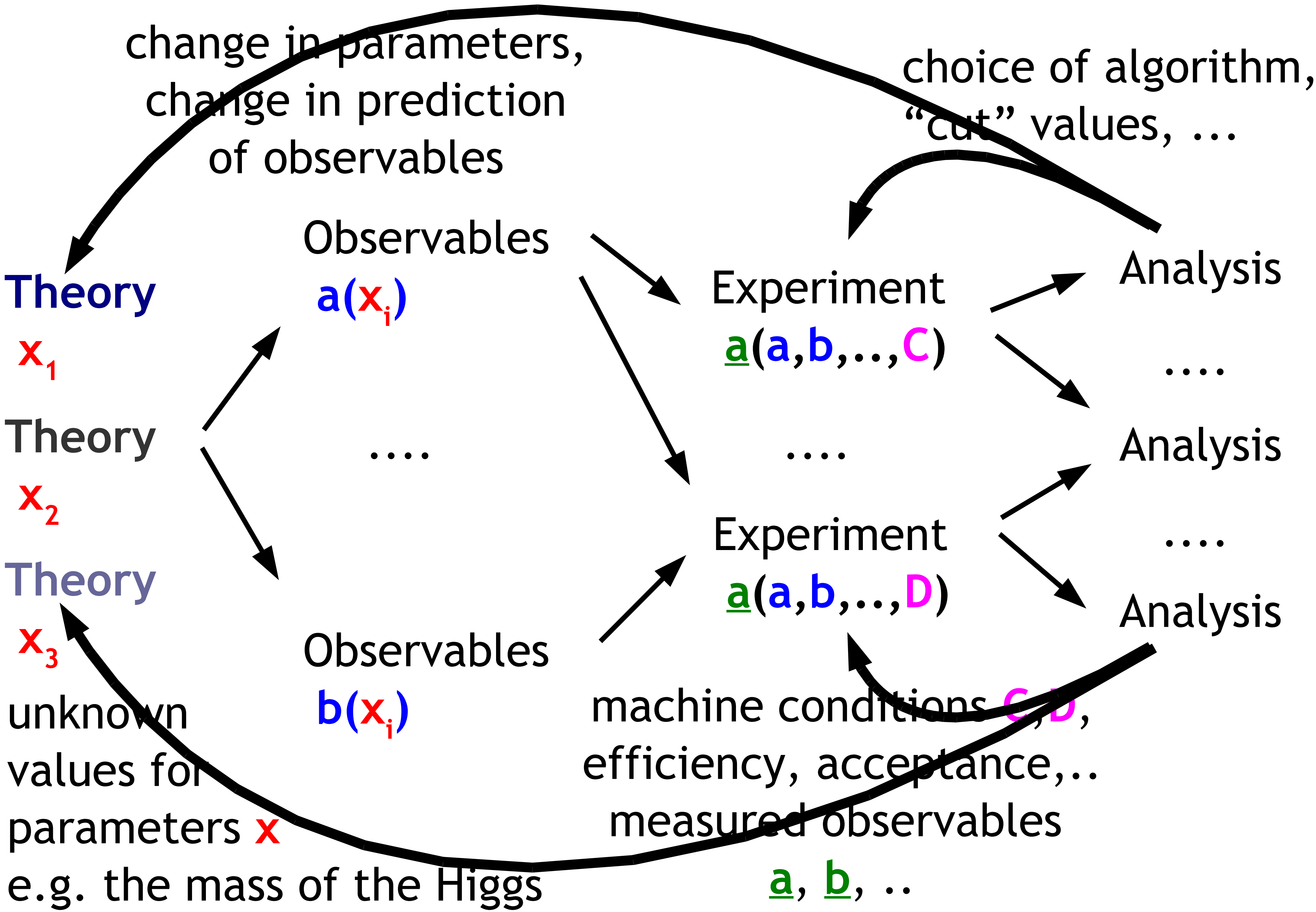
unknown
values for
parameters x
e.g. the mass of the Higgs

machine conditions C,D,
efficiency, acceptance,..
measured observables
a, b, ..


change in parameters,
change in prediction
of observables
choice of algorithm,
“cut” values, ...
Observables
a(x)
Experiment
a(a,b,..,C)
Analysis
....
Theory
x
....
....
Analysis
Experiment
a(a,b,..,D)
....
Analysis
Observables
b(x)
unknown
values for
parameters x
e.g. the mass of the Higgs
machine conditions C,D,
efficiency, acceptance,..
measured observables
a, b, ..


change in parameters, change in prediction of observables
choice of algorithm, "cut" values, ...
Observables a(x)
Experiment a(a,b,..,C)
Analysis
....
Theory x
....
....
Analysis
Experiment a(a,b,..,D)
....
Analysis
Observables b(x)
unknown values for parameters x e.g. the mass of the Higgs
machine conditions C,D, efficiency, acceptance,.. measured observables a, b, ..


change in parameters,
change in prediction
of observables
choice of algorithm,
"cut" values, ...
Observables
a(x)
Experiment
a(a,b,..,C)
Analysis
....
Theory
x
....
....
Analysis
Experiment
....
a(a,b,..,D)
Analysis
Observables
b(x)
unknown
values for
parameters x
e.g. the mass of the Higgs
machine conditions C,D,
efficiency, acceptance,..
measured observables
a, b, ..


change in parameters,
change in prediction
of observables
choice of algorithm,
"cut" values, ...
Theory
x_1
Theory
x_2
Theory
x_3
unknown
values for
parameters x
e.g. the mass of the Higgs
Observables
a(x_i)
....
Observables
b(x_i)
Experiment
a(a,b,..,C)
....
Experiment
a(a,b,..,D)
machine conditions C, D,
efficiency, acceptance,..
measured observables
a, b, ..
Analysis
....
Analysis
....
Analysis

change in parameters,
change in prediction

choice of algorithm,
"cut" values, ..

The
x_1

The
x_2

The
x_3

sis

sis

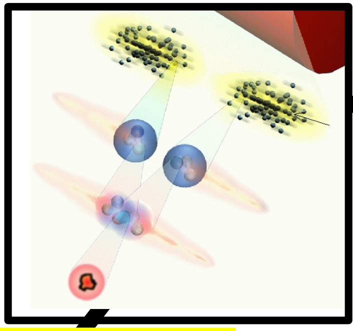
sis

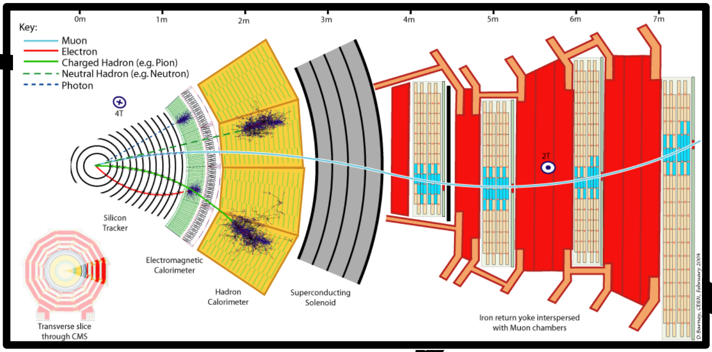
The need for simulation:

Because of the **tremendous multiplicity** of possible parameter constellations, it is impossible to **design, operate, and "understand"** today's HEP experiments without having corresponding simulation programs capable of "scanning" the relevant parameter ranges!

unkn
values for
parameters **x**
e.g. the mass of the Higgs

efficiency, acceptance,..
measured observables
a, **b**, ..





generator
Theory
x
generator
Theory
x
generator
Theory
x_3

Observables
$a(x_i)$

....

Observables
$b(x_i)$

exp. simulation
Experiment
a(a,b,..,C)

....

exp. simulation
Experiment
a(a,b,..,D)

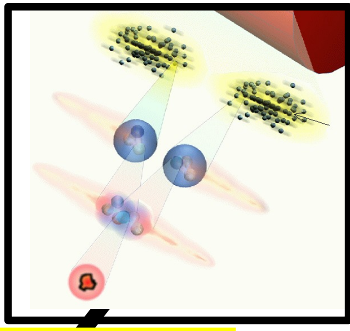
Analysis

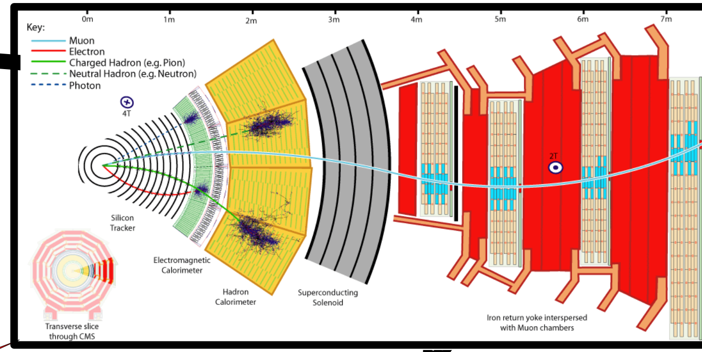
....

Analysis

....

Analysis





generator
Theory
x

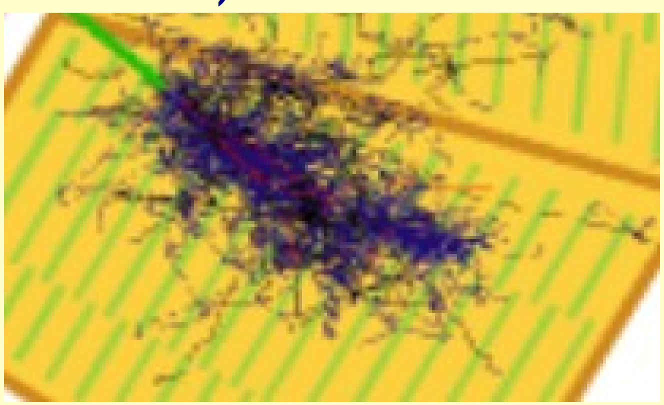
Observables
$x(x_i)$

exp. simulation
Experiment
a(a,b,..,C)

Analysis
....

gen...or
Th
x
gen
Th
x_3

Particle through matter simulation
(Level two)



+

Digitization
(Level three)

signal recorded by electronics
(not in these lectures, highly experiment specific)

using GEANT4 - <u>this lectures,</u>
not experiment specific

GEANT4

"Geant4 is a **toolkit** for simulating the passage of particles through matter. It includes a complete range of functionality including **tracking**, **geometry**, **physics models** and **hits**." [1]

[1] NIM A506 (2003), 250-303

GEANT comes from GEometry ANd Tracking.

History of GEANT goes back to the 1970s (CERN)

Homepage: http://www.cern.ch/geant4

1994–1998: R&D phase, ~100 scientists from >10 experiments world wide;

First production release in 1998;
Today's (2006) release: GEANT4.8.x
=> more than 10 years of work!!

Areas of application: high energy physics, medical applications, space science

Summary ~1~

- **Need of simulation**
  - understanding
    - physics theories
    - experiments
    - analysis of measurements
  - complexity of physics: generators
  - complexity of detectors:
    - passage of particles through matter
    - response simulation ("digitization")
- **Simulation vs. analytical treatment**
  - Mickey Mouse example
- **Types of data:**
  - signal and background
  - minimum bias events
  - noise